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"Human Behavior and Performance as Essential Ingredients in Realistic Modeling of Combat - MORIMOC II"

VOLUME 2

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Army Operations Research
and
Assistant Chief of Staff, Studies and Analyses
HQ US Air Force

This Military Operations Research Society minisymposium proceedings faithfully summarizes the findings of a three day meeting of experts, users, and parties interested in the subject area. While it is not generally intended to be a comprehensive treatise on the subject, it does reflect the major concerns, insights, thoughts, and directions of the authors and discussants at the time of the workshop.

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FATIGUE OF SOLDIERS IN BATTLE

Major Werner Siemon,
A Stud UEbBW/Mil Ber OR - GRP Landkrieg

and

Helmut Wollschlager,
Industrieanlagen - Betriebsgesellschaft
Ottobrun, West Germany

INTRODUCTION

This paper describes recent work we have done on the subject of "stress on the battlefield". Two years ago we were tasked to work on this phenomena by the West German Ministry of Defense. The scope of the task was as defined in Figure 1.

To commence this work, a framework was defined (see Figure 2). The force level chosen for which the influence of stress and fatigue on the battlefield will be shown is the brigade. The battlefield capabilities of the brigade were developed for the basic case (i.e., without stress) and for the case where stress and fatigue were taken into consideration.

The wargame KORA was used for conduct of this task. KORA is a corps level model built by IABG under sponsorship of the West German MOD. The scenario selected was in the area of Franken, in the southern part of Germany, west of Nurnberg (see Figure 3). This investigation focused on Tank Brigade 63, which is defending along the FEBA against attacking RED forces from the East. This unit is used as the example upon which the computer-based analyses are performed.

ORGANIZATION OF THE TANK BRIGADE

Figure 4 shows the organization and the equipment of Tank Brigade 63. The concentration of the antitank defense capability of the brigade is illustrated in Figure 5. The power of the anti-tank defense and the flexibility and mobility of the combat force battalions are evident from the equipment shown for the mechanized infantry companies.

OPERATIONS PLAN OF THE OPPOSING FORCES

Figure 6 shows the deployment of Tank Brigade 63: three tank battalions are deployed side-by-side at the FEBA, and a fourth tank battalion (632) is to the west in reserve. After the delaying forces deployed to the east move to the rear (west), Tank Brigade 63 will engage the RED forces in mobile combat.

At this part of the FEBA, RED motorized infantry devision 53 is attacking (see Figure 7). In this combat sector, the division has four groups (regiments) in first echelon and a regiment in reserve.

Figure 1

TASK

of the study

"FATIGUE OF SOLDIERS IN BATTLE"

- To analylse which influences of fatigue and stress are given in a battle

- Parameters have to be drawn up which correspondingly influence the effective-ness of functions used in operations research studies, such as kill probability, firerate etc.

- To give a brief status report of the re-sults of the fatigue research

- The aim of the study is to be able to take these factors into consideration in an appropriate manner in all combat studies in future

Figure 2

FRAMEWORK

Forcelevel

Brigade

taken from

Wargame

KORA

Figure

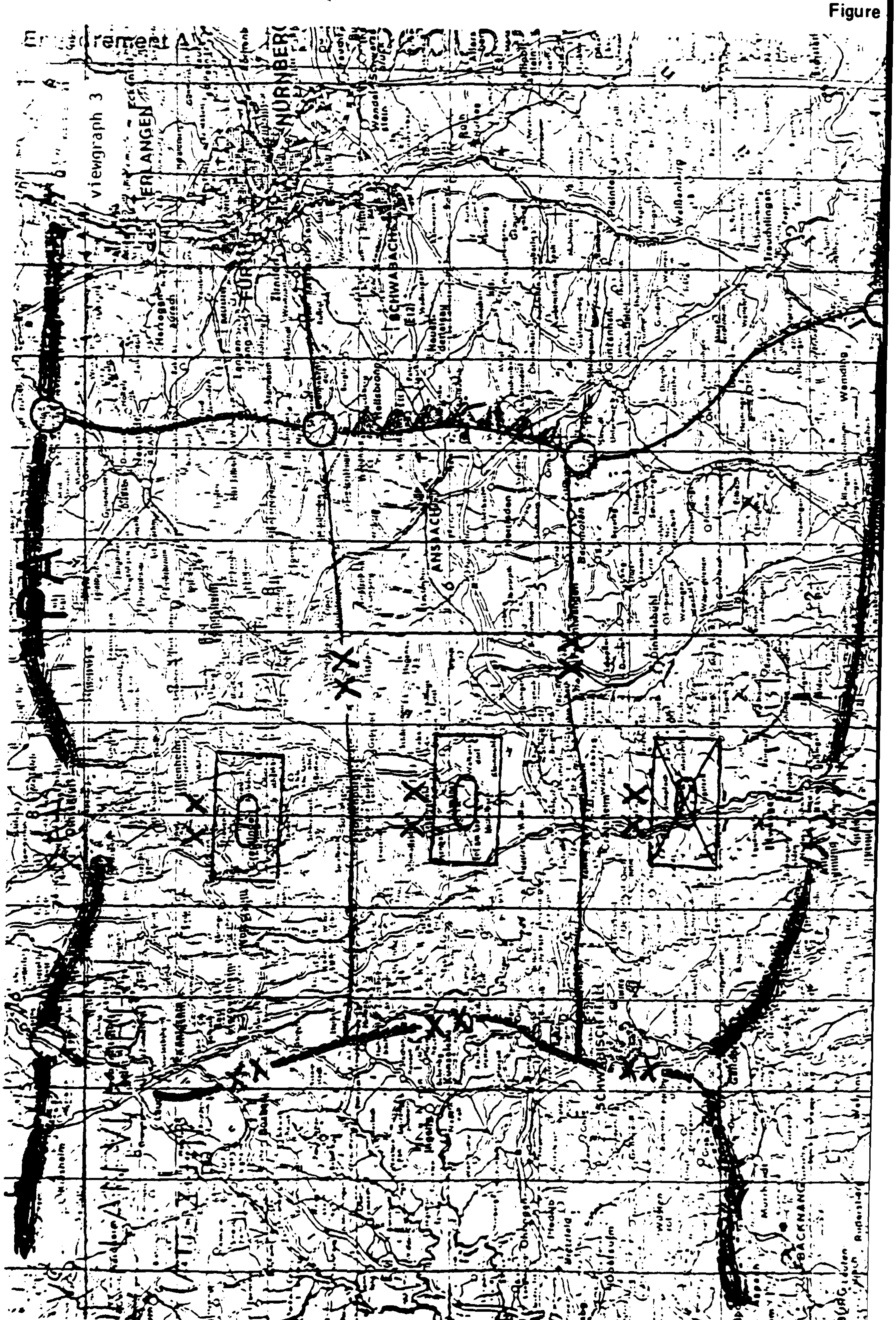
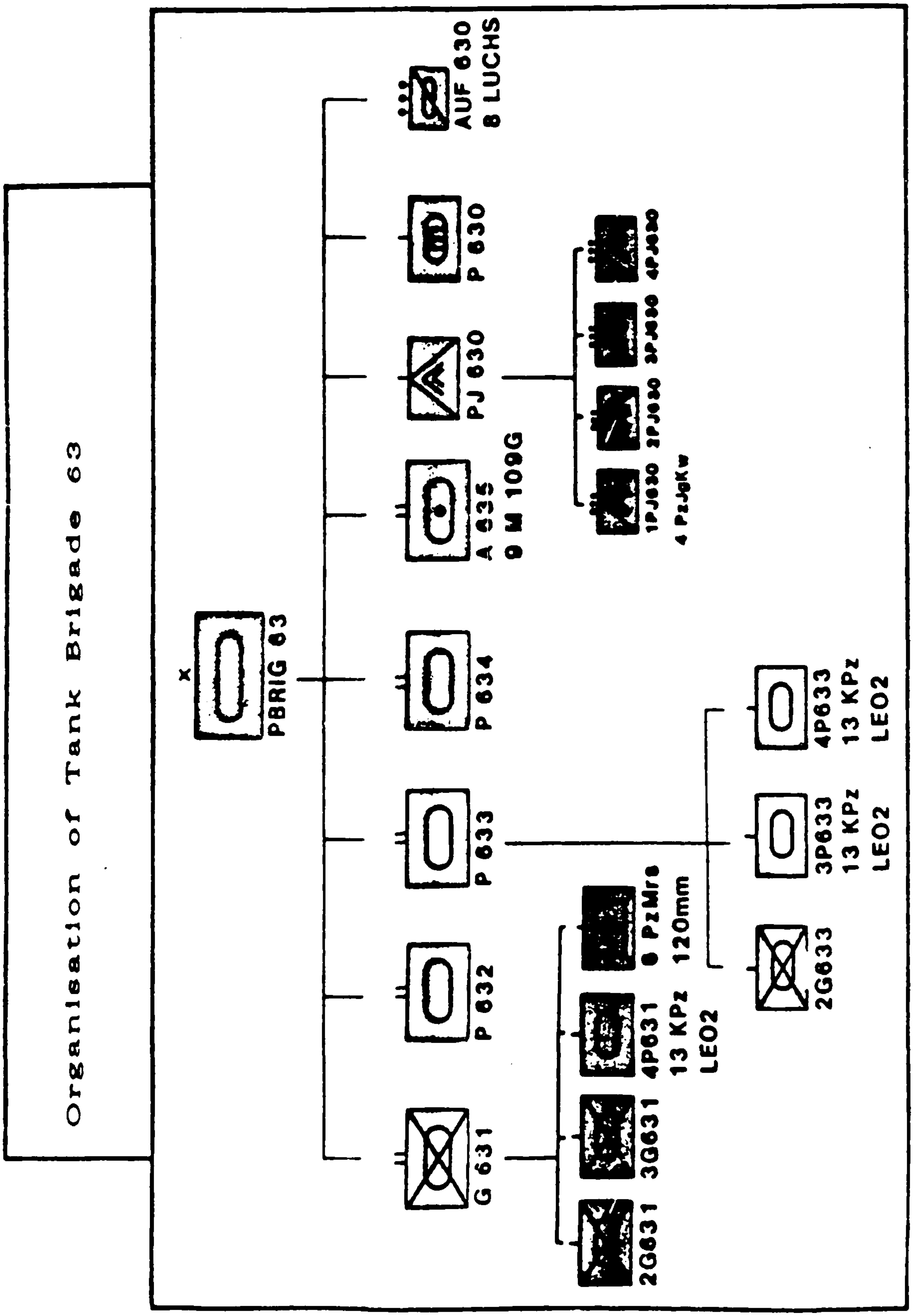


Figure 4



Organisation of Tank Brigade 63
PBRIG 63
G 631
P 632
P 633
P 634
A 635
9 M 109G
PJ 630
P 630
AUF 630
8 LUCHS
2G631
3G631
4P631
13 KPz
LEO2
8 PzMrs
120mm
2G633
3P633
13 KPz
LEO2
4P633
13 KPz
LEO2
1PJ630
2PJ630
3PJ630
4PJ630
4 PzJgKw

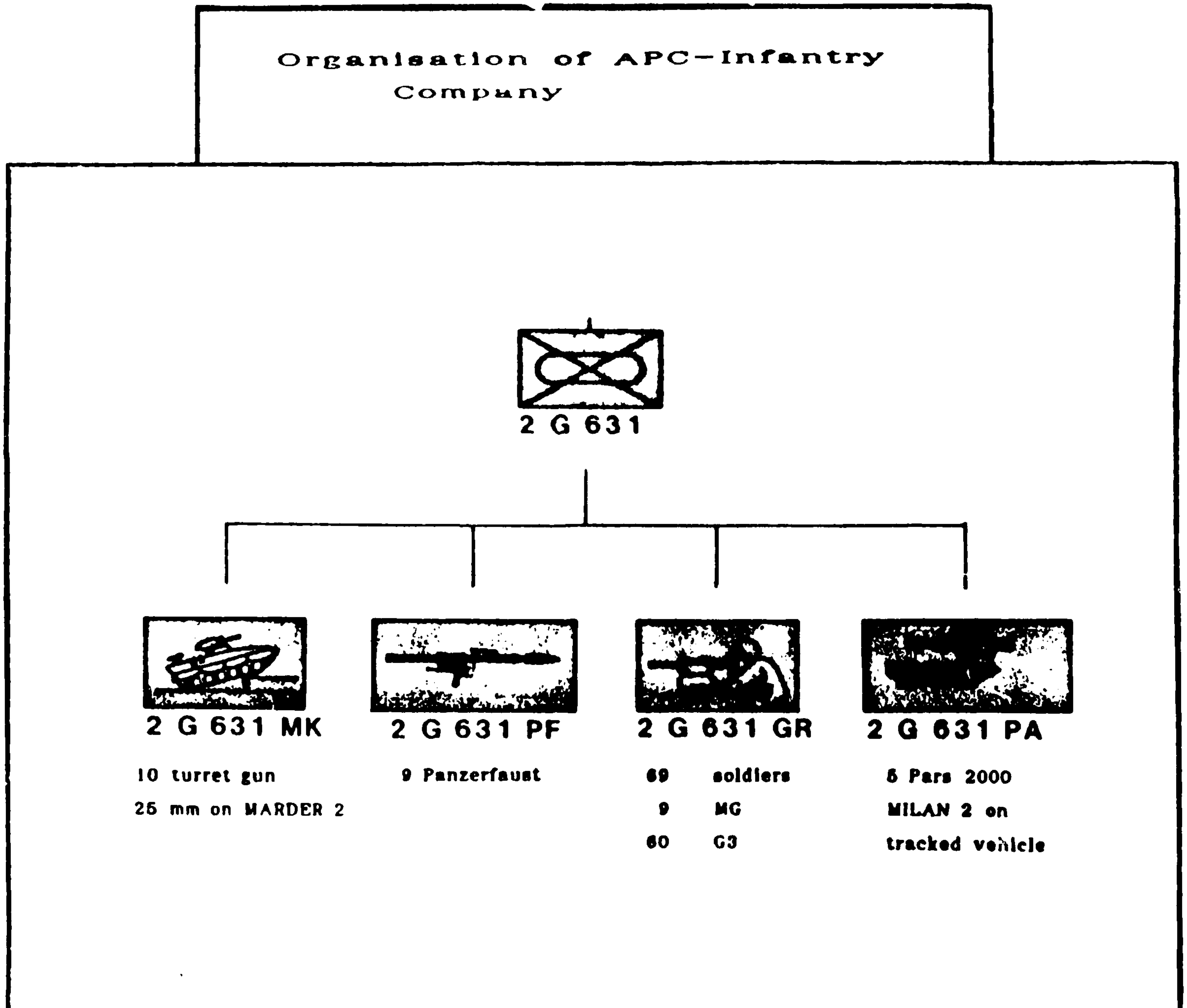

Organisation of APC-Infantry Company
2 G 631
2 G 631 MK
10 turret gun
25 mm on MARDER 2
2 G 631 PF
9 Panzerfaust
2 G 631 GR
69 soldiers
9 MG
60 G3
2 G 631 PA
5 Pars 2000
MILAN 2 on
tracked vehicle

Figure 5

Figure 6

Fatigue of soldiers in battle

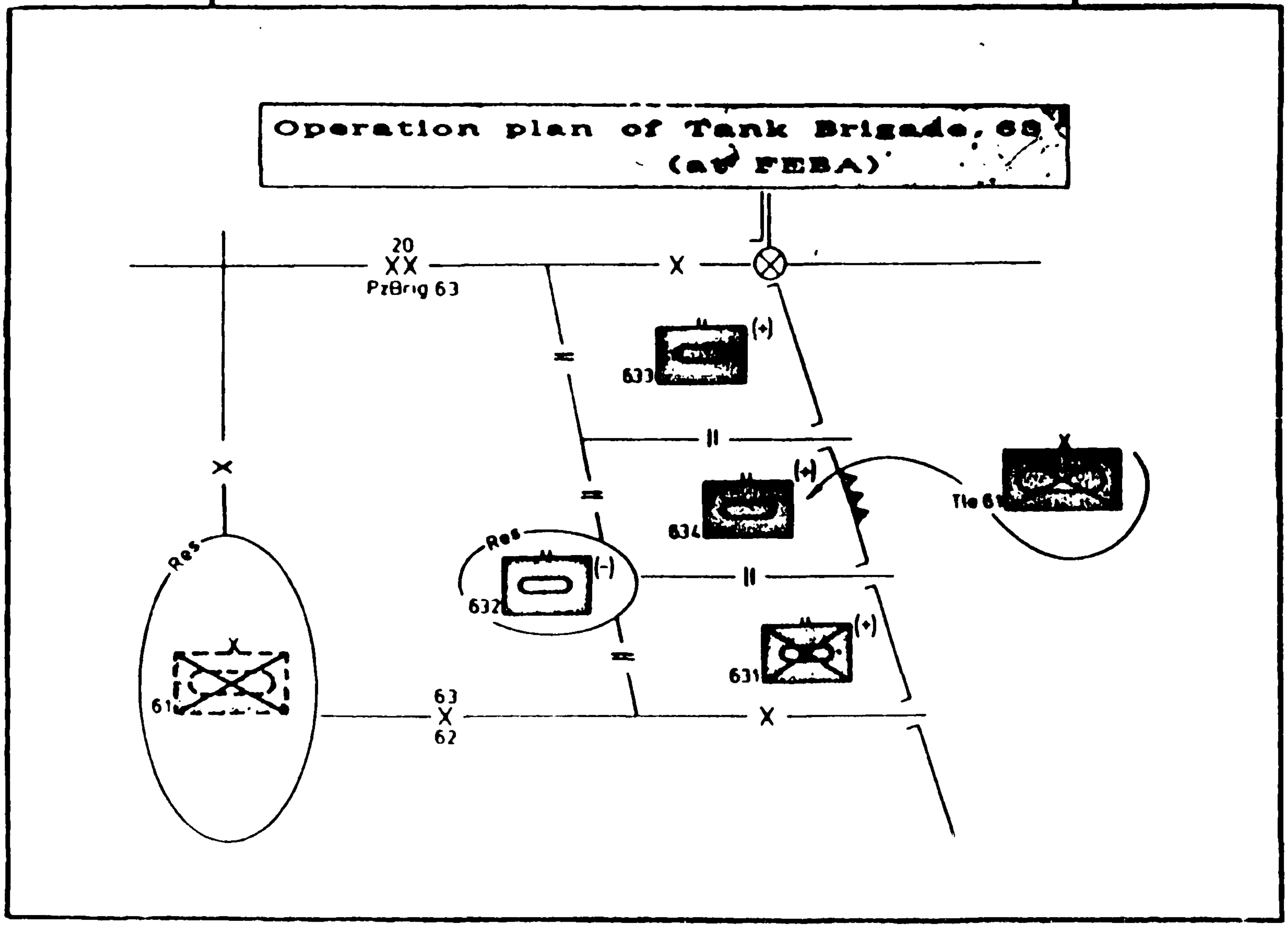
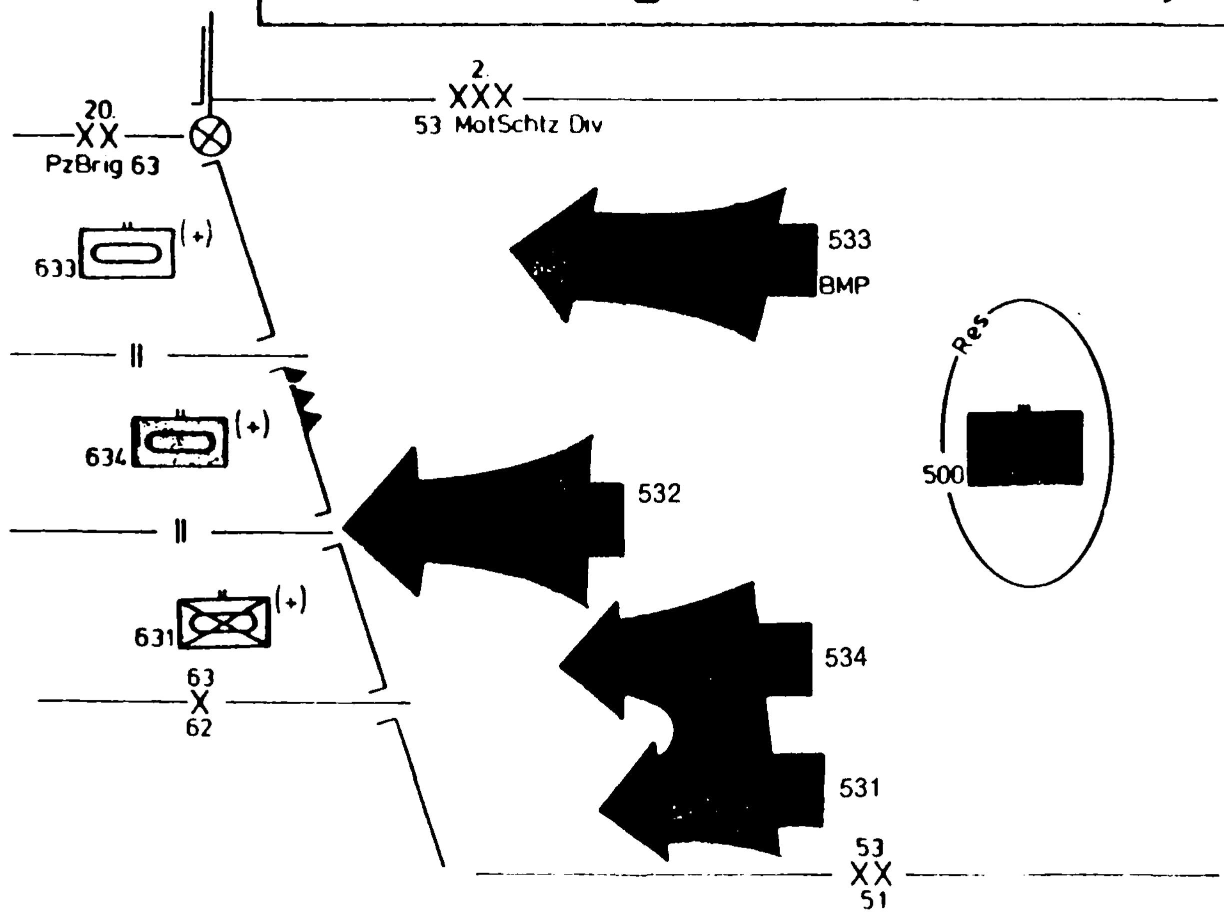


Figure 7

Fatigue of soldiers in battle

Attack of Motorized Division 53. on Tank Brigade 63. (at FEBA)



ASSUMPTIONS

In addition to the deployment of the defending and attacking forces, the following assumptions were made (see Figure 8):

- o No extremes of ambient temperature
- o No employment of NBC weapons
- o No consideration of command and control mistakes

Time-related assumptions were made within the context of the scenario so as to establish the deficit in sleep for the defending and attacking forces before they come into first contact along the FEBA. These are illustrated in Figure 9 and are as follows.

For the RED (attacking) force:

- o Mobile Infantry Division 53 completes its preparation for the next days attack by 2100h of the first day of the war
- o Sleep period begins at 2100h
- o Reveille is at 0200h on the second day
- o March toward the defending forces (to the west) occurs from 0200h to 0500h
- o Attack starts at 0500h
- o Battle continues throughout the covering force area (east of the FEBA) from 0500h to 1900h
- o Strike on the FEBA forces occurs at 1900h

For the defending force:

- o Tank Brigade 63 completes its defense preparations at 2300h on the first day
- o Sleep period begins at 2300h
- o Alert occurs at 0400h
- o Defense forces are in a state of alert from 0400h to 1900h
- o Red forces engage the defending force at the FEBA at 1900h.

During the running of the KORA wargame, the defense forces (company level) and the RED forces (battalion level) are either marching, in battle, or "in position". During the marching and fighting phases, there is no sleep. During the in postion periods, there is the possibility of sleep. To determine when and for how long sleep might be possible, several further assumptions are needed. These were developed by consensus among a panel knowledgeable in land combat operations. The assumptions developed are:

- o Throughout the days of the war, periods of rest and sleep are permitted during "in postion" times. During these times, one third of the units are to be on security watch in two-hour shifts.

Figure 8

Fatigue of soldiers
in battle

Assumptions:

1. No extreme cold
   No extreme heat

2. No employment of NBC–Weapons

3. No consideration of command mistakes

ASSUMPTIONS FOR THE TEMPORAL COURSE TO DETERMINE THE SLEEP LOSS

Proki Nr.:

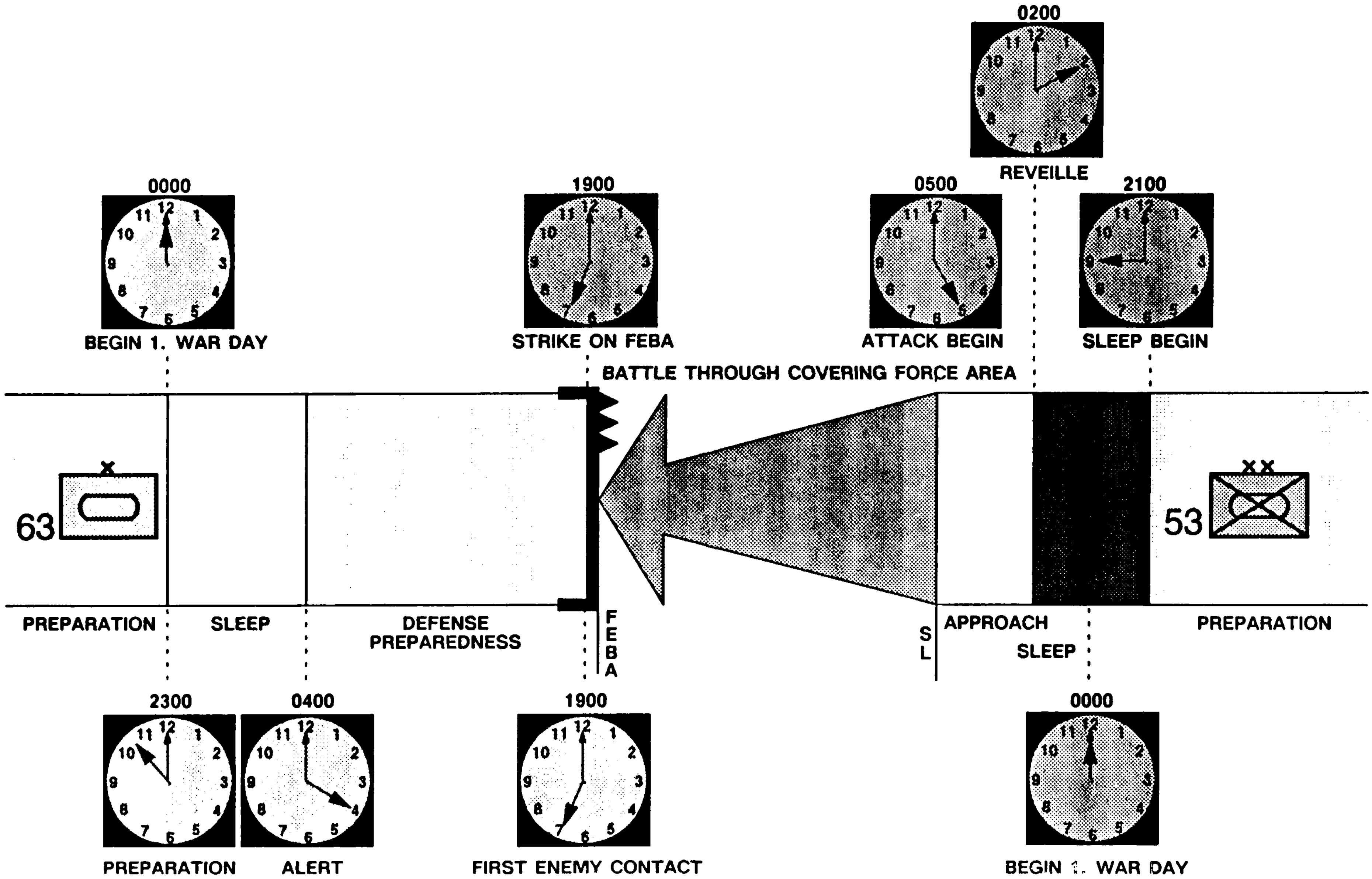


Figure 9

- o During battle or when a portion of a battalion is fighting, the rest of the battalion stays on alert (no sleep allowed).

- o After each period of fighting, an engaged unit expends two hours for such tasks as first aid, emergency maintenance, and for replenishment of ammunition and other expendables (see Figure 10).

- o Similarly, a two hour period is required after each march period, for replishment and maintenance.

- o Units which are not engaged in fighting, but are on alert, have a one-hour post-alert before sleep phase commences (Figure 11).

SEQUENCE OF BATTLE EVENTS

Figure 12 shows the battle situation; we shall focus our attention on the actions of defending tank battalion 634 and RED mobile infantry regiment 532. Using the scenario and the above assumptions in the KORA wargame, a time sequence of events for the first few days of the war for these units is generated. The list of events or occurrences for Tank Brigade 63 is shown in Figure 13.

Across the top of the figure, moving from left to right, are shown a part of the first war day, all of the second day, and part of the third, in one hour increments. On the left side of the figure are listed the units of the brigade. The shading in the boxes indicates the various activities of the brigade's units. The sequence of events for each unit can be understood from the example of the second mechanized infantry company (here the infantry fighting vehicles) as illustrated along the top of the chart.

Note the following:

- o A state of alert exists until 1900 h of day one

- o At 1900 h, the RED forces make contact and fighting starts

- o Following one hour of fighting, a one hour after-fighting period occurs

- o Then a new one hour fight takes place, followed by a two hour after-fighting period

- o Next, there is a two-hour fight followed by one hour of after-fighting period, followed by another hour of fight and another two hour after-fight period

- o Finally, a three hour period for sleep is available, folflowing which fighting, alerts, and after-fight periods follow to 0200h of day 3.

As can be seen, only short periods are available for sleep during this time sequence, especially for the soldiers in P632 and P634. As will be shown, the attackers (RED forces) also have only short periods available for sleep during this time.

Similar time sequences were developed for the other units of the tank brigade; the results for these units are summarized in the lower half of the chart. There are differences in the occurence and duration of sleeping periods among the four battalions.

Figure 10

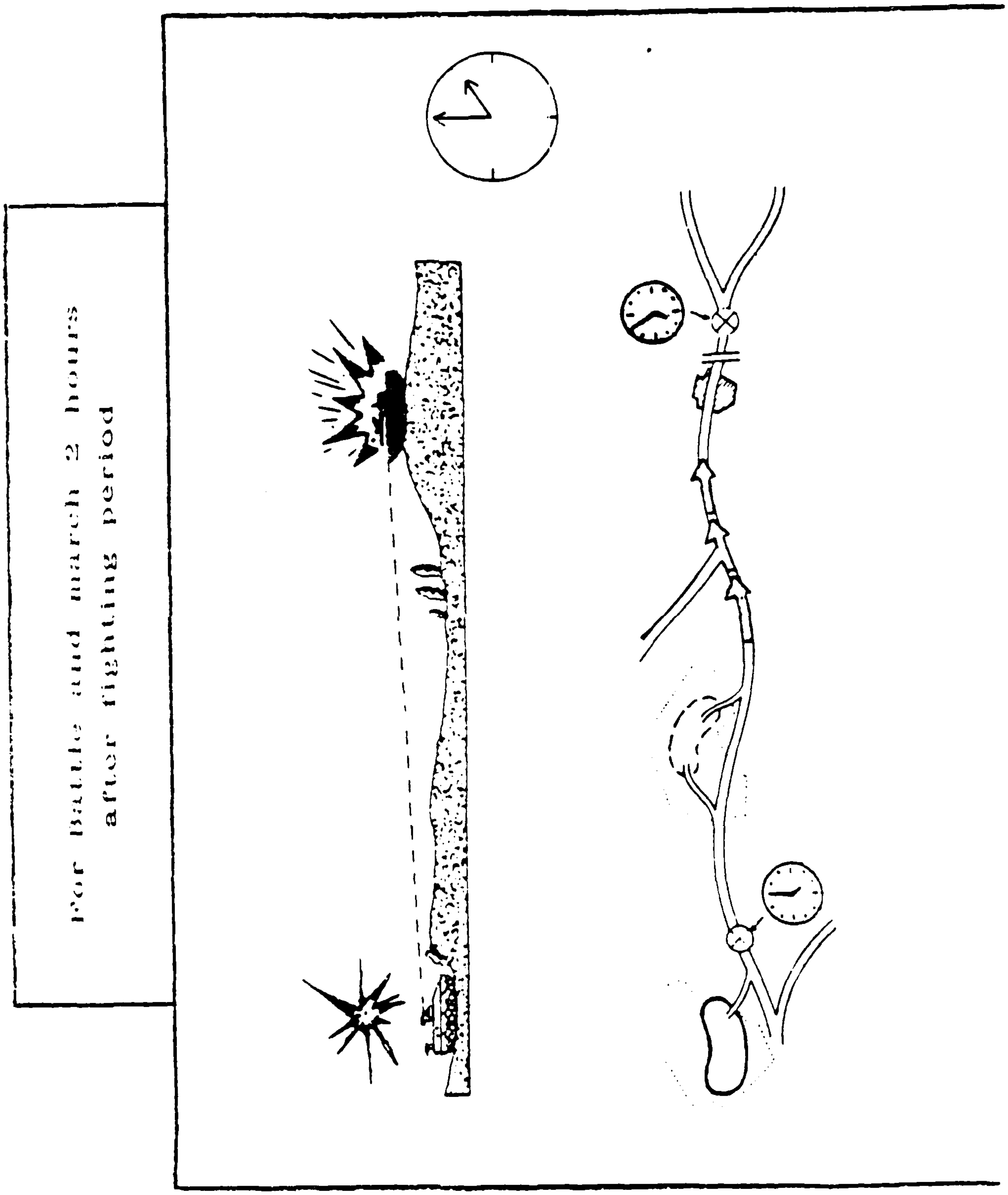


Figure 11

For Alert without battle 1 hour after fighting period

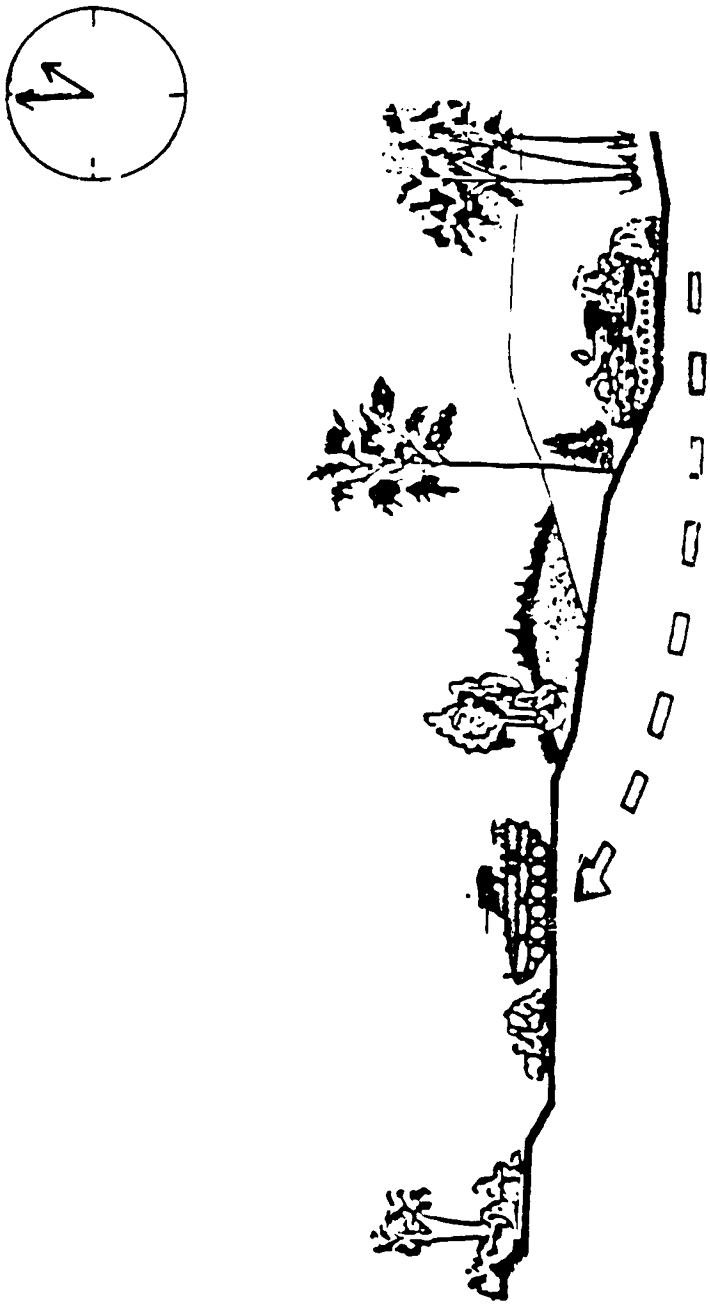
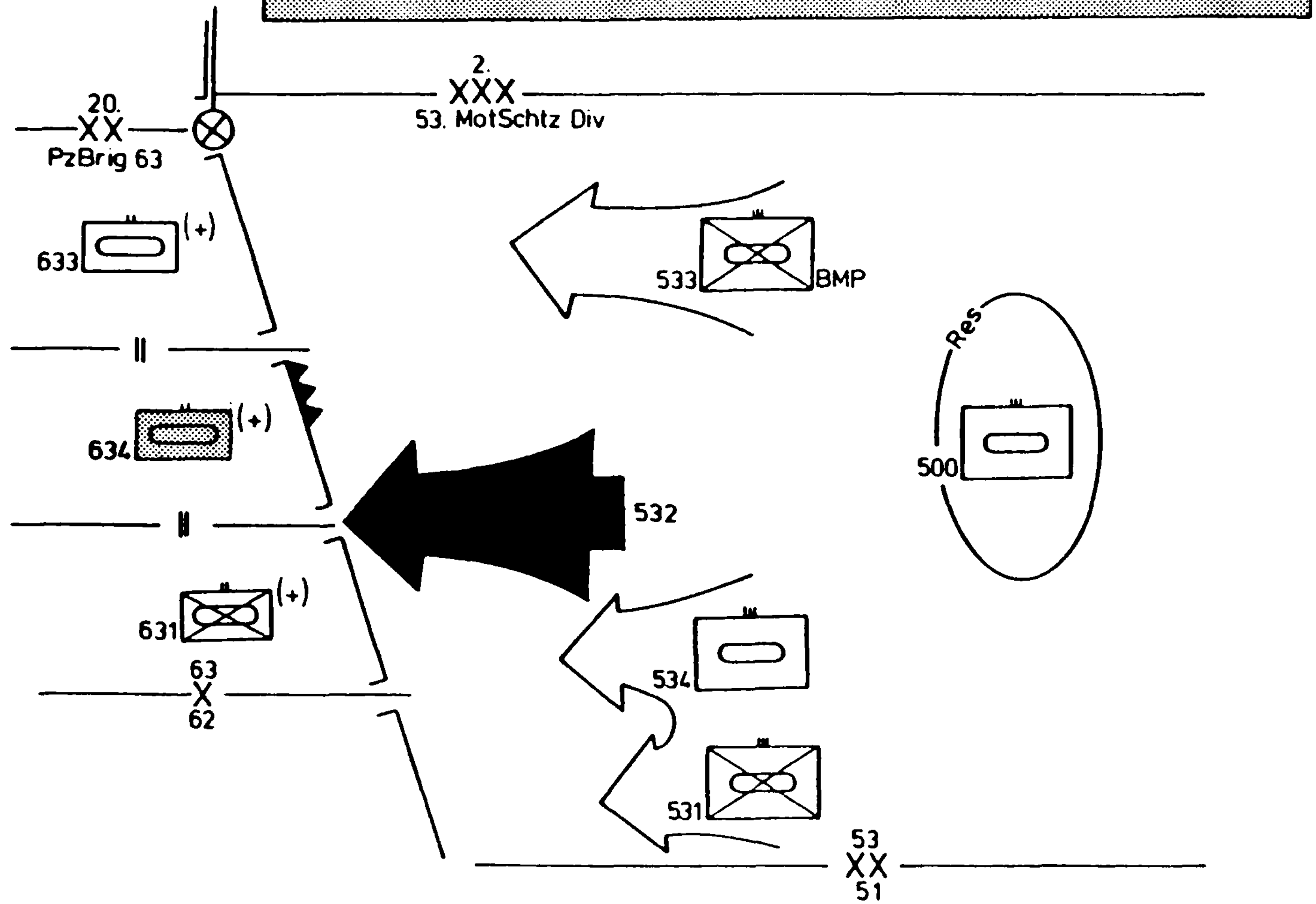


Figure 12

Fatigue of soldiers in battle

Attack of Motorized Division 53. on Tank Brigade 63. (at FEBA)



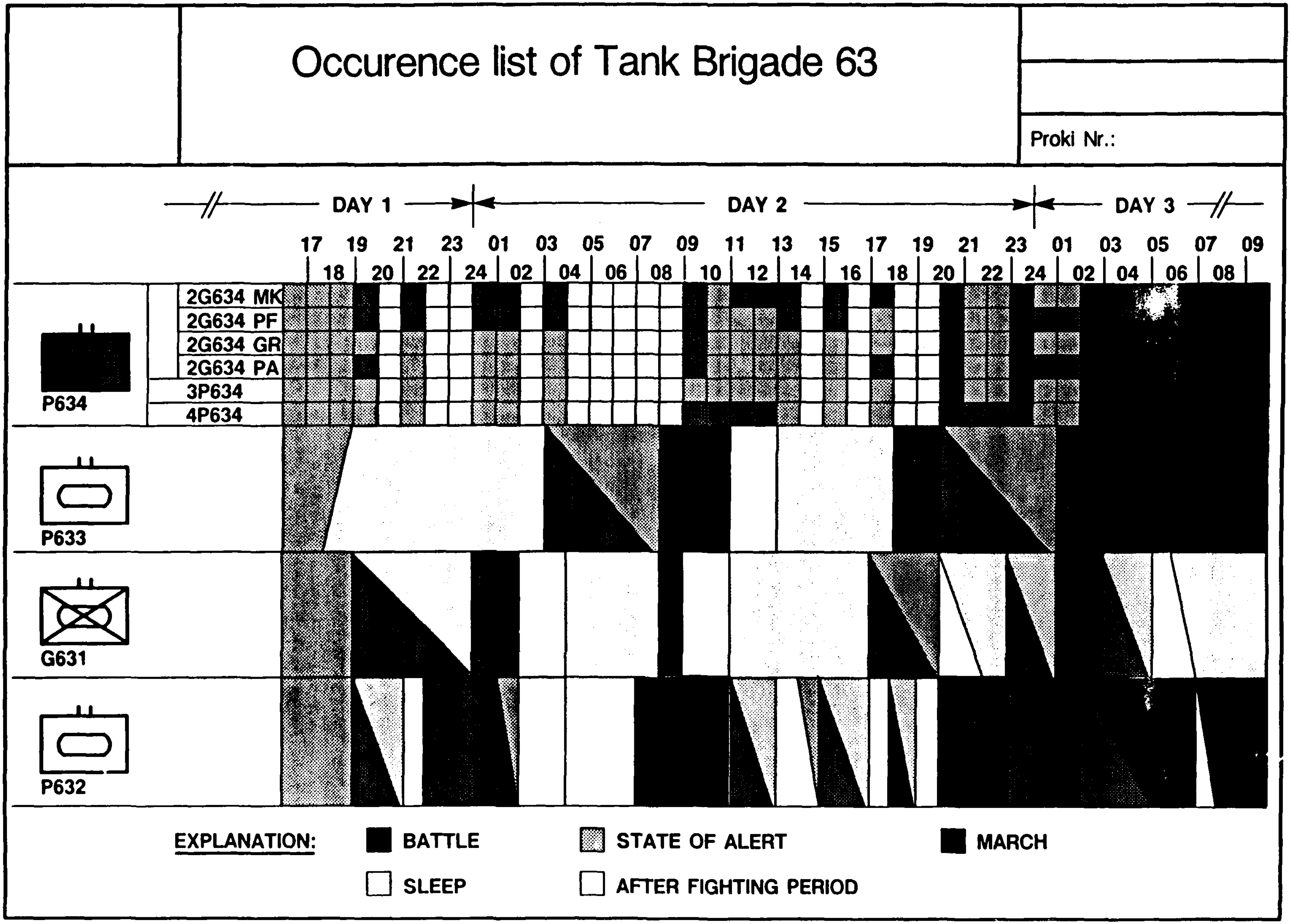

Occurence list of Tank Brigade 63
Proki Nr.:
DAY 1
DAY 2
DAY 3
17 18 19 20 21 22 23 24 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 01 02 03 04 05 06 07 08 09
2G634 MK
2G634 PF
2G634 GR
2G634 PA
3P634
4P634
P634
P633
G631
P632
EXPLANATION:
BATTLE
SLEEP
STATE OF ALERT
AFTER FIGHTING PERIOD
MARCH

Figure 13

Most significant is that tank battalion 632, the reserve, has the least amount of sleeping time available.

Similarly, the sequence of events over the same period is shown in Figure 14 for the RED force. To illustrate, follow the sequence of events for the first company of Tank Battalion 532 (1T532). It is on march in the covering forces and until 1900h on day one, when it contacts the defenders and commences fighting.

- o Fighting continues for ten hours, following which a two hour march takes place to keep pressure on the retreating defenders.
- o After this, fighting and march periods alternate until 1000h on day 2 when this unit has sustained so many losses that it is not able to continue in combat actions.
- o Note also how little time is available for sleep for the troops in battalion 534.

ACCOUNTING FOR STRESS AND FATIGUE IN BATTLE

With this as background, we shall describe the procedure developed for determining the battle effects of stress and fatigue. This procedure has as its purpose the comparison of battle losses with and without these effects. The basis of the procedure is the Lanchester equations, as written in Figure 15, which shows the input data needed. For this study, Lanchester equations were used in a small battle model which calculated the results of combat for a battalion versus a regiment from KORA output. The problem is how to include the effects of stress and fatigue in the required input (right side of the Lanchester equations) to the small battle model.

We started with the number of each type of weapon system and with the number of soldiers for the attackers and defenders as input to KORA. The wargame model determined the losses sustained by the units of the opposing forces for the scenarios of interest, with no account taken of fatigue and stress.

In order to account for these effects, we developed the notion of "stress loss," a datum which is used to determine the number of soldiers unable to engage effectively in combat because of stress and fatigure. We defined stress loss as in Figure 16, and its use is described in Figure 17.

To develop reasonable values for the datum (α), much literature was reviewed and the problem was discussed with the working group who monitored this study. The findings for values of the datum from previous wars are given in Figure 18. These datum values apply to a given conflict and to all soldiers involved who were employing a wide variety of weapons (tanks, artillery, aircraft, etc.). What we needed was a datum value for a unit, such as a company or battalion for army forces. We decidied to evaluate the datum for our needs as shown in Figure 19.

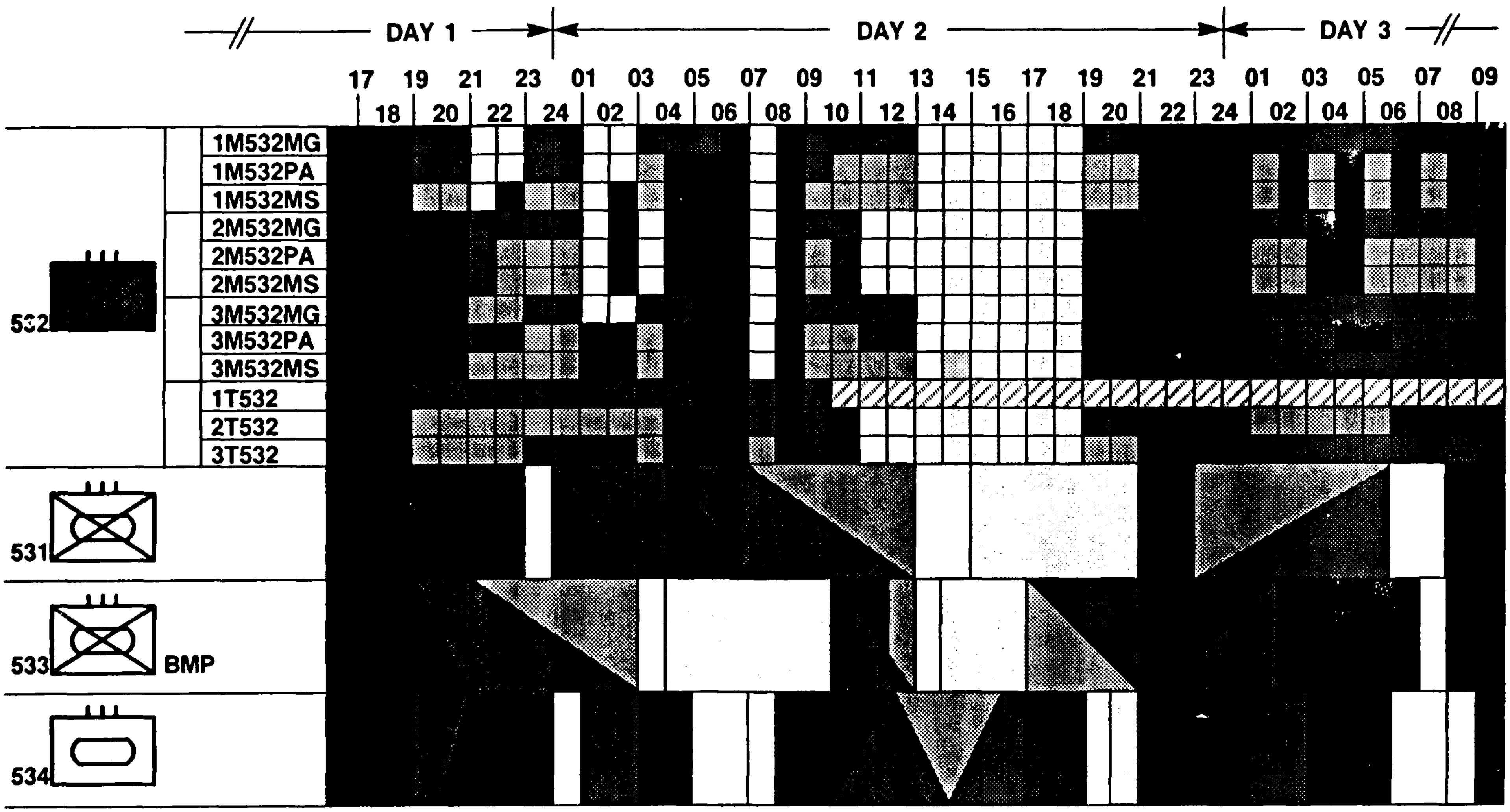
The reference value (on a daily basis) is for the worst situations, and is defined here as:

0.75 for the first and second days of combat
0.60 for the third day
0.50 for the following day

Figure 14

Occurence list of Motorized Division 53 (extract)

Proki Nr.:



EXPLANATION: BATTLE · STATE OF ALERT · MARCH · SLEEP · AFTER FIGHTING PERIOD · ELIMINATION

Figure 15

LANCHESTER EQUATIONS

$$\frac{d\ (\text{Number (RED)})}{dt} = -\ \text{Firerate (BLUE)} * \text{Killprobability (BLUE)} * \text{Number (BLUE)}$$

$$\frac{d\ (\text{Number (BLUE)})}{dt} = -\ \text{Firerate (RED)} * \text{Killprobability (RED)} * \text{Number (RED)}$$

Figure 16

DEFINITION OF STRESS LOSS

Under the notion of stress loss, we mean the loss of soldiers which is not caused by death or injury.

The number of stress losses is described as a function of the losses caused by death or injury.

Figure 17

DESCRIPTION OF THE STRESS LOSS

(for soldiers)

LOSS		LOSS		LOSS
death or injury	+	stress	=	total
death or injury	+	death or injury * α	=	total
5.0	+	5.0 * 0.3	=	6.5

Figure 18

CONFLICT REFERENCED STRESS FACTORS [α]

0.15	Falkland War
0.23	Israel
0.60	Israel
0.75	Amerc. 2. World War
1.00	Amerc. Korean War

Figure 19

CALCULATION OF THE STRESS FACTOR [α]

$$\alpha = \text{Reference Value}_{(\text{day})} * \text{Stress Factor}_{(\text{aktual})}$$

Reference Value ↓

0.75 1. and 2. day
0.60 3. day
0.50 from the 4. day onwards

Stress Factor ↓

value between 0 - 1.00

The decrease in the values as the battle progresses takes into account the adaptation to battle and the battle environment as experienced by new troops (baptism of fire). The values given are for a battle extending over several days. When there is no active combat, the reference value is lower -- this influence will be shown later.

The stress factor (actual) modifies the reference value, resulting in the datum value. Maximum values of the stress factor for different types of stress and the basis for this determination are given in Figure 20. Note that the maximum values given for all the types of stress sum to 1.0. In the case of exposure to all these types of stress simultaneously and to the maximum value, the datum value equals the reference value. If the sum of the stress factors is less than 1.0, then the datum is less than the reference value.

This concept of stress factor determination is key to the whole procedure implemented and described here. Note that the concept has strength in that it appears to be reasonable, but it also has weaknesses. One is that data to support the maximum values of stress factor are hard to develop or acquire. A second weakness is that for the case of enduring several types of stress simultaneously, the correct total value of stress factor may not be the sum of the individual values but may be some other combination.

Next, consider the effects of the stress losses on the effectiveness of the weapons system employed by the soldiers. These losses in effectiveness (fire rate, kill probability) were calculated following the procedure outlined in Figure 21. The number of weapon systems lost in combat are determined in KORA. From this, the losses of soldiers manning these weapon systems are calculated. Using the above procedure, the stress losses to the remaining soldiers are determined. From this, the number of combat capable weapon systems (and their crews) is determined.

A factor which was not included initially, but has since been added, is the potentially important influence of success and failure of each battle group. The parameters of this factor are given in Figure 22. One additional factor which was included was the recovery of the soldiers from stress-related debilitation as a function of time. The assumptions used for recovery of soldiers affected by stress are given in Figure 23.

The next input needed for the Lanchester equations is kill probability. A procedure was used which is similar to that described above in which reference values and stress factors (actual) were developed. Figure 24 presents the reference values used. An example of the use of the data to evaluate the effects of stress losses on the KORA-developed kill probabilities is given in Figure 25. The stress factors (actual) were determined, in a manner similar to that given above for stress losses. The final input needed for the Lanchester equations is fire rate. These were developed in the same way as for kill probability, except that the reference values used are those in Figure 26.

EFFECTS OF BATTLE STRESS AND FATIGUE ON UNIT STRENGTH

The above procedures were used to develop the input to the Lanchester equations so as to quantify measures of the strength of the opposing forces as a function of time into the three day war period for the scenario described at the beginning of this paper. The remaining figures present time histories of the calculated strength of the forces and their stress losses as a function of time using these procedures. They take into account various factors such as recovery rate, differing reference values, and lack of sleep.

Figure 20

CALCULATION OF THE STRESS FACTOR (actual)

Types of stress	maximum value	actual determination
Weapon effect Degree of threat	0.5	Loss suffered by the unit > 10 % of TOE: set maximum value, loss = 0.0 set 0; in between linear curve
Comradeship	0.1	If a period of sleep set 0.0; otherwise set maximum value
Isolation	0.1	TOE strength < 10 %: set maximum value; time of day = night set maximum value, no other intermediate steps
Fatigue Noise Sight/Light Vibrations	0.15	Deprived of sleep for up to 48 hours set 0.0; for deprived of sleep up to 96 hours set maximum value; in between linear curve
Day Rhythm Day/Night	0.05	If sleep period set 0.0; set maximum value if no sleep period; no other intermediate steps
Fear (errors)	0.05	--- " ---
Infornmation deficit Unclear battlesit. Boredom/Surprise	0.05	--- " ---

Figure 21

P R O C E D U R E

to calculate the number of weapon systems
lost due to stress

° Given: losses of weapon systems in K O R A

- calculation of the number of losses of soldiers on these weapon systems
- calculation of stress losses (shown procedure)
- calculation of how many of these stress losses can be transferred to the remaining weapon systems
- remaining to obtain combat capable weapon systems

Figure 22

SUCCESS / FAILURE

Parameters :

- Own number of weapon systems
- Enemy number of weapon systems
- Losses scored
- Losses suffered

Figure 23

RECOVERY

of the soldiers disabled by stress

40 % after 24 hours

20 % after 48 hours

30 % after 96 hours

10 % never

are returned to the fighting units

Figure 24

REFERENCE VALUE FOR KILL PROBABILITY

daytime	ammunition	reference value
day	artillery	0.6
	gun, rifle	0.75
	guided missle	0.7
night	artillery	0.4
	gun, rifle	0.5
	guided missle	0.4

EXAMPLE TO CALCULATE THE KILL PROBABILITY

Accepted from KORA: PKILL for a guided missle 0.6

1. Determination : PKILL cannot be greater than 0.6
2. Determination : PKILL cannot be less than 0.6 * 0.7 = 0.42
3. Determination : For a given stress factor of

0.00	PKILL becomes 0.6
0.50	PKILL becomes 0.51
0.75	PKILL becomes 0.46
1.00	PKILL becomes 0.42

Figure 25

Figure 26

REFERENCE VALUE FOR THE FIRE RATE

daytime	reference value
day	0.8
night	0.5

For example, Figure 27 is a typical result of the residual strength of a defending company without stress effects. The remaining Fiugres present the following results:

Figure 28: Comparison of residual strength for a company with and without stress, plus the stress losses.

Figure 29: Similar results for a different company

Figure 30: Similar results summed for all Main Battle Tank companies in Tank Brigade 63 (defenders)

Figure 31: Similar results for all Infantry Fighting Vehicle companies in Tank Brigade 63

Figure 32: Results for all dismounted companies in Brigade 63

Figure 33: Results for all armored vehicles in Brigade 63

Figure 34: Results for all RED armoured vehicles attacking Brigade 63

Figure 35: Variation in attacker/defender force ratio with and without stress losses.

Figure 36: Variation in residual strength for a Main Battle Tank company as a function of stress loss reference value.

Figure 37: Variation in residual strength for Brigade 63 as a function of "kill probability" reference value.

Figure 38: Variation in residual strength for Brigade 63 as a function of "firing rate" reference vlaue.

Figure 39: Influence of including "success/failure" in Main Battle Tank company residual strength calculations.

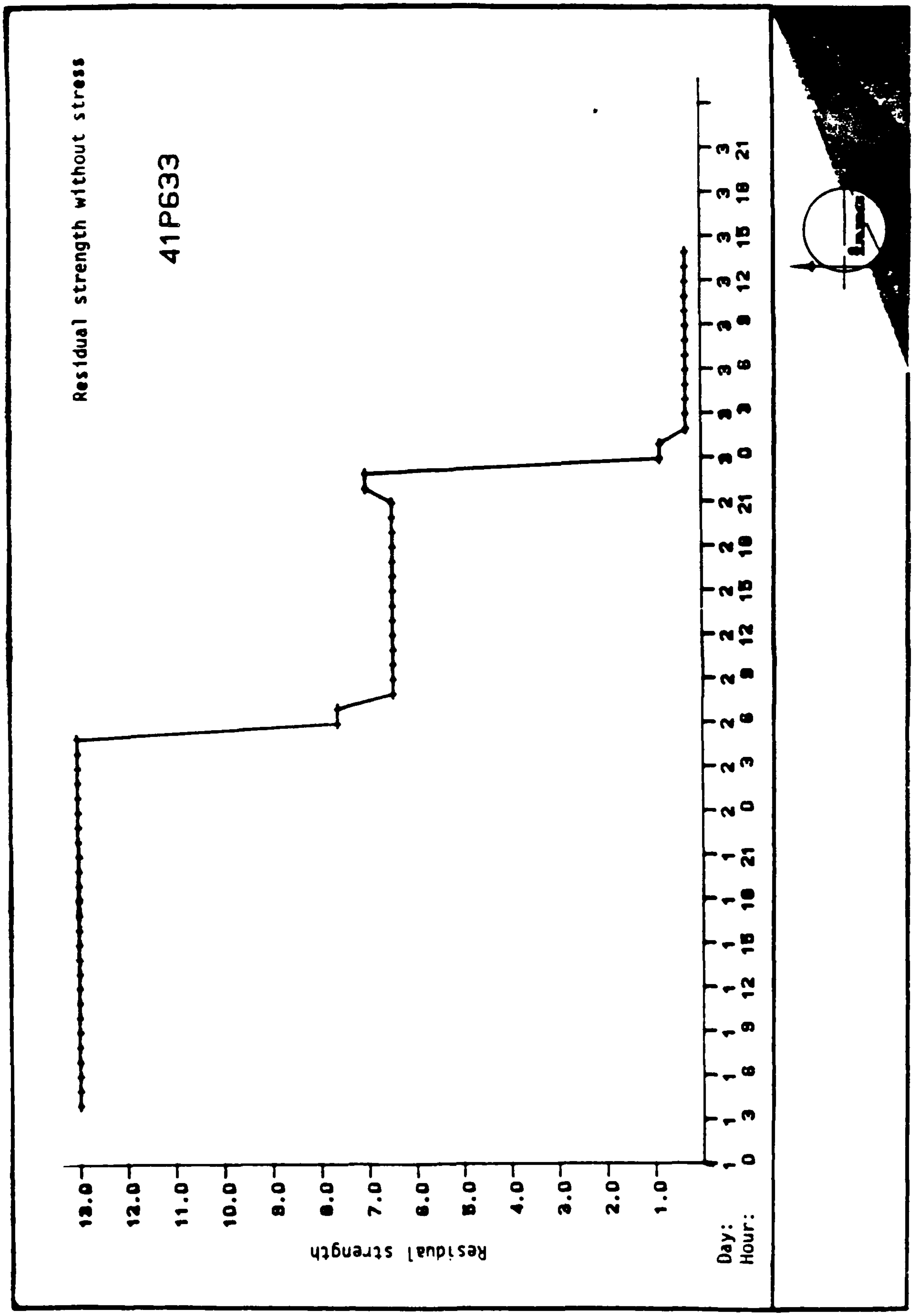
Figure 40: Influence of including soldier recovery from stress in Brigade 63 residual strength calculations.

Figure 41: Influence of sleep loss on Brigade 63 residual strength.

Figure 42: Influence of sleep loss on RED force (attacking Brigade63) residual strength.

The conclusions reached from this analysis and review of the plots of residual strength versus time into the battle are given in Figure 43.

Figure 27



Residual strength without stress
41P633
Residual strength
Day:
Hour:

Figure 28

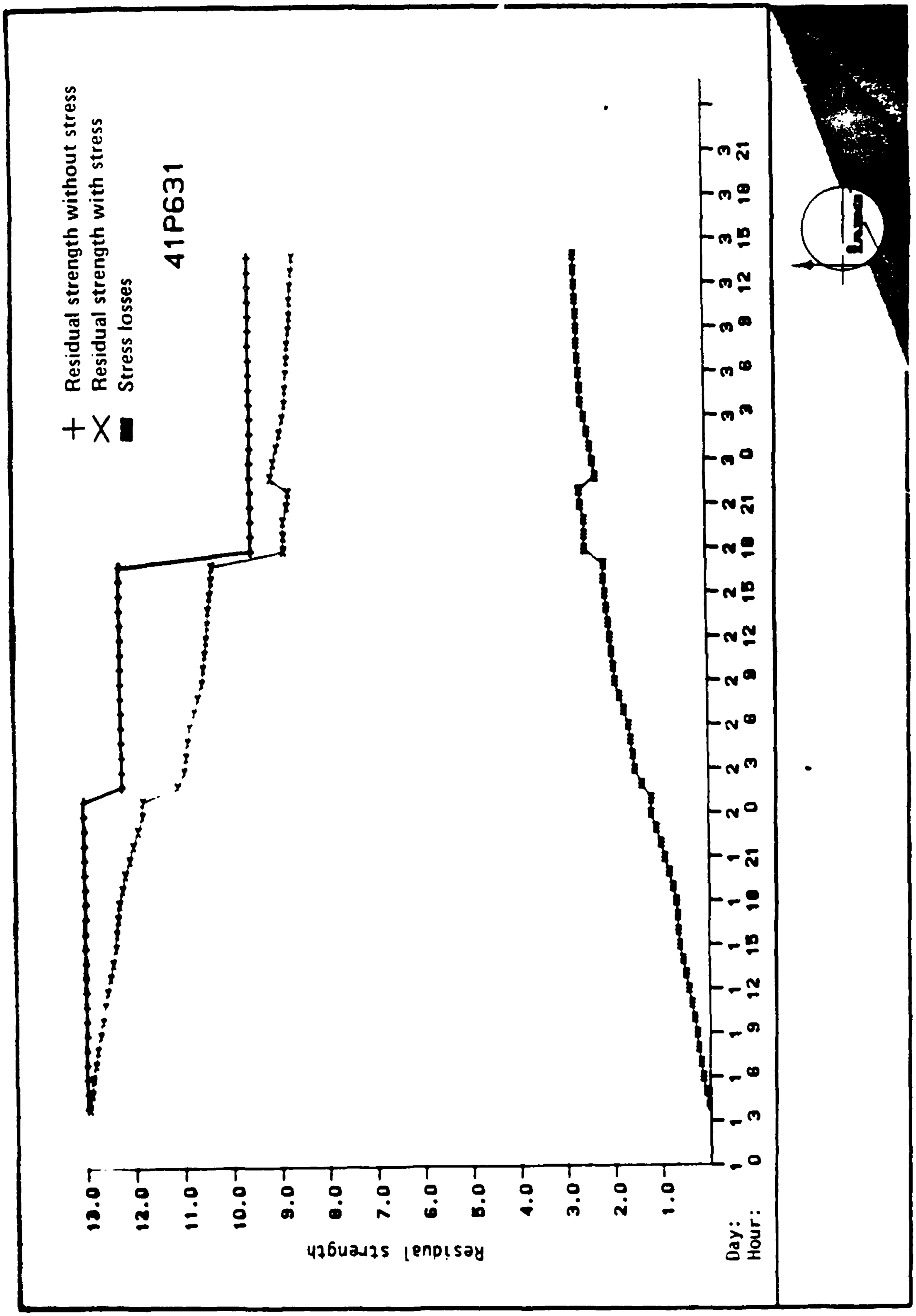
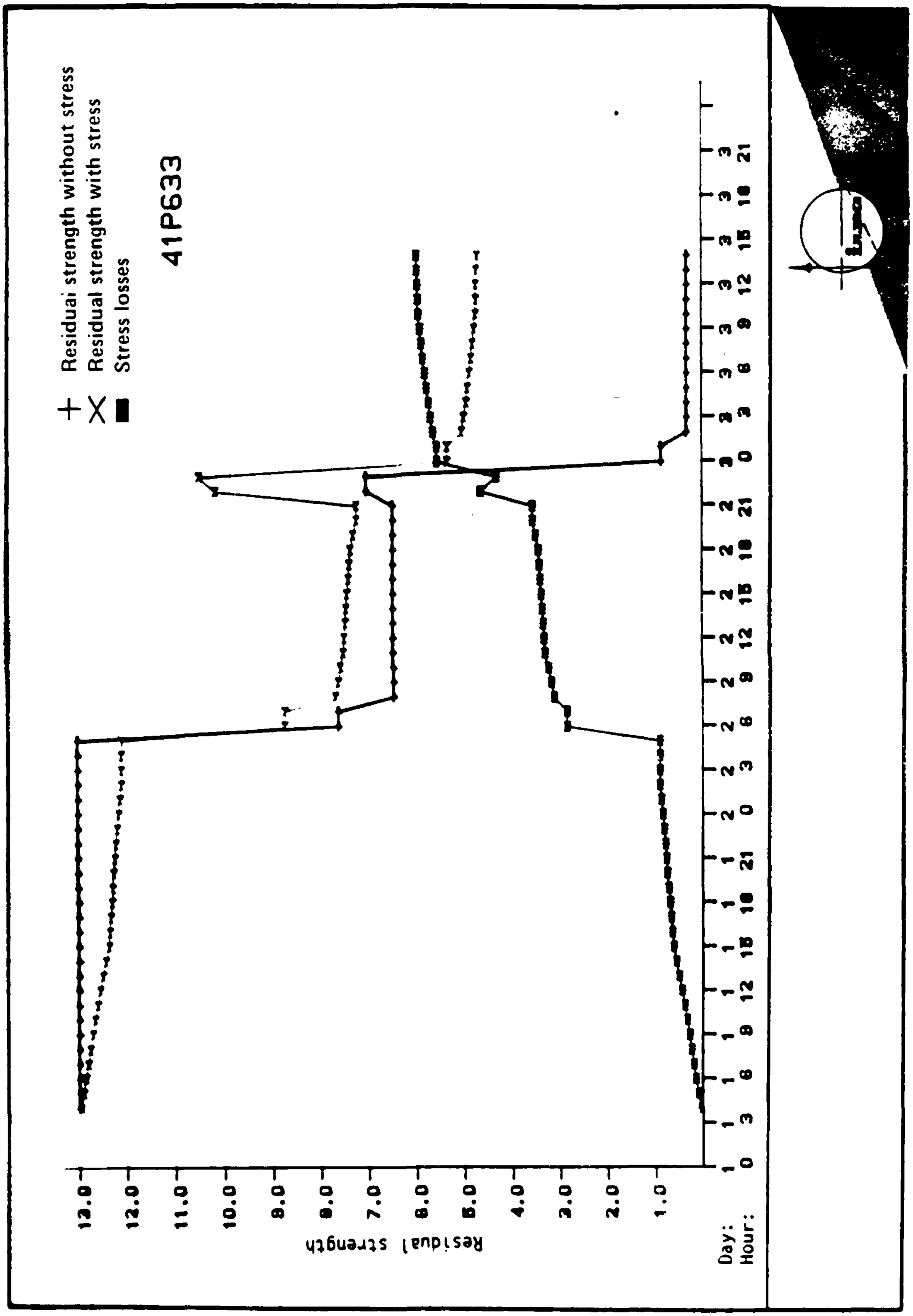

+ Residual strength without stress
X Residual strength with stress
■ Stress losses
41P631
Residual strength
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Day:
Hour:

Figure 29



Residual strength without stress
Residual strength with stress
Stress losses
41P633
Residual strength
Day:
Hour:

Figure 30

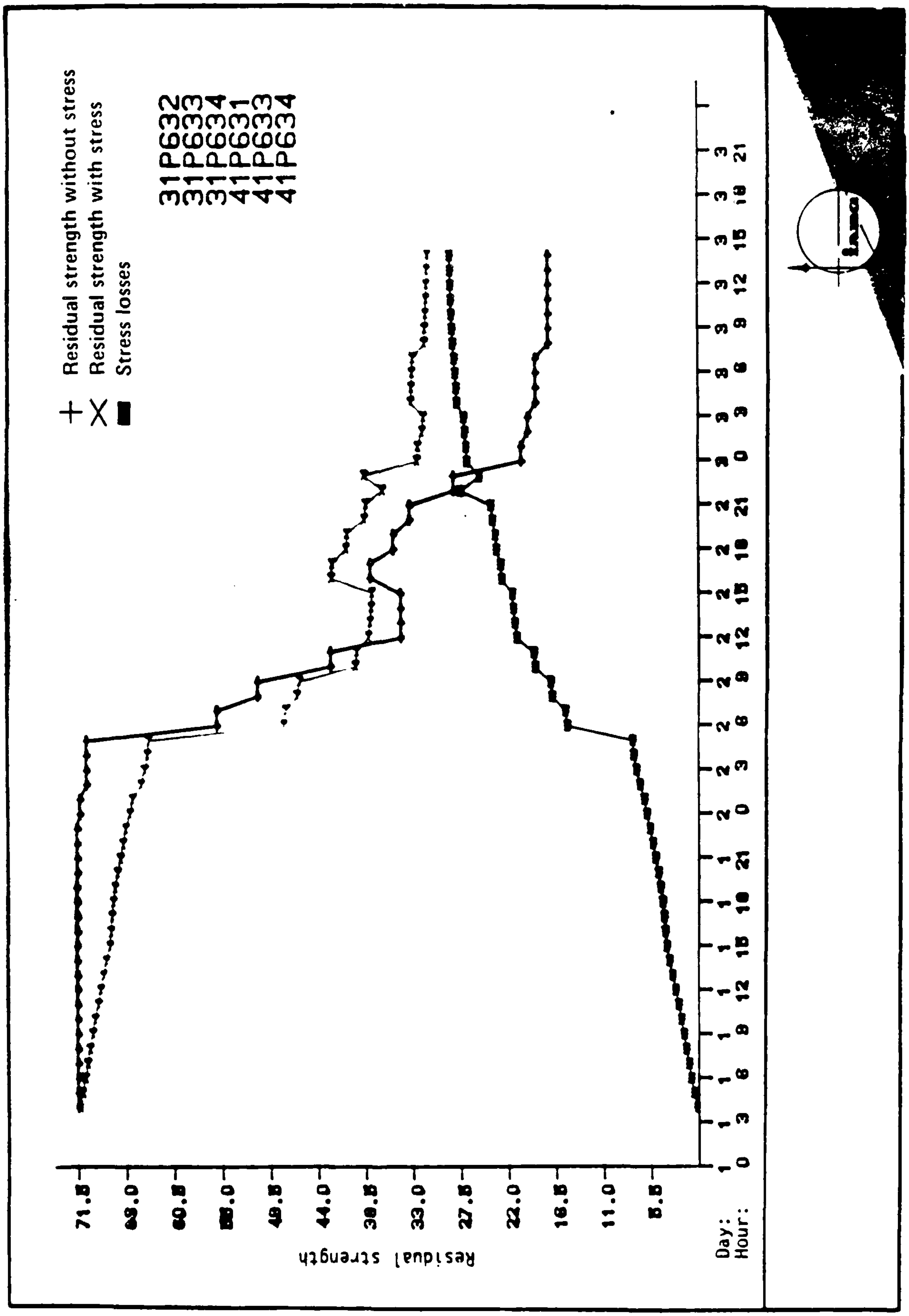

Residual strength without stress
Residual strength with stress
Stress losses
31P632
31P633
31P634
41P631
41P633
41P634
Residual strength
71.5
66.0
60.5
55.0
49.5
44.0
38.5
33.0
27.5
22.0
16.5
11.0
5.5
Day:
Hour:

Figure 31

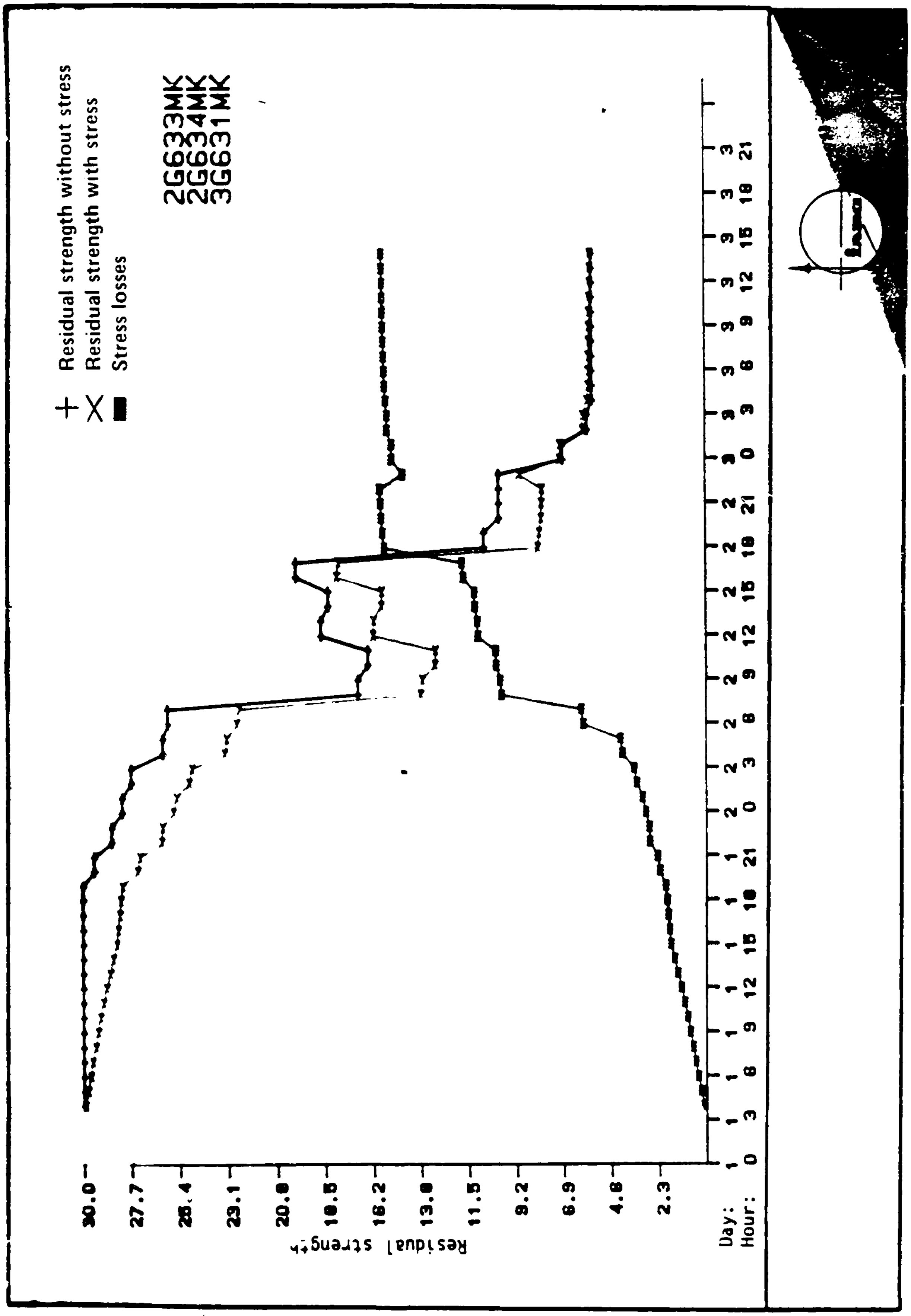

Residual strength without stress
Residual strength with stress
Stress losses
2G633MK
2G634MK
3G631MK
Residual strength
30.0
27.7
25.4
23.1
20.8
18.5
16.2
13.9
11.5
9.2
6.9
4.6
2.3
Day:
Hour:

Figure 32

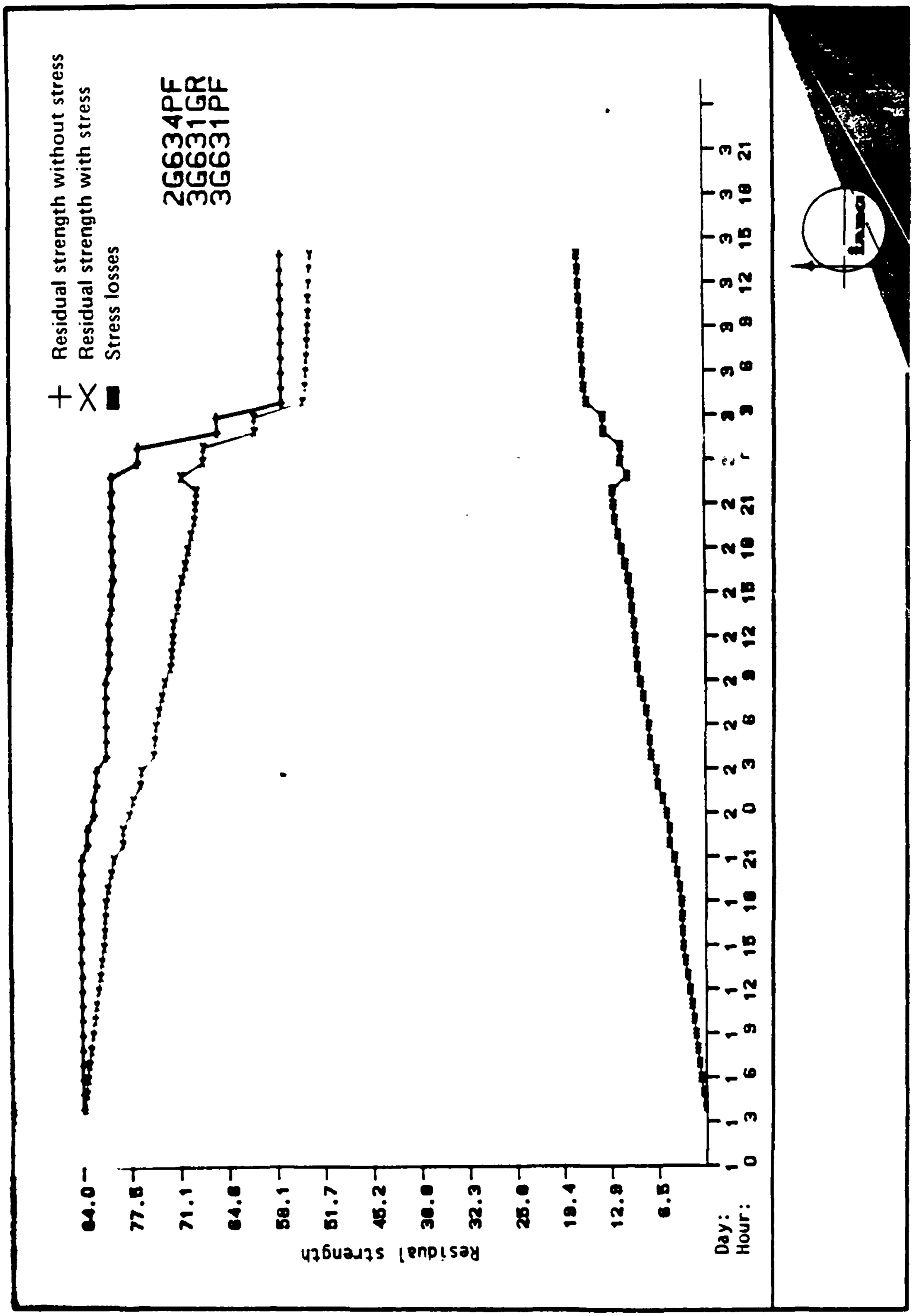

Residual strength without stress
Residual strength with stress
Stress losses
2G634PF
3G631GR
3G631PF
Residual strength
84.0
77.5
71.1
64.6
58.1
51.7
45.2
38.8
32.3
25.8
19.4
12.9
6.5
Day:
Hour:

Figure 33

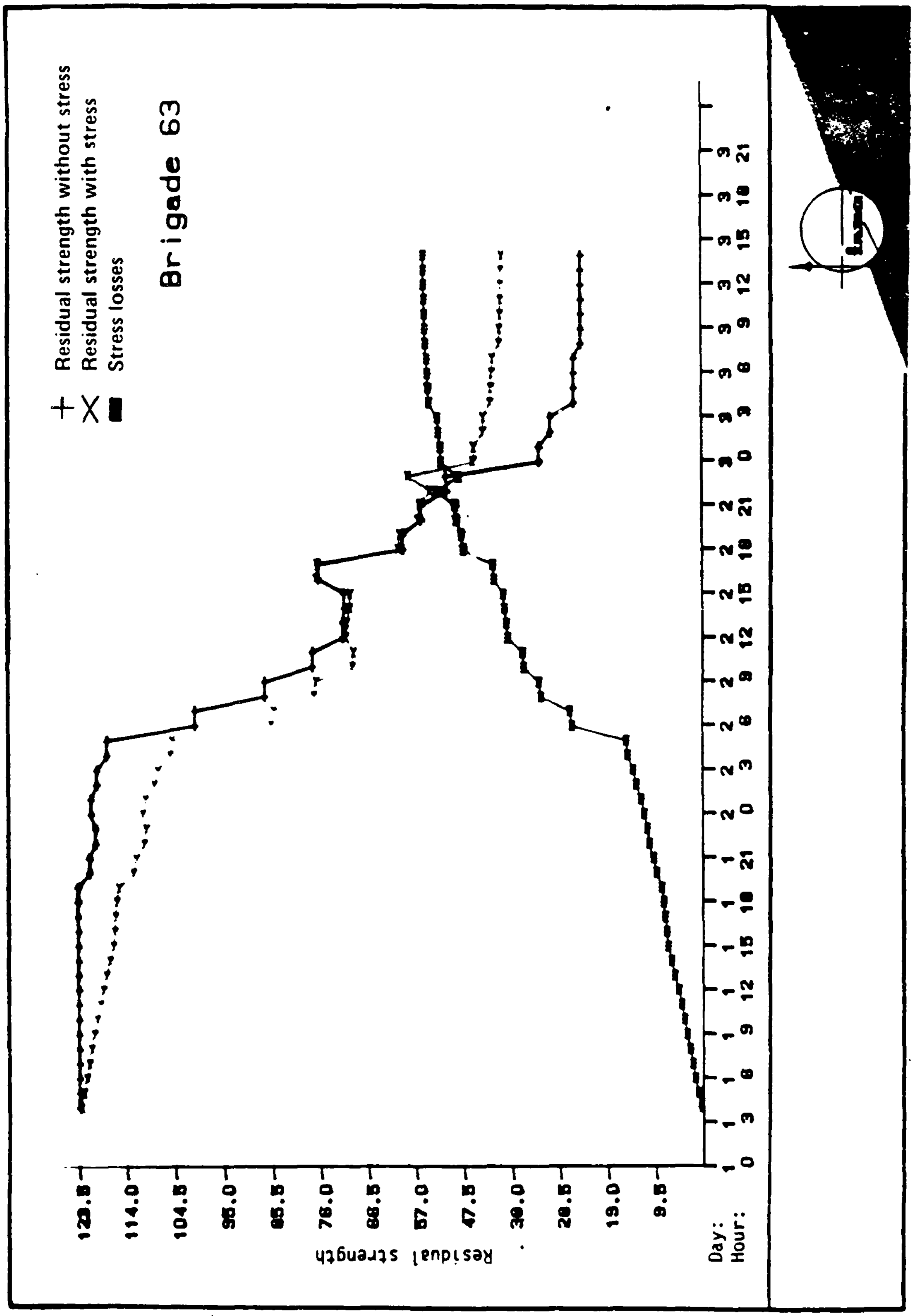

Residual strength without stress
Residual strength with stress
Stress losses
Brigade 63
Residual strength
123.5
114.0
104.5
95.0
85.5
76.0
66.5
57.0
47.5
38.0
28.5
19.0
9.5
Day:
Hour:

Figure 34

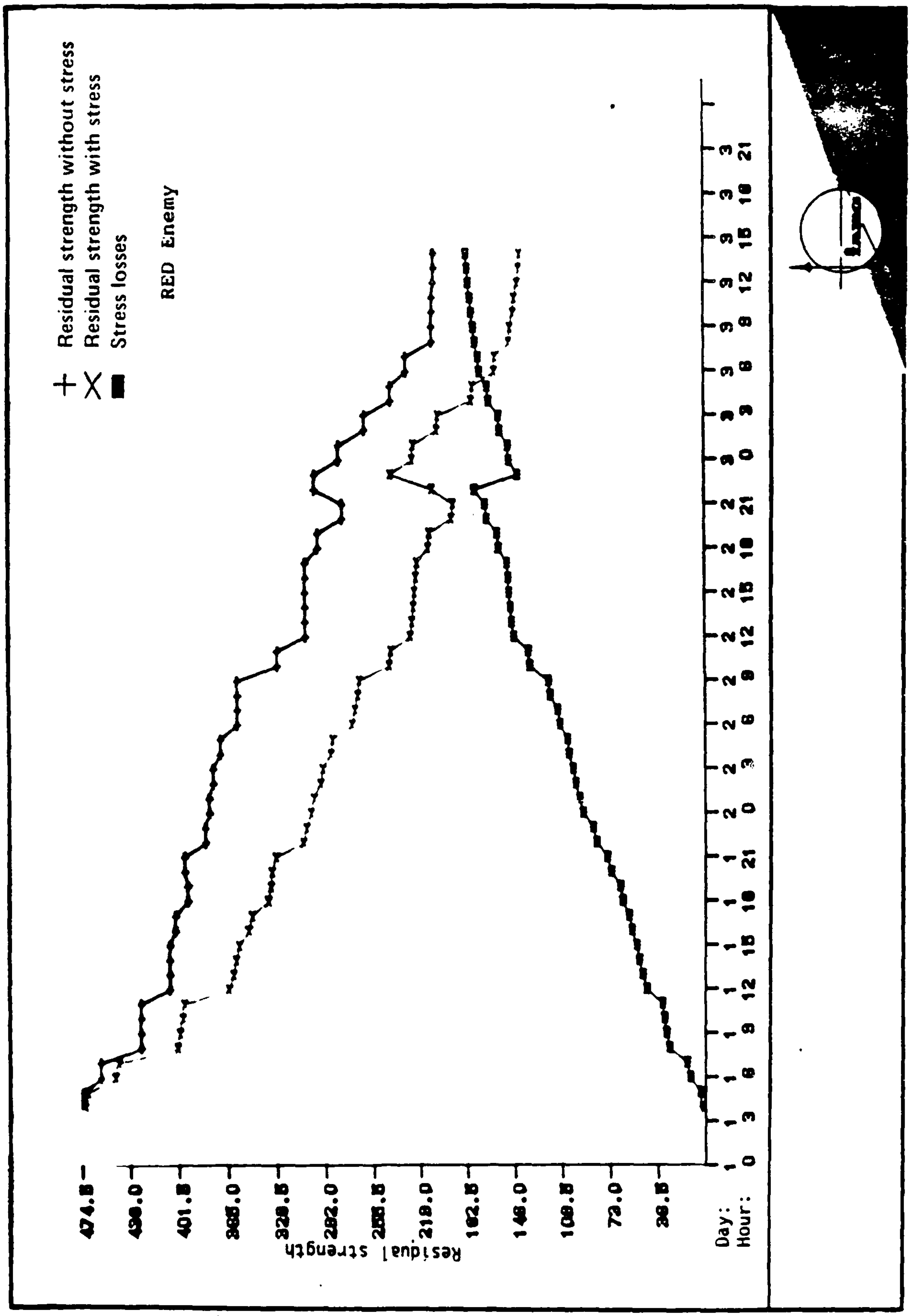

Residual strength without stress
Residual strength with stress
Stress losses
RED Enemy
Residual strength
Day:
Hour:

Figure 35

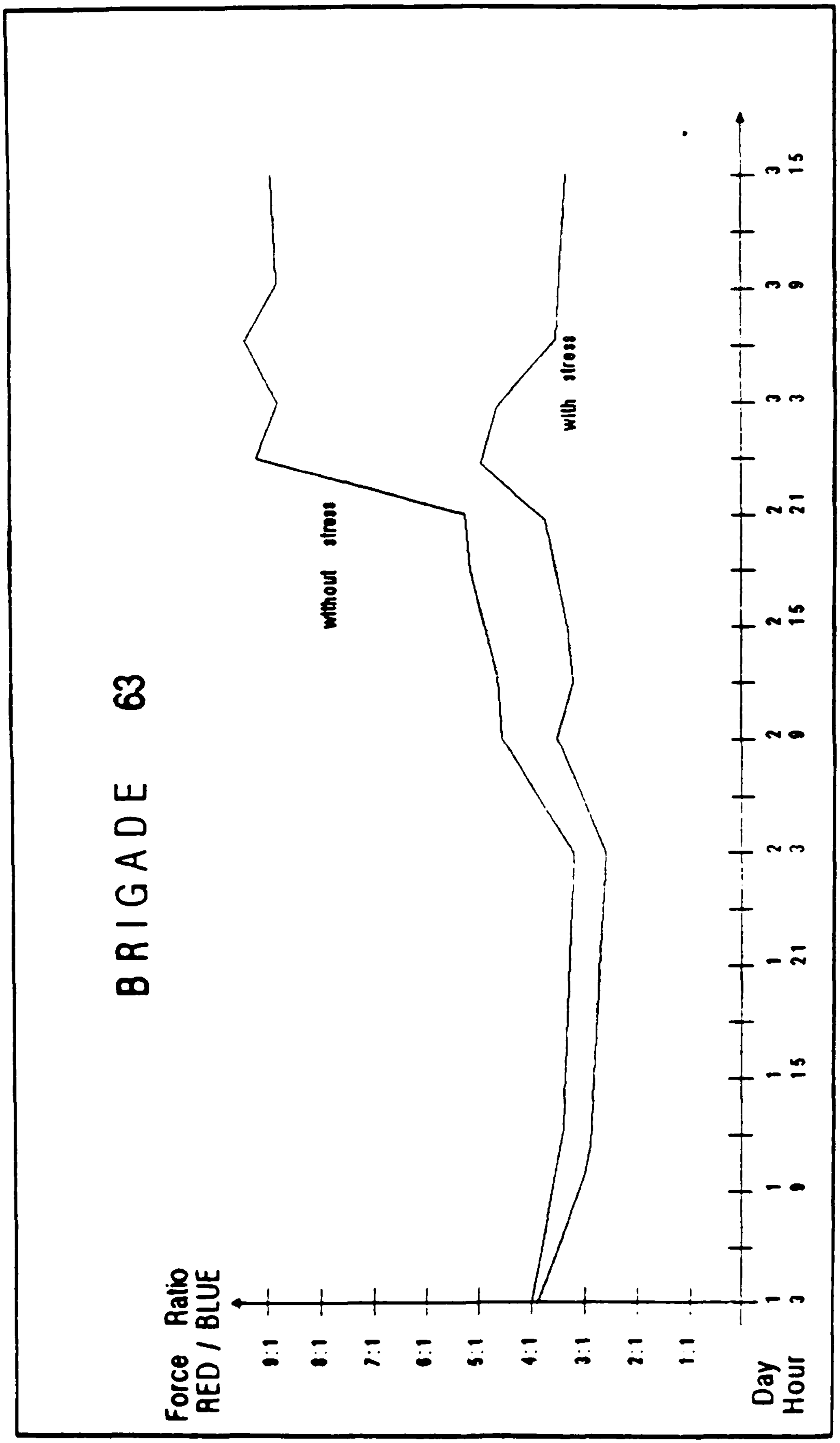
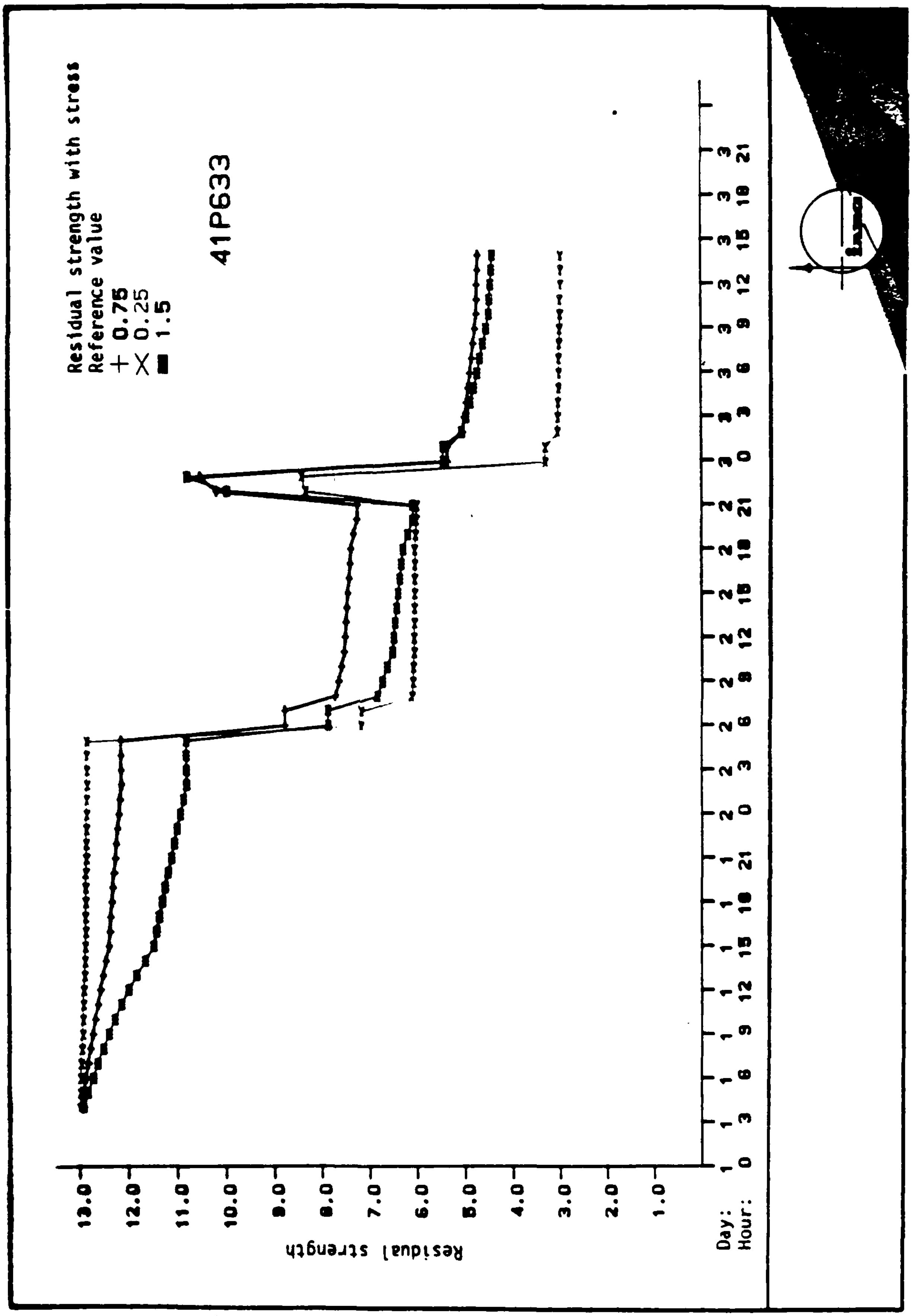
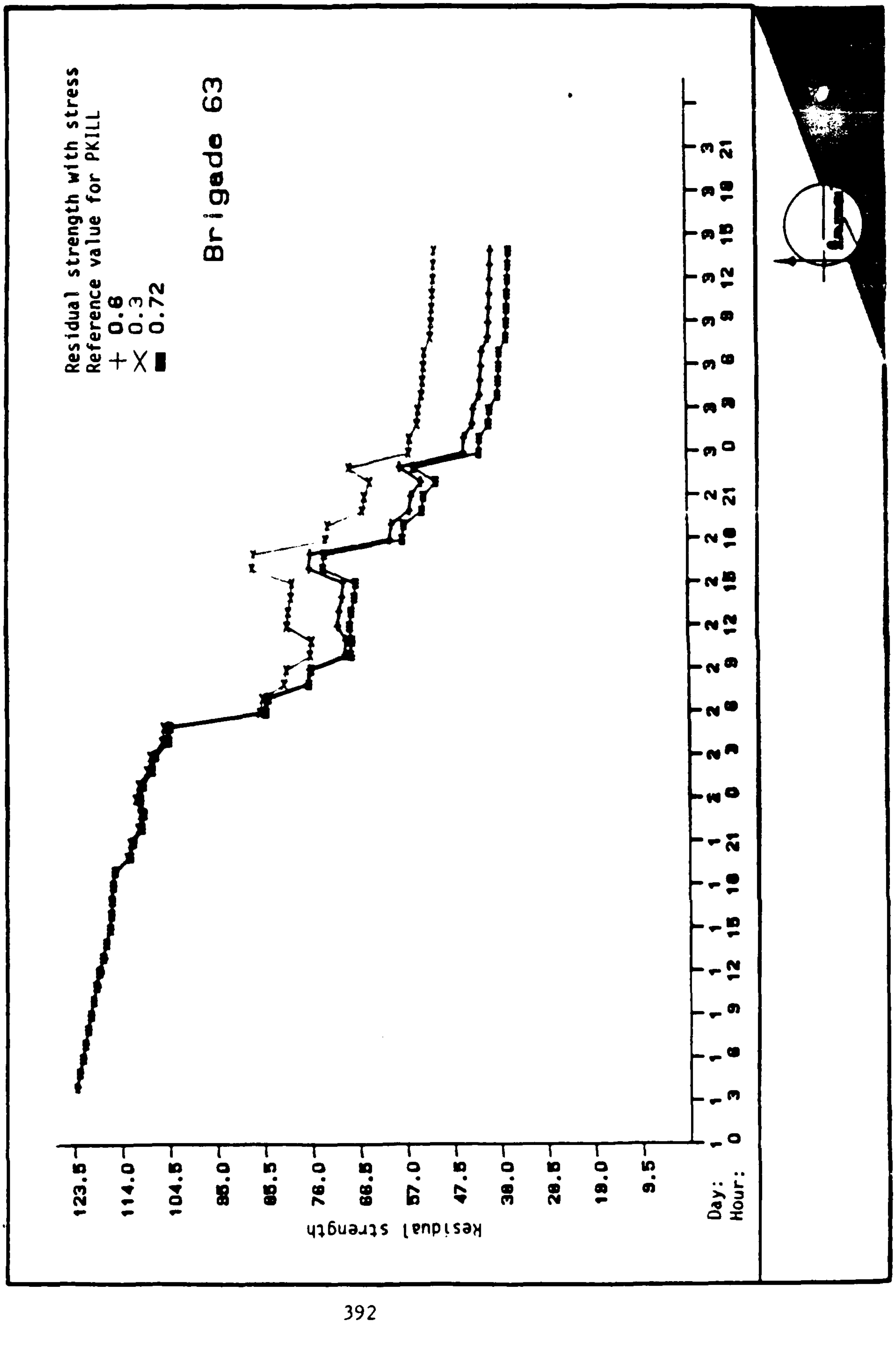

BRIGADE 63
Force Ratio
RED / BLUE
9:1
8:1
7:1
6:1
5:1
4:1
3:1
2:1
1:1
Day
Hour
1 3
1 9
1 15
1 21
2 3
2 9
2 15
2 21
3 3
3 9
3 15
without stress
with stress

Figure 36



Residual strength with stress
Reference value
+ 0.75
X 0.25
■ 1.5
41P633
Residual strength
Day:
Hour:

Figure 37



Residual strength with stress
Reference value for PKILL
+ 0.8
X 0.3
■ 0.72
Brigade 63
Residual strength
123.5
114.0
104.5
95.0
85.5
76.0
66.5
57.0
47.5
38.0
28.5
19.0
9.5
Day:
Hour:

Figure 38

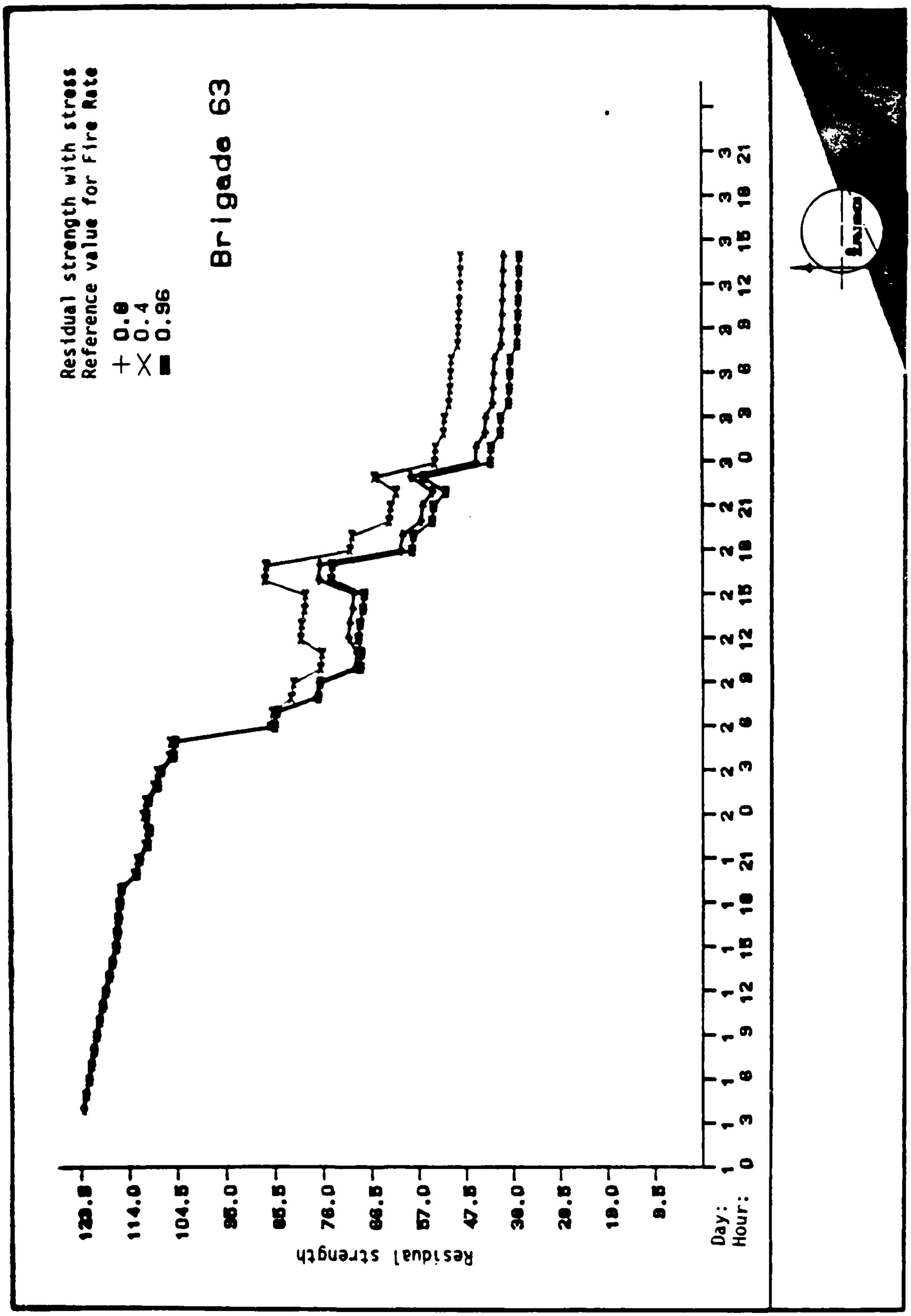
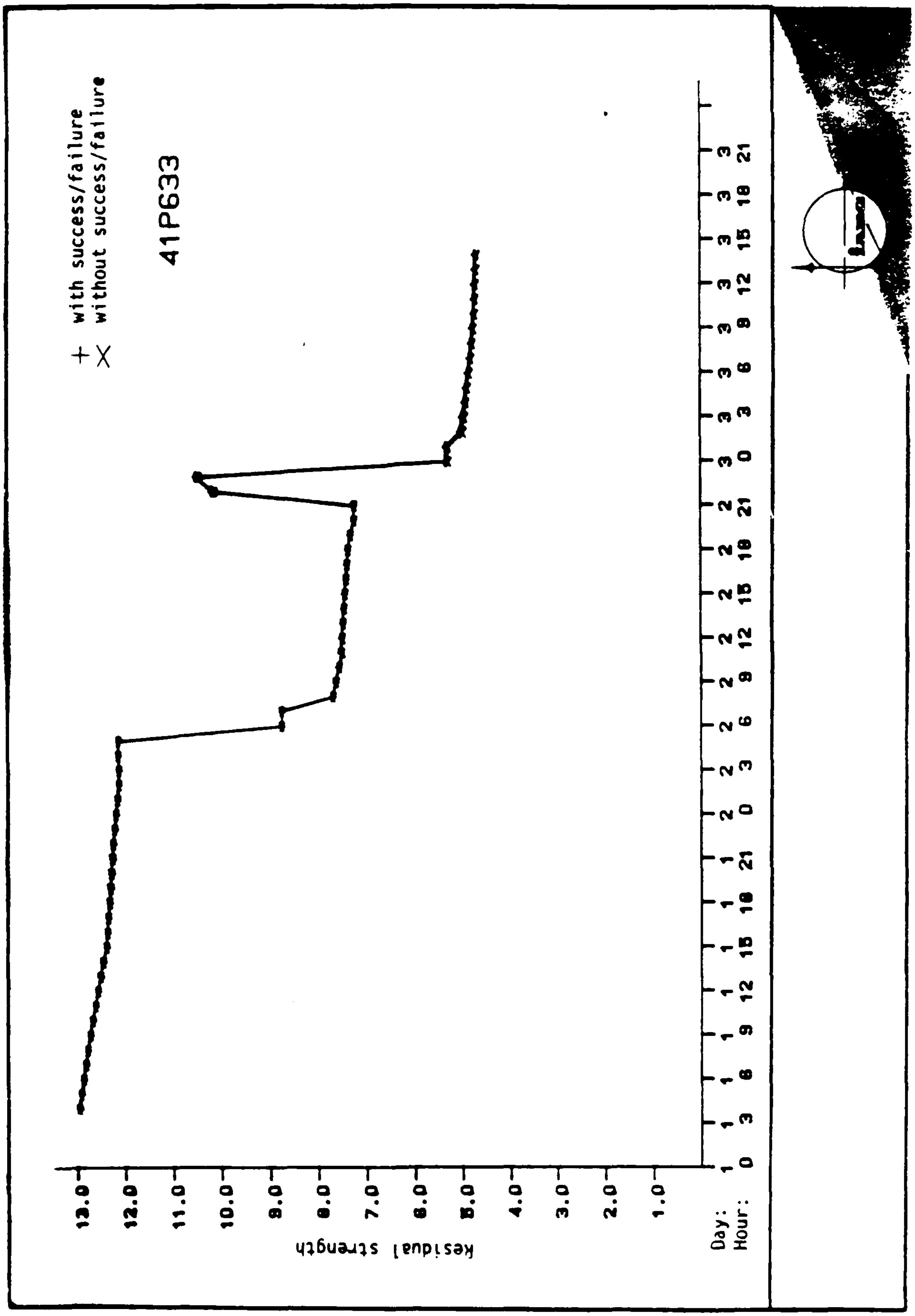

Residual strength with stress
Reference value for Fire Rate
+ 0.8
X 0.4
■ 0.96
Brigade 63
Residual strength
123.5
114.0
104.5
95.0
85.5
76.0
66.5
57.0
47.5
38.0
28.5
19.0
9.5
Day:
Hour:

Figure 39



+ with success/failure
X without success/failure
41P633
Residual strength
Day:
Hour:

Figure 40

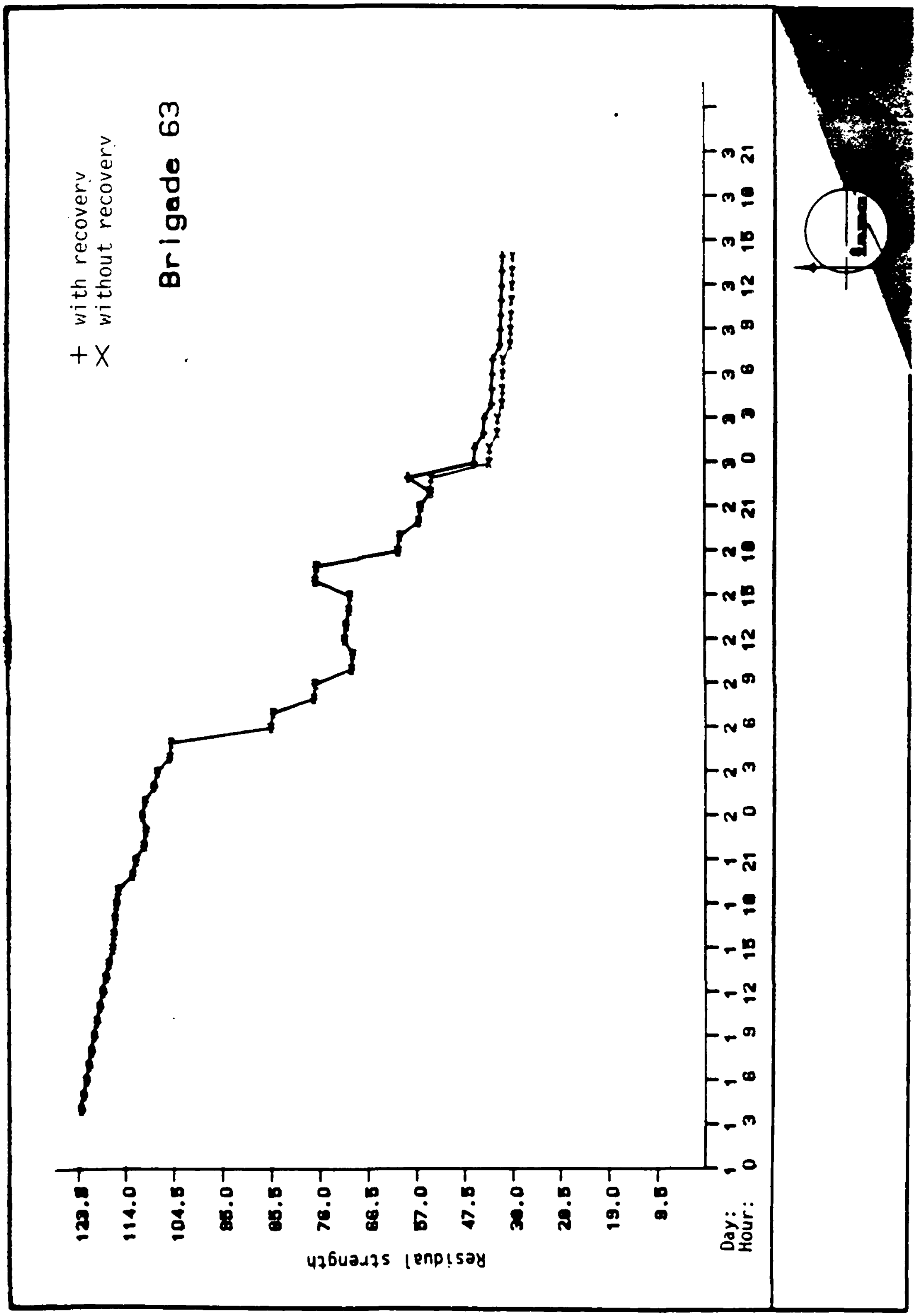

+ with recovery
X without recovery
Brigade 63
Residual strength
123.5
114.0
104.5
95.0
85.5
76.0
66.5
57.0
47.5
38.0
28.5
19.0
9.5
Day:
Hour:

Figure 41

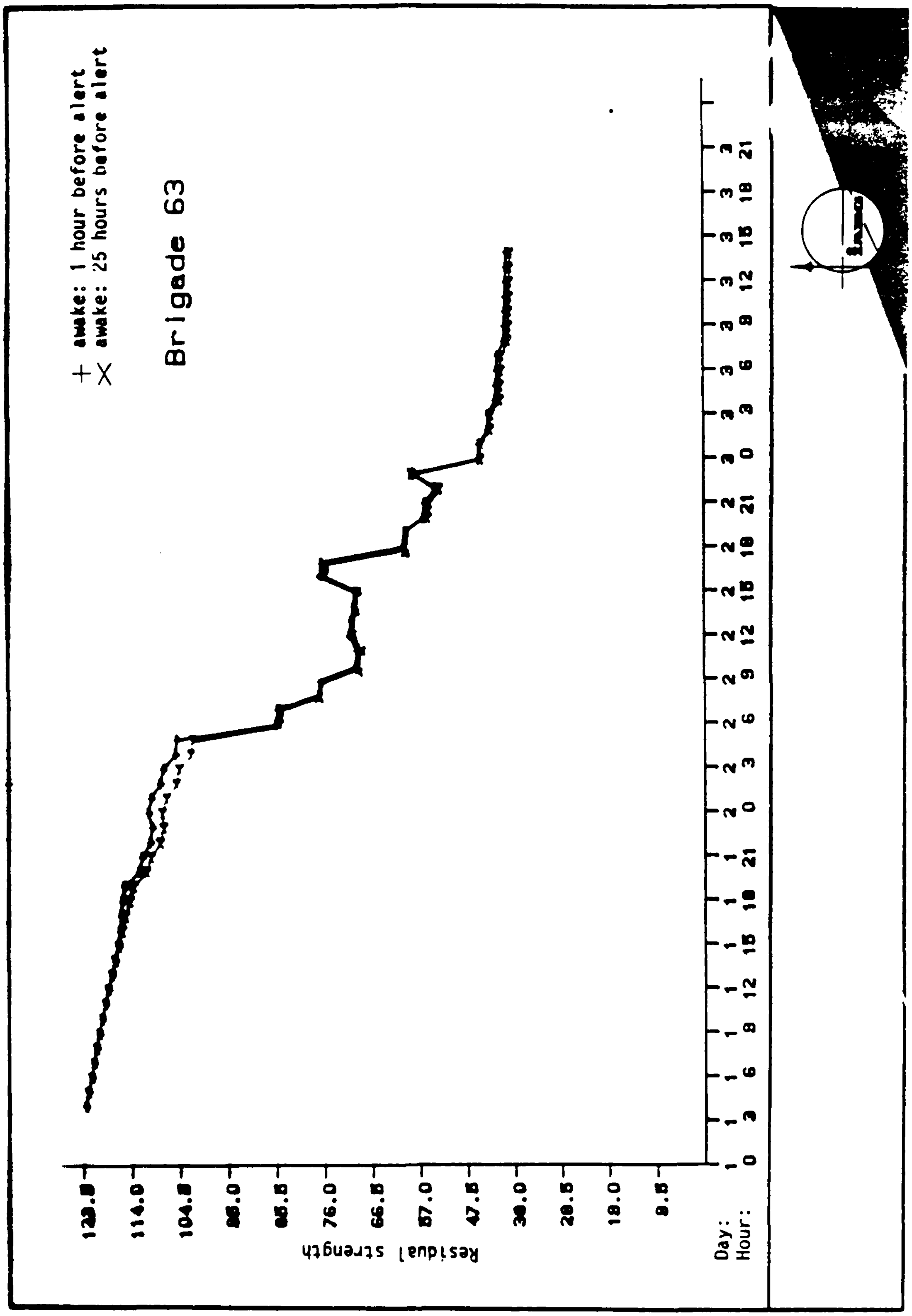
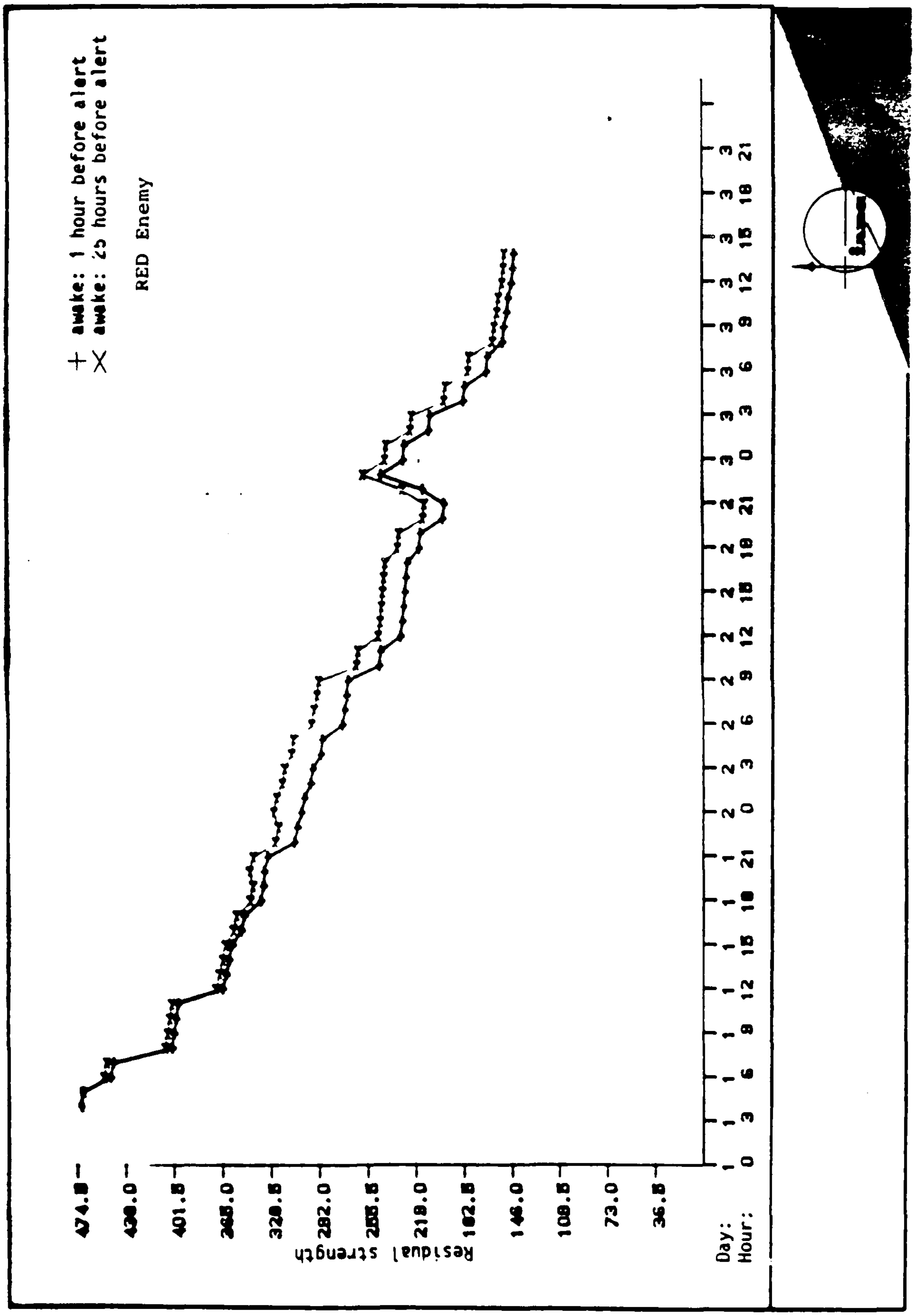

+ awake: 1 hour before alert
X awake: 25 hours before alert
Brigade 63
Residual strength
Day:
Hour:

Figure 42



+ awake: 1 hour before alert
X awake: 25 hours before alert
RED Enemy
Residual strength
Day:
Hour:

Figure 43

Conclusions

- Influence of stress phenomena observed on the combat result is clear

- The complex interaction of the stress influences permits prognoses with reference to their effect on a battle only to a limited extent

- One-sided increase in stress for the opponent can be set against own combat efficiency improvement

- Taking stress recovery into consideration is more important than is visible in the result protocols (too early an end of battle)

- The phenomena success/failure should be investigated further

- The parametric investigations performed give first indications that strength and lack of sleep have a greater influence than firing rate and kill probability

DISCUSSION OF "FATIGUE OF SOLDIERS IN BATTLE"
by Htm. W. Siemon and H. Wollschlager

DISCUSSANT: Sally J. Van Nostrand, US Army Concepts Analysis Agency

This study, Fatigue of Soldiers in Battle, is a landmark study. The paper presents the results of a creative study that is a perfect example of the final goal of those of us involved in planning MORIMOC II. The lack of papers of this type provided the genesis for this symposium.

Fatigue of Soldiers in Battle is the first study I've seen that includes a wide variety of soldier factors in a combat model. Even the scenario includes the sleep discipline. In this study, fatigue means not just the fatigue caused by sleep loss or physical exertion - it means both these physical fatigue factors and the fatigue caused by another large set of factors which affect the soldiers' perception of events. Soldier perceptions intensify the effects of their physical fatigue, and the combination leads to the condition popularly known as "combat fatigue." In this paper, these other factors include: "baptism by fire," psychological impact of unit casualties, cohesion, isolation, noise, ambient light, vibrations, time of day, fear, information deficit, boredom, and surprise. Even the recovery from combat fatigue is included (with, as in the real world, some soldiers never recovering from the effects).

I commend the authors for an exemplary study--both in the content and the presentation. The results were clearly and graphically presented. The only faults that I could find with this study are that (1) I would have liked to see some excursions which would show the sensitivity of the model to the various factors included, and (2) the values for the data were subjectively, rather than empirically, derived. At this stage of development of including the human dimension in combat models, neither of these semi-faults should be considered significant. I suspect that they soon will have finished the additional excursions. Maybe the authors will present those results at another meeting in the not too far distant future. I, for one, will be sure to attend. As for the second, the fact that they were able to generate any values for use should be applauded. I know that the human performance measurement arena is not yet developed to the point that they could have developed empirical values. This is an impressive study, and I wish I could say that we have had some (here in the United States) that are comparable to this.

THE EFFECTS OF FLYING TRAINING ON PILOT PROFICIENCY

LtCol Ronald P. Fuchs & LtCol Thomas E. Cedel
Air Force Center for Studies and Analyses

Executive Summary

The purpose of this study is to quantitatively investigate the relationship of several flying activity and experience factors to pilot proficiency. We define proficiency as a pilot's ability to perform a function after he has learned the basic skills to execute it. The USAF terms this continuation training as compared to the initial learning of a skill (initial or mission qualification training). Our approach was to analyze weapons delivery accuracy as a measure of pilot proficiency. Bombing records covering one year were collected from two A-10 and two F-16 fighter squadrons. These squadrons included an active duty and Air National Guard unit for each aircraft type. The analysis was conducted in two parts. First, the pilots were studied as a group for correlations between bombing accuracy and flying activity or experience factors. Three flying activity factors were used: hours flown per month; sorties flown per month; and number of bombing events accomplished per training cycle. Total pilot flying experience, mission flying experience (time in fighters), and time in aircraft type were used as experience factors. In the second half of the study, individual pilots and their proficiencies were analyzed using a mathematical model.

Of the factors listed above, mission flying experience, i.e., time in fighters, had the highest correlation with increased bombing accuracy for both the A-10 and F-16. Figure 1 illustrates these results for the Low Angle Low

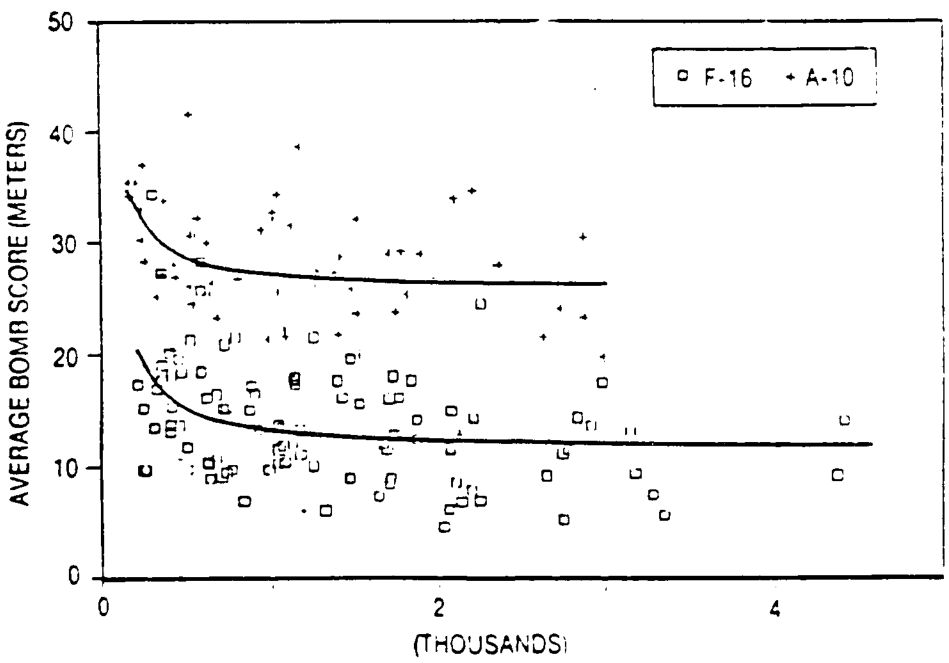


Figure 1. Mission Time vs Bombing Frequency

Drag (LALD) event. We found the same results for bombing accuracy in the Low Angle Bomb (LAB) event. An additional observation from the data shown in Figure 1 is that F-16 aircrews are approximately 15 meters more accurate than A-10 pilots across all experience levels. This equates to a 55 percent increase in kill potential using unguided weapons for F-16 crews. Although the flying frequency measures studied did not result in the highest correlations with increased bombing accuracy, a pilot's accumulation of mission experience is directly dependent on how often he flies.

In the second half of the study, a mathematical model was used to describe pilot capability. Our aircrew bombing data were obtained directly from combat ready fighter squadrons. The purpose of the pilot capability model was to capture, from these data for each individual, parameters which would describe his bombing performance. These parameters were then used to model each pilot and predict his proficiency at various flying frequencies. The results showed that a measurable increase in capability occurs at approximately 900 hours of mission time for the F-16 and 1400 hours for the A-10. Pilots above these thresholds were better than those below them.

Using the results from both parts of our analysis, it is possible to calculate the relationship between flying activity rates and squadron bombing effectiveness for both the A-10 and F-16. Figure 2 illustrates this relation-

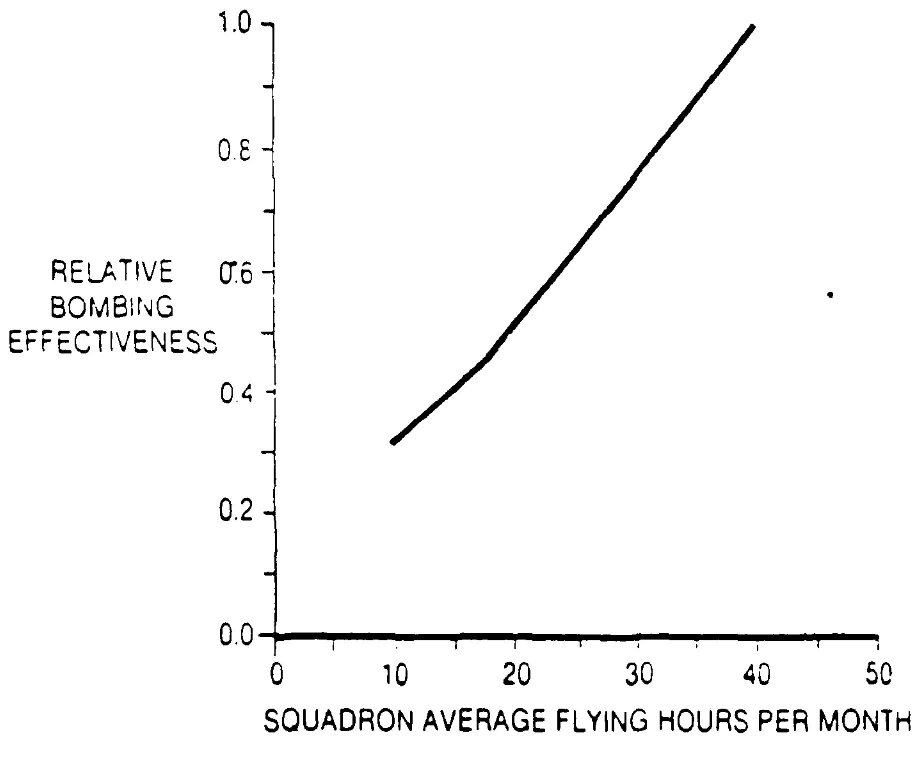


Figure 2. A-10 Squadron Bombing Effectiveness as a Function of Flying Activity

ship for the A-10. There is a nearly linear increase in bombing effectiveness with hours per month. The increase in bombing effectiveness is a result of building average pilot experience and greater practice with increased flying activity.

Figure 3 illustrates the same relationships for the F-16. As the figure shows, the increase in F-16 squadron bombing effectiveness is not linear. Up to approximately 21 hours per month, the rate of return for bombing effectiveness versus flying frequency is steeper for the F-16 than A-10. Also the point of maximum bombing effectiveness is still beyond 40 hours per month.

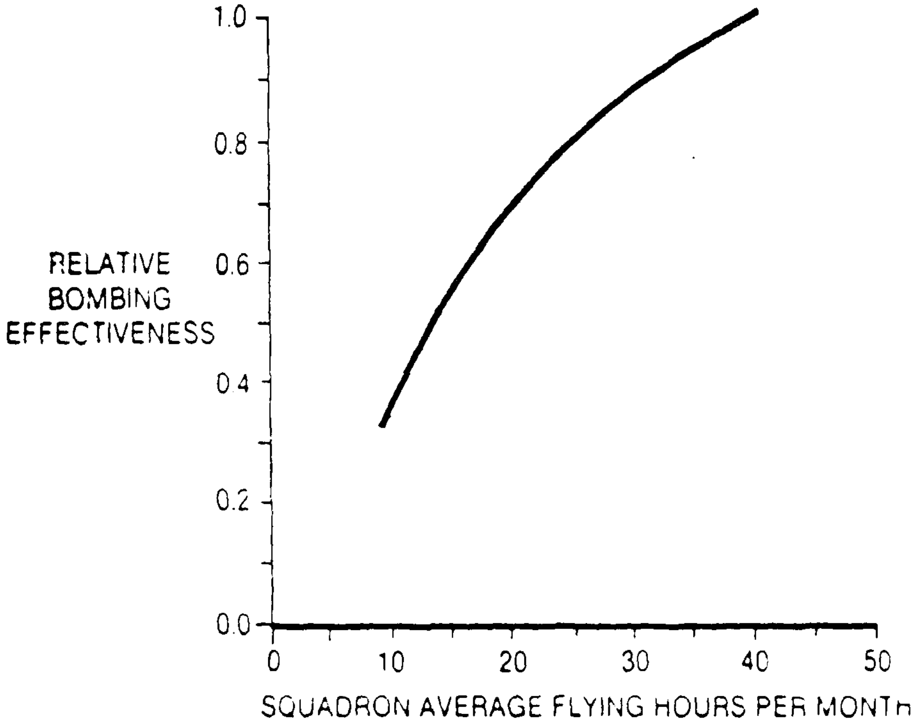


Figure 3. F-16 Squadron Bombing Effectiveness as a Function of Flying Activity

In conclusion, current A-10 and F-16 flying activity rates (23 and 19 hours per month respectively) have not reached the point of maximum bombing effectiveness. The determination of flying time requirements could be based on building average pilot experience in a squadron above measurable proficiency thresholds. The weapons delivery computer in the F-16 has significantly increased the accuracy of squadron pilots and reduced the experience threshold observed in bombing capability by 500 hours. Finally, the methodologies used to calculate the curves in Figures 2 and 3 allow the impact of changes in hours flown per month or pilot experience on squadron bombing effectiveness to be analyzed.

Analytical Approach

In the past, the USAF has attempted to qualitatively measure changes in pilot proficiency with increases or decreases in the amount the pilot flies. Intuitively, it appears obvious that the more a pilot practices the better he will become. The purpose of this study is to quantitatively investigate the relationship of various factors to pilot proficiency.

The first step in our analysis was to identify those factors that could influence pilot proficiency. This was done through discussions with rated officers in the Air Staff and operational flying squadrons. The factors are listed in Table I. They range from flying activity to personnel management functions like command assignment policy and retention. Note that the factors are not listed in any particular order. The factors marked by an asterisk are the ones analyzed in this study. Those chosen do not indicate the relative importance of these factors but rather identify the parameters for which existing quantitative data could be obtained. The use of simulators was not studied because of a lack of range in the simulator data available from flying units. All the aircrews in the units had the same amount of simulator training.

Table I

* Flying Activity (Hours Per Month and Sorties Per Month)
* Number of Time a Training Event is Accomplished
* Pilot Total Flying Experience
* Pilot Mission Flying Experience
* Pilot Experience in a Specific Weapons System
Inherent Pilot Capability
Individual Pilot Motivation
* Aircraft Avionics Suite
Multiple Mission Tasking
Management Factors
Quality of Ground Training
Availability of Resources (Training Ranges, Munitions, etc.)
Use of Simulators
MAJCOM Training Programs
Additional Duty Load
Assignment Continuity and Retention of Aircrews
Other Unknown Factors

The next step in the study was to choose an aircraft and event that could be used to model a basic piloting skill. In this case, a basic piloting skill is defined as a pilot's ability to put an aircraft at a particular point in space in the correct attitude at an airspeed. This type of skill is used in landing approaches, instrument procedures, weapon deliveries, and air combat maneuvers. We chose to study first the A-10 and manual weapons delivery. The A-10 weapon system was selected because it has a single crew member and is relatively simple. There are no computers in the A-10 which could interfere with an evaluation of aircrew performance and, because there is a single crew member, data from this weapon system directly reflects a pilot's proficiency.

Manual weapons delivery scores, the Low Angle Low Drag (LALD) event, were used as a measure of merit. Bomb scores are a relatively objective measure of merit and directly reflect a pilot's ability to put an aircraft at a particular point in space and airspeed. Also weapons delivery accuracy is a major component of combat mission effectiveness and consequently is a measure of combat potential. The LALD event was used because it is a precise event. There are few if any means for the pilot to "guess" the correct release point other than meeting his planned bombing parameters. The second aircraft selected for analysis was the F-16. Again, it is a single aircrew weapon system; however, it has a computerized weapons delivery system. These data were compared to the A-10 to investigate the impact of advanced avionics.

The source of the data were two fighter squadrons for each aircraft type, one from the Air National Guard and one from the active duty USAF. The purpose in using both active duty and National Guard squadrons was to extend the range of our data. The data come directly from squadron bombing records which are the result of normal training. The range of the data is therefore constrained by USAF regulations on the maximum time between bombing events, currency requirements, and minimum flying time requirements.

The data were analyzed in two stages. First, the pilots were studied as a group for correlations between bombing accuracy and the factors asterisked in Table I. Bombing accuracy and a factor (e.g., flying hours per month) were averaged for a pilot over six months; a training cycle. This was done for all the pilots and the results plotted as a scatter diagram. An analysis where the bomb scores are averaged over time assumes that each score is independent of any previous score. This is not necessarily true because the scores may be autocorrelated. A pilot's bomb score at any given time may depend on his previous practice. In order to study better the relationship between practice frequency and bombing accuracy, individual pilot proficiency was also analyzed using an event based mathematical model.

Correlation Analysis

The pilots were studied for correlations between bombing accuracy and the six factors asterisked in Table I. Three factors were measures of flying frequency: hours per month; sorties per month; and number of events accomplished per training cycle. The other three factors were measures of pilot experience: total flying time; mission flying time; and time in aircraft. Data from the A-10 and F-16 were also compared to determine the impact of a weapons delivery computer on bombing accuracy.

The Y-axis in each scatter diagram is the average Low Angle Low Drag (LALD) bomb score for a pilot over 6 months (one training cycle). This value represents a radial error in meters from the desired impact point. A bomb score of zero is a direct hit. The X-axis value is either averaged over the same 6 month period (hours per month, sorties per month), the total number of LALD events accomplished over 6 months, or aircrew experience at the end of the same 6 month training period. We did not use a linear equation to analyze the correlation between the factors and bombing accuracy. This is because a linear form assumes an X and Y intercept. Eventually, based on the slope of the line, the pilots would achieve perfect accuracy, zero for an average bomb score. Because this is extremely unlikely, if not impossible, we used an equation with a functional

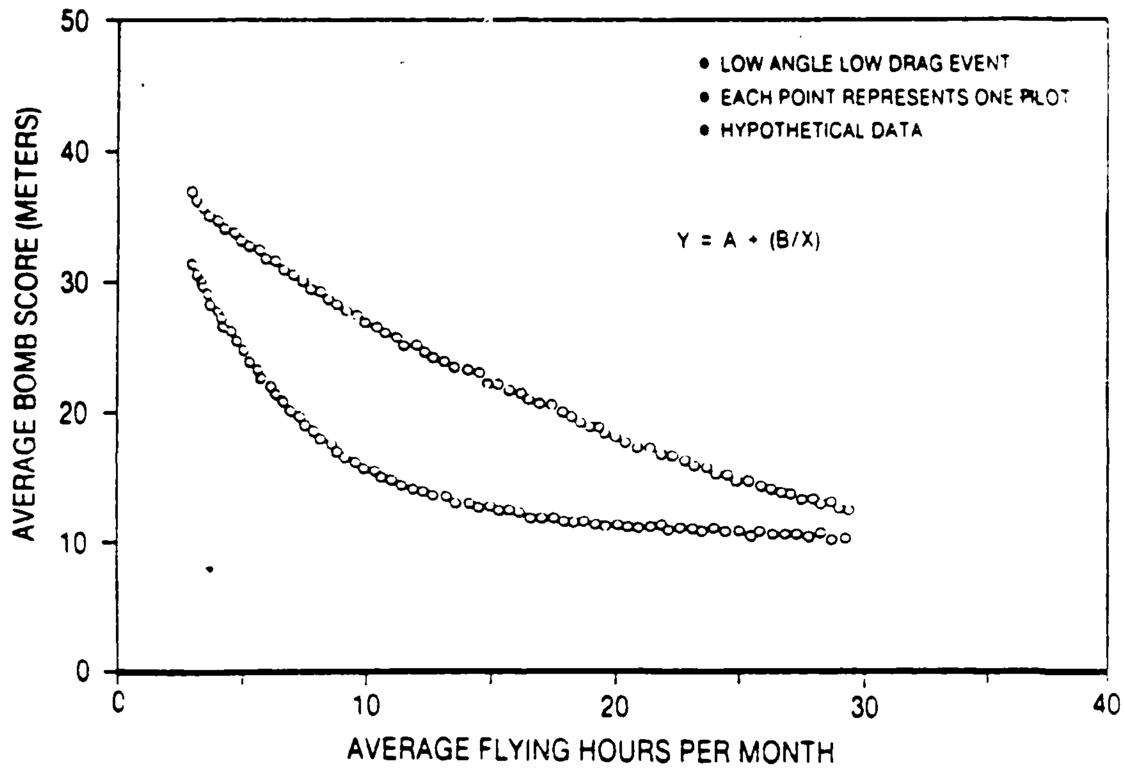


Figure 4. Hypothetical Data

form that was asymptotic to both a line parallel to the X-axis and the Y-axis. The equation is shown in Figure 4. The term "A" is the limit in accuracy as the pilots increase in proficiency and "B" indicates how quickly they reach the limit (smaller B, reach limit sooner). Each point represents one pilot. The data shown in Figure 4 are fabricated just to illustrate the logic behind the correlation analysis. A correlation coefficient is used to measure the goodness of the fit. Figure 5 illustrates the relationship between average flying hours per month and bombing accuracy for the F-16.

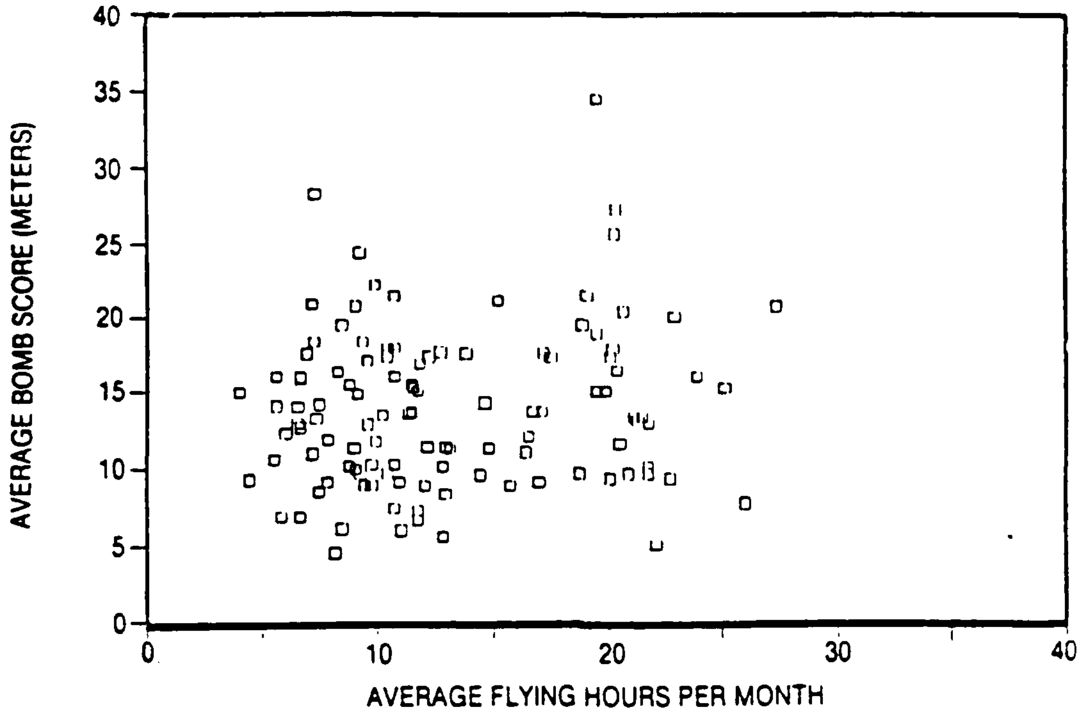


Figure 5. F-16 Hours per Month vs Bombing Accuracy

Based on these data, there is little correlation between this factor and bombing accuracy. The left cluster in the graph is mostly Air National Guard pilots and the right cluster contains data from the active duty pilots. We found similar results for average sorties per month. The data for the A-10 squadrons was the same, no correlation between these two factors and bombing accuracy. However, it should be noted that for the F-16 85 percent of the bomb scores were below 20 meters while for the A-10 65 percent of the bomb scores were above 20 meters. The flying hours shown in Figure 5 include not only flying time accrued while practicing bombing but also all other flying training. One could argue that in order to correctly understand the relationship between flying activity and bombing accuracy, the comparison should be made to the number of times that a particular event is practiced. A scatter diagram of those data does not show any correlation between number of practice events and bombing accuracy for either the A-10 or F-16.

The next step in the correlation analysis was to study the relationship between pilot experience measures and pilot proficiency. For both aircraft, we found correlations between all the experience measures. The highest correlation between experience and bombing accuracy, for both aircraft, was mission time. Figure 6 depicts these data for both the A-10 and F-16. The correlation coefficient for the A-10 data is 0.41 and for the F-16, 0.45. The limit in accuracy the pilots approach is 11 meters for the F-16 and 26 meters for the A-10. The fit, other than the term "A" for the two aircraft is just about the same. The F-16 aircrews are on the average approximately 15 meters more accurate over all experience levels than A-10 pilots. This equates to a 55 percent increase in kill potential when using unguided weapons (calculated using Joint Munitions Effectiveness Manual air-to-surface methods).

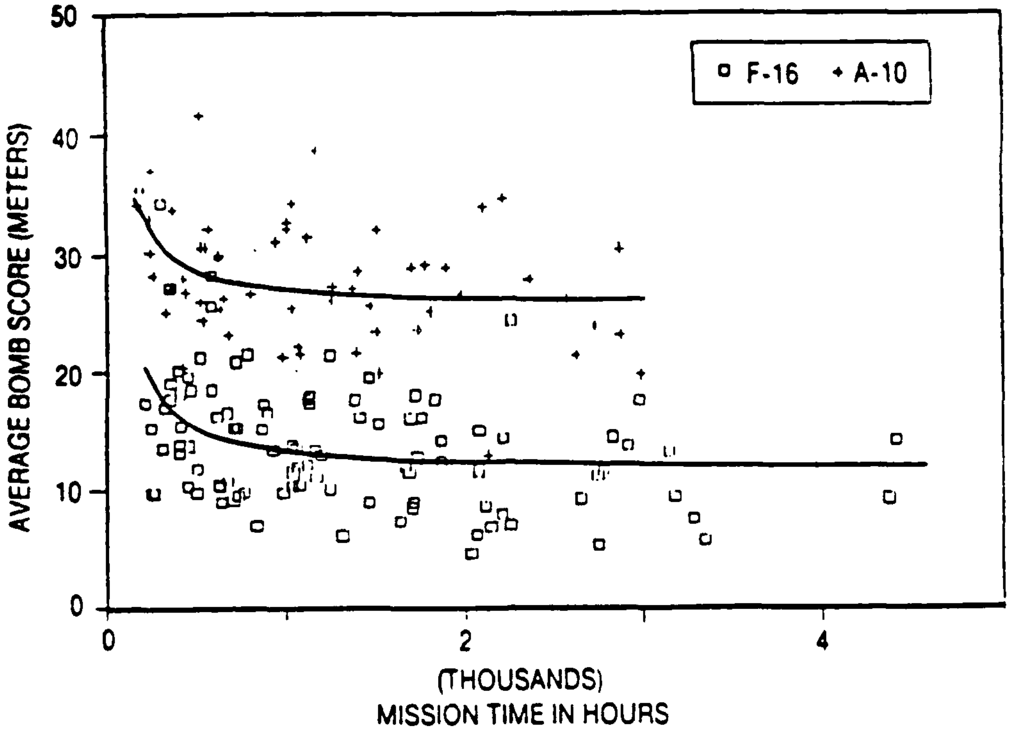


Figure 6. F-16 and A-10 Mission Time vs Bombing Accuracy

The data were also analyzed for the standard deviation of each pilot's average bomb scores. This value represents how consistent the pilot was. The same relationships were found as those described for bombing accuracy. An increase in mission flying experience had the highest correlation with an increase in bombing consistency. Also F-16 pilots were more consistent than A-10 pilots.

In addition we studied another bombing event, Low Angle Bomb (LAB) and found similar results.

An analysis of this type, where the bomb scores are averaged over time assumes that each score is independent of any previous bomb score. This is probably not true. A pilot's bomb score at any given time may depend upon how much he had practiced prior to that event (autocorrelation). For this reason we developed an event based mathematical model to study individual pilots.

Pilot Capability Model

The analytical methods used in the correlation analysis averaged the bomb scores and, for example, flying activity rates for each pilot over six months and then displayed the results as a group. As was mentioned on page 5, the pilot proficiency data were obtained directly from combat ready fighter squadrons. It was not possible to run a controlled experiment in which a group of pilots could be flown at various activity rates and their performance measured.

However, each set of data for a pilot over a year contained variations in the pilot's bombing practice frequency and his resulting bomb scores. The purpose of the pilot capability model was to capture from these data, for each individual, parameters which would describe his performance at varying flying activity levels. The parameters determined from the model are then used to predict the pilots performance at set flying activity rates.

The pilot capability model is graphically illustrated in Figure 7. The Y-axis is the pilot's bomb score in meters and the X-axis is the Julian date on

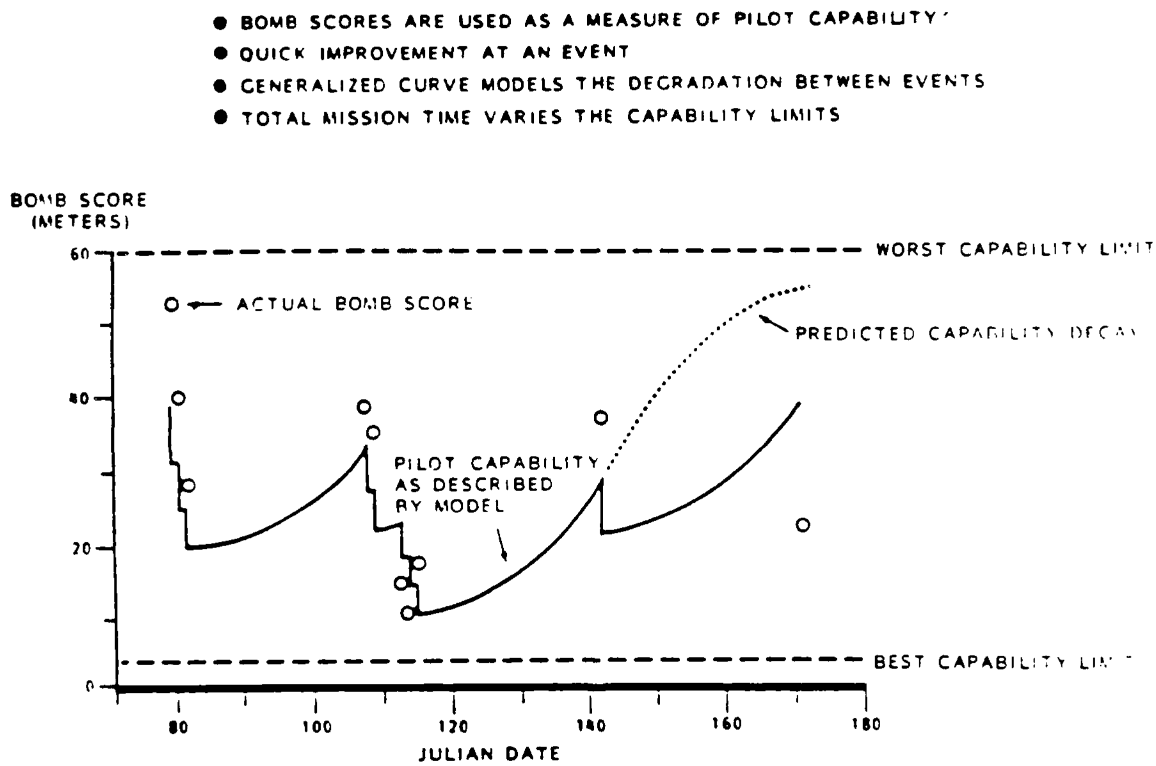


Figure 7. Model Characteristics

which that bombing event was accomplished. A set of model parameters was determined for each of the 40 A-10 pilots and 42 F-16 pilots used in the analysis. The data shown in Figure 7 are for a single pilot over approximately one-third of a year. The pilot's actual bomb scores are shown as open circles. The model prediction for that pilot's bombing proficiency is shown as a solid line. The resolution of the model is one day. Bomb scores were averaged if the pilot practiced more than once per day.

Four basic assumptions went into development of the model. First, it was assumed that bomb scores could be used as a measure of pilot proficiency. The logical basis for this assumption was discussed in the Analytical Approach Section. Next, when a practice bombing event was accomplished, a quick change in capability was modeled. For example, if a pilot practiced and improved, he improved that day not one or two days later. Also, based on the pilot's actual performance, he could improve, degrade, or not change his bombing capability when he practiced. Third, after a practice bombing event, the decay in a pilots capability was described by a generalized curve. This curve could look like a number of different functions depending on the value of a parameter in an equation. Finally, the pilot's capability was bounded by limits. Based on operational experience, we postulated that even if a pilot did not bomb for an extended period of time, he would still have an upper bound (worst capability limit) on how far he would miss the target. Also we hypothesized that even with extensive bombing practice there would be a lower bound (best capability limit) on how good a pilot could become. These capability limits varied between pilots as a function of each pilots inherent capability and his experience. Based on the results of our correlation analysis, mission time was used as an experience parameter to vary the capability limits. An increase in experience or improved pilot capability would tend to lower both bounds.

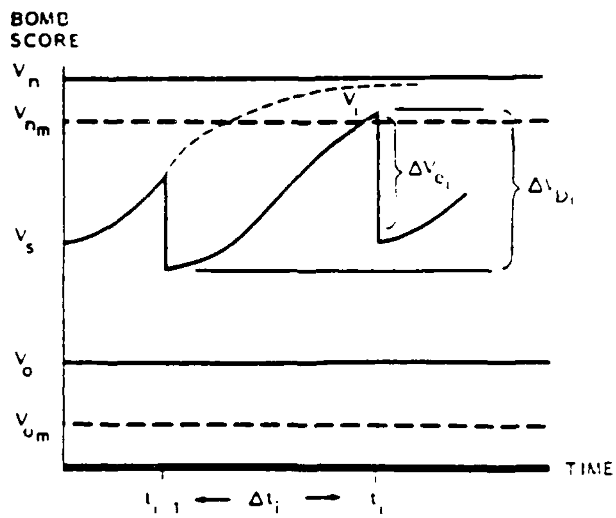
Figure 8 describes the equations used to model each pilot's bombing ability. V_{nm} and V_{om} are defined as the upper and lower capability limits for a pilot.

$$V_n = V_{n_m}(1-e^{\gamma T_f})^{-1}$$

$$V_o = V_{o_m}(1-e^{\zeta T_f})^{-1}$$

$$\Delta V_{e_i} = \beta(V_o - V_i)$$

$$\Delta V_{D_i} = \frac{(V_n - V_{i-1} - \Delta V_{e_{i-1}})\Delta t_i^2}{(\Delta t_i + b)^2}$$



EQUATION 1 $\quad V_\phi = V_s$

EQUATION 2 $\quad V_1 = \dfrac{V_s b^2 - 2bV_s\Delta t_1 + V_{n_m}(1-e^{\gamma T_f})^{-1}\Delta t_1^2}{(\Delta t_1 + b)^2}$

EQUATION 3 $\quad V_i = V_s - \left[V_{n_m}(1-e^{\gamma T_f})^{-1} - \beta V_{o_m}(1-e^{\zeta T_f})^{-1}\right] \displaystyle\sum_{j=1}^{i} \frac{\Delta t_j^2}{(\Delta t_j + b)^2} +$

$$(\beta - 1)\sum_{j=1}^{i} \frac{V_{j-1}\Delta t_j^2}{(\Delta t_j + b)^2} - \beta \sum_{j=1}^{i-1} V_j + \beta(i-1)V_{o_m}(1-e^{\zeta T_f})^{-1} \qquad i = 2, 3, \ldots, n$$

Figure 8. Pilot Bombing Capability Model

These capability limits were adjusted exponentially as a function of mission flying experience, T_f. Two variables, γ and ζ were used to adjust V_{nm} and V_{om}. V_n and V_o then are the final adjusted capability limits. ΔV_{ei} describes the increase or decrease in pilot proficiency when a bombing event is accomplished and is equal to a variable, β, times the difference between the lower capability limit, V_o and the bomb score at the time i, V_i. The change in pilot capability with time is described by ΔV_{Di}. The parameter b used in the description of ΔV_{Di} characterizes the shape of the curve. Finally, V_ϕ is the initial bombing score from which the model begins. It is equal to V_s which is the pilot's initial bombing capability.

Equation 1 defines the starting point for the model. Equation 2 calculates the pilots bombing potential for the first bombing event of the year and equation 3 calculates subsequent bombing capability. There are 7 quantities that are allowed to vary when fitting the model to a pilots actual bombing scores. These are V_s, V_{nm}, V_{om}, γ, ζ, β, and b. The solution was achieved using a combined grid and gradient search minimization technique (IMSL subroutines ZSRCH and ZXMIN). This method minimized the square of the difference between the actual bombing score and the modeled bombing score. Parameters β and b could be either positive or negative.

Each pilot's capability model was used to predict his bombing accuracy at bombing frequencies varying from once a day to once every 30 days. The predictions were accomplished by holding the seven variables for each pilot fixed and varying the time, t, between practices. The results for each pilot were then plotted as predicted bombing accuracy vs number of events per month. One event per month equals a practice every 30 days and 30 events per month equals practicing once a day. This is within the range of actual practice frequencies

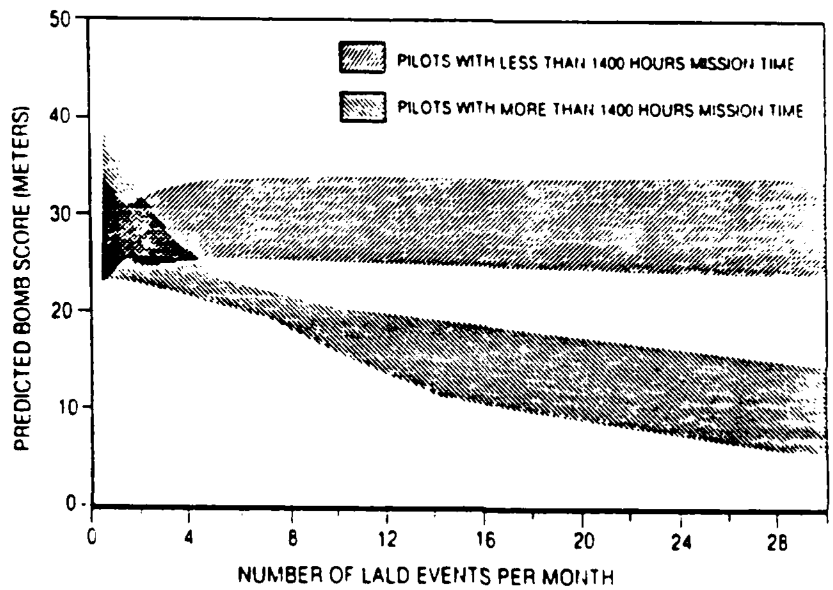


Figure 9. A-10 Predicted Bombing Accuracy vs Training Frequency

for the study data. Figure 9 shows the results of this analysis for the A-10 pilots used in this study. The bands are the 50 percent confidence intervals for all the pilots either above or below 1400 hours of mission time. The Y-axis is predicted bombing accuracy and the X-axis is the number of bombing events accomplished per month. The pilots with less than 1400 hours of mission time do not show an improvement in bombing accuracy with an increased number of events per month. However, the pilots above 1400 hours of mission time show a significant improvement in bombing accuracy. There is an experience threshold for bombing accuracy in the A-10 at approximately 1400 hours of mission time.

Figure 10 illustrates the same results for the F-16. In this case the experience threshold was at 900 hours of mission time. In contrast to the A-10, pilots below the threshold show an improvement in bombing accuracy with increasing practice frequency. The difference between the pilots above and below

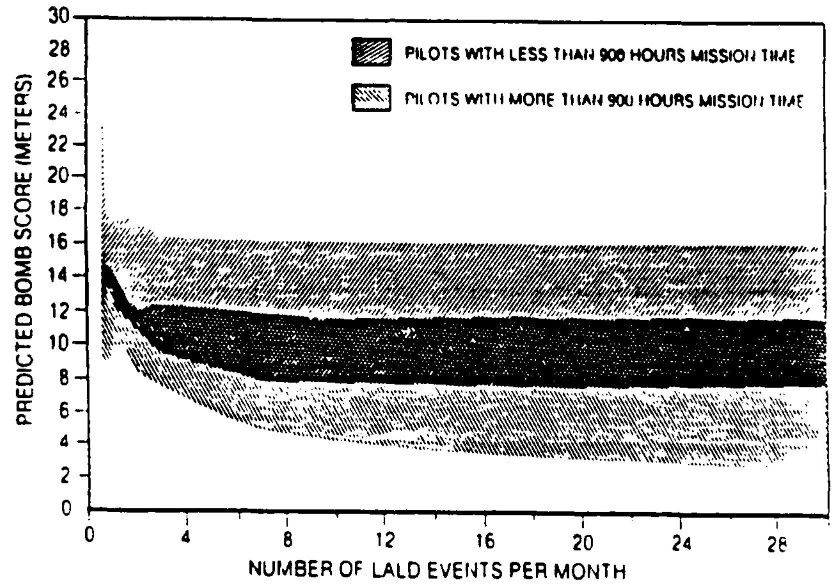


Figure 10. F-16 Predicted Bombing Accuracy vs Training Frequency

this threshold is less than that found for the A-10. The decrease in the experience threshold for the F-16 from the A-10 can be explained by the presence of a computed weapons delivery system in the F-16. Along with improved accuracy, the computer has lowered the threshold for improved pilot performance.

The pilot capability model results support the conclusion reached in the correlation analysis that an accumulation of experience is an important factor in improving pilot proficiency. A threshold in capability was found at 1400 hours of mission time for the A-10 and 900 hours of mission time for the F-16. Pilots over these thresholds demonstrated an increase in bombing accuracy with increasing practice frequency. Also, these result demonstrated that the frequency of bombing practice can influence a pilot's proficiency.

Squadron Experience Distribution

A method for determining flying time rates, hours per month of flying time, could be based on building a particular experience level in an operational squadron. Figure 11 illustrates a method for doing this for the A-10. In the A-10 case we selected 1400 hours of mission flying time as the experience goal for the squadron pilots. The Y-axis is the percent of pilots in the squadron above 1400 hours of mission experience. The X-axis is the average flying time per month for all the pilots in the squadron. The solid line in the figure depicts the relationship between the percent of pilots above 1400 hours in a squadron and average flying time per pilot if the flying time is allocated equally among the pilots. This curve represents the experience distribution if the pilots actively fly for 6 years in combat ready status. Current data on fighter pilots in the USAF indicate that they average 6 years of active flying. This average takes into account retention losses and non-flying assignments. The curve would move to the left if the number of years flying increased and to the right if it decreased. The horizontal line from 10 hours per month to 19 hours per month indicates that currently about 13 percent of the A-10 pilots in the USAF who are actively flying have above 1400 hours of mission time. The curve was calculated by modeling an input and output of pilots into the squadron while allowing them to fly for 6 years. It was assumed that 13 percent of the pilots had above 1400 hours of mission time as a starting condition. The model output, percent of pilots above 1400 hours based on a certain average flying time per month, is a steady state solution, i.e., after the system has stabilized.

The two dashed lines show alternative flying time allocation strategies. In the first case, pilots with over 1400 hours of mission are restricted to a maximum flying time of 14.5 hours per month (approximately GCC level A). As the average flying time per pilot in the squadron increases, flying time above 14.5 hours for the experienced pilots is given to pilots with less than 1400 hours until they reach a maximum of 37.5 hours per month. The upper limit of 37.5 hours per month is above what would be reasonably possible for a pilot to fly and still fulfill his additional duties. At 24 hours per month the boundary stops at 58 percent of the pilots above 1400 hours of mission time because all the inexperienced pilots are flying at the maximum rate. The boundary is then horizontal as flying time is given back to the experienced pilots until it intersects the equal allocation line and all pilots are flying at the maximum strategy. Pilots with less than 1400 hours are restricted to 14.5 hours per month while experienced pilots fly at the maximum rate. The area within the dashed lines defines the options available for the allocation of flying time. Points above the equal allocation line reflect a weighing in flying time distribution toward inexperienced pilots while points below the line imply a weighing toward experienced pilots. The boundary line for restricting experienced pilots only serves to define the theoretical limits of flying time allocation strategies. Sound training practices require experienced pilots to teach inexperienced aircrews and this makes restricting experienced pilots to 14.5 hours per month impractical.

The same type of calculation can be performed for the F-16 except that the experience threshold will be 900 hours of mission time. Figure 12 shows these data. The only difference between the F-16 calculation and those shown in Figure 11 for the A-10, is the 900 hours experience threshold and lower limit for flying activity of 13.3 hours per month.

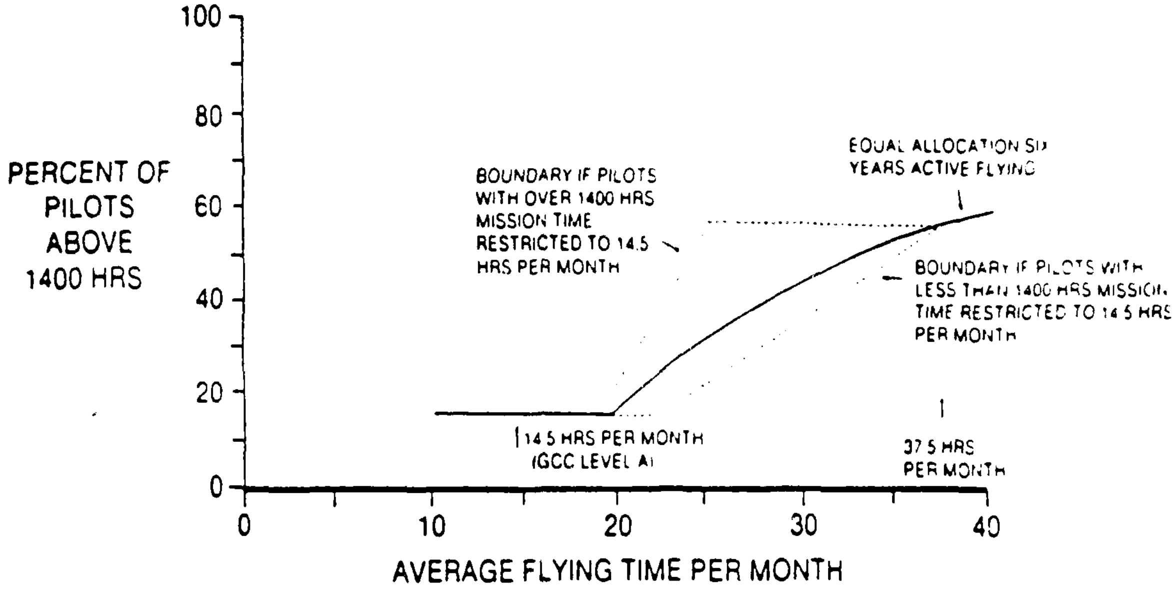


Figure 11. A-10 Squadron Mission Flying Experience Have

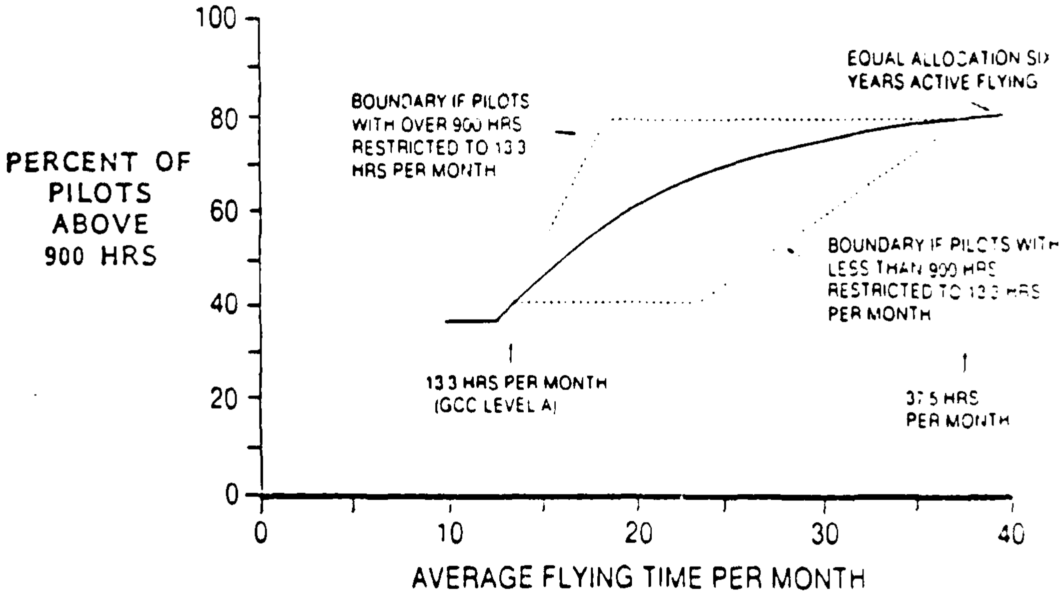


Figure 12. F-16 Squadron Mission Flying Experience

Figures 11 and 12 can be used by first deciding on an experience goal for a squadron. Then, based on an allocation strategy, the flying hours per month required to meet this goal can be determined. As an example, it would require about 24 hours per month of flying time in an A-10 squadron to reach an experience goal of 30 percent using an equal allocation strategy. It is also possible to solve the opposite problem and predict a squadron's experience composition based on how many hours per month they are flying.

Squadron Bombing Effectiveness

Figures 11 and 12 can be used to predict a distribution of pilots within the squadrons above and below the respective experience thresholds as a function of flying hours per month. The line shown in Figure 13 illustrates this calculation for a flying activity rate of 25 hours per month in the A-10. The flying hours per month can then be converted to number of bombing events accomplished per month by: (1) converting the hours per month to sorties per month by using an average sortie duration; and (2) adjusting the number of sorties per month to number of bombing events by multiplying the total sorties by the percent of sorties dedicated to air-to-ground weapons delivery. It is assumed that each air-to-ground weapons delivery sortie will include a weapons delivery event. The bombing proficiency for each experience group at a particular practice frequency, events per month, can be calculated using the data found in Figures 9 and 10. Figure 14 displays this calculation for the same example used in Figure 13. In this case, 25 hours per month equates tc six practice events per month. Note that the prediction of bombing proficienc as a function of practice frequency assumes an equal time interval betwee events. The squadron bombing proficiency is then calculated as a weighte average of the bombing proficiency for the experience groups above and belo the thresholds.

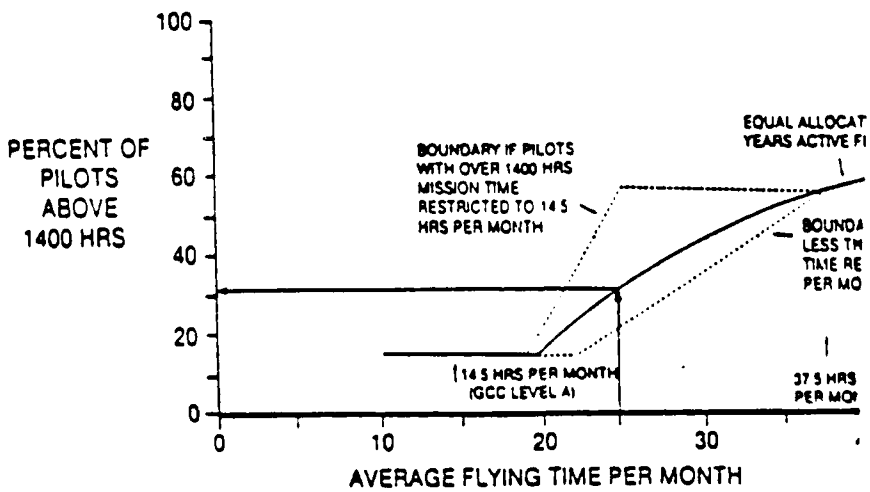


Figure 13. Calculation of Experience Distrib

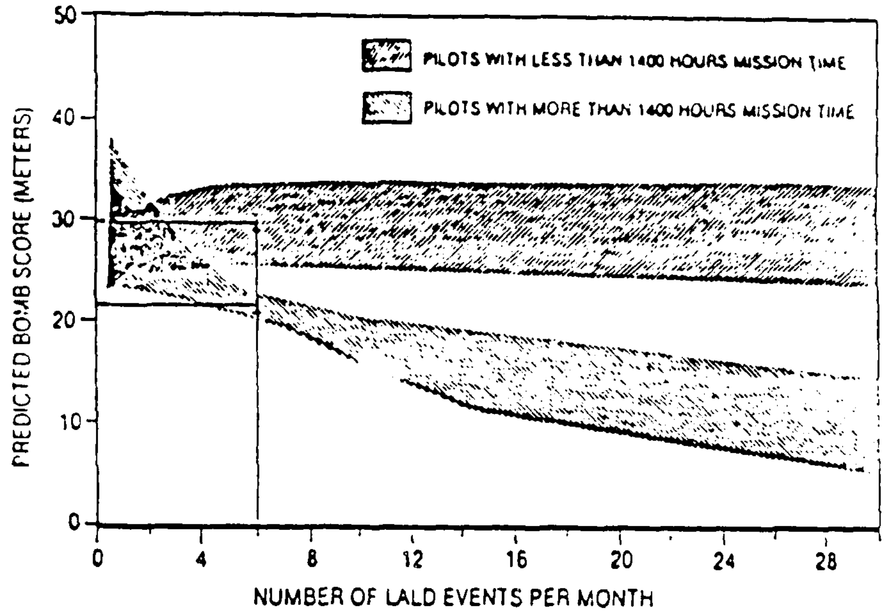


Figure 14. Calculation of Bombing Proficiency

Figures 15 and 16 illustrate the end result of the calculats for the A-10 and F-16 respectively. These curves can then be deriv for various combinations of experience and flying hour allocation distributiorThe relative bombing effectiveness shown on the Y-axis of each figure is propcional to the reciprocal of the square of the predicted squadron bombing profincy.

The results shown in Figures 15 and 16 may at first appeato directly contradict those shown in Figure 5. However, the figures istrate two different aspects of the relationship of flying hours to pilotroficiency. Figure 5 does not take into account either the potential autocorretion of the data or the variation in experience of the pilots. The methods d to build the curves shown in Figures 15 and 16 consider both of these facrs. Also, Figures 15 and 16 describe the change in overall squadron effeceness with flying hours while the data shown in Figure 5 are for individual lots. The data in Figure 5 can be viewed as points clustered around a an bombing effectiveness and flying hour per month that move along the curves scribed in Figures 15 and 16. Figure 17, displays this concept.

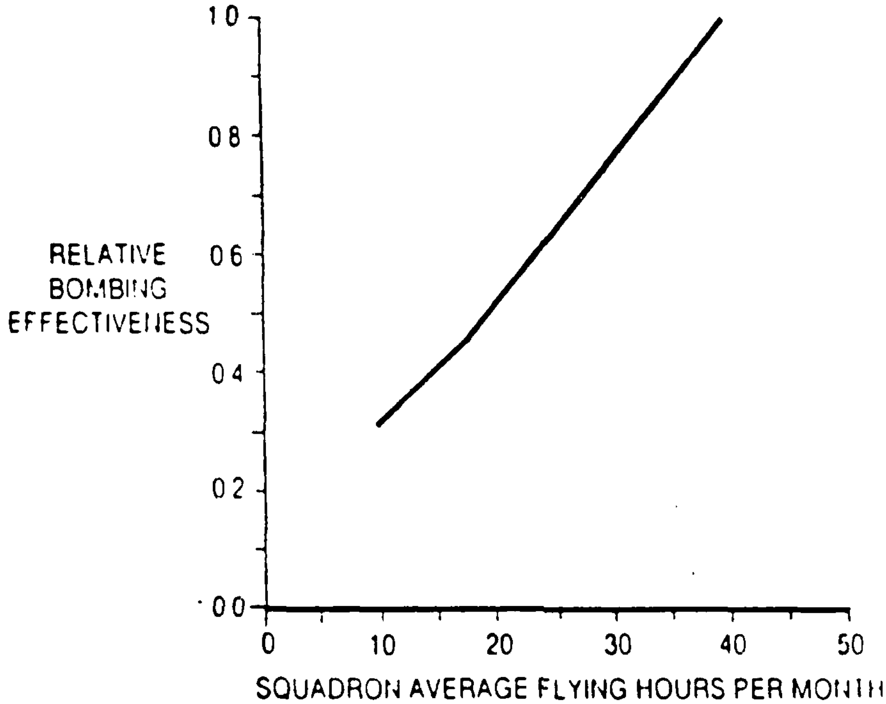


Figure 15. A-10 Squadron Bombing Effectiveness as Function of Flying Activity

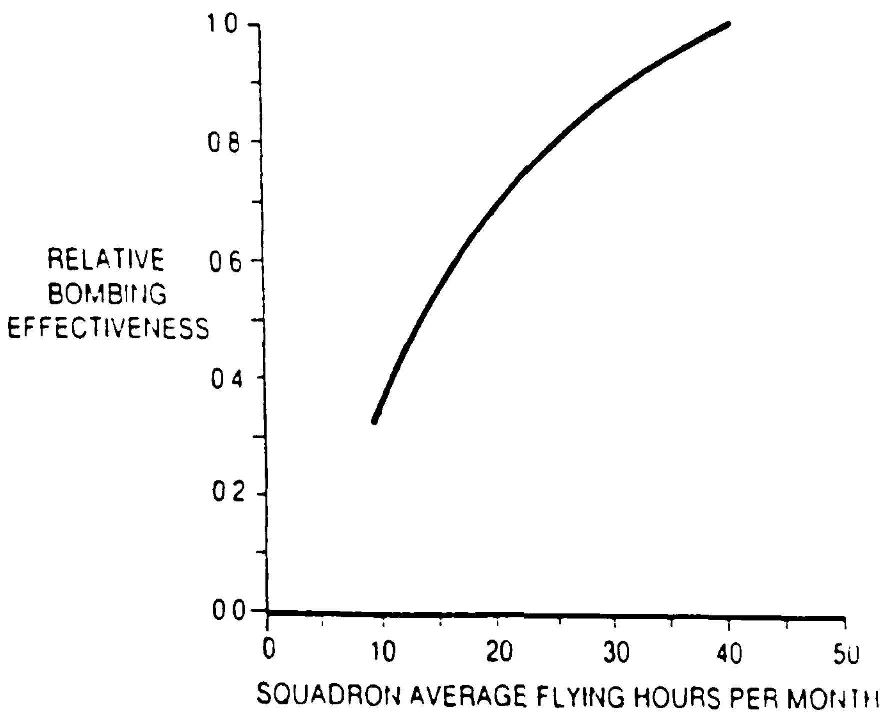


Figure 16. F-16 Squadron Bombing Effectiveness as Function of Flying Activity

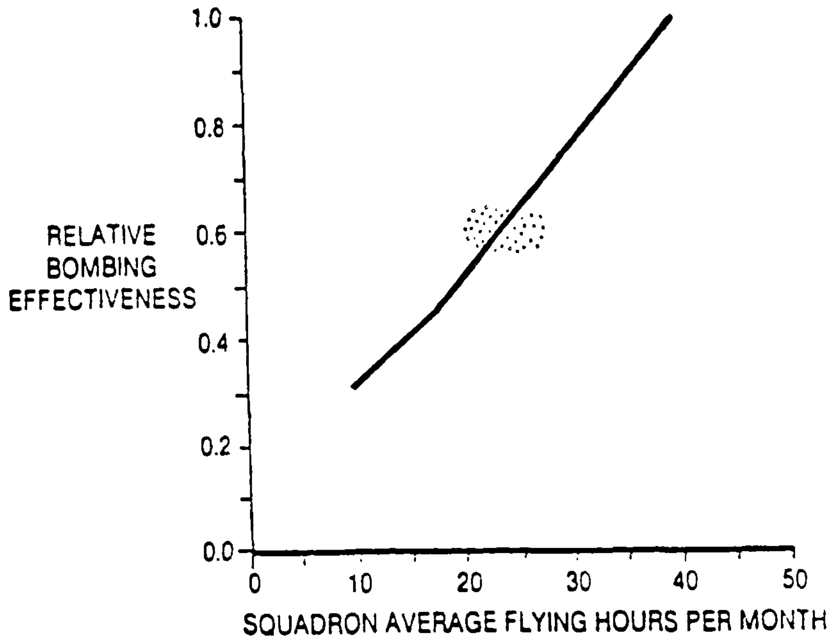


Figure 17. A-10 Squadron Bombing Effectiveness

Conclusion

In conclusion, this analysis shows that current A-10 and F-16 flying activity rates (23 and 19 hours per month respectively) have not reached the point of maximum bombing effectiveness. In the case of the A-10 there is a nearly linear increase in bombing effectiveness with increased flying hours per month. For the F-16, the increase in bombing effectiveness is not linear. Up to approximately 21 hours per month the rate of return for bombing effectiveness versus flying frequency is steeper for the F-16 than the A-10. The increase in bombing effectiveness in both aircraft is a result of both building pilot experience and greater practice frequency with increased flying activity.

DISCUSSION OF "THE EFFECTS OF FLYING TRAINING ON PILOT PROFICIENCY"
by Lt. Col. R. Fuchs and Lt. Col. T. Cedel, AF Center for Studies and Analyses

DISCUSSANT: Daniel F. Purcell, Sr., Syscon Corporation,
Center for Modeling, Simulation and Gaming

The guidance I received when asked to participate as a discussant in the MORIMOC II mini-symposium was to pay particular attention to the MOC (Modeling of Combat). In was in this light that I read the paper presented by Lt. Col. Fuchs.

The paper provides valuable information on what must be done to assure that our squadrons reach a high level of proficiency before a war starts. That is, it answers the questions for which the study was requested. However, it does not address, nor was it intended to, the question of how the execution of combat missions affects a pilot's proficiency.

Is a pilot's proficiency affected by the length of the mission? The density of defenses in the target area? The type of mission (CAS versus interdiction)? How long can a pilot maintain an increased sortie rate? This is the type of information which I, as a combat modeler, can incorporate into a model.

There are models currently available which, with relatively minor modifications, can include these factors in the combat assessment. Analysis is needed to identify the factors which affect combat performance and the availability and form of data. This need has been recognized, that is why there are MORIMOC symposia. With the help of those in attendance this important, and too often omitted, aspect of combat will be included in our assessment of future capabilities.

TACTICAL DETERRENT EFFECTS MODEL

by

George Schecter
James C. Richards
Henry A. Romberg

Battelle Columbus Division
Arlington, Virginia

INTRODUCTION

Background

This report describes a new method for evaluating the tactical deterrent effects of mine systems, a hitherto unquantified and highly significant component of combat utility. To meet the assigned task objective, the empirically determined risk behavior characteristics of Army commanders are combined with assigned mission values and success criteria and with an accepted combined arms casualty model to yield measures of tactical deterrent effects. To the best of our knowledge, this is the first assessment method developed with the capability of quantifying these important (perhaps dominant) "non-casualty" effects of mine systems in combined arms engagements. Application to other munitions is feasible.

Conventionally, resource allocation decisions for force structuring, materiel acquisition, and RDT&E are based largely on system evaluation methods embedded in a variety of combat simulations. Generally, these are representations in which alternatives are assessed on the basis of force movement and attrition in which the elemental measure of effectiveness is the production of casualties. This is basic — and all our quantitative military planning is rooted in the casualty-production MOE.

It is equally fundamental -- as recognized universally by military leaders and borne out by historical experience — that casualties are produced by only a minor fraction of our system expenditures, even of our ordnance expenditures. The ratio of target hits to minitions fired in anger is far, far lower than the hit probability effectiveness we ascribe to our weapon systems — at least two and up to four orders of magnitude lower. It must be concluded that those hundreds, thousands, and tens of thousands of munitions expended with very little expectation of casualty production are expected by hard-nosed military planners and commanders to yield some useful combat effects.

Indeed, it is acknowledged that they do. The effects are called interdiction, suppression, harassment, deterrence, reconnaissance by fire, covering fire, demoralizing, psychological, etc. Here, then, is the essence of our problem. Our acquisition and deployment decisions are based on the casualty production measures of combat effectiveness while the other effects — representing the overwhelming majority of our expenditures — have hitherto not been susceptible to quantitative assessment. In effect, our methodologies are highly developed only for guiding the minor part of our investment decisions.

Purpose

This task was undertaken to quantify the combat utility of mine systems to the field commander in terms of the combined effects of casualty production and deterrence. A method was needed that could accommodate the evaluation of present, developmental, and conceptual mine systems employed in combined arms actions. The desired method was to enable system and concept alternatives to be evaluated more completely and provide a better basis for RDT&E resource allocation and system acquisition decisions. The task was assigned by the Project Manager, Selected Ammunition (PMSA), U.S. Army Armament R&D Command (ARRADCOM), now ARDEC. One of PMSA's key product families is scatterable mines and we were directed to consider this particular class of munitions as well as more conventional types.

Problem Definition

An important component of the combat worth of scatterable mine systems has been missing from the measures of effectiveness used in RDT&E and acquisition investment decisions. This increment of battlefield utility is in the deterrent effect of such systems, that is, the effects other than direct casualty production -- the degradation of attacker capability and mission shortfall, coupled with the casualties produced by the defender's covering fire. The problem is to develop a method for quantifying the effects of deterrence in terms that will be intuitively accepted and practically usable by military planners.

The deterrent effects of mine systems are somewhat analogous to the suppressive effects of firepower systems. Over the past several years, recognition of the importance of firepower suppressive effects has led to considerable analytical and experimental work in the development of new measures of effectiveness. Definitions of levels of suppression have been developed in terms of the degree and duration of degraded combat performance, such as reduced mobility ("pinned down"), reduced firepower ("weapon down"), and reduced observation ("head down"). Experiments have been conducted by the Army Combat Development Experimentation Command (CDEC) to quantify these degradation effects as a function of volume and accuracy of incoming fire. Concurrently, models are being developed by the Naval Postgraduate School and the Naval Weapons Center, China Lake, to represent these interactions in a form suitable for quantitative evaluation. These additional measures of effectiveness are finding acceptance in the acquisition decision process and it is intended that similar acceptance be accorded the deterrent effects of mine systems.

Summary of Accomplishments

In the task we have undertaken, we have examined the related past analytic and experimental efforts as well as the relevant scenarios and attrition models that have been developed. We have discussed the problem and our approach to it with the known experts in the field. Unanimously, they have stated that the task we have undertaken:

- Has not been done before,
- May be difficult to accomplish,
- Is worth the effort.[1]

As another aspect of our "homework," we have examined our current knowledge of relevant USSR/WP doctrine [1, 2, 3]. Pertinent findings are:

- There is a trend toward the conventional (non-nuc) option.
- The infantry combat vehicle (e.g., BMP) role has changed from "post-nuc exploitation against light resistance" to conventional breakthrough against heavier resistance.
- Fighting forces and support elements are more road-bound (e.g., tank-transporter-regiments).
- Second echelon units are more vulnerable.
- Soviet automatic minelayers are deployed in Engineer brigades at Front level.
- A unified Soviet/WP doctrine is evolving.

With regard to scatterable mines, the implications are that conventional warfare preparedness is growing in relative importance; that motorized rifle battalions were not designed for heavy resistance and, therefore, are more vulnerable; that the more road-bound units and second echelons are more readily located and attacked. We interpret this to favor the flexibility and "reach" of scatterable mine systems as means to interdict, attrit, slow, and disrupt WP first and second echelon units on main routes of movement.

With these considerations as background and as added motivation for improving our understanding of all the operational values of advance munitions items, we have synthesized a methodology for this purpose. In general terms, we have developed a risk decision model and integrated it with an attrition model to achieve our objectives. The attrition model is the one used by BRDEC in their work for PMSA and CACDA in evaluating selected SCORES sequences of Red mechanized forces attacking Blue combined arms defenses that use mine systems. Overlaid on this we have developed a step-wise decision/risk method of predicting the attacker's actions as a function of a) the threat he perceives, b) the relative value of his mission, c) criteria for successful penetration of the mine barrier, and d) previously established risk behavior characteristics of military commanders.

Report Organization

The remaining sections of this report are organized in four parts:

- Survey of Prior Relevant Work
- Historical Experience with Mines
- Deterrence Model Description
- Summary of Findings, Conclusions, and Recommendations

SURVEY OF PRIOR RELEVANT WORK

Discussion and Findings

No evidence was found that deterrence, per se, has been addressed in a systematic manner. In our discussions with military modeling and planning experts in the field, they had a tendency to equate deterrence with suppression. The work done on suppression has been extensive in recent years, and the suppressive effects of air-to-ground gun fire, small caliber fire, and field artillery have been modeled with some degree of success. In air-to-ground combat analysis, the term is used somewhat differently; it is used to encompass all effects on air defense systems, for example, including casualty production as well as non-casualty effects. We proceeded initially on the assumption that we could borrow from suppression models and adapt some of the tools to the need for modeling the deterrent effects of mines. Closer study of existing suppression models (a list is presented in Table 1 below) led us to abandon this approach.

Suppression models deal with the phenomena of individual troops trying to protect themselves against perceived firepower threats. On a battlefield, this usually results in seeking a position in defilade to the incoming fire. When the hazard abates, the soldier gets up and resumes his activities. The modeler's interest is mainly to quantify the length of time that the soldier is in various states of reduced combat capability, and the relationships between these suppressed states and durations -- and the fires that cause them.

The deterrent effects of minefields are analogous. In the case of pre-emplaced minefields, an attacking force encounters the minefield on the march and often has the option of avoiding or withdrawing from it. This is not the case, however, when mines are employed in anvil tactics, combined arms situations, and especially in the dynamic "offensive" use of scatterable mine systems, where they are dropped on and around opposing forces. In all cases, the deterrent effects we are looking for are those effects beyond casualty production, i.e., reduction of combat effectiveness: button up, reduce target acquisition, reduce speed, constrain maneuver, reduce rate of aimed fire, divert axis of advance, abort mission. The focus of our study is the combat decision maker, subject to the threat in front of him as well as the command pressure behind him. We looked -- but did not find -- any models that address these problems.

We did find, however, a number of casualty models that treat mine systems. These models are representations of the problem of crossing or breaching a minefield and as such are relatively simple in concept and complex in execution due to the Monte Carlo or Markov techniques used to calculate various probabilities. Measures of effectiveness for these models include the probability of hitting a mine, of being killed by a mine, time delays caused by the mines, etc. Parametrically, a land warfare minefield model is very similar to a naval minefield model, which is to say that the problem has been studied extensively and the important variables generally are known. Our conclusion was that the development of a new casualty model would be a waste of time and that we would adapt an existing model to provide basic input to the deterrence model.

Our problem with existing casualty models was that there was not a way to devise a MOE for "deterrent effects" from their designed outputs because existing models assume (not necessarily realistically) that the attacker continues his attack until he reaches the objective, is annihilated, or breaks off at some arbitrary casualty level. The missing element was to find a way to represent the intermediate cases and to calculate their probability distribution.

Agencies Contacted

Our discussions with various Army agencies revealed a high interest in the objectives and methods of our study. In particular, the U.S. Army Materiel Systems Analysis Activity (AMSAA), the U.S. Army Concepts Analysis Agency (CAA), the Engineer Studies Group (ESG), the Army Engineer Center, Army Armament R&D Command (ARDEC), and the Belvoir RDE Center (BRDEC) all expressed interest in using such an analytical tool to augment their models because it would represent an important increment of military worth and there is no such methodology now available. In general, their feeling was that the key to the utility of a deterrence model to the Army community depends upon an acceptable definition of the problem and a practical approach to its eventual solution. The model methodology must provide a sound logic structure for relating the diverse effects of combat upon decisions made in combat -- and must express assumptions and outputs in terms intuitively acceptable to combat commanders and technically satisfying to military analysts.

We believe that this study has met these needs and provides a practical method for quantifying the deterrence factors.

Descriptions of Prior Mine System Models

The following models were reviewed for potential application to this study:

Table 1. Mine System Models Surveyed

Model Name	Type	MOE	Government Agency
ACT V	Casualty, Monte Carlo	Mine produced casualties and delay time	AFATL/DLYW, Eglin AFB, Florida
MINSIM II	Casualty, Markov	Mean casualties, mean breach time	AFATL/DLYW, Eglin AFB, Florida
MINSIM III	Casualty, Monte Carlo	Mean casualties, mean breach time	AFATL/DLYW, Eglin AFB, Florida
AMSAA 1 & 3	Personnel casualties, Monte Carlo	Mean casualties	AMSAA, Aberdeen Proving Ground, MD
AMSAA 2 & 4	Armor casualties, Monte Carlo	Mean casualties	AMSAA, Aberdeen Proving Ground, MD
AMSAA 5	Casualty, Closed Form	Mean casualties	AMSAA, Aberdeen Proving Ground, MD
AMSWAG	Casualty deterministic	Suppression, time to kill	AMSAA, Aberdeen Proving Ground, MD
NWC-C-1, C-2, G-1	Casualty, Markov	Mean casualties and delay time	Naval Weapons Center, China Lake, California
PA-IR14	Closed Form, casualty	Probability of survival (Personnel)	Picatinny Arsenal, Dover, New Jersey
PA-IR20	Casualty, Markov		
BRDEC/CAC ODM	Casualty, computer-assisted wargame	Increased target exposure, reduced firepower	BRDEC (formerly Systems Office MERADCOM) Ft. Belvoir, VA
Weapon Suppression Model	Suppression, Monte Carlo	Probability of target being ineffective	Naval Weapons Center, China Lake, California
DYNTACS X	Casualty Monte Carlo	Probability of kill, delay time, cost	ARMCOM

Casualty Model Selected

The BRDEC/CAC model was selected to provide input data to the deterrence model. The following description is taken in part from the BRDEC/CAC Report [4]. The model is a computer assisted, manual wargame developed to simulate armor engagements at the Battalion/Company level. The effects of obstacle/vehicle interactions under covering fire are simulated by the Obstacle Direct-fire Model (ODM). Play is controlled by a time or distance sequence of events. Range sensitive weapon parameters and fire/movement tactics are separately loaded for each time or distance interval segment and are held constant over its length. Weapon effects are based on expected values.

Three types of computational function exist: target acquisition, fire distribution, and the predictor-corrector. The first two determine the number of targets available to be fired on and distribute the fire according to a set of target priorities. The predictor-corrector compensates for the varying force size within a given path segment by replicating on the attrition/suppression computation, each time decrementing the force size.

Sub-modules available to operate in conjunction with the ODM Fire Module include: conventional obstacles, breach, breach exploitation, and minefield. The sub-modules operate independently of the Fire Module and the interface must be coupled manually in a series of steps. The Fire Module is run up to the leading edge of the field to determine the number of entering units; the casualties and delay time are then determined by a sub-module and are entered into the Fire Module at a range corresponding to the mid-point of the field by decrementing the clock and surviving force and continuing to run the base game.

Input data per path segment includes the number of rounds to be fired per weapon type, its combined hit probability, direct suppression, detection probability, target priority, and the probability of being suppressed by indirect fire. Tactics, terrain, and climatic conditions are implicitly modeled by variations to the input data. For example, the lethality and target acquisition data base in the ODM was derived from AMSAA and CDEC data used in the CACDA TETAM evaluation. Direct Suppression (DS) is assumed to be proportional to a near miss and is set equal to DS = min P_{hk} or 1/2 (1-P_{hk}), whichever is less. Indirect suppression is arbitrarily set at 50 percent against the Blue antitank guided missiles (ATGM) and at 30 percent for Red ground-launched ATGM. All model runs start at 3000+ meters and stop when the attacker has closed to 500 meters in front of the defender's position. No provision is made for breaking-off the attack when casualties reach high levels.

Model outputs include fractional casualties for both sides over selected time or distance intervals, by target type (tank, APC, etc.).

HISTORICAL EXPERIENCE

The concept of the barrier in warfare is as old as war itself, and mine warfare is almost as old as gunpower. Military historians and analysts have written volumes describing the various aspects of mine warfare, the intended purposes of such barriers, and their interpretation of the net effects of mines. The significant aspect of these accounts is that the trend with time seems to be toward greater use of mines. WW I was the first modern application followed by Vienna in the 1930's, Stalingrad (1942), Kursk (1943), Warsaw (1944), Seoul (1950), Budapest (1956), the Arab-Israeli Wars (1967, 1973), and interdiction mines around Hai Phong and Phnom Penh. The U.S. and its allies in WW II used mines in most campaigns. Despite all these cases, there are almost no detailed data on which a model can be based. G. E. Cooper of the U.S. Army Engineer Studies Group, in a study of barrier effectiveness [5], attempted to find historical data to support an assessment of obstacle effectiveness. His conclusions are similar to ours; he found evidence to be incomplete, outdated, and lacking in comparability. Given this paucity of quantifiable data on the application of mines, we decided to minimize the effort expended on historical research and concentrate on devising a model that logically fitted historical examples of minefield purpose and man's behavior under fire.

Historians do seem to agree on the purposes of mines even if they cannot quantify the effects. G.E. Cooper's list is better than most:

- Destroy or disable attackers
- Delay attacker away from or near the battle area
- Influence the likelihood, position, and width of attack
- Thin or concentrate the density of attacker's force
- Permit thinning or concentration of defender's force (Economy of Force)
- Enhance defender's weapons
- Divert attacker resources into less threatening, less productive roles
- Control enemy penetration
- Distract the attacker's attention
- Cover defender withdrawals
- Create local pileup of enemy forces
- Interdict enemy reinforcements
- Interdict enemy logistics
- Install or disable one or more vehicles to block others

- Deny access to areas and facilities such as airfields, marshalling yards, ports, and storage areas

- Force or encourage mounted attackers to dismount or to button down

The key concept that runs through most accounts of mine warfare is the concept of combined arms or combinations of weapons to achieve large increases in effectiveness. Herman Kahn described this effect in "On Thermonuclear War" where the Germans combined the antitank Teller mine with the anti-personnel S-mine. Each weapon made the other more effective by protecting it. Likewise, Cooper's list implies the same principle.

With regard to scatterable mines, the lesson of history is that many times a mine barrier could have been used but was not because the effort required to emplace a mi eld was too great or time was too short. Operation Barbarossa, the German blitzkrieg against Russia in 1942, would probably have progressed differently if the Russians had had an adequate supply of simple hand-dispersed mines. The list of might-have-been situations is almost as long as the list of modern warfare. The point is that study of modern conflicts leads to the conclusion that a rapidly deployed mine barrier has many very useful tactical applications, not the least of which is deterrence.

The Dictionary of U.S. Army Terms (AR 320-5) defines deterrence as "the prevention from action by fear of consequences and a state of mind brought about by the existence of credible threat or unacceptable counteraction." If risk is higher than acceptable, the decision maker is said to be deterred. If deterrence is related to the amount of risk and can be measured by the cost associated with risk, then the problem lies in trying to determine the risk threshold and then determining the probability of that threshold being exceeded.

Historically, military planners anticipate risk in terms of expected killed and wounded personnel, and destroyed vehicles. Engaged forces use the same measures in real time. For example, Soviet attacks against German positions have been known to falter, stop and retreat. Obviously, the risk threshold of these commanders in terms of battle damage was exceeded. More recently, the Syrian attacks in the Golan Heights were observed to stop, retreat, regroup, and attack again. Likewise, the Israeli attacks against Egyptian forces in the Sinai in the first week of the 1973 October War were also halted short of annihilation.

The point being emphasized here is that the concept of a breakpoint is a real phenomenon. Attacking forces can, and do, assess what is happening to them and adjust their actions accordingly. Literature describing Soviet practices tells us that the average Soviet Commander is more operational analysis oriented than is his American counterpart. Therefore, if the Soviet commander's intelligence and direct observation tell him that a mine barrier will attrit or delay his force more than his mission needs can tolerate, it is unlikely that he will initiate or continue his attack. In that case, the minefield's deterrent effects are a function of perceived risk measured against the requirement of breaching.

History also tells us that some minefields have been breached at very high cost. The deterrent effect in these cases is zero but the overall military effect is (or can be) very significant in that the casualties produced while traversing the minefield are no longer available to prosecute the attack on the objective.

At the opposite end of the scale, a minefield that is not attacked because of its perceived risk has a high deterrent value. Between these two poles are the cases in which an attack fails while in progress.

There are a number of breakpoint theories advocated by respected authorities. Despite their diversity they share a common definition of the breakpoint as being the outset of a condition wherein the combat unit is no longer capable of carrying out its assigned mission. The most commonly used measure or estimator of breakpoint is the percent of casualties sustained by the fighting unit. There is nothing particularly profound about this quantity; its popularity lies in its availability. Casualties are frequently the only reliable statistics that can be found by the analyst once the smoke of battle has cleared.

Casualty production tends to follow a predictable pattern originally recognized in Lanchester's work on Civil War Data. Assuming a 4-to-1 attacker-to-defender force ratio, the analyst can expect the defender's losses to go up as the attacker gets closer to him. In general, the defender pays a price (casualties) that is inversely proportioned to the range between the two forces at the point of break-off. This relationship is important to the following description of the deterrence model.

DETERRENCE MODEL DESCRIPTION

Model Concept

The overall objective of the deterrence model is to define and quantify the deterrent effects of current and future mine systems employed in combined arms engagements. More specifically the model is intended to simulate an attack through a mine barrier and to measure the resulting effects in terms of the attacker's tactical decisions as well as the casualties produced during the attack. Conceptually the model represents the dynamic decision process of an attacking commander based on an underlying casualty model and influenced by the risk behavior of the attacking commander and his superiors. Figure 1 depicts the general concept.

The BRDEC/CAC casualty model is run to produce its normal output. At the same time, the casualty model outputs are operated upon by the deterrence model resulting in a new set of outcomes. The two runs are compared and analyzed for significant differences and deterrent effects are derived from these differences.

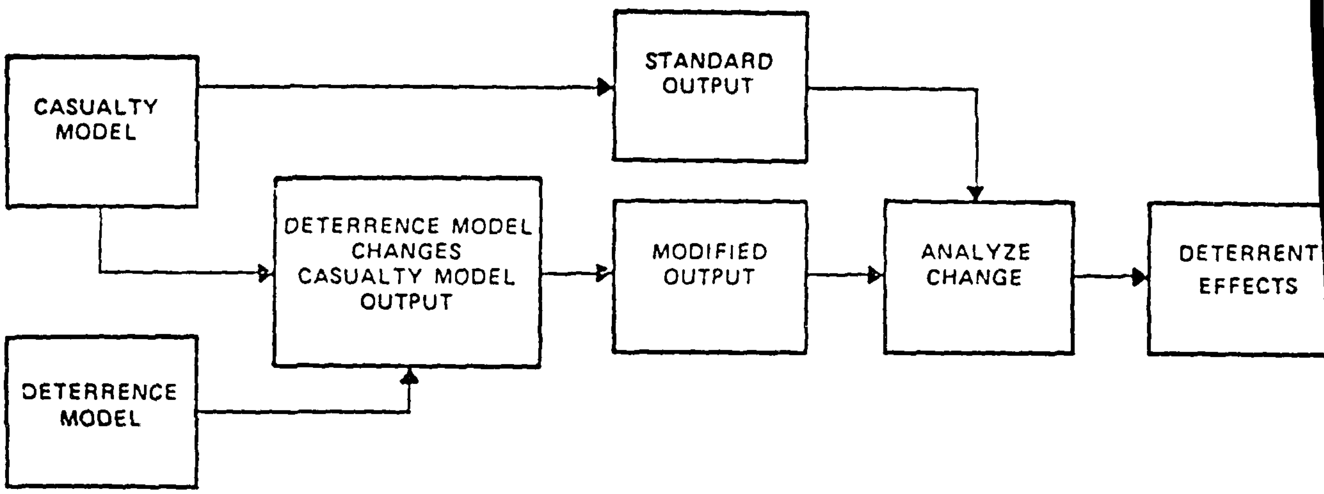


Figure 1. Deterrence Effects Development

Assumptions

The task directive stipulated some assumptions, and in the course of the study a few more were made for the model. They include:

- NATO environment — scenarios from SCORES acceptable to both TRADOC and DARCOM.
- FASCAM and conventional mines are available.
- All minefields are covered by fire.
- Attacker has knowledge of the location of 70 percent of all conventional minefields — an estimate drawn fro. the AMSAA wargame.
- Attacker risk behavior can be estimated based on cardinal utility theory.

Model Inputs

Inputs to the model fall into two sets: those obtained from the BRDEC/CAC model and described earlier in this paper, and those characteristic of the deterrence model. This latter set of inputs includes:

- Mission Requirements which are authoritative estimates of the remaining military force required at given stages of the attack. These input values are derived before model operation begins and are based upon actual combat data and/or judgments of experienced army commanders. They consist of the numbers of attacking tanks, APCs, infantry, etc., that must be operating to continue the attack and take the objective. Mission requirements may be verified through Delphi or KSIM techniques. Each tactical setting will have a unique set of mission requirements. The purpose of the mission requirements is to introduce "real-world" experience into the evaluations. They serve as logical constraints to keep model results within realistic bounds. The mission requirements also state the overall success criteria for the attack — expressed in numbers of fighting units that must survive the attack and their time of arrival at the objective.

- Psychometric Risk Profiles of combat commanders which are derived from the application of cardinal utility theory to the risk-taking characteristics of military officers. These profiles are based on the work of Syracuse University Research Corporation (SURC) and provide a quantitative and logical basis for the deterrence model. In the model, mission requirements and risk behavior are used together to determine if the attacking commander will be deterred or if the attack will continue. The methodology used for assessing risk behavior is discussed in more detail later in this paper.

- Mission Value which is an expression of the military value of achieving the tactical objective. The purpose of establishing a "mission value" for the attack is to reflect the emphasis that higher command echelons naturally exert on the actions of their subordinate combat units. In the vernacular, it is common for a division or brigade commander to indicate his priorities by telling his battalion commanders to "take that hill at all costs" or to "hold position and stay in contact if stiff resistance is met" or to "go to an alternative objective if casualties get too heavy," etc. In the prototype model presented here, it is assumed that the value of military objectives is normally distributed in the statistical sense of the word. We arbitrarily divide all mission values into four quartiles and we place 25 percent in the "high" value category, 50 percent in the "medium value," and the remaining 25 percent in the "low value" objectives. This concept of the use of value allows utility theory and risk behavior theory to be combined in an index [6] (described below) which serves as an estimator of a commander's tactical behavior in the attack.

Model Outputs

Casualty model outputs (i.e., fractional casualties for both sides at each stage by target type) are compared with mission requirement values as well as with risk behavior values at each stage (an interval of range). Based on decision rules, the attack is continued or broken off. The casualty figures at break-off are the principal output of the deterrence model.

Deterrent effects are derived by comparing casualties produced up to the time of break-off with those produced by the (unmodified) casualty model. In particular, the number of additional Blue survivors due to Red deterrence is derived. Any number of alternative mine concepts can be introduced to the model and the resulting outputs can be analyzed for significant characteristics, optimal combinations, and possible tradeoffs. These results now become a means for evaluating such factors as the allocation of RDT&E resources and guides for acquisition decisions.

When the deterrence model is run interactively with the casualty model data, the time penalty associated with countermeasures is also evaluated.

Measures of Effectiveness

The measures of effectiveness used in this analysis are the generalized outputs just described. The three important measures are:

- Increased defender (Blue) survival due to attacker (Red) deterrence.
- Attacker (Red) casualties.
- Attacker (Red) range and time at break-off.

These are discussed in greater detail in the examples that follow.

Functioning of the Model

The BRDEC/CAC casualty model as now designed produces casualty outputs at each of six stages in a given scenario. The deterrent model is overlaid on this model as shown above in Figure 1. Figure 2 below depicts more detail and illustrates that the deterrence problem is basically a decision problem. Figure 3 shows an actual decision tree. An important part of Figure 2 is the box labeled "Mission Criteria" which combines the attacking commander's military risk behavior with the mission values estimated by experienced military commanders. The mission criteria are the required surviving forces at each stage of combat. Each attacking commander and tactical situation will have a different set of criteria depending upon the assigned mission value and the tactical commander's risk behavior characteristics. Decision rules, presented later, will govern the attacker's decision when the mission criteria are compared with casualty production. At these decision points, or stages, the attacking commander will choose one of the options shown in Figure 2.

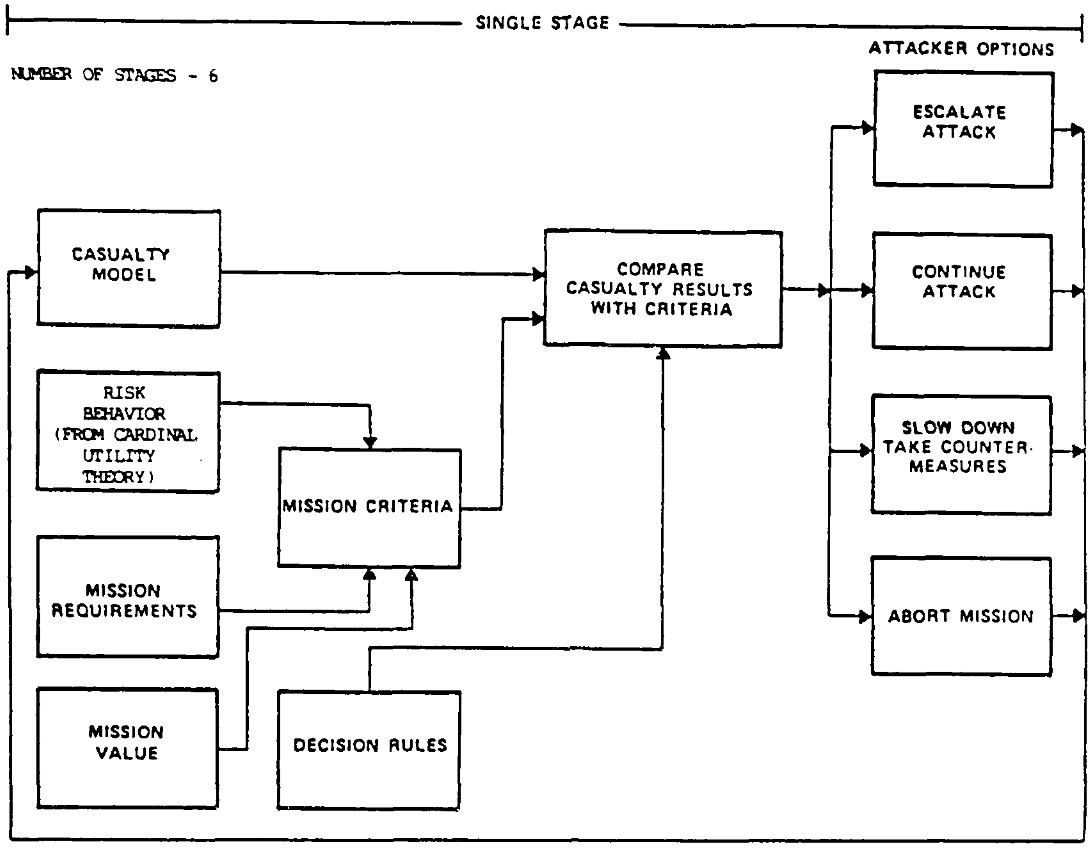


Figure 2. Details of Deterrent Effects Model
Flow for Each Scenario Stage

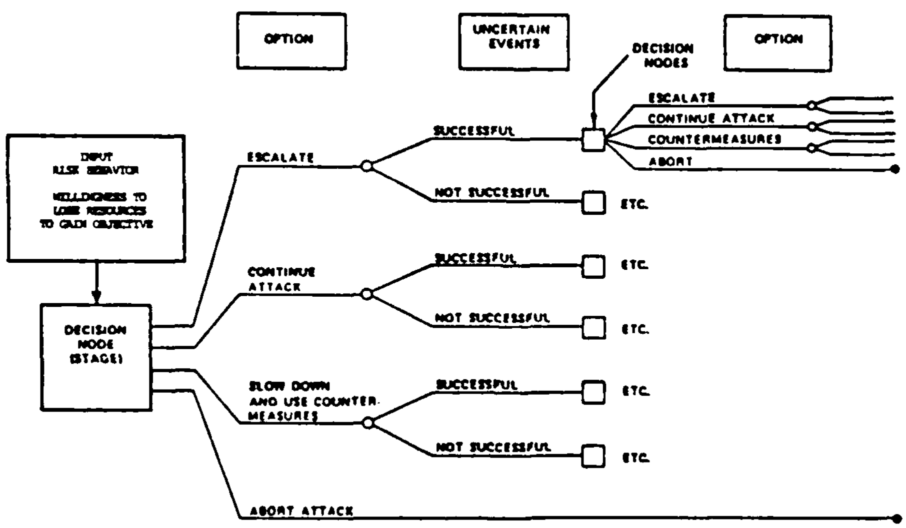


Figure 3. Basic Decision Tree Used in the
Deterrent Estimation Process

Risk Behavior estimates of the attacking commanders are based on individual risk profiles. Figure 4 illustrates the distribution of many such profiles. The three curves depict the variation of risk behavior as determined for a group of Army officers, based on a Syracuse University Research Center behavioral experiment (cited below). Three types of risk behavior are illustrated: risk averse, risk neutral, and risk accepting. The abscissa is a measure of the attacking commander's willingness to lose fighting units in order to reach his objective.

To illustrate the use of the Risk Behavior Curves, consider the case for a .50 Mission Value. The Risk Averse commander is willing to risk losing less of his forces to reach his objective than is the Risk Neutral commander, and the Risk Accepting commander is willing to risk more of his forces (assuming each starts with the same size force). As the Mission Value decreases (say to .25), each of the commanders is shown to be willing to risk less of his forces to achieve a lower value objective.

Note that the willingness to lose resources can be correlated with the size of an attacking force so as to provide estimates, as a function of Mission Value and Risk Behavior, of the surviving forces a commander estimates he needs at each stage of an attack. This is illustrated in the example cases described below and shown in Figure 7.

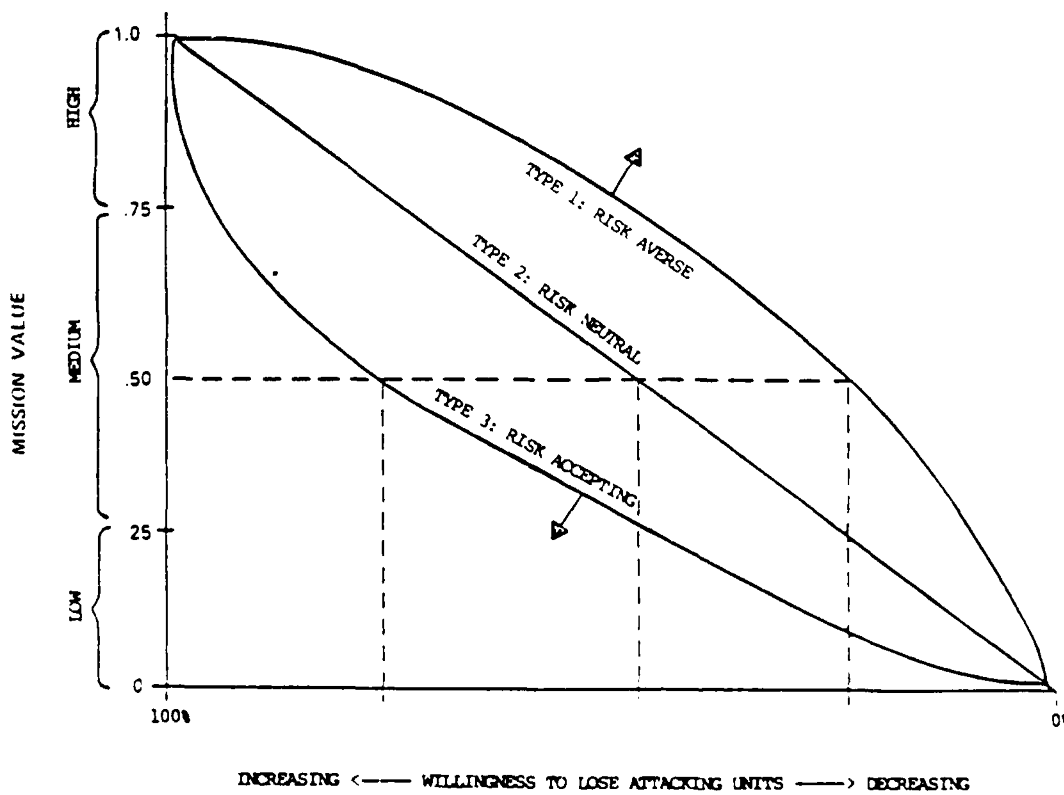


Figure 4. Risk Behavior Curve

Utility Function Determination

Dr. Ralph Swalm of Syracuse University Research Center used cardinal utility theory to design and conduct an experiment to determine the risk preferences (utility functions) of a group of Army commanders. Taking one at a time, individual officers were asked to choose between an alternative which leads to a certain gain (or loss) of a known amount and another alternative which could lead to either of two outcomes. It is assumed that all gains or losses will take place in the very near future. The individual is acting in the capacity of a decision maker for public resources, not private resources. Also, the responses were to represent the actual action he would take if the alternatives were presented today, not what he felt he should do, not what might be expected to be done. The results of the experiment were evaluated and a utility score for that individual derived. These data are empirical, the setting is clinical and the actual sample size is small. A more extensive sample is required before a high degree of reliability can be attributed to the sampling distribution. Nevertheless, the decision risk assessment phenomenon exerts a strong influence in the real-world of tactical combat and if the utility function or population distribution shift somewhat, based on later empirical data, the general methodology described is no less valuable. Meanwhile, the relationships can be examined parametrically to explore a range of sensitivities.

Decision Rules

A set of nine decision rules were found to be necessary to ensure consistency of model results. These rules apply to the attacking commander only, since only he can decide to be deterred. The defender's (Blue's) actions are preset to hold their position unless the attacker (Red) reaches to 500 meters from Blue's position. Blue then withdraws.

The following definitions are used:

- K_t is the number of surviving Red units required at a given stage, t, as stated in the mission requirements.
- FR is the number of forces the Red (attacking) commander estimates he needs to continue the attack - based on his risk behavior.
- T is the actual (calculated) surviving Red force size at any stage t.

The rules are as follows:

1. Establish the Mission Value (MV).
2. Specify the attacking commander's risk behavior - Type 1, 2, or 3 in Figure 4.

3. Determine from Figure 4 (abscissa) the corresponding estimated surviving force required (FR).

4. Define the mission requirement (K_t) - number of units (K) that must survive at each stage (t).

5. Determine the surviving force (T) at stage (t). If T_t > FR and > K_t, continue the attack.

6. If T_t < FR or < K_t, but not both, and Mission Value (MV) is high, commit reserves and take countermeasures, provided that T_t + reserves > FR and > K_t.

7. If Number 6 is followed, and T_t becomes < FR and < K_t, abort mission.

8. If T_t < FR or < K_t, but not both, and MV is not high, slow advance and take countermeasures.

9. If T_t < K_t and < FR and MV is not high, abort mission.

Once the first four steps are completed (the process is repeated at each stage of combat), rules 5 through 9 can follow.

A cautionary note is needed at this point. In the examples that follow, the model logic was applied to casualty model outputs <u>after</u> the entire run was completed. Ideally, the process will be interactive. Rule number 8 illustrates the point. If the Red force is already using countermeasures and advancing at a slow rate, rule 8 requires Red to use more countermeasures and slow down even more. The net effect of this probably will be to increase Red casualties or at least to provide more time for Blue to fire on Red targets.

<u>Example Cases</u>

The methodology can best be demonstrated by example. Two separate runs of the BRDEC/CAC casualty model were chosen:

(1) M15 minefield at 2650 meters using plow tactic at 6M per hour.

(2) M15 minefield at 2650 meters and dynamic (FASCAM) minefield at 2450 meters and Bull tactic at 10KM per hour.

Deterrence was evaluated in both examples in two ways. In the first, attacking tank casualties were the only losses that counted, and in the second all attacking force (tanks, APCs, etc.) casualties were counted. Figure 5 is a matrix showing various combinations in the examples taken.

	EXAMPLE NUMBER			
	1A	1B	2A	2B
CONVENTIONAL MINES ONLY	X	X		
CONVENTIONAL MINES PLUS FASCAM			X	X
TANKS ONLY	X		X	
COMBINES ARMS		X		X
BULL TACTIC @ 10 KM/HR			X	X
PLOW TACTIC @ 6 KM/HR	X	X		

Figure 5. Example Cases

It is emphasized that the following examples were selected more to exercise the model than to demonstrate deterrence values. The selected examples had relatively complete sets of data points. Later, as the model and its associated input values are refined, a larger variety of tactical settings and mine characteristics can be evaluated.

The mission value is selected as "medium" and the attacker's mission requirements require at least 50 percent of the attacking force to be operational upon reaching the objective. For these examples, time to take the objective was not specified. Figure 6 depicts the tactical setting.

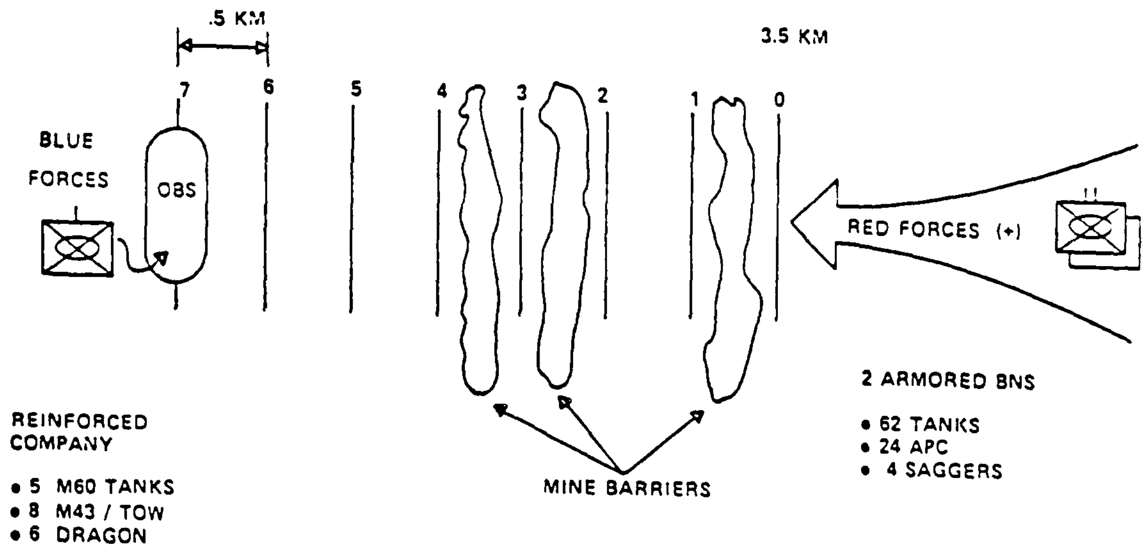


Figure 6. Tactical Settings

The implications of these inputs is illustrated in Figure 7 which converts the willingness to lose resources into the number of attacking units the commander is willing to risk losing as a function of mission value and risk behavior type. Tables 2 and 3, mission criteria regulatory tables, combine both mission requirements and risk behavior criteria by model stage for the medium value mission. Table 2 presents criteria for the tank-only case and Table 3 presents the combined arms case.

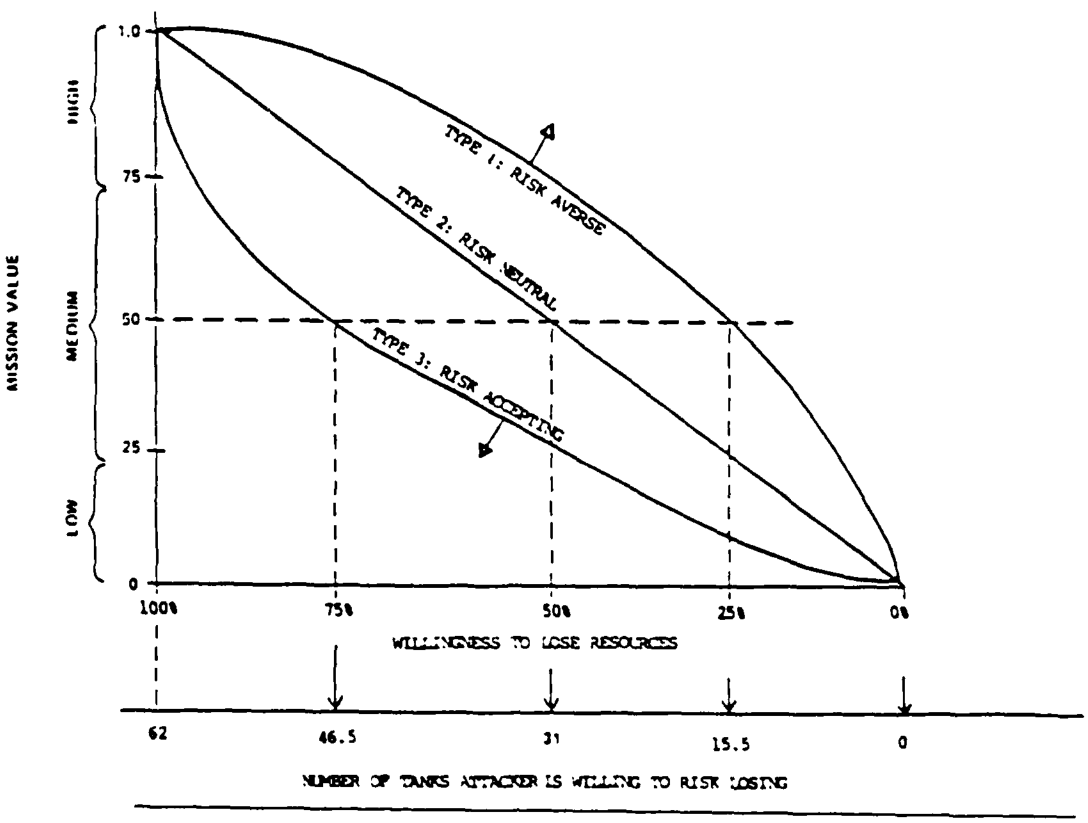


Figure 7. Applied Risk Behavior Curve

RED TANKS ONLY
MEDIUM MISSION
VALUE

STAGE	RANGE (KM)	TIME (MIN)	MISSION REQUIREMENTS*		RISK BEHAVIOR CRITERIA**		
			NO. OF UNITS THAT MUST SURVIVE	FRACTIONAL CASUALTIES %	TYPE 1 (UNITS)	TYPE 2 (UNITS)	TYPE 3 (UNITS)
0	3-4 KM	0	62	0	46.5	31	15.5
1	2.5	4.8	52	16	46.5	31	15.5
2	2.0	7.8	42	32	46.5	31	15.5
3	1.75	10.1	38	39	46.5	31	15.5
4	1.25	14.8	32	48	46.5	31	15.5
5	1.0	17.1	31	50	46.5	31	15.5
6	0.5	21.8	31	50	46.5	31	15.5

*Based on Expert Military Judgment

** Based on Cardinal Utility Theory

Table 2. Mission Criteria Regulatory Table

ALL RED FORCES
MEDIUM MISSION
VALUE

STAGE	RANGE (KM)	TIME (MIN)	MISSION REQUIREMENTS*		RISK BEHAVIOR CRITERIA**		
					NUMBER OF UNITS REQUIRED		
			NO. OF UNITS THAT MUST SURVIVE	FRACTIONAL CASUALTIES %	TYPE 1	TYPE 2	TYPE 3
0	3-4	0	90	0	67.5	45	22.5
1	2.5	4.8	75.6	16	67.5	45	22.5
2	2.0	7.8	61.2	32	67.5	45	22.5
3	1.75	10.1	55.0	39	67.5	45	22.5
4	1.25	14.8	46	48	67.5	45	22.5
5	1.0	17.1	45	50	67.5	45	22.5
6	.5	21.8	45	50	67.5	45	22.5

*Based on Expert Military Judgment

** Based on Cardinal Utility Theory

Table 3. Mission Criteria Regulatory Table: All Red Forces

Notice that each stage has different values listed in the mission requirements column of Tables 2 and 3. These values are estimates made by military commanders who have studied the tactical situation in an overall sense as well as in detail. Their instructions are to quantify the number of units (tanks, APC, etc.) that the attacking commander must have in order to continue to the next stage and also to arrive at the objective with the number of units defined by the success criteria, i.e., n tanks in t time.

Tables 4, 5, 6, and 7 present casualty model results compared with the criteria shown in Tables 2 and 3. In the right hand column are shown the decisions made by the attacking commander based on the decision rules presented earlier. Example 1A (Table 4) presents the case where the attacker (Red) wins against a conventional minefield. ("Wins" being defined as reaching stage 6 which is 500 meters in front of the defender (Blue) at which point Blue withdraws.) Only Red tank casualties were considered and it is easy to see that the deterrent effect of the conventional minefield on heavy armor in this case was not sufficient to stop it. Example 1B (Table 5) shows the same example, however, all casualties to the attacking force were counted and at the end of the third stage the Red force was stopped. Examples 2A and 2B (Tables 6 and 7) show the same basic situation with Red using a bull tactic and with a FASCAM barrier added. Considering only tanks, the attack stops at stage 4; considering all forces, the attack stops at the second stage.

RISK BEHAVIOR TYPE 1
MISSION VALUE MEDIUM
RED TANKS ONLY
CONVENTIONAL MINES

STAGE	RANGE (KM)	TIME (MIN)	DECISION RULE USED	SURVIVING FORCE (1)		MISSION REQUIREMENTS (2)		RISK BEHAVIOR CRITERION (3)	DECISION
				UNITS	F/C%	SURVIVORS	F/C%		
0	3.4	0		62	0	62	0	46.5	
1	2.5	4.8		52.13	15.9	52	16	46.5	
			5						CONTINUE ATTACK
2	2.0	7.8		52.13	15.9	42	32	46.5	
			5						CONTINUE ATTACK
3	1.75	10.1		46.36	25.2	38	39	46.5	
			8						CONTINUE ATTACK AT SLOWER RATE
4	1.25	14.8		34.31	44.7	32	48	46.5	
			8						CONTINUE ATTACK AT SLOWER RATE
5	1.0	17.1		33.21	46.4	31	50	46.5	
			8						CONTINUE ATTACK AT SLOWER RATE
6	0.5	21.8		30.60	50.5	31	50	46.5	RED WINS. BLUE WITHDRAWS WHEN RED
									REACHES 500 METER LINE

(1) From Casualty Model; (2) From Expert Judgment; (3) From Step 3

Table 4. Casualty Model Results Compared with Criteria: Example 1A

RISK BEHAVIOR TYPE 1
MISSION VALUE MEDIUM
RED COMBINED ARMS
CONVENTIONAL MINES

STAGE	RANGE (KM)	TIME (MIN)	DECISION RULE USED	SURVIVING FORCE (1)		MISSION REQUIREMENTS (2)		RISK BEHAVIOR CRITE-RION (3)	DECISION
				UNITS	F/C%	SURVIVORS	F/C%		
0	3-4	0		90	0	90	0	67.5	
1	2.5	4.8		74.46	17.3	75.6	16	67.5	
			8						CONTINUE ATTACK AT SLOWER RATE
2	2.0	7.8		61.22	32	61.2	32	67.5	
			5						CONTINUE ATTACK
3	1.75	10.1		54.15	39.8	55.0	39	67.5	
			9						ABORT MISSION
4	1.25	14.8				40.0	48	67.5	
5	1.0	17.1				45.0	50	67.5	
6	0.5	21.8				45.0	50	67.5	

(1) From Casualty Model; (2) From Expert Judgment; (3) From Step 3

Table 5. Casualty Model Results Compared with Criteria: Example 1B

RISK BEHAVIOR TYPE 1
MISSION VALUE MEDIUM
RED TANKS ONLY
DYNAMIC MINEFIELD

STAGE	RANGE (KM)	TIME (MIN)	DECISION RULE USED	SURVIVING FORCE (1)		MISSION REQUIREMENTS (2)		RISK BEHAVIOR CRITE-RION (3)	DECISION
				UNITS	F/C%	SURVIVORS	F/C%		
0	3-4	0		62	0	62	0	46.5	
1	2.5								
2	2.0	8 MIN		47.01	24.18	52	16	46.5	
			5						CONTINUE ATTACK
3	1.75	10.3		40.68	34.39	38	39	46.5	
			8						SLOW ADVANCE: USE COUNTERMEASURES
4	1.25	15		25.51	58.85	32	48	46.5	
			9						ABORT MISSION
5									
6									

(1) From Casualty Model; (2) From Expert Judgment; (3) From Step 3

Table 6. Casualty Model Results Compared with Criteria: Example 2A

RISK BEHAVIOR TYPE 1
MISSION VALUE MEDIUM
RED COMBINED ARMS
DYNAMIC MINEFIELD

TAGE	RANGE (KM)	TIME (MIN)	DECISION RULE USED	SURVIVING FORCE (1)		MISSION REQUIREMENTS (2)		RISK BEHAVIOR CRITE-RION (3)	DECISION
				UNITS	F/C%	SURVIVORS	F/C%		
0	3-4	0		90	0	90	0	67.5	
1	2.5			72.06	19.9	75.6	16	67.5	
			5						CONTINUE ATTACK
2	2.0	8 MIN		52.69	41.45	61.2	32	67.5	
			9						ABORT MISSION
3	1.75	10.3				55.0	39	67.5	
4	1.25	15.0				48.0	48	67.5	
5	1.0	17.3				45.0	50	67.5	
6	0.5	22				45.0	50	67.5	

(1) From Casualty Model; (2) From Expert Judgment; (3) From Step 3

Table 7. Casualty Model Results Compared with Criteria: Example 2B

Tables 8 and 9 show the resulting improvement in the number of defending forces that survive in each example compared to attacks without the use of the deterrence model. The expression $DE = 1 - \frac{R}{Q}$ is the principal measure of Deterrent Effects. Q is the fractional Blue casualties occurring at the last stage of the unmodified BRDEC/CAC casualty model. R is the fractional Blue casualties at the break-off of the attack. In the case of Example 1A break-off did not occur; consequently no improvement was noted. In the remaining three examples break-off did occur and the above equation provides a measure of improvement.

		STOP STAGE	TIME (MIN)	BLUE CASUALTIES	BLUE F/C%	RED CASUALTIES	RED F/C%	RANGE (KM)
EXAMPLE 1A	CASUALTY MODEL (Q)	6	21.8	5	100	31.31	50.5	.5
	CASUALTY MODEL WITH DETERRENT MODEL (R)	6	21.8	5	100	31.31	50.5	.5
	Δ	0		0	0		0	
EXAMPLE 2A	CASUALTY MODEL (Q)	6	22.0	5	100	42.95	69.27	.5
	CASUALTY MODEL WITH DETERRENT MODEL (R)	4	15.0	4.74	94.8	36.49	58.85	1.25
	Δ	2	7	.26	5.2	6.46	10.42	.75
	$DE = 1 - \frac{R}{Q}$				$1 - \frac{94.8}{100}$	= .05 =	5% IMPROVEMENT	

Table 8. Comparison of Attack Results (Tanks Only)

		STOP STAGE	TIME (MIN)	BLUE CASUALTIES	BLUE F/C%	RED CASUALTIES	RED F/C%	RANGE (KM)
EXAMPLE 1B	CASUALTY MODEL (Q)	6	21.8	15.83	83.3	52.85	58.7	.5
	CASUALTY MODEL WITH DETERRENT MODEL (R)	4	14.8	7.78	40.9	48.85	54.3	1.25
	Δ	2	7	8.05	42.4	4	4.4	.75
	$DE = 1 - \frac{R}{Q}$				$1 - \frac{40.9}{83.3}$	= .51 = 51% IMPROVEMENT		FOR BLUE
EXAMPLE 2B	CASUALTY MODEL (Q)	6	22	13.42	70.6	66.54	73.93	.5
	CASUALTY MODEL WITH DETERRENT MODEL (R)	2	8.0	1.05	5.5	37.31	41.45	2.0
	Δ	4	14.0	12.37	65.1	29.23	32.48	1.5
	$DE = 1 - \frac{R}{Q}$				$1 - \frac{5.5}{70.6}$	= .92 = 92%	IMPROVEMENT FOR BLUE	

Table 9. Comparison of Attack Results (Combined Arms)

Tables 10 and 11 give a summary of deterrent effects observed in Examples 1B and 2B in the form of the expected value of a given type of minefield defending a range of target values and attacked by various risk behavior types. The frequency distribution of each risk behavior type is incorporated in the calculations and presented in the bottom line of the two tables. The numbers in the "Expected Value of Deterrence" column are sums for each target type representing the percentage improvement to the number of surviving Blue combat units at the end of Red's attack. Examples 1A and 2A are not particularly illustrative and are not presented.

	RISK BEHAVIOR TYPE						
	I		II		III		
MISSION VALUE	DE	DE(TD)	DE	DE(TD)	DE	DE(TD)	EXPECTED VALUE OF DETERRENCE (%)
HIGH	40	23.2	25	7	0	0	30.2
MEDIUM	51	29.58	40	11.2	15	2.1	42.88
LOW	70	40.6	50	14.0	40	5.6	60.2
RISK BEHAVIOR TYPE DISTRIBUTION (TD)	.58		.28		.14		DE(TD)

DE = Deterrence Effect
TD = Risk Behavior Type Distribution

Table 10. Deterrent Expected Value: Example 1B

MISSION VALUE	RISK BEHAVIOR TYPE I DE	I DE(TD)	II DE	II DE(TD)	III DE	III DE(TD)	EXPECTED VALUE OF DETERRENCE (%)
HIGH	81	46.98	60	16.8	20	2.8	66.58
MEDIUM	92	53.36	75	21.0	50	7.0	81.36
LOW	99	57.42	90	25.2	65	9.1	91.72
RISK BEHAVIOR TYPE DISTRIBUTION (TD)	.58		.28		.14		$\sum_{I}^{III}$ DE(TD)

Table 11. Deterrent Expected Value: Example 2B

Figure 8 summarizes in graphic form the deterrence effects measured in each of the examples. The vertical dashed line represents the range (or stage) at which the Red force stopped their attack. Blue casualties that would have been suffered if Red had not stopped are taken from the unmodified MERADCOM/CAC model which continued to run until Red advanced to within 500 meters of the Blue defensive line (regardless of consequences.) Graphically, the effect being measured is the difference between the unmodified MERADCOM/CAC Blue casualty data (to the left of the vertical dashed line) and the stopping point determined by the deterrence model.

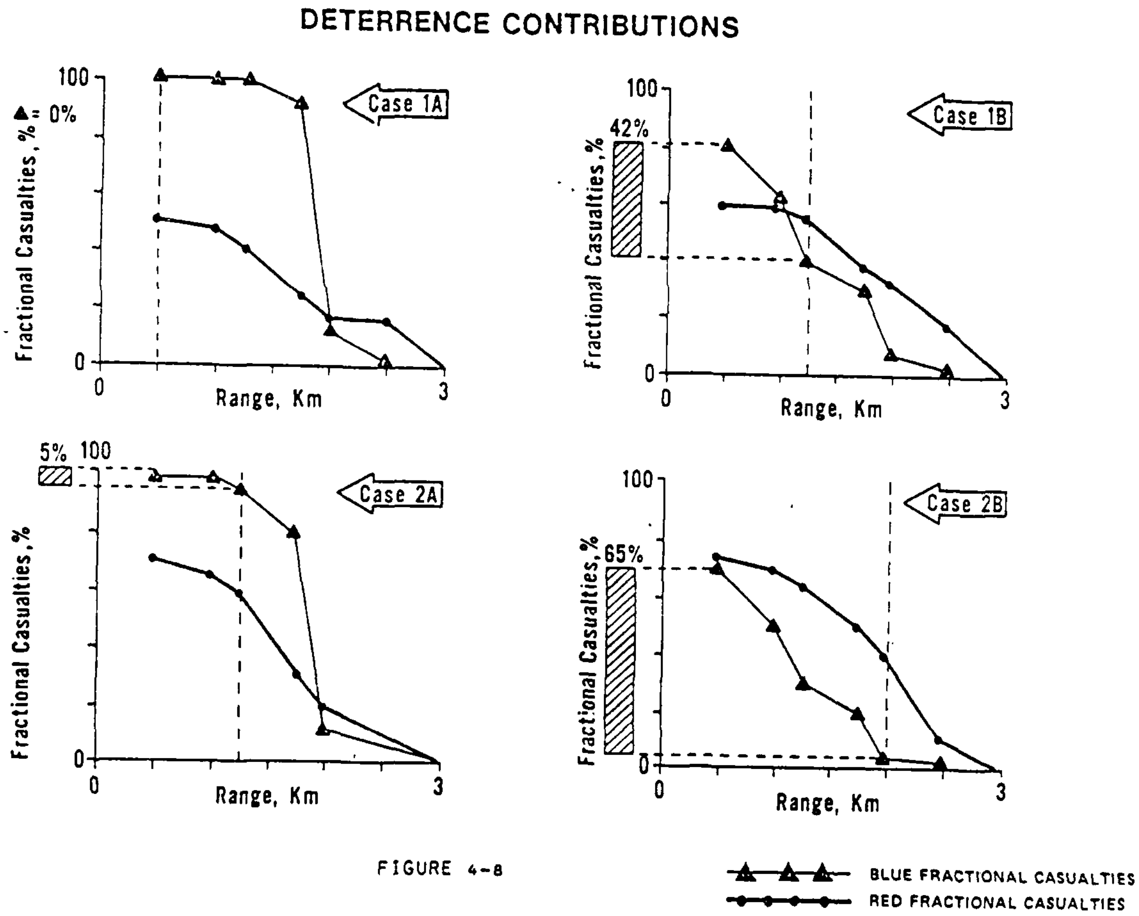


Figure 8. Deterrence Contributions

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Findings

The principal finding is that we have developed an unprecedented, easily used, and intuitively acceptable method for evaluating the most significant effect of mine systems: deterrence.

In the deterrence model, deterrent effects were sensitive to:

- attacker tactics
- mine system configuration
- mission value
- risk behavior of attacking commander.

Figures 9 and 10 depict the deterrent effect for examples 1B and 2B. The shaded area represents the deterrence contribution produced by the deterrence model. The horizontal line marked "casualty model only" represents the final casualty figure for the MERADCOM/CAC model data.

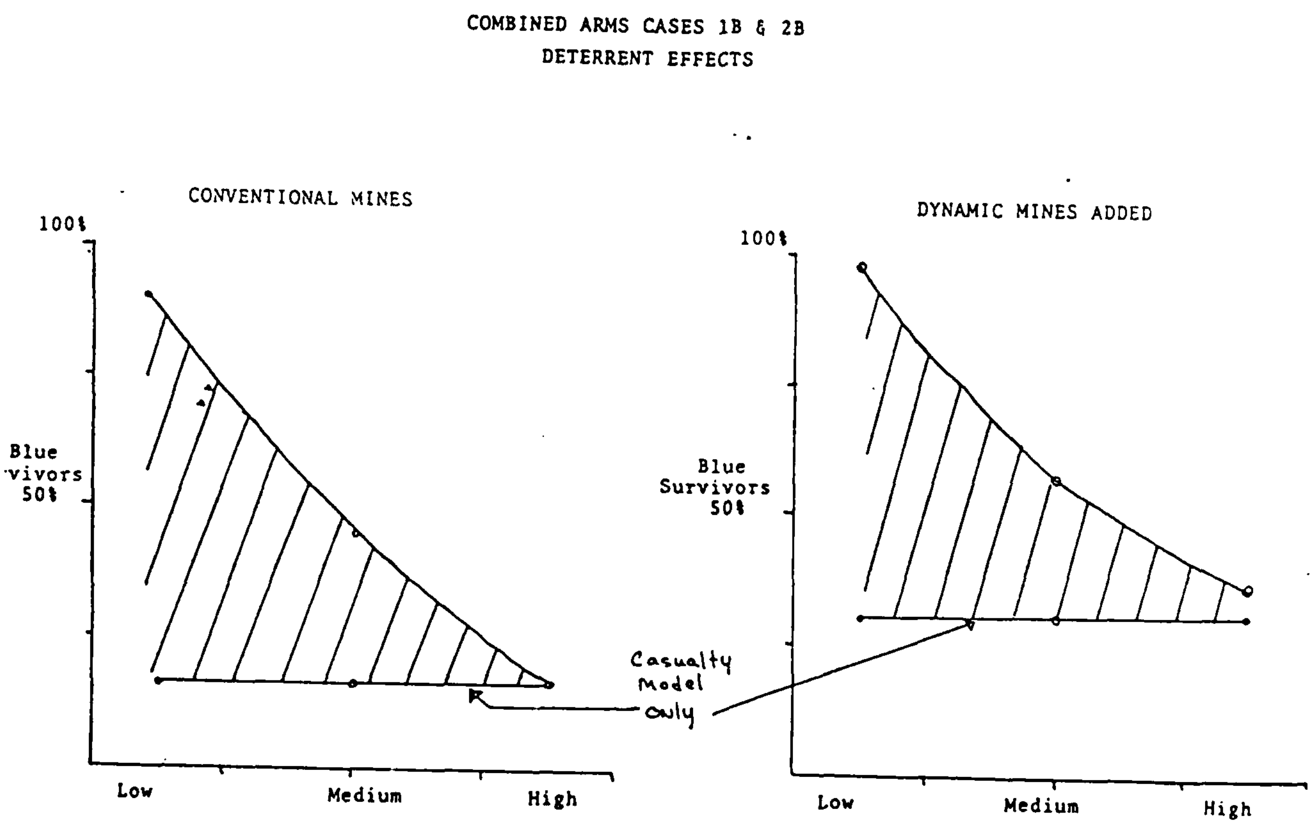


Figure 9. Case 1B:
Combined Arms Deterrent Effects

Figure 10. Case 2B:
Combined Arms Deterrent Effects

Figure 11 shows these two curves superimposed and the shaded area is the deterrent effect due to differing tactics and the use of FASCAM.

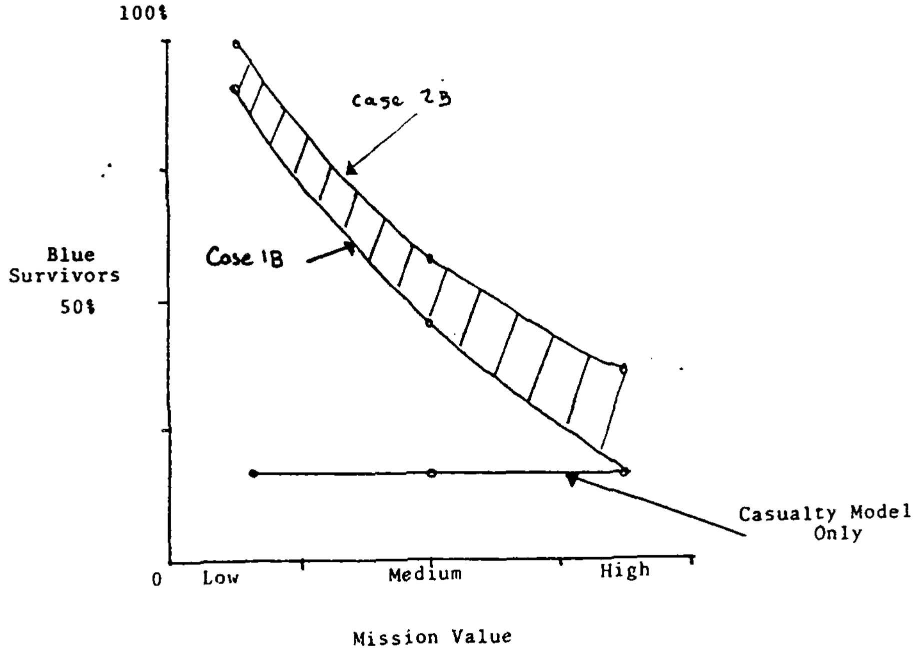


Figure 11. Cases 1B & 2B: FASCAM Deterrent Effects

Figure 12 presents the expected value (in terms of Blue survivors) of deterrent effects weighted by the observed distribution of risk behavior types. These curves present a realistic view of the value of deterrence by accounting for the fact that the majority of commanders are risk averse and only a relative minority can be classed as risk seeking.

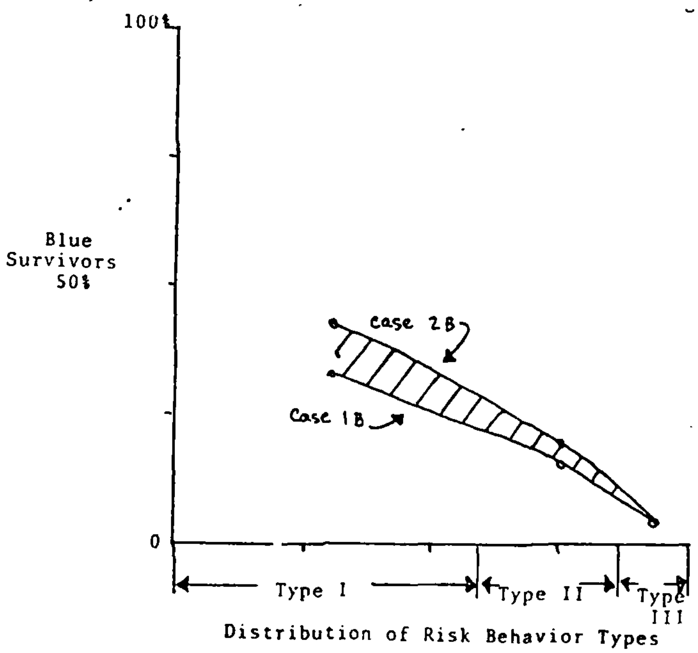


Figure 12. Deterrence Expected Value

The shaded area, again, represents the deterrent effects produced by FASCAM and tactics used by the attacking commander.

In further example, Figure 13 presents the case where the only difference between the three runs is the use of FASCAM. Bull Tactic 1 uses only conventional M15 mines, 2B (the same run used in previous examples) used M15 and one belt of FASCAM, and Bull Tactic 2 used M15 and two separate belts of FASCAM.

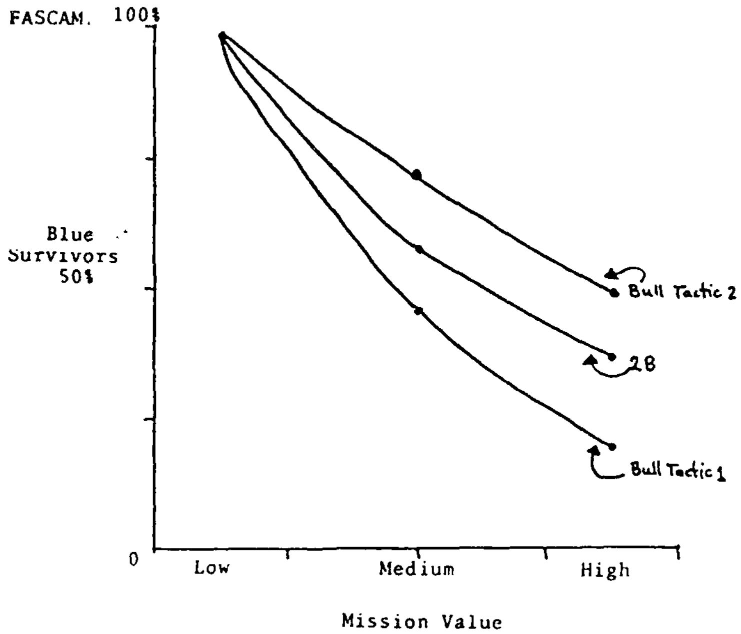


Figure 13. FASCAM Deterrent Effects

Conclusions

a. Deterrent values can be measured and expressed in terms useful to program management decision makers. As shown in the findings, all variables but one can be held constant and the resulting output will reflect the effect produced.

b. Because of the model's sensitivity to mission value and risk behavior, these inputs should be refined; methodology for determining these values should be reviewed and the results verified by rigorous examination in terms of logic, consistency and realism.

c. The model's sensitivity to weapon parameters can be increased by running the deterrence model interactively with the casualty model. This will allow the results of each successive stage of the combined deterrence-casualty model to influence later stages. From a user's point of view, this expanded evaluation capability will provide many additional data points covering a wider range of engagement conditions and more detailed assessments of mine types, densities, performance capabilities, deployment techniques, and their effects on both casualties and deterrence.

Recommendations

The following actions are recommended in sequence:

a. Apply the prototype deterrence model to additional existing casualty model data to produce results useful in program management decisions and to build a data base for subsequent improvements to the prediction of combat outcome.

b. Test and improve risk behavior assumptions and methodology.

c. Validate mission value distribution used in this report.

d. Test and validate mission requirements methodology and the values derived.

e. Establish a deterrence model to casualty model feedback loop.

f. Test the improved model for sensitivity to mine characteristics.

APPENDIX A
BIBLIOGRAPHY

1. Kulikov, General V., Chief of Soviet General Staff, Soviet Military Science Today, Kommunist, May 1976.

2. The Soviet Union, Strategic Review, Winter 1977.

3. Karber, Phillip, The Soviet Anti-tank Debate, Survival, May/June 1976.

4. DA, U.S. Army MERADCOM, Obstacle Enhancement of Covering Fire for Combined Arms Center, Fort Levenworth, Kansas, (U), 12 June 1976, K.J. Dean and C.W. King, Systems Office, MERADCOM (CONFIDENTIAL).

5. Engineer Studies Group, Battlefield Obstacles - An Appraisal of the State of the Art in Measuring Obstacle Effectiveness, Office, Chief of Engineers, Dept. of the Army, September 1976.

6. S. Patten, Dr. M. Miron, J. Selman, R. Swalm, Jr., The Feasibility of Generating Risk Profiles of Military Decision Makers, Final Report, SURCTR 74-200, 30 August 1974, Syracuse University Research Corp., Merrill Lane, University Heights, Syracuse, New York, 13210.

7. A Comparison of Minefield Models, March 1975, Joint Technical Coordinating Group for Munitions Effectiveness, Mine Effectiveness Working Group, 61 JTCG/ME-75-8, U.S. Air Force (UNCLASSIFIED).

8. Philip M. Allen, Review and Evaluation of Current Suppression Models with Proposal for Interim Model, October 1976, U.S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, Maryland.

9. Naval Weapons Center, Modeling of Weapon Suppression Effects, February 1974, D.G. Kinny, Weapons Planning Group, NEX TP5620, Naval Weapons Center, China Lake, California, 93555.

10. Marshall, S.L.A., Men Against Fire, New York, William Morrow and Co., 1947.

11. U.S. Army Combat Development Command, Infantry Agency, Relationship of Supporting Weapon Systems Performance Characteristics to Suppression of Individuals and Small Units, Final Report, R.P. Winter and E.R. Clovis, Litton Systems, Inc., January 1973, TR-73/002.

12. Dan's Div. Battles, 15th-16th Oct. 1973, Time Tables of Operations, English Version, Israel Defense Forces, Dept. of Military History, October 1976 (CONFIDENTIAL).

13. P. Bracken, H. Kahn, A Long Range Concepts Study of Landmine Warfare, Final Report, HI-2292RR, Hudson Institute, Quaker Ridge Road, Croton-on-Hudson, New York, 10520, Limited Distribution. August 28, 1975.

14. ACT VI: A Minefield Evaluation Model Incorporating Covering Fire Effects, AFATL-TR-74-198, Biocentric, Inc., 2233 Hamline Ave. North, St. Paul, Minnesota, 55113, December 1974, Limited Distribution, AD B004160.

15. Engineer Studies Group, Measuring Obstacle Effectiveness, A Fresh Perspective, Volume 1, Office, Chief of Engineers, Dept. of the Army, March 1975.

16. DA, U.S. Army Concepts Analysis Agency, Promulgation of the Conclusions of a Joint TRADOC/CAA Conference on Rules of Target Engagement, 6 October 1976.

17. T.W. Curl, Measuring the Effectiveness of Scatterable Mines in the Armor Combat Environment, Naval Postgraduate School Thesis, Monterey, California, 93940.

18. B.H. Rodin, Methodology for Evaluating Minefield Effectiveness, BRL Report No. 1839, October 1975, USA Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, 21005.

19. USA CDEC, Tactical Effectiveness of Minefields in the Anti-Armor Weapons System (TEMAWS) Project Analysis, June 1976, USA Combat Developments Experimentation Command, Fort Ord, California, 93941.

20. Dr. J. Voevodsky, Behavioral Cybernetics, A Manuscript, San Jose State College, San Jose, California, 95114, Spring 1970.

21. G. Levine, C.J. Burke, Mathematical Model Techniques for Learning Theories, Academic Press, Inc., 111 Fifth Avenue, New York, New York, 10003, 1972.

22. R.R. Bush, F. Mosteller, Stochastic Models for Learning, John Wiley & Sons, Inc., New York, 1955.

23. P. Rulon, D. Tiedeman, M. Tatusuoka, C. Langmuir, Multivariate Statistics for Personnel Classification, John Wiley & Sons, Inc., New York, 1967.

24. E.D. Neimark, W.K. Estes, Stimulus Sampling Theory, Holden-Day, San Francisco, 1967.

25. U.S. Army Engineer School, Family of Scatterable Mines Study, Phase III (U) (Short Title: FASCAM), Volumes I through VI, H.Q. U.S. Army Training and Doctrine Command, Fort Monroe, Virginia, 23651, April 1974, (SECRET).

26. H.R. Blacksten, J.G. Fox, An Analysis of Soviet Counter Mine Equipment and Doctrine in Military Operations in Built-Up Areas, KETRON, Inc., 1400 Wilson Blvd., Arlington, Virginia, 22209, October 1976 (SECRET).

A HUMAN PERFORMANCE DATA BASE FOR TARGET ENGAGEMENTS*

Sally A. Seven
Essex Corporation

and

Frederick A. Muckler
San Diego State University
Center for Effective Organizations (CEO)

ABSTRACT

This paper focuses on a human performance data base derived from a full-scale field operational test and evaluation of a major Army weapon system, the Sgt York Air Defense (DIVAD) gun. System and human performance data were compiled from 271 complete target engagements during the force-on-force phase of the DIVAD Follow-on Evaluation (FOE-I). Complete response time data are provided for the 271 engagements in 11 mission segments. Implications of these data are discussed for such issues as feedback to crews, system modes and the effects of levels of automation, and the use of these data for future system and human performance modeling in more realistic models and predictions of combat performance.

INTRODUCTION

In the spring of 1985, extensive force-on-force field exercises were conducted at the Combat Development Experimentation Center (CDEC) at Fort Hunter-Liggett, California to evaluate the performance of the Sgt York Division Air Defense gun (DIVAD). This DIVAD Follow-on Evaluation I (FOE-I) took more than a month to carry out, exclusive of training time, and involved a large variety of friendly and hostile force components.

In addition to the multi-crew, self-propelled Sgt York fire units, the Blue Force included from three to five Stinger crews (the number varying from trial to trial), two Chaparral fire units deployed to the rear of the battalion task force, from 21 to 26 M-1 tanks, at least 10 but usually 12 or 13 M-3s (infantry fighting vehicles), and an AH-1 attack helicopter. The Red Force included two A-10s representing Frogfoot-type aircraft and two A-7s representing Fitters (all Soviet fixed-wing aircraft), and from two to four AH-64s (attack helicopters) acting as Soviet Havoc or Hind helicopters depending upon the scenario for the test trial. Other support elements were involved including at least 16 M-60 tanks, representing Soviet T-80 tanks.

During the force-on-force phase of DIVAD FOE-I, five different Sgt York fire units (ordinarily four per trial) were involved in 29 valid test trials (i.e., trials which met pre-established criteria for validity). Sgt York FOE-I trials had originally been planned to extend for a duration of 72 hours each, with multiple engagement opportunities, but due to instrumentation constraints

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data collection had to be limited to only 20 to 30 minutes per trial. Although trial duration was therefore only half an hour, crews were in their compartments in the fire units for at least two or three hours per trial.

Test conditions were intended to represent situations that might be encountered on an actual battlefield. The Blue battalion task force was assigned to one of three scenarios for each trial (attack, delay, or road march), under one of three pre-selected electronic warfare conditions, with enemy aircraft employing one of three prescribed variations in tactics. Assisted by computer-based technology contained within their turret systems, the crews were to acquire, identify, classify, and "fire" at hostile flight vehicles. These were not, however, live fire trials; no rounds were actually expended.

The Sgt York weapon system was intended to play a primary role in forward area air defense. Each DIVAD fire unit was a multi-sensor, computer-based, complex man-machine system with a three-man crew, two in the turret and a driver located in the chassis. It was intended to be a highly mobile, rapid-response system capable of destroying enemy flight vehicles up to a range of 4,000 meters and within seven (7) seconds. DIVAD permitted a range of types of interactions between men and machine and required, at a minimum, that an operator initiate firing action by pushing the trigger button. A choice of system operating modes was available to the turret crew allowing them to take certain actions (e.g., selecting and designating targets) in preference to having targeting performed automatically.

DATA COLLECTION

To monitor the performance of the weapon system and to support its subsequent evaluation, three kinds of objective data were collected from each fire unit for each trial: (1) a 1553 digital data bus providing status information on turret system controls and displays by trial and time, (2) crew compartment video tapes, and (3) through-sight videotapes. In addition, RTCA (Real Time Casualty Assessment) and MILES data were generated during each trial as independent data bases. In that the separate data records were all based on the same test exercise, they could be expected to be coincident. To the extent that they reflected different facets of that exercise, they could be expected to vary. Interrelating the data compilations from the various sources was often difficult, always time-consuming, and not without discrepancies.

This paper focuses chiefly on data derived from the 1553 data bus. That data source was actually a record of the time at which events associated with the hardware system took place within the DIVAD fire units. Data on such events were received over the data bus, formatted, and read out as hard copy computer printouts, making them accessible for review and analysis. The events recorded included engaging and releasing the radar pointer, the laser, and the trigger controls. From the printout of the data bus, it was possible to tell not only what was done and when, but also whether the squad leader's or the gunner's controls were used to do it. Data were also available on the status of the radar and laser cue lights and, if they were on, whether they were on fulltime (i.e., "solid") or were blinking.

From the record of events contained in the data base printouts, it was possible to reconstruct the actions of the turret crew members, to tell when they attempted to designate or to "point" targets, when the radar was successfully locked onto a target, when they received feedback from laser or radar cue lights, when they were given firing cues, when they responded by pushing the trigger button, or if they decided to break off an engagement rather than firing at a target.

Other data included on the data bus reflected whether or not the radar was locked on or had broken lock, the Identification Friend or Foe (IFF) classification of a target, and the mode in which the system was operating. Operators had six acquisition and six non-acquisition modes from which to select. Only a sample of the search and classification activity taking place in the fire control computer was represented on the printout. As rich as the record was, providing approximately 10 computer printout lines to represent each second's activity, search events were so dynamic and extensive that complete target status information (how many targets were being followed at each point in time, where they were, what their IFF classification status was) could not be completely recaptured.

THE DATA BASE

Generic Target Engagement Sequence

To explain the data base, the target engagement sequence will be described briefly. Generically, a number of steps lead from target appearance through cease fire:

1. Target appears.
2. Target is detected.
3. Target is identified as foe.
4. Target is tracked.
5. Target elevation, azimuth and range are determined.
6. Aiming point is determined (i.e., firing solution calculated).
7. Weapon system is aimed at target.
8. Decision to fire is made.
9. Firing begins.
10. Firing ceases.

First, in the data presented here, all ten steps will be shown even though there was no live firing. Second, some variation is possible, particularly in the middle of the sequence. Third, how the steps are executed depends very much on the particular implementation of the specific system. Hardware, software, and procedures across systems vary considerably, although obviously the target engagement sequence must begin with search and detection and end with firing.

The Sgt York FOE-I Data Base

Table 1 presents the performance data base, showing trial by trial mean response times for each segment of the target engagement sequence. Table 1 presents data extracted from the records of the actual performance of crew members and fire units as they took part in the Sgt York FOE-I force-on-force test. Fifteen of the 29 valid test trials were the focus of detailed analysis. In Table 1 data on the 271 complete engagements which took place during those 15 trials are ordered by trial number, the first trial presented being Trial 1020 and the last trial presented being Trial 1048. Within each trial, the data are ordered by fire unit number, from 1 to 5, and within fire unit by engagement number. If a fire unit is missing from the record of a given trial, it indicates that the fire unit either did not take part in that trial or did not finish any complete target engagements during that trial.

The events listed in Table 1, all part of the target engagement sequence, represent four different types of events: crew decision times, crew action times, system processing times, and summaries (e.g., total time to fire.) These classifications are noted within the table as "Task Category".

Each of the columns in Table 1 is described and discussed below.

Select/Classify Target. The selection interval began when a target appeared on the plasma display. This event was indicated on a plot of targets displayed that was taken from the 1553 data bus. It showed targets by number or letter with range (0-10 km) shown across the top of the plot with time along the left margin. The selection interval ended when the operator (squad leader or gunner) depressed either the radar pointer or the laser switch to begin target acquisition. The average time taken to select a target was 7.87 seconds.

Point Target. This column records the time it took a crew member to get a target pointed, that is, the interval between pointer depression and pointer release, so long as the release was followed by the appearance on the 1553 data printout of a target number under "Target Pointed". To point a target, a crew member had to track the target while holding the pointer switch depressed. The average time it took to point a target was 2.27 seconds.

Lase Target. This column records the time it took for a crew member to indicate a target by lasing it. The time entered represents the interval between laser depression and laser release, if that release was followed by the appearance on the 1553 data printout of a target number under "Target Engaged". The average time that the laser switch was depressed was 1.13 seconds.

Acquisition of Target. Once the tracking radar had locked onto the target selected and was able to follow it, the 1553 data bus indicated that a radar cue or a laser cue was on. The interval between the time that the crew action (pointing or lasing) terminated and the time that the radar or laser cue came on was recorded as the acquisition interval. The average acquisition time for the 271 engagements recorded in Table 1 was 4.21 seconds.

Fire Solution by Computer: Blinking Cue. Once the target had been acquired by the tracking radar and had range as well as elevation and azimuth information, the fire control computer was able to calculate a fire control solution. When that solution had been obtained, the firing cue came on in the Sgt York crew compartment. A firing cue light might blink on and off, or it might simply come on and stay on. The former case was referred to as a "blinking" firing cue and the latter case was referred to as a "solid" firing cue. A blinking cue indicated a less certain solution than a solid cue. The interval between the appearance of the radar or laser cue and the subsequent appearance of the blinking firing cue was entered as the time it took for fire solution by computer: blinking cue. Whether or not to fire on a blinking cue rather than wait for a solid cue (that might or might not appear) was left to the discretion of the operator. If the firing cue light stopped blinking and became a solid firing cue before the trigger was activated, "NA" was entered in the blinking cue column for that engagement. On 65 of the 271 engagements, firing began on a blinking firing cue. For those 65 cases, the average time needed to obtain that firing solution by computer: blinking cue was 4.02 seconds.

Fire Solution by Computer: Solid Cue. If the firing cue light came on and stayed on, the time between target acquisition (indicated by the appearance of a radar cue or a laser cue light) and the onset of the solid firing cue was entered as fire solution by computer: solid cue. A blinking fire cue might or might not precede a solid fire cue, but the time entered under "solid cue" was always calculated from the end of acquisition. Thus, the time to obtain a solid firing solution was not affected by whether or not a blinking light fire cue occurred, and the time to solid firing cue could be compared across engagements. If a solid firing cue came on after a blinking firing cue and after firing had already begun, the time to onset of a solid cue is shown in parentheses in Table 1 and is not taken into account in calculating the average time. If the firing cue did not stop blinking, "NA" was entered under "Solid Cue". For the 206 engagements for which there was a solid fire cue prior to trigger depression, the mean time to onset of the solid fire cue was 2.58 seconds.

Comparing the average time for fire solution: blinking (4.02 seconds) with average time for fire solution: solid (2.58 seconds) suggests that the crew members may have had some informal criterion for how long they should wait for a fire cue to become solid, and, if the fire cue continued to blink after that time interval had passed, the operator decided not to wait longer but to fire on the blinking cue. Had he waited, perhaps there would have been time for a "fire cue solid" instead of "NA" in that entry. It appears that it takes less time to achieve a solid fire cue than to achieve a blinking fire cue; it may be that for some engagements the solution was more difficult or tenuous and on such engagements the solution not only took longer but only reached the "blinking cue" stage.

Decision to Fire: After Blinking Cue. The time interval between the appearance of a firing cue and trigger depression by a crew member was recorded as decision-to-fire time. As noted earlier, although a solid firing cue indicated a higher probability of a successful engagement, a crew member could decide to fire on a blinking cue. ing began an average of 1.3 seconds following the onset of a blinking fire cue and 0.7 seconds after a solid fire cue. If there is an entry in the column headed "After Blinking Cue", it indicates that on that engagement, the operator fired on a blinking cue. The number entered indicates the delay in seconds from time of onset of blinking fire cue to time of trigger activation. If the trigger was not depressed while the fire cue was blinking, "NA" is entered. The average fire decision time for the 65 engagements in which the gunner fired on a blinking cue was 1.70 seconds.

Decision to Fire: After Solid Cue. The time between onset of a solid fire cue and trigger depression is entered in this column in Table 1. If the operator fired before the solid firing cue appeared, "NA" is entered. On one engagement (Trial 1046, Fire Unit 2, Engagement 6), a negative number, -0.1, is entered under "After Solid Cue". On this occasion, the gunner activated the trigger just prior to the appearance of the firing cue; when the fire cue came on, it was solid from the onset.

Time to Fire. This column represents a summary of the preceding steps of the target engagement sequence. It tells how long it took after target presentation for firing to begin. The overall time to fire for all 271 engagements was 16.52 seconds, except for times enclosed in parentheses; those steps are not included in the time to fire because they occurred simultaneously with other steps.

Fire Duration. This column indicates how long firing continued for each engagement. That is, it records the time interval between the beginning of trigger pull and the end of the engagement. Some engagements were ended when the gunner released the trigger. In other instances, the weapon system ended the engagement (stopped firing) when radar lock-on was lost. According to Sgt York operating manuals, firing was to continue for 3 to 7 seconds when firing in burst select mode. The average firing duration for the 271 engagements was 8.05 seconds.

Total Engagement Duration. This column summarizes the time interval from the appearance of the target to the cessation of firing. The average engagement duration across all 271 engagements was 24.57 seconds.

Table 1

Performance Data Base. Target engagement time durations for Sgt York FOE I Trial 1020 (4 Fire Units; 32 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	62.1	NA	01.0	00.1	NA	03.3	NA	01.1	67.6	11.8	79.4
Engmt. 2	35.7	NA	00.8	00.0	04.8	NA	00.8	NA	42.1	01.2	43.3
Engmt. 3	14.5	NA	01.0	00.1	03.0	NA	01.5	NA	20.1	01.1	21.2
Engmt. 4	0*	00.3	NA	04.7	NA	04.0	NA	00.8	09.8	05.0	14.8
Engmt. 5	29.6	NA	01.1	00.1	03.2	NA	02.0	NA	36.0	04.1	40.1
Engmt. 6	0*	02.2	NA	03.4	NA	02.2	NA	00.4	08.2	09.6	17.8
Engmt. 7	05.7	NA	00.9	00.0	NA	02.3	NA	00.5	09.4	09.3	18.7
Fire Unit 3											
Engmt. 1	18.8	NA	02.0	00.0	NA	06.6	NA	00.7	28.1	12.5	40.6
Engmt. 2	05.6	NA	00.8	00.1	NA	06.5	NA	00.4	13.4	03.6	17.0
Engmt. 3	00.4	02.0	NA	07.1	NA	05.4	NA	00.9	15.8	11.8	27.6
Engmt. 4	01.6	03.0	NA	02.5	NA	25.3	NA	04.4	36.8	01.8	38.6
Engmt. 5	01.8	01.3	NA	07.2	NA	01.2	NA	01.0	12.5	03.4	15.9

*Crew action was first indicator of target appearance.

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1020 (4 Fire Units; 32 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer: Blinking Cue	Fire Solution by Computer: Solid Cue	Decision to Fire: After Blinking Cue	Decision to Fire: After Solid Cue	Time to Fire	Fire Duration	Total Engmt. Duration
Fire Unit 4											
Engmt. 1	06.3	06.4	NA	02.1	NA	01.6	NA	00.6	17.0	06.9	23.9
Engmt. 2	18.8	02.7	NA	03.6	NA	01.5	NA	04.7	31.3	10.9	42.2
Engmt. 3	06.8	02.0	NA	04.1	NA	01.3	NA	00.4	14.6	11.6	26.2
Engmt. 4	04.2	06.9	NA	10.3	NA	01.8	NA	15.3	38.5	02.0	40.5
Engmt. 5	04.0	01.1	NA	10.8	NA	01.3	NA	08.4	25.6	02.7	28.3
Engmt. 6	14.0	03.4	NA	03.5	NA	01.3	NA	02.9	25.1	04.9	30.0
Engmt. 7	01.9	00.0	NA	02.2	NA	01.3	NA	00.5	05.9	02.3	08.2
Engmt. 8	**	**	**	29.1	NA	00.0	NA	00.0	29.1	04.7	33.8
Engmt. 9	**	**	**	08.2	00.0	NA	00.0	NA	08.2	05.6	13.8
Engmt. 10	18.5	03.0	NA	03.5	NA	01.4	NA	00.3	26.7	21.3	48.0
Engmt. 11	0*	NA	01.1	00.2	04.1	(10.8)	00.9	NA	06.3	11.4	17.7
Engmt. 12	**	**	**	00.0	NA	00.0	NA	00.0	00.0	07.9	07.9
Engmt. 13	**	**	**	02.0	NA	00.0	NA	00.0	02.0	11.2	13.2
Engmt. 14	**	**	**	14.8	NA	00.0	NA	00.0	14.8	15.9	30.7
Engmt. 15	09.3	03.6	NA	02.8	01.9	NA	01.0	NA	18.6	03.5	22.1
Engmt. 16	10.2	00.8	NA	05.6	NA	00.8	NA	01.2	18.6	22.8	41.4
Engmt. 17	02.4	01.3	NA	04.1	NA	03.4	NA	00.6	11.8	08.8	20.6
Engmt. 18	**	**	**	08.4	NA	00.0	NA	00.0	08.4	03.4	11.8
Engmt. 19	63.1	03.6	NA	03.8	NA	01.2	NA	02.9	74.6	19.1	93.7
Fire Unit 5											
Engmt. 1	**	**	**	02.6	NA	00.0	NA	00.2	02.8	11.9	14.7

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1021 (3 Fire Units; 14 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	03.0	02.0	NA	06.0	NA	01.2	NA	00.8	13.0	03.9	16.9
Fire Unit 3											
Engmt. 1	0*	03.3	NA	05.2	NA	01.3	NA	01.6	11.4	09.0	20.4
Engmt. 2	**	**	**	10.9	NA	02.1	NA	00.0	13.0	04.3	17.3
Engmt. 3	**	**	**	04.5	00.0	NA	00.0	NA	04.5	03.0	07.5
Engmt. 4	0*	NA	00.5	00.0	NA	02.3	NA	01.6	04.4	05.1	09.5
Engmt. 5	13.0	02.9	NA	05.3	NA	01.3	NA	02.2	24.7	13.1	37.8
Engmt. 6	**	**	**	01.8	NA	00.0	NA	04.7	06.5	03.2	09.7
Fire Unit 5											
Engmt. 1	0*	NA	00.2	00.1	NA	03.1	NA	00.5	03.9	01.8	05.7
Engmt. 2	18.8	01.6	NA	05.4	02.4	(05.8)	01.6	NA	29.8	16.7	46.5
Engmt. 3	00.9	00.2	NA	05.9	NA	00.3	NA	03.0	10.3	00.5	10.8
Engmt. 4	09.6	01.5	NA	04.2	03.5	(17.5)	12.6	NA	31.4	05.9	37.3
Engmt. 5	**	**	**	00.6	NA	00.0	NA	00.0	00.6	05.2	05.8
Engmt. 6	**	**	**	00.0	NA	00.0	NA	00.0	00.0	14.6	14.6
Engmt. 7	**	**	**	05.8	00.0	NA	00.0	NA	05.8	06.4	12.2

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1022 (4 Fire Units; 34 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	0*	NA	02.4	00.2	NA	02.6	NA	00.8	06.0	07.5	13.5
Engmt. 2	0*	03.1	(01.8)	02.6	NA	03.0	NA	00.7	09.4	14.9	24.3
Fire Unit 3											
Engmt. 1	05.2	02.6	NA	03.1	03.9	NA	02.2	NA	17.0	02.1	19.1
Engmt. 2	04.2	01.1	NA	06.0	(03.8)	03.8	(00.6)	00.6	15.7	12.3	28.0
Engmt. 3	06.9	NA	00.7	00.1	NA	03.0	NA	01.2	11.9	00.3	12.2
Engmt. 4	**	**	**	03.0	(00.9)	01.1	(01.1)	00.9	05.0	02.9	07.9
Engmt. 5	**	**	**	15.9	00.0	NA	00.0	NA	15.9	02.2	18.1
Engmt. 6	08.9	02.5	NA	02.4	NA	02.9	NA	00.5	17.2	10.5	27.7
Engmt. 7	06.6	01.0	NA	03.7	NA	02.1	NA	00.6	14.0	04.9	18.9
Engmt. 8	**	**	**	09.3	NA	00.0	NA	00.0	09.3	06.1	15.4
Engmt. 9	25.8	NA	00.9	00.1	NA	02.8	NA	00.7	30.3	16.7	47.0
Engmt. 10	01.9	03.1	NA	05.6	NA	01.9	NA	00.9	13.4	11.7	25.1
Engmt. 11	04.6	01.7	NA	04.3	NA	02.3	NA	00.5	13.4	06.1	19.5
Engmt. 12	0*	NA	03.7	00.1	NA	07.4	NA	04.3	15.5	07.5	23.0
Engmt. 13	18.2	03.5	NA	10.9	(01.5)	01.3	(00.4)	00.6	34.5	01.4	35.9
Engmt. 14	19.1	03.3	NA	04.5	NA	01.3	NA	00.7	28.9	05.8	34.7
Engmt. 15	02.0	01.4	NA	04.1	NA	01.2	NA	01.1	09.8	16.7	26.5
Engmt. 16	**	**	**	05.3	NA	00.0	NA	00.0	05.3	13.1	18.4
Engmt. 17	**	**	**	17.6	NA	00.0	NA	00.0	17.6	01.1	18.7
Engmt. 18	19.1	01.5	NA	07.4	NA	01.2	NA	00.8	30.0	00.9	30.9

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1022</u> (4 Fire Units; 34 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 4											
Engmt. 1	07.3	07.3	(01.6)	10.4	14.3	NA	00.7	NA	40.0	11.5	51.5
Engmt. 2	0*	NA	00.6	00.1	(03.3)	03.2	(00.4)	00.5	04.4	14.1	18.5
Engmt. 3	23.1	NA	00.7	00.1	NA	03.2	NA	00.8	27.9	09.8	37.7
Engmt. 4	0*	NA	00.3	00.2	04.3	(07.1)	00.9	NA	05.7	04.3	10.0
Fire Unit 5											
Engmt. 1	0*	NA	01.3	00.1	NA	02.4	NA	03.0	06.8	17.1	23.9
Engmt. 2	0*	NA	00.4	00.1	03.5	NA	04.8	NA	08.8	29.5	38.3
Engmt. 3	**	**	**	00.0	00.1	NA	00.1	NA	00.2	13.2	13.4
Engmt. 4	0*	NA	01.5	00.0	NA	02.3	NA	00.5	04.3	25.6	29.9
Engmt. 5	0*	NA	02.0	00.0	NA	02.8	NA	00.6	05.4	15.7	21.1
Engmt. 6	0*	NA	03.9	00.1	NA	04.3	NA	01.9	10.2	02.2	12.4
Engmt. 7	0*	NA	00.9	00.0	NA	02.3	NA	00.5	03.7	29.3	33.0
Engmt. 8	0*	NA	01.4	00.1	NA	04.1	NA	00.3	05.9	02.6	08.5
Engmt. 9	0*	NA	04.4	00.2	NA	02.7	NA	00.4	07.7	24.0	31.7
Engmt. 10	0*	NA	03.3	00.2	NA	02.5	NA	00.5	06.5	23.2	29.7

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1023 (3 Fire Units; 13 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	11.2	01.9	NA	04.0	NA	01.5	NA	00.8	19.4	14.8	34.2
Engmt. 2	00.4	06.7	NA	06.7	(04.8)	04.6	(01.1)	01.3	19.7	01.6	21.3
Engmt. 3	0*	NA	01.9	00.1	NA	03.6	NA	00.7	06.3	23.2	29.5
Engmt. 4	00.8	00.7	NA	01.9	NA	01.3	NA	00.7	05.4	09.7	15.1
Engmt. 5	35.2	05.3	(03.2)	02.7	05.4	NA	05.5	NA	54.1	52.8	106.9
Engmt. 6	0*	NA	00.4	00.1	02.9	NA	01.3	NA	04.7	30.7	35.4
Fire Unit 3											
Engmt. 1	17.9	02.6	(01.4)	05.1	03.5	NA	02.5	NA	31.6	07.0	38.6
Engmt. 2	0*	NA	01.3	00.0	NA	02.3	NA	00.8	04.4	51.3	55.7
Engmt. 3	04.9	NA	01.0	00.2	NA	03.7	NA	00.6	10.4	06.7	17.1
Fire Unit 4											
Engmt. 1	19.2	01.6	NA	02.7	NA	02.6	NA	01.9	28.0	06.2	34.2
Engmt. 2	27.6	00.9	NA	03.3	NA	02.9	NA	00.6	35.3	15.1	50.4
Engmt. 3	**	**	**	00.0	(06.5)	09.9	(05.5)	02.1	12.0	17.9	29.9
Engmt. 4	06.6	01.5	NA	03.6	NA	02.7	NA	00.5	14.9	03.3	18.2

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1026 (4 Fire Units; 12 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	01.8	01.7	(04.8)	04.5	03.8	(13.3)	01.8	NA	13.6	08.5	22.1
Engmt. 2	**	**	**	00.0	NA	00.0	NA	00.0	00.0	08.3	08.3
Engmt. 3	09.6	NA	00.6	00.1	NA	03.0	NA	00.3	13.6	08.9	22.5
Fire Unit 3											
Engmt. 1	13.8	NA	00.4	00.2	NA	03.1	NA	00.7	18.2	05.0	23.2
Fire Unit 4											
Engmt. 1	00.4	NA	01.0	00.1	03.0	NA	00.8	NA	05.3	11.5	16.8
Fire Unit 5											
Engmt. 1	0*	NA	01.0	00.2	NA	03.5	NA	00.7	05.4	00.1	05.5
Engmt. 2	15.9	NA	01.2	00.1	04.2	(10.9)	01.3	NA	22.7	14.5	37.2
Engmt. 3	(07.7)	NA	(01.5)	06.3‡	(05.5)	01.3	(00.1)	04.3	11.9	02.8	14.7
Engmt. 4	**	**	**	15.1	02.5	(09.0)	00.1	NA	17.7	19.1	36.8
Engmt. 5	06.6	01.2	(01.6)	06.5	(04.0)	09.0	(06.3)	01.3	24.6	14.2	38.8
Engmt. 6	04.4	NA	00.6	00.1	03.2	NA	00.1	NA	08.4	02.7	11.1
Engmt. 7	(33.5)	(02.1)	NA	31.7‡	06.2	NA	02.7	NA	40.6	03.7	44.3

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.
‡System acquired target prior to crew action.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1027 (4 Fire Units; 25 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer: Blinking Cue	Fire Solution by Computer: Solid Cue	Decision to Fire: After Blinking Cue	Decision to Fire: After Solid Cue	Time to Fire	Fire Duration	Total Engmt. Duration
Fire Unit 1											
Engmt. 1	**	**	**	14.7	NA	00.0	NA	00.5	15.2	12.9	28.1
Fire Unit 3											
Engmt. 1	13.3	00.2	NA	02.5	03.2	NA	01.5	NA	20.7	00.6	21.3
Engmt. 2	0*	07.0	NA	02.5	NA	01.5	NA	00.9	11.9	05.3	17.2
Engmt. 3	12.1	02.8	NA	06.6	NA	01.4	NA	01.8	24.7	03.9	28.6
Engmt. 4	02.1	00.3	NA	04.4	NA	01.3	NA	01.6	09.7	04.1	13.8
Engmt. 5	03.6	01.3	NA	07.3	NA	01.2	NA	00.9	14.3	07.0	21.3
Engmt. 6	04.7	NA	00.3	00.1	NA	03.1	NA	00.0	08.2	05.2	13.4
Engmt. 7	**	**	**	09.4	(00.0)	00.2	(12.0)	11.8	21.4	01.3	22.7
Engmt. 8	**	**	**	09.9	NA	04.7	NA	02.6	17.2	10.3	27.5
Fire Unit 4											
Engmt. 1	02.0	01.9	NA	04.4	04.6	NA	03.5	NA	16.4	01.2	17.6
Engmt. 2	00.4	01.1	NA	02.0	NA	01.6	NA	01.2	06.3	08.1	14.4
Engmt. 3	0*	01.5	NA	03.0	NA	01.6	NA	01.4	07.5	03.1	10.6
Engmt. 4	00.2	02.0	NA	08.6	03.8	(09.5)	02.9	NA	17.5	10.7	28.2
Engmt. 5	06.0	01.9	NA	04.6	NA	04.1	NA	00.7	17.3	08.0	25.3
Engmt. 6	09.3	02.4	NA	12.0	NA	00.3	NA	01.2	25.2	07.6	32.8
Engmt. 7	01.3	02.9	NA	05.3	NA	01.5	NA	01.1	12.1	06.4	18.5
Engmt. 8	14.5	01.9	NA	03.0	NA	02.6	NA	00.5	22.5	00.1	22.6
Engmt. 9	**	**	**	00.0	NA	00.0	NA	00.0	00.0	07.7	07.7
Engmt. 10	05.7	06.2	NA	03.1	NA	01.3	NA	00.4	16.7	02.9	19.6

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1027 (4 Fire Units; 25 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 5											
Engmt. 1	05.2	02.8	(02.8)	03.0	NA	04.0	NA	01.8	16.8	13.2	30.0
Engmt. 2	**	**	**	06.5	NA	00.0	NA	03.4	09.9	02.0	11.9
Engmt. 3	16.3	01.0	(02.1)	01.7	03.7	NA	04.2	NA	26.9	01.0	27.9
Engmt. 4	15.0	00.6	(00.7)	05.1	NA	02.5	NA	01.1	24.3	04.3	28.6
Engmt. 5	03.0	02.6	(01.7)	03.4	NA	01.7	NA	03.6	14.3	04.4	18.7
Engmt. 6	07.7	(01.5)	00.7	00.1	NA	01.3	NA	01.8	11.6	02.5	14.1

**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1029</u> (3 Fire Units; 12 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	00.6	04.0	(01.0)	02.6	NA	01.5	NA	01.6	10.3	15.1	25.4
Engmt. 2	17.8	01.5	(02.0)	02.7	NA	09.8	NA	01.4	33.2	06.5	39.7
Engmt. 3	00.6	02.2	NA	04.9	NA	02.7	NA	00.9	11.3	02.7	14.0
Engmt. 4	**	**	**	07.6	NA	00.0	NA	00.0	07.6	09.4	17.0
Engmt. 5	04.5	02.9	(01.0)	05.4	NA	02.7	NA	02.0	17.5	23.3	40.8
Fire Unit 4											
Engmt. 1	06.2	01.8	NA	03.4	NA	02.2	NA	01.0	14.6	09.7	24.3
Engmt. 2	0*	01.9	NA	03.8	NA	01.4	NA	00.4	07.5	07.4	14.9
Engmt. 3	27.1	01.3	NA	01.9	03.2	NA	02.6	NA	36.1	08.4	44.5
Fire Unit 5											
Engmt. 1	Radar Auto --------->			06.5	01.4	(07.0)	01.3	NA	09.2	05.8	15.0
Engmt. 2	07.1	00.7	NA	06.4	NA	00.3	NA	00.9	15.4	00.2	15.6
Engmt. 3	**	**	**	10.8	NA	00.0	NA	00.0	10.8	00.1	10.9
Engmt. 4	05.2	00.7	(00.9)	08.3	NA	02.4	NA	01.1	17.7	12.9	30.6

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1035 (4 Fire Units; 21 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	0*	NA	00.1	00.2	NA	04.3	NA	01.3	05.9	23.4	29.3
Engmt. 2	(18.6)	NA	(00.1)	14.6‡	07.5	NA	00.9	NA	23.0	25.1	48.1
Engmt. 3	03.7	NA	00.1	00.1	06.8	NA	01.5	NA	12.2	11.7	23.9
Engmt. 4	02.2	02.4	(00.4)	02.3	04.0	NA	02.2	NA	13.1	39.5	52.6
Engmt. 5	0*	NA	00.9	00.0	NA	03.0	NA	00.4	04.3	10.7	15.0
Engmt. 6	00.6	02.2	(00.6)	04.0	NA	01.8	NA	00.6	09.2	10.4	19.6
Engmt. 7	01.6	03.5	(02.3)	02.8	NA	01.8	NA	03.9	13.6	12.1	25.7
Engmt. 8	41.0	NA	01.1	00.1	NA	08.3	NA	00.5	51.0	02.8	53.8
Fire Unit 2											
Engmt. 1	0*	NA	01.1	00.1	NA	02.1	NA	01.2	04.5	06.1	10.6
Engmt. 2	19.3	NA	01.0	00.0	NA	02.4	NA	00.2	22.9	05.0	27.9
Engmt. 3	**	**	**	16.7	NA	00.0	NA	00.0	16.7	00.8	17.5
Engmt. 4	08.8	01.6	NA	03.4	10.4	NA	01.1	NA	25.3	05.0	30.3
Engmt. 5	(18.6)	NA	(03.9)	18.9‡	07.0	NA	00.9	NA	26.8	42.9	69.7

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.
‡System acquired target independent of crew action.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1035</u> (4 Fire Units; 21 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 3											
Engmt. 1	0*	02.5	NA	04.1	NA	03.0	NA	01.6	11.2	27.3	38.5
Engmt. 2	0*	02.3	NA	06.5	NA	00.3	NA	00.8	09.9	00.2	10.1
Engmt. 3	00.2	01.7	NA	05.6	NA	03.6	NA	01.3	12.4	03.2	15.6
Engmt. 4	01.6	03.4	(05.4)	11.1	NA	00.4	NA	32.3	48.8	05.7	54.5
Engmt. 5	21.7	02.2	NA	05.1	NA	01.2	NA	00.1	30.3	00.2	30.5
Fire Unit 4											
Engmt. 1	0*	04.6	NA	03.6	NA	02.1	NA	01.0	11.3	04.5	15.8
Engmt. 2	**	**	**	01.6	NA	00.0	NA	00.0	01.6	06.7	08.3
Engmt. 3	00.7	03.9	NA	07.7	NA	01.5	NA	01.1	14.9	04.0	18.9

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1036</u> (4 Fire Units; 13 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	25.3	02.7	(01.0)	05.3	NA	01.5	NA	00.9	35.7	01.1	36.8
Engmt. 2	**	**	**	11.1	NA	00.0	NA	00.0	11.1	05.1	16.2
Engmt. 3	25.3	NA	01.9	00.0	03.0	NA	00.9	NA	31.1	04.8	35.9
Engmt. 4	08.5	02.1	(01.1)	03.9	NA	02.1	NA	01.7	18.3	19.0	37.3
Fire Unit 2											
Engmt. 1	46.0	00.7	(00.3)	07.2	(01.6)	04.6	(03.6)	00.6	59.1	02.7	61.8
Fire Unit 3											
Engmt. 1	04.4	01.6	NA	03.7	NA	01.4	NA	00.7	11.8	11.1	22.9
Engmt. 2	03.6	00.2	(01.7)	19.6	NA	27.1	NA	00.5	51.0	10.6	61.6
Fire Unit 4											
Engmt. 1	01.6	02.0	NA	03.6	NA	03.6	NA	00.4	11.2	03.5	14.7
Engmt. 2	05.1	00.7	NA	03.5	NA	01.6	NA	00.6	11.5	03.6	15.1
Engmt. 3	0*	01.0	NA	03.6	NA	05.3	NA	01.5	11.4	04.0	15.4
Engmt. 4	20.9	01.0	NA	02.3	01.3	(02.0)	00.5	NA	26.0	03.3	29.3
Engmt. 5	07.4	01.0	NA	05.5	NA	01.2	NA	00.4	15.5	06.3	21.8
Engmt. 6	02.0	01.8	NA	03.5	NA	01.2	NA	00.5	09.0	01.7	10.7

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1039 (4 Fire Units; 18 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	02.4	01.1	NA	04.7	NA	02.9	NA	00.4	11.5	02.2	13.7
Engmt. 2	08.0	00.9	NA	03.7	07.0	NA	01.1	NA	20.7	02.5	23.2
Engmt. 3	13.6	00.4	(00.6)	10.8	NA	05.6	NA	00.7	31.1	09.8	40.9
Engmt. 4	00.3	01.5	(00.7)	22.1	(01.5)	01.5	(00.9)	00.9	26.3	00.1	26.4
Fire Unit 2											
Engmt. 1	01.6	03.6	(01.4)	02.8	03.5	(07.7)	01.8	NA	13.3	10.9	24.2
Engmt. 2	13.7	01.8	NA	02.8	NA	01.2	NA	02.6	22.1	00.8	22.9
Engmt. 3	09.6	02.5	(02.8)	06.7	NA	15.4	NA	00.5	34.7	03.5	38.2
Engmt. 4	03.8	01.0	NA	03.0	NA	01.2	NA	00.5	09.5	10.9	20.4
Fire Unit 3											
Engmt. 1	05.8	01.6	(01.3)	11.4	NA	03.4	NA	01.3	23.5	05.9	29.4
Engmt. 2	34.3	00.6	(00.9)	02.6	NA	05.4	NA	01.0	43.9	01.2	45.1
Engmt. 3	16.2	(00.2)	00.6	00.0	NA	02.0	NA	00.3	19.1	02.0	21.1
Engmt. 4	09.9	NA	00.3	00.1	NA	02.2	NA	00.4	12.9	04.7	17.6
Engmt. 5	07.6	02.0	NA	03.0	NA	02.4	NA	00.5	15.5	05.4	20.9

( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1039 (4 Fire Units; 18 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 4											
Engmt. 1	08.7	03.4	NA	06.3	NA	01.3	NA	00.7	20.4	00.2	20.6
Engmt. 2	18.1	00.7	NA	02.7	01.9	NA	00.7	NA	24.1	03.8	27.9
Engmt. 3	03.0	)2.2	(00.6)	10.6	08.3	(13.7)	00.7	NA	24.8	09.9	34.7
Engmt. 4	01.4	NA	00.5	00.1	(02.5)	04.4	(02.1)	00.2	06.6	10.4	17.0
Engmt. 5	0*	NA	00.2	00.1	NA	01.6	NA	00.5	02.4	08.2	10.6

*Crew action was first indicator of target appearance.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1040</u> (2 Fire Units; 7 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	09.4	04.3	NA	03.9	04.3	NA	01.2	NA	23.1	06.0	29.1
Engmt. 2	02.8	01.0	NA	07.4	06.8	NA	00.6	NA	18.6	00.8	19.4
Engmt. 3	07.2	01.9	NA	02.7	NA	03.5	NA	00.6	15.9	09.3	25.2
Fire Unit 4											
Engmt. 1	00.3	00.8	NA	02.9	07.2	NA	01.5	NA	12.7	00.2	12.9
Engmt. 2	18.1	06.2	NA	02.9	04.2	NA	00.8	NA	32.2	09.4	41.6
Engmt. 3	02.0	00.9	NA	02.9	NA	13.2	NA	00.4	19.4	01.7	21.1
Engmt. 4	05.9	06.3	NA	01.9	NA	04.3	NA	00.5	18.9	06.5	25.4

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1041 (3 Fire Units; 16 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	03.7	02.5	NA	02.7	NA	01.6	NA	00.9	11.4	00.9	12.3
Engmt. 2	32.6	NA	00.2	00.2	NA	02.3	NA	00.4	35.7	00.9	36.6
Fire Unit 3											
Engmt. 1	27.9	01.5	NA	03.9	NA	01.4	NA	00.5	35.2	11.0	46.2
Engmt. 2	01.6	02.8	NA	04.0	03.3	(11.3)	00.7	NA	12.4	07.4	19.8
Fire Unit 5											
Engmt. 1	0*	NA	00.9	00.1	NA	02.2	NA	06.0	09.2	26.8	36.0
Engmt. 2	00.7	02.0	NA	04.9	NA	01.1	NA	00.9	09.6	08.2	17.8
Engmt. 3	**	**	**	03.0	NA	00.0	NA	00.0+	03.0	06.6	09.6
Engmt. 4	**	**	**	01.7	00.0	NA	00.0+	NA	01.7	01.1	02.8
Engmt. 5	0*	NA	01.7	00.2	04.9	NA	01.9	NA	08.7	02.0	10.7
Engmt. 6	06.7	02.4	NA	03.1	NA	02.9	NA	02.0	17.1	32.2	49.3
Engmt. 7	25.2	01.0	(00.8)	04.1	NA	02.4	NA	00.0+	32.7	03.5	36.2
Engmt. 8	01.9	02.1	(01.1)	04.3	03.2	NA	01.5	NA	13.0	01.2	14.2
Engmt. 9	0*	04.5	NA	02.2	NA	01.5	NA	00.6	08.8	09.0	17.8
Engmt. 10	04.1	00.6	NA	00.4	NA	00.0	NA	01.3	06.4	02.6	09.0
Engmt. 11	**	**	**	05.2	NA	03.0	NA	00.4	08.6	02.8	11.4
Engmt. 12	**	**	**	02.9	NA	00.0	NA	00.0+	02.9	14.2	17.1

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.
+No trigger release between targets.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1042 (4 Fire Units; 14 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	21.9	01.8	NA	02.6	04.0	NA	01.1	NA	31.4	13.0	44.4
Engmt. 2	09.6	00.7	NA	02.4	10.8	NA	00.8	NA	24.3	04.9	29.2
Fire Unit 2											
Engmt. 1	00.6	NA	00.8	00.1	10.9	NA	01.3	NA	13.7	05.4	19.1
Engmt. 2	01.1	20.4	NA	04.2	NA	01.2	NA	01.0	27.9	07.6	35.5
Fire Unit 4											
Engmt. 1	14.0	01.3	NA	03.7	NA	01.3	NA	00.5	20.8	01.4	22.2
Engmt. 2	**	**	**	08.9	NA	00.0	NA	00.0	08.9	08.9	17.8
Engmt. 3	01.0	02.5	NA	03.2	NA	02.7	NA	00.3	09.7	05.2	14.9
Engmt. 4	21.0	01.9	NA	05.0	06.0	NA	03.6	NA	37.5	08.8	46.3
Engmt. 5	0*	02.5	NA	05.0	NA	02.7	NA	00.6	10.8	04.8	15.6
Engmt. 6	**	**	**	00.2	NA	00.0	NA	00.0	00.2	00.6	00.8
Fire Unit 5											
Engmt. 1	03.9	01.7	NA	20.9	NA	01.2	NA	01.0	28.7	02.3	31.0
Engmt. 2	01.8	02.0	NA	02.3	NA	03.8	NA	00.4	10.3	18.1	28.4
Engmt. 3	00.4	01.1	NA	07.6	NA	01.2	NA	00.5	10.8	03.2	14.0
Engmt. 4	**	**	**	01.0	00.2	NA	02.3	NA	03.5	05.8	09.3

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1046 (4 Fire Units; 29 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	05.9	NA	00.5	00.2	NA	03.7	NA	00.9	11.2	16.0	27.2
Engmt. 2	00.9	00.9	NA	03.7	NA	02.4	NA	01.6	09.5	06.5	16.0
Engmt. 3	0-	01.1	NA	03.6	NA	01.2	NA	00.5	06.4	04.8	11.2
Engmt. 4	14.0	01.5	NA	02.9	03.5	NA	01.5	NA	23.4	02.8	26.2
Engmt. 5	06.0	01.4	NA	02.0	12.7	NA	01.3	NA	23.4	00.5	23.9
Engmt. 6	**	**	**	00.0	00.0	NA	00.0	NA	00.0	02.7	02.7
Fire Unit 2											
Engmt. 1	00.7	03.8	NA	06.0	NA	02.9	NA	01.0	14.4	02.6	17.0
Engmt. 2	05.7	01.5	NA	12.9	NA	01.4	NA	00.6	22.1	07.4	29.5
Engmt. 3	09.8	00.9	NA	05.8	NA	01.2	NA	00.5	18.2	04.6	22.8
Engmt. 4	02.2	09.5	NA	04.3	NA	02.2	NA	00.0	18.2	00.4	18.6
Engmt. 5	**	**	**	10.0	NA	00.0	NA	00.0	10.0	05.3	15.3
Engmt. 6	02.6	NA	01.6	00.0	NA	01.6	NA	-00.1	05.7	06.8	12.5
Engmt. 7	29.3	NA	01.0	00.1	NA	03.9	NA	00.2	34.5	07.8	42.3
Engmt. 8	20.4	NA	01.5	00.1	03.9	NA	16.0	NA	41.9	15.4	57.3

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1046 (4 Fire Units; 29 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 3											
Engmt. 1	0*	01.0	NA	04.0	(02.7)	01.6	(01.5)	02.6	09.2	07.3	16.5
Engmt. 2	11.2	01.5	NA	05.5	NA	01.3	NA	01.6	21.1	02.1	23.2
Engmt. 3	**	**	**	02.4	NA	00.0	NA	00.0	02.4	09.3	11.7
Fire Unit 5											
Engmt. 1	02.6	01.0	NA	03.1	03.7	(05.4)	00.7	NA	11.1	10.7	21.8
Engmt. 2	0*	NA	02.1	00.1	NA	02.4	NA	01.4	06.0	03.5	09.5
Engmt. 3	03.5	00.7	NA	03.3	NA	01.3	NA	00.5	09.3	01.9	11.2
Engmt. 4	**	**	**	06.7	NA	00.1	NA	00.0	06.8	04.4	11.2
Engmt. 5	05.3	NA	01.0	00.0	NA	01.6	NA	00.5	08.4	00.9	09.3
Engmt. 6	15.7	NA	01.3	00.0	NA	02.4	NA	01.5	20.9	00.9	21.8
Engmt. 7	01.4	02.4	NA	04.2	01.9	NA	00.5	NA	10.4	02.6	13.0
Engmt. 8	00.3	00.9	NA	09.0	NA	02.8	NA	02.5	15.5	11.0	26.5
Engmt. 9	01.1	00.5	NA	08.0	NA	02.1	NA	00.5	12.2	09.9	22.1
Engmt. 10	05.2	(01.2)	01.1	00.0	NA	03.5	NA	00.6	10.4	08.4	18.8
Engmt. 11	17.6	00.3	NA	03.1	02.1	NA	00.9	NA	24.0	03.4	27.4
Engmt. 12	0*	NA	00.5	00.2	NA	07.2	NA	02.3	10.2	01.8	12.0

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 1

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1048 (3 Fire Units; 11 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->					Fire Solution by Computer		Decision to Fire				
	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue	Time to Fire	Fire Duration	Total Engmt. Duration
Fire Unit 3											
Engmt. 1	Radar Auto --->			02.5	NA	01.3	NA	00.7	04.5	03.0	07.5
Engmt. 2	Radar Auto --->			06.5	NA	00.0	NA	00.0+	06.5	06.7	13.2
Fire Unit 4											
Engmt. 1	01.2	NA	00.5	00.2	02.8	NA	01.2	NA	07.1	00.4	07.5
Engmt. 2	0*	NA	01.2	00.1	NA	03.3	NA	01.0	05.6	00.6	06.2
Engmt. 3	06.5	NA	01.0	00.1	NA	07.7	NA	02.3	17.6	06.0	23.6
Engmt. 4	04.7	01.9	NA	02.9	NA	01.8	NA	00.8	12.1	10.4	22.5
Fire Unit 5											
Engmt. 1	07.6	02.3	NA	03.9	NA	01.2	NA	00.9	15.9	11.5	27.4
Engmt. 2	05.8	NA	00.2	00.2	NA	01.9	NA	00.7	08.8	10.0	18.8
Engmt. 3	05.9	00.3	NA	02.3	NA	01.3	NA	00.8	10.6	01.6	12.2
Engmt. 4	16.7	NA	02.4	00.1	NA	08.8	NA	00.6	28.6	04.4	33.0
Engmt. 5	00.2	03.2	NA	02.3	NA	03.3	NA	00.7	09.7	09.4	19.1

*Crew action was first indicator of target appearance.
+No trigger release between targets.

Incomplete engagements. The data base presented here in Table 1 represents completed target engagements, that is, engagements in which the decision to fire was made and carried out. However, engagements could be discontinued or "broken off" at any point in the sequence. No effort was made, as a part of this study, to determine what proportion was continued at every choice point, or whether the discontinuation was appropriate (e.g., target was in fact a "friend"), or an error. But, engagements which were carried through to the point of fire but in which the decision to fire was never made are of particular interest because of the possible parallels to that final go-no go decision required in many other systems.

In this operational test (based on a detailed analysis of three complete trials), the crew actually fired 73% of the times that the system told them to fire (i.e., gave them a solid firing cue). The other 27 percent of the time, they did not fire, whether in error or by good judgment, we do not know.

Level of operator learning. One possible impact on the performance data in Table 1 could be the state of squad leader and gunner system learning. Crew training had been considerably shortened because of changes in test schedules. If crew members were still learning during the test trials, performance may have been unstable. However, comparisons of actual performance at the beginning of the test trials and at the end showed no statistically significant performance differences. These were not naive air defense operators; all had had extensive experience as squad leaders and gunners.

To our knowledge there is no accepted way to estimate the specific skills, knowledges, and abilities of human operators who participate in generating data of the type shown here. Or, for that matter, of estimating these values in operational tests. It is difficult, therefore, to "calibrate" the data for the level of operator performance as a function of learning, both prior to the test and occurring during the test. There might be some compensation if larger sample sizes could be used, but that is rarely practical in tests of this magnitude. But, at the least, one should compare the beginning and end of test performance-- as was done here--for some indication of learning.

SELECTED FINDINGS

The extent of the data and the large number of system, subsystem, and operator variables made the number of possible performance analyses very large. Detailed discussions of how human and system performance times varied as a function of test conditions and system variables have been presented in Babbitt, Seven, and Muckler (1). Five separate areas of concern were addressed:

- o System and subsystem performance
- o Tactical performance variations
- o Individual and crew performance
- o Personnel quality variables
- o Training and experience

More of the specific issues and an outline of research areas are shown in Table 2.

Monte Carlo Model Feedback

Before summarizing the research findings, let us first compare some data obtained from two different sources, the 1553 data bus and the RTCA data base. Table 3 compares the number of target engagements shown in each of these data bases during one specific trial, Trial 1027. As the table shows, there is a discrepancy in the number of engagements credited to each of the participating fire units.

TABLE 2

Research Areas

A. System and Subsystem Performance
   1. System/subsystem response times
   2. System modes and levels of automation
   3. Fire unit comparisons
B. Tactical Performance Variations
   1. Scenario type
   2. Rotary wing tactics
   3. ECM (electronic countermeasures) conditions
   4. Time of day
   5. Target range at first appearance
C. Individual and Crew Performance
   1. Crew action/decision response times
   2. MOPP (Mission-Oriented Protective Posture) level
   3. Target workload
D. Personnel Quality
   1. Personnel characteristic and individual performance
   2. Crew mix, mental categories, and crew performance
E. Training
   1. Previous system experience and individual training
   2. Previous system experience and collective training

TABLE 3

Comparison of Number of Engagements, Trial 1027, Shown by Two Data Sources

Fire Unit	Engagements 1553 Data	Engagements RTCA Data
1	1	3
2	0	0
3	8	4
4	9	7
5	5	4
Total	23	18

Table 4 presents a detail from a portion of the trial. Time intervals made it possible to match the data from the RTCA with those from the 1553 data bus. The time reference of the 1553 data bus was actual clock time and the RTCA recorded in terms of elapsed trial time, i.e., time since the trial started. In both cases, it was possible to construct an order-of-fire for the trials showing which fire unit was engaging a target at a given time according to each of the data bases, and to compare them. Table 4 shows an excerpt from that comparison.

During the actual trial, feedback on the success of a target engagement was provided to the turret crew of a fire unit by means of lights mounted in the crew compartment. These lights would tell the crew whether the target was killed, had survived, or was already dead as a resuit of some previous action.

TABLE 4

Trial 1027: Reconciliation of Events from Two Data Bases

1553 Data		RTCA Data		
Clock Time	Fire Unit	Fire Unit	Trial Time	Hypothetical Outcome
...			...	
10:45:41.7	4	4	05.32	Survived
10:46:44.7	3			
		1	07:16	Killed
10:47:27.7	5	5	07:18	Survived
10:47:44.3	5			
10:48:42.5	5	5	08:33	Survived

The basis of the assessment that was communicated to the crew was a Monte Carlo model designed to evaluate the probability of kill in each specific engagement instance. The "hypothetical outcome" in the far right column of Table 4 shows the RTCA by time and fire unit. For example, 5 minutes and 32 seconds after Trial 1027 started, the crew of fire unit 4 was signalled that the aircraft at which they fired survived the attack. Approximately a minute later fire unit 3 engaged a target but received no feedback on the outcome of the engagement. As might be expected, and as comments from the transcriptions of the crew audio indicated, the absence of feedback was somewhat annoying to the crew.

The next line of Table 4 represents another kind of discrepancy between the data bases, one that could also be disconcerting. In this case fire unit 1 was credited with killing an aircraft at 7 minutes and 16 seconds into Trial 1027, but the data showed no trigger activation at that time. Two seconds later both the 1553 data bus and the RTCA recorded that fire unit 5 engaged a target (which was calculated to have survived). Seventeen seconds later, according to the computer printout of the 1553 data bus, fire unit 5 engaged a different target. Although the trigger was pushed, the RTCA system failed to record that engagement or to give the crew any feedback on its outcome. Less than a minute later, fire unit 5 fired on another target, and both systems recorded that engagement.

Looking at all of the engagements recorded during Trial 1027 shows agreement on 15 engagements and discrepancies on 12. Each of the four fire units participating in the trial had engagements in which they fired on targets but on which no RTCA feedback was provided. In this trial, only fire unit 1 was given credit for "kills" when no trigger activation occurred; in the other cases, the targets were deemed to have survived. In the case of fire unit 1, the crew had a higher probability of kill (2 kills in three engagements) when in fact they did not fire than when they did (1 engagement but no kill). In this trial, the only kills credited to the fire unit came without trigger activation.

Although the nature of the RTCA Monte Carlo model was not one of the concerns of the performance data base development effort, perhaps it is safe to suggest that such models should include trigger activation as a specific variable for which the probability is less than one, frequently considerably less than one, even when the elements up to the point of decision provide a clear cut "fire" cue. Had such a component been taken into account when determining the feedback provided to DIVAD crew members, at least some of the discrepancies between the data bases would not have appeared.

System Response and Automation

The DIVAD system operational requirement called for a maximum time to fire of seven (7) seconds. As Table 5 shows, the average time to fire for the 271 engagements was 16.5 seconds. That means it took more than 16 seconds, on the average, from time of target appearance, to spot it, designate it, calculate a fire solution, and begin to fire on the target.

TABLE 5

System and Subsystem Response Times
(271 Engagements)

Parameter	Mean Time (Seconds)
Actual Time to Fire	16.5
Crew/System Target Analysis	6.4
Crew Action Time	1.6
Automated Decision Support	7.1
Crew Decision to Fire	1.4
System Operational Requirement: Total Time to Fire (Seconds)	7

Of the 16.5 seconds, target analysis took 6.4 seconds and crew target action (pointing or lasing the target to designate it) took 1.6 seconds. Thus it took, on the average, 8 seconds just to complete target designation, an interval already 1 second over the system operational requirement. Automated decision support, averaged over 271 engagements, required 7.1 seconds, itself greater than the operational requirement. Thus it took 15.1 seconds for a fire cue to appear in an average engagement, more than twice the allowed time. Crew decision to fire consumed 1.4 seconds, bringing total time to fire to 16.5 seconds for an average engagement. If the system operational requirement is meaningful, then these times are obviously cause for much concern.

The data analyzed represent a wide cross section of many test variables (scenario, rotary wing tactics, ECM condition, MOPP gear, time of day, etc.). There were major differences in performance times as a function of many test variables, but the seven (7) second response time demanded by the operational requirement was so brief that none of the crews, none of the fire units, and none of the test conditions produced (on average) time to fire responses that short.

DIVAD time to fire represented a combined man-machine system function. It encompassed the target engagement sequence from the time the target appeared on the display until the time a crew member depressed the trigger to fire on that target. Thus, the time included crew decision and crew action time, as well as machine response and calculation time.

DIVAD was designed to operate with different degrees of operator involvement during the target engagement sequence. At one extreme, the Sgt York was capable of acting entirely automatically up to the point of trigger depression.

However, because of the hazard which rapid automatic response could represent to the crew members who were not adequately "buttoned up", safety restrictions did not allow tests of the fully automatic mode of operation. Nevertheless, three (3) of the 271 engagements appeared to have been carried out as fully automatic engagements, i.e., without crew intervention up to the point of begin-fire.

In addition to the automatic mode, there were four other operating modes available to crew members as they acquired and acted against hostile targets. The core of the difference in modes was whether or not the radar pointer was used and whether or not laser tracking was used. Operating mode made a statistical and practical difference in time to fire. As Table 6 shows, only the automatic mode (radar auto), with a mean time to fire of 6.73 seconds, was within the 7-second operational requirement. When both radar pointer and laser tracking were used, time to fire rose to 24.65 seconds.

TABLE 6

System Modes Comparison

System Mode	Mean Time to Fire (Seconds)	Number of Engagements
Radar Auto	6.73	3
Radar Pointer with Laser	24.65	26
Radar Pointer w/o Laser	16.12	162
Radar Optical with Laser	15.69	72
Radar Optical w/o Laser	9.50	8

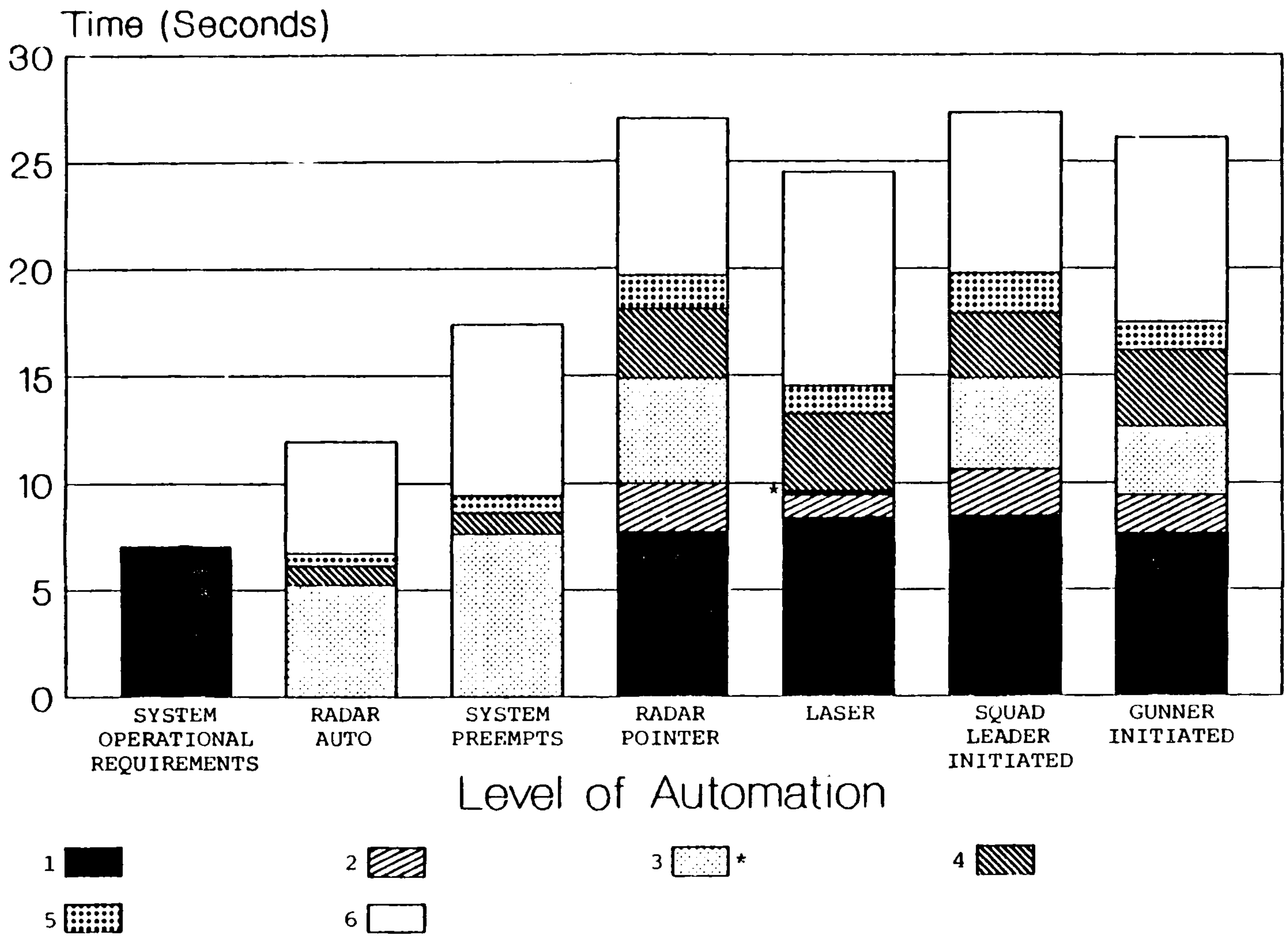
The effect of level of automation on the length of the target engagement is shown in Figure 1. Each bar includes fire duration (the length of time the trigger was held), but fire duration is shown as a blank segment at the top of the bar to facilitate the comparison of time to fire differences. Time to fire is total engagement time minus fire duration. Thus, to compare time to fire, the blank segments of each bar should be disregarded.

For reference, the first bar in Figure 1 depicts the 7-second operational requirement. The second bar summarizes the radar auto engagements, the highest level of automation available in this system. The third bar shows an intermediate level of automation, designated "system preempts", a level not discussed above, not included in descriptions of how the system was supposed to operate, and different from the nominal system modes.

In analyzing the data it became apparent that the crew members decision role had been preempted by the machine system in a number of engagements (47 of the 271). This preemption took two forms, one, an automatic (system-controlled) change of targets while firing action against a target was in progress. That is, firing on an operator-selected target was terminated and another target substituted without crew action. Often after a brief trigger release to confirm the "foe" classification of the new target, the gunner would reengage the trigger and fire purposefully on the machine-selected target.

The other type of preemption would occur earlier in the sequence. With no recorded action by the crew, a target would be engaged by the system. From the 1553 data bus record, it was clear that such non-operator initiated engagements occurred in all modes, not only in Radar Auto (the fully automatic) mode.

Figure 1 permits a comparison of the times taken for six separate portions of the target engagement sequence as a function of degree of automation,



KEY:

1 - Crew Target Analysis
2 - Crew Target Action
3 - System Target Analysis
4 - Automated Decision Support
5 - Crew Decision to Fire
6 - Firing Action

Figure 1. Components of target engagement sequence by levels of automation and by sequence initiator.

primary target designator (radar pointer or laser), and engagement initiator (squad leader or gunner). As the figure makes apparent, integrating human operators into the sequence added additional steps to the sequence (crew action and crew decision steps). The automatic engagements and the system preempt engagements only needed the crew decision to fire.

These data strongly suggest that if operational requirements as stringent as DIVAD's 7-second maximum response time are to be met, system complexity and crew intervention must be sharply restricted. Instead of multi-mode, operator-tuned complexity, future systems may have to be based on highly automated modes that require only manual triggering. Even that step could be automated, of course, but one should remember that one of four times crew members did not fire when faced with a clear signal to fire. A fully automatic system would have fired. Until we understand more fully the price of such total automation, which may involve the loss of friendly vehicles, we should not agree to pay it.

Summary of Other Findings

Short summary statements can be made of other findings relevant to the areas shown in Table 2. For more extended data and discussion, see the report of Babbitt, Seven, and Muckler (1).

Fire Units (A.3). Statistically significant performance differences among fire units were found, with fire unit 5 the best of the five. However, these differences seemed to be based on crew variables rather than fire unit (hardware/software) differences.

Scenarios (B.1). Three different scenarios were used: (1) Delay where the Blue Force maintained a defensive posture, (2) Attack where Blue Force initiated an offensive mission, and (3) Road March where Blue was moving from the rear to the Forward Edge of the Battle Area (FEBA). There were no statistically significant differences for crew decision or action time among scenario conditions.

Rotary Wing Tactics (B.2). Different hostile helicopters (Havoc and Hind) and hover and running tactics were simulated by AH-64s. The Havoc/hover tactic was more difficult for the system to handle than Hind/hover or Hind/running. (Havoc/running was not tested.)

ECM (B.3). There were two electronic countermeasure conditions and one control (benign) condition with no ECM. Acquisition time and engagement time was shortest under the design ECM condition. The most stringent ECM condition had a negative impact on total engagement time, compared with design and benign conditions. In addition, the ECM actions (flares and chaff) also negatively affected target acquisition.

Time of Day (B.4). The time of day at which the target engagement occurred had a classic pattern of results, with early morning trials (Mean = 16.52 seconds time to fire) at intermediate performance levels, midday trials (Mean = 14.59) fastest, and late day trials (Mean = 20.08) slowest. On the other hand, late day trials were found to have the shortest fire duration when compared with early morning and midday trials.

Target Range (B.5). Targets first appeared at a variety of ranges, from 0 to 10 km. It was highly probable that the target would appear anywhere within 4 km distance from the fire unit. The closer the target when it first appeared, the faster the response time of the fire unit.

Crew Response Times (C.1). It was possible to compare the performances of squad leaders and gunners on all crew action/decision responses. There were no differences between them except on "Fire Decision: Solid" where the gunners' time was significantly shorter than the squad leaders'. (See also Figure 1.)

MOPP Gear (C.2). There were no significant differences in target engagement times as a function of whether or not Mission Oriented Protective Posture (MOPP) gear was worn. On the other hand, duration of wearing was insufficient to provide a good test.

Target Workload (C.3). During each target engagement sequence, the operators were frequently faced with multiple targets on the display, ranging from one to 18 simultaneous targets. The data, however, show very few differences as a function of increasing target "workload". What is probably the case is that these skilled operators did not deal with targets except when they came within one kilometer of the fire unit, i.e., when they had to be dealt with.

Individual Differences (D.1). Individual crew members (N = 9) varied considerably in the times they took to detect and respond to a target, ranging from a mean of 4.7 seconds per target (35 engagements) to a mean for another individual of 13.7 seconds per target (31 engagements). Differential performance, however, did not seem to correlate highly with the Armed Services Vocational Aptitude Battery (ASVAB) scores, Armed Forces Qualification Test (AFQT) scores, educational level achieved, or Mental Category.

Crew Differences (D.2). That there was team performance in each fire unit (squad leader and gunner) allowed for comparisons of different crew mixes, and, indeed, different crews varied considerably in terms of mean time to fire (from a mean of 12.1 seconds to a mean of 20.52 seconds). The crews varied also in terms of mixes of Mental Categories; Category III crews tended to be faster in terms of time to fire (Mean = 12.16 seconds) than either Category II (Mean = 17.11 seconds) or Category IV (Mean = 19.74 seconds).

Training (E.1, E.2). Some of the crew members who participated in the Sgt York FOE-I had had previous experience with the Sgt York in prior tests (N = 6). This previous experience varied in its impact on subtask performance during the execution of the target engagement sequence. For example, the inexperienced squad leader was faster in target select/classify but slower in lasing the target. In terms of time to fire, the inexperienced squad leaders tended to fire faster (Mean = 14.55 seconds) than the experienced squad leaders (Mean = 17.86 seconds). We do not know from these data who fired more accurately.

System-specific training was provided to some of the crew members (those who had not participated in the earlier Sgt York tests). There was little systematic relationship apparent between training scores and test performance. Indeed, one crew member who failed individual training had reasonably acceptable test performance scores.

Collective training was given to all crew members, and all passed with a "Satisfactory" rating. Collective training certification was of no value in predicting crew performance.

In many operational tests, as in this one, there have been attempts to assess system training. One may question, as does Meister (2, 302ff), whether one can appropriately evaluate training in operational test where both the training system and the actual training are incomplete. In theory, the whole training system should be available for the operational test, but it almost never is.

TARGET ENGAGEMENT PERFORMANCE MODELS

As Murtaugh (3) and Van Nostrand (4) have pointed out, combat models frequently either ignore the human or assume perfect performance by the humans in the system. That is, the modeller may assume a zero time response element for the human operator(s) or some constant delay term. That neither is sufficient or realistic is clearly shown by the data from this operational test. Table 7 lists some of the performance impacts of a variety of system and human variables on the ranges of time to fire in seconds.

TABLE 7

Performance Variability in Target Engagement Involving Human Behavior*

Variable	Range: Time to Fire (Seconds)
Total 271 Engagements	Mean = 16.52 $\pm$ 11.88
System Modes	6.73 - 24.65
Different Fire Units	12.15 - 19.74
Rotary Wing Tactics	13.96 - 18.06
ECM Condition	14.30 - 17.65
Time of Day	14.59 - 20.08
Individual Crews	12.10 - 19.74
Mental Category: Individuals	14.65 - 20.52
Mental Category: Crews	12.16 - 19.74

* System Response Time Requirement = 7 seconds

For the variables shown in Figure 7, time to fire ranged from about 7 seconds to 25 seconds depending upon the specific variable. It would seem that, for a more realistic combat model, at the very least the range of time to fire for system modes would have to be assessed by the model if valid system response time predictions were to be made.

At the risk of being tedious, the final three entries in Table 7 represent the obvious and familiar cliche: people are different. In this case, that truism applies both to individuals and teams. And, most important for combat modeling, there will be wide differences in system performance measures like time to fire because of individual human variables.

A final point to be made here is that the lack of realism in combat modeling with respect to human behavior does not reflect a lack of available models or data. Rather, it reveals a failure of communication between the operations research and the human factors communities. Modeling of human-system performance has gone on for a long time in the human factors area (cf., 5,6,7), but apparently this technology has had little impact on the operations research modeling community. Perhaps one of the most useful steps at this time might be to encourage communication so that each technical community can see the problems, technologies, and opportunities of the other. It is possible that there might be some pleasant surprises for both.

ACKNOWLEDGEMENTS

Performance data presented in Table 1 were provided to Mr. Richard W. Obermayer, Vreuls Research Corporation, who constructed a computer data base and data analysis system for processing the data. Mr. Obermayer executed the statistical analyses detailed in the full report (1) and referenced in this paper. We are grateful for his skill, experience, and patience not only in building human performance data bases but also in human performance models.

Dr. Bettina A. Babbitt, now in another organizational setting, was program manager for the contract that covered the development of this data

base and was senior author of the final contract report (1). Her contributions to the project and her participation in the data extraction effort are gratefully acknowledged and much appreciated. Had she not departed for greener realms, she doubtless would have joined in the preparation of this report.

REFERENCES

1. Babbitt, B.A., Seven, S.A., and Muckler, F.A. (1987) Human factors performance data for future Forward Area Air Defense Systems (FAADS). Fort Hood, Texas: ARI Field Unit, Contract No. MDA903-86-C-0365, Final Report.

2. Meister, D. (1986) Human factors testing and evaluation. Amsterdam: Elsevier.

3. Murtaugh, S.A. (1987) Of human behavior and actions as an essential ingredient for realism in combat modeling. Phalanx, 22-24.

4. Van Nostrand, S.J. (1986) Model effectiveness as a function of personnel: (ME = f(PER)). Bethesda, Maryland: US Army Concepts Analysis Agency, Study Report CAA-SR-86-34.

5. Chubb, G.P., Laughery, K.R., and Pritsker, A.A.B. (1987) Simulating manned systems. In G. Salvendy (Ed.) Handbook of human factors (Chapter 10.2, pp. 1298-1327). New York: John Wiley.

6. Pew, R.W., Baron, S., Feehrer, C.E., and Miller, D.C. (1977) Critical review and analysis of performance models applicable to man-machine systems evaluation. Washington: AF Office of Scientific Research, Contract No. F44620-76-C-0029, BBN Report No. 3446.

7. Rouse, W. (1980) System engineering models for human-machine interaction. New York: North Holland.

DISCUSSION OF "TACTICAL DETERRENT EFFECTS MODEL"
by G. Schecter, J. Richards and H. A. Romberg
and
"A HUMAN PERFORMANCE DATA BASE FOR TARGET ENCOUNTERS"
by S. Seven and F. A. Muckler

DISCUSSANT: Irving Alderman, US Army Research Institute

These two papers offer different approaches to the estimation of weapon effectiveness; the analytical and the empirical, respectively. Both have potential implications for approaches to improving the realism of combat models by introducing human decision processes and performance to current combat models and by reducing the pace of battle.

The deterrence model offers an innovative approach to estimating the non-casualty effects of mines. It appears to have considerable potential in the modeling of commanders' decision making in the presence of risk and the effects of delay and disruption on the execution of tactical plans. As the authors' note, it is a prototype model requiring testing of the assumptions, verification of various elements and sensitivity testing. I would suggest that the risk taking study should be replicated using a larger sample of military experts selected to represent several levels of command experience. In addition, since the measure of concern is with the risk taking behavior of the opposing force commanders, the differences between both groups of commanders should be examined.

The second paper demonstrates what can be done with human performance data collected during a field test. If the system were to be fielded, and this one is not, system performance data would be available for inclusion in a combat model. However, this would presume algorithms are available to adjust the performance levels to the conditions being represented by the model. The opportunity to collect field test data from which the performance of operator tasks and equipment functions can be estimated is a first step to introducing system performance to combat models. However, field performance is not combat performance. A method for transforming field test performance to an estimate of expected combat performance is a critical and continuing need. Unfortunately, test plans are not always realized in the field. In this case, the authors note deficiencies in training and feedback to the operators. The collection of field performance data and its transformation for combat models is a very complicated process that is not within current technology but the need to do so is recognized and the tools are emerging.

TOE NONAVAILABILITY FACTORS STUDY

Stuart H. Rakoff, F. Freeman Marvin, and Monica M. Constantine
Decision Science Consortium, Inc.
1895 Preston White Drive, Suite 300
Reston, VA 22091
(703) 620-0660

INTRODUCTION

This paper presents final results and conclusions from a study of Army nonavailability factors conducted by Decision Science Consortium, Inc. for the United States Army Manpower Requirements and Documentation Agency (USAMARDA) under the terms of Contract Number MDA903-85-C-0488. The purpose of this study was to update and improve the estimates of nonavailable time for combat support and combat service support personnel in an extended NATO wartime scenario. These nonavailability factors will be used by Army manpower analysts and TOE designers in building the manpower requirements for these units. The study is limited to nonsupervisory enlisted personnel in grades E-5 and below.

This paper is based on a detailed review of a previous study[3], a series of interviews and field visits with a wide range of Army and other personnel, the development and testing of a conceptual model of the allocation of personnel time based upon multiattribute utility theory, generally accepted methods used to collect and analyze expert judgments, and exercise of the model. The results are presented as three alternative formulations of nonavailability factors for use by Army TOE designers and manpower analysts.

Statement of the Problem

The process of determining manpower requirements associated with the Army force structure is a complex interaction of assumptions and judgments which is critical to the success of Army manpower programs, but is poorly understood by many who must deal with the results. Increasingly, the process and its product--Tables of Organization and Equipment (TOE)--have come under scrutiny both inside and outside the Army. This is because adoption of new Army force structures such as Division 86 and the Army of Excellence has caused massive changes in the organization of many Army units. Force modernization with high technology weapons has also required basic changes in the shape and size of units at all levels. Doctrinal changes embodied in AirLand Battle and Army 21 have fundamentally altered traditional relationships between combat, combat support, and combat service support functions. Resource constraints, especially for trained manpower, have increased the Army's concern with finding efficiencies in its force structure. And external agencies, particularly the congressional committees and staffs, are beginning to look more closely at the service statements of manpower requirements and their origins.

The Army uses the Manpower Requirements Criteria (MARC) program to determine the number of soldiers needed to perform combat support and combat service support functions in deployable units. This program supports development of TOEs for these units and has a direct effect on the programming and budgeting of 650,000 positions--about 57 percent of total Army manpower requirements. Compensation costs alone for personnel who would fill positions determined by the MARC program comprise $9.4 billion of the Army's military personnel budget. A one percent error in the process could cause as much as $94 million in unnecessary costs or result in the loss of 6,500 personnel needed for support in TOE units[2].

Using MARC, TOE developers determine support manpower requirements by two methods: standard position criteria and variable, or workload-driven, criteria. Standard position criteria normally apply to full-time supervisors and other positions in which work output is not readily measurable or is not directly related to manhours worked. Determination of these positions is usually based upon organizational doctrine. For example, each company-sized unit gets a first sergeant, and each tank crew has 4 requirements. Variable, or workload-driven, criteria apply to most enlisted combat support and combat service support positions.

TOE developers base manpower requirements for all variable, workload-driven positions supported by MARC on the formula:

$$\frac{A x B}{C} = R$$

where: A = Productive manhours required per work unit; B = Number of work units; C = Annual available MOS productive manhours (AAMPM); and R = Manpower requirement. The denominator on the left-hand side of the equation, also known as the Basic Planning Factor, is based on the concept of providing minimum essential manning to perform specific wartime functions in sustained combat in a European environment.

Basic Planning Factors are calculated by subtracting annual nonavailable time and indirect productive time from the total number of manhours per individual in a year (8760). Thus, in order to develop manpower requirements for workload-driven TOE/MTOE positions, developers must have valid, accurate and traceable nonavailability and indirect productive factors.

In peacetime, nonavailable time is usually estimated by conducting surveys of the actual experience of units, by examining administrative records, or by doing time studies of units at work. These approaches yield valid and reliable estimates of current Army practices--how much time members actually spend in training, in medical appointments, counseling, or other personal activities, or performing other non-MOS duties which are part of the peacetime routine. Recently completed surveys of Army peacetime (TDA) nonavailable time have been incorporated into manpower estimation for these TDA units.

However, estimating wartime nonavailability factors is a much different problem. No direct observations or measures of individual behavior are possible, meaning that the usual survey research approach which asks for self-reporting, augmented by administrative data, is not sufficient. This is especially true because individual perceptions of the intensity of conflict, the particular missions which units will perform, and the wide variety in wartime organization, locations, and movement patterns are difficult to control in a survey research setting. As a result, estimates of nonavailable time (and hence, available productive time and required manpower) for a wartime organization derived from traditional survey research techniques are apt to be of low reliability and validity.

There is no accepted definition of minimum essential manning, but it implies a manning level at which all "essential" work is performed while no "nonessential" work is performed. Currently, the Army provides estimates of workloads for support MOS functions and the MARC formula implies that all of this work is essential. The Army does not provide estimates of workloads for other wartime functions (e.g., base security, individual training, unit movement) and where workload estimates have been attempted, it is not clear how much of this workload is "essential" and how much is "nonessential." For example, many Army estimates exist for soldier sleep during wartime, including levels that are "sufficient" or "relatively effective,"[7] and "complete" or "substantial,"[1] but none that are considered essential.

Finally, there is no accepted definition of "sustained combat in a European environment." The MARC are designed for a "steady-state" combat environment approximately 90 to 180 days into a general conventional war in central Europe. The Army uses a variety of models and simulations to predict the resources, missions, and outcomes of a war in the European environment, but none of them describe anything resembling a steady state of operations nor extend for a six-month duration. Thus, development of new basic planning factors for the MARC equation requires a substantial use of professional judgment in the absence of direct observations and well-defined goals and assumptions.

As an alternative to the typical survey research instrument, DSC designed, built, and implemented a multiattribute utility model of the manpower utilization process as it occurs in wartime units. Underlying our choice of this approach is the concept that unit commanders, faced with a series of demands for the use of their support manpower including direct support functions, indirect support functions (cleaning tools, clearing work areas, etc.) and a number of non-MOS functions such as local security, unit movement, and sleep, make difficult choices between which jobs get done and which jobs are neglected or postponed.

A unit commander, when allocating his limited manpower, must make a series of judgments about how he will use his personnel to accomplish different missions in a given combat scenario. Essentially, he must trade off the value of each task against the alternative uses of manpower, by deciding the value, for instance, of additional hours of MOS function time versus additional unit security. Based on these tradeoffs, the commander will arrive at a series of decisions on manpower utilization including nonavailable, available productive and indirect productive tasks. By aggregating these individual judgments, it is possible to estimate systematically the amount of time, by unit type, unit location, unit mission and scenario, that commanders would allocate for available productive time, and hence the number of support personnel required.

<u>A Decision Analysis Approach</u>

Decision analysis is a collection of techniques for evaluating alternatives by focusing on their values or utility, the outcomes associated with each alternative, and the probabilities of those outcomes. A complex decision problem is first divided into clearly defined components: options, uncertainties, and cost. The problem is then structured, often as a formal decision model or diagram. The components are then quantified as probabilities and utilities in light of the decision maker's perceptions, using the best information and expertise available. Logical implications of the model (such as the identification of the most cost-efficient set of programs) are deduced, displayed, and incorporated into the decision-making process.

Decision analysis facilitates the decision process primarily by enabling attention to be directed selectively at different components in a complex problem and by properly integrating the various components for the decision maker. Several individuals or groups may become involved, especially if they differ in their expertise regarding different problem components. In addition, decision makers--whether individuals or groups--can use decision analysis to discipline their informal reasoning and to facilitate communications among individuals in command structures, committees, or various interest groups. For example, decision analysis can be used to communicate the grounds for a recommendation, to identify sources of disagreement, to focus different expertise on appropriate parts of a problem, to determine the critically important aspects of a complex decision problem, and to promote a group consensus.

An important and distinctive aspect of decision-analytic approaches pertains to how judgment enters into an analysis. Many non-decision-analytic approaches try to ignore judgmental input altogether, seeking a spurious form of objectivity. Other approaches recognize that the judgments and opinions of the decision maker are valid inputs, but treat them in an informal fashion. Decision analysis is distinctive in part because it involves the careful quantification of both values (using utility theory) and uncertainty (using personal probability theory). It explicitly introduces such subjective quantities into the analysis rather than analyzing only "objective" components. The theoretical basis underlying this use of subjectivity is well-developed, and practical applications are extensive.

Decision analysis, however, does not rely solely on judgmental input. A unique feature of many decision-analytic tools is their capability to use either objective or subjective inputs, and more specifically, their capability to combine both types of inputs when both are available. That is, decision-analytic models can utilize the best information available bearing on the problem at hand, regardless of the exact type or form of information.

This study applied a decision-analytic approach to the problem of estimating wartime manpower requirements, in particular, nonavailable and indirect productive time. The detailed technical approach given in a following section builds upon this theoretical perspective and combines the power of the method with a computerized decision model to facilitate the formulation of the manpower utilization choices facing commanders, and the tradeoffs among these choices. The method further extends this decision-analytic perspective to a robust, yet cost-effective, data collection technique which ensured that valid and reliable data, fully compatible with the required models, were produced by the research effort, and may be updated as desired at low cost. The result of this combination of decision-analysis theory and method will be significant improvement over the current state-of-the-art in estimating wartime manpower requirements.

Outline of Paper

This paper is organized into five sections that explain the background of the problem, the Commander's Decision Model, the data sampling design and collection, the analysis of the data and results. Only major sources examined and major issues investigated are reported in the background section. Further background material may be found in three interim reports dated January 1986[4], April 1986[5], and June 1986[6]. Some of the more relevant considerations from this background review are summarized in Appendix A. The section on the Commander's Decision Model explains the concepts used in the model and the data necessary for its use as an analytic tool. The third section explains the sample design and data collection process used in the study. Finally, the last two sections examine the model outputs and report results and conclusions.

BACKGROUND

This study of Army nonavailable time factors was requested by the Office of the Deputy Chief of Staff for Personnel (DCSPER) because of criticisms by the General Accounting Office (GAO) of a 1983 study by the U.S. Army Logistics Center and the procedures for estimating manpower requirements and because of dissatisfaction with the current factors by some Army staff. Our initial effort on the project, therefore, was to carefully review prior studies and current methods, interview relevant Army staff, review the practices of the other Services and then use these findings to formulate a new approach to the problem of estimating nonavailable time. The results of these initial activities are presented in Appendix A. This section summarizes the impact of this review for the project design.

Our major concern at this stage of the project was to be able to specify the assumptions and underlying policies which would drive any non-available time result. To accomplish this, our reviews and meetings centered on looking at the current manpower planning factors, doctrines, and computer models which describe Army policy and practice, as well as at parallel information for the other Services where it was relevant. As our review proceeded, it became clear that there were significant differences in approach and assumptions in different parts of the Army, and between the Army and the other Services.

These differences are largely along two dimensions:

- Army doctrine, as represented by the AirLand Battle concept, is much more strenuous with regard to manpower requirements and non-available time than the Army's resourcing (as reflected in current TOEs and computer simulation exercises);
- The Army approach to nonavailable time and manpower planning, based on allocating all of a 24-hour day, is much more demanding than the doctrine-driven work day used by the other services.

The first set of differences is clearly the most important for this project. The second reflects real differences in how the Services organize and plan for war, and it is likely that the experience of the other Services is not especially relevant for how the Army must do business. That is, we do not believe that any alternative to manpower planning based on a 24-hour day is likely to be a feasible solution to Army needs.

The differences between Army doctrine and Army resources are, on the other hand, a serious concern for this study. As detailed below, current Army doctrine assumes a very rigorous battlefield, multi-dimensional in its threat, and of very high lethality. Any future NATO war is assumed by Army doctrine writers to include non-conventional munitions and non-linear attack and defense maneuvers. Deep battle and rear battle concepts will require troops to be more mobile, security-conscious and responsive than did past active defense doctrine. Yet, planning models generally assume a linear, conventional war. The disconnects suggested above may arise because these new doctrines have not yet been absorbed in the resource planning simulation models, or they may exist because of an inability by doctrine writers and resource planners to articulate a common definition of acceptable risk when balancing goals and resources.

Our response to these problems was to design the Commander's Decision Model with as much flexibility as possible. This offers two advantages. First, the sensitivity of the outputs (estimated nonavailable time) to alternative assumptions and judgments can be tested using the model. Second, as new doctrines and workload estimates mature and are integrated into resource models and field operations, new data can be easily incorporated in the model to re-estimate the nonavailable factors.

MODEL DESIGN

Concept

In this section we will describe the conceptual underpinnings of the model of nonavailable time computation. Unlike the other Services, the Army does not assume a standard or doctrinaire wartime workday, but rather begins with the assumption that soldiers are available for duty 24 hours per day. Commanders will allocate their available manpower across a range of tasks in combinations they believe will maximize mission accomplishment. The crucial decisions on manpower utilization will be made by commanders of TOE units, and for that reason TOE designers need to pay careful attention to the ways in which manpower will actually be used by commanders.

A wide variety of tasks contribute to mission accomplishment. In the past, these were considered as falling into five categories:

- Direct MOS time;
- Indirect MOS time, only for maintenance personnel;
- Nonproductive MOS time, for mechanic travel and delays;
- Non-MOS (Unit Mission) time, such as security and unit movement;
- Not available for duty time, such as casualties and sleep.

Everything except direct MOS time is loosely referred to as "nonavailable time." Most nonavailable tasks, however, are critical to mission accomplishment. Some tasks, of course, do not contribute to the mission and the commander will not explicitly allocate time to them. Still, time lost due to such factors as casualties which are not immediately replaced is an overhead cost which must be borne by the unit.

If commanders are assumed to be empowered to allocate each soldier's available 24 hours a day (minus casualty time) across these tasks, and are also assumed to want to maximize mission accomplishment, how will they allocate these manhours? Our conceptual approach to this problem answers this question by arguing that these commanders will make judgments about the relative contribution of incremental manhours of labor - that is, they will prioritize tasks and do as much as possible with the soldiers on-hand. These decisions are likely to be very scenario-dependent and not based on an explicit enumeration of tasks, but on implicit judgments of relative priorities.

There are several dangers with this concept that must be understood. First, judgments about the relative priority of different tasks on the battlefield are no better than the estimates of the task workloads themselves. Modern combat is characterized by violent fluctuations in firepower and maneuver by the units in contact, which have direct effects on supporting units and personnel who must "feed, fuel, and fix" the combat forces. Combat support and service support do not function in a steady-state production-line fashion, but in a quick reaction and totally responsive mode. Task priorities may fluctuate to cope with changing workloads and may not be fully predictable by the commanders themselves, beforehand.

Second, it's still true that "work expands to fill the time available." This means that once the available productive tasks are being properly serviced and the essential nonavailable tasks are completed, additional marginal personnel will be assigned to "nice to have" tasks in either mission support or nonavailable areas in order to reduce the risks to the unit, build redundancy, prepare for future contingencies, and develop new capabilities. Thus, a unit with a very high nonavailability factor may be overmanned under a strict interpretation of minimum essential manning, but be undermanned according to a "risk averse" commander.

Third, by treating direct MOS time as a single category, we can trade off this "task" against nonavailable tasks to find an average nonavailability factor for a given-sized unit. But we know that not all direct MOS tasks have the same value to the commander. Commanders may use critical MOS skills, such as operating room specialists, more often for productive tasks than they would use non-critical skills, such as patient administrative clerks. Thus, we can either accept an inequitable unit in which soldiers have different nonavailable factors depending on their MOS skills, or we can accept an inefficient unit in which all soldiers have the same nonavailable factor regardless of the value of their time to mission accomplishment.

The important point to acknowledge is that the development of any nonavailability factors depends on many assumptions and personal risk assessments. Basic planning factors which are used for unit design should conform to "common sense" judgments about the context of the scenario, the level of task detail, the scope of the MARC process, and the support of Army doctrine. Our methodology is a systematic combination of Army doctrine supported by reasonable expert judgment by senior and junior Army officers which produces balanced, common-sense estimates of nonavailability factors.

Commander's Decision Model

A simple approach to calculating nonavailability factors, based on the MARC process, assumes that a unit has a certain fixed combat support and combat service support workload requirement (W) expressed in daily manhours. The unit also has support personnel assigned who each have a certain daily availability in their duty specialty, again expressed in daily manhours. Availability is the difference between the maximum amount of time available in a day (24 hours) and the nonavailable time (Y) spent doing other worthwhile tasks or absent from duty. By dividing the daily workload by the daily available hours per soldier, the number of support soldiers required to handle the daily workload is calculated (X). This relationship is shown below:

$$\frac{W}{(24-Y)} = X$$

By holding W constant in this equation (for example, 300 manhours/day), a curve can be drawn showing the nonavailable time that will result from varying the assigned numbers of personnel in the unit. Since the Army's only design criterion for workload-driven positions is that all MOS functional work is performed, the Army is satisfied at any point along the curve.

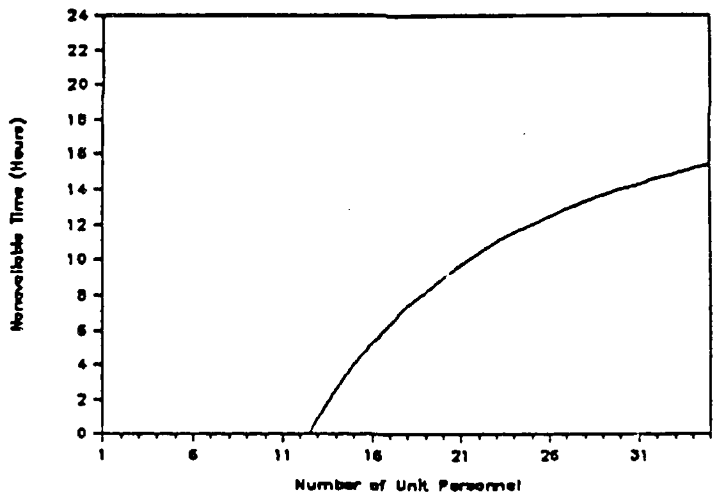


Figure 1: Baseline Nonavailability Factors

We can also view the problem from the perspective of the unit commander who will look carefully at the marginal utility for nonavailable tasks as well as for MOS tasks before assigning duties to his soldiers. For example, one of the smallest tactical units in the Army today is the Forward Area Alerting Radar (FAAR) team. Consisting of two enlisted 24N mechanic/operators, its mission is to move its truck-mounted radar to a designated location (usually on top of the highest hill in the area) and relay information on enemy aircraft to divisional air defense units. The team commander, usually a staff sergeant, must provide for continuous daytime operation, local security, operator rest, site improvement, and numerous other nonavailable tasks. In fact, sometimes he relocates his team and cannot begin operation for hours while he secures his position, rests, and performs operator maintenance on his equipment. It does not ease his predicament to know that his team was designed by standard criteria rather than by workload criteria. He does the best with what he has at hand. His marginal utility for nonavailable tasks is lower than for MOS tasks, meaning that if he had another operator, the new man would spend most of his time operating the radar. This would lower the unit's average nonavailable time.

On the other hand, a typical ordnance company in support of a corps rear area is a very large unit, sometimes numbering 300 or more officers and enlisted men and women. The commander, often a major, must provide for the same things as the FAAR team commander: continuous operations, local security, sleep and personal time, site improvement, etc. In contrast, however, the day following a unit move may include at least one hot meal and perhaps a hot shower for all unit personnel because the MOS tasks are all being performed. His marginal utility for nonavailable tasks is higher than for MOS tasks. A new mechanic in the unit would probably be assigned to digging new foxholes, camouflaging the position, and pulling guard duty, resulting in an increase in the unit's average nonavailable time.

Thus, there is a commander's function for support personnel which can be expressed in terms of average nonavailable time per soldier. To illustrate this concept, we can make the following assumptions of the relative priority the commander assigns to the tasks described above. These "weights" represent an assessment of the relative contribution of each task to accomplishing the overall mission. For each task, we have provided maximum daily hours which the commander might choose, and have assumed that any more time spent on these tasks would have no value for the unit. Sleep might have a minimum requirement of 4 hours to ensure physical survival, while minimum movement requires 1.8 hours per day.

Table 1: Example of Commander's Decision Model

Six Tasks	Minimum	Maximum (Hours/Day)	Weight
MOS TASKS	0	300 per unit	.30
SLEEP	4	9 per individual	.25
GUARD DUTY	0	216 per unit	.20
UNIT MOVEMENT	1.8	8.5 per individual	.15
OPERATOR MAINTENANCE	0	4 per individual	.05
IMPROVING SITE	0	80 per unit	.05

Note that the times are expressed in two rather different ways: as hours per unit and hours per individual. Tasks expressed as hours per unit represent tasks whose performance can be divided up among members of the unit. Hence, as unit size changes, the amount of these unit tasks allocated to each individual (on average) will also change. Tasks expressed as hours per individual must be performed by each soldier and may not be shared, regardless of unit size. The weights assumed here reflect a commander's judgment that MOS tasks contribute most to mission accomplishment (.30), followed by sleep (.25) and guard duty (.20), then by unit movement, operator maintenance, and improving the site.

Not all hours of a particular task have the same value, however. The marginal utility of an hour of any task can be expressed on a utility curve, also called a benefit graph. The minimum time required to perform the task is established as a baseline providing 0% of the task benefit and the maximum useful time is considered to provide 100% of the task benefit. Typically, earlier hours of a task provide more marginal benefit than later hours of the task.

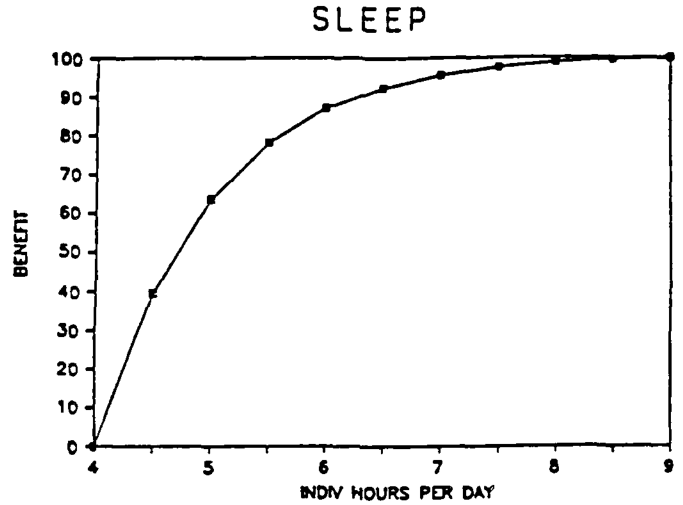


Figure 2: Benefit Graph

Each task may be divided into "increments" and the marginal benefit of the increments converted to marginal benefit "points" as shown in Table 2.

Table 2: Marginal Benefit Points

	Marginal Benefit Per Time Increment									
Increment	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
MOS TASKS	10	10	10	10	10	10	10	10	10	10
SLEEP	40	24	15	9	5	3	2	1	1	0
GUARD DUTY	34	23	15	10	7	5	3	2	1	1
UNIT MOVEMENT	40	20	12	8	6	4	3	3	2	2
OPERATOR MAINTENANCE	21	17	14	12	9	8	6	5	4	3
IMPROVING SITE	15	14	12	11	10	9	8	7	7	6

Finally, each increment may be multiplied by the relative weight of the task and divided by the number of hours in the increment to calculate a total value per hour for the increment. Notice that all times are converted to individual hours to allow for comparison of the values of unit tasks and individual tasks by dividing unit task times by the number of soldiers in the unit. The 60 task increments are then prioritized by total value per hour.

Table 3: Marginal Task List for a 20-Soldier Unit

Task	Increment	Marginal Benefit/Incr	×	Relative Weight	+	Indiv Hrs/Incr	=	Total Value/Hr	Cum Hours
SLEEP	I1	40		0.25		0.5		19.81	7.3
SLEEP	I2	24		0.25		0.5		12.01	7.8
MOVEMENT	I1	40		0.15		0.7		8.96	8.5
SLEEP	I3	15		0.25		0.5		7.29	9.0
GUARD	I1	34		0.20		1.1		6.22	10.1
MOVEMENT	I2	20		0.15		0.7		4.48	10.8
SLEEP	I4	9		0.25		0.5		4.42	11.3
GUARD	I2	23		0.20		1.1		4.17	12.4
GUARD	I3	15		0.20		1.1		2.79	13.5
MOVEMENT	I3	12		0.15		0.7		2.69	14.2
SLEEP	I5	5		0.25		0.5		2.68	14.7
MAINT	I1	21		0.05		0.4		2.62	15.1
MAINT	I2	17		0.05		0.4		2.15	15.5
MOS	I1	10		0.30		1.5		2.00	17.0
MOS	I2	10		0.30		1.5		2.00	18.5
MOS	I3	10		0.30		1.5		2.00	20.0
MOS	I4	10		0.30		1.5		2.00	21.5
MOS	I5	10		0.30		1.5		2.00	23.0
MOS	I6	10		0.30		1.5		2.00	24.0

Since we have a physical constraint of 24 hours per day to perform tasks, it is an easy matter to start at the top of the list and allocate incremental hours until we reach 24 hours. Assuming one hour for medical reasons in this example, we begin with 6.8 hours minimum average nonavailable time. Total average nonavailable time at this unit size is 15.5 hours. The graph which follows portrays the average nonavailable time per soldier as unit size increases in this example.

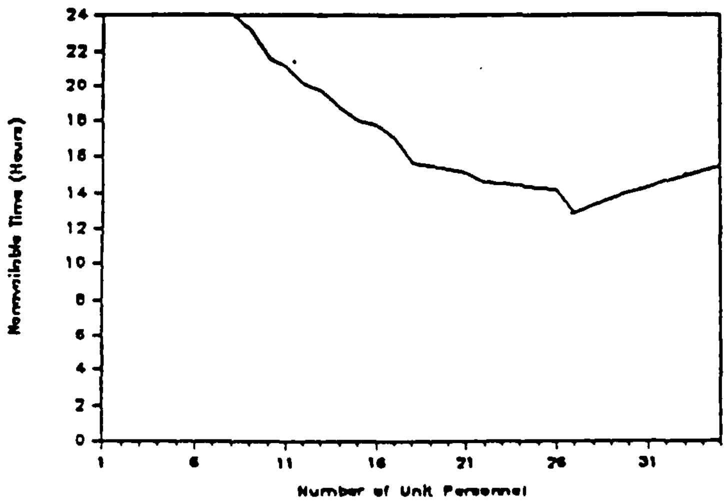


Figure 3: Commander's Nonavailability Factors

Note that until the unit reaches a minimum of 8 personnel, all time is allocated to nonavailable tasks--reflecting the high weights assigned to guard duty and sleep. From a unit size of 9 up to a unit of 27, nonavailable time declines to approximately 13 hours per person. This decline happens because the unit nonavailable tasks are spread over more personnel, and because increased time is allocated to MOS tasks. At a unit size of 27, all MOS work (300 manhours) is performed. Beyond this point, average nonavailable time increases as the remainder of the marginal nonavailable tasks are performed.

By combining these two graphs, a unique solution to the nonavailability factor problem can be reached, and the most efficient size at which to design units, along with the nonavailable time per soldier, can be estimated. The next figure shows that the intersection of the two curves is at a unit size of 27 and results in an average nonavailable time of 12.9 hours. At this point, the unit is at the most advantageous position with regard to these factors. Assigning fewer personnel will decrease the performance of both MOS and nonavailable tasks. Assigning additional personnel will only increase the performance of nonavailable tasks which have smaller marginal utility to the commander than the last hour of MOS work.

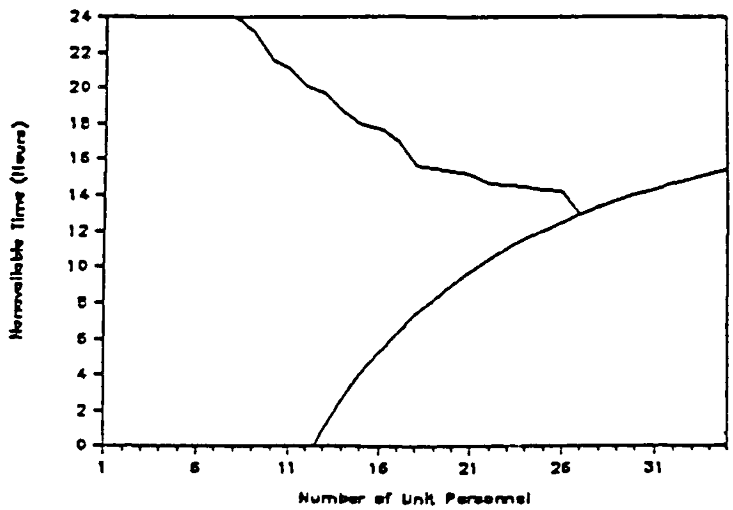


Figure 4: Nonavailability Solution

Given this model for determining average nonavailability factors, the manpower analyst needs to collect valid and reliable data inputs. First, the baseline curves have a known shape (the MARC equation), so all he needs to know to complete them are the unit direct MOS workloads. One method to collect these data is directly from the Army Maintenance Manhours Data Base (AMMDB) and other source publications. While there is at least one computerized system for retrieving some of these data efficiently (MRPL), most of the data would require an extensive collection effort. An alternative method, used in this study, is to estimate these data indirectly by extracting the required number of manpower spaces for MARC functions from the current TOEs and multiplying by the available times given in the 1969 AR 570-2. Since the current TOEs were, indeed, built using the MARC equation, then this alternative method must give us a correct estimate of current direct MOS workloads.

These current workloads generally do not include battle damage repairs for maintenance functions and combat scenarios for other functions seem to vary by proponent. Therefore, the estimated MOS workloads must be viewed only as a baseline for the model construction. The model inputs may be updated as better methods are developed for calculating direct MOS workloads under a combat scenario.

The commander's nonavailability curves are more difficult to derive. The analyst must find their shapes as well as "anchor" them to the same scenario used to derive direct MOS workloads. The field survey used by the LOGCEN was the right idea (asking Army experts), but it had two problems which created bias and unreliability. First, respondents were merely asked how much time they thought they would need to accomplish the list of nonavailable tasks they were shown. Respondents gave multiple partial answers, one task at a time: first the number of people involved in the task, then the time needed to complete the task, and finally, the frequency of the task. Never was a respondent confronted with the totals or even the task subtotals for an opportunity to reconcile his answers. Not surprisingly, the LOGCEN suspected that total nonavailability factors had been systematically overestimated.

Second, the responses from units of various sizes, MOS mixes, and missions, were pooled to find a mean and median for all units of a certain type in a certain area of the battlefield. No account or control was taken of unit size, indicating a major reliability problem. Future company-sized units may generally get larger (as in a Division '86 type force structure) or get smaller (as in the Army of Excellence force structure). Thus, there was no control on reliability in the LOGCEN study.

Input data for the Commander's Decision Model uses the multiattribute utility model itself as the personnel interview survey data collection instrument. This model is implemented with user-friendly software on an IBM PC-compatible microcomputer that the analyst may use to elicit judgments from Army experts in a controlled and systematic way. Rapid model runs allow feedback to the experts so that adjustments may be made to their initial responses.

The model presents the expert with a multiattribute framework with which he develops utility curves associated with each nonavailable task. The expert imagines himself as a commander of the unit type under the given scenario conditions. He is then asked to assign weights to each task based on the mission and scenario. Finally, the expert is presented with the implications of his judgments so that he may confirm or revise them.

Model Assumptions and Definitions

The Commander's Decision Model is valid under the following assumptions:

1. Officers and NCOs will not perform any of the unit security, MOS workload or unit details. For units in which officers and NCOs perform MOS/AOC functions, those positions and their associated workloads should be analyzed separately from nonsupervisory E-5 and below.
2. All soldiers will share the workload for each task equally.
3. Within each category of tasks, it is not important for unit design

purposes to know exactly how a commander would utilize available personnel. Whenever a commander faces more tasks than he has available personnel to complete the tasks sequentially, he may choose to allow some tasks to be performed concurrently or he may choose to postpone or neglect some tasks.

The Commander's Decision Model produces nonavailability factors for use under specific scenario assumptions. This study is based on the same scenario upon which the TAAs are based--a NATO-Warsaw Pact war in Central Europe from D-Day to D+180 days into combat. This scenario, called the "Illustrative Planning Scenario," is described in general terms in the Army Force Planning Data and Assumptions (AFPDA) document. Although this document is sufficient for force programming purposes, it does not provide the level of detail necessary for this study. Therefore, the scenario details are based upon the unclassified TRADOC Common Teaching Scenario. This scenario describes four distinct operations which are described in Appendix B.

Identifying nonavailable tasks is the final step in the model design. Finding a "common sense" focus on the level of detail involves tradeoffs between the reliability of the broader factors and the validity of the narrow tasks. For example, in the broader task of PERSONAL NEEDS, we may predict a reliable time factor but not be sure exactly what subtasks it encompasses on any given day. If, however, we predict times for WRITING LETTERS, SHAVING, and SHOWERING, we have a more valid description of the tasks, but are less sure about the time allocated to each one on any given day.

This study redefined the definitions of the use of time for MARC purposes. The 24 hours that all soldiers begin with is called the COMBAT DUTY DAY, just as the peacetime duty day is normally 8 hours. Some time is NOT AVAILABLE FOR DUTY because of leave, pass, AWOL, TDY, injury and nonhospitalized illness. The rest of the duty day is AVAILABLE FOR DUTY time. While a soldier is available for duty, he may be assigned either MOS TASKS or NON-MOS TASKS. The breakdown of non-MOS tasks is into five categories: personal needs; base security; unit movement; training, maintenance and administration; and unit details. Any time during the duty day that is "lost" due to direct enemy actions or that requires hospitalization is not considered in TOE development under these categories. Time lost to direct enemy actions is entirely situational and should be handled through personnel management procedures, replacement systems, and other command-directed policies. Hospitalized DNBI patients are more readily predicted based on historical rates, but replacement policies do not define an average time to replace a DNBI casualty.

The multiattribute utility structure could break down tasks into infinitely small categories. We feel that the level of task detail appropriate for estimating non-MOS task time should be relatively aggregated. Thus, we see no need for structuring the model below the five major categories. However, justification for the minimum and maximum times may be necessary for some tasks at lower levels. Table 4 shows the task list and the subtasks used in this study.

Table 4: Task List

1. PERSONAL NEEDS

   Sleep and rest
   Messing
   Personal hygiene (laundry, shower)
   Counseling/religious time
   Correspondence/mail call/pay call

2. BASE SECURITY

   Perimeter guard (day, night)
   Interior guard (fire, theft, prisoners, refugees)
   Early warning posts (listening posts, observation posts)

3. UNIT MOVEMENT

   Reconnaissance (road guides, security team, NBC team)
   Disassemble Equipment
   Load vehicles
   Police site
   Convoy (delays, wrong turns)
   Unload vehicles
   Assemble equipment

4. TRAINING, MAINTENANCE & ADMINISTRATION.

   Refresher training (common skills, MOS skills)
   New skills training (new procedures, cross-skills)
   Operator maintenance (vehicles, equipment, weapons)
   Retrieve parts (salvage, cannibalization)
   Shop/work area cleaning/maintenance
   Meetings and briefings (shift change, commander talks)
   Tool box/shop set cleaning/maintenance
   Maintenance administration (requisition parts, inventories, logbooks)
   Contact team/maintenance support team travel

5. UNIT DETAILS

   Unit resupply
   Messenger duty
   Radio/switchboard operation
   Ammunition handling
   Clerk duty
   Improve base and facilities (latrines, policing, unexploded ordnance)
   Improving defensive positions (clear fields of fire, lay minefields, lay barbed wire, build fighting positions, camouflage)
   Charge of quarters
   Personnel inspections
   Head count
   KP

In addition to the not available for duty time and these five non-MOS duty categories, we must take care of the old "variable" indirect tasks that are workload-related. These include:

- Stock fetch (DX, PLL, ASL);
- Tool fetch;
- Special equipment operations;
- In/out processing.

These types of tasks have not been included in the direct MOS times in the numerator of the MARC equation in the past, but they are so few that we recommend that MRSA be responsible for them from now on. The personnel and administrative MARC functions include all their workload variable indirect time in the numerator. The maintenance MARC functions logically should be able to do the same.

SAMPLE DESIGN AND DATA COLLECTION PLAN

Unlike the LOGCEN study, which took a traditional survey research approach to the estimation of nonavailable time, the present study has adopted a more robust decision analysis modeling approach to the problem. The choice of this conceptual paradigm in turn dictated that different modes of data collection be used. In particular, rather than sampling from a universe of individual units, and selecting respondents from these units, the sampling frame was a set of unit cells for which individual nonavailable times were estimated. Further, since the intent was to gather expert judgments on utilities and weights used in the Commander's Decision Model, the selection of respondents was concentrated to the 16 TRADOC schools and AHS. Finally, the decision analysis approach led to the choice of a group setting for the data collection, rather than individual questionnaires or interviews. Details of the sampling and data collection plans are presented in this section.

Sample Design

While many units are similar to each other in the support required for combat, others are quite different. The level at which nonavailability factors from different TOEs may be combined may vary between mission areas.

A logical region pattern and unit type description was used in the LOGCEN study to group units into nine statistical cells. This pattern

breaks down the battlefield into the divisional area of operations, the corps rear area, and the rear areas of all echelons above corps. While distance from the FLOT is certainly an important consideration in estimating nonavailable time, it is by no means a complete description. Other important considerations include size of the base, distance from other bases and expected frequency of unit movement.

Combat, combat support, and combat service support units will operate out of a variety of support "bases." These bases, according to FM 100-10, *Combat Service Support*, "are structured to allow units to be tailored to fit the assigned mission and situation." There are generally five types of support configurations: mobile teams, unit trains, support areas, fixed facilities, and tactical sites.

1. *Mobile Teams*. Many support units deploy teams to perform maintenance, surveillance, or radio relay functions. These teams nor-

mally travel alone at night in one or two vehicles. When they arrive at their duty locations, they either have the perimeter protection of the supported unit or utilize passive security measures such as camouflage and sensors. The size of these teams is usually established by doctrine. Therefore, there is no need to estimate the nonavailable time for mobile teams.

2. *Unit Trains*. The battalion task force trains consist of the logistic elements of the task force. Battalion task force trains can be located at one place (unit trains), or they can be echeloned into field trains kept in the rear and combat trains kept forward. Use of unit trains depends on the mission, the area in which the force has to operate, and the combat, combat support, and combat service support assets available. Echeloning the battalion trains will provide immediately responsive support, flexibility, and increased survivability of assets. When trains are echeloned, the battalion S-4 normally will control the combat trains and will designate the support platoon leader to control the field trains. Combat trains are tailored for the tactical situation. Normally, they contain petroleum, oil, and lubricant (POL) assets, ammunition and other ordnance items, maintenance support teams and the battalion aid station.

3. *Support Areas*. A support area is a geographic location where the logistic elements of a division or a brigade operate in proximity to each other. They must be located along good roads because of the large volume of supplies and equipment they handle. The units found in a brigade support area (BSA) will include the three battalion field trains, the brigade trains and a Forward Support Battalion. The brigade S-4 (logistics staff officer) is responsible for the BSA.

   The three battalion field trains normally include the battalions' remaining POL assets, the ammunition supply vehicles of the support platoons' transportation section, the remaining elements of the maintenance platoon, the support platoon headquarters, the supply section and the mess section.

   The brigade trains consist of the S-1, S-4, and S-5 and their staffs and equipment.

   The Forward Support Battalion has a forward supply company, a maintenance company and a medical company. The forward supply company provides supply classes I, II, III, IV, and VII and operates an ammunition transfer point (ATP). The maintenance company provides direct support maintenance, repair parts, area support, backup recovery support, and maintenance support teams for all equipment in the brigade area. The medical company provides division level health services on an area basis.

   The units found in a division support area (DSA) will include the Division Support Command (DISCOM) headquarters, a transportation aircraft maintenance company and a main support battalion consisting of seven support companies (headquarters, supply and service, transportation, light maintenance, heavy maintenance, missile maintenance and medical).

4. *Fixed Facilities.* Many support units at the corps and theater level operate out of fixed facilities. These include hospitals, administrative units, and many headquarters. The support unit generally does not move and may not provide its own perimeter security.

5. *Tactical Site.* Finally, many support units perform their mission in a separate field location or a tactical site. These include constructi›n engineers, ammunition units and some combat aviation units. These units have many doctrine-driven functional personnel working side-by-side with MARC functional personnel.

Table 5 shows the sample cell matrix used in the data collection phase. This is a "common sense" focus on only the major variations among support elements of units and their MARC functional personnel.

Table 5: Sample Cell Matrix

Cell	Type Unit	Type Base
A	COMBAT	UNIT TRAINS
B	COMBAT	TACTICAL SITE
C	COMBAT SUPPORT	TACTICAL SITE
D	COMBAT SUPPORT COMBAT SERVICE SUPPORT	BRIGADE/DIVISION SUPPORT AREA
E	COMBAT SUPPORT COMBAT SERVICE SUPPORT	*CORPS SUPPORT AREA*
F	COMBAT SUPPORT COMBAT SERVICE SUPPORT	AIRFIELDS/PORTS/TERMINALS

The sampling design for the nonavailability factors differed significantly from that used in the LOGCEN study. The purpose was still to allow descriptive and comparative statistical testing of the data, but because the data collection was based upon a more robust methodology (multiattribute utility theory), statistical cells and cell sample sizes could be considerably smaller.

In each cell, structured group sessions using computerized models were conducted to gather data, with 30-45 individuals in each cell, divided into 2-3 groups, providing a total sample size of 255. The three unit type categories corresponded to the MARC definitions of combat, combat support, and combat service support categories. The four base configurations consisted of trains, tactical sites, support areas and fixed facilities. Each group of interviewees consisted of company grade officers with command experience from a single Army branch proponent.

Each group provided data for only one specific SRC within their branch. The reason for this more detailed sampling design is the hypothesis that wide variance occurs in nonavailable and indirect productive time between different kinds of units, even if they perform similar functions (combat, combat support, combat service support) and are located in the same battlefield area. Should an analysis of variance prove that

SRCs within a single cell have significantly different nonavailability factors, then it is a simple matter to separate SRCs into separate cells. This process could continue (with further data collection) until MARC officials were confident that an optimum number of different nonavailability factors had been developed.

Data Collection Plan

Prior studies of nonavailable time have focused their data collection efforts on commanders and senior enlisted personnel in field units. Typical of this approach was the 1983 LOGCEN study, which interviewed over 300 Army officers and NCOs in European units in building a database. These interviewees were asked to estimate the amount of time which they would devote to discrete tasks.

Rather than take this traditional survey research approach, the present study has adapted a more robust decision analysis modeling approach to the problem. The choice of this conceptual paradigm in turn dictated that different modes of data collection must be used. The decision-analytic approach required a plan that:

- took advantage of existing Army expertise;
- emphasized commanders well schooled in Army doctrine;
- used a group setting to elicit required information;
- minimized resources necessary to collect the data.

The project team, therefore, conducted a series of group meetings with officers at each of the 16 TRADOC branch centers and at the Academy of Health Sciences. The meetings were divided up among the six sample cells as shown in Table 6.

Table 6: Sample Data Collection Plan

	COMBAT UNITS	COMBAT SUPPORT/COMBAT SERVICE SUPPORT UNITS
UNIT TRAINS	IN, AR	
TACTICAL SITE	FA, AD	EN, SC, CM
BDE/DIV SUPPORT AREA		MP, OD, QM, AHS
CORPS/EAC SUPPORT AREA		MM, AG, TR
AIRFIELDS		AV, AL, MI

At each site visited, two major objectives were pursued. First, we wanted to spend time with the combat development, tactical development, and MARC personnel in each school. The morning of each visit day was set aside for this purpose. Second, we wanted to conduct structured group interviews to collect the model input data.

The reason for the morning meetings at each location was twofold. First, we wanted to collect additional information on the current doctrine and tactical content at each school, particularly with regard to how units will be organized, located, and utilized in a European scenario. Second, we wanted to collect information on how MARC analysts and TOE designers actually use nonavailable factors, to be sure that the final products from this project met Army needs.

From our discussions with doctrinal developers, it was clear that recent changes in combat doctrine under AirLand Battle had far less impact on their thinking than did Army of Excellence force structure changes. While AirLand Battle concepts emphasize rear area security and frequent movement of units, these requirements have always been present for the doctrine writers. More pressing concerns seem to be how to organize, locate, and utilize fewer soldiers to still accomplish the mission. Each school seemed to be approaching this problem with one of two strategies. One approach was to find innovative ways to reduce or shift workload. For example, the New Feeding System not only eliminates the need for many cooks, but also for kitchen police (KPs) in the units. Logistical doctrine calls for more local security to be provided by the supported units or military police, such as at ammunition transfer points (ATPs). The second way was to use available resources more efficiently. This usually involved elimination of redundant or duplicative manpower (one driver per truck instead of two) or more intensive use of manpower (two or three units sharing a mess facility on shifts).

Airland Battle concepts were not the primary reason most of these changes in doctrine were being made. In fact, AirLand Battle concepts would sometimes have driven organization, location, and utilization of manpower in a much different direction, according to the doctrine writers.

Our discussions with many MARC analysts and TOE designers showed that they currently have few tools to relate operational capability with reductions in force structure under Army of Excellence. For example, a pre-AOE unit with 120 personnel which required 4.3 hours of daily security time per soldier under MARC would require 5.1 hours per soldier if the unit were pared to 100 soldiers and expected to maintain the same capability. However, we found that TOE designers would continue to use the basic planning factor from AR 570-2 and not make any remark on the TOE about the reduced capability of the unit to provide local security. Anomalies in the MARC process such as the truck driver who must work a 12-hour day and his PAC clerk who must only work an 8.5 hour day seemed to bother the analysts, but as individuals they felt they had no means or responsibility to correct the system.

The afternoon at each location was spent in a group session with selected company grade officers. The criterion for selection was that each officer had held a command position. Each local POC was requested to provide 10-15 such officers for the afternoon session. In actual practice, groups of from 8 to 14 were made available. In some cases, schedule conflicts prevented some officers from attending, but no group was so small that the results from that group were unusable.

The group meetings followed identical formats. First, an introductory briefing on the project and the purpose of the visit and the group meeting was presented. Following this initial 20-30 minute introduction, the officers were given copies of the general scenario to read, along with a specific scenario for a unit in their branch to be examined in more detail. These units were drawn from actual TOEs. Officers were asked to review these general and specific scenarios and units, and the laydown, employment and use of the unit in the scenario were discussed by the group to ensure that everyone had a common understanding.

The next step was to establish minimum and maximum times for each non-available task. Officers were instructed to think about the most time they would possibly have their troops spend at each task and the minimum time they would always require. The specific items in each task were discussed. Group discussion was used to arrive at a consensus on the maximum and minimum times for each task. In the course of the discussion, the session leader would interject to ensure that the officers were considering all of the relevant factors, and that the concept of maximum and minimum were understood.

Once having established maximum and minimum times for each of the non-available tasks, the session turned to the process of drawing utility curves for each task. A utility curve relates the level of relative benefit resulting from a task to the amount of that task performed over and above the minimum. Thus, at the maximum time for a task, 100% of the benefit is achieved, while at the minimum time, 0% of the benefit is achieved. Each officer was given a set of blank grids and asked to sketch in a curve joining the determined endpoints. An example was illustrated by the session leader as a prelude, then the officers drew a utility curve for Personal Needs. Once each officer had completed this initial curve, the group discussed the curves and drew a consensus curve, with the session leader eliciting the benefit points at a number of points on the curve and drawing on an overhead projector. This group curve was altered until the group was satisfied with its general shape, then entered into the computer model by the staff as a mathematical estimate for an exponential curve. The group then repeated the process for the remaining nonavailable tasks.

Next, relative weights for the tasks were elicited from the group. The common perception of a weight is that it answers the question, "How important is task A relative to task B?" Unfortunately, such a measure is unsteady in this and many other cases because it fails to take into account the ranges across which A and B can vary (in this case, the minimum and maximum times). A more pertinent question to ask is "How important is the difference in the range of values for task A versus the difference for task B?" This question includes both the importance of the task as well as the "swing" in the range of times of the tasks.

Relative (swing) weights were elicited from the group by offering them the opportunity to approve or disapprove of the behavior of two hypothetical commanders who chose different time allocations, for example:

	Commander A	Commander B
MOS	100%	90%
Personal Needs	80%	100%

In this example, the officers were asked to choose between a commander who chose to accomplish 100% of his MOS work, but only 80% of his troops' personal needs, as opposed to Commander B who accomplished 90% of his MOS work but 100% of personal needs. Officers were asked which they preferred and why. Then the values were changed to move the group to the point where they thought the two commanders were about equal--an indifference point. The group was led to reach that indifference point through a series of iterations; usually 5 or 6 iterations were required to reach that point. These final values were then entered into the computer model and used to calculate weights. This exercise was then repeated for additional pairs of nonavailable time against MOS time, and a complete set of weights calculated.

The final step in the group sessions was to run the computer model and present the officers with the results of their decisions on the allocations. At the current unit size, the officers were shown the normalized swing weights for each task and the time allocations which resulted. These model outputs were then discussed and the officers were asked to comment on the reality of the outputs. Generally, there were no surprises to the officers when they saw the results, but in some cases, the officers thought the results were too high or too low in some categories. Adjustments were then made to the weights by group consensus and the model was rerun.

DATA ANALYSIS

Sample Input and Output Data

As described in the data collection plan, group interviews at 16 TRADOC schools and AHS were held to collect inputs for use in the Commander's Decision Model. Each of the groups was asked to consider the use of time by soldiers in a specific unit in that branch. The interviewed officers were asked to provide the "minimum required" (MIN) and "maximum useful" (MAX) daily times in hours, the relative weight, and the shape of the benefit curve for each non-MOS (except unit movement) task for the TOE unit. The non-MOS duties were grouped into five non-MOS "tasks:" Personal Needs (PER), Base Security (SEC), Unit Movement (MOV), Training, Maintenance, and Administration (TMA), and Unit Details (DET). The relative weight expresses the combination of two task attributes: the relative importance of the task itself and the relative importance of the difference between the MIN and MAX values. The benefit curves provided by the officers were converted to exponential functions of the form:

$$y = 1 - e^{-ax}$$

where "a" is a coefficient (COEF) which describes the shape of the benefit curve.

In order to calculate minimum and maximum average daily unit movement times, the officers provided the convoy speed, average load/unload times per move, and the range of frequency of movement for the unit. The benefit curve was scaled according to the number of kilometers away from the FLOT the unit would be when it moved.

The daily required MOS workload for the unit was estimated by multiplying the unit's current TOE required strength of non-supervisory enlisted soldiers in the grade E-5 and below by the unit's current daily available factor. These factors are 6.9 hours for Combat units, 7.4 hours for Combat Support units, and 8.5 hours for Combat Service Support units. The shape of the MOS benefit curve was established at its most extreme range (a straight line with a coefficient of .001) in order to calculate the minimum essential manning requirement. That is, it was assumed that each marginal hour of MOS time was equally important as all previous hours up to the unit's maximum time.

The results of the group interviews at the 16 TRADOC Schools and AHS are shown in Appendix C. Times for personal needs, unit movement, and training, maintenance and administration are expressed as "hours per individual," while times for base security, unit details, and MOS workload are in "hours per unit."

In addition to these commanders' inputs, the model requires an estimate of the time that cannot be allocated by the commanders--the average daily "not available for duty" time. This time could include unit losses for KIA, WIA, DNBI, MIA, POW, AWOL and unit sick call.

The Army has developed several sets of casualty factors (see Appendix A). A wide range of assumptions were used in the development of these factors, including assumptions about total medical casualties, total forces in the combat zone, location of medical treatment, number of soldiers returned to duty (RTD), and treatment time for RTD soldiers. Several common assumptions do not make sense when viewed in the context of overall Army policy and doctrine:

- All the studies assumed that there was no replacement "pipeline" that pushes replacements down to the unit level before D-Day with "shelf requisitions" so that units will not lose available time due to medical casualties. Yet, there are plans for such "push packages."
- All the studies held unit vacancies open for recuperating soldiers until they returned to duty--as much as 17 days. Yet, replacement plans call for casualties who require more than 72 hours of medical care to be hospitalized and simply replaced in their unit. RTDs are then sent back to the replacement pool when they are fit for duty and assigned to whatever unit has a requirement for their MOS at that time.
- Gross casualty numbers were not separated by type unit or MOS, so that support functions had the same medical nonavailability factor as the combat functions.

Discussions at the Soldier Support Center led to a conclusion that battle casualty factors should not be included in the MARC basic planning factors. There is absolutely no way to predict if, how, or when a unit will begin to operate at a "steady state" manning level during wartime because the replacement system is not well defined. Commanders will expect that as the criticality of their unit increases (due perhaps to the need to support specific theater operations), the delivery of replacement personnel will also increase to keep them at full strength by compensating for lost personnel. For this reason, it is not necessary to deduct time from daily available hours for personnel who are KIA, WIA, MIA, AWOL on emergency leave or otherwise lost to the commander for long-term medical or similar reasons because dealing with losses is a function of the replacement system.

We must, however, continue to include a factor to account for time lost within a unit due to normal disease and non-battle injuries (DNBI), usually for colds and flu. To get an estimate of what the DNBI factor would be, we used the AHS estimate of total DNBI rate of 30 per 1000 soldiers per day. Historically about 90% of all soldiers reporting for sick call, or 27 per 1000, are not hospitalized, but are treated and allowed to recover in the unit. One quarter of these can be expected to require 2 hours recovery time, and 25% each will require one day, two days, or three days recovery time, for a total of 985.5 hours of duty time lost per 1000 soldiers per day. This means an average of about one hour not available for duty (NAFD) time per soldier per day due primarily to DNBI for which the replacement system does not compensate the unit.

With an estimate of average daily NAFD time, the model inputs were completed. These model inputs were used in the Commander's Decision Model to calculate average daily availability factors (MOS duty) and the resulting nonavailability factors per soldier in hours. These are shown below in Table 7.

Table 7: Data Outputs from the Commander's Decision Model

UNIT	CURRENT SIZE	OPTIMUM SIZE	TUC	ULC	SAMPLE CELL	PER	SEC	MOV	TMA	DET	NAFD	MOS	NON-MOS & NAFD
HC INF BN	70	56	1	1	A	5.0	1.9	4.0	2.2	1.3	1.0	8.6	15.4
HHC TANK BN	48	34	1	1	A	4.0	4.2	2.5	0.0	2.5	1.0	9.7	14.3
LANCE BTRY	30	32	1	2	B	6.2	4.4	2.7	2.0	1.2	1.0	6.5	17.5
HAWK BTRY	61	44	1	2	B	7.2	3.2	2.8	0.1	0.1	1.0	9.6	14.4
NBC CO	17	16	2	1	C	7.0	1.8	3.5	2.7	0.1	1.0	7.9	16.1
HHC SIG BN	66	48	2	1	C	4.0	4.5	3.0	0.1	1.2	1.0	10.2	13.8
HHC ENG BN	104	117	2	1	C	5.7	4.5	3.2	2.0	1.0	1.0	6.6	17.4
S&S CO	158	139	3	1	D	6.4	1.0	4.0	0.4	1.7	1.0	9.7	14.3
HVY MNT CO	143	236	3	1	D	9.5	3.1	4.6	0.1	0.6	1.0	5.1	18.9
HHD MP BN	32	24	2	1	D	4.0	4.5	3.5	1.0	0.1	1.0	9.9	14.1
MED CLEAR CO	65	48	3	1	D	5.3	2.5	2.3	0.1	1.3	1.0	11.5	12.5
MDM TRK CO	27	29	3	2	E	7.1	3.7	0.9	2.2	1.2	1.0	7.9	16.1
AMMN ORD CO	138	73	3	2	E	4.0	0.0	0.0	1.0	1.9	1.0	16.1	7.9
HHC PERS COM	244	128	3	3	E	4.3	0.0	0.0	0.1	2.4	1.0	16.2	7.8
TR AV MNT CO	200	252	3	1	F	6.0	2.9	2.4	3.5	1.5	1.0	6.7	17.3
AVN CO CEWI	68	56	2	2	F	6.0	1.3	3.2	2.0	1.5	1.0	9.0	15.0
CPS AVN CO	122	112	2	2	F	4.4	4.3	3.1	2.2	0.9	1.0	8.1	15.9

The Current Size for each sample is the total nonsupervisory enlisted E-5 and below currently required in the unit. The Optimum Size is the smallest unit size at which the Commander's Decision Model shows that a commander would complete 100 percent of the unit's daily MOS workload. Therefore, optimum size represents the minimum essential manning for each unit. The type unit code, unit location code, sample cell, and estimated times for each non-MOS duty are also shown. The not available for duty (NAFD) time in all cases is one hour (see Appendix A).

Sample Data Analysis

The output values for available times (MOS duties) were plotted according to their sample cell as shown in Figure 5. This scatter plot shows that there appear to be no clear trends in the data when organized by sample cells. The factors were averaged for each sample cell and the standard deviation of each factor was computed as shown in Table 8.

The standard deviations of the resulting available times (measures of the variability or spread in the data) show that the sample cell Unit Trains has the least dispersion while Corps/EAC Support Area has the most

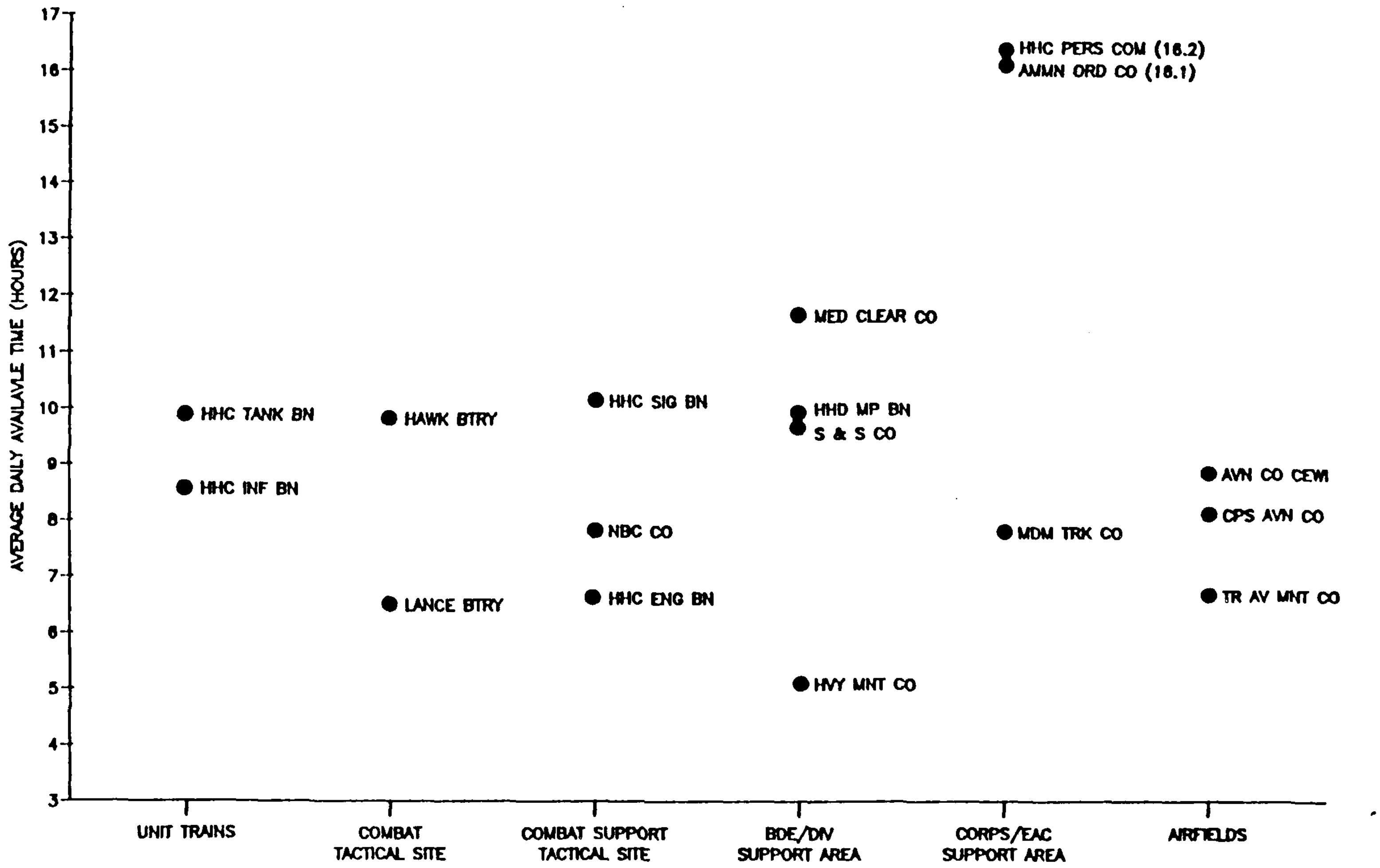


Figure 5: Available Times by Sample Cell

Table 8: Sample Cell Averages and Standard Deviations

UNIT TRAINS

MEMBERS SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
HHC Inf Bn	PER	4.00	4.50	5.00	.71
HHC Tank Bn	SEC	1.90	3.05	4.20	1.63
	MOV	2.50	3.25	4.00	1.06
	TMA	.00	1.10	2.20	1.56
	DET	1.30	1.90	2.50	.85

COMBAT TACTICAL SITE

MEMBERS SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
Hawk Btry	PER	6.20	6.70	7.20	.71
Lance Btry	SEC	3.20	3.80	4.40	.85
	MOV	2.70	2.75	2.80	.07
	TMA	.10	1.05	2.00	1.34
	DET	.10	.65	1.20	.78

COMBAT SUPPORT TACTICAL SITE

MEMBERS SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
HHC Sig Bn	PER	4.00	5.56	7.00	1.50
Nbc Co	SEC	1.80	3.60	4.50	1.56
HHC Eng Bn	MOV	3.00	3.23	3.50	.25
	TMA	.10	1.60	2.70	1.34
	DET	.10	0.77	1.20	.58

BDE/DIV SUPPORT AREA

MEMBERS SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
Med Clear Co	PER	4.00	6.30	9.50	2.35
S & S Co	SEC	1.00	2.77	4.50	1.45
HHD MP Bn	MOV	2.30	3.60	4.60	.98
Hvy Mnt Co	TMA	.10	.40	1.00	.42
	DET	.10	.93	1.70	.71

CORPS/EAC SUPPORT AREA

MEMBERS SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
HHC Pers Com	PER	4.00	5.13	7.10	1.71
Ammn Ord Co	SEC	.00	1.23	3.70	2.14
Mdm Trk Co	MOV	.00	.30	0.90	.52
	TMA	.10	1.10	2.20	1.05
	DET	1.20	1.83	2.40	.60

AIRFIELDS

MEMBERS SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
Avn Co Cewi	PER	4.40	5.47	6.00	.92
Cps Avn Co	SEC	1.30	2.83	4.30	1.50
Tr Av Mnt Co	MOV	2.40	2.90	3.20	.44
	TMA	2.00	2.57	3.50	.81
	DET	.90	1.30	1.50	.35

dispersion. An analysis of variance was used to test whether this within cell variance outweighed the between cell variance. A standard measure of variance between cells is the F-ratio, which is the variance between sample cell means (MSA) divided by the variance within the samples (MSE). Table 9 gives the F-ratio for each of the 5 non-MOS tasks and its corresponding level of significance (P) (probability of rejecting a true hypothesis that the mean non-MOS times for each cell are the same).

Table 9: Analysis of Variance of Sample Cells

TASK	MSA	MSE	F-RATIO	P
PER	1.492	2.693	0.554	0.733
SEC	2.282	2.561	0.891	0.519
MOV	4.420	0.458	9.654	0.001
TMA	1.728	1.085	1.593	0.241
DET	0.737	0.410	1.799	0.194

As the table shows, all the non-MOS tasks except Unit Movement indicate a high probability that, if the sample cells are used to explain the variance in nonavailable time, we will be wrong. Only Unit Movement indicates that the sample cells may correctly explain the variance in nonavailable time.

Since the original sample cells were not a powerful clustering, and in order to determine whether or not the data formed any natural groupings, a "kmeans" cluster analysis was performed using SYSTAT, a statistical software package. Generally, cluster analysis is a multivariate procedure for detecting natural groupings in data. Kmeans clustering divides the samples into a specific number of clusters such that samples within a cluster are closer to one another than the samples in different clusters.

The cluster analysis attempted to find similarities in the Commander's Decision Model output for each unit type based on the estimated time spent on unit movement, base security, personal needs, unit details, and training, maintenance and administration. Table 10 shows the between-cluster (MSA) and within-cluster (MSE) variations of four-, five-, and six-cluster solutions. MSA refers to the sum of squares between the cluster means divided by its degrees of freedom and is a measure of the variability between groups. MSE refers to the sum of squares within the clusters divided by its degrees of freedom and is a measure of the variability within groups. The F-ratio compares the between cluster variation to the within cluster variation. A large F-ratio indicates that cases in different clusters are widely separated, but cases within the same cluster show little variation.

The F-ratios will show which variables are good discriminators of the clusters. A variable with a large F-ratio indicates that the particular variable is a good discriminator of the clusters. For example, in the four-cluster solution, security (SEC) has the highest F-ratio (28.931) indicating that this variable is important in determining the clustering. Training, maintenance, and administration (TMA) is not a discriminator of the group since the F-ratio is .675. From the F-ratios, we can rank the five variables in terms of how important that particular variable is in determining the groupings. Base security is the most important factor, followed by unit movement, personal needs, unit details, and least importantly, training, maintenance, and administration. Unit movement again stands out as a significant discriminator among clusters.

Table 10: Cluster Analysis

Summary Statistics for 4 Clusters

TASK	MSA	MSE	F-RATIO	P
PER	8.623	0.862	9.996	0.001
SEC	11.474	0.082	28.931	0.000
MOV	5.710	0.769	7.417	0.004
TMA	0.924	1.369	0.675	0.583
DET	1.038	0.390	2.659	0.092

Summary Statistics for 5 Clusters

TASK	MSA	MSE	F-RATIO	P
PER	6.953	0.772	9.003	0.001
SEC	9.165	0.243	37.736	0.000
MOV	5.697	0.362	15.724	0.000
TMA	1.761	1.127	1.563	0.247
DET	0.629	0.473	1.329	0.315

Summary Statistics for 6 Clusters

TASK	MSA	MSE	F-RATIO	P
PER	6.179	0.562	10.987	0.001
SEC	7.332	0.265	27.673	0.000
MOV	4.558	0.395	11.531	0.000
TMA	2.276	0.835	2.724	0.077
DET	0.519	0.508	1.021	0.451

The variation between the clusters increases as the number of clusters increases. The variation within a cluster decreases as the number of clusters increases. From this general observation, it may seem that the 6-cluster solution is better than either the four- or five-cluster solution, since it has the lowest within-cluster variation and highest between-cluster variation. However, further examination of the five- and six-cluster solutions showed that they included a cluster containing only one unit, which would account for the apparently better fit (HVY MNT CO was in its own cluster in both the 5- and 6-cluster solutions). Further, it did not seem reasonable that this unit was so different that it shared nothing in common with any of the other 16 units examined. Because the 5- and 6-cluster solutions failed the "reasonableness" test, the 4-cluster solution was selected as the best natural grouping of the data. It seemed to maximize between-cluster variation, minimize within-cluster variation, and produce a reasonable natural grouping of the 17 unit types. The resulting clusters are illustrated in Table 11.

Comparing the mean times for the five variables (PER, SEC, MOV, TMA, DET) in each group against the overall means illustrates the distinctive characteristics of these 4 clusters:

- *CLUSTER 1 - AMMN ORD CO, HHC PERS COM.* Basically, very low security and very low movement makes this cluster distinctive. As seen from the statistics for cluster 1, there is no time allocated

Table 11: Best Natural Clustering of Sample Data

CLUSTER NUMBER: 1

MEMBERS		STATISTICS			
SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
AMMN ORD CO	PER	4.00	4.15	4.30	.15
HHC PERS COM	SEC	.00	.00	.00	.00
	MOV	.00	.00	.00	.00
	TMA	.10	.55	1.00	.45
	DET	1.90	2.15	2.40	.25

CLUSTER NUMBER: 2

MEMBERS		STATISTICS			
SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
HHC INF BN	PER	5.00	5.68	6.40	.55
S & S CO	SEC	1.00	1.68	2.50	.58
MED CLEAR CO	MOV	2.30	3.38	4.00	.70
AVN CO CEWI	TMA	.10	1.18	2.20	.93
	DET	1.30	1.45	1.70	.17

CLUSTER NUMBER: 3

MEMBERS		STATISTICS			
SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
HHC TANK BN	PER	4.00	4.42	5.70	.66
HHC SIG BN	SEC	4.20	4.40	4.50	.13
HHC ENG BN	MOV	2.50	3.06	3.50	.33
HHD MP BN	TMA	.00	1.06	2.20	.92
CPS AVN CO	DET	.10	1.14	2.50	.78

CLUSTER NUMBER: 4

MEMBERS		STATISTICS			
SAMPLE	VARIABLE	MINIMUM	MEAN	MAXIMUM	ST.DEV.
LANCE BTRY	PER	6.00	7.17	9.50	1.14
HAWK BTRY	SEC	1.80	3.18	4.40	.79
NBC CO	MOV	.90	2.82	4.60	1.12
HVY MNT CO	TMA	.10	1.77	3.50	1.27
MDM TRK CO	DET	.10	.78	1.50	.55
TR AV MNT CO					

for either security or movement. On the average, 2.68 hours were allocated for movement and 2.81 hours allocated for security.

- *CLUSTER 2 - HHC INF BN, S&S CO, MED CLEAR CO, AVN CO CEWI.* This cluster is basically characterized by high movement. For all 17 units, the average movement time was 2.68 hours, but for this particular cluster, average movement time was 3.38 hours. The medical unit shows an average movement time but was probably brought into this cluster by the relatively low security time. The overall average for security was 2.81 hours, but the cluster average for security was 1.68 hours.
- *CLUSTER 3 - HHC TANK BN, HHC SIG BN, HHC ENG BN, HHD MP BN, CPS AVN CO.* Generally, this cluster seems to be characterized by high security. The overall average was 2.81 hours, while the average for the cluster was 4.40. This cluster showed slightly higher movement time; the overall average was 2.68 and the cluster average was 3.06.
- *CLUSTER 4 - LANCE BTRY, HAWK BTRY, NBC CO, HVY MNT CO, MDM TRK CO, TR AV MNT CO.* This group is characterized by the high personal needs. The overall personal needs average from the 17 units was 5.65 while this group had an average of 7.17 hours allocated. This cluster seems to consist of units whose work has high physical demands. Because of high physical demands, this cluster may require more sleep in order to perform its MOS duties in a wartime scenario.

These results indicate that units can be grouped by their needs rather than by their base configuration on the battlefield (see Figure 6). The cluster analysis suggests that the units can be divided *into four classes:* high security, high movement, low movement/low security, and high physical demands (high personal needs).

There are many other tests of within-cell variance which may be performed, including estimates of coefficient of skewness, coefficient of kurtosis, median, minimum, maximum, range, and some distribution-free tolerance limits. Other between-cell comparative tests could be performed as well. However, because of the relatively simple composition of the sample cells, there is no need to perform these more complex tests on the sample data. The results of the statistical analysis indicate that there is little reason to keep the original sample cell matrix. They also indicate that the natural groupings of the data generally reflect the fact that security and movement are primary tasks which differentiate unit categories.

<u>Presentation of Data Results</u>

We examined three alternative ways to interpret and present the model output data: as a single availability factor for all units, as a matrix of availability factors similar to the LOGCEN matrix, and as an expanded set of 180 availability factors as now mandated by AR 570-2. Each of these alternatives has advantages and disadvantages.

Single Availability Factor. The model output data were first arrayed from lowest available time to highest available time, and the standard deviation was calculated. This is displayed in Figure 7:

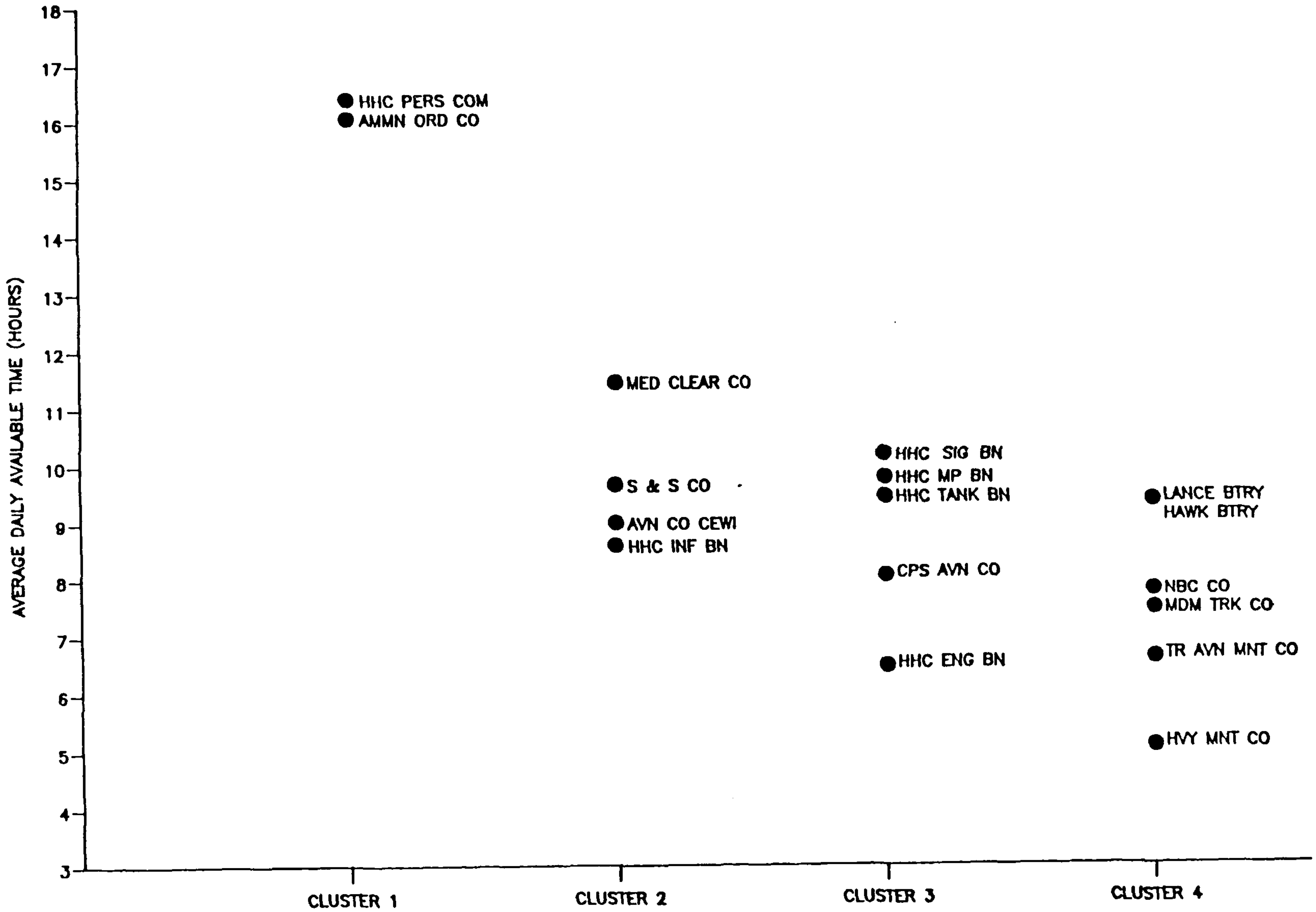


Figure 6: Unit Available Times by Best Natural Clusters

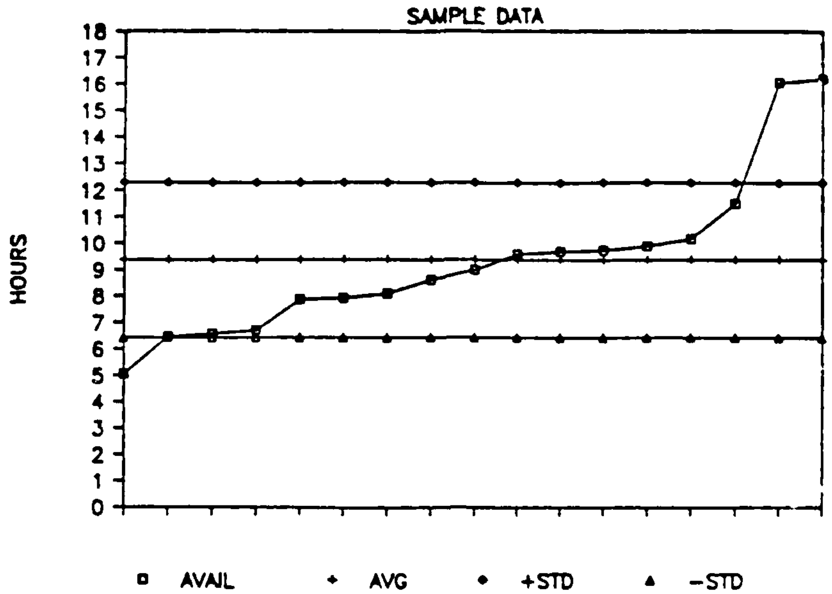


Figure 7: Daily Available Times

The graph shows that the average for all samples is 9.3 hours. Moreover, fourteen of the samples lie within one standard deviation of the mean. This would indicate that a single availability factor of about 9 hours could be used with good confidence. This would have several advantages:

1. As a planning factor, the 9-hour availability factor would reflect a reasonable estimate based on sound doctrine which is easy for Army policy makers to understand and justify.
2. The use of a single factor would be consistent with the other Services. The Air Force uses a doctrinal 12-hour workday with 12 hours per day "nonavailable," regardless of type of unit or location. The Navy uses a doctrinal 10.5 hour workday for watchstanders and 9.4 hours per day for non-watchstanders. Only the Army has keyed available time to the battlefield location and type of unit.
3. One number would be easy for TOE developers to use and would provide a consistent planning factor for all Army units regardless of mission area.

The disadvantages are that a single availability factor may not be as efficient as using a separate factor for different kinds of units in different locations and that it would not make use of the MARC Codes currently being developed for each TOE.

Nine-Cell Matrix. The second alternative was to develop a small matrix of available factors based on the unit category and logical region. This was the approach used in the LOGCEN study which resulted in 9 different factors. This current study collected data in seven of the nine cells used by the LOGCEN.

This nine-cell matrix of availability factors is shown in Table 12. The table also shows the non-MOS task times and the not-available-for-duty time as calculated by averaging output from the Commander's Decision Model. Because there were no samples of TUC1 or TUC2 units in the EAC area, these cells use the same data as TUC1 and TUC2 units in the corps area. The data for TUC3 units in the EAC area were combined with TUC3 units in the corps area to derive a single set of factors for both areas.

Table 12: Nine-Cell Matrix of Availability Factors

TUC/ULC	PER	SEC	MOV	TMA	DET	NAFD	MOS	NON-MOS & NAFD
1/1	4.5	3.1	3.2	1.1	1.9	1.0	9.2	14.8
1/2	6.7	3.8	2.8	1.1	0.7	1.0	8.0	16.0
1/3	6.7	3.8	2.8	1.1	0.7	1.0	8.0	16.0
2/1	5.2	3.8	3.3	1.4	0.6	1.0	8.6	15.4
2/2	5.2	2.8	3.1	2.1	1.2	1.0	8.6	15.4
2/3	5.2	2.8	3.1	2.1	1.2	1.0	8.6	15.4
3/1	6.8	2.4	3.3	1.0	1.3	1.0	8.2	15.8
3/2	5.1	1.2	0.3	1.1	1.8	1.0	13.4	10.6
3/3	5.1	1.2	0.3	1.1	1.8	1.0	13.4	10.6

The availability and nonavailability factors are displayed, along with the results of the 1983 LOGCEN study (as updated in 1984), in Figures 8 and 9. The LOGCEN factors include 2.3 hours of indirect productive time currently used only for maintenance MARC. Notice that the LOGCEN found available time by simply subtracting the nonavailability factors from a 24-hour day. Whatever time remained was available for MOS work. The Commander's Decision Model, on the other hand, considers the importance of the MOS functional tasks as well as the non-MOS tasks and determines the best balance between them all.

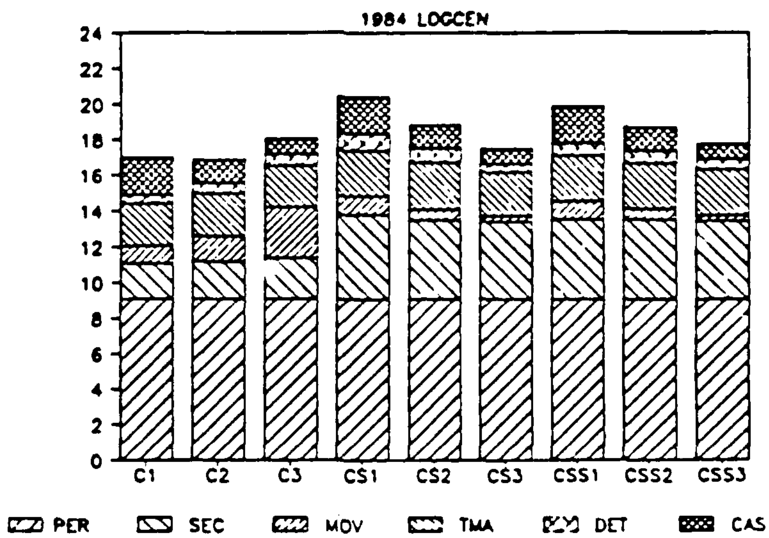


Figure 8: Nonavailability Factors from LOGCEN Study

The advantages of this grouping of the data are that it corresponds to the commonly understood separations between different types of units, yet

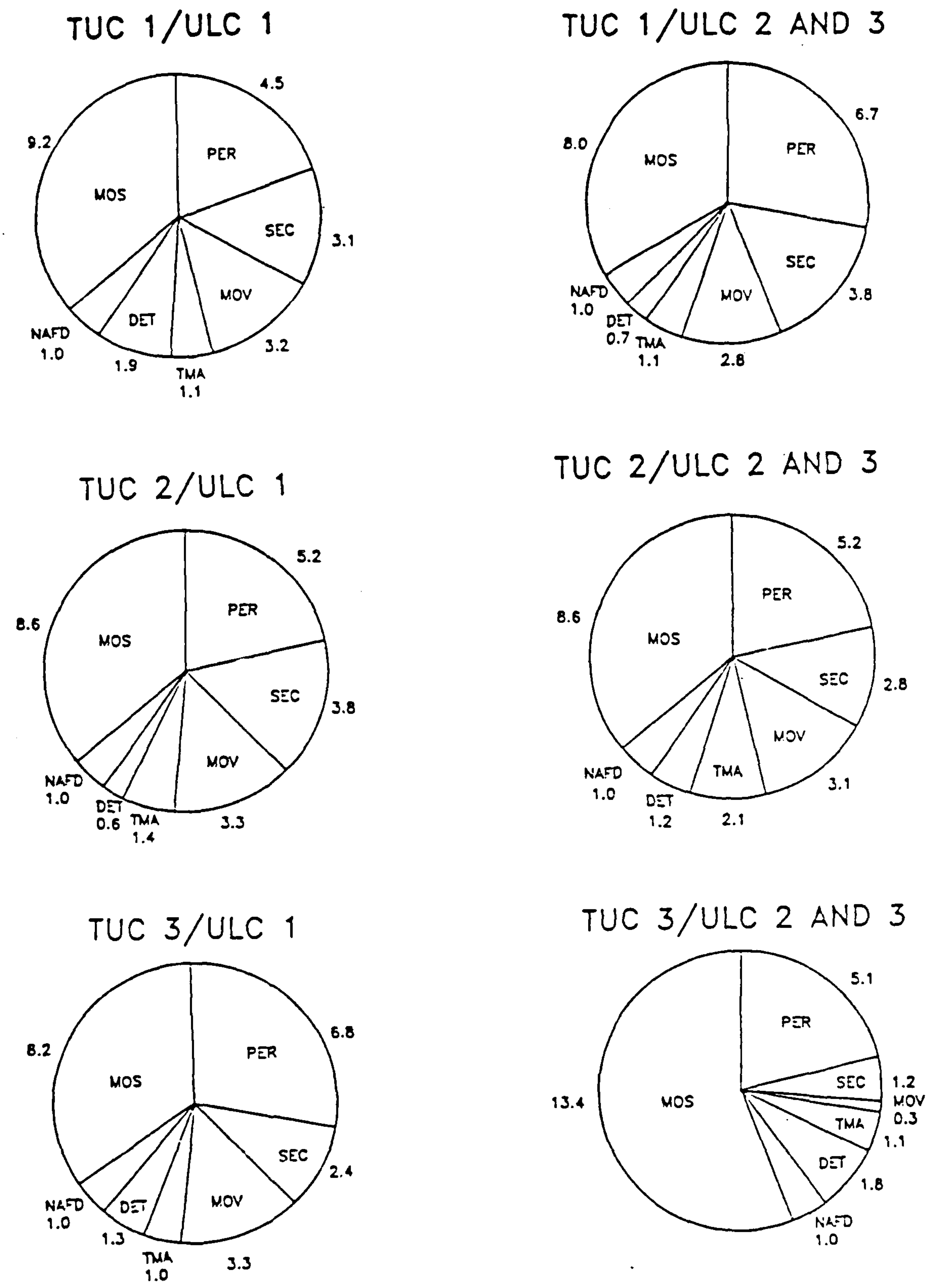


Figure 9: Nonavailability Factors from DSC Study

it forms a sufficiently small set of factors to be manageable. The major disadvantage is that it does not allow doctrinal variations of movement and security factors using the MARC codes.

180 Expanded Factors. The third alternative was to expand the data to 180 factors, as was done to the results of the LOGCEN study by using the MARC codes. This was accomplished by averaging the model input data for each of the nine cells described above and then varying the security requirements in four ways and the movement requirements in five ways.

The base security requirements assume four base configurations, according to AR 570-2: (A) single unit base, (B) 2-3 unit base, (C) four unit base, and (D) no security requirement. The average daily base security minimum and maximum times for each of the nine cells were, therefore, divided by 1, 2.5, and 4 to derive inputs for the first three configurations and were set at 0 for the fourth. These parametric variations assume that the base perimeter remains relatively constant for up to four units located within it.

We found that doctrinal experts believe that a unit at a 2-, 3-, and 4-unit base requires essentially the same basic daily security requirements as a unit on a 1-unit base. The advantage of bases and base clusters comes from coordinated base defense efforts in case of an attack, which must be understood as being different from a unit's daily security requirements.

Tactical bases in AirLand Battle Doctrine do not resemble "fire bases" used in Vietnam. There, many units "colocated" and built a semi-permanent defensive perimeter for which all units helped provide daily guards under control of a single commander. In AirLand Battle Doctrine, each unit maintains its own unit area and unit integrity, and daily security requirements remain nearly the same regardless of how many units are "colocated" near each other. Tactical units move often under AirLand Battle Doctrine so they do not build a semi-permanent perimeter. Therefore, the expanded security factors assume that a "base" implies a semi-permanent perimeter within which 1, 2, 3, or 4 units may be placed and may contribute to a partial share of daily guard duty. If a "base" is assumed to be configured as in AirLand Battle Doctrine, then Security Factor A should be used regardless of the number of colocated units.

The unit movement factors for the nine cells were varied for five frequency-of-movement ranges as shown in AR 570-2: (A) 12 hours/move to 3 days/move; (B) 4-7 days/move; (C) 8-17 days/move; (D) 18-39 days/move; and (E) no movement. Unit load and unload times per move remained unchanged. However, distance per move varied because the model assumed a flot movement rate of 10 kilometers/day. The fewer moves that a unit makes, the longer the distance it must travel on each move. The results of these parametric variations of the sample input data are shown in Appendix C (Table C-2).

The outputs of the Commander's Decision Model for the 180 unit variations are shown in Appendix C (Table C-3). The model shows that by reducing the security and movement requirements of a unit, the commander will: (a) require fewer soldiers to accomplish all MOS workload; (b) allow soldiers to perform more of other non-MOS tasks; and (c) increase the average daily available time per soldier. The magnitude of these changes depends upon the commander's estimate of the relative value of each task. Appendix Table C-4 compares the available times from the Commander's Decision Model with the current MARC factors. For each unit, the current MARC daily available time for non-maintenance positions is shown in the first column, the current MARC available time for maintenance positions is shown in the second column, and the results of the Commander's Decision Model are shown in the third column.

FINDINGS AND CONCLUSIONS

Findings

The Commander's Decision Model calculates the relative importance of various combat tasks and then fits the most important tasks into the 24-hour combat duty day. The results of the model runs are shown in the preceding section. However, the output of the model is a reflection of the assumptions, values and judgments that were entered into the model by the interviewed officers. During the course of the study, we gained many insights into these assumptions, values, and judgments.

The current Army resource planning factors call for the creation of units with capability to fight an extended war with no replacement by fresh units. Replacement of individuals within the units will only occur as they become casualties. This concept implies that unit commanders should be trained to sustain their units for long periods of time by "pacing" the units' operations, weighting activities such as training and operator maintenance, and providing for high levels of daily sleep. We found, however, that company-grade officers are training to conduct war "all out" every day. Their philosophy is that one cannot fight the war tomorrow unless one wins today's battle. Doctrinal publications, training exercises, and computer simulation models reinforce this philosophy that any war in Europe will not last beyond a month or two, so that unit sustainment activities may be given low priority. This means that units developed under minimum essential manning standards will tend to "burn out" if the war extends six months or longer and before replacement units are trained and equipped to assume responsibility for the battle.

The company grade officers generally believed that the threat in the rear areas of the battlefield would require them to maintain a large daily security force at trains areas and other support areas. This force would consume up to one-third of the daily manhours in the unit. The threat was viewed as coming from terrorist-type agents, Spetznaz, and Operational Maneuver Groups (OMGs). Many experienced field grade officers generally believed that the threat to the rear areas would require much less local security on a daily basis. Their view holds that a minimum set of early warning posts is all that units in the rear area require on a daily basis. When an actual attack occurs, then all other activities stop and all personnel take up their fighting positions. Part of the problem seemed to be a different emphasis on the risks and probabilities involved. The junior officers focused on reducing the risk to themselves and their units if they were attacked, while the senior officers focused on the relatively low probability of any single support unit being targeted by the limited threat rear battle forces. If the senior officers' risk assessment is more reflective of Army policy, then the junior officers' view of the nature of the threat may have led many to overestimate daily security requirements.

The eight-hour minimum direct MOS work, as directed by the MARC General Officer Steering Group in December 1985, is not an unrealistic planning factor. It is possible to reduce unit size of many units in accordance with AOE force structure goals and increase the average direct MOS work per soldier. If differentiation between types of units is desired, it is clear that combat units and some combat support units must perform more non-MOS duties per soldier than combat service support and some combat support units. Generally, this study found available factors that were comparable to the factors in the previous LOGCEN study for combat units, up to 3 hours greater for combat support units, and up to 6 hours greater for some rear area combat service support units.

It must be emphasized that these increased available times entail a higher risk of catastrophic failure of units during combat because they will cause design of units at minimum essential manning levels based on daily average requirements. Units designed to meet average demands may break under pressure during peak demand periods.

Conclusions

Army Planning Scenario. The "steady state" war is a myth. Rather, the task demands/workloads of units will vary considerably, peaking at different phases of the war. However, the total time spent on non-MOS duties may only vary by several hours, even though time spent on specific non-MOS tasks may vary considerably. For instance, movement and security tasks may predominate during the early retrograde phase of the war at the expense of sleep and other personal needs. As fatigue and attrition settle in on the opposing forces, units may become less mobile and require more time for personal needs. Thus, while the requirement was to develop planning factors for a "steady state" phase of a war, judgments based on the early (and conceivable) phases of a war are sufficient and acceptable.

Non-MOS Tasks (General). Four general statements about the relationship of non-MOS tasks to different types of units across the battlefield follow:

1. Unit movement and base security tasks are allocated more time per soldier in all types of units operating in the division area than in units operating to the rear. This is the same conclusion reached in the LOGCEN study. The introduction of AirLand Battle doctrine does not seem to have significantly affected the way commanders view their day-to-day operations in the rear areas.
2. Within the division area, combat support unit (TUC2) commanders generally allocate more time per soldier for unit movement and base security than combat unit (TUC1) commanders. This also confirms the findings of the LOGCEN study. The higher unit movement reflects a combination of the higher frequency of movement for some support units and the longer load and unload times for other support units. The higher base security reflects the greater battlefield signature and isolation in the face of the threat perceived by many combat support unit commanders.
3. Units with very high unit movement and base security generally tend to be combat units (TUC1) which employ indirect fire systems, such as missile and cannon units, and support units in the division area.
4. Contrary to the results of fatigue experiments, commanders of

units with high densities of mechanics and other manual labor functions perceived a requirement for more sleep and rest, regardless of location on the battlefield. These units are generally TUC2 and TUC3 support units.

Personal Needs. Undoubtedly, the greatest personal need on the battlefield is for sleep and rest. The amount of sleep soldiers need and the amount they are likely to get in combat are critical, yet controversial, subjects throughout the Army. Sleep and personal needs seems low when compared to previous estimates. The AR 570-2 factors from 1969 gave a soldier 12 hours off from the duty day, while the LOGCEN study and current factors give soldiers 7 hours of sleep alone. Yet, company-level commanders are convinced that there will be little time to sleep and rest during the time that a unit is engaged in combat activities. They seem to believe FM 22-9, *Soldier Performance in Continuous Operations*, which says that "complete recovery" can occur with "12 hours sleep-rest after 36-48 hours of complete sleep loss with light to moderate workload." This gives an average of 4.8 to 6 hours sleep per day for continuous operations.

Base Security. As noted in the study findings, there seems to be no consensus within the Army about units' security requirements. The interviews conducted by the LOGCEN found between 3.72 and 10.06 hours per soldier per day devoted to base security. Group panels conducted later by the LOGCEN gave combat units 1.73 hours and CS/CSS units 4.27 hours per soldier for security. Those group panels, however, were based on discussions with a total of 6 company grade officers. The Commander's Decision Model outputs were based on the judgments of many company grade officers representing all branches in the Army. Moreover, the *Commander's Decision Model* allows other assumptions about security requirements to be tested (such as the judgments of field grade or general officers) and the results compared with the current results. The most important difference, however, between the LOGCEN methodology and the Commander's Decision Model is that the LOGCEN estimates are based on the judgments of officers who were asked to provide their desired level of security, independent of the resources available (unit size) and of other required tasks (e.g., MOS workload). The Commander's Decision Model corrects this deficiency and, therefore, provides results which have much greater face validity.

Unit Movement. The difficulty of providing estimates of average daily movement factors was recognized by the LOGCEN in the 1982 study. The LOGCEN decided to use a map analysis of the SCORES wargames conducted at the Combined Arms Center, Ft. Leavenworth, KS. The wargames, however, are based on specific assumptions about the rate of change of the battle lines. Moreover, the wargames do not include dynamic "play" of combat service support units. While the Commander's Decision Model also requires an assumption about the rate of change of the forward line of troops (FLOT), the assumption may be varied easily to test for availability factors under different scenarios. Movement factors for combat service support units may be calculated as easily as for other units. The generally higher movement factors found using the Commander's Decision Model are due to a slightly faster pace of battle (10 km/day average FLOT movement vs. LOGCEN 8.36 km/day), higher load/unload times provided by the most recently interviewed commanders, and slower average rates of movement across the battlefield provided by commanders (between 10 and 30 km/hr vs. 40 km/hr used by the

LOGCEN). The validity of the unit movement factors is highly dependent on the scenario that was chosen; however, the Commander's Decision Model can easily accommodate different assumptions by future Army decision makers.

Indirect Productive Time. The study of indirect productive time led to the conclusion that variable workload indirect productive time should be placed in the numerator of the MARC equation. The LOGCEN study showed the impossibility of trying to estimate a nonavailability factor for a workload variable task. These workload variable tasks include stock fetch (DX, PLL, ASL), tool fetch, special equipment operations, and in/out processing of damaged/repaired equipment. These tasks are all associated with a direct maintenance action and may be estimated during sample data collection (SDC) efforts now underway. The "overhead" indirect productive time, however, is nothing more than another non-MOS task and should be included in the denominator of the MARC equation. These activities have been included in this current study under the task, "Training, Maintenance and Administration." These activities include salvage and cannibalization of usable equipment and repair parts, shop/work area cleaning, tool/shop set cleaning and maintenance administration (publications, forms, inventories, logbooks).

APPENDIX A: BACKGROUND FACTORS AND LITERATURE REVIEW

Review of the 1983 U.S. Army Logistics Center Study

We started by reviewing the survey design and study methodology used in the U.S. Army Logistics Center (LOGCEN) study entitled "Manpower Non-availability Factors" (September 1983) to identify its strengths and weaknesses. The General Accounting Office had reviewed the study in 1984 and found that the data and analysis "may not be valid or reliable for use." The GAO had three specific criticisms of the study. First, the survey questionnaire approach was criticized as being too costly to use on a continuous basis for updating the factors. Since each MARC will be updated every three years, GAO felt that the nonavailability factors should be updated at least as often. The questionnaires could not be revised without revalidating them and could not be implemented without trained interviewers. Second, the estimates of unit movement times were based on SCORES wargame simulations which take up to a year to generate 30 days of simulated combat and which do not include combat service support units and units at echelons above corps.

Finally, the GAO questioned the definition and validity of indirect time data. Unit-related indirect time was collected as if it were another nonavailability factor which was only identified for maintenance functions. Indirect time for other functions was not considered. Task-related indirect time was not well-defined, leading to the conclusion that the reliability of these times was low.

Our own review found additional problems with the study. Most significantly, the structured interview document for the field survey did not require the unit commanders and first sergeants to weigh the importance of nonavailable tasks against the importance of MOS productive tasks. They were not asked how much time they would spend on MOS tasks; rather, time spent on MOS tasks was assumed to be whatever was left over after performance of all nonavailable tasks. This may have resulted in overestimation of the nonavailability factors. In fact, our informal discussions with field grade officers have shown that some commanders expect to work soldiers up to twelve hours per day on MOS-related tasks. Clearly, these commanders will have to weigh the importance of MOS and nonavailable tasks against each other in order to determine the time allocated to each one. This problem is related to the lack of control for several critical parameters including unit size and the mix of combat and support personnel. While some nonavailable tasks are only loosely related to unit size and mix (e.g., personal hygiene), others may be highly dependent upon these characteristics.

Second, the LOGCEN estimated unit movement factors from an analysis of the map overlays used in TRADOC's SCORES (Scenario Oriented Recurring Evaluation System), Europe III, Sequence 2a. The analysis made several major assumptions, including the estimation of combat unit movement based on the daily FEBA trace and unit movement speeds of 40 kilometers per hour. The main problem with the use of SCORES to determine movement factors is that SCORES does not simulate combat support and combat service support units at the theater level or combat units at corps or theater. Thus, data for four out of nine "cells" were not available. In addition, SCORES does not differentiate between most CS and CSS units. Even if use of the SCORES map overlays provided reasonable estimates of some headquarters-directed, or mandatory, movement factors, the methodology does not allow for estimation of the commander-initiated, or discretionary, movement.

Third, the LOGCEN discarded the unit security factors derived from the field survey and conducted officer and NCO panels to develop new factors reached by panel consensus. Then the LOGCEN discarded the NCO panel results and used the officer panel results solely. The average security factors reported from the field survey and the officer panels are shown below in hours per soldier per day:

Unit Location	Combat	Combat Support	Combat Service Support
Division	6.57	3.72	4.61
Corps Rear	8.20	7.31	7.72
COMMZ	10.06	5.63	6.61
Panels	1.73	4.27	4.27

Notice that the panels discounted location on the battlefield as a significant factor in security. The security factor for combat units was four to six times greater in the field surveys than in the panels. The factors for CS and CSS units was only slightly greater in the field surveys.

Finally, the LOGCEN study determined that an "interim" figure of 2.3 hours should be used to estimate indirect productive time for maintenance functions. This time was to be subtracted from the denominator in the MARC equation and was treated as an additional nonavailable task for mechanics. This represented a methodological change from previous calculations of required manpower.

The indirect productive factor in the 1969 MACRIT equatio. was a forty percent "inflation factor" in the numerator and thus, was a "variable cost of doing business." The LOGCEN study treats indirect productive time as a "fixed cost of doing business" which does not vary with the workload. Our discussions with field grade officers supports the "fixed cost" method for most indirect tasks which implies that unit-related indirect productive time is nothing other than a nonavailable task. Task-related indirect productive tasks vary with the functional workload and may be estimated at the time the MARC functional workload is estimated.

The LOGCEN study collected times for seventeen other nonavailability factors which were added together as if each task was performed sequentially. Many of the tasks were reported as taking an average of less than five minutes per day. While it is clear that many tasks will be performed infrequently or can be performed in less than five minutes, we doubt the validity of trying to estimate nonavailability factors at such a detailed level.

Army Planning Models and Scenarios

Many of the inputs for the Army manpower requirements process are derived from computer simulation models which are used to determine the force structure against which units are designed. Therefore, one of our areas of concern was to gain a better understanding of the planning models and scenario assumptions currently used by the Army. The results of that review, based upon interviews with staff at DCSOPS at the Pentagon, at the Concept Analysis Agency (CAA) and at the Combined Armed Center (CAC) at Fort Leavenworth, Kansas, are summarized below. More details on these interviews were presented in our earlier interim report, dated January 1986.

The LOGCEN study typified the difficulty of determining a standard Army planning scenario For example, respondents were verbally instructed that the timeframe of the scenario was D+180 to D+270--a steady-state war--and that nuclear and chemical weapons had not been used. Yet the written guide for the interviewer stated that "When the initial attack begins to stall, the Warsaw Pact will quickly transition to chemical warfare to maintain the momentum of the attack." Such problems arise from trying to combine assumptions from the multitude of Army simulation models.

DCSOPS, in conjunction with CAA, is responsible for Army modeling of combat, particularly the OMNIBUS process, which is based on the current force structure, and Total Army Analysis (TAA), which is based on the force structure expected at the end of the current POM period. OMNIBUS is now based on the new FORCEM (Force Evaluation Model) which was first used for the OMNIBUS 85 as a replacement for an earlier model, CEM (Concepts Evaluation Model), but has not yet been used for a TAA because it still has a number of problems which CAA is attempting to fix. These models are low-resolution, theater-level, force-on-force simulations which do not maneuver units on a terrain map, but rather exchange firepower until one side is decimated.

In these models, the algorithms are such that equipment always attrits faster than personnel, leading one to believe that there will be different "peaks and valleys" in workloads for different kinds of support units as the scenario wears on. FORCEM will actually include some aspects of Air-Land Battle, but will not include deep interdiction. It will have some rear battle engagements and attrition and some air attacks in the rear area.

FASTALS is another model used by resource planners. FASTALS receives outputs from a combat simulation model (Concepts Evaluation Model or Force Evaluation Model) and develops the time-phased, logistical force requirements necessary to support the designated combat force in a specific theater of operations.

The FASTALS Model is used in Army force planning studies that address current, program and mid-range force structure analyses. Major studies supported include the U.S. Army Operational Readiness Analysis (OMNIBUS), Total Army Analysis (TAA), and Joint Program Assessment Memorandum (JPAM).

Since its development, modifications and upgrades have been made to keep the model's computational logic consistent with evolving logistical support doctrine. The initial design and subsequent modifications were accomplished prior to the emergence of structured programming techniques; hence, the model is complex and difficult to maintain in accordance with emerging concepts in force development.

CEM, FORCEM, and FASTALS are all based on the Army Force Planning Data and Assumptions (AFPDA) Handbook which describes classified generalizations about the scenario. None of this information was of use to us in determining nonavailable time because it is vague enough to allow any conclusions to be drawn about scenario timeframe, tactical operations, and combat intensity that one desires.

Finally, we reviewed the Scenario Oriented Recurring Evaluation System (SCORES) models used by the Combined Arms Operations Research Activity (CAORA) at Ft. Leavenworth, Kansas. SCORES is actually a term for the process of defining the mobilization period (Road to War), the threat and the "blue" order of battle at the Corps level and below, and running several simulations (JIFFY, CORDIVEM, and DIME) to get a baseline out to several weeks after D-Day for use by combat developers.

JIFFY is the oldest model and has been used for all SCORES reports to date. It does not play logistics and is unconstrained by resources. CORDIVEM is under development but will play corps logistics, casualties, transportation, and host nation support. It currently plays a 1986 AOE force against the projected 1990-1992 Soviet threat. DIME (Division Integrative Model Evaluation) is a very simple, low resolution model for quick responses.

While SCORES Sequence Europe III2A played out 30 days of combat, the more recent Europe V played only 10 days and Europe VI will play only 5 days. Europe VI should be available by spring of 1987. Thus, SCORES modeling is intended to replicate intensive combat for weapons system developers, not to provide workloads and soldiers tasks for the manpower determination process out to six months of war.

None of the current resource planning models provided the level of detail needed for establishing the study parameters. We, therefore, turned to the training community and the TRADOC Common Teaching Scenario for our assumptions and scenarios. This scenario, provided in the section on model design, was found to be accepted throughout TRADOC and provided a simple, yet complete basis for the conduct of the study.

Casualties and Replacements

The LOGCEN study calculated three different nonavailability factors for medical reasons which corresponded to the three Logical Regions of the battlefield. These factors were derived from an Academy of Health Sciences (AHS) study, "Nonavailability Time (NAT) Factor for Medical Reasons (August 1981)" included as Appendix I to the LOGCEN study. The AHS factors were corrected twice: once to eliminate an arithmetic error in the calculation of the time lost for evacuated medical casualties, and again in an attempt to correct for "double accounting." The LOGCEN study factors were to replace the single "casualty" factor used in the 1969 edition of AR 570-2. However, in May 1985, the Operations Analysis Office at AHS recalculated the medical factors based on new assumptions and recommended that they be used in place of the LOGCEN factors.

The five sets of factors are shown below:

Medical Nonavailability Factors (hours/person/day)

	Division	Corps Rear	EAC
AR 570-2 (1969)	.36	.36	.36
AHS (1981)	2.47	2.18	1.21
LOGCEN (1983)	2.83	1.76	1.21
LOGCEN (1984)	2.01	1.25	.86
AHS (1985)	.85	.85	.40

The AR 570-2 (1969) factor was 3% of a 12-hour workday. The audit trail for this factor has been lost, but the 1981 AHS study assumes it was based upon one hour of sick call plus one day of rest per soldier per month, which would be an average of 7% of each 24-hour day.

The AHS (1981) study and the LOGCEN (1983) study are identical in assumptions and methodology with the LOGCEN study deriving the mathematically correct factors. The LOGCEN (1984) factors were derived by dividing the same number of total medical nonavailable hours across a larger assumed population.

Since there seemed to be a wide range of assumptions used in these studies, we conducted a comparative analysis between the 1983 LOGCEN study and the 1985 AHS study to highlight some of the reasons for the great difference in the medical nonavailability factors. There are five fundamental differences between the two studies. To illustrate the differences, we have used the AHS method of combining the division and corps rear areas into a single "combat zone."

- *Total Medical Casualties.* LOGCEN used a scenario based upon the Total Army Analysis 1987 (TAA-87) and averaged the daily casualties for the first ten days of combat (D-Day through D+9). AHS used a scenario based upon the TAA-90 and averaged the daily casualties for the first 30 days of combat (D-Day through D+29). Because of these differences, average daily casualties in the combat zone were much greater in the LOGCEN study (1444) than in the AHS study (703).
- *Total Forces in the Combat Zone.* LOGCEN assumed that there were 20,000 soldiers working in the division area and 17,200 soldiers in the corps rear for a total of 37,200 personnel. AHS assumed

that there were 47,000 total personnel in the combat zone. This difference allowed AHS to divide medical nonavailable time over a greater population, reducing average medical nonavailability factors.

- *Location of Medical Treatment*. LOGCEN calculated its factors based upon 52 percent of casualties being treated and returned to duty at the division clearing station or below. AHS assumed that 63 percent could be treated at this level. Nonavailable time increases greatly as a patient is moved to a hospital in the corps or theater areas.
- *Soldiers Returned to Duty*. LOGCEN found that 65 percent of medical casualties could be returned to duty after treatment. AHS was able to return 74 percent to duty. Because time lost to a soldier who is returned to duty (RTD) is much less than time lost when a soldier is evacuated (replacement takes 72 hours in both studies), AHS was able to save considerable nonavailable time.
- *Treatment Time for RTD Soldiers*. LOGCEN assumed that the average treatment time for soldiers who would be returned to duty was 53.9 hours, while AHS assumed the average treatment time was only 51.7 hours. Thus, not only did AHS return more soldiers to duty, but it also was able to treat them faster for additional savings of medical nonavailable time.

The reasons for these different assumptions about the scenario and the ability of the medical system to treat patients is because there are no definitive historical or analytical data to draw upon. The casualty estimation process begins with the Defense Guidance from OSD that is used in the *OMNIBUS* and *TAA* processes. *Casualties are estimated in both cases* by a series of computer models. These models make a number of assumptions and use some analytic shortcuts which impact the calculation of nonavailable time. Specifically:

- The models are run in 10 to 30 day blocks, then repeated to get estimates out as far as 180 days. However, there is general agreement that the models do not correctly depict the level of activity at the D+180 point when it is conceived as identical to D+30.
- The models currently do not include substantial application of AirLand Battle concepts, especially rear battle which has serious implication for the nonavailable time devoted to security and movement, as well as for medical nonavailability.
- Disease and Non-Battle Injuries (DNBI) rates currently used in the models appear to be high, based on an historic level of 2.16 hospital admissions per thousand per day. No modeling of factors which might effect that rate, especially climate and combat intensity, is currently performed.
- The previous study assumed that personnel will be replaced after 72 hours, but current Army policy on replacements does not support this assumption and is now under review by the Soldier Support Center.

The Surgeon General's Office (TSG) is responsible for providing the Disease and Non-Battle Injuries (DNBI) factor for the models. DNBI rates are very hard to predict because they are driven by both weather conditions and combat intensity. Historical data may not be sufficient because of gross summarization or particular conditions affecting the rates during the data collection period. FM 101-10-1 reports the WW II DNBI rate now used in a division area of 2.16 hospital admissions per thousand troops per day, but it is very difficult to generalize about the total DNBI incident rates from this hospital admittance number because the historical data is so controversial.

Counterbalancing the flow of casualties from a unit is the replacement flow of soldiers into a unit. There is currently no well-defined policy on the time required to replace a casualty in a unit. In fact, replacement policy is highly dependent on the scenario and period of the war. Normally, when a casualty arrives at the battalion aid station, a triage is performed and the physician's assistant decides whether the patient can be returned to duty within 72 hours or must be immediately evacuated to a hospital. The battalion S-1 then submits a daily Personnel Requirements Report (PRR) through his headquarters to requisition replacements for casualties evacuated that day. There is also a goal (assumed in the LOGCEN study, but which research has not confirmed as actual Army policy) of 72 hours to get a replacement who has entered the theater to his unit of assignment. But several "unknowns" prevent us from using these replacement policies to estimate unit nonavailable time.

First, under the demand "pull" system which takes over from the shelf requisition "push" system at about D+90, replacement for a casualty must be "requisitioned" from CONUS through the chain of command. The time it takes the replacement to get to the theater of operations is unknown. Thus, even though we know how long it takes the replacement to get to his unit once he is in theater, we do not know how long it takes him to get to the theater.

Second, rarely does a replacement requisitioned for a unit vacancy end up filling that vacancy. Replacements are put into a "pipeline" and when they get to the end of the pipeline, they are assigned to whatever unit has a vacancy for their MOS/grade. Theoretically, in a steady state war the pipeline should be full with the correct number/grade/MOS of soldiers to replace casualties on a daily basis. Each day, casualties are evacuated and replacements are brought to the unit, with no significant manhours lost to the unit. Army analysts, however, felt that the pipeline would never be full, so that units would have a constantly decreasing strength as daily casualties exceeded daily replacements. The reasons why the pipeline can never be filled are many, but include limited strategic and intratheater transportation, limited replacement of destroyed weapon systems for replacements to use, a limited training base and limited stockpiles of rations and ammunition which cannot be replenished fast enough by the industrial base.

Third, the higher headquarters commanders have the authority to divert replacements to priority units and "overfill" those units prior to an operation, while causing delays in the replacement of casualties in lower priority units. Commanders also can create new units from replacements. Thus, even if the replacement pipeline were full so that total daily replacements to the theater equaled total daily casualties in the theater, there is no method to predict which units are more likely to be kept overfilled and which kept underfilled.

Finally, Army analysts were convinced that the military manpower pool in the United States was not large enough to continue to produce replacements for casualties at D+180 and beyond. Even with a perfect replacement system, the manpower would not be available to keep up with the casualties predicted by the CEM model and the Casualty Stratification Model.

The Soldier Support Center is currently at work on a DA-directed study of the Wartime Replacement System (WRS) and should have initial findings to brief in October 1986. The study will use simulation modeling as well as historical data. Currently, SSC uses an extrapolation of CEM model output to predict losses for up to D+365. The WRS Study will use a module developed at CAORA for CORDIVEM, which includes personnel service support functions, and possibly several other models. In general, however, the study will be a balance of computer simulation and analysis of history. Several alternatives to the individual replacement system will be considered, including unit replacement and reconstitution (e.g., combining four attrited companies into three full strength companies).

Replacement policy analysts seemed only vaguely aware that MARC gives TOEs a nonavailable factor that compensates for some unit losses. They seemed to believe that the replacement system must continue to try to fill units to the "required" strength, when in fact, a unit filled to the required strength is slightly "overstrength" because of the casualty nonavailable factor. The replacement system and MARC really constitute a joint system for keeping unit strength up to mission strength: MARC, by starting the unit off with a few extra soldiers, and the replacement system, by importing new soldiers to the unit. It is obvious that these two methods are interactive and can compensate for each other. It is also obvious that one cannot be designed without the other.

Sleep and Rest

Sleep is the single largest nonavailable task. The LOGCEN study used the current Army standard of six to eight hours per day as provided by the Soldier Support Center (SSC). The SSC referenced a 1979 study by the U.S. Army Research Institute entitled "Research Product 80-4a, Human Performance in Continuous Operations." This range is based on a large sample survey of American adults conducted by the Department of Health, Education and Welfare. That study found that the mean sleep length is eight hours with a nearly normal distribution and a standard deviation of approximately one hour. The SSC evidently felt that the soldier population in wartime would average one hour of sleep less per day than "normal," placing the mean sleep nonavailable factor at seven hours.

This seems to be the best data available for estimating the sleep requirements of soldiers in extended combat. Many studies have examined the effects of short periods (5 to 7 days) of sleep deprivation and sleep denial on soldiers. These effects include degradation of cognitive skills, neglect of personal hygiene, and loss of planning and innovative foresight. In all these studies, the ill effects of sleep deprivation were found to be cumulative until a period of sleep recuperation occurred. There seems to be no way, however, of extrapolating the reduced performance on these short period experiments to the reduced performance for extended periods of sleep loss (90 days).

Several of the persons we interviewed suggested interviewing officers with combat experience and researching historical data from World War II. While studies have shown that soldiers in combat units that fought for extended periods during WW II averaged only 3 to 3.5 hours of daily sleep, the experts we consulted noted that these units experienced 800 to 900 percent turnover of personnel during the period of combat--including many losses due to combat fatigue.

The results of some Army studies show that the minimum amount of sleep that soldiers need to function at all is 3 to 4 hours per day of quality sleep. Factors which affect the amount of sleep required include:

- *Quality*: This is defined as deep sleep where the brainwave activity is low and level. This is critical to the 6-8 hour optimum Army policy.
- *Time of Day*: The body rhythms include circadian and diurnal cycles which make sleep more useful at certain hours of the day and month.
- *Frequency*: Research is ongoing to identify the differences between a daily long sleep period and several "catnaps."
- *Tasks*: Soldiers require more sleep to perform optimally at cognitive tasks than at physical tasks. Physical activity can, in fact, be a stimulant to the body.
- *Stress*: Adrenal secretions can stimulate the body for short periods of time, but quickly degenerate the body and cause a requirement for more sleep.
- *Fatigue*: If the body is tired, it may be in a sleep "deficit." The body then requires more sleep for several days in order to regain optimum performance.

FM 22-9, *Soldier Performance in Continuous Operations*, lists some ways soldiers and commanders can mediate the effects of sleep deprivation, but there is no method yet developed which can train soldiers to require less sleep than normal for their physiology.

Other Services

The USAF calculation of nonavailable time in wartime differs fundamentally from the approach taken by the Army, essentially substituting doctrine for data. The Air Force position is most recently stated in the *Wartime Military Man-Hour Availability Study* completed by the Air Force Management Engineering Agency in January 1985. As part of the review for the estimation of Army nonavailability factors, we reviewed this Air Force study and interviewed its primary authors.

The Air Force approach is based on the concept of a doctrinally defined work week, rather than on a 24-hour day. Thus, the current AF study recommended that the standard hours per month for wartime planning should be:

- *Wartime Surge* - D-Day to D+30 - 7 days per week, 12 hours per day;
- *Wartime Emergency* - D+31 to D+180 - 6 days per week, 12 hours per day;
- *Wartime Sustained* - beyond D+180 - 6 days per week, 10 hours per day.

From the AF study

TABLE 5

	WARTIME SURGE	WARTIME EMERGENCY	WARTIME SUSTAINED
ASSIGNED HRS	(To D+30) 365.25	(D+31-D+180) 313.07	(Beyond D+180) 260.89
ACTIVITY			
LEAVE			
In Unit	0	0	0
Pass	0	0	0
PCS Related			
In-Out Processing	0	0*	1.431
Family Settlement	0	0	0
Medical			
Inpatient/Quarters	1.178	0.539	0.539
Dental Visits	0.020	0.450	0.450
Outpatient	1.372	1.369	1.369
Physicals	0	0	0
Organizational Duties			
Commander's Call	0	C	0.975
Physical Fitness	0	0	0
Counciling & Reviews	0	0	1.023
Boards & Councils	0	0	0
Retreats & Parades	0	0	0
Details	0	0	0.559
Charge of Qtrs	0	0	0
Qtrs Inspect. Prep	0	0	0
Additional Duties	0	0	0.148
Sponsor Duties	0	0	0
Education & Training			
Testing	0	0	0.476
Gen Ed & Tng	0	0	0
TDY Tech Tng	0	0	0
High School/IDEA	0	0	0
Surveys	0	0	0
Social Actions			
Drug Rehab	0	0	0.011
Alcohol Rehab	0	0	0.023
Miscellaneous			
Voting	0	0	0.062
Court	0	0	0.179
AWOL/Deserter	0	0	0.020
Total Nonavailable	2.570	2.358	7.265
Total Available	362.680	310.712	253.625
Availability Factor	362	310	253
Current Factors	309	244	

*DODI 1100.19 states that upon mobilization all PCS moves are at the convenience of the government. It seems reasonable to delay the man-hour expense of PCS processing as long as possible.

From this standard work week, the AF subtracts nonavailable tasks as shown on the following table from the AF study. In the period to D+180, only personal time for medical reasons is subtracted from total assigned hours; in the sustained period, additional time is subtracted for PCS processing, organizational duties, and miscellaneous activities. In total, only 2.5 hours per month of nonavailable time are included in the D-Day to D+180 period, and about 7.2 hours per month thereafter.

The AF study does not include the nonavailable tasks which are the major drivers of Army nonavailable time. Sleeping, eating, and personal time are assumed to be accomplished outside of the assigned hours. Security and movement are not included at all (base security is provided by the APs). Tasks which the Army considers to be indirect productive time (such as cleaning tools) are included in the estimate of productive time. In general, no consideration was given to "additional duties." In fact, the nonavailable time was only seven minutes per day and included only time for medical facility visits with return to duty. Twelve hours per day were taken for all personal nonavailable tasks (sleep, eating, etc.) but this list was not defined. Casualties were assumed to be replaced instantly with no time loss. All other potential nonavailable tasks were "zeroed out."

The Navy also establishes manpower requirements with doctrinally determined workweeks as opposed to using nonavailable time calculations. Section 509 of OPNAVINST 1000.16E contains Navy policy and procedure on the standard workweek. Interviews with Navy staff indicate no change is currently being planned for either the approach or the workweek numbers.

The Navy standard workweek provides "guidelines for sustained personnel utilization under projected wartime conditions." Separate standard workweeks have been calculated for sea, squadron at sea, ship in port and shore units; within each of these categories, standards are calculated for both watchstanders and non-watchstanders.

The Navy policy has established the following standard workweeks for use as planning factors:

	Hours Per Week	
	Watchstanders	Non-watchstanders
Ships at Sea	74	66
Squadron at Sea	--	70
Ship in Port	45	41
Ashore - with Dependents	40	40
- w/o Dependents	66	57
Ashore - Mobilization M to M+60	60	60
Ashore - Mobilization M+61+	48	48

Note that ashore personnel have lower workweeks in peacetime when accompanied by dependents, but that this distinction is dropped at mobilization.

The standard workweeks are derived from a series of assumed allocations of time. The analysis for the first category, ships at sea, is reported here as illustrative of the Navy process.

	Watchstander	Non-Watchstander
Total Weekly Hours	168	168
Less Nonavailable Time		
Sleep	56	56
Messing	14	14
Personal Needs	21	21
Sunday (full-time)	3	11
Available Worktime	74	66
Components of Workweek		
Watch	56	--
Service Diversions & Training	4.5	6
Work	13.5	60

Service diversions include general drills and general quarters, but no further detail is provided in the instructions, nor could Navy staff contacted provide additional details. Similarly, there is no documentation for the estimated nonavailable times.

APPENDIX B: SCENARIOS

The first operation is a defense in sector. This operation lasts from four to seven days. The NATO forces are fighting a retrograde operation and are outnumbered throughout the front and at major axes of enemy advance. The pace of the operation is fast, chaotic and stressful. The enemy threat to the rear areas consists of saboteurs, raids, massive air attacks and division-sized breakthroughs.

The second operation is a continued defensive operation and preparation to attack to seize objectives west of the Inter-German Border (IGB) that will establish a base from which to conduct a northern movement. This operation lasts for seven days. The pace of the battle is still intense. The threat to the rear areas consists of small unit insertions.

The third operation is an offensive operation to sever the lines of communications of the Northern and Western Soviet Fronts. This operation lasts for seven days. The pace of the operation picks up, but is more directed than in the first phase. The enemy threat to the rear decreases, perhaps to agents and saboteurs, as more of his resources are required to defend.

The fourth operation is a continued attack to defeat all forces in zone and restore NATO territory. This operation lasts from 7 to 14 days.

Nuclear and chemical weapons are not employed in the scenario.

The phase of operations and the intensity of the threat to the rear areas are the major factors in time allocation decisions. The terrain and weather are of less concern. While there will remain only 24 hours in a duty day, the ratio of MOS duty time and non-MOS time will likely vary with these factors. In addition, the mix of non-MOS tasks might change. For example, during the first phase, MOS time, base security and unit movement may increase, while sleep and personal time, training, maintenance and administration and unit details may decrease. For this study, the fourth operational phase of the scenario was used, as this is the operational phase that would continue through the end of the war. The scenario which was presented to the expert groups is described below.

General Scenario

The Warsaw Pact (WP) and NATO entered a period of heightened tension caused by increased Soviet military and political pressure in the Mideast that threatened to end NATO access to Mideast oil supplies. NATO economic sanctions against the Soviet Union and the movement of substantial US Naval forces to the Indian Ocean convinced the WP to invade western Europe.

The WP launched an attack into NATO using the deception of large-scale training maneuvers to deploy its forces. Although NATO recognized the build-up as preparation for invasion, it was unable to provide significant reinforcement to NATO prior to D+16. The main WP attack was launched across the North German Plain in the Northern Army Group (NORTHAG) area with minimum warning. The initial Front objective was to capture the German industrial heartland in the Ruhr. The subsequent objective was to capture the German and Dutch seaports on the North Sea and prevent the reinforcement of NATO by sea.

The WP also launched a supporting attack in the Central Army Group (CENTAG) area to fix US forces. The primary objective was to capture the Frankfurt, Wiesbaden, Mainz industrial complex and secure Rhine River crossing sites. A supporting attack was also launched in the direction of Stuttgart. US forces in the CENTAG region have faced at least two armies in the 1st echelon with a total of 8-10 divisions. US forces are assigned to V and VII (US) Corps and are under CENTAG command structure.

These attacks were supported by massive airstrikes conducted by Frontal aviation and long range aviation assets. Initial strikes were against NATO airfields, air defense, and communications sites. Once NATO air defense was neutralized, air attacks were conducted throughout the depth of the battlefield and concentrated on nuclear storage sites, POMCUS storage sites, headquarters, and logistics facilities.

The Warsaw Pact did not utilize chemical munitions at first because the element of surprise favored a conventional attack, but a chemical attack is possible at any time. The initial delivery of chemical weapons will be massive and coordinated across the Front to create the maximum surprise effect. Non-persistent agents would be delivered along the FLOT to support maneuver forces. Persistent agents would be delivered to protect the flanks of major attacks and throughout the depth of the battlefield to contaminate CS and CSS units and deny access to key terrain and supplies. After this initial use, each Threat Army commander would utilize chemicals to support operations as required. NATO can expect that enemy nuclear weapons will be held in reserve and would be utilized if the chemical munitions were not successful in re-establishing momentum. Additionally, the Soviets might launch a preemptive strike against NATO if they could locate the NATO nuclear delivery systems and NATO appeared ready to launch its own strike.

Special Situation

NATO forces have slowed the Warsaw Pact offensive just east of the Rhine and after a short preparation phase have begun counteroffensive operations to eject WP forces from NATO territory. The pace of the war has slowed as both sides have expended initial stocks of ammunition. Reinforced U.S. forces are now beginning offensive operations in the V Corps sector. This phase will consist of continuous operations (day and night) and units must be prepared to sustain operations indefinitely.

The threat to the rear areas consists of all levels and categories of enemy activities. The WP forces rarely fight across orderly, distinct lines. Massive concentrations of forces and fires have made penetrations all but inevitable with the result that NATO and WP forces have been intermingled and traditional lines have been blurred. On this nonlinear battlefield, there is little distinction between rear and forward areas. Support elements must plan for their own defense against level I and level II attack and provide a base of fire against level III attack.

The area of operations has rolling terrain, lightly covered with trees and other vegetation, with an elevation variation of 100 to 200 meters per kilometer produced by small hills with gentle slopes causing a slight reduction of cross-country movement. Roads are mostly paved, with dirt roads and firebreaks running through all wooded areas. Numerous built-up areas exist which provide excellent cover, concealment, and facilities for CSS operations. The season is late summer, with temperatures above 60 degrees Fahrenheit in the day, dropping to above 32 degrees at night. Light to moderate precipitation is expected during the operation and will not have significant CSS impact. Ground fog is common in the early morning and evening hours.

APPENDIX C: DATA DISPLAYS

Table C-1: Data Inputs to the Commander's Decision Model

Infantry School

HHC, Infantry Battalion Field Trains (70 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	5.0	12.5	4.5	0.04				
SEC	108	576	0.5	0.10				
MOV	1.5	6.5	*	0.28	24.0	3.0	.5	3
TMA	0.0	4.0	3.0	0.19				
DET	0	140	3.5	0.12				

Daily MOS Workload Required = 483.0

Armor School

HHC, Tank Battalion Field Trains (48 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	4.0	13.0	4.0	0.08				
SEC	144	432	0.5	0.10				
MOV	2.5	4.5	*	0.04	25.0	4.0	1	2
TMA	0.0	8.0	0.5	0.11				
DET	0	108	2.0	0.24				

Daily MOS Workload Required = 331.2

Table C-1: Data Inputs to the Commander's Decision Model (continued)

Field Artillery School
Lance Battery, Headquarters (30 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	4.0	11.5	3.0	0.26				
SEC	108	192	2.0	0.14				
MOV	1.8	6.3	*	0.16	35.0	3.0	.5	2
TMA	2.0	10.0	2.0	0.05				
DET	40	190	4.0	0.05				

Daily MOS Workload Required = 207.0

Air Defense Artillery School
Improved HAWK Battery (61 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	4.0	15.0	1.5	0.30				
SEC	96	540	2.5	0.19				
MOV	1.9	6.4	*	0.10	30.0	3.0	.5	2
TMA	0.0	5.0	2.0	0.04				
DET	0	133	2.5	0.03				

Daily MOS Workload Required = 420.9

Quartermaster School
Supply and Service Company (158 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	5.0	12.0	2.5	0.17				
SEC	132	720	0.5	0.06				
MOV	3.9	5.2	*	0.04	10.0	8.0	2	3
TMA	0.0	3.5	3.0	0.06				
DET	0	258	2.0	0.23				

Daily MOS Workload Required = 1343

Ordnance School
Heavy Maintenance Company (143 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	8.0	14.0	2.0	0.19				
SEC	432	864	4.0	0.38				
MOV	4.6	9.2	*	0.02	10.0	24.0	3	7
TMA	0.0	8.0	3.0	0.10				
DET	0	247	3.0	0.08				

Daily MOS Workload Required = 1215.5

Table C-1: Data Inputs to the Commander's Decision Model (continued)

Aviation Logistics School
Transportation Aviation Maintenance Company (200 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
					MOVEMENT DATA			
PER	5.0	10.0	2.5	0.06				
SEC	360	720	2.5	0.23				
MOV	1.3	2.4	*	0.10	20.0	9.0	5	13
TMA	0.0	7.0	5.0	0.31				
DET	150	400	4.0	0.17				

Daily MOS Workload Required = 1700

Chemical School
NBC Company Headquarters (17 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
					MOVEMENT DATA			
PER	4.0	11.5	1.5	0.18				
SEC	0	144	1.0	0.20				
MOV	1.4	8.4	*	0.20	30.0	4.0	.5	4
TMA	0.0	7.0	0.5	0.18				
DET	0	37	2.5	0.02				

Daily MOS Workload Required = 125.8

Signal School
HHC, Signal Battalion (66 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
					MOVEMENT DATA			
PER	4.0	14.0	4.0	0.10				
SEC	216	396	3.5	0.04				
MOV	1.0	5.0	*	0.28	24.0	9.0	2	14
TMA	0.0	6.0	2.5	0.06				
DET	0	138	2.0	0.11				

Daily MOS Workload Required = 488.4

Engineer School
HHC, Engineer Battalion (104 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
					MOVEMENT DATA			
PER	5.0	11.5	2.5	0.16				
SEC	350	1200	1.5	0.27				
MOV	2.2	4.2	*	0.14	10.0	3.0	1	3
TMA	2.0	7.0	3.5	0.03				
DET	70	120	0.5	0.06				

Daily MOS Workload Required = 769.6

Table C-1: Data Inputs to the Commander's Decision Model (continued)

Military Police School
HHD, Military Police Battalion (32 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	4.0	14.0	1.0	0.14				
SEC	108	504	0.5	0.26				
MOV	2.2	14.5	*	0.13	24.0	7.0	.5	4
TMA	0.0	7.0	1.0	0.14				
DET	0	68	1.5	0.04				

Daily MOS Workload Required = 236.8

Military Intelligence School
Aviation Company, CEWI Battalion (68 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	6.0	12.0	4.5	0.04				
SEC	72	216	1.5	0.05				
MOV	2.2	4.5	*	0.10	25.0	12.0	3	7
TMA	2.0	5.0	4.0	0.03				
DET	0	140	4.0	0.32				

Daily MOS Workload Required = 503.2

Academy of Health Sciences
Medical Clearing Company (65 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	5.0	11.0	2.0	0.14				
SEC	120	240	2.0	0.03				
MOV	2.3	6.3	*	0.06	40.0	6.0	1	3
TMA	0.0	8.0	2.0	0.12				
DET	50	101	4.0	0.04				

Daily MOS Workload Required = 552.5

Aviation School
Corps Aviation Company (122 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	4.0	11.5	2.5	0.10				
SEC	0	540	1.5	0.30				
MOV	2.2	4.5	*	0.08	24.0	12.0	3	7
TMA	0.0	5.5	1.5	0.16				
DET	0	172	2.0	0.07				

Daily MOS Workload Required = 902.8

Table C-1: Data Inputs to the Commander's Decision Model (continued)

Missiles and Munitions School
Conventional Ammunition Ordnance Company (138 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	4.0	13.0	1.5	0.12				
SEC	0	720	1.5	0.14				
MOV	0.0	0.0	*	0.00	10.0	7.0	—	—
TMA	0.0	5.0	5.0	0.08				
DET	100	218	2.5	0.04				

Daily MOS Workload Required = 1173.0

Transportation School
Medium Truck Company (27 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	5.0	12.0	3.5	0.24				
SEC	108	216	0.5	0.06				
MOV	0.9	1.7	*	0.00	35.0	4.0	3	7
TMA	0.0	5.0	2.5	0.22				
DET	12	36	2.0	0.09				

Daily MOS Workload Required = 229.5

Soldier Support Center
HHC, Personnel Command (244 soldiers)

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)	MAX (DAYS)	MIN (DAYS)
PER	4.0	12.0	2.0	0.08				
SEC	0	1944	0.5	0.23				
MOV	0.0	0.0	*	0.00	24.0	24.0	—	—
TMA	0.0	4.0	0.5	0.04				
DET	0	316	0.5	0.27				

Daily MOS Workload Required = 2074.0

Table C-2: Inputs to the Commander's Decision Model for 180 Expanded Factors

TUC 1/ULC 1

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)
PER	4.5	12.8	4.3	.06		
TMA	0.0	6.0	1.8	.15		
DET	0	124	2.7	.18		
MOS	0	407.1	0.01	.35		
SEC-A	126	504	.5	.10		
SEC-B	50	202	.5	.10		
SEC-C	32	126	.5	.10		
SEC-D	0	0	*	.10		
MOV-A	1.7	7.5	*	.16	24.5	3.5
MOV-B	1.0	1.4	*	.16		
MOV-C	.7	0.9	*	.16		
MOV-D	.6	0.7	*	.16		
MOV-E	0	0	*	.16		

TUC 1/ULC 2 and 3

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)
PER	4.0	13.3	2.3	.28		
TMA	1.0	7.5	2.0	.05		
DET	20	162	3.2	.03		
MOS	0	314.0	0.01	.34		
SEC-A	102	366	2.5	.17		
SEC-B	41	146	2.5	.17		
SEC-C	26	92	2.5	.17		
SEC-D	0	0	*	.17		
MOV-A	1.4	6.4	*	.13	32.5	3.0
MOV-B	0.8	1.1	*	.13		
MOV-C	.5	.7	*	.13		
MOV-D	.4	.5	*	.13		
MOV-E	0	0	*	.13		

TUC 2/ULC 1

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	LOAD/UNLOAD (HRS)
PER	4.3	12.8	2.3	.15		
TMA	.5	6.8	1.9	.10		
DET	18	91	1.6	.06		
MOS	0	405.2	.001	.30		
SEC-A	169	561	1.6	.19		
SEC-B	67	224	1.6	.19		
SEC-C	42	140	1.6	.19		
SEC-D	0	0	*	.19		
MOV-A	2.5	12.1	*	.20	22.0	5.8
MOV-B	1.4	2.0	*	.20		
MOV-C	.9	1.3	*	.20		
MOV-D	.7	0.9	*	.20		
MOV-E	0	0	*	.20		

Table C-2: Inputs to the Commander's Decision Model for 180 Expanded Factors (continued)

TUC 2/ULC 2 and 3

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	MOVEMENT DATA LOAD/UNLOAD (HRS)
PER	5.0	11.8	3.5	.07		
TMA	1.0	5.3	2.8	.10		
DET	0	156	3.0	.20		
MOS	0	703	.001	.36		
SEC-A	36	378	1.5	.18		
SEC-B	14	151	1.5	.18		
SEC-C	9	95	1.5	.18		
SEC-D	0	0	*	.18		
MOV-A	4.5	24.0	*	.09	24.5	12.0
MOV-B	2.2	3.5	*	.09		
MOV-C	1.2	2.0	*	.09		
MOV-D	.8	1.2	*	.09		
MOV-E	0	0	*	.09		

TUC 3/ULC 1

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	MOVEMENT DATA LOAD/UNLOAD (HRS)
PER	5.8	11.8	2.3	.14		
TMA	0	6.6	3.3	.15		
DET	50	252	3.3	.13		
MOS	0	1202.8	.001	.35		
SEC-A	261	636	2.3	.18		
SEC-B	104	254	2.3	.18		
SEC-C	65	159	2.3	.18		
SEC-D	0	0	*	.18		
MOV-A	4.5	24	*	.05	20.0	11.8
MOV-B	2.3	3.6	*	.05		
MOV-C	1.3	2.1	*	.05		
MOV-D	.9	1.3	*	.05		
MOV-E	0	0	*	.05		

TUC 3/ULC 2 and 3

TASK	MIN (HRS)	MAX (HRS)	COEF	WEIGHT	MOVEMENT DATA SPEED (KM/HR)	MOVEMENT DATA LOAD/UNLOAD (HRS)
PER	4.3	12.3	2.3	.16		
TMA	0	4.7	2.7	.11		
DET	37	190	1.1	.13		
MOS	0	1158.8	.001	.46		
SEC-A	36	960	.8	.14		
SEC-B	14	384	.8	.14		
SEC-C	9	240	.8	.14		
SEC-D	0	0	*	.14		
MOV-A	4.4	23.9	*	.00	23.0	11.7
MOV-B	2.2	3.4	*	.00		
MOV-C	1.2	2.0	*	.00		
MOV-D	.8	1.2	*	.00		
MOV-E	0	0	*	.00		

Table C-3: Outputs from the Commander's Decision Model for 180 Expanded Factors

MARC CODE	PER	SEC	MOV	TMA	DET	NAFD	MOS	NON-MOS & NAFD
11AA	4.5	2.8	3.2	1.8	1.7	1.0	9.0	15.0
11AB	4.5	3.1	1.4	1.9	1.9	1.0	10.2	13.8
11AC	4.5	3.1	0.9	2.4	1.9	1.0	10.2	13.8
11AD	4.5	3.3	0.7	1.8	2.0	1.0	10.7	13.3
11AE	4.5	3.4	0.0	2.1	2.0	1.0	11.0	13.0
11BA	4.5	1.3	3.4	1.8	1.9	1.0	10.2	13.8
11BB	4.5	1.7	1.4	2.4	2.0	1.0	11.0	13.0
11BC	4.5	2.2	0.9	2.4	2.0	1.0	11.0	13.0
11BD	4.5	2.2	0.7	2.4	2.2	1.0	11.0	13.0
11BE	4.5	1.9	0.0	2.4	2.2	1.0	12.0	12.0
11CA	4.5	2.6	2.9	1.3	1.8	1.0	9.9	14.1
11CB	4.5	3.1	1.4	1.9	1.9	1.0	10.2	13.8
11CC	4.5	3.1	0.9	1.8	2.0	1.0	10.7	13.3
11CD	4.5	3.0	0.7	1.8	2.0	1.0	11.0	13.0
11CE	4.5	3.4	0.0	2.1	2.0	1.0	11.0	13.0
11DA	4.5	0.0	3.4	2.0	2.0	1.0	11.0	13.0
11DB	5.0	0.0	1.4	2.4	2.2	1.0	12.0	12.0
11DC	4.7	0.0	0.9	2.4	2.3	1.0	12.7	11.3
11DD	4.9	0.0	0.7	2.4	2.3	1.0	12.7	11.3
11DE	4.6	0.0	0.0	2.4	2.5	1.0	13.6	10.4
12AA	6.8	4.5	2.4	1.0	0.5	1.0	7.8	16.1
12AB	7.3	4.8	1.1	1.0	0.5	1.0	8.3	15.7
12AC	6.9	4.6	0.7	1.0	0.6	1.0	9.2	14.8
12AD	7.1	4.6	0.5	1.0	0.6	1.0	9.2	14.8
12AE	7.6	4.6	0.0	1.0	0.6	1.0	9.2	14.8
12BA	7.7	2.7	2.8	1.0	0.5	1.0	8.3	15.7
12BB	7.2	3.2	1.1	1.0	0.6	1.0	9.8	14.2
12BC	7.6	3.2	0.7	1.0	0.6	1.0	9.8	14.2
12BD	7.8	3.2	0.5	1.0	0.6	1.0	9.8	14.2
12BE	8.3	3.2	0.0	1.0	0.6	1.0	9.8	14.2
12CA	6.9	2.3	2.4	1.0	0.6	1.0	9.8	14.2
12CB	8.0	2.5	1.1	1.0	0.6	1.0	9.8	14.2
12CC	8.4	2.5	0.7	1.0	0.6	1.0	9.8	14.2
12CD	7.7	2.6	0.5	1.0	0.7	1.0	10.5	13.5
12CE	7.8	2.7	0.0	1.0	0.7	1.0	10.8	13.2
12DA	7.7	0.0	2.8	1.0	0.7	1.0	10.8	13.2
12DB	8.0	0.0	1.1	1.0	0.8	1.0	12.1	11.9
12DC	8.4	0.0	0.7	1.0	0.8	1.0	12.1	11.9
12DD	8.6	0.0	0.5	1.0	0.8	1.0	12.1	11.9
12DE	9.2	0.0	0.0	1.0	0.8	1.0	12.1	11.9

Table C-3: Outputs from the Commander's Decision Model for 180 Expanded Factors (continued)

MARC CODE	PER	SEC	MOV	TMA	DET	NAFD	MOS	NON-MOS & NAFD
13AA	6.8	4.5	2.4	1.0	0.5	1.0	7.8	16.1
13AB	7.3	4.8	1.1	1.0	0.5	1.0	8.3	15.7
13AC	6.9	4.6	0.7	1.0	0.6	1.0	9.2	14.8
13AD	7.1	4.6	0.5	1.0	0.6	1.0	9.2	14.8
13AE	7.6	4.6	0.0	1.0	0.6	1.0	9.2	14.8
13BA	7.7	2.7	2.8	1.0	0.5	1.0	8.3	15.7
13BB	7.2	3.2	1.1	1.0	0.6	1.0	9.8	14.2
13BC	7.6	3.2	0.7	1.0	0.6	1.0	9.8	14.2
13BD	7.8	3.2	0.5	1.0	0.6	1.0	9.8	14.2
13BE	8.3	3.2	0.0	1.0	0.6	1.0	9.8	14.2
13CA	6.9	2.3	2.4	1.0	0.6	1.0	9.8	14.2
13CB	8.0	2.5	1.1	1.0	0.6	1.0	9.8	14.2
13CC	8.4	2.5	0.7	1.0	0.6	1.0	9.8	14.2
13CD	7.7	2.6	0.5	1.0	0.7	1.0	10.5	13.5
13CE	7.8	2.7	0.0	1.0	0.7	1.0	10.8	13.2
13DA	7.7	0.0	2.8	1.0	0.7	1.0	10.8	13.2
13DB	8.0	0.0	1.1	1.0	0.8	1.0	12.1	11.9
13DC	8.4	0.0	0.7	1.0	0.8	1.0	12.1	11.9
13DD	8.6	0.0	0.5	1.0	0.8	1.0	12.1	11.9
13DE	9.2	0.0	0.0	1.0	0.8	1.0	12.1	11.9
21AA	5.1	4.5	4.4	0.5	1.1	1.0	7.4	16.6
21AB	5.5	5.3	2.0	0.5	1.2	1.0	8.6	15.4
21AC	6.0	5.3	1.3	0.7	1.2	1.0	8.6	15.4
21AD	5.2	5.8	0.9	0.5	1.3	1.0	9.4	14.6
21AE	6.0	5.8	0.0	0.6	1.3	1.0	9.4	14.6
21BA	5.1	3.7	4.4	0.5	1.1	1.0	8.1	15.9
21BB	5.7	4.1	2.0	0.5	1.3	1.0	9.4	14.6
21BC	6.0	4.1	1.3	0.9	1.3	1.0	9.4	14.6
21BD	6.0	4.3	0.9	1.1	1.3	1.0	9.4	14.6
21BE	6.0	4.6	0.0	1.3	1.5	1.0	9.6	14.4
21CA	5.3	3.0	4.4	0.5	1.2	1.0	8.6	15.4
21CB	6.0	3.3	2.0	1.1	1.3	1.0	9.4	14.6
21CC	6.0	3.3	1.3	1.2	1.5	1.0	9.6	14.4
21CD	6.0	3.3	0.9	1.6	1.5	1.0	9.6	14.4
21CE	6.0	3.7	0.0	1.2	1.4	1.0	10.7	13.3
21DA	6.0	0.0	4.4	1.5	1.5	1.0	9.6	14.4
21DB	6.5	0.0	2.0	1.8	1.5	1.0	11.3	12.7
21DC	6.4	0.0	1.3	1.8	1.6	1.0	11.9	12.1
21DD	6.8	0.0	0.9	1.8	1.6	1.0	11.9	12.1
21DE	6.8	0.0	0.0	1.8	1.7	1.0	12.7	11.3

Table C-3: Outputs from the Commander's Decision Model
for 180 Expanded Factors (continued)

MARC CODE	PER	SEC	MOV	TMA	DET	NAFD	MOS	NON-MOS & NAFD
22AA	5.0	2.4	4.5	1.9	1.2	1.0	8.0	16.0
22AB	5.0	2.6	3.5	1.9	1.3	1.0	8.7	15.3
22AC	5.0	2.8	2.0	2.2	1.5	1.0	9.5	14.5
22AD	5.0	3.0	1.2	2.2	1.6	1.0	10.0	14.0
22AE	5.3	3.1	0.0	2.3	1.7	1.0	10.7	13.3
22BA	5.0	1.8	4.5	2.0	1.3	1.0	8.4	15.6
22BB	5.0	2.0	3.5	2.0	1.4	1.0	9.1	14.9
22BC	5.0	2.2	2 0	2.2	1.6	1.0	10.0	14.0
22BD	5.7	2.2	1.2	2.3	1.6	1.0	10.0	14.0
22BE	5.4	2.4	0.0	2.3	1.7	1.0	11.2	12.8
22CA	5.0	1.2	4.5	1.9	1.4	1.0	9.0	15.0
22CB	5.0	1.3	3.5	1.9	1.5	1.0	9.8	14.2
22CC	5.7	1.4	2.0	2.3	1.6	1.0	10.0	14.0
22CD	5.1	1.5	1.2	2.3	1.7	1.0	11.2	12.8
22CE	5.7	1.6	0.0	2.4	1.8	1.0	11.5	12.5
22DA	5.0	0.0	4.5	1.9	1.6	1.0	10.0	14.0
22DB	5.6	0.0	3.5	2.3	1.6	1.0	10.0	14.0
22DC	5.4	0.0	2.0	2.3	1.8	1.0	11.5	12.5
22DD	5.7	0.0	1.2	2.6	1.8	1.0	11.7	12.3
22DE	5.7	0.0	0.0	2.6	2.0	1.0	12.8	11.2
23AA	5.0	2.4	4.5	1.9	1.2	1.0	8.0	16.0
23AB	5.0	2.6	3.5	1.9	1.3	1.0	8.7	15.3
23AC	5.0	2.8	2.0	2.2	1.5	1.0	9.5	14.5
23AD	5.0	3.0	1.2	2.2	1.6	1.0	10.0	14.0
23AE	5.3	3.1	0.0	2.3	1.7	1.0	10.7	13.3
23BA	5.0	1.8	4.5	2.0	1.3	1.0	8.4	15.6
23BB	5.0	2.0	3.5	2.0	1.4	1.0	9.1	14.9
23BC	5.0	2.2	2.0	2.2	1.6	1.0	10.0	14.0
23BD	5.7	2.2	1.2	2.3	1.6	1.0	10.0	14.0
23BE	5.4	2.4	0.0	2.3	1.7	1.0	11.2	12.8
23CA	5.0	1.2	4.5	1.9	1.4	1.0	9.0	15.0
23CB	5.0	1.3	3.5	1.9	1.5	1.0	9.8	14.2
23CC	5.7	1.4	2.0	2.3	1.6	1.0	10.0	14.0
23CD	5.1	1.5	1.2	2.3	1.7	1.0	11.2	12.8
23CE	5.7	1.6	0.0	2.4	1.8	1.0	11.5	12.5
23DA	5.0	0.0	4.5	1.9	1.6	1.0	10.0	14.0
23DB	5.6	0.0	3.5	2.3	1.6	1.0	10.0	14.0
23DC	5.4	0.0	2.0	2.3	1.8	1.0	11.5	12.5
23DD	5.7	0.0	1.2	2.6	1.8	1.0	11.7	12.3
23DE	5.7	0.0	0.0	2.6	2.0	1.0	12.8	11.2

Table C-3: Outputs from the Commander's Decision Model for 180 Expanded Factors (continued)

MARC CODE	PER	SEC	MOV	TMA	DET	NAFD	MOS	NON-MOS & NAFD
31AA	6.4	2.9	4.5	0.8	1.0	1.0	7.3	16.7
31AB	6.4	3.3	2.7	1.3	1.2	1.0	8.1	15.9
31AC	7.0	3.4	1.9	1.3	1.2	1.0	8.3	15.7
31AD	7.0	3.6	1.3	1.3	1.2	1.0	8.5	15.5
31AE	7.0	3.9	0.0	1.3	1.3	1.0	9.5	14.5
31BA	6.5	1.7	4.5	1.3	1.1	1.0	7.9	16.1
31BB	7.0	1.8	2.9	1.3	1.2	1.0	8.7	15.3
31BC	7.0	2.0	2.0	1.4	1.3	1.0	9.3	14.7
31BD	7.0	2.1	1.3	1.5	1.4	1.0	9.8	14.2
31BE	7.2	2.2	0.0	2.0	1.5	1.0	10.2	13.8
31CA	6.6	1.1	4.5	1.3	1.2	1.0	8.3	15.7
31CB	7.0	1.2	2.9	1.4	1.4	1.0	9.0	15.0
31CC	7.0	1.3	2.0	1.5	1.4	1.0	9.8	14.2
31CD	7.0	1.3	1.3	1.7	1.5	1.0	10.2	13.8
31CE	7.5	1.4	0.0	2.0	1.5	1.0	10.6	13.4
31DA	7.0	0.0	4.5	1.3	1.3	1.0	8.9	15.1
31DB	7.0	0.0	2.9	1.4	1.5	1.0	10.2	13.8
31DC	7.1	0.0	2.0	2.0	1.5	1.0	10.5	13.5
31DD	7.6	0.0	1.3	2.0	1.5	1.0	10.6	13.4
31DE	7.6	0.0	0.0	2.0	1.7	1.0	11.7	12.3
32AA	5.2	0.3	4.4	0.9	1.7	1.0	10.4	13.6
32AB	5.3	0.4	2.2	0.9	2.0	1.0	12.2	11.8
32AC	5.8	0.4	1.2	0.9	2.1	1.0	12.6	11.4
32AD	5.9	0.4	0.8	1.2	2.1	1.0	12.6	11.4
32AE	6.2	0.4	0.0	1.4	2.1	1.0	12.9	11.1
32BA	5.1	1.7	4.4	0.6	1.6	1.0	9.7	14.3
32BB	5.1	1.7	2.2	0.9	1.8	1.0	11.3	12.7
32BC	5.1	1.9	1.2	0.9	2.0	1.0	11.9	12.1
32BD	5.4	1.7	0.8	0.9	2.0	1.0	12.2	11.8
32BE	5.6	1.8	0.0	0.9	2.1	1.0	12.6	11.4
32CA	4.9	2.0	4.4	0.5	1.6	1.0	9.7	14.3
32CB	5.1	2.2	2.2	0.9	1.8	1.0	10.7	13.3
32CC	5.1	2.4	1.2	0.9	1.9	1.0	11.5	12.5
32CD	5.4	2.4	0.8	0.9	1.9	1.0	11.6	12.4
32CE	5.3	2.5	0.0	0.9	2.0	1.0	12.2	11.8
32DA	5.2	0.0	4.4	0.9	1.8	1.0	10.7	13.3
32DB	5.2	0.0	2.2	0.9	2.1	1.0	12.6	11.4
32DC	5.9	0.0	1.2	1.2	2.1	1.0	12.6	11.4
32DD	5.9	0.0	0.8	1.3	2.1	1.0	12.9	11.1
32DE	6.6	0.0	0.0	1.4	2.1	1.0	12.9	11.1

Table C-3: Outputs from the Commander's Decision Model for 180 Expanded Factors (continued)

MARC CODE	PER	SEC	MOV	TMA	DET	NAFD	MOS	NON-MOS & NAFD
33AA	5.2	0.3	4.4	0.9	1.7	1.0	10.4	13.6
33AB	5.3	0.4	2.2	0.9	2.0	1.0	12.2	11.8
33AC	5.8	0.4	1.2	0.9	2.1	1.0	12.6	11.4
33AD	5.9	0.4	0.8	1.2	2.1	1.0	12.6	11.4
33AE	6.2	0.4	0.0	1.4	2.1	1.0	12.9	11.1
33BA	5.1	1.7	4.4	0.6	1.6	1.0	9.7	14.3
33BB	5.1	1.7	2.2	0.9	1.8	1.0	11.3	12.7
33BC	5.1	1.9	1.2	0.9	2.0	1.0	11.9	12.1
33BD	5.4	1.7	0.8	0.9	2.0	1.0	12.2	11.8
33BE	5.6	1.8	0.0	0.9	2.1	1.0	12.6	11.4
33CA	4.9	2.0	4.4	0.5	1.6	1.0	9.7	14.3
33CB	5.1	2.2	2.2	0.9	1.8	1.0	10.7	13.3
33CC	5.1	2.4	1.2	0.9	1.9	1.0	11.5	12.5
33CD	5.4	2.4	0.8	0.9	1.9	1.0	11.6	12.4
33CE	5.3	2.5	0.0	0.9	2.0	1.0	12.2	11.8
33DA	5.2	0.0	4.4	0.9	1.8	1.0	10.7	13.3
33DB	5.2	0.0	2.2	0.9	2.1	1.0	12.6	11.4
33DC	5.9	0.0	1.2	1.2	2.1	1.0	12.6	11.4
33DD	5.9	0.0	0.8	1.3	2.1	1.0	12.9	11.1
33DE	6.6	0.0	0.0	1.4	2.1	1.0	12.9	11.1

Table C-4: Average Daily Available Times

		MARC ULC1	MAINT MARC ULC1	DSC ULC1	MARC ULC2	TUC 1 MAINT MARC ULC2	DSC ULC2	MARC ULC3	MAINT MARC ULC3	DSC ULC3
USC A	UMC A	9.3	7.0	9.0	9.4	7.1	7.8	8.3	6.0	7.8
	UMC B	9.9	7.6	10.2	10.2	7.9	8.3	9.9	7.6	8.3
	UMC C	10.1	7.8	10.2	10.6	8.3	9.2	10.6	8.3	9.2
	UMC D	10.2	7.9	10.7	10.7	8.4	9.2	10.9	8.6	9.2
	UMC E	10.3	8.0	11.0	10.8	8.5	9.2	11.1	8.8	9.2
USC B	UMC A	10.3	8.0	10.2	10.4	8.1	8.3	9.3	7.0	8.3
	UMC B	10.9	8.6	11.0	11.2	8.9	9.8	10.9	8.6	9.8
	UMC C	11.1	8.8	11.0	11.6	9.3	9.8	1'.6	9.3	9.8
	UMC D	11.2	8.9	11.0	11.7	9.4	9.8	11.9	9.6	9.8
	UMC E	11.3	9.0	12.0	11.8	9.5	9.8	12.2	9.9	9.8
USC C	UMC A	10.6	8.3	9.9	10.7	8.4	9.8	9.6	7.3	9.8
	UMC B	11.2	8.9	10.2	11.5	9.2	9.8	11.2	8.9	9.8
	UMC C	11.4	9.1	10.7	11.8	9.5	9.8	11.9	9.6	9.8
	UMC D	11.5	9.2	11.0	12.0	9.7	10.5	12.2	9.9	10.5
	UMC E	11.6	9.3	11.0	12.1	9.8	10.8	12.4	10.1	10.8
USC D	UMC A	11.0	8.7	11.0	11.1	8.8	10.8	10.0	7.7	10.8
	UMC B	11.6	9.3	12.0	11.9	9.6	12.1	11.6	9.3	12.1
	UMC C	11.8	9.5	12.7	12.3	10.0	12.1	12.3	10.0	12.1
	UMC D	11.9	9.6	12.7	12.4	10.1	12.1	12.6	10.3	12.1
	UMC E	12.0	9.7	13.6	12.5	10.2	12.1	12.9	10.6	12.1

Table C-4: Average Daily Available Times (continued)

		TUC 2								
		MARC ULC1	MAINT MARC ULC1	DSC ULC1	MARC ULC2	MAINT MARC ULC2	DSC ULC2	MARC ULC3	MAINT MARC ULC3	DSC ULC3
USC A	UMC A	4.6	2.3	7.4	4.9	2.6	8.0	6.4	4.1	8.0
	UMC B	5.9	3.6	8.6	6.7	4.4	8.7	7.9	5.6	8.7
	UMC C	6.5	4.2	8.6	7.5	5.2	9.5	8.6	6.3	9.5
	UMC D	6.8	4.5	9.4	7.8	5.5	10.0	8.9	6.6	10.0
	UMC E	6.9	4.6	9.4	8.1	5.8	10.7	9.1	6.8	10.7
USC B	UMC A	7.1	4.8	8.1	7.4	5.1	8.4	9.0	6.7	8.4
	UMC B	8.5	6.2	9.4	9.3	7.0	9.1	10.5	8.2	9.1
	UMC C	9.1	6.8	9.4	10.1	7.8	10.0	11.2	8.9	10.0
	UMC D	9.3	7.0	9.4	10.4	8.1	10.0	11.5	9.2	10.0
	UMC E	9.5	7.2	9.6	10.7	8.4	11.2	11.7	9.4	11.2
USC C	UMC A	7.8	5.5	8.6	8.1	5.8	9.0	9.6	7.3	9.0
	UMC B	9.1	6.8	9.4	9.9	7.6	9.8	11.1	8.8	9.8
	UMC C	9.7	7.4	9.6	10.7	8.4	10.0	11.8	9.5	10.0
	UMC D	10.0	7.7	9.6	11.1	8.8	11.2	12.1	9.8	11.2
	UMC E	10.1	7.8	10.7	11.3	9.0	[illegible]	12.3	10.0	11.5
USC D	UMC A	8.8	6.5	9.6	9.1	6.8	[illegible]	10.7	8.4	10.0
	UMC B	10.2	7.9	11.3	11.0	8.7	10.0	12.2	9.9	10.0
	UMC C	10.8	8.5	11.9	11.8	9.5	11.5	12.9	10.6	11.5
	UMC D	11.0	8.7	11.9	12.1	9.8	11.7	13.2	10.9	11.7
	UMC E	11.2	8.9	12.7	12.4	10.1	12.8	13.4	11.1	12.8

Table C-4: Average Daily Available Times (continued)

		TUC 3								
		MARC ULC1	MAINT MARC ULC1	DSC ULC1	MARC ULC2	MAINT MARC ULC2	DSC ULC2	MARC ULC3	MAINT MARC ULC3	DSC ULC3
USC A	UMC A	5.1	2.8	7.3	5.0	2.7	10.4	6.1	3.8	10.4
	UMC B	6.4	4.1	8.1	6.8	4.5	12.2	7.6	5.3	12.2
	UMC C	7.0	4.7	8.3	7.6	5.3	12.6	8.3	6.0	12.6
	UMC D	7.2	4.9	8.5	7.9	5.6	12.6	8.6	6.3	12.6
	UMC E	7.4	5.1	9.5	8.2	5.9	12.9	8.8	6.5	12.9
USC B	UMC A	7.6	5.3	7.9	7.5	5.2	9.7	8.7	6.4	9.7
	UMC B	9.0	6.7	8.7	9.4	7.1	11.3	10.2	7.9	11.3
	UMC C	9.6	7.3	9.3	10.2	7.9	11.9	10.9	8.6	11.9
	UMC D	9.8	7.5	9.8	10.5	8.2	12.2	11.2	8.9	12.2
	UMC E	10.0	7.7	10.2	10.8	8.5	12.6	11.4	9.1	12.6
USC C	UMC A	8.3	6.0	8.3	8.2	5.9	9.7	9.3	7.0	9.7
	UMC B	9.6	7.3	9.0	10.0	7.7	10.7	10.8	8.5	10.7
	UMC C	10.2	7.9	9.8	10.8	8.5	11.5	11.5	9.2	11.5
	UMC D	10.5	8.2	10.2	11.2	8.9	11.6	11.8	9.5	11.6
	UMC E	10.6	8.3	10.6	11.4	9.1	12.2	12.0	9.7	12.2
USC D	UMC A	9.3	7.0	8.9	9.2	6.9	10.7	10.4	8.1	10.7
	UMC B	10.7	8.4	10.2	11.1	8.8	12.6	11.9	9.6	12.6
	UMC C	11.3	9.0	10.5	11.9	9.6	12.6	12.6	10.3	12.6
	UMC D	11.5	9.2	10.6	12.2	9.9	12.9	12.9	10.6	12.9
	UMC E	11.7	9.4	11.7	12.5	10.2	12.9	13.1	10.8	12.9

APPENDIX D: QUALITATIVE DATA ANALYSIS

Interviewer Bias

Interviewer bias was not considered to be a problem because of the small interviewing team and the group elicitation technique. All the group sessions were led by one of two trained decision analysts. A second team member entered the data in real time into a portable computer. The interviewers explained the exercises and then allowed the group to complete the worksheets as individuals before opening the floor for discussion. Then a group consensus was sought for each input. The interviewers provided guidance only when needed to keep the discussions focused. Following the completion of the inputs, the model was run and the output times for the tasks were presented to the officers for discussion. The interviewers facilitated adjustments to the inputs when the group was dissatisfied with one or more outputs. Therefore, while the interviewers interacted with the group members throughout the sessions, the model outputs were subjected to critique by the group in the end which should have eliminated any interviewer bias during the elicitation of the model inputs.

Confidence in Model Inputs

There is generally good confidence that the sample data is representative of the sample population. It is important to emphasize that confidence is not entirely a matter of statistical confidence levels. It is possible to collect a large number of data points, each sharing a common bias, and produce a tight confidence interval, but with all the values within the confidence interval being unreasonable. More useful to the Army is a wider confidence bound around a reasonable estimate, attained in a justifiable manner, with considerable face validity, which allows the implications of changes in assumptions to be explored.

The model inputs were collected during 17 consensus group sessions from approximately 255 officers, most of whom are former commanders. The groups gave considerable thought to the relative worth of various combat tasks, as opposed to the officers interviewed in the previous non-availability factors study who provided times desired to perform each task independently of other tasks. The tasks used in this study consisted of five high-level non-MOS tasks and one aggregated MOS task. More detailed input data for up to 15 non-MOS tasks have been tested and the total non-available time found not to differ significantly from the higher-level analysis. This indicates that the reliability of the total nonavailable time is not greatly affected by the validity of any particular lower-level task. Therefore, more detailed breakdown of non-MOS tasks does not increase confidence in the total nonavailable time.

The greatest uncertainty in the model inputs comes from the estimates of MOS workload requirements. The estimates assumed that all nonsupervisory enlisted E-5 and below required in current TOE units were based on the availability factors provided in the 1969 edition of AR 570-2. It assumed these factors for standard positions as well as workload variable positions. Even if these assumptions provide reasonable estimates of the MOS workload at the time of the development of the unit TOE, the workloads are continually being updated in the AMMDB and other source documents.

The current TOE units (H and J series) were not in all cases designed using the approved MARC planning factors. Some positions were eliminated without being documented on the published TOE document. In addition, many standard positions imply available times larger than the available times for workload variable positions. Therefore, unit workload estimates used in this study may be underestimated.

The impact of the uncertainty in the MOS workload, however, is not great. A ten percent increase in the MOS workload for the unit changes the optimum unit size by less than ten percent, and the average available time per soldier increases by less than 30 minutes in most cases.

REFERENCES

[1] FM 22-9, *Soldier Performance in Continuous Operations*, December 1983, p. 3-9.

[2] General Accounting Office. *Observations on the Army's Manpower Requirements Criteria Program* (GAO/NSIAD-84-78), March 27, 1984.

[3] *Manpower Nonavailability Factors*, U.S. Army Logistics Center, Fort Lee, VA, September 1983 (ACN58967).

[4] Rakoff, S.H., and Marvin, F.F. *TOE nonavailability factors study* (Interim Report I). Falls Church, VA: Decision Science Consortium, Inc., January 1986.

[5] Rakoff, S.H., and Marvin, F.F. *TOE nonavailability factors study: Model design, sample design, and data collection plan* (Interim Report II). Falls Church, VA: Decision Science Consortium, Inc., April 1986.

[6] Rakoff, S.H., and Marvin, F.F. *TOE nonavailability factors study: TRADOC school visits and data collection report* (Interim Report III). Falls Church, VA: Decision Science Consortium, Inc., June 1986.

[7] Walter Reed Army Institute of Research. Information Paper dated 7 January 1986.

DISCUSSION OF "TOE NONAVAILABILITY FACTORS STUDY"
by S. Rakoff, F. Marvin and M. Constantine

DISCUSSANT: Gerald A. Klopp, TRADOC, Ft. Benjamin Harrison, IN

The paper which I critique below was written by Stuart H. Rakoff, F. Freeman Marvin, and Monica M. Constantine of Decision Science Consortium, Inc. Following Dr. Rakoff's presentation, we had a brief discussion of the paper and my critique. Many of the points which I discuss below are, indeed, being addressed in an update to the original study. I think that the revised study methodology will be worthwhile reading when the report is finished.

In reviewing the paper, I had two objectives in mind: first, a technical critique of the methodology used and second, an assessment of the usefulness of the method in combat modeling. In my critique of the technical approach, (be it this specific paper or any technical paper), I like to keep one principle in mind: it is always easier to criticize than it is to do a study. One consequence of this principle, then, is that if I criticize an aspect of a study, I must offer a solution on how I would improve the results or admit that I could not do better than what was offered.

Overall, I think that the methodology is an improvement over what was previously used and the paper presented an excellent discussion on the new methodology. While explaining very well the dilemma of steady state calculations and the opposing considerations for surge requirements, the authors did not adequately assess the risk associated with their estimates. In designing TOE, equipment, doctrine, etc., we must design for war and modify for peace. This modification process leads us to want to minimize the importance of start-up work, surge requirements, unanticipated tasks, etc. Since we will go to war with what we have, it will do a commander little good to think that, on the average, there are enough people to accomplish the work in the long run when his survival in the short run is in question. Under the concept of minimal essential manning, we do away with redundancy and, therefore, reduce our ability to deal with unexpected contingencies.

One way of assessing risk is to evaluate the differences in the subject matter experts' opinions. However, the methodology used in this study forced the experts to agree on a single utility curve. The disagreement could very well have been due to different perspectives, different conditions being evaluated, different experiences, and other differences between the experts. When asked (or forced) to make an estimate under uncertainty, one tends to underestimate what is truly needed. The estimates could also have been influenced by dominant (perhaps senior) members of the expert panel.

All of the assumptions were not explicitly stated in Section 3.3. The scenario used, steady state conditions, and a rational decision maker are just as much an assumption as the three which were explicitly stated. I would guess that the results could be radically changed if any of these implicitly stated and discussed assumptions were to change. Another risk assessment could be made if some of the stated and implicit assumptions were to change.

Another area in the methodology which could be improved is in the use of fixed weights for all increments of tasks. For example, the first four hours of sleep might have a higher weight (or importance) than the last four hours of sleep. In addition, the utility curve might not be anchored at the end points of zero utility at the minimum task level and 100 utility units at the maximum task level. For example, the minimum sleep level was four hours, which had no (zero) utility. I would think that one or two hours of sleep would certainly be better than no sleep; yet, all would have the same zero utility value in this analysis (also, weighting the zero utility value will always result in zero value regardless of the weight).

The authors missed an opportunity to validate several assumptions on task completion time. There are six tasks if MOS available time were included. However, the subject matter experts did not provide estimates on all six. Instead, the current TOE method was used for estimating MOS availability time.

To achieve the second objective of my critique, I considered the usefulness of the technique in modeling some level of war. The very limiting factors for using this in a war model are the implicit assumptions of steady state and rational decision makers. If the methodology were more dynamic and allowed for changing priorities, it could be used for task allocation in war models. I would like to see more scenario or situation specific variables to account for the changing conditions which affect decision making under the stressful conditions of battle.

The views which I presented above are my own and are not to be considered official US Army policy. I think that the report presents an advancement in the methodology previously used, but there is room for more improvement (as there is in most analytical projects).

SESSION IV: COMBAT AS A DATA SOURCE

SESSION CHAIR: Capt. Wayne P. Hughes, Jr., USN (Retired); NPGS

This session is so rich that the important thing for me to do is to tell everyone to pay attention and then sit down. Besides the prestige and authority of the four speakers, the session gets at the very heart of our MORIMOC problem: the best measurement--nay, very nearly the only measurement--of the influence of human factors for modeling combat operations is combat operations. Sad to say, the systematic collection of the historical data is not very great despite the superabundance of historians' and journalists' accounts. Their writing is dominated by anecdotes, descriptions, and interpretations that focus not on regular performance but on the heroic or despicable, usually drawn from climactic battles which almost by definition are statistical outliers in the study of war.

The writing of the journalist-General, S. L. A. Marshall, illustrates. His seminal book, Men Against Fire, caused a sensation when he said only a small percentage of soldiers pulled a trigger when engaged. But the book and his later work didn't create enough of a sensation to foster the kind of careful investigation warranted by his extraordinary conclusion. Just lately Men Against Fire has itself come under fire. I don't know how this new debate will come out, but it is important to both the combat leader and the combat analyst to settle the matter even at this late date with Marshall's perceptions so deeply ingrained. You will find David Rowland's paper not only instructive on its merits, but coincidentally highly pertinent in interpreting Marshall.

Each of the following speakers breaks the historian/journalist mold. Each in his own way will present a prototype of what can and should be done to produce useful data, and make the historical record more relevant.

THE FUNDAMENTAL INFORMATION BASE FOR MODELING HUMAN BEHAVIOR IN COMBAT

By

Col. Trevor N. Dupuy, USA, Retired

Fear in a Lethal Environment

Clausewitz and Behavioral Factors

Early in Book One of On War, Clausewitz emphasized the significance of passion in war. He dismissed the efforts of those who would study war as though it were merely an intellectual exercise. Of course intellect is import, he asserted, but simply to analyze combat in terms of numbers, he suggested somewhat contemptuously, is "kind of war by algebra." Among other things, he wrote: "... the impulse to destroy the enemy ... is central to the very idea of war." He then went on, in a brief chapter, to discuss "Danger in War." Time and time again he made the point that the activities of participants in combat involve passion and emotion, and are performed in a pervasive environment of fear.[1]

In these early pages Clausewitz touched lightly on points to which he devoted more attention later in the book. Numbers are important. So is rational analysis; for instance, numbers are less important for defenders than attackers because "defense is a stronger form of fighting than attack." Intellect and "genius" play a very significant role in successful combat.[2]

But he returned, time and again, to passion, emotion, and fear as the fundamental characteristics of combat.

No one who has participated in combat can disagree with this Clausewitzean emphasis on passion, emotion, and fear. Without doubt, the single most distinctive and pervasive characteristic of combat is fear: fear in a lethal environment.

There are, of course, mitigating factors. Discipline, training, and the inspirational influence of leadership can to a considerable degree offset--but never eliminate--the impact of fear on the activities of men in a combat environment. Also offsetting the degrading and depressing effects of fear, to some extent, are excitement and exhiliration experienced by some men (far from all) when offered an opportunity to excel in a risky situation. Yet even these brave, or foolhardy, men cannot completely escape the often-paralyzing effects of fear.

Quantifying the Effects of Fear

Since presumably all present at this meeting are here because they would agree with Clausewitz that human factors are important in war, I may be accused of preaching to the choir in my emphasis on those three human characteristics of passion, emotion, and fear. Perhaps I am guilty. But I suspect not. Just as many OR analysts often ignore the human element in war, so even among those who have not forgotten that element, there is a tendency to overlook the ubiquity of that one emotion which I have been emphasizing for the past few minutes: fear. Fear, I repeat, is the most pervasive aspect of combat, from which even the bravest are not immune.

We cannot replicate fear in laboratory experiments. We cannot introduce fear into field tests. We cannot create an environment of fear in training or in field exercises.

So, to study human reaction in a battlefield environment we have no choice but to go to the battlefield, not the laboratory, not the proving ground, not the training reservation. But, because of the nature of the very characteristics of combat which we want to study, we can't study them during the battle. We can only do so retrospectively.

We have no choice but to rely on military history. This is why military history has been called the laboratory of the soldier.

This does not invalidate the results of non-battlefield experiments. It does not mean that we cannot learn from field tests and field exercises. It means that these results are not quite the real thing. They are to some extent distorted. We can eliminate the distortion only through studying such non-battlefield results through the prism of military history.

Military History: Indispensable, but Imperfect

Please do not get the impression that I am saying that military history analysis will provide all answers to questions about human behavior in combat, or that from military history analysis alone we can determine how to represent human behavior in combat simulations. I am saying two things:

1. We cannot get the true answers about human behavior in combat without analysis of military history, and

2. Simulation factors that are inconsistent with historical experience are almost certainly wrong.

I must also make clear my recognition that military history data is far from perfect, and that--even at best--it reflects the actions and interactions of unpredictable human beings. Extreme caution must be exercised when using or analyzing military history. A single historical example can be misleading for either of two reasons: (a) The data is inaccurate, or (b) The example may be true, but also be untypical.

Beware a statement which asserts: "Military History proves that . . . " (Who among us has not seen such a statement?!) Military history doesn't prove anything. Good military history simply reflects--within the constraints of numerous human frailties--what has happened in the past under a great variety of circumstances, each set of which is probably non-reproduceable. But, when a number of respectable examples from history show consistent patterns of human behavior, then we can have confidence that behavior in accordance with the pattern is typical, and that behavior inconsistent with the pattern is either untypical, or is inaccurately represented.

My approach to historical analysis is actuarial. We cannot predict the future in any single instance. But, on the basis of a large set of reliable experience data, we can predict what is likely to occur under a given set of circumstances. It is this actuarial approach which permits insurance companies to predict likely human life spans, and to make modifications to those predictions on the basis of varying circumstances--such as the smoking habits of an individual.

One last general word about the value, and the limitations, of military history for analysis purposes.

Some operations research analysts believe that we cannot be confident that historical data is reliable--whether because of limitations on accuracy, or because of human unpredictability. Thus, they suggest, the data is unscientific, and so it should be ignored. They insist that our simulations should be based on scientifically provable data.

There are two things wrong with that approach.

In the first place it is impossible. Every model is based upon some fundamental assumptions that are entirely intuitive and totally unprovable.

In the second place, for the reasons I pointed out at the beginning, to ignore reality in favor of the laboratory is to assure failure to represent human behavior in combat.

For all of its shortcomings, military history is essential to good simulation of combat. From it we can substantiate our model assumptions. And from it we can see how humans really behave under the real circumstances of passion, emotion and fear. We have no choice but to recognize that there are shortcomings, and to do our best to eliminate those shortcomings by the greatest possible accuracy, combined with an actuarial approach.

Combat Phenomena Related to Human Behavior

Before considering how military history can provide us with a fundamental and indispensable basis for analysis of human factors in war, it might be helpful to review some of the more important combat phenomena that are directly or indirectly related to human behavior. I recognize ten such phenomena. While my list may not be exhaustive, I believe it is comprehensive.

Dispersion. There is one basic reason for the dispersal of troops on modern battlefields: to mitigate the lethal effects of firepower upon troops. As Lewis Richardson wrote in The Statistics of Deadly Quarrels, there is a limit to the amount of punishment human beings can sustain.[3] Dispersion was resorted to as a tactical response to firepower mostly because--as weapons became more lethal in the 17th Century--soldiers were already beginning to disperse without official sanction. This was because they sensed that on the bloody battlefields of that century they were approaching the limit of the punishment men can stand.

Defensive Posture. When men believe that their chances of survival in a combat situation become less than some value (which is probably quantifiable, and is unquestionably related to a strength ratio or a power ratio), they cannot and will not advance. They take cover so as to obtain some protection, and by so doing they redress the strength or power imbalance. A force with strength y (a strength less than opponent's strength x) has its strength multiplied by the effect of defensive posture (let's give it the symbol p) to a greater power value, so that power py approaches, equals, or exceeds x, the unenhanced power value of the force with the greater strength x. It was because of this that Clausewitz--who considered that battle outcome was the result of a mathematical equation--wrote that "defense is a stronger form of fighting than attack."[4] There is no question that he considered that defensive posture was a combat multiplier in this equation. It is obvious that the phenomenon of the strengthening effect of defensive posture is a combination of physical and human factors.

Surprise. A military force that is surprised is severely disrupted, and its fighting capability is severely degraded. Surprise is usually achieved by the side that has the initiative, and that is attacking. However, it can be achieved by a defending force. The most common example of defensive surprise is the ambush. Perhaps the best example of surprise achieved by a defender was that which Hannibal gained over the Romans at the Battle of Cannae, 216 BC, in which the Romans were suprised by the unexpected defensive maneuver of the Carthaginians. This permitted the outnumbered force, aided by the multiplying effect of suprise, to achieve a double envelopment of their numerically stronger force. It has been hypothesized, and the hypothesis rather conclusively substantiated, that surprise can be quantified in terms of the enhanced mobility (quantifiable) which surprise provides to the suprising force, by the reduced vulnerability (quantifiable) of the supriser, and the increased vulnerabillty (quantifiable) of the side that is surprised.

Fatigue. The effectiveness of a military force declines steadily every day that it is engaged in sustained combat. This is an indication that fear has a physical effect on human beings equatable with severe exertion. S.L.A. Marshall documented this extremely well in a report that he wrote a few years before he died.[5] I shall shortly have more to say about S.L.A. Marshall.

An approximate value for the daily effect of fatigue upon the effectiveness of weapons employment emerged from a HERO study several years ago.[6] There is no question that fatigue has a comparable degrading effect upon the ability of a force to advance. I know of no research to ascertain that effect. Until such research is performed, I have arbitrarily assumed that the degrading effect of fatigue upon advance rates is the same as its degrading effect upon weapons effectiveness. To those who might be shocked at such an assumption, my response is: We know there is an effect; it is better to use a crude approximation of that effect than to ignore it.

Combat Intensity. No one who has paid any attention at all to historical combat statistics can have failed to notice that some battles have been very bloody and hard-fought, while others--often under circumstances superficially similar--have reached a conclusion with relatively light casualties on one or both sides. I don't believe that it is terribly important to find a quantitative reason for such differences, mainly because I don't think there is any quantitative reason. The differences are usually due to such things as the general circumstances existing when the battles are fought, the personalities of the commanders, and the natures of the missions or objectives of one or both of the hostile forces, and the interactions of these personalities and missions.

From my standpoint the principal reason for trying to quantify the intensity of a battle is for purposes of comparative analysis. Just because casualties are relatively low on one or both sides does not necessarily mean that the battle was not intensive. And if the casualty rates are misinterpreted, then the analysis of the outcome can be distorted. For instance, a battle fought on a flat plain between two military forces will almost invariably have higher casualty rates for both sides than will a battle between those same two forces in mountainous terrain. A battle between those two forces in a heavy downpour, or in cold, wintry weather, will have lower casualties than when the forces are opposed to each other, under otherwise identical circumstances, in good weather. Casualty rates for small forces in a given set of circumstances are invariably higher than the rates for larger forces under otherwise identical circumstances.

If all of these things are taken into consideration, then it is possible to assess combat intensity fairly consistently. The formula I use is as follows:

$$CI = CR/(sz' \times rc \times hc) \qquad (1)$$

When: CI = Combat Intensity Measure

CR = Casualty rate in percent per day

sz' = Square root of sz, a factor reflecting the effect of size upon casualty rates, derived from historical experience

rc = The effect of terrain on casualty rates, derived from historical experience

hc = The effect of weather on casualty rates, derived from historical experience

I then (somewhat arbitrarily) identify seven levels of intensity:

0.00 to 0.49 Very low intensity (1)

0.50 to 0.99 Low intensity (56)

1.00 to 1.99 Normal intensity (213)

2.00 to 2.99 High intensity (101)

3.00 to 3.99 Very high intensity (30)

4.00 to 5.00 Extremely high intensity (17)

Over 5.00 Catastrophic outcome (20)

The numbers in parentheses show the distribution of intensity on each side in 219 battles in DMSi's QJM data base. The catastrophic battles include: the Russians in the Battles of Tannenberg and Gorlice Tarnow on the Eastern Front in World War I; the Russians on the first day of the Battle of Kursk in July 1943; a British defeat in Malaya in December, 1941; and 16 Japanese defeats on Okinawa. Each of these catastrophic instances, quantitatively identified, is consistent with a qualitative assessment of the outcome.

Suppression. Suppression is perhaps the most obvious and most extensive manifestation of the impact of fear on the battlefield. The British did some interesting but inconclusive work on suppression in their battlefield operations research in World War II. In the United States I am aware of considerable talk about suppression, but very little accomplishment, over the past 20 years. In the light of the significance of suppression, our failure to come to grips with the issue is really quite disgraceful.

We at HERO believe that we have a potential methodology, but have been unable to arouse any official interest in our approach. In brief that approach is to measure the relative combat effectiveness value (CEV) of two forces in a historical battle under "normal" combat circumstances, and then measure it again in a battle in which one side made extensive use of suppressive fire. Comparison of the two CEVs, in consideration of the ammunition expenditure rates in the two battles, should give a handle on the relationship of suppressive effect to volume of firepower. Results with one or two such comparisons have been promising.

Friction. Very briefly friction, as described by Clausewitz in On War, is simply degredation of the effectiveness of a force resulting from numbers of human interactions; i.e., numerical strength. I discuss friction fairly thoroughly in my book Understanding War.[7] Time precludes any elaboration on this at this time. This concept of friction, however, appears to me to be the only possible explanation of the unquestioned pattern of differences of casualty rates incurred and inflicted by forces of different sizes. This pattern, incidentally, exists, even after all due allowances for the proportions of larger forces in supporting and reserve roles. It provides the answer, in my opinion, to most of the problems of relationships in hierarchies of models.

Diminishing Returns. This, also, is discussed in Understanding War. Again time precludes any extensive discussion here. The important thing is that an understanding of the operation of the phenomenon of Diminishing Returns should facilitate application of the principle of Economy of Force.

Interaction of Variable Factors. It is almost undeniable that there must be some interaction among and within the effects of physical as well as behavioral variable factors. I know of no way of measuring this. One thing that is reasonably certain is that the use of the bottom-up approach to model design and development cannot capture such interactions. (Most models in use today are bottom-up models, built up from one-on-one weapons interactions to many-on-many.) Presumably these interactions are captured in a top-down model derived from historical experience, of which there is at least one in existence.

Finally:

Combat Effectiveness. Those of you familiar with my books Numbers, Predictions, and War[8] and Understanding War; History and Theory of Combat, will be aware that I have in recent years devoted much attention to the concept of Relative Combat Effectiveness and its quantification. The results of that work are considered by some people to be controversial. I am, however, sufficiently satisfied with the almost total consistency of those results with observed historical combat phenomena to have no doubt as to the validity of my concepts, arrogant though such a statement may seem. I am less satisfied--though not dissatisfied--with the specific relative Combat Effectiveness Values (CEVs) that emerge from my efforts at quantifying the results. Let me briefly summarize the concept, and its quantification.

Most of the physical factors affecting combat outcomes lend themselves to quantification in one fashion or another. Few of the behavioral factors are so readily quantifiable. I do believe, for reasons I have noted above, that some behavioral factors are quantifiable from observation of results; surprise is one such behavioral factor that I believe is quantifiable, as I have indicated above. But, in general, most behavioral factors are intangible, and not readily quantifiable. This, of course, is why we are meeting in this mini-symposium.

According to Clausewitz's "Law of Numbers" the outcome of a battle can be represented as follows:

$$Pr/Pb = (Nr \times Vr \times Qr)/(Nb \times Vb \times Qb) \qquad (2)$$

When: P = the combat power of a force

N = numerical strength

V = variable factors representing "circumstances of the combat"

Q = quality of a forces, which Clausewitz says "is a given quantity"

r = Red force identifier

b = Blue force identifier

The values for N and V are physical values, and can be obtained or derived from the historical data. The quantified ratio of the two qualities (Qr and Qb) provides us with a relative combat effectiveness value (CEV) for the forces in the engagement.

Thus:

$$Pr/Pb = [(Nr \times Vr)/(Nb \times Vb)] \times CEVr \qquad (3)$$

When: $CEVr = Qr/Qb$ (Obviously $CEVb = Qb/Qr$)

The theoretical outcome of a battle, without consideration of the intangible behavioral factors, is:

$$P'r/P'b = (Nr \times Vr)/(Nb \times Vb) \qquad (4)$$

When: P' = Combat power without considering qualitative factors

Thus:

$$Pr/Pb = (P'r/P'b) \times CEVr \qquad (5)$$

I have also demonstrated, fairly conclusively I believe, that the actual outcome of a battle can also be represented by another ratio:

$$Rr/Rb = (MFr + Espr + Ecasr)/(MFb + Espb + Ecasb) \qquad (6)$$

When: R = Result value for a force in a battle

MF = Mission accomplishment factor (an expert judgment assessment)

Esp = Spatial effectiveness factor (ability to gain or hold ground, equation empirically derived)

Ecas = Casualty effectiveness factor empirically derived; (considers strengths and losses of both sides)

Thus,

$$Rr/Rb = Pr/Pb = (P'r/P'b) \times CEVr \qquad (7)$$

or:

$$CEVr = (Rr/Rb)/(P'r/P'b) \qquad (8)$$

Or, verbally, the relative combat effectiveness value of one force with respect to another is equal to the ratio of their result values divided by the ratio of the theoretical outcome (combat power ratio without consideration of intangible factors).

Using this approach, the overall or combined quantitative effect of all of the intangibles--practically all behavioral factors other than suprise (which is also a circumstantial factor)--can be determined in individual historical battles from a study of the historical records. So, even if we are never able to break down the individual effects of the components of relative combat effectiveness, this method provides a value for a composite of these intangibles, which we can call combat effectiveness, or troop quality.

Why am I satisfied with my results? For two reasons.

First, in any set of battles involving two specific opponents, or two specific national military forces, the CEV ratios cluster in groups quite consistent with historical observation of the relative capability of the oppoments. For instance, the CEV values marking the superiority of Germans over Western Allies in World Wars I and II cluster around 1.2. In other words the Germans were consistently better than the Americans, British, and French, but only by a relatively narrow--even though consistent--margin, about 20%. The values for the German superiority over Russians in those World Wars cluster between 2.0 and 2.5, with the German superiority declining to about 1.8 in late 1944 and 1945. The values for Israeli superiority over Arab opponents cluster in separate groups for combat with Jordanians, Syrians, and Egyptians, but they all average close to 2.0.

The second reason for my satisfaction with the concept is that there is an obviously close relationship between the CEVs so calculated and the exchange ratios by which these opponents inflict casualties on each other. Almost invariably 100 Germans inflicted casualties on their opponents on all fronts at a higher rate than 100 of their opponents were able to inflict on them. This, of course, is not conjecture, and is not the result of any manipulation of numbers. This is solid, quantitative historical fact. And the same is true of the relative casualty-inflicting capability of Israelis and Arabs.

Let me elaborate briefly.

<u>The New Square Law</u>. Some years ago it became evident to me that the CEV values in a battle were similar to, but always less than, the ratio of the casualty-inflicting capabilities of the two forces. After some experimentation, it became obvious that the relationship was as follows:

$$CEVr = \sqrt{(Lr/Lb)} \qquad (9)$$

When: L = The casualty inflicting capability of a force, derived, of course, from the casualties incurred.

I called this "The New Square Law." I soon discovered that this relationship had several, interesting uses.

In the first place, it permitted calculation of the coefficients for the Lanchester Equations for these battles.[9]

Second, it provided an alternative way of calculating the relative combat effectiveness of the opposing forces, simply on the basis of strength and casualty figures of the battle.

Third, and perhaps most important, it demonstrated that Napoleon was almost right when he said something like: "The moral is to the physical as three is to one." The New Square Law says that the "moral is the equivalent of the physical squared," and that the importance of the human element in war is exponentially greater than that of the physical element (i.e., people are more important than weapons.)

Let me demonstrate the significance of this with respect to the current confrontation of NATO and Warsaw Pact in Europe.

Our potential enemy has about twice as many troops and major weapons as we do. We cannot make weapons twice as good. NATO's political leadership will never double the strength of our forces. But if we can, through emphasis on troop quality and the human factors, increase the CEVs of our troops with respect to the Soviets to a factor of 1.41 (not a hopeless possibility, as demonstrated in World War II), we can offset the enemy's twofold numerical superiority. This is because the square of 1.41 is 2.0.

Components of Relative Combat Effectiveness

Now, then, what are the components of Relative Combat Effectiveness values, or CEVs? I believe that they are all of the intangible factors--behavioral, or behavioral mixed with physical--that I have been able to identify, but not yet satisfactorily quantify. I shall not take time to discuss any of these, but I shall list them. The first four or five are, I believe, the most important, and probably make up the bulk of the CEV value. The values of the others I simply do not know, but I am sure they have some value, and cannot be ignored:

- Leadership
- Training or Experience
- Morale, which may or may not include
- Cohesion
- Logistical effectiveness
- Time and Space
- Momentum
- Technical Command, Control, Communications
- Intelligence
- Initiative
- Chance

Is chance, or luck, a behavioral factor? Quite frankly I do not know. But I do remember Napoleon's famous remark: "Give me lucky generals."

Status of Historical Research in Behavioral Factors

Before World War II

We know from their writings that two, and possibly three, 19th Century military scholars were obviously aware that it was possible to quantify behavioral factors. These were Clausewitz; the American military historian, Theodore Ayrault Dodge; and possibly another American military historian, Thomas L. Livermore.

As to Livermore, in his classic Numbers and Losses in the Civil War[10], he clearly recognized that the exchange ratio of casualty infliction was an indication of relative combat effectiveness. However, the quality differential between Union and Confederate forces was negligible, and so Livermore had little to say about the potential measurement significance of this quantitative approach, which he pioneered.

Clausewitz, despite the common perception that he ignored numbers and concentrated on qualitative concepts, demonstrated in On War[11] his understanding of the quantitative, or scalar, significance of such things as leadership, troop quality, defensive posture, and friction. In one of his more obscure works there is also a clear statement, in unambiguous quantitative terms, of the concepts which we now call the Lanchester Equations. Unfortunately, however, he never did more than express his general ideas on quantitative relationships, and (except for the Lanchester-like concept) one looks in vain in his writings for numerical historical data relating to these concepts.

Dodge was the first scholar to translate Clausewitz's ideas about friction into numerical values.[12] It is doubtful if Dodge realized that he was putting flesh on the Clausewitz concept of friction by using a large historical data base to arrive at what were really friction coefficients. Of course he realized what he was doing; he simply doesn't seem to have been aware of what Clausewitz had written on the subject. (There was little appreciation of Clausewitz in the United States in his time.) From his data base he also formulated some quantified hypotheses about the effects of fatigue on troop movements in a combat environment.

There is some evidence that German General Staff officers were interested in trying to adapt Delbruck's quantitative historical comparisons to historical combat analysis. However, I know of no published works reporting on such adaptations.

Surprisingly J.F.C. Fuller, who in so many other ways stressed the importance of military history analysis, does not seem to have given any special consideration to the quantification of behavioral factors.

Since World War II

In the last half century there have been four or five examples of quantitative analysis of historical combat data by individuals or institutions, but only two of these seem to have been either extensive or systematic.

During World War II when Colonel S.L.A. Marshall was the Chief Historian of the US European Theater of Operations, he undertook a number of interviews of units just after they had been in combat. After the war, in his book Men Against Fire, Marshall asserted that his interviews revealed that only 15% of US infantry soldiers fired their small arms weapons in combat. This revelation created something of a sensation at the time.

It has since been demonstrated that Marshall did not really have solid, scientific data for his assertion. But those who criticise Marshall for unscholarly, unscientific work should realize that in private life he was an exceptionally good newspaper reporter. His conclusions, based upon his observations, may have been largely intuitive, but I am convinced that they were generally, if not specifically, sound.

Undoubtedly the most massive effort to analyze historical combat data has been that of the Soviet Military History Institute, operating under the direction of the Soviet Army General Staff.[13] We do not know too much about that Institute. Apparently it is made up of some 300 professional scholars, led by a lieutenant general, devoting themselves to the application of historical experience to the current problems of the Soviet armed forces.

In my opinion, nothing better demonstrates the application of the results of historical analysis to combat theory than the official statement of the Soviet concept of "Correlation of Forces and Means." Summarized below is a three-page exposition of that concept as it appears in the official Soviet Military Encyclopedia:

> An indicator of the fighting power of opposing sides, showing the degree of superiority of one over the other. It is determined by comparison of existing quantitative and qualitative data of opposing forces.
>
> An analysis of the correlation of forces permits a deeper investigation into the essence of past battles and engagements. It is usually calculated during preparation for battle.
>
> An estimate is made of the quantity of forces and means necessary for accomplishing missions.
>
> A correlation of forces was estimated during the great patriotic war based on the combat and numerical strength of our own forces and the enemy's. This method of calculating the correlation of forces is also useful today.
>
> Where combat capabilities differ significantly, estimated coefficients of comparability of combat potentials are used. The following are also taken into account: opposing organizations, training, nationality, moral and fighting qualities, armament and equipment, leadership, terrain, etc. Factors are compared with the aid of coefficients.
>
> Modern computers speed up computation. Changes during combat can be determined by modeling.[14]

The United States Armed Forces pay lip service to the importance of military history. Officers are urged to read military history, but given little guidance on how military history can be really useful to them. The fundamental difference between the Soviet approach and the American approach, as I see it, is that the American officer is invited (but not really encouraged) to be a military history dilettante. The Soviets seriously study, and use military history. Figure 1 summarizes the differences in approaches of the U.S. and the Soviet armed forces to military history analysis.

One of the few examples of the use of military history in the West in recent years was an important study done at the British Defence Operational Analysis Establishment (DOAE) by David Rowland. An unclassified condensation of that study was published in the June 1986 issue of the Journal of the Royal United Services Institution (RUSI). The article, "Assessments of Combat Degradation," demonstrates conclusively that, in historical combat, small arms weapons have had only one-seventh to one-tenth of their theoretical effectiveness. Rowland does not attempt to say why this is so, but it is interesting that his value of one-seventh is very close to the S. L. A. Marshall 15% figure. Both values translate into casualty effects very similar to those that have emerged from my own research.

Figure 1
Comparison of US and Soviet
Use of Military History

Characteristics	US Mil. Establishment	Soviet Mil. Establishment
Emphasis On:	Inputs & Mathematical Forms	Outputs & Reality
Treatment of "Intangibles"	Omitted as not Measurable	Included & Effects Assessed
Size of Data	Small, Selective, & Theoretical Base	Large & Comprehensive
Attitude on Analysis	Non-Quantifiable for Analysis; Use of Quantified "Norms"	Essential to History:
Use of History:	Infrequent, Selective, & Subjective	Comprehensive, (& Objective?)
Scientific Rigor:	Fair	Good
Confidence in Results:	Dubious	Substantial

I should also mention Sally Van Nostrand at the U.S. Army Concepts Analysis Agency. With the encouragement of the Director, E.B. Vandiver, she has been doing some interesting work analyzing historical data on human performance.

I believe it is safe to say, however, that the most intensive work on the analysis of military historical data west of Moscow has been done by my own Historical Evaluation and Research Organization, known by its modest acronym, HERO. I cannot comment on our work objectively, of course, but I believe that our greatest contribution has been in focusing attention on the importance of behavioral factors in combat, and in demonstrating that it is dangerous to ignore these factors, simply because we don't have good values for them.

Unfortunately, however, HERO has had no endowment, and no regularized funding support that would enable us to undertake a comprehensive, systematic approach to the analysis of historical data. HERO has eked out a bare survival existence over the past 25 years only by scrambling for crumbs from the tables of large OR projects, in which any historical analysis has usually been an afterthought.

Over this quarter century HERO has performed more than 160 studies directly or indirectly for the US Government. Some of these have, in one way or another, produced results of actual or potential value to the modeling community. The prinicipal study reports in this category are listed in Appendix "A". Other studies have, in many instances, led to conclusions and recommendations about actions that could be (or should be) taken to improve our understanding of and (implicity or explicitly) our representation of, behavioral factors in combat. I recently made a survey of 15 of these reports, for the purpose of assessing what has been done about the recommendations presented in them.

The result of my survey (See Appendix B) was quite discouraging. For all practical purposes, nothing has been done. In its wisdom, the Government has spent a substantial sum of money (although, Lord knows, not much for any single one of these studies) to seek the application of our expertise in research and analyses, and has then virtually ignored what we did. This implies an inefficiency which is mind-boggling.

Let me summarize what I believe HERO has done over the past quarter century on a listing of Behavioral, or Moral, Factors in War, in Figure 2. Shown here are some 22 different behavioral factors, in four rather general categories. We have produced some sort of quantification hypothesis for 14 of those factors.

What Needs to be Done

I hope I have conclusively demonstrated three things:

First, military history can contribute greatly to our understanding, and quantitative representation, of behavioral factors in combat.

Second, behavioral factor research without military history will provide results that are at best distorted and at worst wrong.

Figure 2
BEHAVIORAL (MORAL) FACTORS IN WAR

o <u>Leadership</u>

- Training/Experience
- Application of Combat Multipliers*
- Set-Piece Battle Preparations*
- Logistical Effectiveness

o <u>Disruption</u>

- Surprise*
- Suppression*
- Unit "Breakpoints"*

o <u>Quality of Forces & Manpower</u>

- Relative Combat Effectiveness*
- Trends over Time*
- Morale
- Cohesion
- Fatigue*

o <u>Relationship of Moral & Physical Factors*</u>

- Interaction of Firepower, Mobility, Dispersion*
- Combat Intensity*
- Friction*
- Defensive Posture*
- Momentum
- Time & Space

* Quantification hypotheses exist

Third, the United States defense establishment does not adequately use military history for operations research analysis.

If I am right, something needs to be done. I shall conclude by presenting an approach to getting something done.

I have ideas on a comprehensive program for military history research, to provide data for further study of the impact of behavioral factors on combat operations. However, given the background of the status of military history research in the United States, a preliminary assessment of requirements is necessary. This should be a reasoned and objective consideration of the merits and demerits of historical analysis as an addition to the arsenal of analytic tools used in DoD. I would propose that this consideration should be by a qualified mixed military-civilian study team in terms of five tasks, as follows:

In the early Nineteenth Century, Gerhard von Scharnhorst struggled vainly for several years to overcome the intellectual rigidity and regimentation of the Prussian Junker officer corps, and their deep suspicion of academic achievement in both history and science. Nevertheless (admittedly with some assistance from Napoleon and the thrashings he gave the Prussians at Jena, Auerstadt, and Friedland), by 1814 Scharnhorst had initiated a military system that would soon bring to the Prussian/German military establishment a well-deserved reputation for technical efficiency combined with historically-inspired, imaginative, innovative leadership and flexible combat doctrine and tactics.

In large part this achievement was possible because Scharnhorst's creation, the Prussian General Staff, deliberately attempted to offset the stultifying effects of typical German rigidity and regimentation by inculcating in its officer corps the concepts of initiative and flexibility, concepts which were not typical of Germans, but which Germans could learn and apply. The General Staff did this by institutionalizing military genius, and then imparting these learned (non-inherent) traits to the entire German officer corps.

If the Germans could institutionalize non-typical, non-traditional characteristics in their General Staff and officer corps, so can we. What is needed is a conscious decision, like that of the Prussians after 1807. The institution by the Department of Defense of a multi-year program of military historical analysis, adequately funded and enthusiastically supported, can accomplish what is needed. Here are some of the results that would flow from such a program:

- Immediate meaning and focus would be provided to the pro-forma military history instruction in service schools and war colleges.
- Military history would be used consistently in all of the services, in DOD, and the Joint Staff.
- Decision-makers and planners would be encouraged to use, and to rely upon, analyses based on military history.
- A truly focussed effort would be made to use history to bring realism to the simulation of human behavior in our combat models.

Sam, such a dream could come to pass. And your ghost could take comfort in knowing that Americans really can learn!

Appendix A

HERO REPORTS CONTRIBUTING TO
MODEL DEVELOPMENT

Rprt No. Report Title	Significance
4. Historical Trends Related to Weapons Lethality (CDC, 1964)	1. Relating weapons changes to tactical & doctrinal change 2. Theoretical Lethality Index (comparison of weapons effectiveness)
16. Average Casualty Rates for War Games, Based on Historical Combat Data (RAC, 1966)	1. Provided basis for casualty rates for ATLAS (CEM? FORCEM?) & other models
17. Developing a Methodology to Relate Mobility to Combat Effectiveness (RAC, 1967)	1. Showed historical significance of Mobility 2. A step toward quantifying effectiveness
27...35. Historical Data Research on Air Interdiction in WW-II (USAF, S&A, 1969-72)	1. Survey tactical air support & interdiction, Tunisia to Germany, 1942-1945 2. Relationship of ground & air operations
32. Use of Historical Data in Evaluating Military Effectiveness (USAF, S&A, 1969)	1. Effort to quantify data & factors to represent air supported ground operations 2. Beginning of ground battle data base
34. A Study of the Relationship of Tactical Air Support to Land Combat (DOAE, 1970)	1. Quantification of data & factors in QJM 2. Quantified relationship of air & ground combat
50. Combat Data Subscription Service (1975-1977)	1. Comprehensive quantification of miscellaneous combat data
51. A Survey of "Quick Wins" in Modern War (N/A, 1975	1. Importance of Quality (troops, leaders, staffs 2. Importance of Mobility (technological, conceptual) 3. Importance of Surprise
52. A Study of Breakthrough Operations (DNA, 1976)	1. Quantification of "Multipliers" 2. Quantification of Attacker & Defender norms 3. Recognized Relative Combat Effectiveness

Rprt No.	Report Title	Significance
56.	Assessment of Arab & Israeli Combat Effectiveness 1967 & 1973 Wars (CIA, 1977)	1. Detailed breakdown of engagement data 2. Evaluation of Relative Combat Effectiveness of Israelis & several Arab armies
95.	Analysis of Factors.... A Data Base of Battles & Engagements (CAA, 1983)	1. Comprehensive data base 603 battles & engagements, 1600-1973
165.	Comparison of Relative Combat Effectiveness, Offense, Defense (DOAE, 1988)	1. Comprehensive review of CEV methodology 2. Compares national CEVs, and effect of offensive & defensive postures
166.	Forced Changes of Combat Postures ("Breakpoints") (CAA, 1988)	1. Compilation & analysis of factors associated with "breakpoints" 2. Development of breakpoint models for regt & division, time-step & event-sequence 3. Demolishes idea of attrition-related thresholds or breakpoints

SOME HERO RECOMMENDATIONS AND GOVERNMENT
ACTIONS ON SELECTED HERO REPORTS

HERO Rprt No.	Report Title	Recommended Action	Government Action Y	Government Action N
20.	Comparative Analysis of Armored Conflict Experience (DOD, PA&E, 1967)			
		1. Review existing historical data to determine characteristics of tank endurance & reliability		x
		2. Establish armored conflict experience data base		x
		3. Review previous studies of such experience		x
		4. Review campaign experience of US, British, and German armored units in World War II		x
28.	Disruption in Combat (USAF, 1970)			
		1. Systematic exploration of historical effects of combat disruption	#	
		2. Determine historical relation of disruption & behavioral factors		x
36.	Opposed Rates of Advance of Large Forces in Europe (ORALFORE) (USA, DCSOPS, 1972)			
		1. Tentatvely adopt detailed rates establshed in study		x
		2. Develop advance rate data base to refine rates		x
41.	Rate of Ammunition Expenditure in Relation to Posture (SHAPE, 1973)			
		1. Develop historical data base for determination of method to calculate combat intensity	*	
		2. Determine systematically the relationship of historical expenditures to posture & intensity		x
44.	Historical Evaluation of Barrier Effectiveness (CAA, 1974)			
		1. Verify detailed historical defense & delay factors for barriers & terrain found in study		x
		2. Verify detailed historical factors for constraints on construction efforts found in study.		x

HERO Rprt No.	Report Title	Recommended Action	Government Action Y	N
58.	Assessment of Danger of Surprise Attack in Europe, & NATO Vulnerability (USAF, 1977)			
		1. Comprehensive assessment of historical factors in chievement or frustration of surprise	#	
		2. Review & reassess past related studies	#	
61.	Implications of Surprise in Conventional & Tactical Nuclear Combat in Europe (DNA, DCSOPS. 1978)			
		1. Refine tac nuclear combt model designed in study		x
		2. Comprehensive study to relate historical effects of surprise on advnce rates, force ratios, attrtion, etc.		x
62.	Search for Historical Records Records of High Rate Artillery Fire in Combat (HEL, 1978)			
		1. Establish artillery combat data base		x
		2. Review historical data to test results of preliminary investigation in this study		x
65.	Effects of Combat Losses & Fatigue on Operational Performance (TRADOC, 1979)			
		1. Verify findings regarding Fatigue Indicators		x
		2. Verify findings regarding degradation factors		x
71.	The Value of Field Fortifications in Modern Warfare (DNA, 1979)			
		1. Extend, refine, & validate factors in earlier Barrier study		x
		2. Verify findings on establishing barrier in Europe		x
73.	The Impact of Nuclear Weapons Employment on Factors of Combat (DNA, 1980)			
		1. Establish historical combat engagement data base	*	
		2. Undertake detailed survey of data base design		x

HERO Rprt No.	Report Title	Recommended Action	Government Action Y	N
81.	Soldier Capability-Army Combat Effectiveness (SCACE); Historical Analyses (USA Soldier Spt Ctr, 1980)			
		1. Compare combat effectiveness of selected US divs in WW-I & WW-II		x
		2. Assess small unit performance in historical data of 1st and 2d Divisions in WWI		x
		3. Explore relationship of national manpower quality & demonstrated historical combat effectiveness		x
		4. Investigate & analyze relevant Israeli experience	#	
		5. Examine conscript & volunteer performance in Franco-Prussian War		x
		6. Examine historical experience of US Army & US Marine Corps combat effectiveness		x
		7. Compare troop performance & capability in field training exercises	#	
		8. Survey 20th Cent US manpower capability experience in combat & suppport, for draftees & volunteers		x
		9. Examine historical records of elite units' performance, and effect on non-elite units		x
88.	The US Army 88th Division in World War II (OASD-MRA&L, 1981)			
		1. Make comparable analyses of other 88th Div engagenments		x
		2. Compare training & combat performance records of 88th and 85th Divisions		x
		3. Compare findings with literature relative to morale & esprit de corps		x
91A.	Conventional Attrition & Battle Termination Criteria (DNA, 1982)			
		1. Develop a QJM methodology for naval warfare	*	
		2. Develop historical naval warfare data base		x
136.	Handbook on Ground Forces Attrition in Modern Warfare (CIA, 1986)			
		1. Verify handbook data from further historical study		x
		2. Verify concept of Relative Combat Effectiveness		x
		3. Verify Attrition Verities from more historcal data		x

Summary

Actions Taken on HERO Recommendations

Action may have been taken:	5
Action taken for another reason: (Same action in two cases; non-funded in the other)	3
No action taken	33-38

NOTES

1. Clausewitz, *On War*, Howard-Paret translation, Princeton, 1984, Chapter One, Book One, *passim*.

2. *Ibid*.

3. Richardson, Lewis F., *The Statistics of Deadly Quarrels*, Pittsburgh, 1960.

4. *Ibid*., pg. 84, Section 17.

5. "The Shock Impact of Combined Arms Forces in World War II Amphibious Operations," *History, Numbers and War*, Vol. 2, Number 1, Spring, 1978.

6. *HERO Combat Data Subscription Service*, Winter, 1975, p. 80.

7. Dupuy, T.N., *Understanding War; History and Theory of Combat*, New york, 1987, Chapter 14.

8. Dupuy, T.N., *Numbers, Predictions and War* (Revised Edition), Fairfax, VA, 1984.

9. *Understanding War*, *op cit*, Chapter 16.

10. Livermore, Thomas 1., *Numbers and Losses in the Civil War*, Bloomington, IN, 1957.

11. Clausewitz, Carl Von, *On War*, Translated by Michael Howard and Peter Paret, Princeton, NJ, 1976.

12. Dodge, Theodore Ayrault, *Great Captains*, *Alexander*, *Hannibal*, *Gustavus Adolphus*, *Napoleon*, Boston, 1890-1904.

13. See *Understanding War*, *op cit*, Chapter 5.

14. Extract from V.I. Belyakov, *Soviet Military Encyclopedia*, Moscow, 1979.

ASSESSMENT OF COMBAT PERFORMANCE WITH SMALL ARMS

DAVID ROWLAND

Defence Operational Analysis Establishment
West Byfleet, Surrey

INTRODUCTION

Estimates of human performance in battle are notoriously difficult to make both because of the great many differences between the circumstances of individual battles, and the large variability between the course of battles in the same circumstances.

Extensive effort is expended in battle in attempting to degrade the performance of the other side - large parts of the effect of artillery fire, small arms and tank fire are expended in the belief that they do have some finite effect; however these degradation factors are seldom fully represented in combat models and equally cannot be assessed in peacetime trials because of difficulty in representing the danger inherent in their use.

This paper presents the result of a study into some aspects of combat degradation, mainly those relating to small arms fire in defence; the main rural combat study started by looking for one or two factors, and ended with a set of eight. The types of degradation accorded with military opinion, but the extent, especially of the combined factors, has surprised many.

The study will be presented in the following form:

a. First of all it will go through the background as to why the study was required and the reasoning behind the approach taken.

b. It will then take you through rural battles in which only rifles were used then go on to battles with only rifles and MGs.

c. It will consider the effect of artillery.

d. It will then look at the armour and anti-armour effects including obstacles.

e. It will then consider differences in making a similar comparison with urban combat.

f. Finally it will outline the approach to representing the factors in a combat model.

BACKGROUND

Over the past ten years the Field Studies Division of the Defence Operational Analysis Establishment has conducted a series of trials in which simulated direct fire combat has been represented by the use of pulsed laser weapons simulators.

These two sided trials with the capability for real time interaction allow realistic play and promote the motivation of the players. They thus provide good training for those taking part and an opportunity to collect data on appropriate types of combat to a level of resolution which would not be possible in war.

When we extended the use of this technique from armour/anti-armour combat to small arms fire there were cautions sounded on the limits of what could be represented using weapons simulators instead of live fire to represent small arms. In support of these cautions, the main evidence cited was SLA Marshal's post combat interviews with American servicemen in World War II. (Ref 1) It is appropriate to give the gist of his findings that on average only 15 men in 100 would take any active part with their weapons, and seldom above about 25% even under intense local pressure. Men with heavier weapons showed higher participation than this 15% mean, and thus the participation of riflemen tended to be lower.

We discussed the problem and rationalised that in our trials we would be representing those who did participate, and that we should, in parallel, test how relevant Marshal's data was to our data in combat modelling. However, whilst we have found a variety of responses from individuals to Marshal's work there has been no general acceptance that his findings for GIs in World War II applied to other situations - for example modern British troops.

The tactical trials themselves provided the necessary base to this analysis; they helped both in examination of historical data and in allowing the bringing together of comparative data from different sources. In particular they enable estimates to be made of the physical limitations of small arms combat in the absence of fear and, from their detail, they allow an important relationship with force ratio to be deduced and, as will be seen, tested against historical data.

RESULTS FROM TACTICAL TRIALS

The results of our close combat trials showed considerable degradation from what might have been expected from the results of live fire in range firing, so we had a reliable datum based on this live fire range situation with static targets. Comparing this range capability with defenders in our tactical trials we found several aspects of relative degradation in the latter. These resulted from overkill and from less accurate fire due partly to target movement and partly to a slower rate of fire in the tactical situation - especially for rifles. Putting these factors together we obtained total degradations of the order of ten times between range and tactical trials although larger for rifles, and smaller for machine guns.

The degradation in rate of fire, which was most marked with few targets available to fire at, was also studied. As the graph in Fig 1 takes the same form as those in figs 3 and 4, let me first explain the axes. The number of targets available is expressed as force ratio on the horizontal axis. The effect of rate of fire as attack casualties per defender (over the whole battle is on the vertical axis. Each axis on these graphs is plotted to a logarithmic scale as it allows a wide range of values to be represented, and also allows the expected relationship to be approximated by a straight line.

This graph (Fig 1) summarising casualties inflicted during tactical trials shows the variation of attack casualties per defence weapon for rifles and machine guns. At a 4:1 force ratio the casualties are approximately double those at 1:1 force ratio. Another significant finding from all our simulated combat trials is the large variation in contributions, between individuals even among those who do participate. Turning to real combat data, how could we compare the fragmentary and superficial data from this source with our detailed trials data?

ESTIMATES FROM HISTORICAL DATA

Given the nature of recorded combat data the comparison could only be at a fairly high level of aggregation between overall totals of attack casualties in an attempted assault, without knowing at which stage they occurred or what caused them, compared with the quantity of defence weapons or men.

In comparing these figures we were also faced with the possible variations of degradation between weapons - Marshal data indicated greater non-participation by riflemen than by heavy weapon crews, so we could not ignore that possible difference, nor could we ignore the effects of defence or attack indirect fire.

Fig 2 is a diagram of weapon usage through time; it indicates the way into the problem. It may be seen that in the 1860s rifles replaced muskets, and were for the next 50 years the main small arms in use; although machine guns were used in the Boer War, their major use started during World War I. At about the same time artillery fire changed from direct to observed indirect fire, and tanks came into use as a means of reducing the defence's direct fire advantage. Anti-tank guns, other than simple expedients, dated from World War II.

By considering battles before 1914 we were able to confine our analysis to examining the degradation to rifle fire. We can then consider the other weapon effects by selecting battles in which only some were present, working forward to include eventually all those battles for which data are available.

HISTORICAL DATA ON RIFLE AND M.G. EFFECTIVENESS IN BATTLE

Thus it was decided to attempt to obtain first an estimate of rifle effectiveness by considering battles before machine guns and indirect fire became significant; sets from battles in the Boer and US Civil Wars were used.

There was however tremendous scatter in the combat results; eventually - remembering the sensitivity of trials firing rate to number of targets, I examined the results for the effect of force ratio, and these showed a significant relationship which allowed much of the apparent scatter to be explained. Examination of separate results by war and by success of attack allowed the data extracted from these two wars to be pooled and used for analysis together. Results are shown in Fig 3. As with the trials results, these are plotted as attack casualties/defender against force ratio (a measure of target availability).

Other battles were also examined for evidence of any differences from the trend - the Franco-Prussian War, Rorkes Drift in the Zulu War, and notably three battles in World War I with British rifle defence (Landrecies, Mons, Neuve Chappelle) all follow the trend closely.

Altogether a total of 47 battles in which rifles were the main defensive weapon provided a good estimate of the relationship between attack casualties/defender and force ratio - with 65% of the variation explained by force ratio, and the remaining 35% giving a spread similar to that expected from comparison between similar battles under trial conditions.

However the order of effectiveness for rifles in defence was very different from the combat trials results. Fig 3 also shows these simulated battle results, reduced to the same form and scale and assuming that our highest trial level of combat, with up to a company visible to a defender, is a representative slice of the generally larger battles from historical data. The similarity in trend of casualties with force ratio is at once evident from the gradients, but with battle casualties/rifleman about one tenth those attributable on trials, possibly down to one eighth at 3:1 force ratio. In absolute value, attack casualties inflicted by each defending rifleman present in a real battle were about 0.5 at 3:1 force ratio falling to the 0.25 at unity force ratio.

This 10:1 ratio between the trials results and the results of the wars studied, is consistent with Marshal's participation factor of at most 15% for riflemen (which implies a degradation factor of at least 7:1 (Ref 1). The results of trials and analysis of past wars studied are together consistent in that the slopes (in fig 3) are similar and Marshal's findings could explain the difference in kill ratio for rifles; but what about heavy weapons which Marshal found less degraded?

In general, defensive forces with machine guns also deployed mortars. In order to make any examination of these heavy weapons, it was therefore necessary to separate the effectiveness of MGs in causing casualties from mortar effectiveness (Ref 2). With this defence indirect fire relationship and the estimated effectiveness of defence rifle fire, it was now possible to use attack casualty data, deduct casualties attributable to defence rifles and then apportion those remaining between "equivalent machine guns".

Figure 4 indicates that MGs in combat were about 15-25% as effective as on interactive combat trials, a degradation factor of about 1 in 5, and notably better than for rifles; this again is generally consistent with Marshal's findings.

When I now plot the results of World War II battles (except the D-Day beaches) as attack casualties/defence m.g. against attack AFV/defence mg there is a significant relationship (see fig 8). While the points do at first sight appear scattered, the correlation coefficient of 0.8 is fairly high indicating 65% of the variation is explained by the relationship. Moreover the best fit line through the points is robust to the inclusion of the extreme point (for Ops Veritable) which might be thought to have been driving it; the broken line represents the relationship if Op VERITABLE is excluded. Fig 9 compares the D-Day beaches and other World War II battles, both relationships show remarkably similar gradients.

There still remained another discrepancy however, whilst these results showed a marked trend to suppression of the defence it is not very significant at about 2 tanks/defending machine gun. Consider by contrast the effective suppression of the Australian defences at Tobruk on 1st May 1941. Typical actions described in the Australian Official History recounted the attack on each half platoon post by two German tanks. These bombarded the posts, then a few infantry dismounted under cover of tank fire and dropped grenades into the weapon pits forcing the defenders to surrender.

Here near total suppression was achieved with two tanks per machine gun, and it was suppression of resolute defenders as earlier battles had shown. The Australian problem was lack of anti-tank guns, so how would the presence of defence anti-tank fire effect attacking tanks? Either simple imagination or a little further analysis of history suggests the answer - defensive anti-tank fire dilutes the attacking tanks' attention to defence small arms since a share of this attention is given to detecting and engaging the immediate threat to the tanks themselves.

A closer examination of battles with attack tanks but with no effective anti-tank fire is possible by an examination of World War I battles in which tanks were used. These included the major battles such as Cambrai and Amiens, in which the use of tanks was remarkably successful and smaller local actions for which data were available. When plotted in the same way as before we obtain a similar curve, Fig 10 - but here there is a marked degradation (by a factor of 10) at about 2 tanks/m.g. as noted incidentally for Tobruk, instead of at 8 tanks/mg as for most World War II battles - as shown to this scale on the two broken line curves - brought forward from previous Figures. This means that the tanks in WWI caused a generally greater degradation, for a given number, than tanks in World War II.

The hypothesis of dilution of attention suggests a means of combining the two sets of data - to equate the attention given to an anti-tank gun to that given to say 'x' machine guns - 'x' will be expected to be bigger for more powerful guns but as a first step we will consider a 'typical' World War II anti-tank gun, since to do more would strain the limits of available data. A value of x was estimated from the extreme of the World War II battles - Ops VERITABLE and CLIPPER - the value obtained was used in all those battles with anti-tank weapons to calculate a total of equivalent defence mg including the attention due to representative machine guns.

Effects of Attack Artillery

Further examination of the World War I and II battles showed many whose rifle and machine gun effectiveness was even lower than that described above. It was possible to associate some of these with the after effects of preparatory attack artillery bombardment. Again some World War II operational research studies (unpublished) had examined sets of battles and produced estimates of artillery bombardment duration (from fire plans) and density from crater count.

Each set was characterised by a different duration of bombardment - several minutes for D-Day, several hours for Ops Veritable and Clipper and days for the Pacific Island assaults. Bearing in mind their relative durations, the relative slopes of these lines form a consistent pattern - for a given total weight of bombardment the shortest/sharpest provides the greatest degradation. Thus, for example, the Normandy landings show the greatest degradation for a given weight of bombardment, and the bombardment was the shortest of the three in duration.

Fig 7 shows the relationship between the density and duration of bombardment required to achieve a given level of degradation is linear when plotted on a log-log basis. Thus, for example, to achieve 90% degradation a density of 0.4 lb. HE/square yard over a duration of one hour is as effectie as a density of 4 lb.HE/square yard in 100 hours. It should be noted, here, that 90% degradation imples a further factor of 10, on the effectiveness in figs 3 and 4.

From these curves a relationship for degradation due to artillery can be devised in terms of density and duration - thus results of these and other individual battles can be corrected to zero artillery bombardment - increasing the actual casualties to a notional figure to be expected had there been no preparatory bombardment.

Effects of Attack AFV

Even after applying the correction for preparatory artillery bombardment there remained several battles in which defence weapon effectiveness was substantially lower than the figures I have quoted.

Qualitative comments on the effectiveness of attack AFVs in suppressing defence small arms fire are not rare; however, although this was the original raison d'etre of the tank in World War I and great effort and ingenuity were expended to get them ashore on D-Day, there has apparently been no attempt at assessing their effect in the role of infantry suppression.

Collecting together the available casualty data, deducting casualties due to rifles, correcting for defence indirect fire and attack preparatory bombardment, I then attempted an examination against a measure of tank density. In order to bring together different size battles the tank density was represented as a type of force ratio - as attack tanks per defence machine gun.

Plotting World War II battles as tanks per equivalent defence mg when anti-tank weapons are included in the equivalence, in Fig 11, shows the results of the two wars merge together into one general relationship. World War I points are indicated by circles showing that results from the two wars are consistent after the correction based on one World War II set of battles.

Turning from attack AFV and defence anti-tank, a completely different factor can now be seen to be associated with a part of the remaining scatter in the results - the difference between battles in which the defence have prepared positions and obstacles - open points, and those in which they have not - shown by solid points. If these points are divided on this simple description, two nearly parallel lines are obtained, the lower without preparation - the upper with; the ratio of the two providing an estimate of the effect of this type of preparation as being a 1.65 factor in defence effectiveness. This accounts for the differences in absolute levels in Fig 9, 10 and 11.

Final estimates of Machine Gun Effectiveness in Battle including the Effects of Armour.

If all results are now corrected to the zero fortification case, using this 1.65 factor, we find these sets of points overlayed as in Fig 12. While there is still some scatter, the line shows a correlation coefficient of 0.94 - which means that nearly 90% of the variation between battles is explained by the factors we have isolated. The remaining variation is equivalent to that between battles on our interactive trials indicating that we can reduce it little further. The intercept of Fig 12 at zero AFV and zero fortification indicates 2 casualties /m.g. at 1:1 force ratio, close to that derived in the preliminary analysis in Fig 4, and indicating a degradation factor of 6 on tactical trials.

Thus the militarily believed value of AFVs in the attack is confirmed by three independent sets of results, which can themselves be related by taking account of defence anti-tank weapons and obstacles. While the suppressive effect of tanks on infantry in defence has been lost sight of in recent analyses which have concentrated on the armoured battle, it can now be represented in combat simulation, as can the effect of defence anti-tank weapons in attack infantry casualties.

URBAN COMBAT

As we planned the urban trials we were aware of these live fire differences but had no way of representing them without militarily unacceptable limitations to the defenders. Thus our approach was the same as that used in our analysis of rural battles, to conduct trials followed by historical analyses. We also found it necessary to carry out two separate trial's simulating

a. Within house combat

b. between house combat using rules developed from a.

The preliminary urban trials representing house clearing operations indicated a benefit to the attack from experience in the role. Fig 13 illustrates the effect showing a 50% reduction in exchange ratio with experience.

When we came to the main external trial we were concerned to test whether there could be a similar benefit in the company assault to clear an urban area. (Here I must note that although we brought forward rules for house clearance casualties from the earlier trials we did not bring forward any experience effects so that any such effects detailed in this trial could subsequently be added to those obtained from the earlier house clearance trials.)

In designing our main external trial we were able to include a simple test for this effect by interchanging attack company and defence platoon at different times, partway through the trials (Fig 14). Examining these results we found, on the basis of attack casualties/defender present, no detectable benefit with defence experience. However there was a slight but non significant benefit to the attack with experience.

The effect of attack experience was more marked if considered against exchange ratio, that is attack casualties divided by defence casualties. In the conditions of trials battles this measure is a better indication of defenders included in battle - because defenders tended to stay and fight until killed, and also because trial battles were also terminated at arbitrary end points.

A plot of these exchange ratios against experience is shown in Fig 15, for three companies in several interactive battles when using VP attack tactics. Despite the scatter there is a significant trend to reduced exchange ratio with experience. This negative exponential fit indicates a halving in ratio after 10 battles. (A linear regression shows a similar correlation coefficient, but does not represent the expected form of learning curve so well).

Turning now to a comparison of historical and trials data, the first area for comparison is that of defence casualties. As mentioned earlier, on trials battles, with no more real threat than simulators, most defenders fought to the end - that is until 'killed' - given that there were sufficient attackers to achieve this. In real, live fire, battles a very different picture was apparent (Fig 16); unless they could withdraw, then twice as many defenders surrendered, or surrendered wounded, as were killed. So given the possibility of defence withdrawal the outcome would typically be as shown here. These ratios were not sensitive to attack AFV density or force ratio - or to anything except to being totally surrounded.

As a result of our examination of attack casualties in real European battles for comparison with the earlier, rural trials data available, it was obviously worth checking for the effect of force ratio and attack tanks. We divided the battles into groups by tank density, (Fig 17) which would be expected to offset these curves. The main groups are shown here, plotting attack casualties/defender against infantry force ratio. Each shows a significant trend with force ratio, the gradient of which, as the graphs are plotted on logarithmic axes corresponds to the index of force ratio. These independent sets yield very similar powers of about 0.50, lower than the value for open country battles (0.685 Ref 2) indicating that attack casualties are less affected by force ratio in urban attacks. The pattern of offset or vertical shift of these four curves with tank density is broadly as expected; this effect is considered below.

This relationship with force ratio was used to reduce all battles to unity force ratio to test for the effects of AFV density, now using all 73 available battles. (Fig 18). In this graph, as in the equivalent open country, "casualties/defender" is plotted against "attack tanks/equivalent defence machine gun", taking the same attack tank dilution factor as derived in the rural study, for defence anti-tank guns. These results also show a significant suppressive effect from the use of attack tanks. The general trend can be compared with that from rural battles; it is the same order of effect, a result which has surprised many.

The comparison also allows the absolute casualty values of rural and urban defence to be compared - urban being 60% less effective with no attack tanks. Having explored these effects we can now attempt a comparison of attack casualties/defender between trials and live urban battles at an equivalent force ratio and at zero tank suppression. This comparison yields a live battle figure of 0.51 cas/defender at trial force ratio (of approx 3:1)to set against trial figures of 2 to 3.8:1 ranging with experience - differing by a factor of between 3.7 and 7.2:1 respectively, to be compared to the 7.2:1 to be expected in rural combat (for a machine gun-rifle mix.)

Study of the regimental histories of the units involved in urban attacks shows that few battalions made many, that they were interspersed with rural combat and that as the units took significant casualties they are issued with replacements which would dilute the value of experience. Making allowance for these factors it is estimated that the mean equivalent starting experience was approx 3 to 4 KINGS RIDE battles corresponding to a 3.0:1 trial exchange ratio. This differs by a factor of 6 from the live battles, in close agreement with the rural figure of 7.2 from an independent set of data.

The supplementary question which comes to mind is, if this learning is significant and applies to real combat, can it be derived from that data too?

The sample of data included had been extended after a pilot study to those sets where battalions have fought urban battles without significant replacement, and could be traced through war diary data.

These are shown in Fig 19, a total of 42 battles (of the 73 live battles used previously). Each battalion with sufficient experience to give a comparison shows a trend to benefit from experience, and the combined set shows a significant trend. For comparison if we now bring forward the previous trials curve for experience in Fig 20, the results are confirmatory both in order and in effect of experience, a very robust confirmation in view of the independent derivation of the two sets.

Another set of historical data also supports the effect of attack experience. The set for 24 village and urban battles in Burma when analysed in the same way showed a similar effect. Fig 20 illustrates this, with a very similar order of attack casualties and a similar but lesser effect of experience. The notable difference for this set (not shown) was the insensitivity to attack AFV density.

THE REPRESENTATION OF DEGRADATION AND SUPPRESSION IN MODELLING

Each of the degradations discussed here, shows factors of up to an order of difference in capability. Although the broad effect of each was now quantified and available to modify our detailed trials data, we had to decide how to do this, bearing in mind the inevitable lack of lower level detail inevitable from historical data sources.

A third source was also available on defence suppression (Refs 3,4): this constituting a detailed study of the relative effects of weapon type, size, rates of fire and accuracy - but with the safety limitations necessary in such experiments removing the absolute values of each.

The approach towards investigating the combined use of historical analysis and trials data in operational analysis was first to design and test a model of the detailed interactions recorded in the trials situation using weapon simulators. This constituted a Phase I model, with personnel subject only to physical limitations and with simulated weapons calibrated to the performance of the real weapons measured in clinical field trials. This Phase I model was then successively elaborated by including other factors assessed from the other trials and historical data sources to include: live fire, suppression, close quarter battle and surrender, and in Phase 2 represented all physical and psychological limits which had been observed.

The process is shown diagrammatically in Fig 21. This also indicates that the model output was tested at appropriate stages - initially against trials scenarios, later against generalised results from historical data, and finally against two real battles for which the samples of replicated runs could be compared against similar sets of assaults within larger battles.

The model construction was conducted under contract by Hunting Engineering Ltd (HEL) hence the model name HELICCS (HEL Infantry Close Combat Simulation).

In Phase I a low level high resolution stochastic model of company platoon combat was set up. This specifically represented the factors shown in Fig 22, derived from analyses of the reconstructed battles of our rural trials (Ex KINGS RIDE I and II.) Following calibration to these, the comparison between a set of 12 replicated platoon attacks (in KINGS RIDE I) and the model is shown in Fig 23. A comparison with the individual scenarios of company attacks in (KINGS RIDE II) is shown in Fig 24.

The stochastic model was elaborated in Phase II to include the factors shown in Fig 25:

a,. b. Data for suppression were derived from historical data for absolute value, US trials for relative effects.

c. The degradation effect of live fire was based on historical analysis.

e. The effect of defence artillery was based on modelling the effects of individual rounds and calibrating the overall effect against historical data.

f. The effects of infantry anti-tank weapons were derived from trials (Ex KINGS RIDE IIA and IIB.)

g. The continuation to the overrun or close quarter battle was based on specific very short range trials at DOAE, (Ex KINGS RIDE IIC), modified by historical data on degradation.

h. Probabilities of withdrawal and surrender were based on analyses of historical data.

A comparison of the effects of attack AFV suppression as modelled and the broad results from historical analysis is shown in Fig 26.

Final comparisons were made with two sets of battle in which separate results from broadly similar attacks were available, to test the variability of model output against that between real combat situations. The two chosen were:

a. The British attack on the first day of the Somme (July 1916) in which a purely infantry force, with 84 battalions attacking suffered enormous casualties. (Fig 27)

b. The British attacks on the Normandy beaches (6 June 1944) when massive AFV support played a part in securing light attack casualties. the data are for six battalion attacks in two company waves.(Fig 28)

The comparisons indicate good agreement in both means and in the variability of the casualties between local 'replications'.

Having now consolidated our separate sources of data into a model which represented company-platoon combat in considerable detail - and which could be a useful investigation tool, we had to make the output usable for higher level models. This, Phase 3 of the development used the HELICCS model to generate distributions for a simplified Model of Infantry Close Combat (SMICC). This was developed as:

a. a stochastic model producing win/lose probabilities and expected casualties.

b. a model capable of functioning as a subroutine to a more general model of combat including armour/anti-armour.

This development is now complete for open country battles, we are examining the possibility of its extension both to woods and to parts of the urban battle.

References

1. Marshall S L A 1946
   Men Against Fire
   Infantry Journal and Morrow NY

2. Rowland D 1986
   Assessments of Combat Degradation
   RUSI 131 No 2.

3. Anon 1976
   SASE Small Arms Suppression Evaluation
   USA CDEC

4. Anon 1977-78
   SUPEX: Suppression Experiment
   USA CDEC

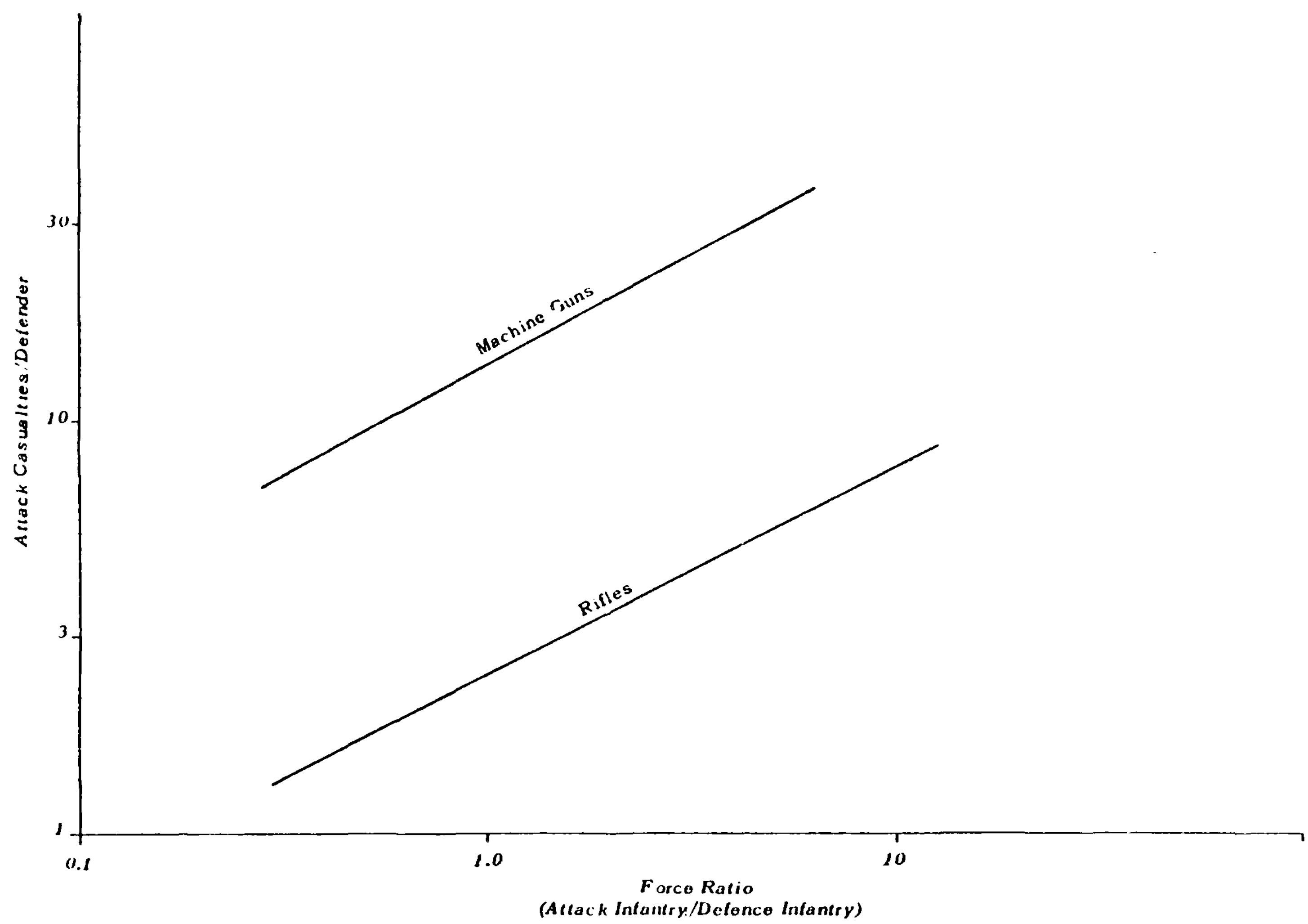


FIG 1. VARIATION OF ATTACK CASUALTIES/DEFENCE WEAPON WITH FORCE RATIO FROM INTERATIVE TRIALS DATA

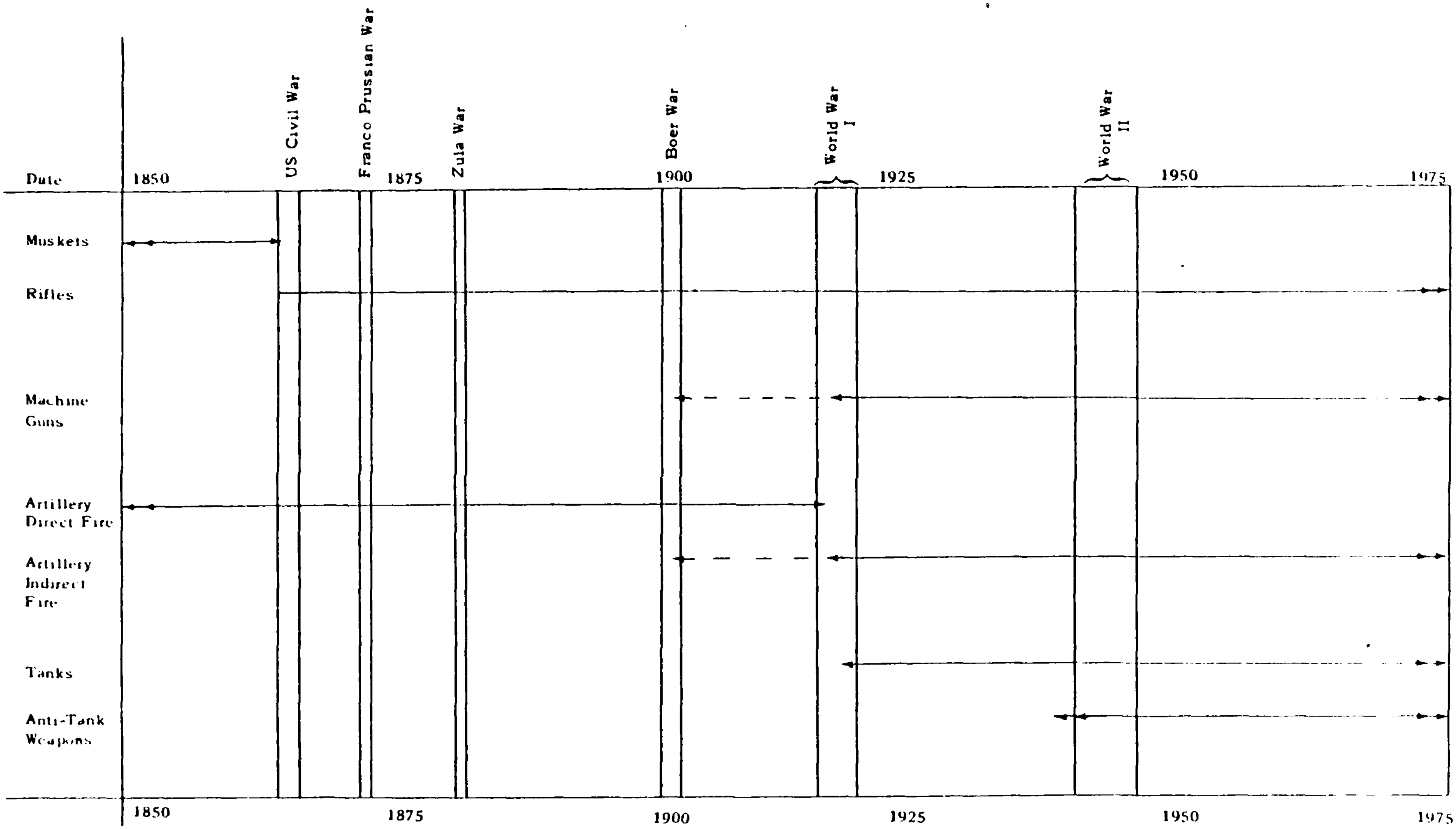


FIG 2. WEAPONS IN USE IN SPECIFIC CONFLICTS

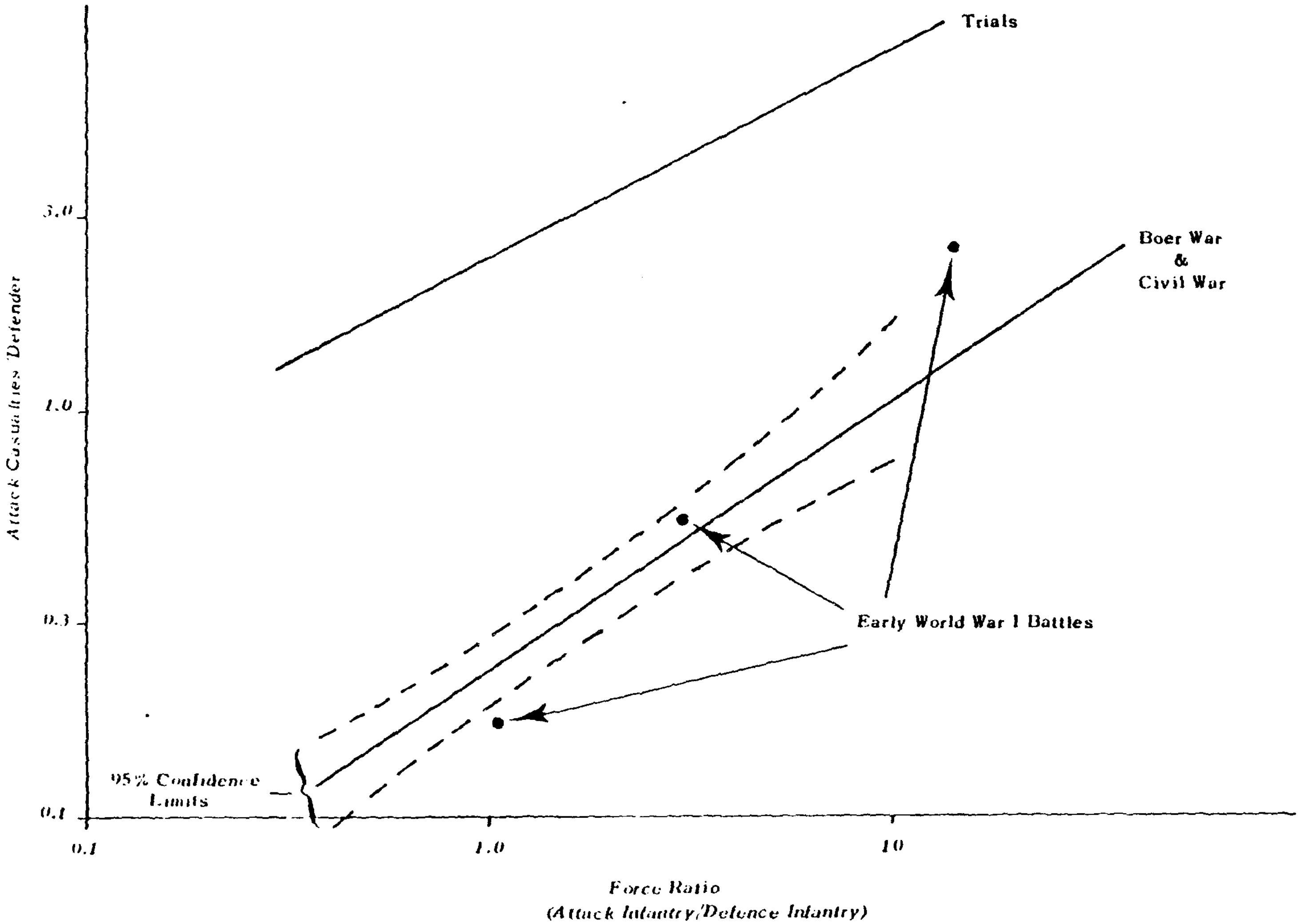


FIG 3. COMPARISON OF RIFLE CASUALTY ESTIMATES FROM TRIALS DATA, BOER WAR & CIVIL WAR (POOLED) AND WORLD WAR I

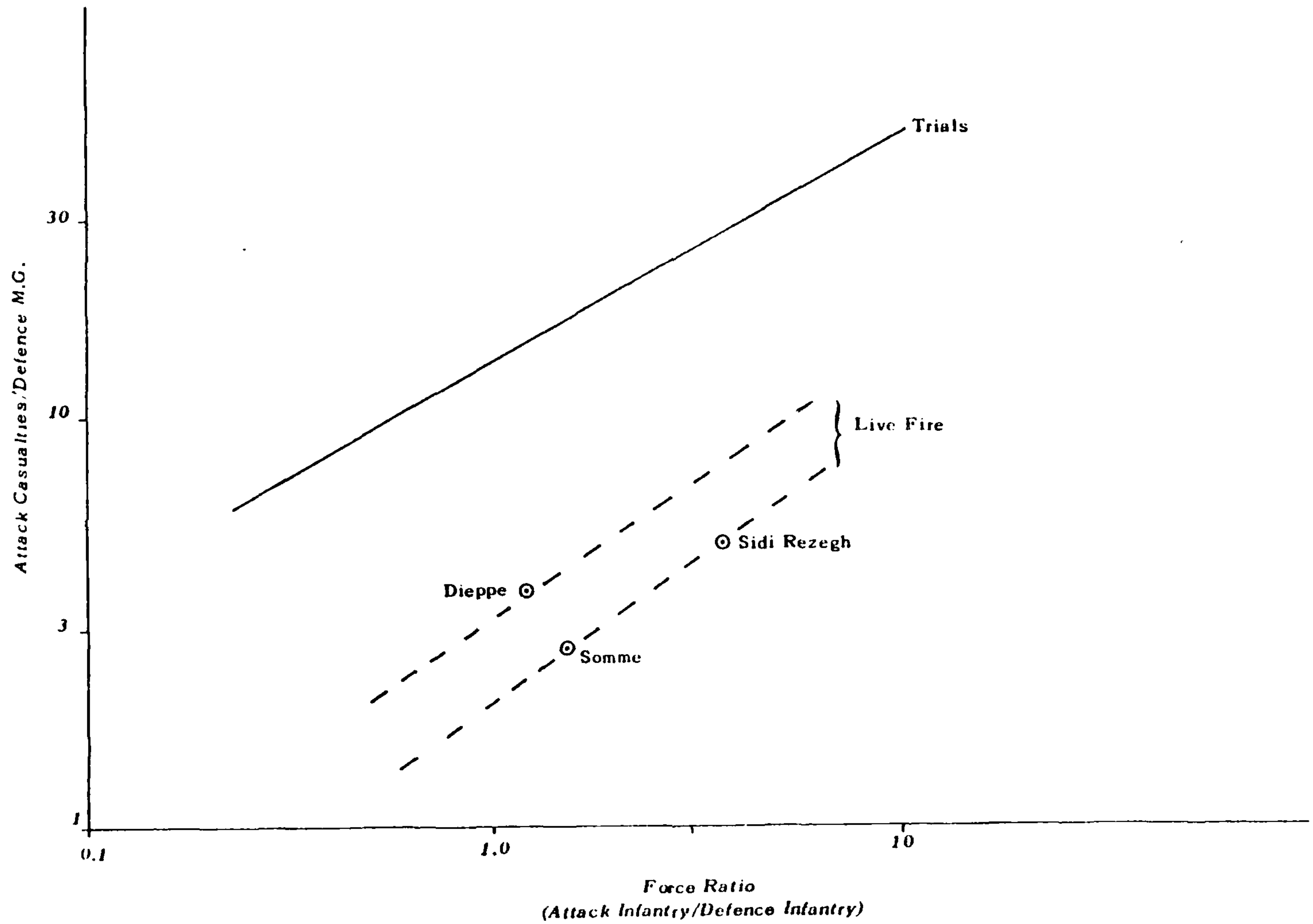


FIG 4. COMPARISON OF MG CASUALTY ESTIMATES FROM TRIALS AND COMBAT DATA

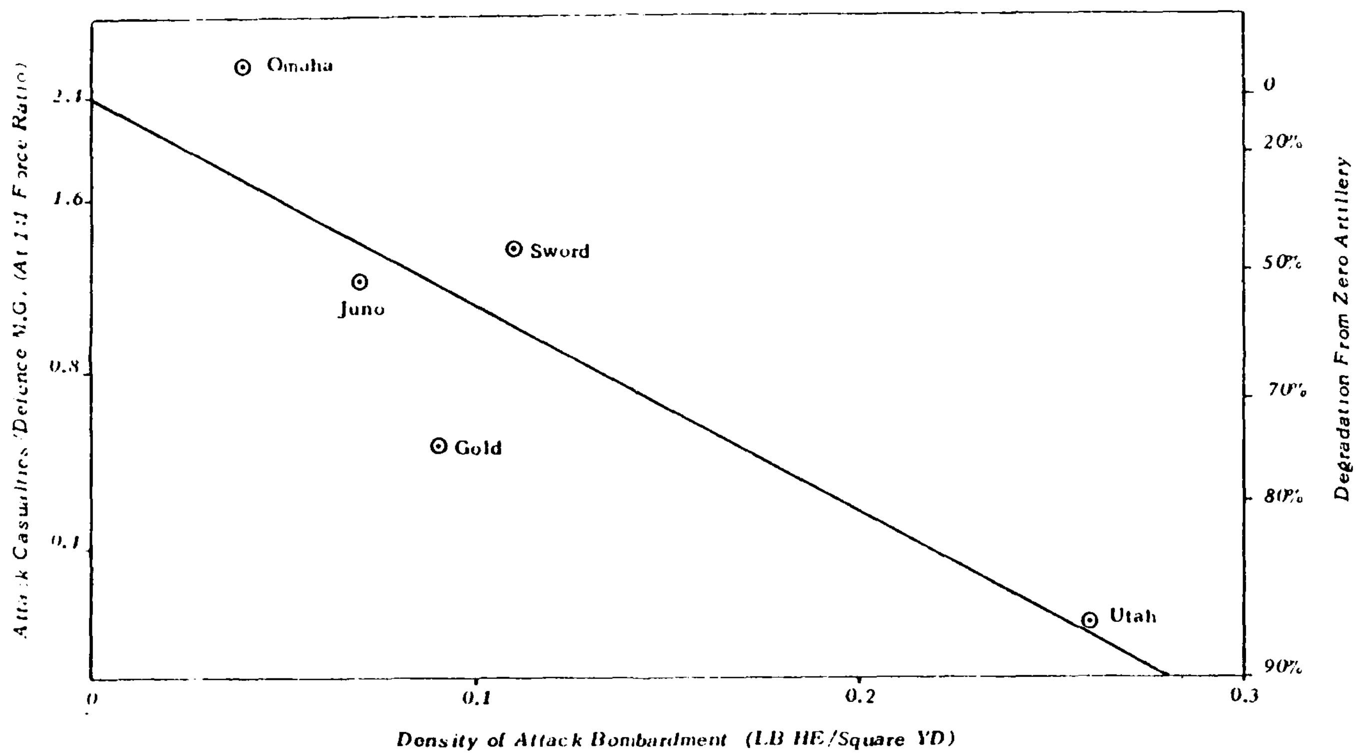


FIG 5. EFFECT OF DENSITY OF PREPARATORY ATTACK BOMBARDMENT ON ATTACK CASUALTIES/DEFENDER, HENCE DEFENCE DEGRADATION

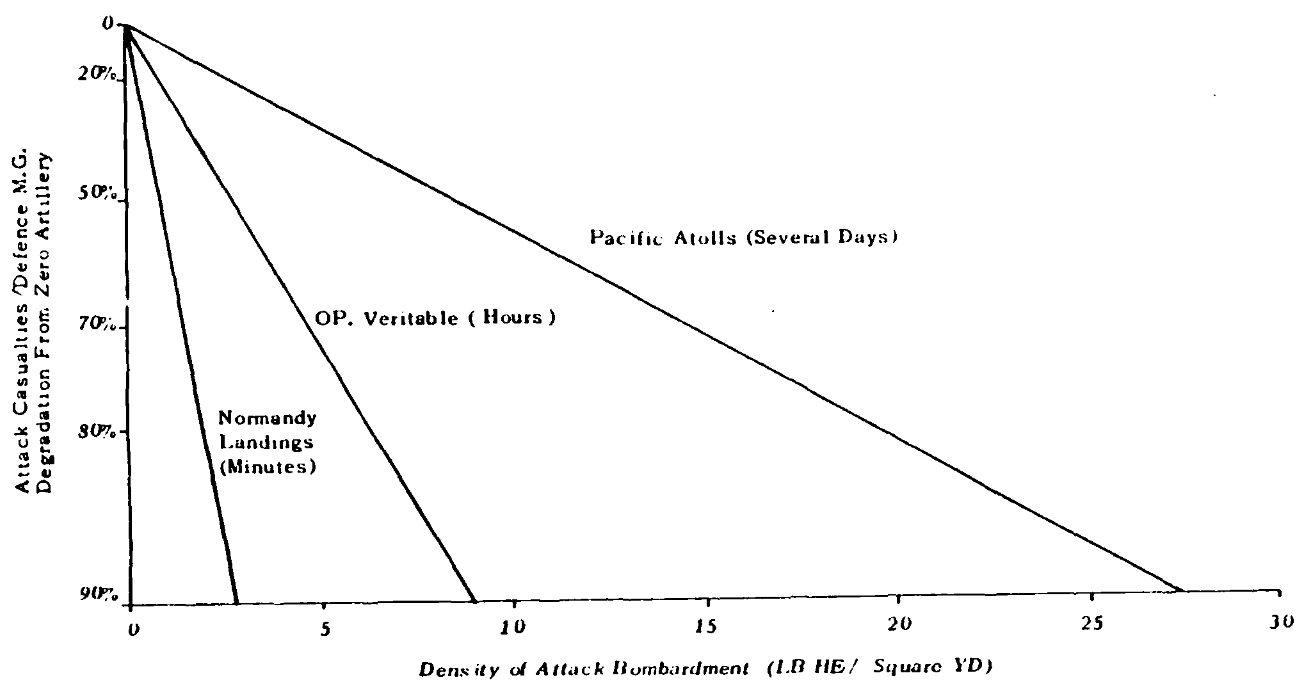


FIG 6. EFFECT OF DURATION OF BOMBARDMENT ON THE DEGRADATION IN INFANTRY FIREPOWER FOR A GIVEN DENSITY OF BOMBARDMENT

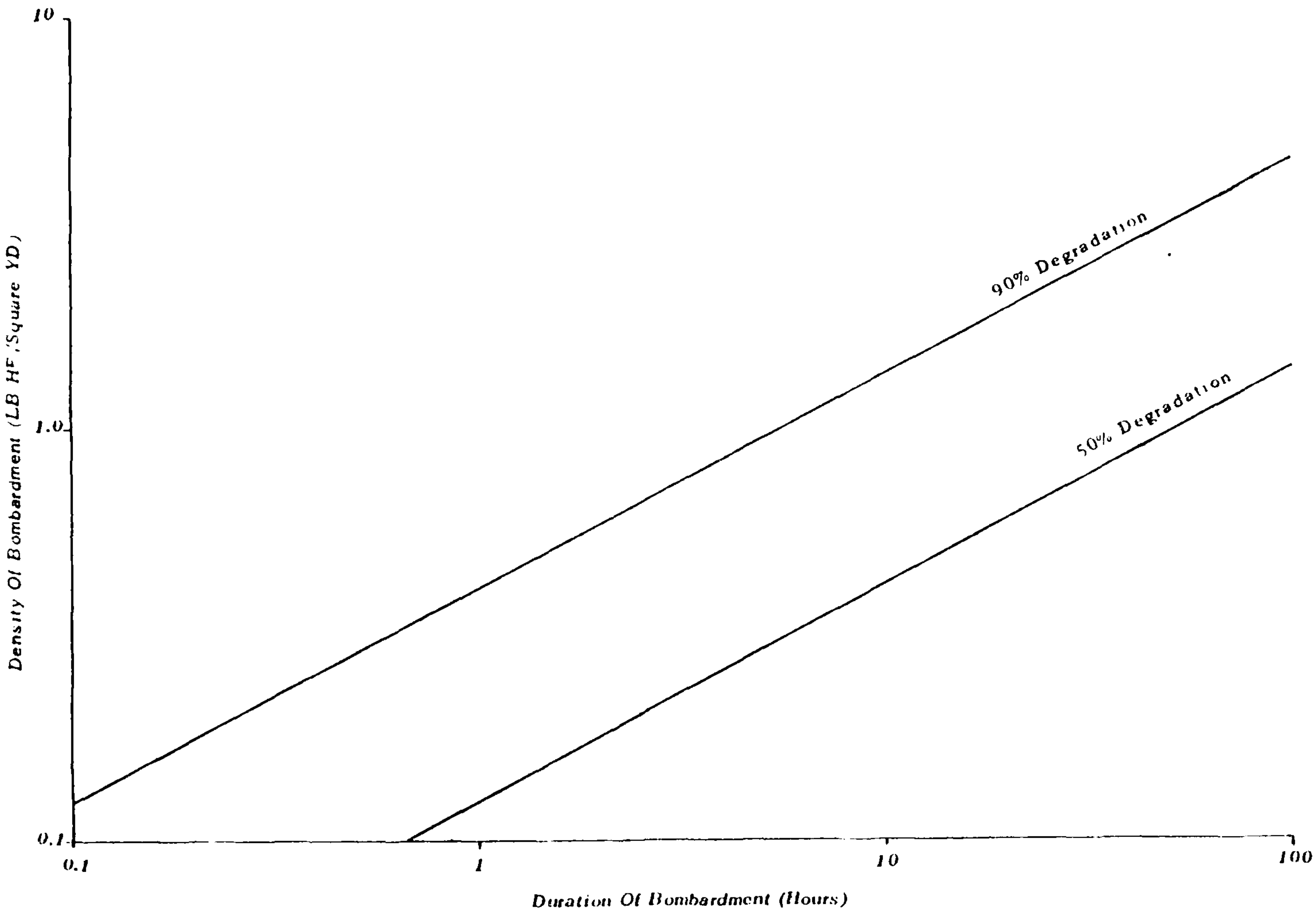


FIG 7. RELATIONSHIP BETWEEN DENSITY OF PREPARATORY ATTACK BOMBARDMENT AND ITS DURATION TO ACHIEVE A GIVEN LEVEL OF DEGRADATION IN INFANTRY FIREPOWER, FROM ZERO ARTILLERY DENSITY

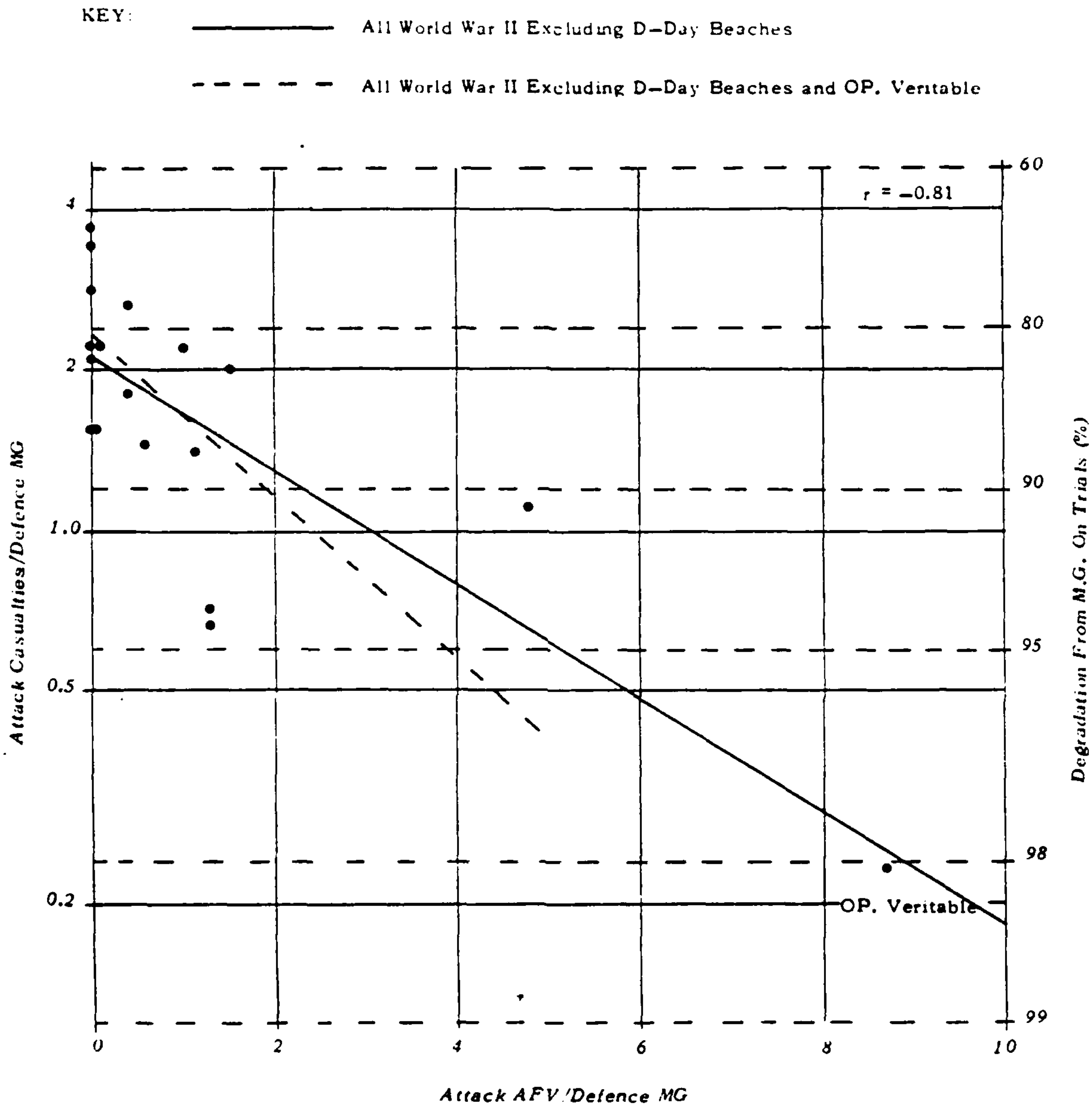


FIG 8. DEFENCE MG. EFFECTIVENESS AND ATTACK TANK DENSITY FOR WORLD WAR II BATTLES EXCLUDING D-DAY BEACHES

(At 1:1 Force Ratio Zero Artillery Bombardment)

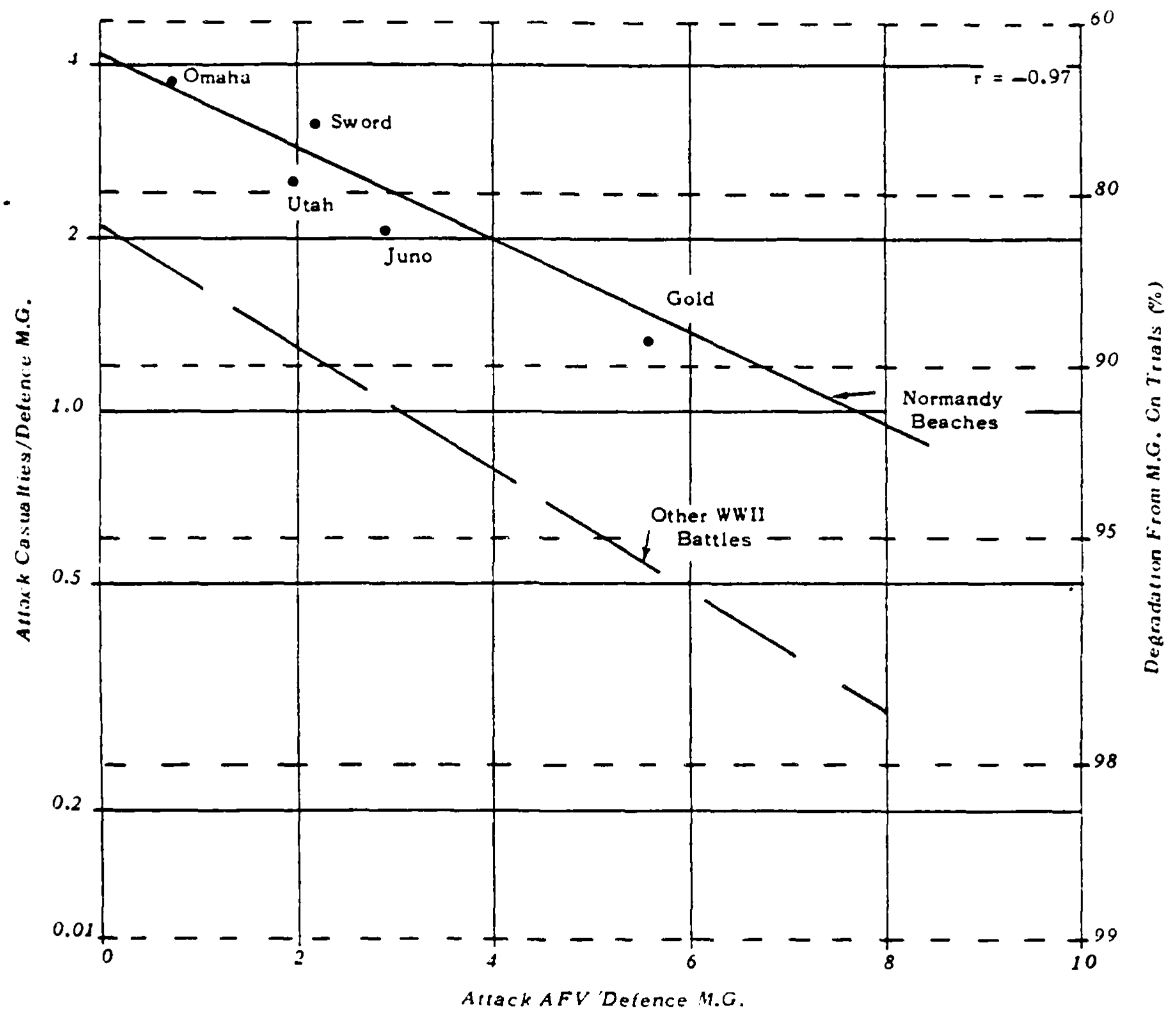


FIG 9. DEFENCE M.G. EFFECTIVENESS AND ATTACK TANK DENSITY FOR NORMANDY BEACHES, WWII

(At 1:1 Force Ratio, Zero Artillery Bombardment)

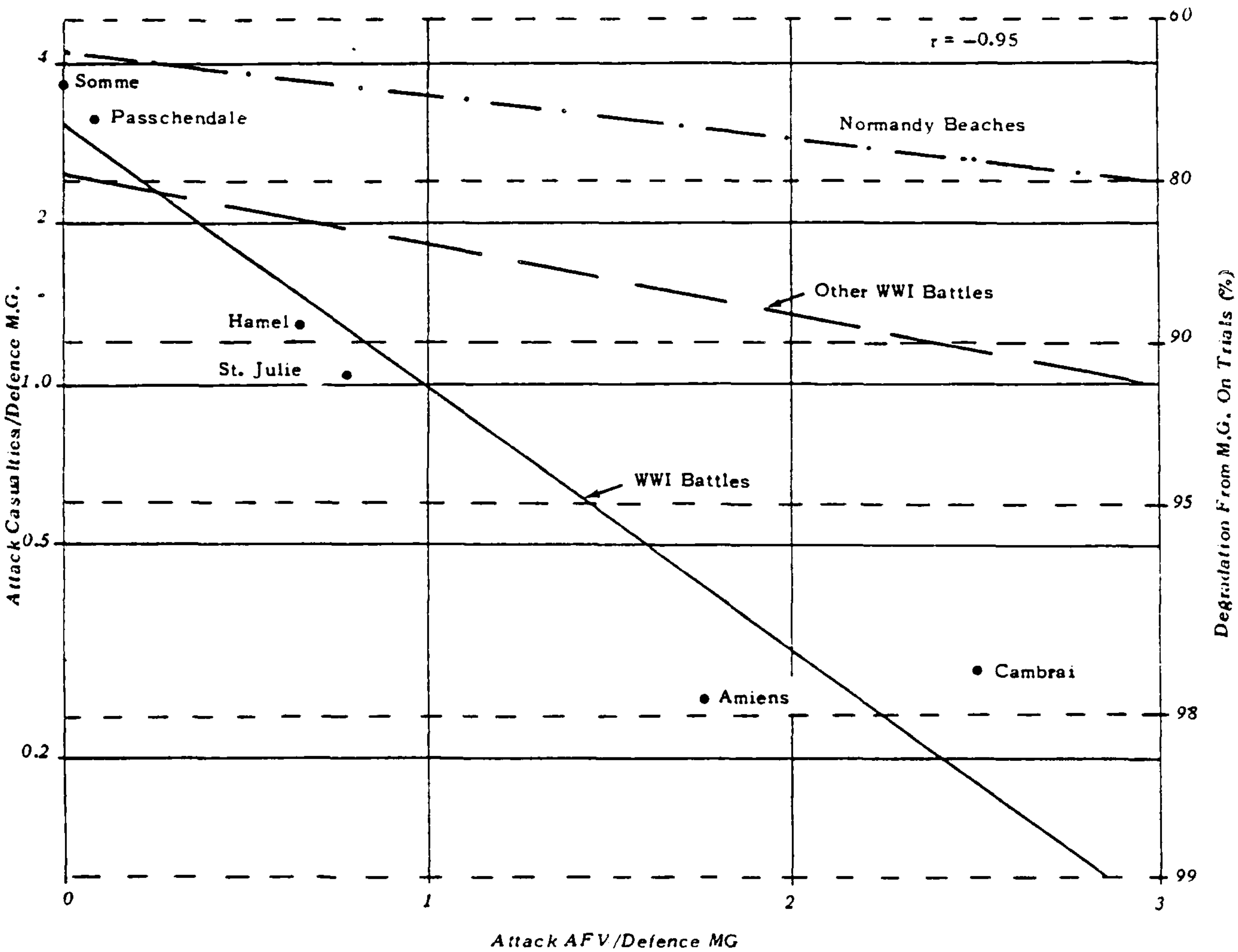


FIG 10. DEFENCE M.G. EFFECTIVENESS AND ATTACK TANK DENSITY FOR WORLD WAR I BATTLES

(At 1:1 Force Ratio Zero Artillery Bombardment)

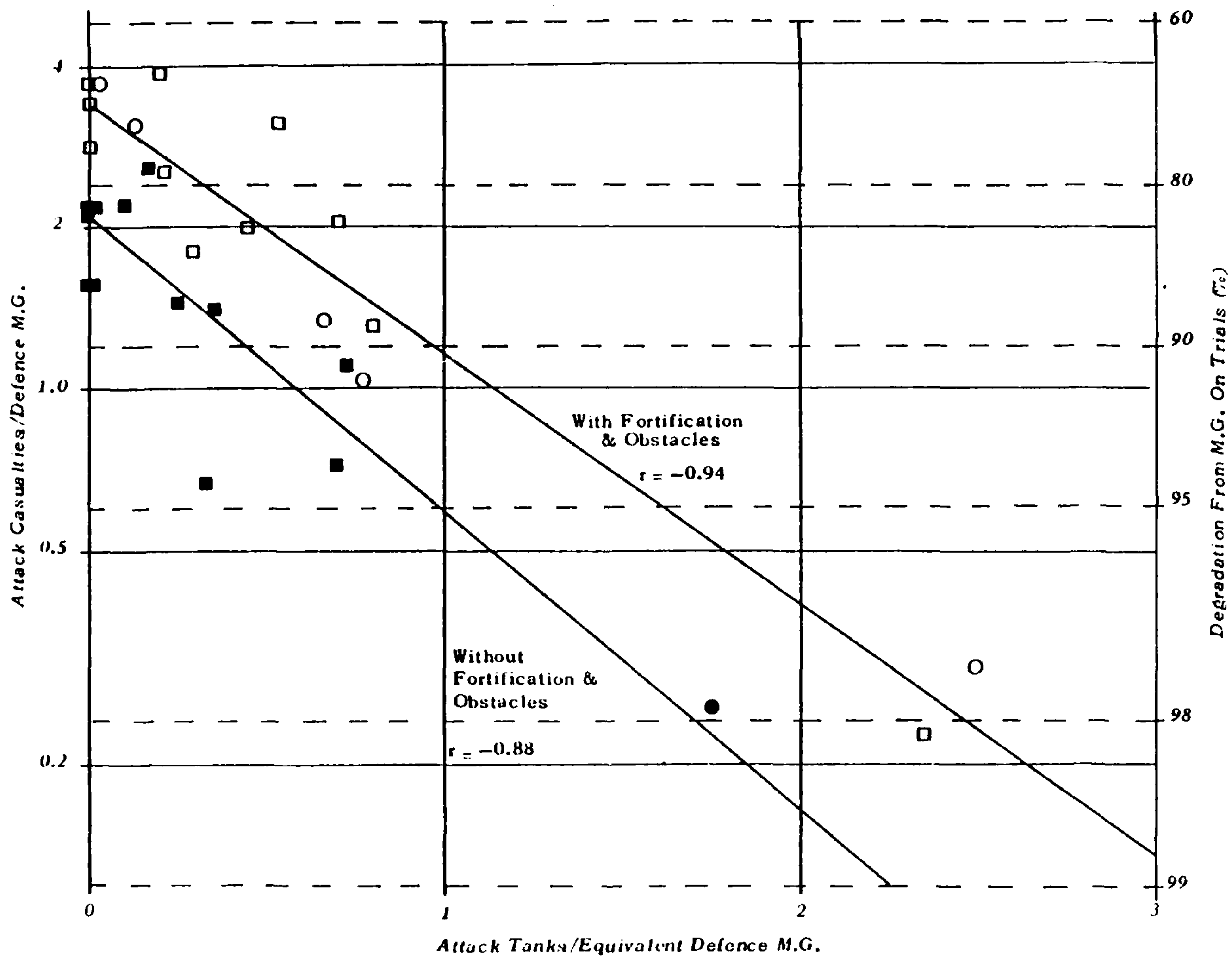


FIG 11. DEFENCE M.G. EFFECTIVENESS AND TANK DENSITY, TAKING ACCOUNT OF DEFENCE ANTI-TANK WEAPONS AS EQUIVALENT M.G.

(At 1:1Force Ratio, Zero Artillery Bombardment)

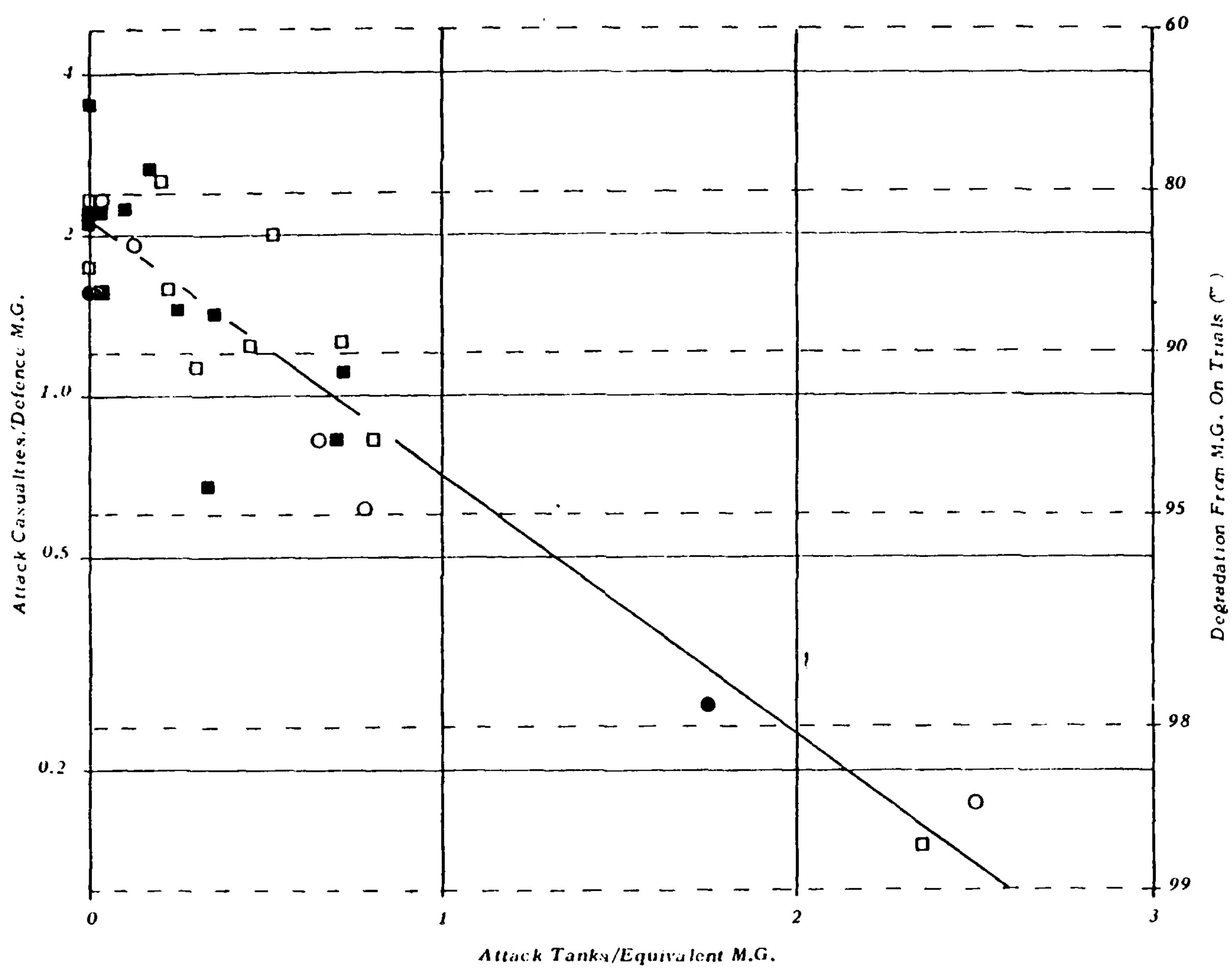


FIG 12. DEFENCE M.G. EFFECTIVENESS AND TANK DENSITY, CORRECTED TO ZERO FORTIFICATION

(At 1:1 Force Ratio, Zero Artillery Bombardment)

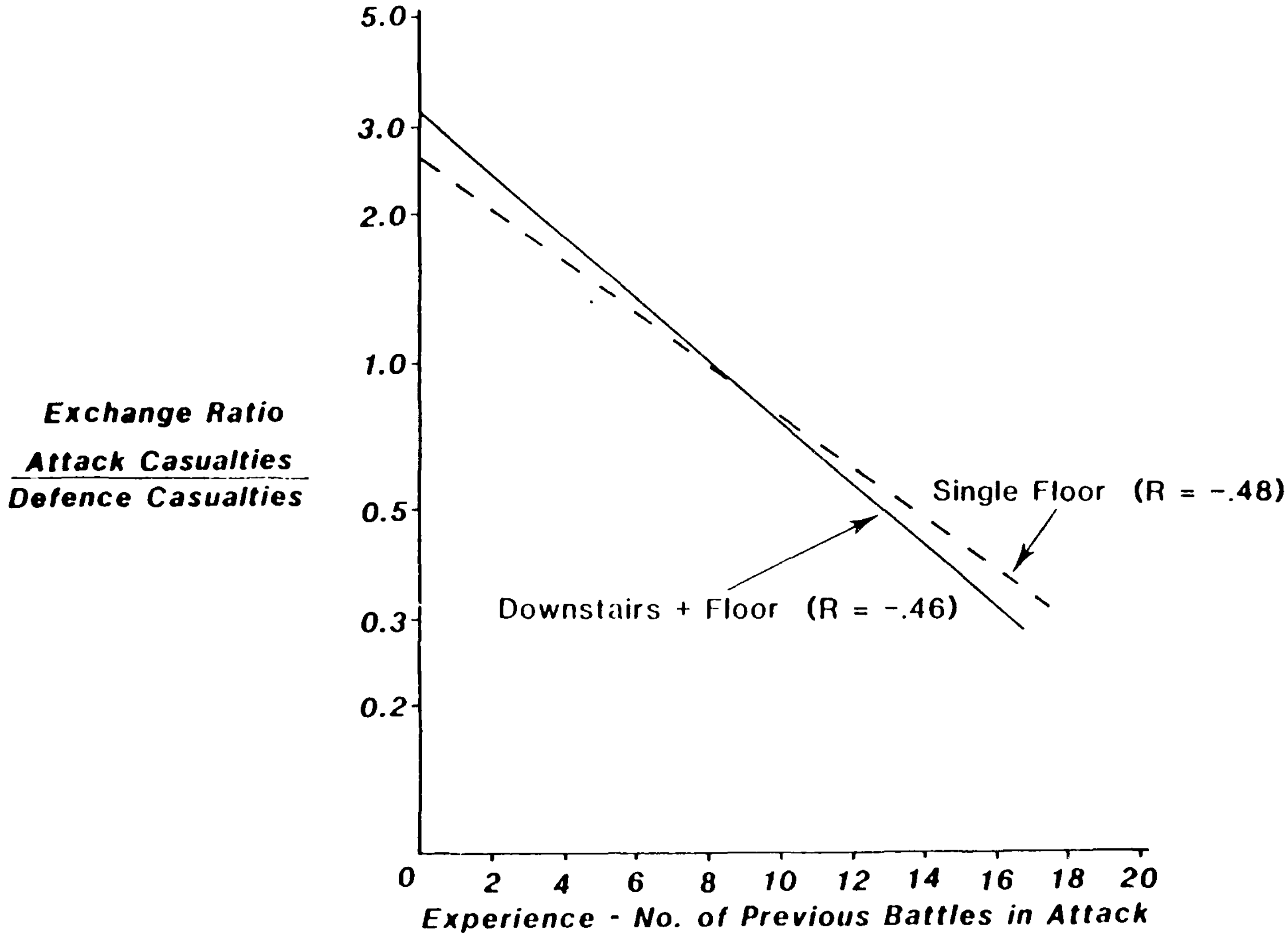


FIG 13. FIBUA – HOUSE CLEARANCE
EFFECT OF EXPERIENCE

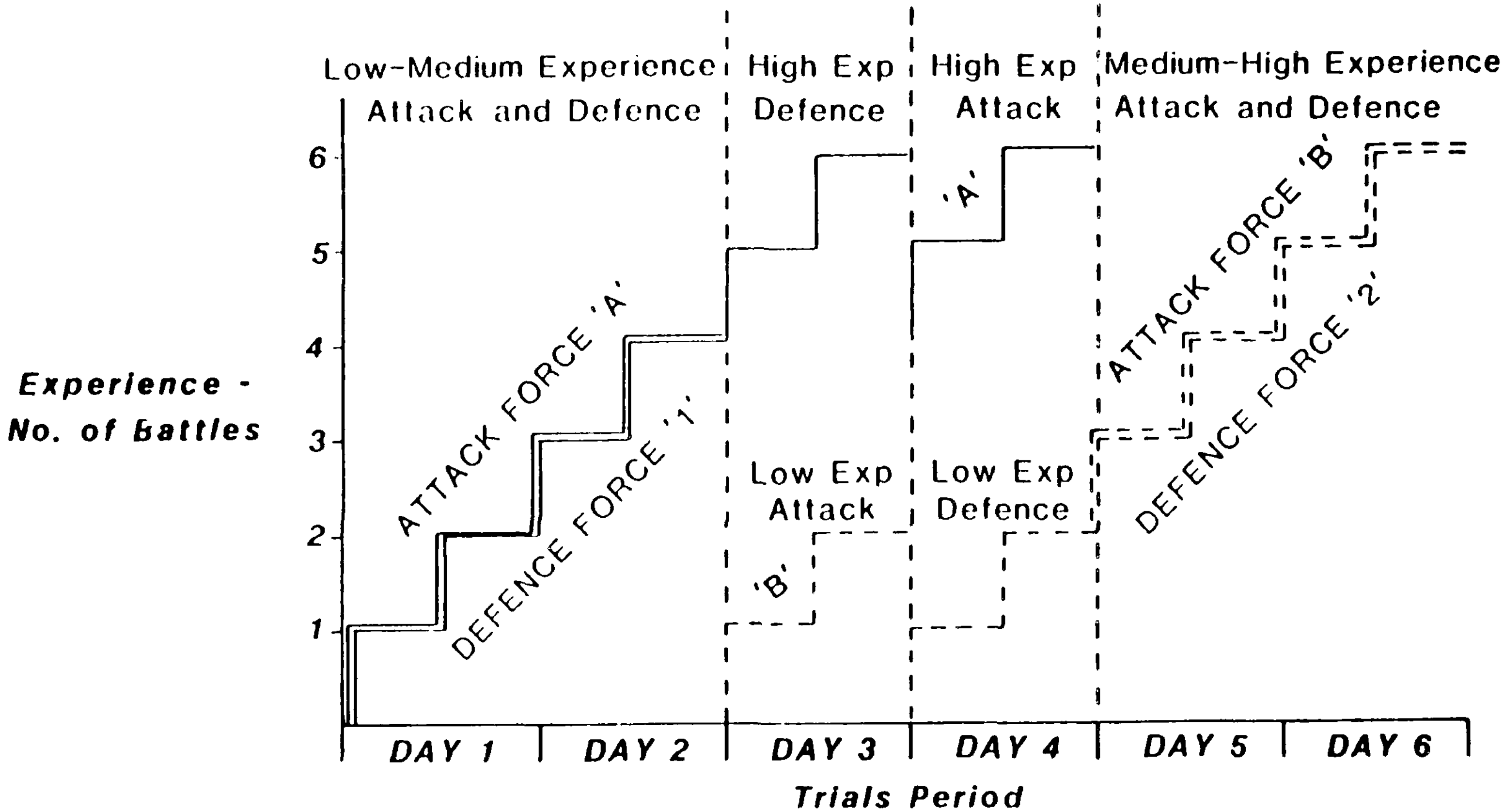


FIG 14. FIBUA TRIAL – BERLIN 1985
DESIGN

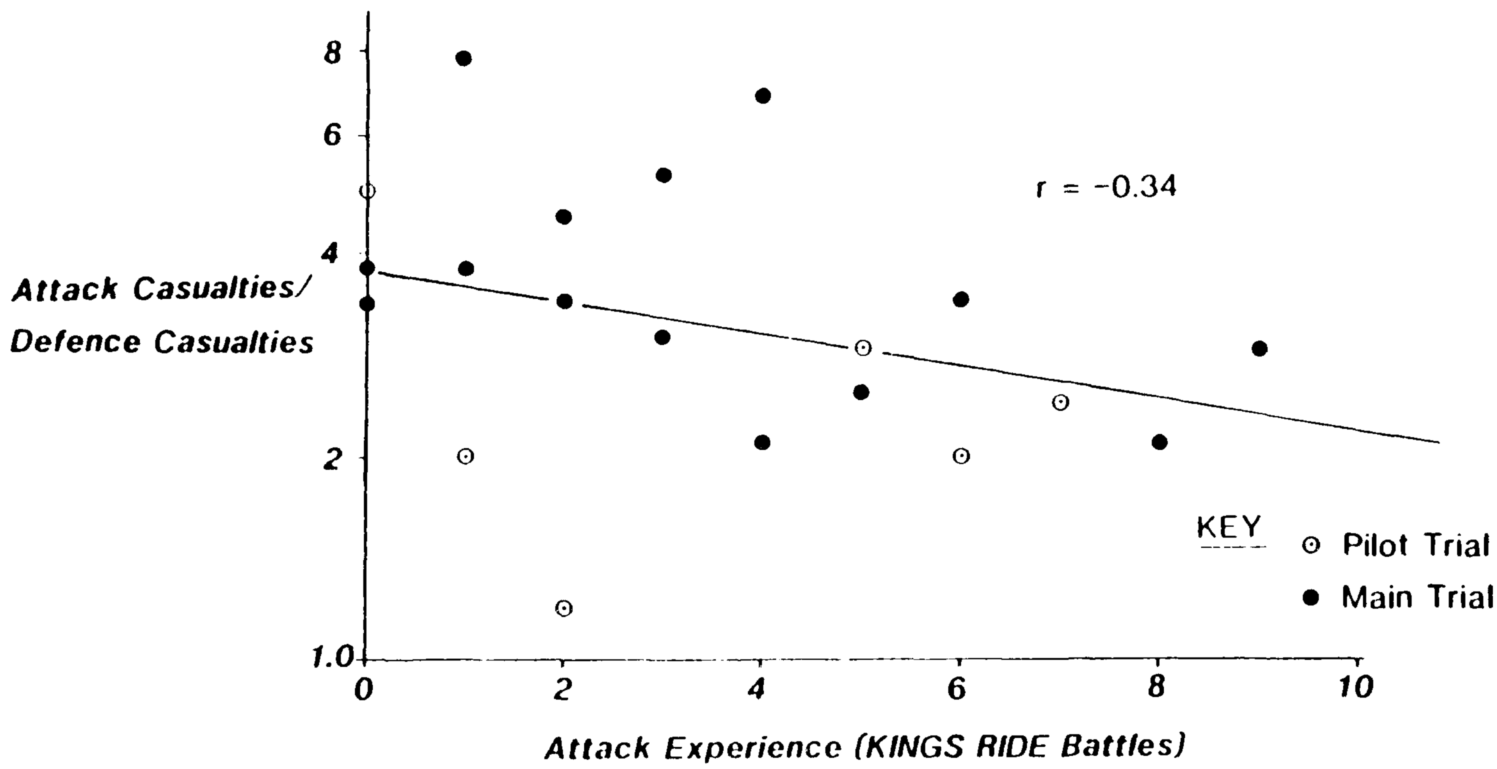


FIG 15. EFFECT OF ATTACK EXPERIENCE ON EXCHANGE RATIO AS A MEASURE OF DEFENCE EFFECTIVENESS (3.5:1 FORCE RATIO)

SIMULATED COMBAT		LIVE COMBAT
100	KILLED	20
0	WOUNDED/POW	60
0	ESCAPE/WITHDRAW	20

FIG 16. DEFENCE CASUALTIES (%)

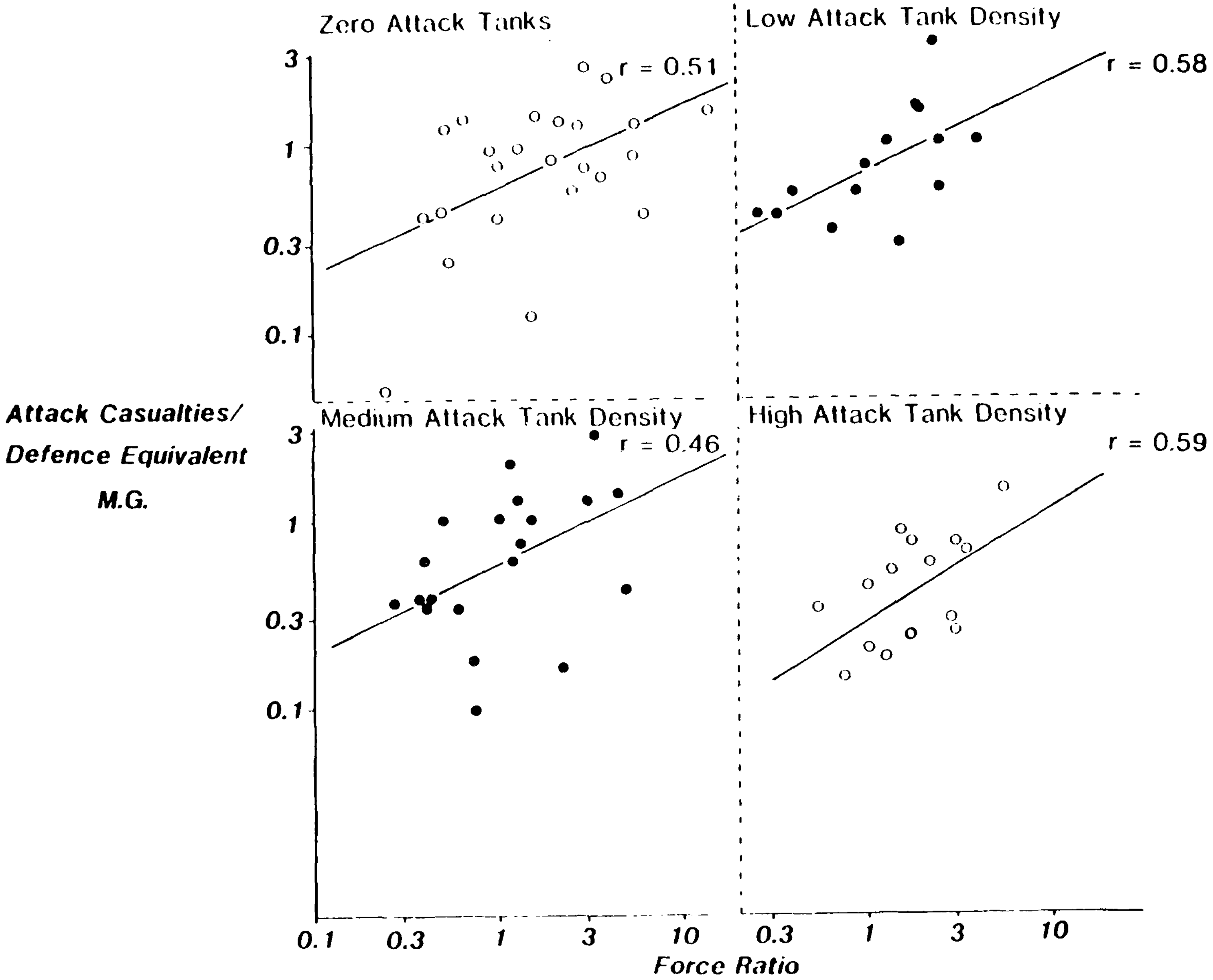


FIG 17. EFFECT OF FORCE RATIO ON ATTACK CASUALTIES/DEFENDER

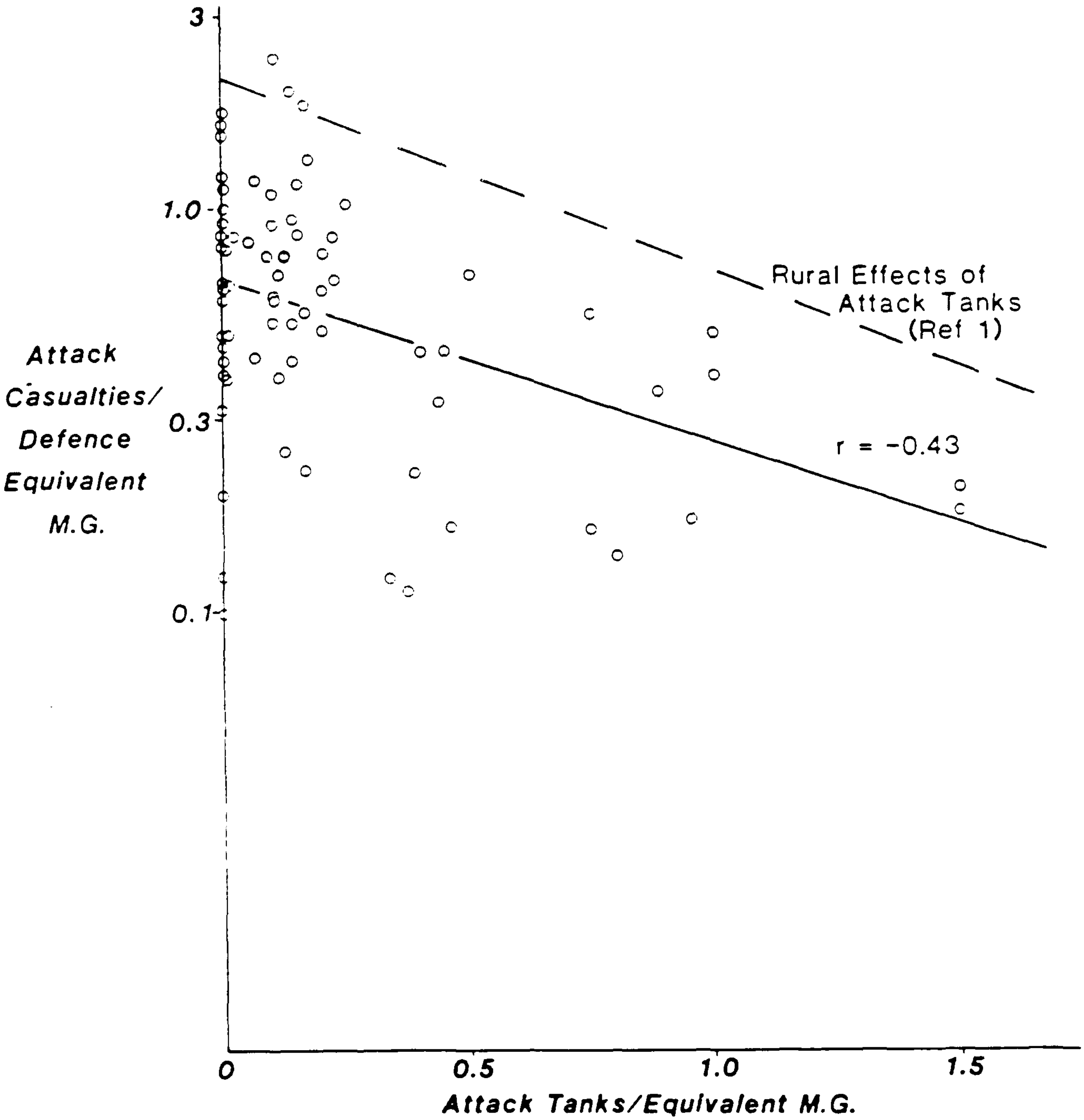


FIG 18. EFFECT OF ATTACK TANKS ON DEFENCE INFANTRY EFFECTIVENESS (AT 1:1 FORCE RATIO)

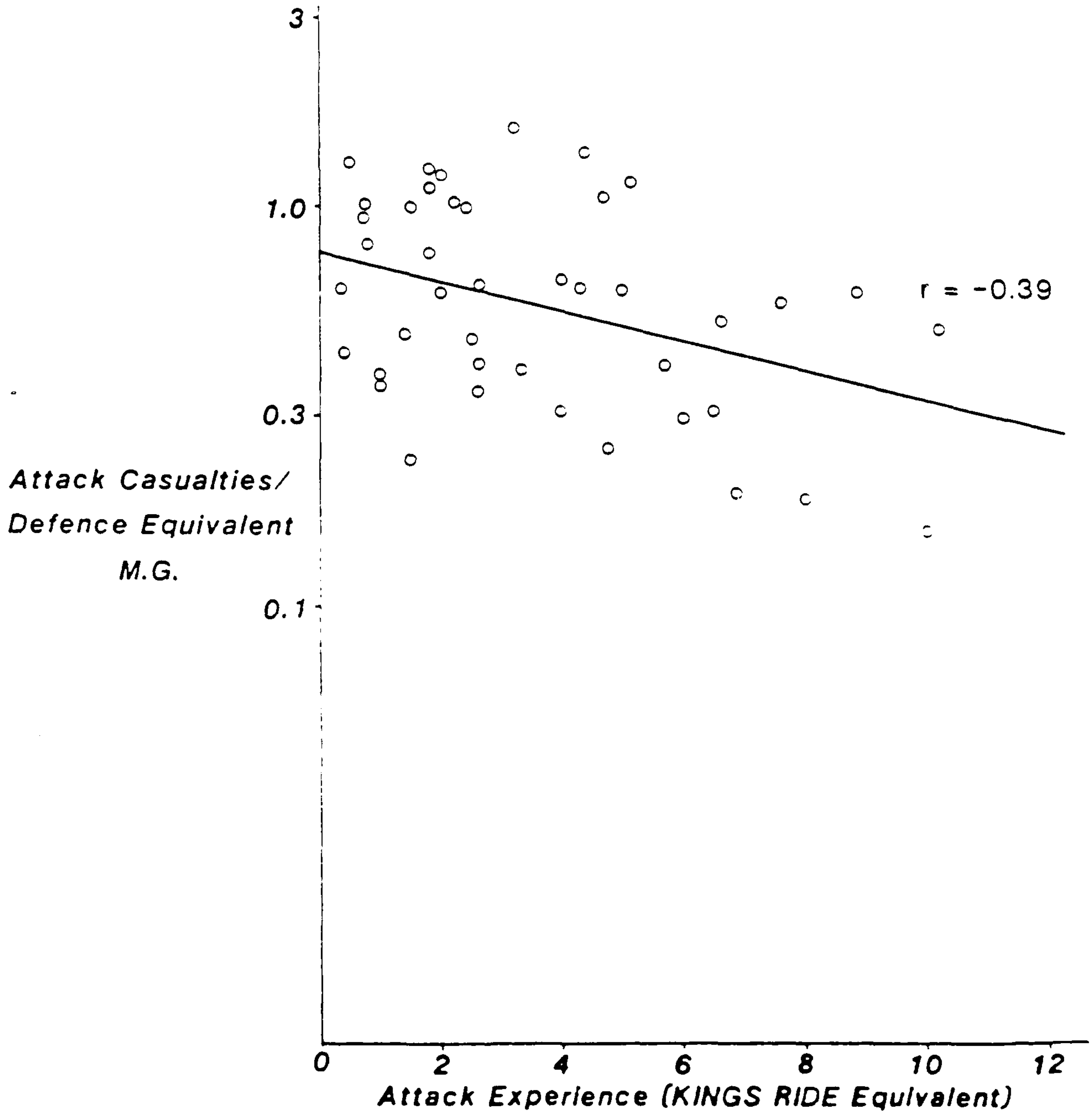


FIG 19. EFFECT OF ATTACK EXPERIENCE ON DEFENCE INFANTRY EFFECTIVENESS
(AT 1:1 FORCE RATIO, ZERO ATTACK TANKS)

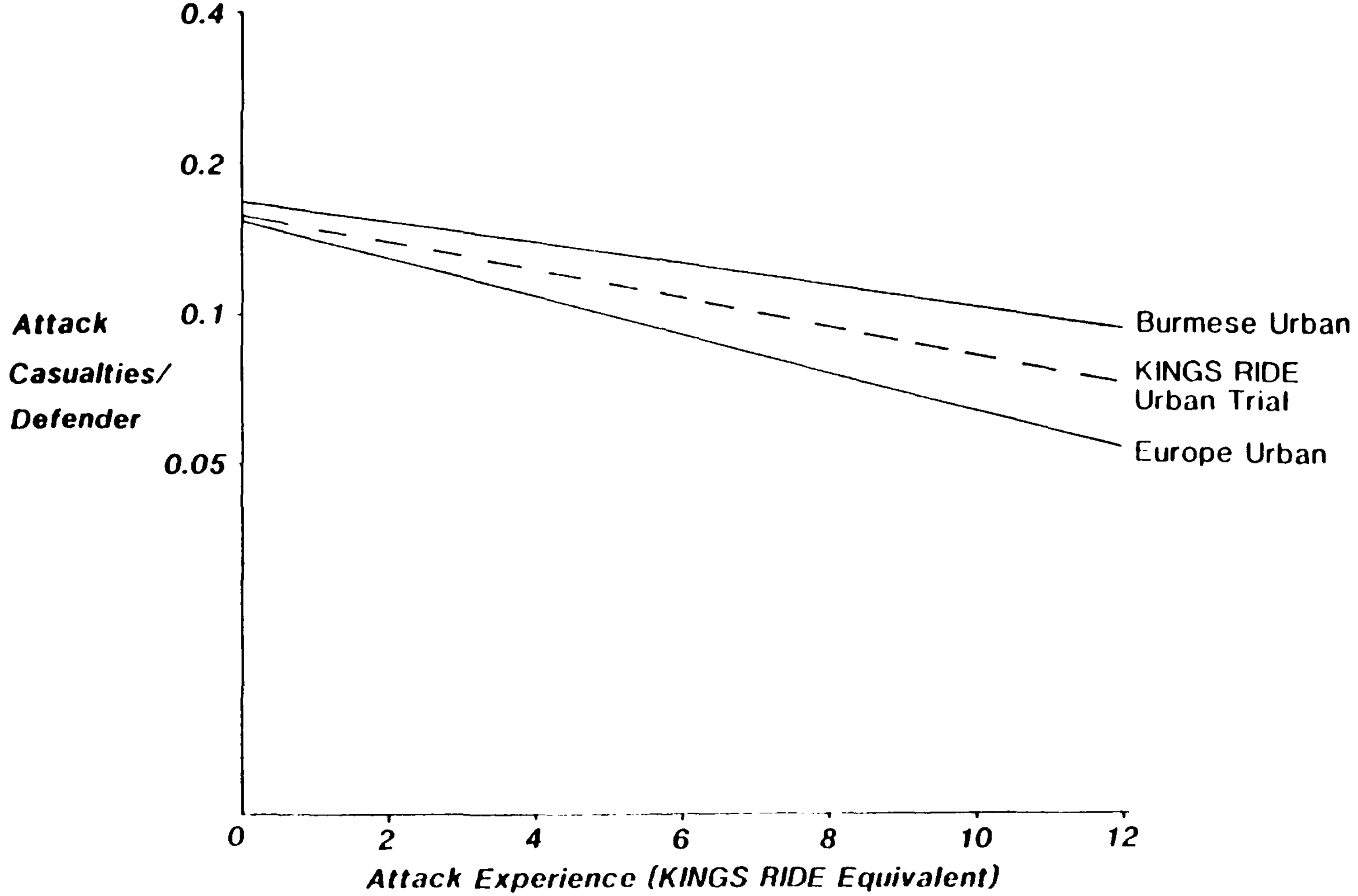


FIG 20. COMPARISON OF BURMESE URBAN WITH OTHER DATA SOURCES
(1:1 FORCE RATIO, ZERO ATTACK TANKS, 1 MG/SECTION)

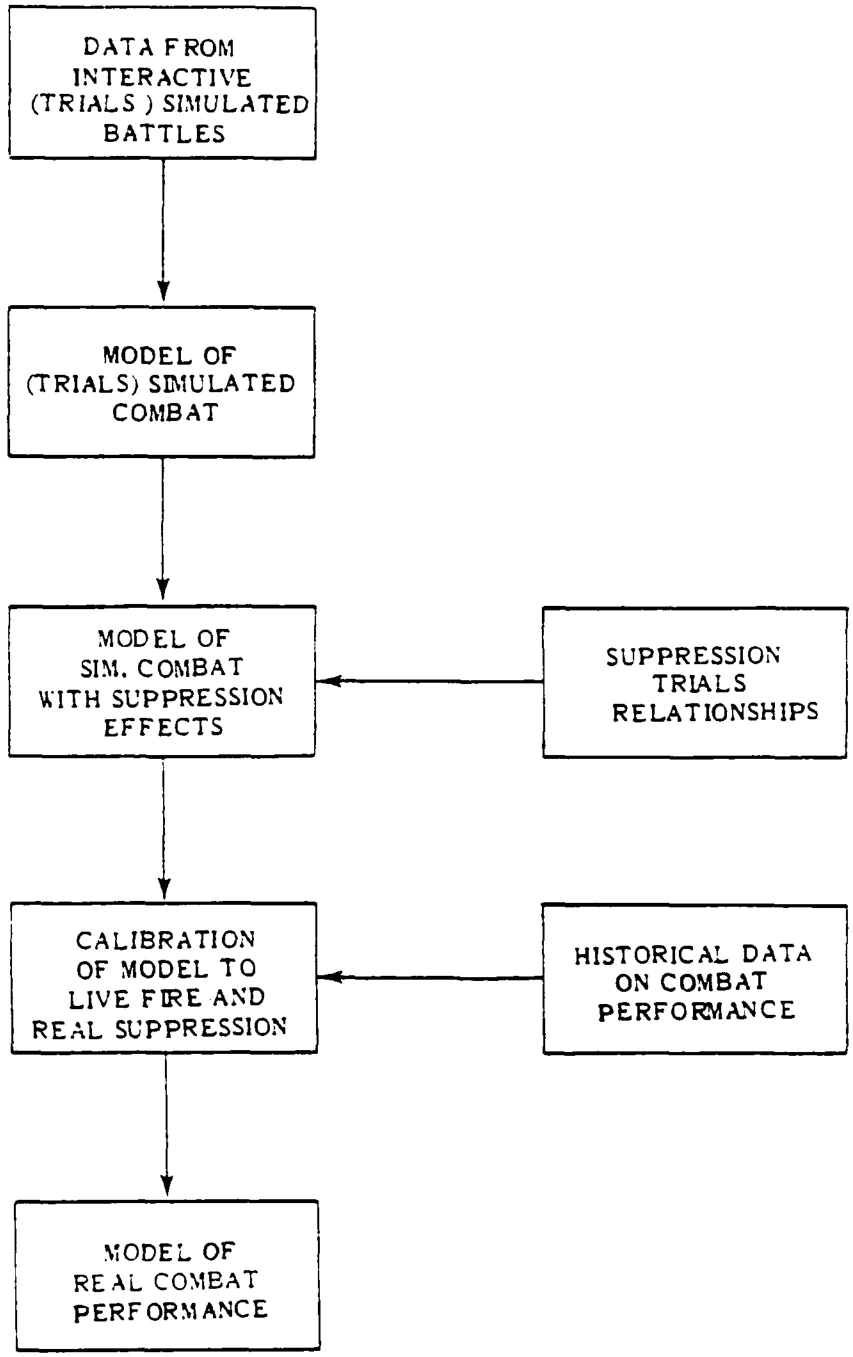


FIG 21. SCHEMATIC DIAGRAM OF COMBAT MODEL DEVELOPMENT (HELICCS) INCORPORATING HISTROICAL DATA

At Phase 1 a stochastic model was constructed which specifically represented:-

a. Individual weapons and men.

b. Attack movement in two dimensions (specified in scenario).

c. Intervisibility.

d. Weapon rates of fire with target availabilities search arc and range.

e. Lethality of each weapon firing - both in exercise (weapon simulators) and live fire conditions (weapons with live ammunition).

f. Overkill.

g. Defence open fire rules.

FIG 22. PHASE 1: DEVELOPMENT OF THE HIGH RESOLUTION MODEL HELICCS

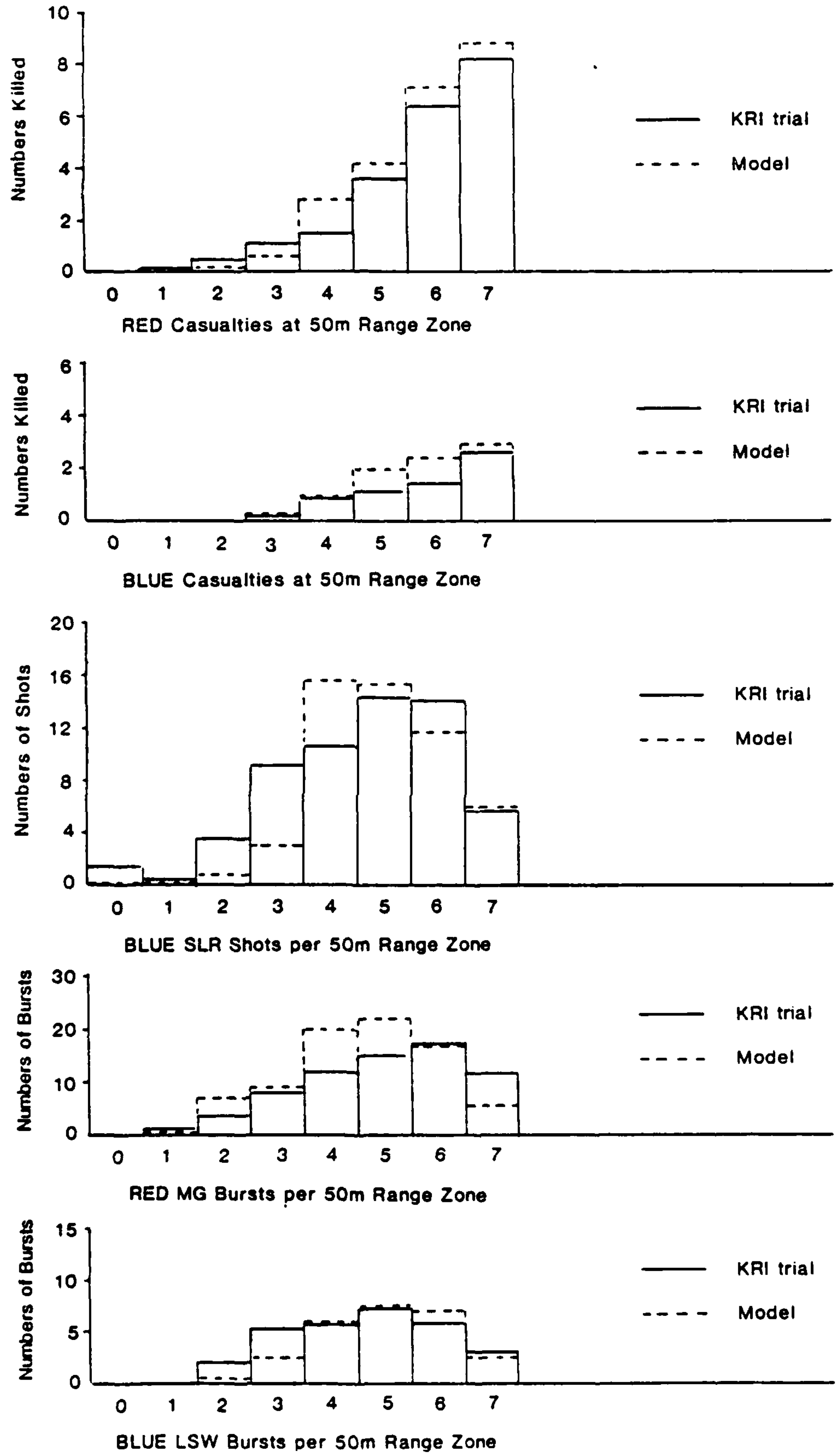


FIG 23. A COMPARISON OF MEAN MODEL AND TRIAL PARAMETERS - EX KINGS RIDE I

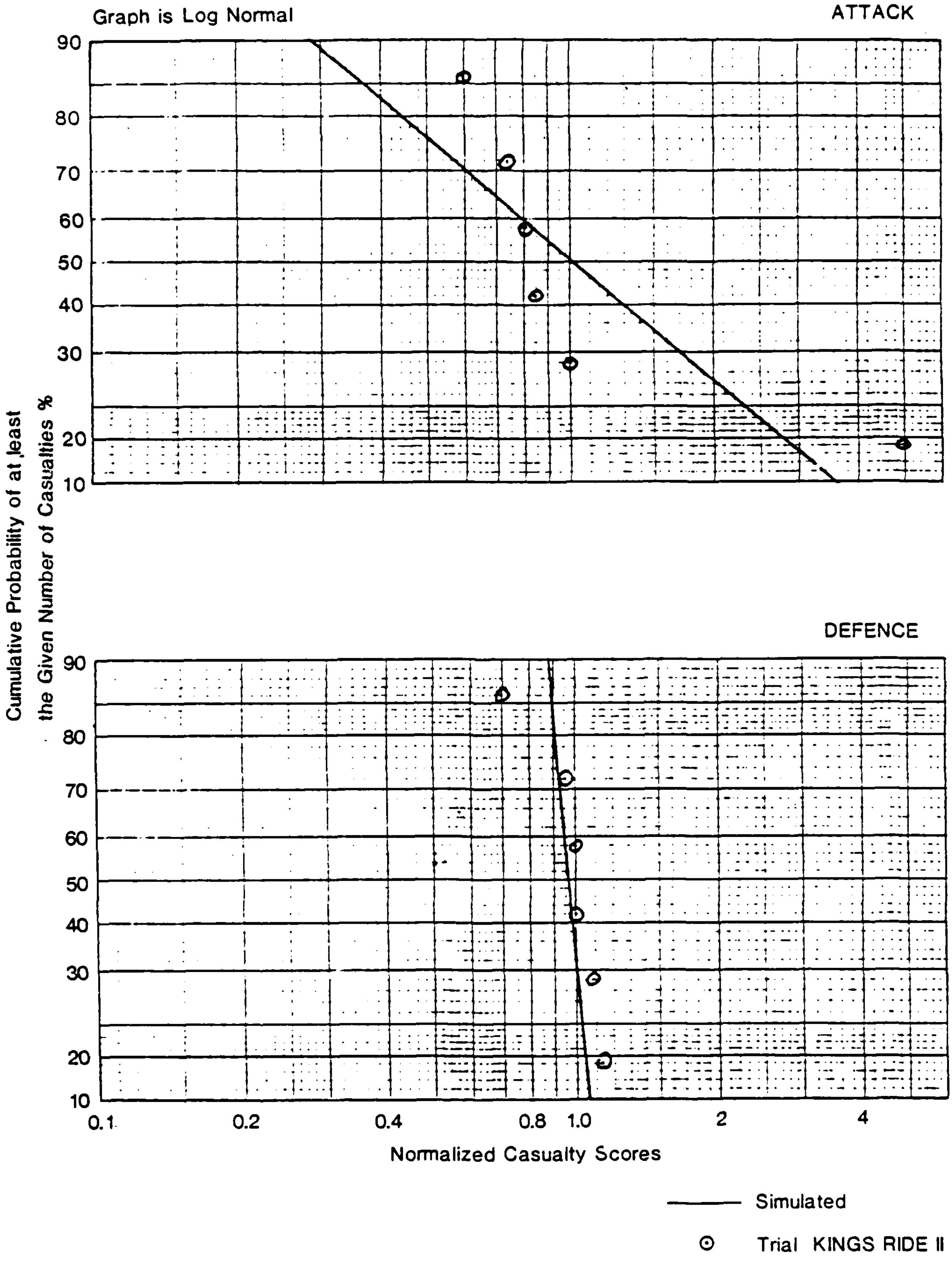


FIG 24. A COMPARISON OF MEAN MODEL AND TRIAL PARAMETERS - EX KINGS RIDE II

The Elaboration phase developed the Phase 1 model to include representation of:-

a. Direct fire suppression by small arms.

b. Direct fire suppression by AFV.

c. Degradation, as a result of suppression due to presence of live fire.

d. The effect of attack artillery in causing defence casualties and subsequent suppression.

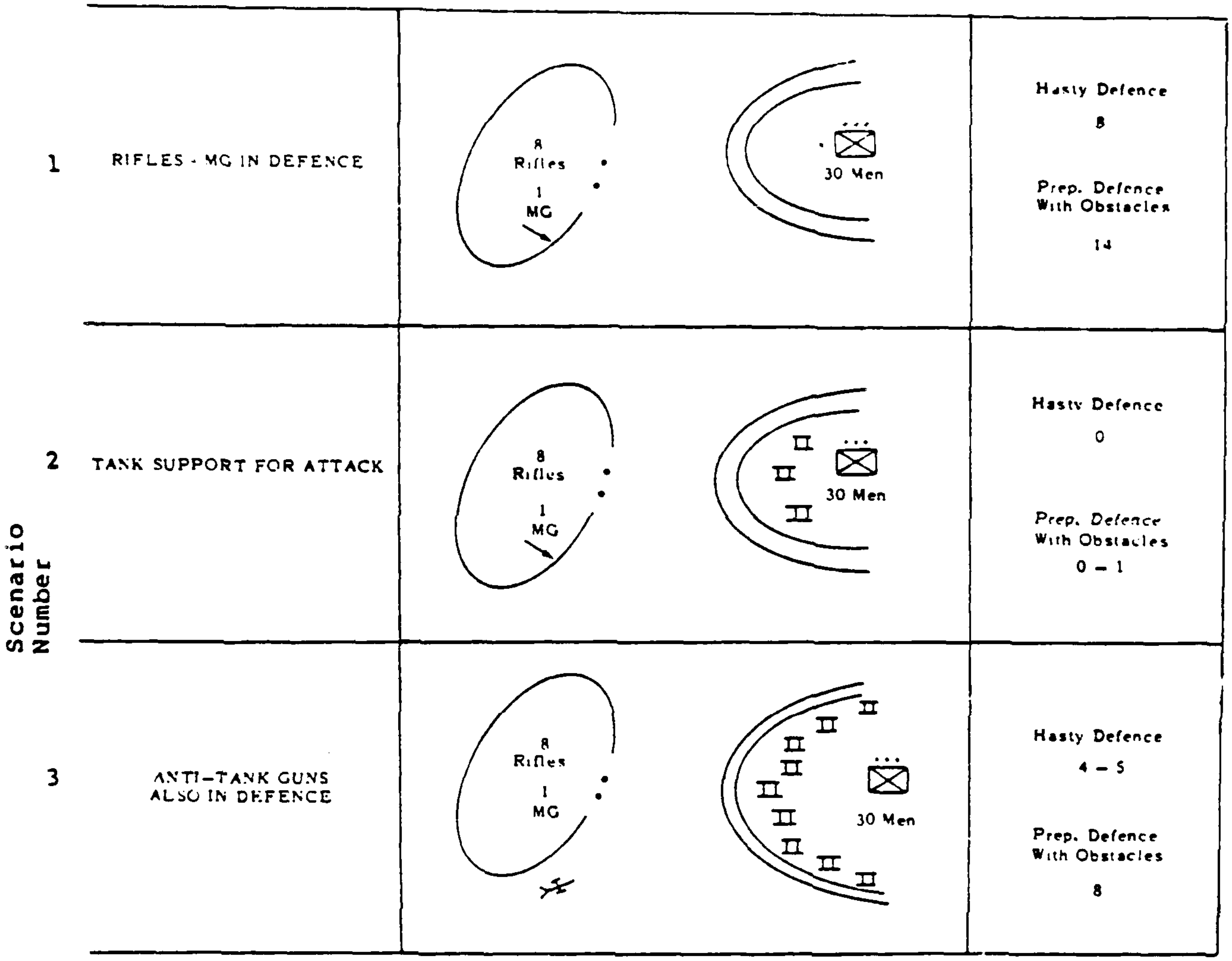
e. The effect of defence artillery in causing attack casualties.

f. Infantry anti-tank weapons.

g. The continuation of the battle to the overrun or close quarters battle phase, using data from Ex Kings Ride IIC.

h. The probability of attack withdrawal, defence withdrawal or defence surrender with casualty level and other factors.

FIG 25. PHASE 2: ELABORATION OF THE HELICCS MODEL



Run/Study Description	Attack Casualties for Scenario 1	2	3
Final simulation set all calibration complete. Mean from 10 replications	8.2	0.8	6.1
Repeat of the above with 25 replications per Scenario. Mean	7.7	1.6	6.1
s.d.	2.6	1.8	2.4
DOAE study results for unprepared defence	8	0	4.5
DOAE study results for prepared defence (ie: with obstacles)	14	0-1	8

FIG 26. SUMMARY OF CALIBRATION OF SUPPRESSION RESULTS

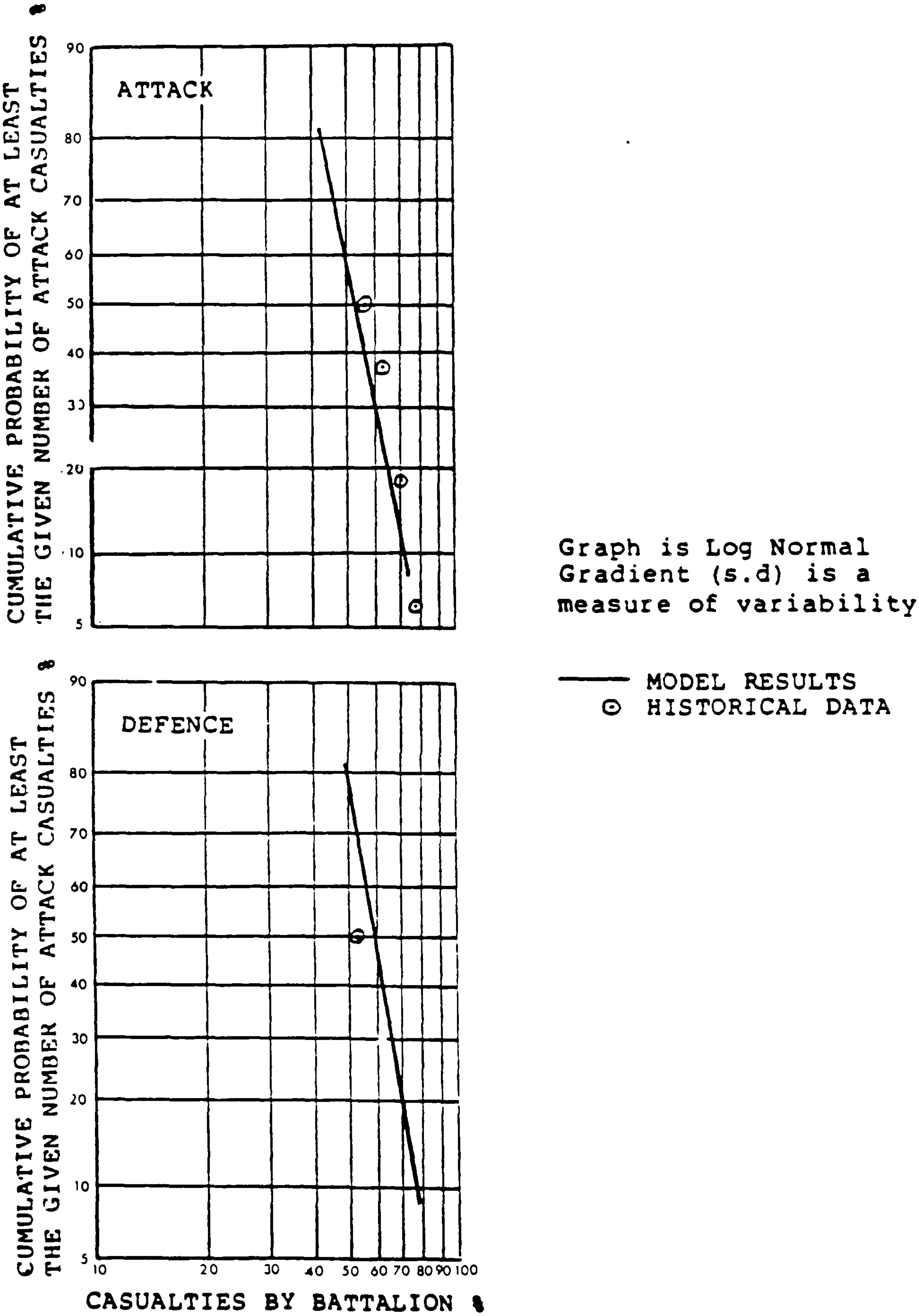
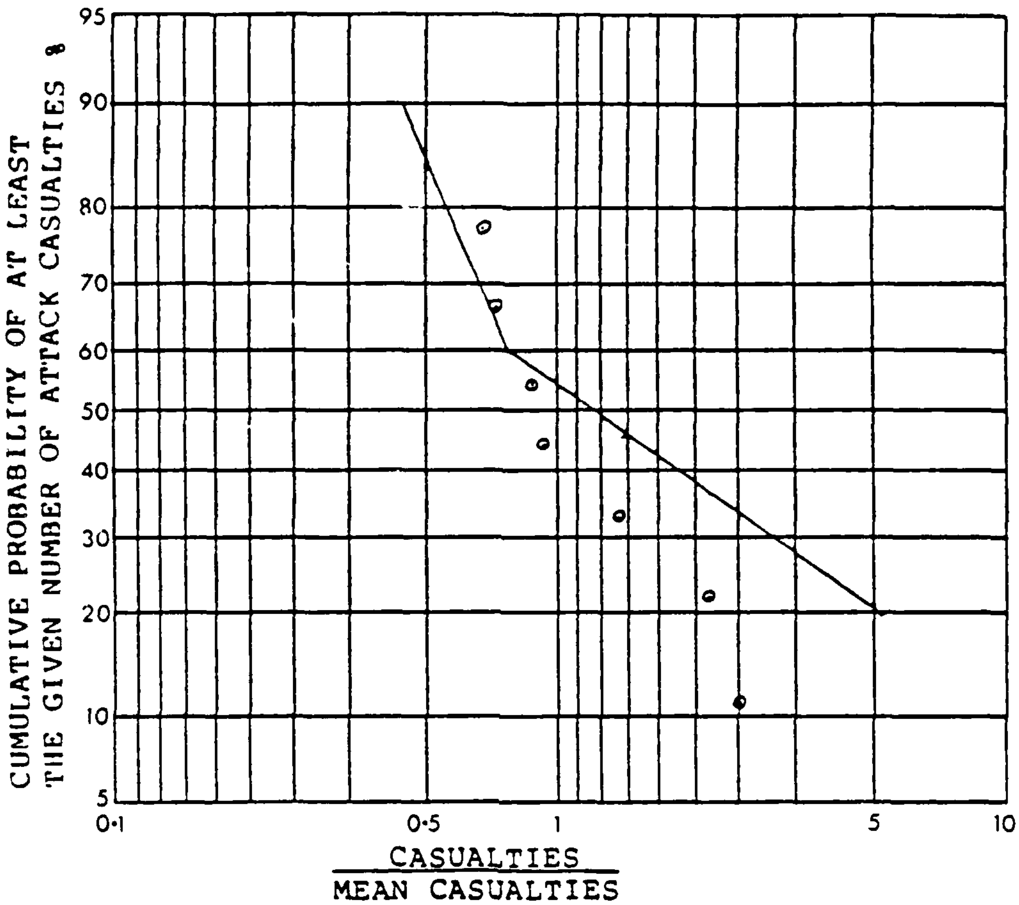


FIG 27. COMPARISON OF MODEL AND RECORDED CASUALTIES FOR THE FIRST DAY ON THE SOMME



Graph is Log Normal
Gradient (s.d) is a measure of variability

—— MODEL RESULTS
⊙ HISTORICAL DATA

FIG 28. COMPARISON OF THE MODEL AND RECORDED ATTACK CASUALTIES FOR THE D-DAY BEACH LANDINGS

COMBAT OPERATIONAL DATA ANALYSIS
AN EXAMINATION OF WORLD WAR II SUPPRESSION DATA

Charles L. Frame
Brian R. McEnany
Kurt A. Kladivko

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
Military Operations Analysis Division
1710 Goodridge Drive
McLean, Virginia 22102

INTRODUCTION

As part of its operational force and weapons planning tasks, the US Army uses division and theater-level simulation models to project wartime combat scenarios. Because of the significance of the decisions which the Army makes based upon the results of combat simulation modeling, the validity of combat simulation results is always an issue and efforts to improve the reality of combat models are continually on-going.

Combat is the struggle between opposing forces so that the will of one force may be imposed upon the other. Undoubtedly, the earliest combat was simply a hand-to-hand fight between individuals armed only with weapons like sticks and rocks provided by nature. Although man's ingenuity and technological advances have, over the centuries, allowed him to develop sophisticated weapons which often require only minimal input from the individual, the human element of combat remains essential. Combat modeling, however, has tended to focus on the purely physical effects of weapons with only indirect or implied human performance being included. Recently the Army, as well as the other Services, has stressed the importance of the human dimension in combat modeling and has explored new ways of including more operational realism in combat modeling. This study contributes to these efforts by making a detailed examination of the data available on the suppressive effects of bombardment.

BACKGROUND

Interest in human performance under fire is not new. The suppressive effects of artillery, aerial, and naval gunfire attacks have been formally investigated for over forty years.

During World War II, the United Kingdom, recognizing the need for scientific assistance for their operational commands, created Operational Research (OR) Groups as a part of British forces stationed both in England and overseas. These OR Groups collected measurements on the tactical performance and battlefield effectiveness of weapons, both Allied and German. The amount of data collected was quite extensive, and included correlations between rates of advance and casualties suffered; strength of opposition; damage to structures and personnel resulting from bombing; material and morale effects of bombardment; and, accuracy and lethality of ground and air weapons. Scientists of varied academic disciplines assigned to these small groups regularly gathered specific information on the effects of suppressive attacks by artillery, naval gunfire, and aviation attacks upon enemy targets.

Numerous reports, written immediately following various engagements, contain much quantitative information not normally found in operational reports created by military personnel. The principal value of these reports is their attention to quantitative detail. The scientific methods used for collection make the data adaptable for use in mathematical models. Prior to this study a portion of these data had been compiled by Professor Ronald W. Shephard of the United Kingdom's Centre for Operational Research and Defence Analysis (CORDA) for the Human Engineering Laboratory (HEL), Aberdeen Proving Ground. Examination of this data indicated a hopeful prospect of extracting information for application to US Army combat simulation modeling.

The British, however, are not the only ones to have done research into the effects of artillery. Suppressive effects of artillery fire have also been estimated for use in models by Fort Sill. Numerous experiments, including several by the Army's Combat Developments Experimentation Command (CDEC), over the past twenty years have addressed suppression's impact upon combat performance. Additionally, the Army Research Institute (ARI) has conducted experiments to assess the impact of small arms upon human performance. Since many of these reports cite earlier works completed during or shortly after World War II in the United Kingdom, the importance of the early British work cannot be overstated.

UNDERSTANDING THE PROBLEM

There are inherent problems in assessing force effectiveness by using combat simulation models. Data describing suppression, or the parameters and effects of bombardment, are important in developing a realistic casualty scenario for a simulation. Data currently used in these descriptions are either lacking entirely or are not easily validated since there has been no benchmark data available with which to relate simulation results to historical events. Data on the characteristics and effects of suppression need to be collected, compiled, and analyzed in order to improve and enhance the effectiveness of division and theater-level simulation models and provide more confidence in the results.

Historically, the US Army has not stressed collecting and analyzing human performance data and their effect within the battlefield environment or on the battle outcome. It has long been obvious that suppression effects and human performance factors are highly correlated. There is a renewed interest in determining what this correlation is, how predictions of human performance can influence suppression and casualty modeling in combat simulations, and how to actually incorporate suppression effects in the simulation models being used.

STUDY OBJECTIVES

This study was conducted by the Science Applications International Corporation (SAIC) at the request of the US Army Concepts Analysis Agency (CAA). The objectives of the study were:

> To compile, reduce, and analyze data from existing operational analysis reports generated during World War II in order to provide; (1) source data for modeling suppression effects due to fire support in division and theater level models and, (2) to benchmark or develop approximate standards against which to judge artillery expenditure results from division and theater level models.

The intent of this study was not to develop a specific definition of suppression, to develop or test hypotheses, or to develop algorithms which would incorporate the effects of suppressive fires into current combat models. The essence of this effort was to attempt to determine what data were readily available, collect them, and organize them for further analysis and evaluation. As the study progressed, effort focused on the following specific questions:

- What data are available in the CORDA collection?
- What can be done with the data as they exist?
- What use can be made of the data for modeling?
- What lessons can be learned from the process?
- What direction should future work take?

The answers to these questions are found in the sections that follow.

METHODOLOGY OVERVIEW

In order to compile, reduce, and analyze World War II operational data to achieve the study objectives, SAIC established a technical approach composed of the four basic tasks summarized below. Each of these tasks is explained in detail in subsequent sections of this paper.

DATA COLLECTION

In 1987, Professor Shephard of CORDA extracted data describing the suppressive effects of artillery and aerial attacks on enemy targets from reports originally created by British Operations Research Units during and immediately after World War II. Those data, collected under contract for the HEL at Aberdeen Proving Ground and compiled in a two volume set titled "A Survey of Suppression," formed the initial data set for this study.

In 1988, Professor Shephard, under subcontract to SAIC, extracted additional data from the original set of reports to supplement those already available in Volumes I and II. These data were recorded in two additional volumes which became Volumes III and IV of the "A Survey of Suppression" set. This study utilized the data recorded in all four volumes.

DATA DESCRIPTION

All data in Volumes I through IV of the "Survey of Suppression" set were subjected to detailed examination for the purpose of identifying the set of variables which would completely describe each operational engagement. These variables were then categorized as either; identification data, serial data, target data, firing data, results data, or calculated data. These data categories provided the building blocks for structuring of the data base.

DATA BASE DEVELOPMENT

All data were recorded in a format conducive to data analysis during this study and any subsequent efforts. A three-tier data base structure, using dBASE III PLUS software, was used to enhance the usefulness of the CORDA data by recording the data <u>as recorded in British Operational Reports and extracted by Professor Shephard</u>. The data base was designed to ensure that all operational data pertinent to the identification and measurement of suppression effects were recorded. Data were recorded in the data base <u>without enhancement by interpretation</u>, that is, exactly as reported in the CORDA volumes. Thus the data base provided a tool for conducting a preliminary evaluation of the usefulness of the <u>original</u> data.

DATA EVALUATION

Data evaluation focused on answering three of the five questions identified earlier, namely:

- o What data are available in the CORDA collection?
- o What can be done with the data as they exist?
- o What use can be made of the data for modeling?

Of course data evaluation was not done exclusively in this part of the study. The description of the data, in preparation for the structuring of the data base, also contributed significantly to the understanding and evaluation of the data. The evaluation of data recorded in the data base concentrated on describing the density and location of data within the data base and estimating the number of data points available for estimating functional relationships between key variables.

DATA COLLECTION

SOURCES

The source of the data evaluated by SAIC was the four volume set of abstracts compiled by Professor Shephard titled "A Survey of Suppression." They were created by defining a framework for data collection, reviewing and cross-checking the original sources of data in the United Kingdom repositories (especially the Public Records Office), and creating a bombardment analysis sheet for each engagement.

Professor Shephard had previously compiled an annotated bibliography of a large number of the nearly 3000 operations research reports created by the United Kingdom's OR Groups during World War II. Research conducted for HEL in 1987 produced a smaller bibliography of 75 reports which addressed suppression effects.

This smaller bibliography was further broken into two distinct parts. Category A contains reports for a number of operations in Germany, Italy, and various Pacific islands. The size of the operations were from squad to corps and some reports had subreports due to the length or duration of the operation. These reports included data extracted by the OR Groups on suppressive effects of bombardment by artillery, naval gunfire, and aircraft.

Category B reports document efforts by OR personnel back in England to extrapolate the earlier findings and create models or estimates of the effects on human performance. There were a small number of these still in the United Kingdom repositories.

The effort sponsored by HEL in 1987 concentrated upon the Category A reports. The SAIC effort, somewhat constrained by resources, continued data collection from the Category A bibliography. It was thought that papers in this Category would be of most interest initially, and that they should be dealt with before those in Category B (which rely mainly upon papers in Category A for basic data). The study sponsor elected to request selected Category B reports from the UK. Three of the eight reports requested were received at the end of the current study period, too late for use during the study. They are expected to contain some hypotheses concerning the important parameters associated with the evaluation of suppressive data at the end of World War II, and so could be of use in future hypothesis development efforts.

SAIC and Professor Shephard agreed with CAA that additional data collection of United Kingdom operational data would greatly assist in preserving important information before it is lost. The study sponsor wished to pursue collecting as much information related to suppression from these documents as possible. Hence, Professor Shephard continued extracting bombardment data from the Category A operational reports within the resources allowed for data collection in this study effort.

FORMAT

The terms of reference for the HEL study asked for abstracts to be prepared of each report or document listed. For the sake of uniformity, each abstract, referred to as a Serial, follows a standard format (as far as circumstances will allow) and records the following details:

- The location and date of the action, a map of the area, and the reference from which the data have been abstracted,
- A description of the plan for the action and the enemy dispositions,

- Details of the bombardment including the units involved, the targets engaged, and the program (i.e., schedule) of fire,
- A note on any factors that might have influenced the effect of the bombardment,
- Casualties to both sides and observations on suppressive effects noted at the time or obtained from interviews afterwards, and,
- A Bombardment Analysis Sheet (BAS) giving numbers of rounds fired, density of bombardment, duration of fire, etc., where known.

Each abstract is identified by a unique serial number which appears in the top right-hand corner of the sheet. As has been mentioned, some serials contain details of more than one bombardment. Serial 10, for example, contains reports of ten separate actions. Figure 1 provides an example of Report 8 of Serial 10 and includes two pages of narrative describing the action and a two page BAS providing tabular data on the bombardment.

A total of twenty-six abstracts (serials) were reported by Professor Shephard for HEL in Volumes I and II of the "A Survey of Suppression" set. Figure 1 is an example of the format in which the data were recorded. The survey was developed during the HEL work and was continued in two additional volumes (CORDA Volumes III and IV) prepared specifically for this study. Volumes III and IV were provided to CAA as a part of this study. The Figure 1 example was chosen because it provides good opportunities to discuss data limitations and the process of recording the data in the data base.

LIMITATIONS

Each serial reported by Professor Shephard includes not only a reference to the original World War II report from which data were extracted for that report, but also an indication of the source of the data which World War II researchers recorded in the original reports. The data sources were varied, as were the techniques used by individual researchers to gather the data, particularly quantitative data. Professor Shephard discussed the effects of the variation in data sources and collection techniques in CORDA Volume I. Several of his comments are quoted in the remainder of this section.

__The Effect of Variation of Data Sources__.

In discussing the effect of the variation in data sources Professor Shephard stated, "It is obvious that, from their very nature, the accuracy of the data given in the abstracts is uneven and varies from source to source. Some of the best is probably that which is annotated as being based on "ground recce." At the other end of the scale will be that based on the memory of soldiers who were subjected to bombardment. In between are data based on "planned figures" when there is no guarantee that these were achieved in practice." (p. 3)

CONTINUATION SHEET

LOCATION Italy | DATE | SERIAL NO

REPORT 3

1. SCENARIO

1.1 General

H hour was 2300 hrs.

1.2 The British plan

Artillery was to support an attack on a hill top by (hopefully) persuading the Germans to evacuate their positions. A "crash and harass" plan was adopted. (The "crashes" would seem to be short intense periods of fire).

1.3 The German dispositions

The German positions were on a hill top.

1.4 The attack

The position was strongly defended by MG fire when the infantry advanced after the bombardment.

2. ARTILLERY BOMBARDMENT

2.1 Supporting units

Three field regiments, one medium regiment, and one heavy battery were used.

2.2 The artillery programme

Generally the programme was as follows. Each troop was allocated a target. Three of these targets were on the position to be assaulted, the rest were supposed to be suppressed.

These targets were engaged in the following time table. (Note that the shelling by the heavy battery was not recorded).

FIGURE 1. CORDA ABSTRACT FORMAT

CONTINUATION SHEET

LOCATION Italy DATE SERIAL [illegible]

Start	Stop	Rpg. (Fd)	Rpg. (Med).
H-60 (Crash)		6	3
H-60	H-30	20	10
H-25	H-15	12	6
H-14 (Crash)		4	2
H (Crash)		10	5
H-5	H+30	20	10
H+30	H+60	15	8 (15 on objective)
H+60	H+85	15	7
H+90 (Crash)		5	3
H+95	H+180	40	20
H+180	H+420	30	15 (single rounds spread over time).

After H+60 fire refers to subsidiary targets. Fire was by prediction.

2.3 Distribution of fire

The artillery fire seemed to be widely scattered over an area of 2,500 yards by 6,000 yards.

3. OTHER FACTORS

None.

4. CASUALTIES

Not known.

5. CONCLUSION

The position was not suppressed at the time of the infantry attack.

FIGURE 1. CORDA ABSTRACT FORMAT (CONTINUED)

BOMBARDMENT ANALYSIS SHEET

LOCATION Italy　　**DATE**　　**SERIAL** 10

(It has been assumed that the 7.2in howitzers fired at half the rate of the 5.5in guns. It has also been assumed that the 3 troops firing at the objective were 2 field troops and 1 medium troop).

THE OBJECTIVE

TIME (from - to)	BARRAGE TYPE	25pr				5.5in				Total Rounds 25pr + 5.5in
		No of Guns	rpg	Fuze	Rds fired	No of Guns	rpg	Fuze	Rds fired	
H-60		8	6		48	4	3		12	60
H-60 to H-30		8	20		160	4	10		40	200
H-25 to H-15		8	12		96	4	6		24	120
H-14		8	4		32	4	2		8	40
H		8	10		80	4	5		20	100
H+5 to H+30		8	15		120	4	15		40	200
H+30 to H+60		8	20		120	4	10		60	180
TOTAL DURATION 90 min		TOTAL RDS			696	TOTAL RDS			204	TOTAL 900

Target Area　1,875,000 yd^2 (estimated by abstractor)

FIGURE 1. CORDA ABSTRACT FORMAT (CONTINUED)

BOMBARDMENT ANALYSIS SHEET

LOCATION Italy　　**DATE**　　**SERIAL** 10

Average Density

25pr:		0.000371 rds/yd^2
	=	0.00928 lb/yd^2 in '20 min
5.5in:		0.000109 rds/yd^2
	=	0.00870 lb/yd^2 in 120 min
	=	0.00722 lb/yd^2 equiv 25pr (Factor = 0.830)
Total		0.000480 rds/yd^2 in 120 min
	=	0.0180 lb/yd^2 actual wt in 120 min
	=	0.0165 lb/yd^2 equiv 25pr in 120 min

FIGURE 1. CORDA ABSTRACT FORMAT (CONTINUED)

Professor Shephard, referring to himself and his research assistant, further noted that, "The authors (of Volumes I and II), aware of these difficulties, made every effort to check and cross-check all the figures they recorded. Any estimates that they made for quantities not recorded in the original reports are annotated accordingly. They believe that the abstracts are as accurate as possible and they have ensured that they are internally consistent." (p. 3)

For this study SAIC also reviewed all of the abstracts, including those in Volumes I and II, and reported a number of inconsistencies to Professor Shephard. Professor Shephard and his research assistant have again investigated each of these inconsistencies and, while some have been resolved[1], have reported that in some cases the original operational reports contained the inconsistencies. According to Professor Shephard, this situation is not unusual given the difficulties of collecting battle data and the adverse circumstances under which many of the original reports were written. In fact, he reports that the quality of the original battle data, from which the abstracts were taken, is considered to be very good in comparison to other combat data sets. Despite this, some cases of conflicting data could not be resolved. An example of this situation will be discussed later.

The Effect of Quantitative Estimation Techniques.

With respect to issues concerning quantitative data, Professor Shephard stated, "The quantity recorded that has caused the most difficulty in this respect, and which must be treated with the most suspicion if quoted, is that for "target area" (and hence bombardment density). The numbers of rounds fired, and the period over which they were fired, is generally precisely known. However, different reports are not always consistent in what they mean by target area; sometimes the area given is that of a notional rectangle within which all the parts of the target complex are believed to lie; sometimes it is that based on a ground survey of the distribution of craters; sometimes on the expected dispersion of rounds as given by range tables. The authors of the present report preferred to quote an area similar to the first of these alternatives - namely, the area of the target as it might be outlined on a map. But this has not been easy to estimate to any high degree of accuracy and they would be the first to admit it.... The reader can only be asked to note these comments and to include appropriate reservations in any analyses based on the figures quoted here." (p. 3) (emphasis added)

While Professor Shephard was specifically referring to Volumes I and II in his comments on target area, the same difficulty exists in the serials reported in Volumes III and IV. The study team has concluded that operations above battalion level are generally difficult to describe accurately and collect data on. This difficulty extends not only to target area but also to the

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[1] Inconsistencies which existed in the original drafts of Volumes III and IV have been corrected in the final versions of these volumes. Inconsistencies in Volumes I and II were corrected via publication of an errata sheet (Corrigendum) for each volume. These were provided to CAA as a part of this study.

recording of bombardment and results data. The operations in Volumes III and IV which involve amphibious landings, for example, are often so large, and the data aggregated to such a level, as to call into question their usefulness in modeling suppression. Smaller operations involving squads and regiments can generally be assumed to have more reliable bombardment and results data, and are thus believed to be of greater potential use in modeling. This issue will be discussed more fully later in this paper.

<u>The Use of "Equivalent" Bombardment Factors</u>.

Returning to Professor Shephard's comments concerning data limitations in Volume I, he stated, "Finally, it may be noted that in common with most reports of WW II vintage, bombardment densities have been quoted in terms of "equivalent 25 pounders" using conversion factors universally quoted to convert for other calibers. The concept of "equivalent 25 pounders" is not easy to justify rigorously, nor indeed did it meet with uniform approval by analysts in the war years." (p. 4)

Because this gun was the most common artillery piece in service with the field force units of the Royal Artillery during World War II, it became common practice for OR Group researchers to normalize bombardment data on "pounds of explosive" to 25-pounder equivalent data. According to <u>Jane's Weapons Systems 1979-80</u>, the 25-pounder, first designed in 1935 as a replacement for the 18-pounder used during World War I, was a towed, 88mm gun with high explosive shells weighing 11.3 kilograms and a maximum range of 12,252 meters.

Especially troubling to Professor Shephard, however, is the fact that the conversion factors refer more to lethality effects than suppressive effects. He feels that it may be more appropriate to use the number of rounds and/or pounds data, rather than equivalent pounds data, in any analytical efforts.

<u>Examples of Data Limitations</u>.

Figure 1 (Report 8 of Serial 10) illustrates problems encountered with conflicting data in the original reports. The table listed under paragraph 2.2 of the abstract contains data which conflict with data contained in the BAS. In the phase of the artillery bombardment extending from time H+5 to time H+30, the paragraph 2.2 table indicates that 20 rounds per field (fd) gun (i.e., 25 pounder) and 10 rounds per medium (med) gun (i.e., 5.5 inch) were fired. The BAS, however, indicates that 15 rounds per 25 pounder gun and 15 rounds per 5.5 inch gun were fired. Similarly, the data for the time period H+30 to H+60 varies between the paragraph 2.2 table and the BAS. Since the correct data cannot be determined from the original report, the data are presented as they appear in the original.

Figure 1 also provides an example of incomplete data in the original reports. Since no firing data were reported in the original report for the 7.2 inch howitzers, it had to be assumed that the heavy battery did not actually participate in the bombardment of the objective. Additionally, it had to be assumed that the three troops which fired on the objective were two field troops and one medium troop. Without these assumptions about information which was not provided in the original reports, and without an estimation of the target area by the data abstractor, the BASs and calculations for rounds per square yard, pounds per square yard, and equivalent pounds per square yard could not have been completed. Even some basic data, such as the geographic location of the engagement and the date of the engagement, were not recorded in the original report.

DATA DESCRIPTION

OVERVIEW OF CORDA VOLUMES I - IV

In Volumes I and II, twenty-six serials were reported. All but one serial reported single combat actions in which one force engaged another force. Serial 10, however, included ten separate reports, thus bringing the total number of reports in these volumes to 35. Of these, four were not reports of a specific combat action. Three of the four reports included only subjective evaluations of the effect of suppressive artillery fire on troops without reference to specific combat actions. The fourth report was of a series of experiments which had been done to test whether a series of explosions simulating a bombardment would reduce the efficiency of men exposed to the explosions. Thus Volumes I and II contain reports on a total of 31 combat actions. An overview is provided in Table 1.

Clearly the actions reported in Volumes I and II are very similar in many aspects. All involved combat action between opposing ground forces and, as indicated in the column labeled "G" (for ground artillery), all involved some level of bombardment by artillery units in support of the ground forces. Only two actions involved the aerial bombardment of enemy targets and there were no actions which included bombardment by naval gunfire. Although there were four actions in which British troops were attacked by German units, 24 of the actions were similar in that German troops were attacked by British units.

TABLE 1. OVERVIEW OF CORDA VOLUMES I AND II

TYPE ACTION	ATTACKER	DEFENDER	LOCATION	NO. OF ACTIONS	BOMBARDMENT G	A	N
Ground	British	German	Italy	23	23	-	-
Ground	British	German	France	1	1	1	-
Ground	N. Zealand	German	Italy	1	1	1	-
Ground	British	Italian	Egypt	2	2	-	-
Ground	German	British	Italy	4	4	-	-
			Totals	31	31	2	0

G - Ground A - Air N - Naval

The homogeneous nature of the actions reported in these volumes contrasts significantly with that of the actions reported in Volumes III and IV. As discussed previously, the preparation of Volumes III and IV as a part of this research effort was driven primarily by the desire to collect as much data as possible from the original operational reports within the fiscal resources available. Since data were not being collected with any particular hypotheses in mind, the effort concentrated on those original reports from which data could be most easily extracted. In all, 23 additional serials were reported in Volumes III and IV with each reporting on a single combat action in which one force engaged another. Table 2 provides an overview of these 23 actions.

TABLE 2. OVERVIEW OF CORDA VOLUMES III AND IV

TYPE ACTION	ATTACKER	DEFENDER	LOCATION	NO. OF ACTIONS	BOMBARDMENT G	A	N
Ground	British	German	Italy	3	2	-	-
Ground	British	German	France	4	3	4	-
Ground	British	German	Holland	2	-	2	-
Ground	British	German	Germany	1	-	1	-
Landing	US	Japanese	Pacific	12	9	12	12
Landing	British	German	France	1	1	1	1
			Totals	23	15	20	13

G - Ground A - Air N - Naval

Unlike the actions reported in Volumes I and II, the actions in these volumes were quite dissimilar in type of action and type of bombardment. While all 31 of the actions reported in Volumes I and II were of combat action between opposing ground forces, over half of the actions reported in Volumes III and IV involved amphibious landings. Each of the 13 landing operations was similar in that both aerial and naval gunfire bombardments were employed in the attempts to suppress the enemy forces opposing the landing. Although ten of the landings were also supported by ground artillery positioned on already captured beaches or islands, the primary firepower supporting the landings was provided by naval aircraft and naval gunfire.

Ten additional ground combat actions were also reported in Volumes III and IV. These too, however, differed from the actions in previous volumes. Of the ten ground actions, only five involved support of ground forces by ground artillery units, while seven included support in the form of aerial bombardment. One action between an attacking British force and German defenders in Italy actually involved no reported bombardment of the German position.

The diverse nature of the combat actions reported in Volumes III and IV provided an unexpected challenge in the development of a data base structure and format capable of recording pertinent data from all four volumes. The next subsection describes the results of an analysis conducted to provide an understanding of the data to a level of detail which would permit the proper data base structure to allow for the accomplishment of the study objectives.

In all, a total of 54 actual combat actions were reported in Volumes I-IV. In terms of describing the suppressive effects of bombardment, whether the bombardment be artillery, aerial, or naval gunfire, more detailed information than provided in Tables 1 and 2 about each action was required. Specifically, the data were analyzed to describe more fully the combat operation in terms of targets engaged, the artillery fire plans, and the scope of the operations. Additionally. the variables which describe the combat actions were identified and categorized to provide the basis for a data base structure.

SCOPE OF COMBAT OPERATIONS

In any attempt to describe the suppression effects of bombardment, it is essential to have as complete an understanding of the target and of the bombardment plan as possible. As the initial step in gaining an understanding of the data in these important areas, each of the 54 actions reported was analyzed to determine the number of distinct targets which were engaged during the action and the number of phases in the fire plan for each target. This information is presented in Table 3 below.

TABLE 3. TARGET AND BOMBARDMENT PHASE DATA

TYPE ACTION	NO. OF ACTIONS	NO. OF TARGETS	NO. OF PHASES
Ground	41	86	167
Landing	13	16	20
Totals	54	102	187

Seventeen of the 41 ground combat actions involved the bombardment of more than one target, including one action in which seven distinct targets were engaged and three other actions in each of which six distinct targets were engaged. The bombardment plans for the 86 targets indicated that 33 were engaged in multiple phases, with the maximum number of phases reported for the engagement of a single target being ten. The remainder of the targets were engaged in a single-phased fire plan.

In the reports of amphibious landings only three actions involved the engagement of multiple targets and in each case the number of targets engaged was two. Identification of the phases of the bombardment plans supporting amphibious landings was more difficult than for most of the ground actions because of the inclusion of both aerial bombardment and naval gunfire in the fire plans. For three targets, however, it was possible to determine that the bombardment plans did include distinct phases. In these cases, two targets were engaged in two phases each and one target was engaged in a three phase plan.

The scope of the combat operations reported in the 54 actions was broad:

- The size of attacking forces ranged from a single infantry squad to multiple corps.
- The size of defending forces ranged from a single platoon to multiple divisions.

- o The size of the target area over which the bombardments occurred ranged from 2,000 square yards to an entire Pacific island of approximately 50 square miles.

- o The weapons used in the bombardments ranged from mortars to 16-inch naval shells weighing 1,900 pounds and bombs weighing 2,000 pounds.

- o The bombardment times for phases of an engagement ranged from one minute to 49 days.

The diverse nature of the actions reported and the scope of the combat operations provided a significant challenge in the development of a data base in which all actions could be recorded and our understanding of suppression enhanced.

IDENTIFICATION OF KEY VARIABLES

In order to develop a data base structure in which combat actions could be recorded, a list of variables was developed which permitted the description of each action. This list included 48 variables, both quantitative and qualitative, which were then grouped into six categories depending upon the type of data which each variable described. The six categories are:

o Identification Data	o Firing Data
o Serial Data	o Results Data
o Target Data	o Calculated Data

Identification data includes nine variables and provide a way to reference combat data to both the Serial Reports in CORDA Volumes I-IV and the original British Operational Reports from which the CORDA data were extracted. Identification data also provide a means by which one data base record can be referenced to another data base record dealing with the same combat action. Specific variables which provide identification data are displayed in Figure 2.

IDENTIFICATION DATA VARIABLES

Serial Number
Reference Number
Original Reference
Reference Title
Data Source
Target Number
Number of Phases
Phase Number
Time

FIGURE 2. IDENTIFICATION DATA VARIABLES

Serial data are defined by 15 variables which describe the opposing forces; the date, location, weather, and time of the action; the serial tactics; and the number of targets and phases of the engagement of each target. Serial data variables are presented at Figure 3.

<u>SERIAL DATA VARIABLES</u>

Side 1 Country
Side 1 Units
Side 1 Posture
Side 2 Country
Side 2 Units
Side 2 Posture
Date of Action
Country
Region
Terrain
Weather
Time
Serial Tactics
Number of Targets
Number of Phases per Target

FIGURE 3. SERIAL DATA VARIABLES

Target data are defined by four variables include the target area, the tactics of the overall target bombardment, and the tactics involved in each phase of the fire plan. The target data var;ables are presented in Figure 4.

<u>TARGET DATA VARIABLES</u>

Target Description
Target Area
Target Tactics
Phase Tactics

FIGURE 4. TARGET DATA VARIABLES

Firing data are represented by seven variables which describe the firing unit, weapon types, rounds, and duration of the bombardment. The firing data variables are presented in Figure 5.

<u>FIRING DATA VARIABLES</u>
Fire Unit Type of Weapons Number of Tubes Type of Ammunition Rounds per Gun Number of Rounds Fire Duration

FIGURE 5. FIRING DATA VARIABLES

Results data are identified by seven variables which describe the results of both the bombardment and the infantry attack. Of particular interest is the variable which describes the suppressive results of the bombardment. Figure 6 presents the results data variables.

<u>RESULTS DATA VARIABLES</u>
Attack Delay Time Time to Objective Casualties Equipment Damage Other Factors Other Results Suppression

FIGURE 6. RESULTS DATA VARIABLES

Calculated data are represented by six variables which describe the density and intensity of the bombardment. Calculated data variables are presented in Figure 7.

CALCULATED DATA VARIABLES
Rounds per Square Yard
Rounds per Square Yard per Minute
Pounds per Square Yard
Pounds per Square Yard per Minute
Equivalent Pounds per Square Yard
Equivalent Pounds per Squara Yard per Minute

FIGURE 7. CALCULATED DATA VARIABLES

The variables in the six categories can be used to describe the actions at three levels, i.e., Serial, Target, and Phase. Since not all variables are applicable to all levels, the variable categories can be used as building blocks to create a three-tier data base structure as described below.

DATA BASE DEVELOPMENT

CONCEPT

There are dangers implicit in creating a data base from abstracts of the original data. To minimize these dangers, every attempt has been to faithfully replicate the CORDA data in the SAIC data base.

The data base[2] records and preserves the combat operational data and provides a tool for evaluating the usefulness of the original d..a. The data base should only be used in conjunction with the abstracts.

As noted earlier, the guiding principle in developing the data base was to record the data as it was reported in the abstracts. No interpretations or assumptions were used to enhance or supplement the information.

STRUCTURE

Data in the abstracts occur at three different levels. Some data apply to the action or engagement as a whole. Examples of such data would be the nationalities of the combatants and the location of the engagement.

Other data apply to a target within an engagement. Since an engagement may involve multiple targets, data may be given on each particular target. Examples of such data would be the target size and a description of the target.

[2] Technically, three distinct data bases were developed. However, for simplicity, reference will be made to the data base.

Since a particular target may have a fire plan associated with it which contains multiple phases, a third level of data exists. Examples of data at the phase level would be the number of guns of a particular type, the number of rounds per gun fired in that phase, and the duration of the phase.

SAIC developed a three-tiered, hierarchical data base structure to best represent the data; a SERIAL data base, a TARGET data base, and a PHASE data base. In the SERIAL data base, each engagement has its own record. In the TARGET data base, each target of the engagement has its own record. In the PHASE data base, each phase of a target of an engagement has its own record. For example, if an engagement has two targets, each target having three phases, then there would be six records for that engagement in the PHASE data base.

DATA ENTRY

Two principles guided the data entry effort. First, data were recorded at the lowest level possible in the three-tier structure. The reason for doing this is that data can always be "rolled up" to the next higher level, but they cannot always be broken out to the next lower level. For example, if a target had only one phase, and the firing data in the abstracts were reported at the target level, then the firing data were recorded at the phase level in the data base.

Second, data were recorded at only one level in the three-tier structure. At the other levels, the particular data field would refer to the level at which the data were recorded. For example, if suppression data were entered at the SERIAL level, then the suppression field in the TARGET and PHASE records for that serial number would contain "SERIAL LEVEL." This informs the user that suppression data are available in the SERIAL data base.

Due to practical limitations in field lengths, codes were developed for each type of weapon. These codes, along with their corresponding weapon description, are at Table 4. This allows codes to be entered into the data base instead of lengthy weapon descriptions.

To assist in discussing data entry conventions, examples of data base listings are presented in Figures 8 through 11. The examples used are from the same serial (Serial 10, Report 8) described in Figure 1 and referred to in the data bases as Serial 10.08.

In certain cases, slashes (/) were used in the data fields to separate each target's number of phases. There are two types of situations in which slashes were used. First, they were used in the "NO. PHASES/TGT" field, which indicates the number of phases per target. In Serial 10.08 (Figure 8), there are two bombardment targets. The "NO. PHASES/TGT" field contains "7/10." This indicates that the first target has seven phases and the second target has ten phases.

TABLE 4. WEAPON CODES

CODE	WEAPON TYPE	NATIONALITY
A	25pr gun	British
B	60pr gun	British
C	3.7in mountain howitzer	British
D	4.2in mortar	British
E	4.5in gun	British
F	5.5in gun (80 lb shell)	British
G	6in howitzer	British
H	7.2in howitzer	British
J	105mm gun	German,American
K	150mm gun	German
L	88mm gun	German
M	14in gun (Naval)	American
N	8in gun (Naval)	American
P	5in gun (Naval)	American
Q	16in gun (Naval)	American
R	6in HE gun (Naval)	American
S	6in AP gun (Naval)	American
T	Unidentified Bombs	British
U	4in gun (Naval)	American
V	4.5in rocket	American
W	4.2in mortar	American
X	Field Gun	British
Y	Various Calibers	British
AA	500lb bomb	American
BB	100lb bomb	American
CC	5in antiaircraft	American
DD	155mm howitzer	American
EE	1000lb bomb	British
FF	75mm gun	American

The second situation in which slashes are used is when data for different targets are recorded at different levels. Although Serial 10.08 does not provide an example of this situation, consider a serial which has six targets. If the first and second targets each have three phases, while Target Numbers 3 through 6 each have one phase, then the "BOMBARD TARGET" field, which gives a description of the bombardment target, might contain "TARGET/TARGET/PHASE/PHASE/PHASE/PHASE." This indicates that a description of the bombardment target can be found in the TARGET data base for the first and second targets and in the PHASE data base for Target Numbers 3 through 6.

Commas were used in the data fields to separate numbers corresponding to weapon types. For example, in Serial 10.08, Target Number 1, Phase Number 1 (Figure 10), commas are used to separate numbers corresponding to weapon types A and F. The "NUMBER TUBES" field contains "8A,4F," indicating that eight guns of type A and four guns of type F were used in this phase of the bombardment. Commas were used most frequently in the firing data category and the calculated data category.

SERIAL DATA

SERIAL	10.08
REF NUMBER:	A9
ORIG REF.	ORS 1/24 PART II
REF TITLE:	THE EFFECTIVENESS OF ARTILLERY IN ITALY, 1944
DATA SOURCE:	ACTION REPORT NUMBER 8
------------------- SERIAL DATA -----------------	
SIDE 1 COUNTRY:	BRITAIN
SIDE 1 UNITS:	3 FD REGT, 1 MD REGT, 1 HV BATT
SIDE 1 POSTURE:	ATTACKING
SIDE 2 COUNTRY:	GERMANY
SIDE 2 UNITS:	??
SIDE 2 POSTURE:	DEFENDING
DATE OF ACTION:	??
COUNTRY:	ITALY
REGION:	??
TERRAIN:	HILL TOP
WEATHER:	??
TIME:	2300
SERIAL TACTICS:	EMPLOY CRASH AND HARASS PLAN TO SUPPORT ATTACK BY FORCING GERMANS TO EVACUATE POSITIONS.
NO. BMBRD TARGETS:	2
NO. PHASES/TGT:	7/10
------------------- TARGET DATA --------------------	
BOMBARD TARGET:	TARGET LEVEL
BOMBARD TGT AREA:	TARGET LEVEL
BOMBARD TACTICS:	TARGET LEVEL
------------------- FIRING DATA --------------------	
FIRE UNIT:	PHASE LEVEL
TYPE WEAPONS:	PHASE LEVEL
NUMBER TUBES:	PHASE LEVEL
TYPE AMMO:	PHASE LEVEL
ROUNDS PER GUN:	PHASE LEVEL
NUMBER ROUNDS:	PHASE LEVEL
FIRE DURATION:	TARGET LEVEL AND PHASE LEVEL
------------------- RESULTS DATA -------------------	
ATTACK DELAY TIME:	??
TIME TO OBJECTIVE:	??
CASUALTIES:	UNKNOWN (GERMAN);UNKNOWN (BRITISH)
EQUIPMENT DAMAGE:	??;??
OTHER FACTORS:	NONE
OTHER RESULTS:	??
SUPPRESSION:	POSITION WAS NOT SUPPRESSED AT THE TIME OF THE INFANTRY ATTACK;POSITION WAS STRONGLY DEFENDED BY MG FIRE WHEN INFANTRY ADVANCED
------------------- CALCULATED DATA ----------------	
RDS/SQ YD:	TARGET LEVEL
RDS/SQ YD/MIN:	TARGET LEVEL
LBS/SQ YD:	TARGET LEVEL
LBS/SQ YD/MIN:	TARGET LEVEL
LBS/SQ YD (EQ):	TARGET LEVEL
LBS/SQ YD/MIN (EQ):	TARGET LEVEL

FIGURE 8. SERIAL RECORD

Semicolons separate data relating to the two sides involved in the engagement. Data for Side 1 are always listed first, followed by a semicolon and then the data for Side 2. The nationalities of the sides are usually given in parentheses if the field length permits. In serial 10.08, for example, the "CASUALTIES" field, referring to personnel casualties, contains the entry "UNKNOWN (GERMAN); UNKNOWN (BRITISH)" meaning that personnel casualties for each side are unknown. Semicolons were used most frequently in the results data category, especially when referring to casualties or equipment damage.

```
                               TARGET DATA

SERIAL                 10.08
TARGET NUMBER:         1
NUMBER PHASES:         7
TIME:                  2200
------------------- TARGET DATA --------------------
TARGET                 GERMAN POSITIONS ON HILL TOP

TARGET AREA.           1875000
TARGET TACTICS:        THREE CRASH PHASES (1,4,5) AND FOUR HARASS PHASES (2,3,6,7)

------------------- FIRING DATA --------------------
FIRE UNIT:             PHASE LEVEL
TYPE WEAPONS:          PHASE LEVEL
NUMBER TUBES:          PHASE LEVEL
TYPE AMMO:             PHASE LEVEL
ROUNDS PER GUN:        PHASE LEVEL
NUMBER ROUNDS:         PHASE LEVEL
FIRE DURATION:         120
------------------- RESULTS DATA -------------------
ATTACK DELAY TIME:     SERIAL LEVEL
TIME TO OBJECTIVE:     SERIAL LEVEL
CASUALTIES:            SERIAL LEVEL
EQUIPMENT DAMAGE:      SERIAL LEVEL
OTHER FACTORS:         SERIAL LEVEL

OTHER RESULTS:         SERIAL LEVEL
SUPPRESSION:           SERIAL LEVEL


------------------- CALCULATED DATA ----------------
RDS/SQ YD:             0.000371A,0.000109F
RDS/SQ YD/MIN:         ??A,??F
LBS/SQ YD:             0.00928A,0.0087F
LBS/SQ YD/MIN:         ??A,??F
LBS/SQ YD (EQ):        0.00928A,0.00722F
LBS/SQ YD/MIN (EQ):??A,??F
```

FIGURE 9. TARGET RECORD

To distinguish between instances where a report does not mention a particular piece of information and where a report states that the particular piece of information was unknown or unavailable, a simple convention was used. When a report does not mention a piece of information, "??" is entered into the field. When a report states that the piece of information was unknown, "UNKNOWN" is entered into the field. Thus, no field is ever left blank. At the same time, the distinction between unreported and unknown data is preserved. The distinction is not always important or useful, but SAIC wanted to record the data as faithfully as possible and not make the assumption that the terms "unknown" and "unreported" have the same meaning.

```
                                PHASE DATA

SERIAL:            10.08
TARGET NUMBER:     1
PHASE NUMBER:      1
TIME:              2200
------------------- TARGET DATA -------------------
TARGET:            TARGET LEVEL

TARGET AREA:       TARGET LEVEL
PHASE TACTICS:     CRASH

------------------- FIRING DATA -------------------
FIRE UNIT:         2 FD TROOPS,1 MD BATT
TYPE WEAPONS:      A,F
NUMBER TUBES:      8A,4F
TYPE AMMO:         ??A,??F
ROUNDS PER GUN:    6A,3F
NUMBER ROUNDS:     48A,12F
FIRE DURATION:     ??
------------------- RESULTS DATA -------------------
ATTACK DELAY TIME: SERIAL LEVEL
TIME TO OBJECTIVE: SERIAL LEVEL
CASUALTIES:        SERIAL LEVEL
EQUIPMENT DAMAGE:  SERIAL LEVEL
OTHER FACTORS:     SERIAL LEVEL

OTHER RESULTS:     SERIAL LEVEL
SUPPRESSION:       SERIAL LEVEL


------------------- CALCULATED DATA -------------------
RDS/SQ YD:         TARGET LEVEL
RDS/SQ YD/MIN:     TARGET LEVEL
LBS/SQ YD:         TARGET LEVEL
LBS/SQ YD/MIN:     TARGET LEVEL
LBS/SQ YD (EQ):    TARGET LEVEL
LBS/SQ YD/MIN (EQ):TARGET LEVEL
```

FIGURE 10. PHASE RECORD 1

DATA BASE EXAMPLE

This paragraph discusses an example extracted from the data base. The partial data base listings at Figures 8 through 11 deal with serial 10.08, for which the actual CORDA abstract was presented in Figure 1 during discussion of the data collection effort. Only one of the two TARGET records and two of the 17 PHASE records are listed. Once the reader understands these records, it would be tedious and redundant to discuss all 20 records associated with serial 10.08.

```
                                PHASE DATA

SERIAL               10 08
TARGET NUMBER        1
PHASE NUMBER:        2
TIME:                2200
-------------------  TARGET DATA  -------------------
TARGET               TARGET LEVEL

TARGET AREA:         TARGET LEVEL
PHASE TACTICS:       SUSTAINED FIRE

-------------------  FIRING DATA  -------------------
FIRE UNIT:           2 FD TROOPS,1 MD TROOP
TYPE WEAPONS:        A,F
NUMBER TUBES:        8A,4F
TYPE AMMO:           ??A,??F
ROUNDS PER GUN:      20A,10F
NUMBER ROUNDS:       160A,40F
FIRE DURATION:       30
-------------------  RESULTS DATA  -------------------
ATTACK DELAY TIME:   SERIAL LEVEL
TIME TO OBJECTIVE:   SERIAL LEVEL
CASUALTIES:          SERIAL LEVEL
EQUIPMENT DAMAGE:    SERIAL LEVEL
OTHER FACTORS:       SERIAL LEVEL

OTHER RESULTS:       SERIAL LEVEL
SUPPRESSION:         SERIAL LEVEL


-------------------  CALCULATED DATA  ----------------
RDS/SQ YD:           TARGET LEVEL
RDS/SQ YD/MIN:       TARGET LEVEL
LBS/SQ YD:           TARGET LEVEL
LBS/SQ YD/MIN:       TARGET LEVEL
LBS/SQ YD (EQ):      TARGET LEVEL
LBS/SQ YD/MIN (EQ):  TARGET LEVEL
```

FIGURE 11. PHASE RECORD 2

In the identification data category of the SERIAL record (Figure 8), the reader can see that the record pertains to action report number eight of serial number 10 and deals with the effects of artillery in Italy in 1944. In the serial data category, the data fields indicate that British Infantry and fire support units (consisting of three fields regiments, one medium regiment, and one heavy battery) were attacking German positions, the nature of which was unreported. The date of the attack was also unreported, but it occurred on a hill top somewhere in Italy. The British used a crash and harass plan designed to force the Germans to abandon their position. The attack began at 2300 hours, and involved the bombardment of two targets. The first target was engaged in seven phases, while the engagement of the second target had 10 phases.

The target data category indicates that the data for these fields can be found in the TARGET data base. The TARGET data base record for target number one (Figure 9) indicates that the target was German positions on a hill top. The target area was 1,875,000 square yards, and the plan was to alternate crash phases with harass phases.

Turning back to the SERIAL record, all of the firing data can be found in the PHASE data base. Figure 10 presents the record for Phase Number 1 of Target Number 1, and Figure 11 presents the record for Phase Number 2. In Phase Number 1, two field troops and one medium battery used eight 25 pounder guns and four 5.5 inch guns in the bombardment. Each 25 pounder gun fired six rounds, and each 5.5 inch gun fired three rounds, for a total of 48 25 pounder rounds and 12 5.5 inch rounds in the phase. The type of round (high explosive, armor piercing, etc.) and the duration of the phase were not stated in the source documents on this action.

In Phase Number 2, the same units used the same types and numbers of guns, but they fired a different number of rounds. They fired a total of 160 25 pounder rounds and 40 5.5 inch rounds over a period of 30 minutes.

The results data category for Serial 10.08 contain several data fields which were not mentioned in the abstract. The attack delay, time to the objective, equipment damage, and other results were never mentioned. However, the abstract does state explicitly that casualty data were unknown for both sides. The abstract also clearly states that suppression was not achieved at the time of the British Infantry attack.

Information for the calculated data category can be found in the TARGET data base. The TARGET data base record for Target Number 1 (Figure 9) records data on the number of rounds per square yard, pounds per square yard, and equivalent pounds per square yard for both 25 pounder and 5.5 inch rounds. Although the data fields for rounds per square yard per minute, pounds per square yard per minute, and equivalent pounds per square yard per minute were not given in the abstract, they can be inferred since the fire duration was given (120 minutes).

Now that all of the data categories in the SERIAL record have been discussed, we turn our attention to the TARGET records (Figure 9). For the sake of brevity, only the record for Target Number 1 is presented. The identification, target, and calculated data categories have already been discussed. The firing data category, with the exception of fire duration, contains only references to the PHASE data base. Fire duration is recorded in the TARGET data base because some of the phases may overlap. Therefore, the fire duration for the target cannot be calculated by summing the fire durations for each phase of the target fire plan. The results data category contains only references to the SERIAL data base. The data in these fields were discussed earlier.

We can now turn our attention to the PHASE records, presented in Figures 10 and 11. The data in the firing data category were already discussed. The data in the identification category simply identify the particular phase and state what time the phase began. In the TARGET data category, the description and size were given in the TARGET data base. Phase Number 1 was a "crash" phase, while Phase Number 2 was a "sustained fire" phase. All of the data fields in the results category were entered at the SERIAL level, and all of the data fields in the calculated category were entered at the TARGET level.

This section has attempted to explain the structure and contents of the data bases. The principles, codes, notations, and conventions were explained and then illustrated by example. The next section will focus on an evaluation of the availability and the usefulness of the data entered into the data base.

DATA EVALUATION

FOCUS AND METHODOLOGY

These questions provided focus for continued examination of the data described in the preceding sections.

- o What data are available in the CORDA collection?
- o What can be done with the data as they exist?
- o What use can be made of the data for modeling?

The availability of data can be determined by investigating the density and the location of information. Density provides a measure of how much data is available while location indicates whether the data are recorded at the SERIAL, TARGET, or PHASE level of the data base. Together these characteristics of the data set provide a measure of the number of data points which the original data provide for use in modeling.

A small set of variables believed to be useful in the analysis of suppressive effects were xamined. These variables are suppression, rounds per square yard, pounds per square yard, equivalent pounds per square yard, and duration of bombardment. The variables were selected because of their obvious, intuitive appeal related to the study of suppression effects.

The density and location of data in these variables, at the three different levels, are important in determining their usefulness. If information exists at all three levels, then the maximum number of data points is available as a basis for the future development of hypotheses. At the opposite extreme, if only partial data exists at the three levels, specific suppression effects gathered from the original reports may not be as valuable as hoped.

DATA AVAILABILITY

The following table represents the density and location of the selected variables and gives a general impression of the availability of data contained in the abstracts.

A complete and valuable set of data would include data entries for all variables in each of the 54 SERIAL, 102 TARGET, and 187 PHASE records. The examination of data in the data base at these three levels, however, showed that not all variables had data at all three levels. For example, Table 5 indicates that the suppression variable had data recorded in only 41 of the 54 SERIAL records, only 32 of the 102 TARGET records, and only 24 of the 187 PHASE records. Similarly, Table 5 shows that bombardment duration data was recorded in 35 of the SERIAL records, 79 of the TARGET records, and 158 of the PHASE records.

TABLE 5. DATA DENSITY AND LOCATION OF SELECTED VARIABLES

Variables	Serial (54)	Target (102)	Phase (187)
Suppression	41	32	24
Rounds per Square Yard	32	6	35
Pounds per Square Yard	33	69	44
Equiv. Pounds per Square Yard	32	67	43
Duration	35	79	158

The true usefulness of the suppression data, however, is dependent upon the density and location of data for those other variables which may be hypothesized as functionally related to the suppression variable. Each of the remaining variables in Table 5 could be classified as independent variables in this type of functional relationship and thus information contained in the data base for these variables would be key to an examination of suppression. Although 32 SERIAL records contain data entries for the rounds per square yard variable, only 27 of the 41 SERIAL records which contained information on suppression also contain this data. Similarly, of the 41 records containing suppression data, only 28 contained information on pounds per square yard, only 27 had equivalent pounds per square yard data, and only ' had duration data. Thus, in testing hypotheses of relationships between the calculated data variables and suppression, fewer than 41 data points would be available. If other variables are also considered or added to a hypothesis, such as unit level or target size, then additional limitations on the number of complete data points available for analysis would be imposed.

The sparseness of the data when they were examined at the three levels was obvious. Even though detailed firing data was often available at the PHASE level, calculated data often existed only at the TARGET level while results information could only be found at the SERIAL level. Analysis, therefore, would be possible only at that level at which sufficient and complete data existed, which for this example and this original data set would be the SERIAL level.

DATA USEFULNESS

Evaluation of the density and location of data collected from the abstracts at the three tiers of information answered the first question -- data availability. In short, the data were collected and preserved in their original form, which was limited in usefulness for analyzing suppressive effects for models and human behavior because of the sparseness of data at all three levels examined.

Although the data taken from the abstracts, without further enhancement, offer no great amount of directly useful information, some interpretation or manipulation of data would permit additional fill of data entries at lower levels. Through the application of military judgement, military facts, or straightforward arithmetic calculations, additional data points could almost certainly be added to the appropriate tier of the data base. This would increase the number of data points available for analysis and directly improve the usefulness of the data.

The idea of interpretation of data, or the proper application of military judgment to the situations described in the abstracts, would not jeopardize the validity of the data. The application of military judgment would simply permit the extraction of additional data which was not explicitly stated in the abstracts. For example, a "medium regiment" identified in support of the engaged UK force generally contained 24 guns or Howitzers. This information was defined in other abstracts. Where "medium regiments" were specified in support of UK forces and the number of guns were not separately identified, an enhancement to the original data would add 24 guns for the "medium regiment" included in the engagement abstract. If necessary, enhancements such as this could be validated by collecting operational data from other sources such as war diaries.

Finally, the original documents used by Professor Shephard to prepare the abstracts primarily contained bombardment data. Operational data about the maneuver plans of combat units were limited. This did not allow analysts to appreciate fully how the maneuver forces attacked the various targets identified in the abstracts. Where errors in the firing data were obvious, the availability of additional operational information assisted in correcting the data.

The second question asked by the sponsor addressed what can be done with the data. The data, in their original form, contain inconsistencies and errors. The data have been cross checked, and those errors are not a result of transcription errors during the extraction process. The sparseness of information in key variables limits the number of usable data points to statistically small samples where it would be difficult to draw conclusions for the population as a whole. Therefore, without enhancement of information, the original data should be used cautiously for analysis purposes.

The final question addressed use of the data for modeling. The use of these suppression effects data for direct comparison with Army model output is questionable. There are limited casualty results recorded for personnel or equipment in sufficient quantities to act as a validation set. The sparseness of data in key variables, which are expected to be related to suppression, limits the direct use of the original data as a source of information for algorithm development. The lack of a hypothesis during data collection, as well as resource limitations, allowed data from many engagements to be collected, but the scope of the combat operations reported was broad. As discussed in the following section, it is believed that the most complete data relating to suppression effects may be found at the battalion level. Thus if further data collection is undertaken, it should be focused upon battalion level operations so that the usefulness of the data set may be enhanced.

LESSONS LEARNED

From this modest effort over an eigh. month period, a series of lessons learned can be drawn. The lessons fall into two groups. The first involves lessons pertinent to the operational data and their collection and interpretation, while the second deals more with administrative matters related to the effort. These include:

- **The World War II data, in their original form, do not support a clear understanding of the suppressive effects of bombardment on personnel**

The 46 abstracts collected from the original World War II reports by Professor Shephard contained bombardment information on engagements which ranged from squad to corps size and durations which lasted from minutes to days. The quantitative information which specified the number of rounds fired, the time of firing, the type of weapons doing the firing, and, in some instances, the patterns of bombardment (fire plans) were sufficiently covered in the original reports.

On the other hand, the suppressive effects one would like to identify were not clearly identified in the original reports. Review of the comments made by the commanders on the ground or the scientists collecting the data, did not identify quantitative measures of performance or data in sufficient numbers to come to any conclusions. Therefore, the usefulness of the data as a direct source of information to validate existing models of suppression is limited. Further, analysis of the data and the application of military judgement, to include interpretation of original data, to form a data set more useable for analysis is required.

- **Interpretation of original data may increase their useability**

The original data are sparse in specific maneuver and fire support unit identifications. Terms such as "coys", "medium regiments", and "light regiments" were used frequently. In these cases, the data did not reflect total numbers of weapons firing, nor the caliber of the weapons. Consequently, this limited the useability of the data even if specific suppressive effects were annotated in the reports.

Similarly, the identification of suppressive results in the various original reports was very limited. Comments made by the various commanders, some indications of casualties or losses, or comments reflecting unit performance were not frequent. This also limits the useability of the data in their original form.

Inference of the effects of suppressive fires can be attempted, but must be cast as military judgment based upon other information about the engagement. Terms such as "met light resistance" or "few casualties were sustained" suggest that the suppressive fires were successful, but they must be tempered by the time between the end of bombardment and the actual engagement of maneuver forces.

By the application of military judgement, military facts such as the number and type of guns in various units, and in many cases simply by completing straightforward arithmetic calculations, the density of the data in the data base may be increased from its original level. This "enhancement" of the data set would create additional data points and hence increase the usefulness of the data for the development of hypotheses and mathematical models.

- **The collection of information concerning suppressive effects is best found at battalion level**

Professor Shephard, after reviewing a large number of original documents, is convinced that specific comments concerning the effects of suppressive fires are best obtained by searching for them in battalion level engagement reports. It is his impression that comments made by that level have the highest probability of containing exact comments about the nature or effects of suppressive fires. At higher levels of reports (brigade, division, corps, etc.) the effects of bombardments are often lost in the summarization of the many battalion level engagement reports.

- **Additional operational data concerning the maneuver plans of the forces engaged are needed to fully understand the fire plans and results shown in the operations research reports**

The operations research reports concentrated upon quantitative data associated with the firing units. Limited information was included concerning the actual maneuver of the units engaged. Access to that information may allow a better representation of suppressive effects by combining the results of the maneuver units with that of firing units. This would require research into war diaries as well as operational data from sources other than the UK operations research bibliography.

- **Suppression effects are multi-faceted**

The lack of clear definitions of suppression leads one to the conclusion that the topic is not well understood. From the research and reading done in conjunction with this effort, it is clear that the following can be stated, but not proven yet.

- Human performance is related to morale effects.
- Suppressive fires affect unit performance during the time the fires are conducted.
- The density of fires upon a target does have some durational effect after the bombardment ceases. This effect is transitory and may be associated with the training or experience of the unit.
- Suppressive fires conducted over lengthy periods of time may have a direct effect upon unit morale and performance.
- There is a lower threshold (minimum intensity) below which no suppressive effects occur and unit performance is not degraded.

- Morale effects can be related to average intensity and to the variation in the pattern of bombardment.

- Suppression effects may best be measured in levels. The UK literature and reports do not use the term suppression, but instead use "neutralizing and demoralization fires" as two separate terms or levels of effect.

- Morale effects may be caused by irrational fears such as the belief that a certain weapon, believed to be very dangerous, may be used by the enemy when in fact that weapon is not available to the enemy forces.

- **The time associated with the extraction, understanding, and organization of operational data is substantial. This should be considered when planning a project of this nature so that adequate time remains for analysis**

One primary goal of this study was to collect and preserve data from World War II documents which may have been able to shed some light on the topic of suppression and bombardment upon units in combat. Organization of data into categories which lend themselves to future analysis is often the key to opening the door to better understanding of information. Careful validation and corroboration of data elements leads to confidence that the data collected truly represent its original form. Careful examination and questioning of apparent errors, although rather small in comparison to other judgmental factors such as target area, required a large amount of time to cross-check original data in the UK. As such, the amount of time for analysis of the results was insufficient for anything but preliminary conclusions concerning the usefulness of the data.

- **Inconsistencies do exist in original reports**

Correction and cross-checking of data did take place on Volumes III and IV. Because SAIC had access to the first two volumes, the data in those volumes (not collected under this contract) were also subjected to the same attention to detail. Professor Shephard has produced an errata sheet for the first two volumes and corrections, where his abstracts differed from the original reports, are included in the final SAIC report. Time to verify and cross-check data must be taken into account in future efforts of this type.

- **Additional operational reports were uncovered during the data collection effort**

During the data collection phase of this effort, Professor Shephard and his associate uncovered additional reports which had not been part of the original bibliography used to find and abstract information. These reports are categorized as predominantly battalion level operational reports, but some deal with larger unit operations, air support for ground forces in the Pacific, counter-battery fire, air crew effects, morale effects, and effects of flamethrower tanks. These would be sources of information for continued data collection efforts. A bibliography of these reports has been distributed to Government organizations and personnel involved with this study.

- **Additional operational data are required to fully evaluate the operations research reports**

It became clear, as data inconsistencies arose and additional information was needed to correct or confirm the original data, that operational data at the maneuver unit level would be needed to fully appreciate the military significance of suppressive fires on combat units. This is essential to fully understand and interpret the results of the OR reports.

- **The organization of data extracted from operational reports should be focused upon the intended use of the final product**

A data base was created as a tool for analysis of the CORDA data. The format of this data base lends itself to further analysis efforts and may provide a good framework for guiding future historical data collection efforts.

DIRECTIONS FOR FUTURE RESEARCH

One objective of this study was to provide recommendations for future research based upon an evaluation of the data collected and the preliminary analysis of their usefulness. Future efforts should be guided by the outline of a study plan contained in this section

OUTLINE OF FUTURE EFFORT

It became obvious, as the study progressed, that analysis and development of algorithms of suppression specifically focused upon Army models could not be created with the data in their original form. A continued effort to collect information (focused upon battalion level engagements), development of hypotheses, testing of hypothesis, and development of a methodology based upon the results is clearly called for. The following paragraphs will explain the need for the effort in each of these areas.

REVIEW OF SUPPRESSION LITERATURE

The World War II bibliography compiled earlier by Professor Shephard, and updated with this study, provides a basis for reviewing the operations research reports created during World War II which were directed at modeling or summarizing the field reports. Operation research units in the field provided their initial reports to parent organizations in the UK. The reports were reviewed and summarized (often by the same people who had collected the field data), hypotheses were sometimes established, checked, rejected and/or followed, and final reports written. These final Category B reports have been the basis for subsequent efforts to understand suppression in both the US and the UK.

During the current effort, a request for documents was forwarded to the UK through Government channels. The report request has been acknowledged, but during the period of this study only three of eight documents requested were received. These were received too late to provide input to this study. It is believed that these reports must be reviewed to determine what hypotheses were established and which ones were rejected. This review will cause the development of hypotheses to concentrate upon those which have merit in their own right and to reject those which were earlier proven to be wrong or incapable of testing.

Recently, Vector Research Incorporated produced an updated report of suppression literature for the HEL. This source, and selected UK Category B reports, can form the basis for an extended review of suppression.

DEVELOPMENT OF HYPOTHESES

The two efforts under which data were collected (HEL and the current effort), accomplished the task of preserving data thought useful in the study of suppression. The data collection effort did not have a hypothesis or definition against which data were to be collected. A definition of suppression was provided during the HEL effort, but it was difficult to apply and did not specify the types of data required to be collected. Consequently, the collection was left to the experienced hand of Professor Shephard, with the resources available, to delve into the historical records.

The usefulness of the data collected has been described previously. Preservation of data is still a high priority, but based upon what is known about the data collected already, emphasis should be given first to the collection of data on battalion level engagements and below. Data collection should be initiated with two objectives in mind.

First, data collection should continue after one or more hypotheses have been established. This will serve to focus upon the collection of data needed to test the hypotheses being examined. Secondly, the collection of more data is necessary to validate hypotheses created from existing data. No collection of data should begin until these steps have been undertaken, unless loss of data through age or regulatory changes threaten to eliminate access to the original sources.

TESTING OF HYPOTHESES

The data base created from the four volumes of data abstracts during this study effort can be used as a source of information for development of hypotheses. Preliminary efforts to utilize the data in this way have been encouraging.

The obvious dependent variable, the occurrence of suppression, is believed to be described by a multi-variate function. So far, <u>the density of rounds</u>

expended upon the target; intensity of bombardment; duration; and effects upon target have been examined. The time parameter associated with duration and the pattern of the bombardment are also felt to be important variables to be considered. There is some evidence to believe that psychological variables (number of shell shock casualties) may be appropriate for inclusion in any deterministic function to be developed.

The goal of such analysis would be the development of an algorithm capable of describing the effects of suppression for Army models, and the creation of a historical data set useful for validation purposes. These goals can best be achieved through the development and testing of several competing hypotheses and measures of effectiveness which are directed at developing a better description of suppressive effects for use in models. This development should be part of any future study efforts.

At the same time work should be done in extending the existing data through interpretation, thereby transforming the data base into a useful analytic tool. Additional data collected in support of future efforts at battalion level will be particularly useful evaluating competing hypotheses.

ALGORITHM DEVELOPMENT

After selecting a hypothesis to represent suppression, algorithms for specific Army models should then be created. The three principal models are CASTFOREM, VIC, and FORCEM. Each model has a different fire support section and each must be reviewed separately to determine what is the best approach for the addition of suppression algorithms based upon this work. It is clear that a conceptual algorithm must be developed. Then specific, detailed implementations of this work should be developed for each model.

STUDY RESULTS

GENERAL

The purpose of this study was:

> To compile, reduce, and analyze data from existing operational analysis reports generated during World War II in order to provide; (1) source data for modeling suppression effects due to fire support in division and theater level models and, (2) to benchmark or develop approximate standards against which to judge artillery expenditure results from division and theater level models.

Data were abstracted from British World War II operational data reports dealing with the subject of suppression by Professor R. W. Shephard of CORDA. These data were combined with that compiled by Professor Shephard for HEL in 1987. The resulting data set was recorded in a three-tiered data base designed to provide an initial means to evaluate it and to enhance its usefulness modeling suppression in US combat models. A preliminary analysis of the CORDA data was accomplished.

CONCLUSIONS

The CORDA data was determined to be:

- o Inadequate in its original form for modeling suppressive effects of bombardment or judging model results in division and theater level models.
- o Adequate for initial efforts to develop hypotheses and to identify focused data collection requirements.

REFERENCES

Frame, C. L., McEnany, B. R. and Kladivko, K. A. Combat Operational Data Analysis, An Examination of World War II Suppression Data. Science Applications International Corporation, Technical Report SAIC-89/1098, February, 1989.

Jane's Weapons Systems 1979-80, Tenth Edition, R. T. Pretty, editor. New York, Franklin Watts Inc., 1979.

Shephard, R. W. and Goodman, R. C. A Survey of Suppression: Volume I Source List and Abstracts 1-11. CAP Scientific Limited, London, England, September 1987.

Shephard, R. W. and Goodman, R. C. A Survey of Suppression: Volume II Abstracts 12-26. CAP Scientific Limited, London, England, September, 1987.

Shephard, R. W. and Goodman, R. C. A Survey of Suppression: Volume III Abstracts 27-37. CORDA Limited, London, England, January, 1989.

Shephard, R. W. and Goodman, R. C. A Survey of Suppression: Volume IV Abstracts 38-49. CORDA Limited, London, England, January, 1989.

Shephard, R. W. and Goodman, R. C. A Survey of Suppression: A Revised List of Sources, Jan 89. CORDA Limited, London, England, January, 1989.

Shephard, R. W. and Goodman, R. C. A Survey of Suppression: Volume I Corrigendum. CORDA Limited, London, England, February, 1989.

Shephard, R. W. and Goodman, R. C. A Survey of Suppression: Volume II Corrigendum. CORDA Limited, London, England, February, 1989.

ON THE DISTRIBUTION OF COMBAT HEROES

by

J. J. BOLMARCICH
QUANTICS Inc.

INTRODUCTION

In his classic magnum opus "On War" (reference [1]), Clausewitz defines war as:

"an act of violence intended to compel our opponent to fulfil our will."

Our opponent is apt to measure our ability to apply violence in a future battle by adding up his people and things that our people and things have killed in past battles. Clausewitz says that the total number we need to kill in order to win will depend on political motivation:

"Further, the smaller our political object, the less value shall we set upon it, and the more easily shall we be induced to give it up altogether."

In fact, the kill counts of recent wars show wide variations. Nonetheless, we typically still find that a few of our combatants end up killing many of the enemy's number; we call them heroes.

The purpose of this paper is to show that there is an invariant structure to the occasioning of combat heroes -- this despite differences in: wars, areas of warfare, types of combatants, and numbers of combatants on each side both participating and killed. Such a discovery supports one fundamental precept of Operations Research as related by Morse and Kimball in reference [2]:

"large bodies of men and equipment carrying out complex operations behave in an astonishingly regular manner, so that one can predict the outcome of such operations to a degree not foreseen by most natural scientists."

Specifically, we will show that the structure of the variability in warfare kills among similar combatants remains remarkably regular.

Why are there heroes? How do such extraordinary performances come to be? More generally: what is the cause of the variability in kill performance from combatant to combatant? Is it raw talent? is it opportunity? is it luck? is it training? is it the perversity of nature? Clausewitz is of little help in clarifying the cause; he says in various places in "On War":

"War is the province of chance."

"But together with chance, the accidental, and along with it good luck, occupy a great place in War."

"War ... is so often thwarted by unexpected and singular accidents [that] more must be generally left to talent..."

"What genius does must be the best of all rules,"

"Habituation to War no General can give his Army at once, [but] It is of immense importance that the soldier ... should not have to encounter in War those things which, when seen for the first time, set him in astonishment and perplexity; if he has only met with them one single time before, even by that he is half acquainted with them."

Our thesis is that the variability in kill performance in warfare can be "explained" by a combination of the concepts of "chance" and "habituation to war". Most combat studies focus on improving the predictability of the "average outcome" of combat models by refining the causes producing outcome effects. But this paper is not about War and Causality; it is about War and Chance. It is inspired by Max Born's insight into the twentieth century's contribution to the methodology of science (quoted in reference [3]):

"The conception of chance enters into the very first steps of scientific activity in virtue of the fact that no observation is absolutely correct. I think chance is a more fundamental conception than causality, for whether in a concrete case, a cause-effect relation holds or not can only be judged by applying the laws of chance to the observation."

In application to warfare, this statement is even more compelling due to similar commentary by Clausewitz one century prior to Born:

> **"As respects the tracing of effects to cause, that is often attended with the insuperable difficulty that the real causes are not known. In none of the relations of life does this so frequently happen as in War, where events are seldom fully known, ... or have been of such a transient and accidental character that they have been lost for history."**
>
> **"Each commander can only fully know his own position; that of his opponent can only be known to him from reports, which are uncertain;"**

Just as "chance" is fundamental to the theory of quantum mechanics, so too is chance fundamental to any thorough theory of warfare.

Finally, Morse and Kimball lend support concerning both "chance" and "habituation to war".

> **"The RAF Fighter Command Operations Research Group has studied the chance of a pilot being shot down as a function of the number of combats the pilot has been in. This chance decreases by about a factor of 3 from the first to the sixth combat. A study made by the Operations Research Group, U.S. Army Air Forces, indicates that the chance of shooting down the enemy when once in a combat increases by 50 per cent or more with increasing experience."**

In addition, popular culture claims that prior experience in sports' championships is beneficial to any player participating in those pressured events. If these "authorities" are correct, then a chance mechanism, operating through a "habituation to war" heuristic, might well help clarify the variability we see in human performance in warfare.

We claim that the chance mechanism which best represents the variability in the behavior of human beings in warfare is almost identical to the chance mechanism which best represents the variability in the behavior of atoms in the physical universe. This does not say that men are molecules. This does say that the underlying theories of probability which best explain our observations concerning the variability in the outcome of the activities of both men and molecules rests on a single common assumption concerning the structure of *randomness in our world*.

We support this claim: 1) with data concerning variability in kill performance, and 2) through a method of measuring this variability in performance for different wars, different areas of warfare, different kinds and numbers of combatants participating, and different numbers killed. Exhibit 1 displays the kind of data of interest. It profiles how kills of Japanese ships ended up apportioned to U.S. submarines operating in the Pacific in World War II, in left to right order of best ship killer to poorest.

The **resolution** in Exhibit 1 is less than that of the reference [4]'s data which shows that 248 U.S. submarines participated in the Pacific (48 of them lost.) Each submarine portrayed in Exhibit 1 represents a group of 16 submarines (8 by the rightmost). Stacked above each submarine portrayed is the median number of kills ascribed to the members of its group by a post-war reconstruction which attributed 1312 total kills to U.S. submariners. For example, the 16 submarines in the best group had a median of 19 kills: the best performer in this group killed 26 ships and the poorest 16. The other groups show deviations from the median of less than ±2. Thus, the visual distortion is mostly confined to the best group of combatants and the rightmost "tail".

Similarly, Exhibit 2 profiles reference [5]'s 64 air-to-air combat kills of North Vietnamese aircraft by U.S. Carrier-based aircraft during the Vietnam War. Exhibit 2 looks amazingly like Exhibit 1 although the wars, the types of warfare, and the numbers of participants on both sides were quite different. These warfare performance statistics clearly represent some rule of **the-higher-the-fewer** in which a few notable combatants account for a large fraction of the kills while notably many others got few or none.

The bibliography supports the observation that this kind of **skewed** pattern is typical in the performance of human beings in many areas of endeavor. Such **skewed** statistics can be described quite well by probability distributions with "long tails". Areas in which they arise include: Distribution of Wealth and Industrial Capacity, Frequency of Words in Text, Number of Publications by

EXHIBIT 1

U.S. SUBMARINE KILLS OF JAPANESE SHIPS IN WORLD WAR II

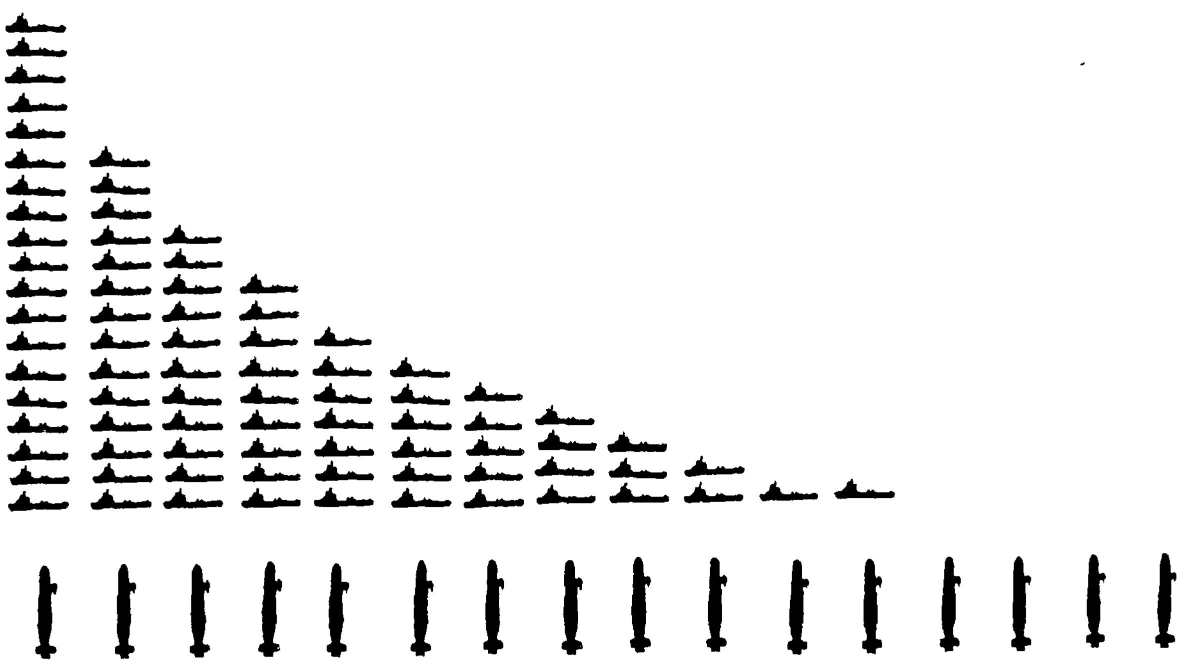
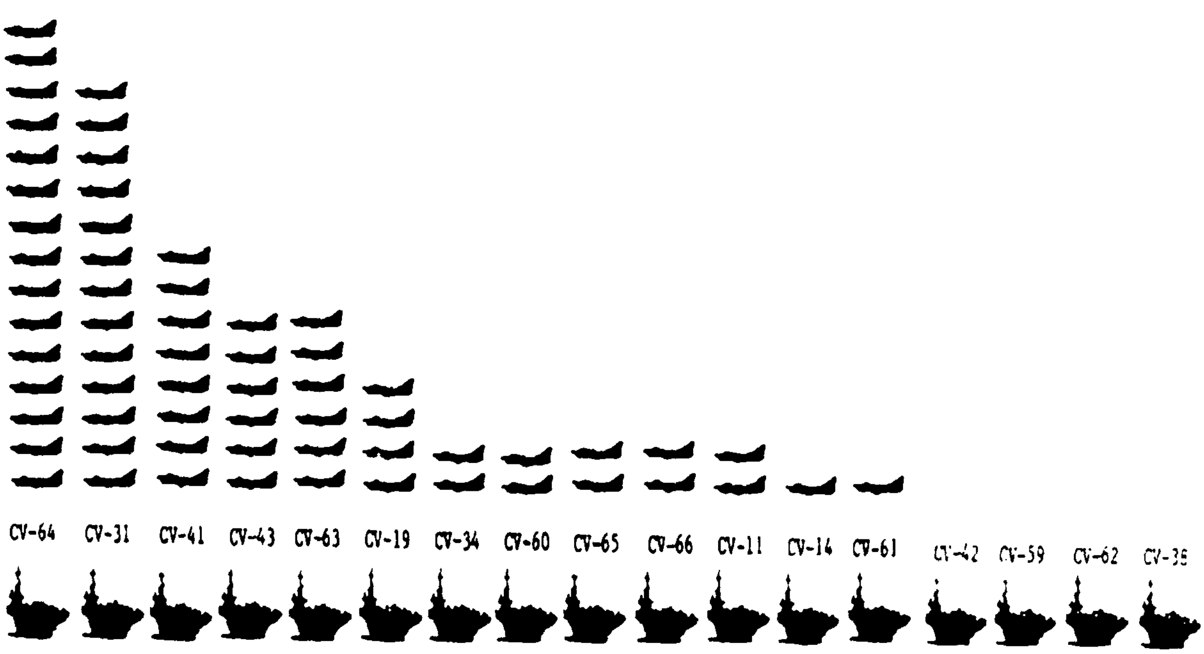


EXHIBIT 2

U. S. NAVAL AIR-TO-AIR WARFARE KILLS: VIETNAM 1965-1972



Authors, Sizes of Cities, Numbers of Biological Species, Numbers of Deaths in Epidemics, and Number of Industrial Accidents.

In the particular case of warfare kills, we have uncovered a known family of **skew distributions**, and have used it (in references [6], [7], [8], [9], [10]) to fit data such as those in Exhibits 1 and 2. It is a **one-parameter** family called the Multivariate Homogeneous Polya Distributions (see reference [11]). **For each warfare data set, one can identify the single Polya Parameter value characterizing the best fitting member of this family.** This family inherently provides an appropriate scaling within which the one parameter can be interpreted as the **measure of skewness of the diverse performance results effected by different combatants, wars, and warfare areas.**

The ability to use a single measure of skewness across warfare results is important. For example, roughly speaking, Exhibit 2 says that 12% (= 2 of 17) of the Carriers in Vietnam can be credited with killing 44% (= 28 of 64) of all enemy airplanes killed by Carriers. How can you compare this performance to reference [12]'s statement that 2% of U-Boat commanders in World War II were responsible for 30% of the Allied ships sunk by all U-Boats? Any attempt to compare these single point statistics to each other is not convincing, since it might be identically true for both cases that 15% of the combatants can claim 50% of the kills! This is why it is difficult to assess **just how few killed how many** in any simple quantitative way. The advantage of the Polya Distributions is that they can serve as a precise **measuring stick** so that no further quantitative nor visual rhetoric is necessary to make Exhibits such as 1 and 2 comparable. The next Section develops the Polya Distributions.

To date, we have measured 23 Polya Parameter values from air, sea, and land wars -- some from different parts of the longer wars. The measurements lie between -0.8 and $+0.1$. These measurements are uncannily tight when compared to the possible range of $\pm\infty$. Within this range: Polya Parameter value ∞ represents a multinomial distribution, value 0 represents the Bose-Einstein distribution used in statistical mechanics (this is where men and molecules behave alike), and value $-\infty$ represents the "maximally-skewed" distribution in which some one combatant gets all the kills. The tightness of these measurements seems to evidence some **law of human group behavior** with a stability rivaling that of the physical sciences. The third and final Section presents a summary of the data analyses completed to date.

THE POLYA DISTRIBUTIONS

We want to show that the Multivariate Homogeneous Polya Distributions provide a good **measuring stick** to gauge the variability in kill performance observed among similar warfare combatants. Because this measuring stick produces like values over a variety of wars and warfare areas, it may serve as one means of validation for any combat model. That is, combat model results of kill distributions should indicate readings consistent with the measurements from past combat. In addition, the underlying "probability model" generating the Multivariate Homogeneous Polya Distributions might point to the true operant stochastic processes governing combat.

This underlying "probability model" is a generalization, essentially proposed in reference [13], of the **urn scheme** created in 1923 by Polya and Eggenberger in reference [14] to analyze the distribution of the number of deaths per month due to the contagious disease of smallpox. The **Polya Urn Scheme** is the standard probability model of "contagious processes". With this beginning, there is no compelling theoretical reason why Polya Distributions should work well in portraying the distribution of kills among combatants in warfare. Similarly, there is no compelling theoretical reason why Pareto Distributions work well in describing the distribution of income among human populations.

The following description of the Multivariate Homogeneous Polya Urn Scheme, referred to henceforth as **Our** Polya Urn Scheme, is not the one typically portrayed in academic textbooks (see reference [15] for example.) Rather, it is meant to portray the fundamental probability mechanism in terms of a warfare analogy designed to characterize how a notional distribution of kills might develop. The basic idea is reasonably straightforward. You begin with the following **urn scheme**:

You associate with each of your combatants an **urn**; that is, when you have **n** combatants you picture **n** urns, one representing each combatant. Similarly, you associate a **ball** with each enemy killed. You could use such a one-to-one association as a bookkeeping procedure to keep score of a war in progress. For example, each time one of your combatants kills an enemy during the war, you place a ball in that combatant's corresponding urn. At war's end, the **disposition** of the balls in the urns precisely mimics the **disposition** of killed enemy among your combatants.

You might wonder if such a disposition of balls in urns could be replicated by some method of allocating balls to urns without looking at the war. For example, Our Polya Urn Scheme can be implemented in terms of "tossing" a ball into an urn at random, but with chances depending on the current number of balls already in each urn due to some previous tosses. A **trial**, consisting of tossing balls one-at-a-time into urns under this chance mechanism, will generate some **disposition** of balls in urns after all tossing ends. It turns out that this chance mechanism is sufficiently adjustable through just one parameter, that the disposition of balls in urns averaged over many trials approximates the disposition of real enemy killed by real combatants.

This Polya chance mechanism can be qualitatively characterized by the following notion typical of "contagion" and representative of the idea of "habituation to war": any combatant (urn) already with some kills (balls) will tend to accumulate more kills (balls) with greater likelihood than some other combatant (urn) with fewer kills (balls). How much greater is the one controllable parameter! This seems not an unreasonable metaphor. If you: 1) give someone the current combat statistics, 2) inform that someone that another enemy has just been killed, then 3) ask that someone to bet on the identity of the combatant who got it; that someone might well bet on some one battle-proven combatant.

We can quantitatively flesh out this notion by constructing an urn model experiment. Let's fashion each ball from a mass of one **drab**, an arbitrary unit of mass. Let's also fashion each urn from β **drabs** of mass. Now implement the Polya chance mechanism by randomly tossing the next ball into the urns, in proportion to the relative **weight of each urn**. **By the weight of each urn,** we mean the weight due to both the mass of each urn *plus the mass of its contents.* Thus, urns with many balls will have greater weight and so a greater propensity to get the next ball as compared to urns with few or no balls. The propensity is governed by the adjustable β. (In what follows, we use **drabs** as a measure of both mass and weight to simplify our syntax.)

Let's give an example: Panel 1 of Exhibit 3 reveals that before any balls have been tossed none of the **n** urns has any contents. Thus, each urn has the same weight, namely β drabs, and so each urn has the same chance (**1/n**) of getting the first ball. Let's suppose that the first ball lands in **Urn i** as shown in Panel 2 of Exhibit 3. Now, the second ball no longer has the same prospects of getting into any urn. Urn i has a greater chance to acquire the second ball than any other single urn, because Urn i now has weight $\beta+1$ drabs, while all other urns still have weight β drabs. The **relative** difference in weight, you see, depends on the value of β.

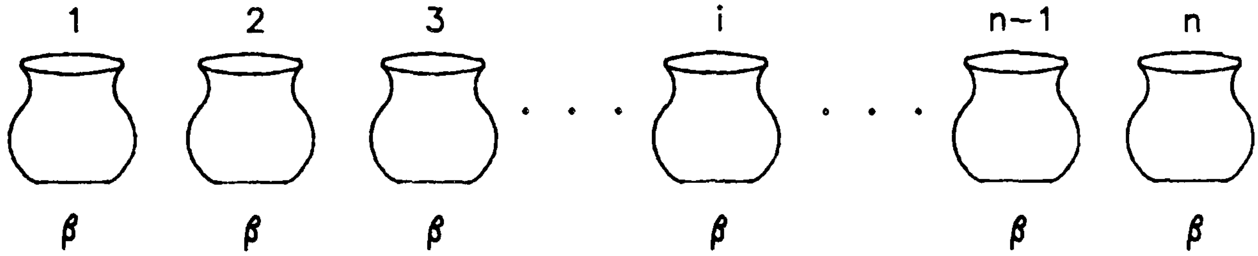
For example, for β large, say 100, $\beta+1$ is just 101 and not all that much more than β. So the disposition of the second ball still has almost uniform chances. This trend will tend to continue, and the final disposition of balls in urns will tend to be relatively even. The most even case occurs as β goes to infinity which yields a multinomial distribution. For β small, say $\beta=0.01$, Urn i has 101 times the weight of any other urn due to its acquisition of the first ball. Now, Urn i is 101 times more likely than any other single urn of getting the next ball. Again, this trend will tend to continue, and the final disposition of balls in urns will tend to be heavily **skewed**. The most skewed case occurs as β goes to 0. In this extreme case all balls following the first go into the same Urn i getting the first.

For $\beta=1$, Urn i has exactly twice the weight of any other urn due to its acquisition of the first ball. Thus, it is twice as likely as any other urn to get the next ball. As you will see, Our Polya Urn Scheme at $\beta=1$ produces all dispositions with equal chances. This $\beta=1$ discrete multivariate distribution is a favorite of physicists because it models the statistical mechanics of the

EXHIBIT 3

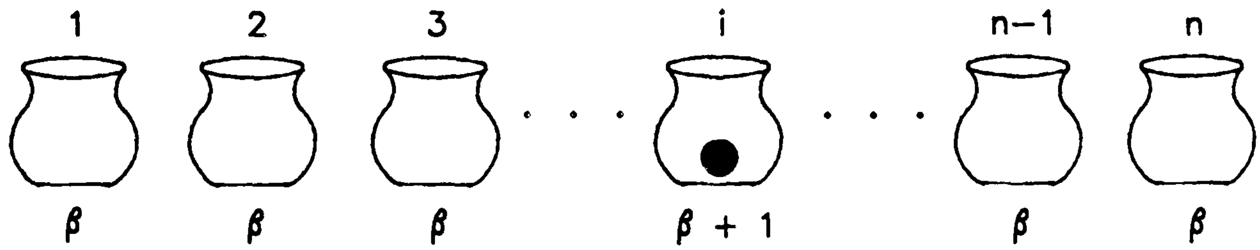
BASIC POLYA URN MECHANISM

1. No Balls Tossed



$$\Pr\{\text{urn } i \text{ gets the first ball}\} = \frac{\text{weight of urn } i}{\text{weight of all urns}} = \frac{\beta}{n\beta} = \frac{1}{n}$$

2. One Ball Tossed

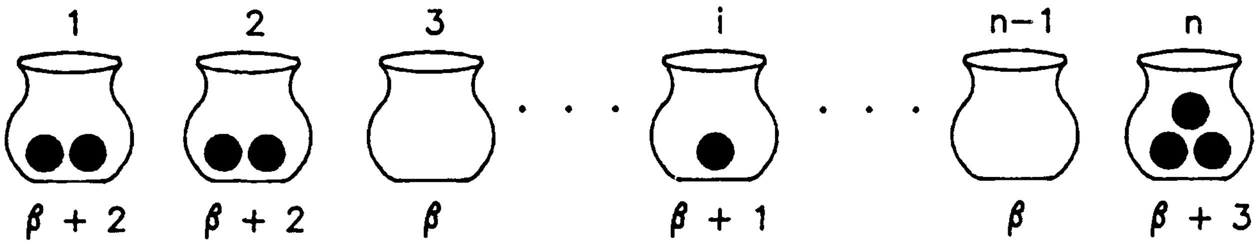


$$\Pr\{\text{urn } j \text{ gets the second ball}\} = \frac{\text{weight of urn } j}{\text{weight of all urns}}$$

$$= \begin{cases} \dfrac{\beta}{n\beta + 1} & j \neq i \\[2ex] \dfrac{\beta + 1}{n\beta + 1} & j = i \end{cases}$$

EXHIBIT 4

BASIC POLYA DISTRIBUTION RESULTS



K_j = random number of balls in urn j after k tosses

$K = \left(K_1, K_2, \ldots, K_n\right)$ kill vector with $\sum_{j=1}^{n} K_j = k$

Then

$$\Pr\{\text{urn } j \text{ gets the } k+1^{st} \text{ ball} \mid K = (k_1, k_2, \ldots, k_n)\}$$

$$= \frac{k_j + \beta}{\sum_{i=1}^{n}(k_i + \beta)} = \frac{k_j + \beta}{k + n\beta}. \qquad (1)$$

$$\Pr\{K = (k_1, k_2, \ldots, k_n)\} = \frac{\binom{-\beta}{k_1}\binom{-\beta}{k_2}\cdots\binom{-\beta}{k_n}}{\binom{-n\beta}{k}} \qquad (2)$$

EXHIBIT 4 (continued)

BASIC POLYA DISTRIBUTION RESULTS

N_i = random number of urns holding i balls after k tosses

$N = \left(N_0, N_1, N_2, \ldots, N_k\right)$ pattern vector has

$$n = N_0 + N_1 + N_2 + \ldots + N_k$$

$$k = N_1 + 2N_2 + 3N_3 + \ldots + kN_k$$

$Pr\{ N = (n_0, n_1, n_2, \ldots, n_k)\} =$

$$\frac{n!}{n_0!\, n_1! \ldots n_k!} \; \frac{\binom{-\beta}{0}^{n_0} \binom{-\beta}{1}^{n_1} \cdots \binom{-\beta}{k}^{n_k}}{\binom{-n\beta}{k}} \qquad (3)$$

important particles they call "Bosons". They call the $\beta=1$ distribution the Bose-Einstein distribution.

Equation (1) in Exhibit 4 states the chance mechanism for urn weight changes. Equation (1) represents all the conditional probabilities concerning the allocation of the next ball, given the current contents of individual urns. The resulting Multivariate Polya Distribution appears in equation (2) of Exhibit 4, in terms of negative binomial coefficients. The proof of this result can be found in reference [11]. In fact, the proof in reference [11] is more general. It allows each Urn i to have a different β_i's in equation (1). This results in an equation in the form of equation (2), but with β_i in the i^{th} binomial coefficient in the numerator, and the sum of the β_is replacing the $n\beta$ in the binomial coefficient in the denominator. We will use this fact later.

Equation (2) can evaluate the probability of any possible disposition as a function of β. Note that for any positive and finite β, there is a positive probability that any disposition will be produced. In this sense, the trials coming from Our Polya Urn Scheme encompass the broadest spectrum of possibilities. This property has made these Polya Distributions a good tool to incorporate conservative estimates of the impact of this kind of chance into some existing methods of material requirements planning for warfare. Most particularly, note for $\beta=1$ that all the binomial coefficients in the numerator disappear; you then get **the classic definition of the Bose-Einstein distribution: that all dispositions are equally likely to occur**.

Equation (2) is called the Multivariate **Homogeneous** Polya Distribution because each urn has the same value of β. Since all the urns are initially equal in this way, exchanging the identities of any two urns will not change the likelihood value coming from equation (2). In fact, the **skewness** property is best displayed, as in Exhibits 1 and 2, by ordering the disposition from the best to the poorest performer. What is important to this likelihood value then is not which urns have balls, but what might be called the **disposition pattern**, which is meant to represent how many urns have how many balls: that is, how many urns $\mathbf{n_0}$ have no balls, how many urns $\mathbf{n_1}$ have one, how many $\mathbf{n_2}$ have two, how many $\mathbf{n_3}$ have three, etc. Equation (3) of Exhibit 4 gives the probability of any disposition pattern. Exhibit 5 displays two forms of the disposition pattern for the data in Exhibit 2.

The bars in Exhibit 5 represent the disposition pattern: they show the number of combatants credited with various numbers of kills. They also form the "sample probability distribution": $P_{17}(x)$ =

{Number of Combatants With Exactly x Kills} ÷ 17,

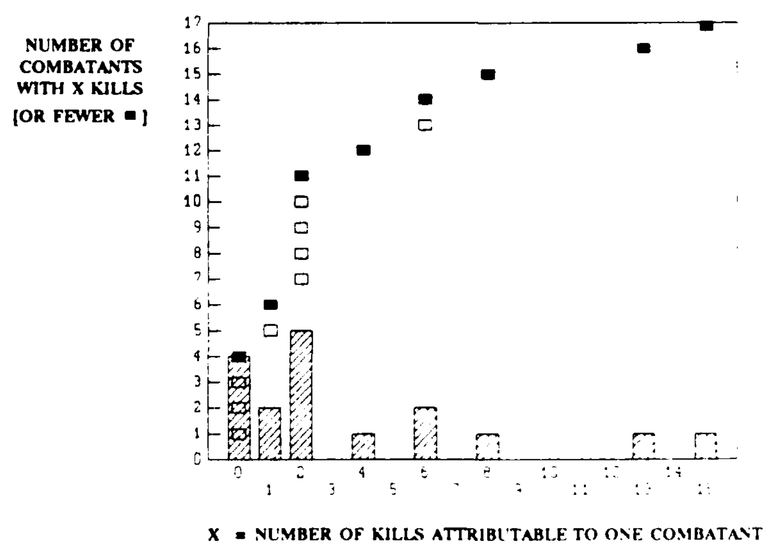
when the Y-axis is relabelled from 0 to 1. The filled blocks mark the **cumulative disposition pattern** or, again when the Y-axis is relabelled from 0 to 1, the "sample cumulative distribution function": $C_{17}(x)$ =

{Number of Combatants With x Kills or Fewer} ÷ 17.

You can construct the cumulative directly: 1) by stacking up the combatants on the Y-axis

EXHIBIT 5

DISPOSITION PATTERN AND ITS CUMULATIVE FOR THE AIR-TO-AIR DATA OF EXHIBIT 2



with the poorest performer on the bottom and the best at the top of the stack, 2) by associating across from each combatant an unfilled block at the X-value equal to the kills that that combatant obtained, and 3) by filling in each block at the top of each X-value stack.

How can you calculate the probability that a particular disposition pattern will arise as a trial outcome of Our Polya Urn Scheme with Urn weight β? Again, equation (3) of Exhibit 4 gives the likelihood of any **disposition pattern**. This is in contrast to equation (2) which gives the likelihood of any one **disposition** in which the urns are identified. As suggested above, the disposition pattern depends on the values of the set of $\{\mathbf{n}_i\}$s but not on which urn has which $\mathbf{n}_i$. Equation (3) comes from equation (2) in two simple parts: 1) count up the number of ways $\mathbf{n}$ urns can circulate identities for which $\mathbf{n}_0$ have no balls, which $\mathbf{n}_1$ have one ball, which $\mathbf{n}_2$ have two, etc. -- this is the multinomial coefficient on the left of equation (3), and then 2) multiply by the likelihood of any one of them in terms of the $\mathbf{n}_i$s rather than of the $\mathbf{k}_i$s.

Equation (3) can be used to adjust the value of β which best fits warfare data as in Exhibit 5. **This means that you can gauge the variability in the performance of combatants in terms of the value of β which best characterizes the skewness of the disposition pattern.** Exhibit 6 summarizes the procedure which identifies the best value of β: From the warfare data, count up the number $\mathbf{n}_0$ of combatants with no kills; count up the number $\mathbf{n}_1$ of combatants with 1 kill; count up the number $\mathbf{n}_2$ of combatants with 2 kills; the number $\mathbf{n}_3$ of combatants with 3 kills; etc., up to the number $\mathbf{n}_m$ of combatants with the largest number $\mathbf{m}$ of kills. Then calculate the total number of combatants $\mathbf{n}$ and the total number of kills $\mathbf{k}$ as shown in Exhibit 6.

The procedure in Exhibit 6 means that Our Polya Urn Scheme using urns of mass β^* is the one most likely to replicate the data. (In fact, since only β varies in equation (3), using equation (2) in the same way would produce the same β^*.) References [6/7/8/9/10] did this, and produced β^* values between 0.45 and 1.1. As an example, Exhibit 7 displays the relative likelihood values calculated by applying equation (3) to the disposition pattern in Exhibit 5 for a range of values of the <u>natural logarithm</u> of β, denoted here as **Log β**. This likelihood peaks at just about Log β = -¼. Notice that the likelihood function is almost symmetric in Log β. Because of this symmetry, we call Log β the Polya Parameter, and it lives in the interval $(-\infty, \infty)$. Therefore,

EXHIBIT 6

PROCEDURE FOR FINDING β^* -- THE BEST β

- **Put all the n_i values into equation (3) along with k, n, and β.**

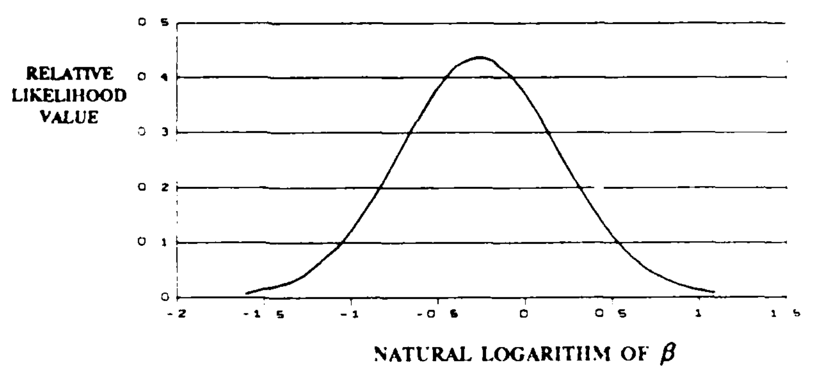
$$\mathbf{n} = \mathbf{n}_0 + \mathbf{n}_1 + \ldots + \mathbf{n}_m; \text{ and}$$

$$\mathbf{k} = \mathbf{n}_1 + 2\times\mathbf{n}_2 + \ldots + m\times\mathbf{n}_m.$$

- **Adjust β until you get the maximum of that likelihood expression.**
- **Label the β producing this maximum by β^*.**

EXHIBIT 7

BEST β FOR THE DISPOSITION PATTERN IN EXHIBIT 5



as the Introduction states, the warfare data analyzed to date show a "skewness" appropriate to a Our Polya Urn Scheme with Polya Parameter in **[-0.8, 0.1]**.

Even though this likelihood peaks for some value of Log β, this does not necessarily mean that the Polya Distributions provide a **good fit** to the data. It only says that of all possible Polya fits, the one at Polya Parameter value Log $\beta = -\frac{1}{4}$ is about the best of the lot. To call the Polya Distributions an adequate representation of the data, we need to show, at the very least, that the best of them "looks like" the data displayed in Exhibit 5. But the Polya Distributions have positive probability at every disposition. Thus we must define what "look like" means.

For example, one could define "look like" to accommodate Pearson's famous statistic for the Chi-Square Test. For our case this "look like" would mean that the **average disposition pattern** from Our Polya Urn Scheme (the sum of all disposition patterns weighted by their likelihood values from equation (3)) should portray: 1) a fraction of combatants with no kills which is close to the observed fraction $\mathbf{n_0/n}$ of combatants with no kills; 2) a fraction of combatants with one kill which is close to the observed fraction $\mathbf{n_1/n}$ of combatants with 1 kill; 3) a fraction of combatants with two kills which is close to the observed fraction $\mathbf{n_2/n}$ of combatants with 2 kills; etc. This construction and use of the **average disposition pattern** is reminiscent of the way quantum mechanics uses expectations to construct distributions for the possible values of observables.

EXHIBIT 8

AVERAGE DISPOSITION PATTERN FOR THE MULTIVARIATE HOMOGENOUS POLYA URN SCHEME

The **Average Fraction** of n Combatants with Exactly i of k Total Kills

$$= \Pr\{\text{Any Given Combatant Gets i Kills}\}$$

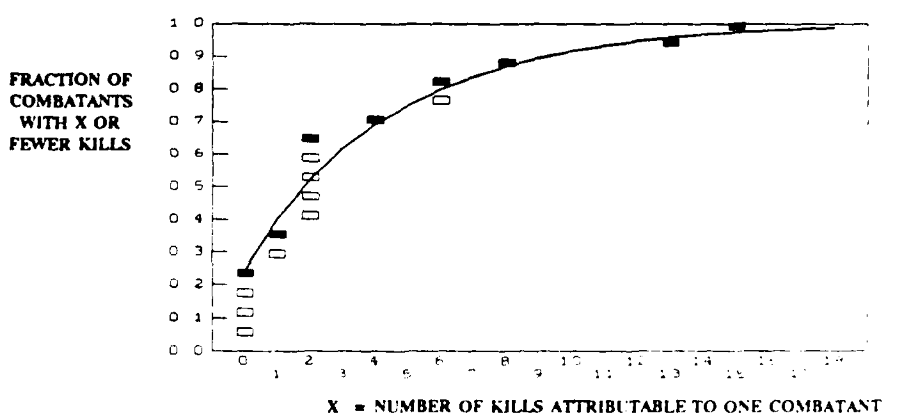
$$= \frac{\left[\begin{matrix}-\beta \\ i\end{matrix}\right]\left[\begin{matrix}-(n-1)\beta \\ k-i\end{matrix}\right]}{\left[\begin{matrix}-n\beta \\ k\end{matrix}\right]}$$

It is relatively easy to obtain the **average disposition pattern** from Our Polya Urn Scheme because of the homogeneity. Exhibit 8 summarizes the result as the one-dimensional marginal to the multivariate distribution. **This one-dimensional marginal is what is typically called the <u>Polya distribution</u>.** It can be obtained by summing equation (2) over any n-1 combatants. In addition, you can obtain the result more directly: 1) coalesce any n-1 combatants into a single big urn with weight $(n-1)\beta$, and 2) apply the non-homogeneous generalization of equation (2) to a Polya Urn Scheme with one big urn ($(n-1)\beta$) and one normal urn (β).

Exhibit 9 compares the sample cumulative distribution function drawn from Exhibit 5 (filled blocks) to a curve representing the one-dimensional cumulative Polya distribution function from Exhibit 8 at Polya Parameter Log $\beta = -\frac{1}{4}$. (The distribution of Exhibit 8 is, of course, discrete; we use a curve only to facilitate a compar-

EXHIBIT 9

SAMPLE CUMULATIVE DISTRIBUTION FROM EXHIBIT 5 (▬) AND THE CUMULATIVE POLYA DISTRIBUTION (——) AT Log $\beta = -\frac{1}{4}$



ison.) The filled blocks in Exhibit 9 at each X-value denote the fraction of combatants observed with X or fewer kills. The deviation at X = 2 is the largest due to the large number of Carriers with 2 kills. Despite this deviation, the fit is excellent. For those of you who must live life the hard way, we now undertake the usual array of goodness-of-fit tests.

There are three tests typically used to assess whether or not a distribution sample comes from some hypothesized probability distribution. They are: 1) the Chi-Square Test, 2) the Kolmogorov-Smirnov Test, and 3) the Cramer-von Mises Test (see reference [16] for example.) Each test is based on a **statistic** formulated to measure the deviation of the distribution sample from the hypothesized distribution. The idea is: 1) calculate the value of that deviation statistic applied to the observed distribution sample, 2) calculate many values of that statistic applied to many distribution samples drawn from the hypothesized distribution itself, and 3) accept that the observed sample comes from the hypothesized distribution unless the observed sample statistic exceeds α% of the self-constructed sample statistics. As the size of the sample increases, it becomes increasingly unlikely that the deviation statistic will remain small if the sample does not "look like" it comes from the hypothesized distribution.

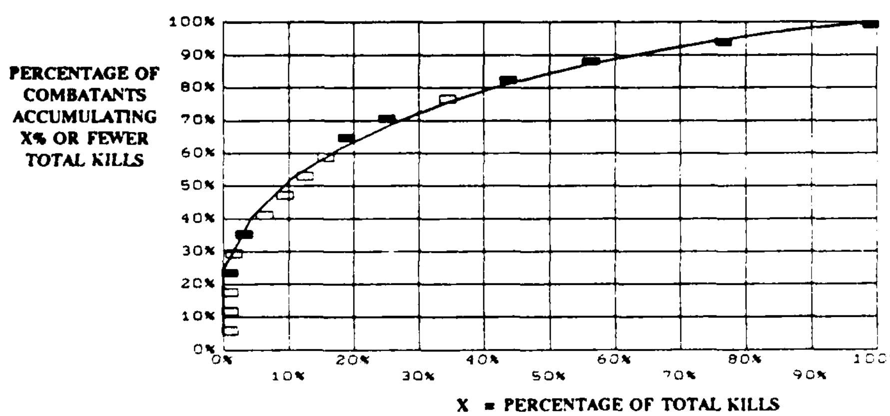
With a sample such as that in Exhibit 5, none of these goodness-of-fit tests apply in the normal cookbook fashion. This is because they depend on independent multiple samples and asymptotic formulas for the distribution of each of the three statistics. (Because the three distributions corresponding to the three statistics all turn out to be asymptotically independent of the hypothesized distribution, these tests are called "non-parametric".) Nevertheless, we can use the three deviation statistics on which these three tests are based and construct the distribution of these statistics from Monte Carlo samples drawn from Our Polya Urn Scheme. We can then see where each statistic's value for our warfare sample falls with respect to the distribution of each statistic.

Each of the three statistics indicates that the air-to-air warfare sample is indistinguishable from Polya Urn samples drawn at Log $\beta = -\frac{1}{4}$. The statistic values of the warfare sample rank as follows: in the lower 55% for the Chi-Square, the lower 53% for Kolmogorov-Smirnov, and the lower 23% for Cramer-von Mises. That is, the air-to-air warfare sample looks more like it comes from Our Polya Urn Scheme at Log $\beta = -\frac{1}{4}$ than do about half of the random samples drawn directly from Our Polya Urn Scheme. <u>This is a good fit</u>.

There is another depiction of such warfare results from which it is easier to interpret the goodness-of-fit. We call it the **Double Cumulative Distribution**. It is similar to the cumulative

EXHIBIT 10

DOUBLE CUMULATIVE DISTRIBUTION FORMS FOR THE SAMPLE AND POLYA DISTRIBUTIONS OF EXHIBIT 9



distribution function in Exhibit 9, **but with the X-axis expressed in terms of the <u>fraction of all kills</u>**, just as the Y-axis is expressed in terms of the fraction of all combatants. In addition, both axes get labelled in percentage terms. It is completely equivalent to the cumulative distribution form as displayed in Exhibit 9. Exhibit 10 redisplays Exhibit 9 in this form.

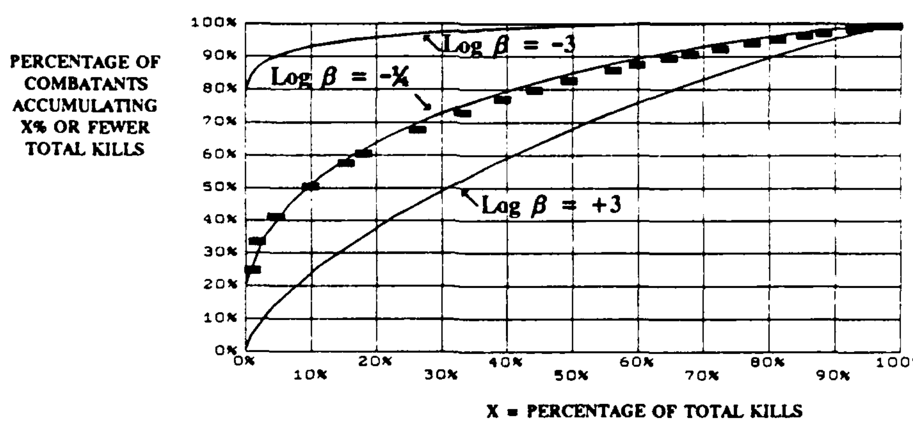
You can construct the double cumulative form by stacking up your combatants on the Y-axis, with the poorest performers at the bottom and the best at the top of the stack. At the Y-value representing one of your combatants, associate an X-value equal to that combatant's kills plus all the kills of all the combatants beneath him. Note again that the Polya curve has its true Y-values only for those X-values marked by the position of the filled blocks.

In this Double Cumulative Form, the one-dimensional Polya distribution curve can be used to interpolate between warfare data points. This allows us to make convenient statements of **the-higher-the-fewer** kind. For example, Exhibit 10 says that **10% of combatants were responsible for 38% of the kills.** This is because the top 10 percent of combatants (between 90% and 100% on the Y-axis) killed the "top" 38 percent of the enemy (between 62% and 100% on the X-axis.) Also, you can say that **15% of the combatants got 50% of the kills**. This comes from looking at the 50% point on the X-axis and finding the Y-intercept on the Polya distribution curve.

As another comparison, Exhibit 11 displays the associated double cumulative distribution form for the World War II U.S. submarine data underlying Exhibit 1. Incredibly, the best Polya Parameter is again about Log $\beta = -\frac{1}{4}$, and again the deviations are quite small. In addition, for the same numbers of combatants and kills, we also plot the Polya distributions associated with Log $\beta = -3$ and Log $\beta = +3$ in Exhibit 11. It is clear that these other Polya distributions are nowhere near the positions of the data. The Polya distribution curves for Log $\beta = -\frac{1}{4}$ in Exhibits 10 and 11 are just slightly different because of the different numbers of kills and combatants.

EXHIBIT 11

DOUBLE CUMULATIVE DISTRIBUTION FOR THE DATA OF EXHIBIT 1 COMPARED TO THREE POLYA DISTRIBUTIONS



If we accept the hypothesis that disposition patterns are the result of chance operating within warfare, then these good fits could be extrapolated to suggest that Our Polya Urn Scheme at Polya Parameter Log $\beta = -\frac{1}{4}$ provides the underlying mechanism of chance. A weaker statement, and the one we prefer, is that some Polya distribution is a good candidate as the underlying distribution **characterizing** the mechanism of chance, <u>whether it is Polya's chance mechanism within Our Urn Scheme or some other</u>. All we want to substantiate just now is that the Polya Distributions make a good **measuring stick** for the comparison of such disposition patterns. This is the operant supposition of the next Section.

In our opinion, even these good results do not justify the claim that the Multivariate Homogeneous Polya Urn Scheme is a good chance model of warfare. To interpret it as a model of warfare you need to make warfare sense out of its two critical modeling assumptions: (A) initially, each combatant has equal chances of killing targets, and (B) during war something happens with/to/around the combatants accumulating kills which tends to set up circumstances leading them to more kills -- in fact, at any moment a combatant with i kills enjoys an independent stochastic advantage over a combatant with $j<i$ kills in the approximate proportion of $i+1$ to $j+1$.

Does (A) make any warfare sense? Our Polya Urn Scheme has all combatants always ready to receive kills. But warfare data show that new combatants are employed over time, and that some surviving older combatants retire. This seems to imply that real combatants do not satisfy the initial conditions of Our Polya Urn Scheme. So why does it get the right result? One facile answer is that these factors tend to increase skewness, as does any other initial inequality of combatants, and the best Polya Distribution fit compensates by picking values of Log β slightly more negative than it would otherwise. So if there were some better Polya-Urn-type model which accounted for this inhomogeneity, then we might find Log $\beta = 0$ within that model.

And what about attrition? Our Polya Urn Scheme never excludes urns explicitly, but combatants are lost in real wars, as the data in references [6/7/8] show. So why would an attritionless Polya Urn Scheme give good results? The facile answer is that attrition is another means of inhomogeneity, and the best Polya Distribution fit compensates by choosing a more negative value of Log β as above. A better answer is that a believable model of attrition is **built-into** the Polya Distributions. Reference [17] describes an extension of Our Polya Urn Scheme which modifies the interpretation of a ball being tossed into an urn to mean either the combatant kills an enemy or is killed himself. This Generalized Urn Scheme reproduces the <u>same Polya Distributions</u>.

Finally, there is the stochastic relationship between a combatant with i kills and a combatant with j kills which, 1) portrays some quantitative idea of "habituation to war", 2) looks like some multivariate generalization of Laplace's Law of Succession, and 3) makes little direct warfare sense. Neither does it make any physical sense if statistical mechanics were approached from this point of view. We believe the problem has to do with our <u>habituation to causal thinking</u>.

The view taken by statistical mechanics is undiluted global chance: **nature behaves as if all dispositions were equally likely**. You might think this OK for molecules, but for men you want to derive it by mixing an understandable human concept of causality (habituation to war) with an understandable human concept of chance (a simple urn model.) In our opinion, Physics get Log $\beta = 0$ as the answer because it has been smart enough to get the **states of the system** properly defined. Warfare won't get Log $\beta = 0$ with Our Polya Urn Scheme because it doesn't have the states quite right.

The same problem persists with a "raw talent" approach. Reference [11] shows that the Multivariate Homogeneous Polya Distributions can also be generated as a Multinomial mixture with the Dirichlet distribution. We can explain this with an **urn scheme** in which: 1) each urn has a different beginning mass $\boldsymbol{\beta}_i$ (raw talent), and 2) balls are allocated to urns in proportion to the β_is without consideration for the contents (no contagion.) This probability model will generate a multinomial distribution.

In addition, suppose the $\{\beta_i\}$s are themselves random variables distributed according to a Homogeneous Dirichlet Distribution (essentially describing how talent is randomly distributed among the population), so that each $\boldsymbol{\beta}_i$ has the same average value. Then the disposition balls in urns will be Polya, even though derived from a random inhomogeneity among the combatant population. Nonetheless, this approach gets us no closer to understanding how the talent inhomogeneity happens (is it learning? is it genetics? etc.?) and some concept of opportunity may still need to be injected since you can't show your skill if you don't get to play. The Appendix reviews the history of the two derivations of the Polya Distributions.

APPLYING THE POLYA DISTRIBUTIONS TO DATA

The previous Section argued that the Multivariate Homogeneous Polya Distributions, no matter how generated, have the makings of a good **measuring stick** to gauge the variability in kill performance observed among warfare participants. The PROCEDURE in Exhibit 6 tells us how to fit such Polya Distributions to appropriate warfare data. To date, references [6/7/8/9/10] report five data fits. Exhibit 12 summarizes the kinds of data. Please note three things. First, the 4.a. data concerns **ships killed per torpedo taken to sea** from which we estimated ships killed per commander. There is now a complete, and large, data set on who killed ships, but we are yet to perform the fit. Second, we have not discovered all USAF crew data in open publications, so we must suppress details; for Fighter Wings, where the details are openly known, we are yet to perform the fit. Third, all the details of the tank-versus-tank warfare data are classified, but we can show the general shape of the **the-higher-the-fewer** type. We deal with these data in separate subsections below.

> **EXHIBIT 12**
>
> **DATA SOURCES FOR VARIABILITY IN SHOOTER PERFORMANCE**
>
> 1. U.S. NAVY AIR-TO-AIR KILLS IN VIETNAM
>   a. Kills per Carrier/Wing/Squadron with date
>   b. Kills per Crew with date, but the number of crews with no kills (**a critical parameter**) is unknown
>
> 2. U.S. AIR FORCE AIR-TO-AIR KILLS IN VIETNAM
>   a. Verbal description of the disposition of kills per crew implying three possibilities
>   b. *Kills per Fighter Wing with date (data not yet fit)*
>
> 3. U.S. SUBMARINE KILLS OF JAPANESE SHIPS, WWII
>   a. Kills per Submarine per patrol cruise as recorded in the ship's log with patrol departure date
>   b. Kills per Submarine per patrol cruise as reconstructed after the war
>
> 4. GERMAN U-BOAT KILLS OF ALLIED SHIPS, WWII
>   a. Estimated average torpedo kills per U-Boat Commander derived using a MOD UK analysis of U-Boat logs.
>   b. *Kills by U-Boat with date supplemented by deployed U-Boats without kills from a MOD UK Study (data not yet fitted)*
>
> 5. ISRAELI TANK KILLS OF ARAB TANKS IN 1973 WAR
>   a. Post-war debriefing of Tankers by Rank
>   b. A second set of totals by geographical area

U.S. NAVY AIR-TO-AIR KILLS

Our best reading of reference [5] indicates that seventeen attack-configured Aircraft Carriers (see Exhibit 2) participated in Southeast Asia from 1965 to 1973. They participated for various lengths of time: some for 7 full cruises, some for less than one -- the Forrestal being the most notable example; it was a deck fire casualty (an attrition) after only five days on station.

The Naval air combat activity over Vietnam seems to separate naturally into three periods. The first period shows 38 aircraft kills and covers the escalation of the air war from the Rolling Thunder Campaign, beginning about March 1965, until the bombing halt declared in November 1968. The second period, which shows only one kill, covers the beginning of the US troop withdrawal in November 1968 until the North Vietnamese preparation for the Easter Invasion beginning about December 1971. The third period shows 25 kills and covers the relatively high intensity final period beginning December 1971 until the cease fire on 23 January 1973.

Interestingly, 3 of the 64 kills in Exhibit 2 were by Attack (VA) Aircraft rather than by Fighter (VF) Aircraft which bear the air-to-air warfare mission. The profile for Fighter-aircraft-kills-only can be had from Exhibit 2 by deleting one kill each from the Intrepid (CV-34), the Bon Homme Richard (CV-31), and the Midway (CV-41). The relative likelihood values as a function of the Polya Parameter look almost exactly as those in Exhibit 7. With this information, and the combat intensity structure, we can group the 61 VF kills into three time periods: **1) the initial escalation period -- the Front End, 2) the final intense period -- the Back End, and 3) the Whole War.** Exhibit 13 displays the tabulation, including the best Polya Parameter **Log β***. As an aside, kills typically occur within minutes of each other by carrier mates. For example, on 10 May 1972, four crews from the Constellation (CV-64) scored 7 (=3+2+1+1) kills; on two occasions four crews from the Bon Homme Richard (CV-31) each scored one kill -- first on 19 May 1967 and then again on 21 July 1967; finally, 26 other kills occurred as 13 pairs by carrier mates.

Although you will find 17 Carriers in operation, there were only 16 Air Wings. To some extent the Air Wings stayed in place while the Carriers rotated beneath them. Thus, it might be that the disposition of kills over Wings looks different from the disposition over Carrier. In fact, there is a slight effect of this sort. Exhibit 12 displays the disposition of kills over AirWings by period accompanied by the evaluated Polya Parameter. The results indicate slightly less skewness for the Wing data than for the comparable Carrier data. Note that the **Back End** of the war has exactly the same numerical entries for **AirWings** as for **Carriers** since there was no rotation during this one year period.

In the case of Carriers and Wings, we have precise data on which Carrier/Wing killed enemy aircraft and which did not. But our information concerning which **squadrons** killed targets is less complete. Nominally there

EXHIBIT 13

VF KILLS PER CARRIER IN THREE PERIODS

CARRIER	FRONT END	BACK END	WHOLE WAR
Constellation	5	9	15[1]
Bon Homme Richard	12	-	12
Midway	2	5	7
Coral Sea	1	5	6
Kitty Hawk	4	2	6
John Hancock	4	0	4
Oriskany	2	0	2
Saratoga	-	2	2
Enterprise	1	1	2
America	1	1	2
Intrepid	1	-	1
Ticonderoga	1	-	1
Ranger	1	-	1
Shangri-la	-	-	0
F. D. Roosevelt	0	-	0
Forrestal	0	-	0
Independence	0	-	0
Log β*	**0.04**	**0.03**	**-0.27**

Notes: 1. Includes the single kill in the middle period.

EXHIBIT 14

VF KILLS PER AIRWING IN THREE PERIODS

AIRWING	FRONT END	BACK END	WHOLE WAR
CVW-21	13	-	13
CVW-9	2	9	11
CVW-15	3	5	8
CVW-5	2	5	7
CVW-11	4	2	6
CVW-14	4	1	6[1]
CVW-2	2	-	2
CVW-16	2	0	2
CVW-3	-	2	2
CVW-6	1	-	1
CVW-10	1	-	1
CVW-19	1	0	1
CVW-8	-	1	1
CVW-1	0	-	0
CVW-7	0	-	0
CVW-17	0	-	0
Log β*	**0.10**	**0.03**	**-0.14**

Notes: 1. Includes the single kill in the middle period.

are two VF squadrons per Wing, but this may not be exact since some squadrons cycled through various Carriers and Wings, and those with **no kills** tend not to be mentioned. Exhibit 15 displays the disposition patterns for VF squadron kills for the same three time periods considered in Exhibits 13 and 14. Italics represent our best guess.

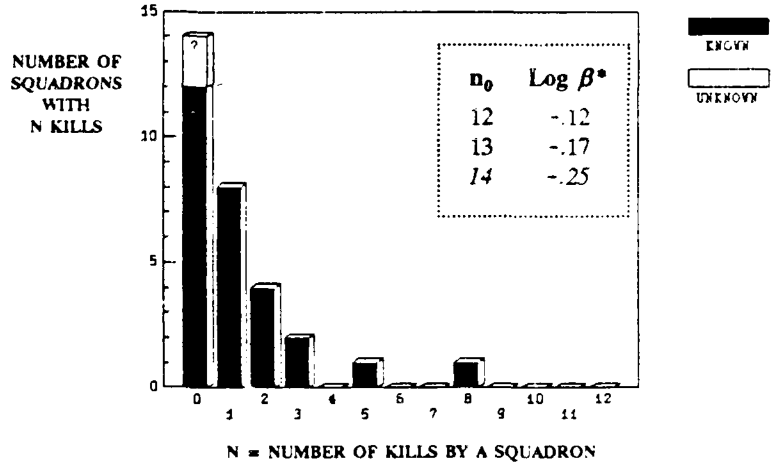
For the Front End, we can assess that at least 12 squadrons had 0 kills, and we speculate that perhaps as many as two more with 0 kills may have participated. Also, Panel 1 of Exhibit 15 shows how the Polya Parameter changes as the value of $\mathbf{n_0}$ changes. Basically, as $\mathbf{n_0}$ increases, the disposition pattern measures as more skew. Panel 2 of Exhibit 15 displays the situation for the Back End. Since this period is short, we speculate that at most one additional squadron could have been present. Panel 3 displays the Whole War results. In general, the squadron disposition patterns show more skewness than those of Wings or Carriers.

For crews, the number with no kills is even more difficult to ascertain from the sources reviewed. We prefer not to speculate here on that number. We must say, however, that the "ace" crew with 5 kills in the Back End of the war could drive Log β^* down to -1.7. But, in this case, with a tiny average number of kills per crew, the likelihood function has such a broad peak, that positive values of Log β are almost as likely to have generated the true disposition pattern.

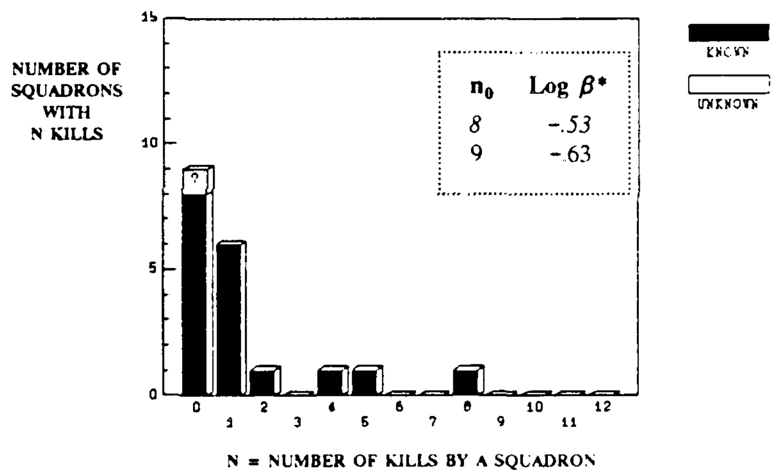
EXHIBIT 15

DISPOSITION PATTERN OF SQUADRON KILLS

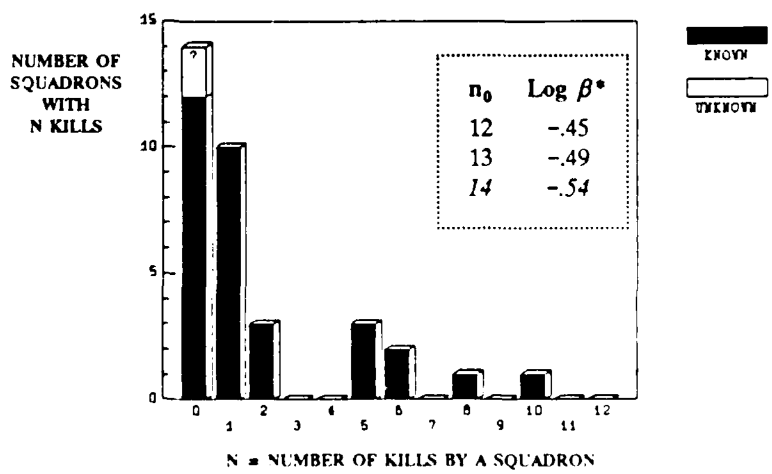
1. FRONT END



2. BACK END



3. WHOLE WAR



U.S. AIR FORCE AIR-TO-AIR KILLS

Reference [6] fits the Polya Distributions to a record of USAF air-to-air kills per crew in Vietnam from 1965 through 1968. This corresponds to the **Front End** (as used in the previous subsection) of the Vietnam War. The data come from the still classified reference [18] in terms of three pieces of information: 1) the number of MIGs killed, 2) two citations in text of two percentages describing crews with multiple kills in ratio to the total number of crews with any kills, and 3) the total number of USAF fighter crews.

EXHIBIT 16

THREE POSSIBLE USAF CREW DISPOSITION PATTERNS

	A	B	C
n_0	DATA INTENTIONALLY OMITTED		
n_1			
n_2			
n_3			
n_4			
Log β*	**-0.20**	**-0.42**	**-0.58**

From these data, reference [6] produces five feasible assessments of the disposition pattern assuming: 1) that the quoted percentages were rounded to the nearest integer, and 2) that no crew killed six or more. Today we can reduce the number to 3 since reference [19] tells us that the largest number of kills by one crew was four.

Since we have been unable to find all the data in the public domain (in particular, the number of crews that served), Exhibit 16 does not display the disposition patterns; it simply quotes the best Polya Parameter arising from the possibilities covered in reference [6].

U.S. NAVY SUBMARINE KILLS OF JAPANESE SHIPS IN WORLD WAR II

Reference [4] contains data on the U.S. submarines' sinking of Japanese Navy and Japanese merchant ships during World War II. The data is segregated into two kinds: 1) kills per submarine hull per patrol as reported during Wartime, and 2) kills per submarine hull per patrol as reconstructed by a Joint Army-Navy Assessment Committee (JANAC) subsequent to the war. During Wartime, the 248 U.S. submarines participating in the Pacific reported 1849 kills while incurring 48 losses themselves. The JANAC reconstruction allowed only 1312 kills. Reference [20] (soon to be published) is advertised to contain the most complete set of data concerning the performance of all submarines in the Pacific. We hope reference [20] will contain complete data per individual submarine commander. (Since commanders rotated somewhat from submarine to submarine, their kill disposition will be different from that of the hulls.)

With so many U.S. submarines participating, it is impractical to display the disposition of ship kills per submarine in the same way as Exhibit 2 displays the disposition of aircraft kills among Carriers. Exhibit 1 was chosen to provide a visual analogue to Exhibit 2 in terms of a "low resolution" portrayal of the JANAC data. A good way to depict the entire data set is in terms of a disposition pattern such as that profiled in Exhibit 15. Exhibit 17 displays this disposition pattern: Panel 1 displays the Wartime data and Panel 2 displays the JANAC data.

In Exhibit 17, the Wartime reports reflect the "flatter" disposition pattern with 41 submarines reporting no kills and three submarines reporting in excess of 30. The JANAC reconstruction turns out more skewed since it assessed 61 submarines with no kills and a high of only 26 kills. The two best ship killers in the JANAC assessment were the two reporting 31 kills during Wartime. JANAC assessed the submarine reporting 34 kills with but 17. There are other exaggerations even more proportionately flamboyant. Of the 248 submarines, JANAC credited but two with more kills than they reported. Modesty of achievement would not seem characteristic within the warrior class.

By counting up the kills attributable to the 6 best ship killers on both Panels 1 and 2 of Exhibit 17, you can see that about 2% of U.S. submarines were responsible for sinking about 10% of those Japanese ships sunk by all U.S. submarines. (Recall that the total number of kills are different -- 1849 in Wartime and 1312 in JANAC.) Again, this contrasts to reference [12]'s statement that 2% of WWII U-Boat commanders can be credited with sinking 30% of those Allied ships sunk by all U-Boats. As discussed in the second section, such statements can be better visualized by converting the disposition pattern into the **Double Cumulative Distribution Form**. For example, Exhibit 11 displays the Polya fit to the JANAC data in this form, and Panel 3 of Exhibit 17 compares the Wartime data to the JANAC data in this form.

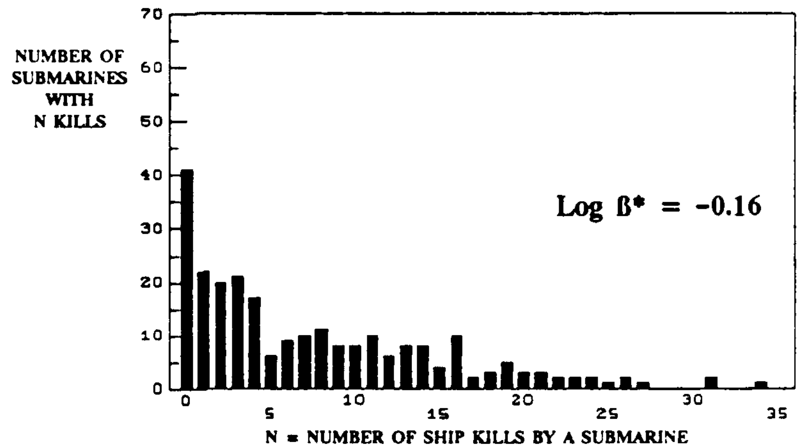
Recall that you can construct this form directly from the disposition patterns in Panels 1 and 2 as follows: 1) stack up your shooters on the Y-axis in order of performance with the poorest performers at the bottom and the best at the top of the stack; 2) at the Y-value representing one of your shooters, associate an X-value equal to that shooters kills plus all the kills of all the shooters beneath him (you can just plot the points where the shooters change their number of kills since this double cumulative will be linear in between); and 3) relabel both axes from **numbers** to **percentages** of total.

Both data sets tell about the same relative disposition story in double cumulative form. This is because the respective Log ß*s are close, and the kill counts are not too disparate.

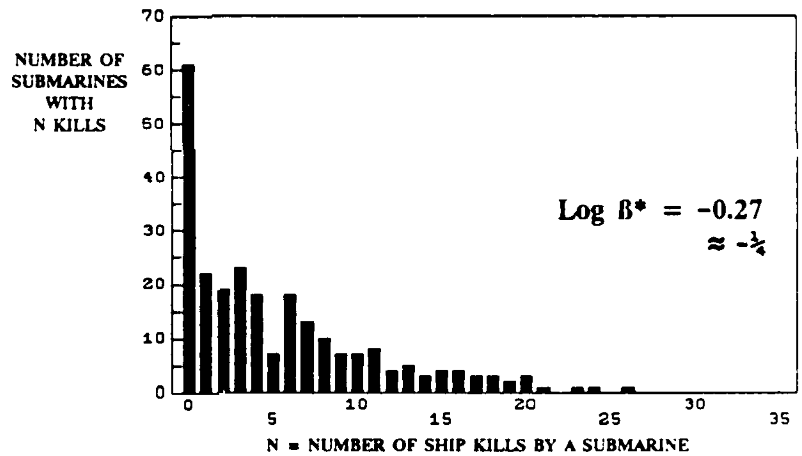
EXHIBIT 17

DISPOSITION PATTERN OF JAPANESE SHIPS KILLED BY U.S. SUBMARINES IN WORLD WAR II

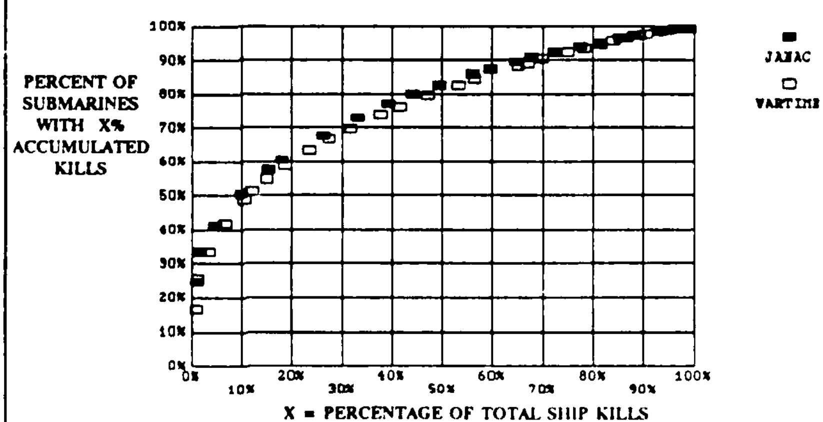
1. WARTIME DATA



2. JANAC DATA



3. DOUBLE CUMULATIVE FORM



U-BOAT COMMANDER PERFORMANCE AGAINST ALLIED SHIPPING IN WWII

Reference [8] contains a preliminary analysis of the distribution of torpedo kills by U-Boat commanders during World War II. The distribution is distinctly speculative since it was not based on direct data but was constructed from more aggregated information concerning U-Boat commanders' performances. Precise data is now available in reference [21] concerning ships killed by U-Boats, but we are yet to analyze them.

The data available to reference [8] concerns the **ratio** of ships-killed-by-torpedo to torpedoes-taken-to-sea by some 895 U-Boat commanders. Such a performance ratio, among others, was the topic of the undated MOD UK study (reference [22]) which was based on an analysis of the U-Boat logs in MOD UK's possession. One of the stated reasons for the study was:

"a desire to gain some further insight into the incidence of these 'Morale and Skill' factors."

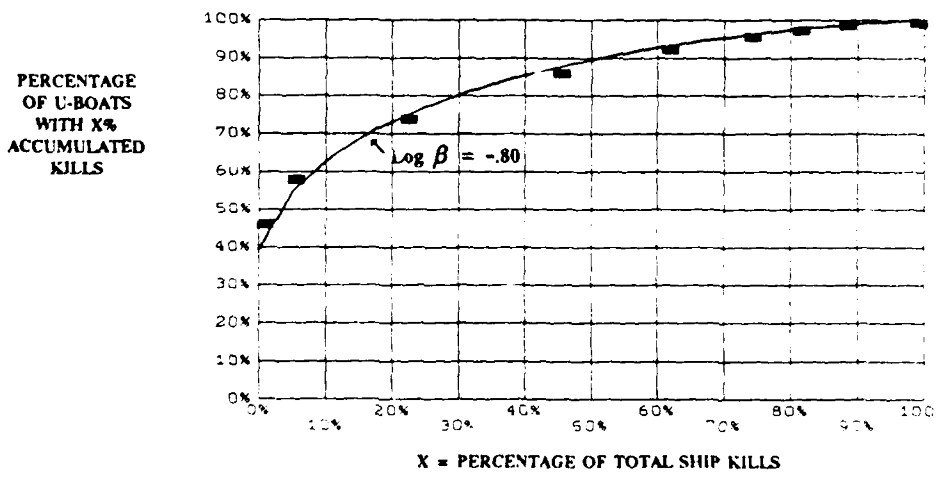
The study developed several measures of effectiveness involving **ratios** of factors such as: casualties produced, engagements, patrols, torpedoes taken to sea, torpedoes expended, etc.

Reference [22] counts up the U-Boat commanders within bands of width 0.05 with respect to the ratio of ship-killed-by-torpedo to torpedoes-taken-to-sea. It also provides aggregated information concerning the numbers of torpedo taken to sea. Reference [8] uses such information to construct an estimate of the number of kills achieved by the U-Boat commanders within the bands already provided by reference [22]. The estimated disposition cannot be particularly good since reference [22] acknowledges that there is correlation between increasing numbers of torpedoes taken to sea and increased performance on the kills-per-torpedoes-taken-to-sea ratio. The best reference [8] could do was to break the torpedoes taken to sea into two categories: 1) those taken by commanders with no kills, and 2) those taken by commanders with kills.

The filled rectangles in Exhibit 18 depict reference [8]'s best estimate of the number of kills by U-Boat commander in double cumulative form. Exhibit 18 also presents the best "eyeball" Polya distribution (from Exhibit 8) in double cumulative form. You can see that the estimated kill data at the upper end is not very accurate since the graph shows that the top 2% of commanders achieve only about 20% of the kills rather than the 30% quoted in reference [12]. Nonetheless, the general shape seems to conform well to the contours of the Polya distribution.

EXHIBIT 18

ESTIMATED DOUBLE CUMULATIVE PROFILE FOR SHIP KILLS BY U-BOATS FIT WITH A POLYA DISTRIBUTION



THE DISPOSITION OF ARAB TANK KILLS AS REPORTED BY ISRAELI TANK COMMANDERS AFTER THE 1973 ARAB-ISRAELI WAR

Reference [23] documents a summary of interviews with some, but not anywhere near all, Israeli tank commanders subsequent to the 1973 Arab-Israeli War. The data represent each interviewed (and obviously non-attrited) commander's estimate of the number of tanks he killed. The basic data are organized by rank: 1) tank commander, 2) platoon leader, 3) company first officer, and 4) company commander. There is also some aggregated data by geographical area.

The method of finding the best Polya Parameter needs to be modified slightly from that in Exhibit 6. This is because tank commanders reporting large number of kills are not credited in detail; rather they are lumped into a single category "number who killed **m** or more". This makes it impossible to calculate the total number of kills **k** as shown in Exhibit 6. Reference [10] modifies the method of Exhibit 6 so as to accommodate data of this form. The basic idea is to perform a "two-dimensional" fit on both **k** and β using a modification of equation (3). Analytically, the key is to sum equation (3) over all the possible ways that the best shooters could apportion, say, **r** kills among themselves so that the total number of kills **k** would be equal to **r** + the kills known to belong to the shooters with fewer than **m** kills. Exhibit 19 outlines the procedure.

Exhibit 20 displays five double cumulative forms: one each for the four ranks of tank commander (tank commander, platoon leader, company first officer, and company commander) and one for the composite performance of all commanders. In order to plot curves in this double cumulative form, you need to know the total number of kills. But the number of kills by the best performers within each rank is unknown to us. Thus, Exhibit

EXHIBIT 19

FITTING THE POLYA DISTRIBUTION WHEN THE EXACT NUMBER OF KILLS BY COMBATANTS KILLING MORE THAN m IS NOT SPECIFIED

- Put all known n_i values into the equation below with n, β, and an estimate of k:

$$\frac{\binom{-\beta}{1}^{n_1}\binom{-\beta}{2}^{n_2}\cdots\binom{-\beta}{m}^{n_m}\Psi(n,k,\beta)}{\binom{-n\beta}{k}}$$

where Ψ is quite ugly and is derived in reference [10] in a recursive form.

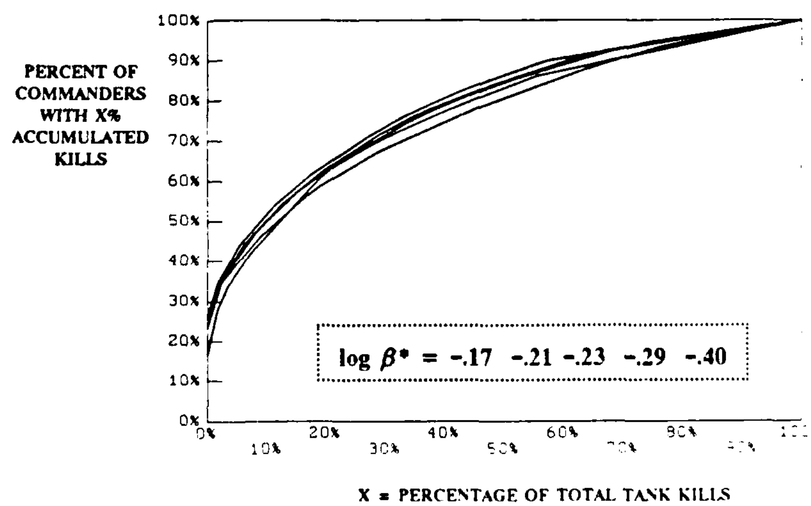
- For each β adjust k to get the maximum of the above expression.

- Adjust β until you get the maximum of these maxima.

- Label the β producing this maximum of the maxima by β^*.

EXHIBIT 20

DOUBLE CUMULATIVE PROFILE FOR TANK COMMANDERS IN FOUR RANKS



20's plots use the number of kills which falls out of the evaluation of the best Polya Parameter as delineated in Exhibit 19. The five are almost on top of each other; the best Polya Parameter tabular insert shows the distinctions.

Exhibit 21 performs the same service for another three sets of data. Two come from different geographical area, and the third is the composite. The composite here differs from the composite in Exhibit 20 because a different number of interviews contributed to the result.

CONCLUSIONS

This Section has presented measurements of 23 values of Log β^* (includes just the italicized figures in Exhibit 15, but all three values in Exhibit 16.) The median of these values is -.23, the mean is -.28, and the sample standard deviation is .20. Exhibit 22 graphically portrays the spread. It would seem that a Polya Parameter value of **Log β = -¼** adequately summarizes the results. Nonetheless, for the reasons discussed at the end of the second Section, we believe **Log β = 0** to be nearer "the truth" because Our Polya Urn Scheme best fits data with shooter inhomogeneities (such as different lengths of service) by selecting a more negative Polya Parameter. The Appendix continues our discussion of chance models which might produce Polya-like distributions when inhomogeneities exist.

EXHIBIT 21

DOUBLE CUMULATIVE PROFILE FOR TANK COMMANDERS IN TWO GEOGRAPHICAL AREAS

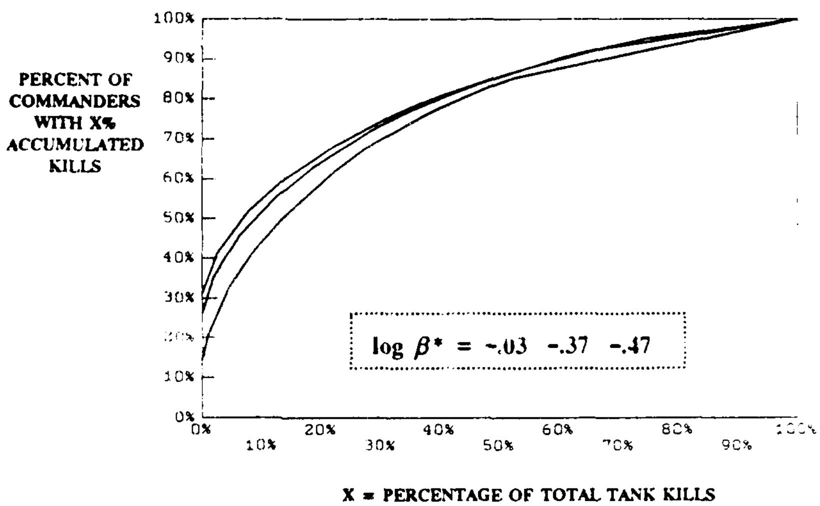
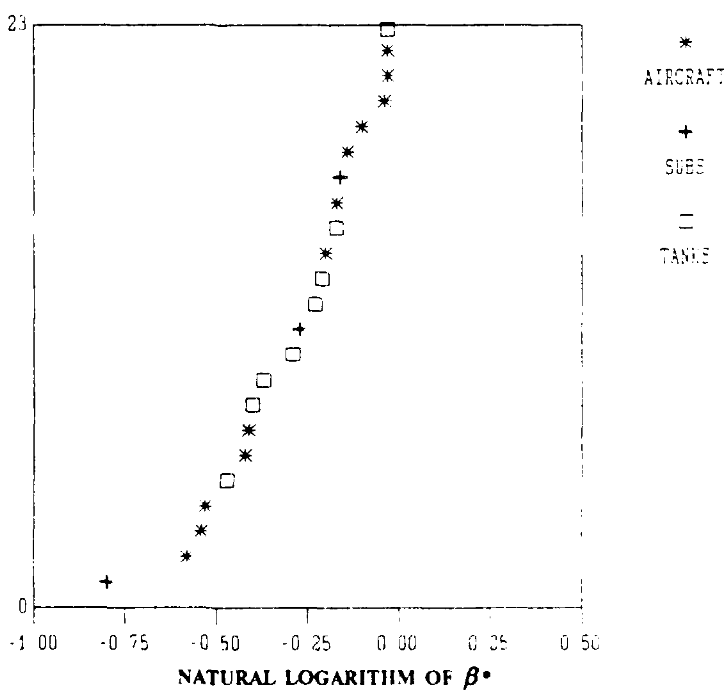


EXHIBIT 22

THE 23 MEASURED VALUES OF THE BEST POLYA PARAMETER = Log β^*



REFERENCES

[1] On War (Vom Kriege -- 1832), by Carl von Clausewitz, translated by Col.J.J.Graham, edited by Col.F.N.Maude, Pelican Classics, 1968

[2] Methods of Operations Research, by P.M.Morse & G.E.Kimball, National Defense Research Committee, Washington, 1946. Also by John Wiley, New York, 1951.

[3] Lady Luck: The Theory of Probability, by Warren Weaver, Anchor Book, New York, 1963. Also by Dover Publications Inc., New york, 1982.

[4] Silent Victory, The U.S. Submarine War Against Japan, (Second Edition) by C.Blair,Jr., J.B.Lippincott Co., New York, 1975

[5] The Naval Air War in Vietnam, by P.B.Mersky & N.Polmar, The Nautical and Aviation Publishing Company of America, Baltimore, Maryland, 1986

[6] "Comparing Red Baron Data to the Polya Threat Model", by J.J.Bolmarcich, QTN 10:78, QUANTICS inc., Wayne PA, 7 April 1978, SECRET

[7] "Analysis of World War II U.S. Submarine Warfare Data", by J.J.Bolmarcich and J.Simpson. QTN 22:79, QUANTICS inc., Wayne PA, 30 July 1979, UNCLASSIFIED.

[8] "On the Distribution of Allied Shipping Kills by German U-Boat Commanders", by J.J.Bolmarcich, QTN 7:80, QUANTICS inc., Wayne PA, 14 April 1980, CONFIDENTIAL.

[9] "Analysis of Naval Air-to-Air Combat Kills in Southeast Asia", by J.J.Bolmarcich, G.B.Orr, & E.F.Arnold; QM 11:88, QUANTICS inc. Wayne PA, 4 March 1988. UNCLASSIFIED

[10] "Estimating Target Overlap for Anti-Tank Warfare Sustainability (U)", by J.J.Bolmarcich, QR 12:88, QUANTICS inc., Wayne PA, September 1988, SECRET NOFORN

[11] "On the Multivariate Polya Distribution: A Model of Contagion for Data with Multiple counts", K.G.Janardin & G.P.Patil, Random Counts in Scientific Work II, Random Counts in Physical Science, Geo-science, and Business (Ed.G.P.Patil), The Pennsylvania State University Press, pp143-162, 1970.

[12] U-Boats Under the Swastika (2nd Ed.), by J.P.Mallmann Showell, Naval Institute Press, Annapolis MD, 1987.

[13] "Sur quelques points de la theorie des probabilities", G.Polya, Annales de l'Institut Henri Poincare, 1, pp117-161, 1931.

[14] "Uber die Statistik verketteter Vorgange", F.Eggenberger & G.Polya, Zeitschrift fur angeuandte Mathematik und Mechanik, 1, pp279-289, 1923.

[15] Urn Models and Their Application, N.L.Johnson and S.Kotz, John Wiley & Sons, New York NY, 1977

[16] Simulation and the Monte Carlo Method, by R.Y. Rubinstein, John Wiley & Sons, New York NY, 1981

[17] Navy (and Marine Air) Non-nuclear Ordnance Requirements -- POM-85 Update, OPNAV-NOTE S8000, Volume 4 -- Threat-Oriented Methodology, Office of the Chief of Naval Operations, USA, 1985. UNCLASSIFIED

[18] Project Red Baron II -- Air-to-Air Encounters in Southeast Asia (U), Volume II: Analysis, Part 2: Ordnance Firings; USAF Tactical Fighter Weapons Center, Nellis AFB, January 1973. SECRET

[19] The United States Air Force in Southeast Asia -- aces and aerial victories, 1965 to 1973, by R.F.Futrell et al., Office of Air Force History, Bolling Air Force Base, Washington DC, 1976

[20] U.S. Submarine Attacks During World War II, by John D. Alden, Naval Institute Press, Annapolis MD, 1989

[21] Axis Submarine Successes 1939-1945, by Jürgen Rohwer, Naval Institute Press, Annapolis MD, 1983

[22] "The U-Boat Logs 1939-1945", by W.E.Dawson, Directorate of Operational Research, Ministry of Defense, United Kingdom, Undated, RESTRICTED

[23] "Data from the October 1973 Middle East War", Volume III - Israeli Defense Force - Ground Force, Weapon System Evaluation Group Report #237, Office of the Joint Chiefs of Staff, USA, July 1975. SECRET NOFORN

APPENDIX: A SHORT TOUR THROUGH SKEW DISTRIBUTIONS

(Citations in this Appendix refer to the bibliography and are denoted, for example, as bib (a).)

Our culture today tends to value people in proportion to their "productiveness". You can think of this virtue as embracing three ingredients: 1) a mixture of abilities appropriate to the productive task, 2) the opportunity to apply them, and 3) the willingness to apply them -- in other words, ability, fortune, and desire. But nature seems to have disbursed these three ingredients among the population in such a manner that just a few people possess a winning combination.

Our culture today commonly takes wealth or income as the measure of valued production. Thus, we are not surprised to observe that a minority of people possess a good majority of the wealth. A quantitative description of this phenomenon was first provided by Vilfredo Pareto in 1897 using world-wide economic data spanning 1471 to 1894 (bib (a)). He found that all societies for which he had data revealed a few extremely wealthy people and many poor.

Exhibit A displays a more recent example of the kind of data Pareto found (data taken from bib (b)). This highly "skewed" pattern seems to be remarkably stable across centuries, countries and continents. In fact, M.G.Kendall, in his Presidential Address to the Royal Statistical Society in 1960 said:

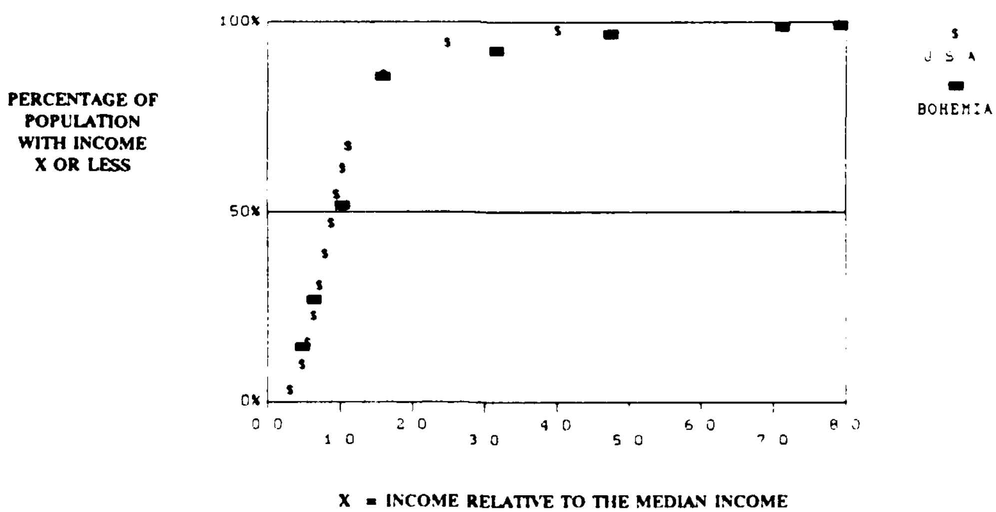
> **"Pareto showed that such a distribution held for practically every country which was developed enough to provide the statistics required to check it ... The law still holds today, at least as a good approximation, and considering what has been done in the way of redistributing income since Pareto enunciated the law in 1895, the pattern has proved remarkably stable."** (bib (c) pp3-4)

In fact, this "Pareto distribution" has been used to uncover cases of income tax evasion when reported income failed to conform to the pattern (see bib (d) p74.) Pareto considered this shape to be an empirical law representing a simple **"fact of human nature"**:

> **"Yet no one has yet produced a satisfactory explanation as to why income distribution over a long period of time shows a striking *stability*."** *(bib (d) p77)*

EXHIBIT A

CUMULATIVE DISTRIBUTION OF INCOME RELATIVE TO MEDIAN INCOME IN USA (1918) AND BOHEMIA (1933)



The most comprehensive attempt at such an explanation was undertaken by G.K.Zipf (bib (e)). In trying to deduce all behavior from the single principle of the minimization of effort, he obtained a general rule of "**the-higher-the-fewer**", of which the Pareto law is a particular case:

"It says in effect for certain kinds of [human] activity with a measurable size X, the number Y of individuals greater than or equal to X is given by

$$Y = a \cdot X^{-C}$$

where C is a constant quite often close to 1. (bib (c) p4)

During warfare it is much the same: we tend to value people in proportion to their productiveness -- <u>of casualties among the enemy</u>. Again nature seems to have distributed the necessary mix of ability, fortune, and desire in such a way that a minority of the combatants produce a good majority of enemy casualties. Exhibits 1 and 2 in the text display such information from relatively recent warfare data. These warfare performance statistics, when viewed in cumulative form as in Exhibit 5, are skewed similarly to the economic data in Exhibit A.

Research in the past half century or so has revealed that several varieties of things people do have statistical attributes similar to those of the above Exhibits. These statistics can be described quite well by probability distributions with "long tails". Such probability distributions are known as "skew" distributions. The areas studied (many discussed in bibs (c) and (e)) include: Industrial Capacity (h),(i),(j); Frequency of Words in Text -- (e),(k),(l),(m),(n),(o),(p); Authors of Scientific Publications -- (c),(e),(o), (q),(r),(s); Sizes of Cities -- (e),(o),(t),(u),(v),(w); Biological Species -- (o),(x),(y),(z),(aa),(ab); Epidemics -- (ac),(ad),(ae),(af),(ag),(ah); Industrial Accidents -- (ai),(aj),(ak),(al),(am),(an),(ao), (ap); and some miscellaneous applications -- (c),(f),(g),(aq),(ar), (as),(at), and (au).

In the particular case of warfare kills, which is the topic of this paper, there has been <u>a family of skew distributions</u> in use (see bib (f)) to fit data such as in Exhibits 1 and 2 in the text. The underlying "probability model" is a generalization (essentially proposed in bib (ad)) of the one created in 1923 (bib (ac)) to analyze the distribution of deaths by month due to a contagious disease (smallpox). It is the <u>standard</u> probability model of "contagion". We call it the Polya Urn Scheme, and we have developed a multivariate implementation of it in the text.

Skew distributions arising from studies of accidents and contagious diseases (such as the seminal studies of bibs (ac) and (ai)) tend to be more applicable to the study of human performance in warfare than other skew distributions. The reason is that studies of accidents, for example, use a <u>fixed number</u> of subjects each of which acquires accidents, over a defined period of time. Similarly, in warfare we use a <u>fixed number</u> of combatants each of which acquires target kills over a limited period of time. Studies on the distribution of income tend to need as their basis increasing numbers of participants and an infinite time horizon. Bib (w) describes a connection between the two.

The original Polya Urn Scheme was generalized first in bib (ax), and further studied in bibs (ay), (az), (ba), and (bb). There are other generalizations concerning the Polya Urn Scheme, many of which are discussed in bib (bd). There is nothing compelling in any of them concerning the variability in human performance in warfare. In particular, there seems no hope for any closed analytic solution following the general line of approach with differential-difference equations as pursued in bib (as). A more fruitful line of investigation might be found by returning to the roots of the study of "contagious" distributions.

Bib (ai), published under the Journal topic area Miscellanea, seems to be the first to give a thorough mathematical treatment to statistical variations in disease or accidents cases. This very fundamental paper of Greenwood and Yule was apparently unknown to Eggenberger and Polya when they undertook their study in bib (ac) which produced the Polya Urn Scheme. Bib (ai) makes a clear statement of the problem they were to consider (they later relate it to wounds distributed among soldiers):

"Of n households exposed to risk, m_0 returned 0 cases of disease, m_1 returned each a single case, m_2 each two cases . . . m_n each n cases. Might such a distribution have arisen from sampling a 'population', each member of which was subject to a constant chance of infection throughout the period of exposure, or is the form of the distribution valid evidence that particular households were especially prone to take the disease in question?

"A precisely similar problem is to be solved when we desire to ascertain whether the frequency of multiple accidents sustained by individual operatives in a factory is the product of uniform or of variable cause groups."

Greenwood and Yule talk in terms of balls and pigeonholes. They discuss the notion that pigeonholes expand when they get balls and thus squeeze out the pigeonholes with no balls. Their analytical method is a simple extension of Bernoulli trials where only pigeonholes with no balls are downgraded in their ability to receive the next ball. They get a generalized Poisson distribution since the number of pigeonholes is large. (This "pigeonhole scheme" is not nearly as robust as the Polya Urn Scheme.)

In the end, they reject this approach as unsatisfactory. It did not correspond too well to the data they had:

"As we have seen, the method just examined involves the assumption that the happening of the event not only improves the prospects of the successful candidates but militates against the chances of those who had hitherto failed; this assumption cannot be entertained and we proceed to develop a frequency system not involving it."

Greenwood and Yule go on to consider a scheme in which each of a large number of pigeonholes has its own probability of receiving a ball:

"We now suppose that the population at risk consists of persons (or other variates), the liabilities or susceptibilities of whom to accident vary, the frequencies being assigned by the ordinate of $f(\lambda)$ where λ is a variable parameter."

They posit the form of f should be skew and that:

"The choice of skew curves is arbitrary."

They choose f to be what we now call the Gamma distribution, primarily because when it is integrated over (compounded with) the Poisson distribution it yields a tractable form. The tractable form turns out to be a negative binomial distribution. It fits the data quite well. Thus, on the basis of <u>no contagion</u>, Greenwood and Yule generate a negative binomial distribution which turns out to be exactly the conclusion of Eggenberger and Polya when they modeled <u>contagion</u> in a more general manner and looked at the limiting distribution for large numbers of balls and "pigeonholes".

The first widely available paper discussing the Greenwood/Yule and Eggenberger/Polya results together was bib (bf), which was inspired by the work of bib (bg) on a new class of contagious distributions. (Bib (al) actually preceded bib (bf) in this regard, but it was not widely available.) In bib (bf), Feller gives an excellent overview of the dichotomy. He distinguishes "true" contagion in the first sense of Greenwood/Yule and Eggenberger/Polya from "apparent" contagion as studied by Greenwood/Yule in their second sense.

He says:

"...and an apparent contagion is actually due to an inhomogeneity of the population."

"It is therefore most remarkable that Greenwood and Yule found their distribution assuming an apparent contagion; in their opinion this distribution contradicts true contagion. On the contrary, Polya and Eggenberger arrived at the same distribution assuming true contagion, while the possibility of an apparent contagion due to inhomogeneity seems not to have been noticed by them."

Bib (bf) then goes on to develop a general theory of compound distributions, as well as what he called generalized distributions. Bib (bf) concludes with a discussion of the nature of contagion. The major statement is:

"...an excellent fit of Polya's distribution *[meaning here the negative binomial type of distribution actually derived in bib (ac)]* **to observations is not necessarily indicative of any phenomenon of contagion in the mechanism behind the observed distribution. In order to decide whether or not there is contagion, ... a detailed study of the correlation between various time intervals is necessary."**

Correlation tests have been performed in accident studies as in bib (al), and the theory of such correlation developed in bibs (an), (ao) and (ap). However, it is not easy to apply the necessary tests. According to bib (ap):

"Finally, it should be noted that the tests of this section apply to accident data in which each individual has the same length of time of exposure to accidents..."

We know from warfare data that this requirement ("equal time warring") will not be met. There has also been work on the possibility of the identification of mixtures. Bib (bh) gives a good review up till its date of publication.

Thus, it may not be possible for us to measure whether warfare proceeds from a basic inhomogeneity in the participants or whether true contagion is present, as would be manifested when participants gain increased skill or increased opportunity or increased desire over time. In order to do so we would need a large data base with kills identified by both participant and time, and an extended theory to account for new participants. Currently, we can only rely on the observations of past analyses:

"The RAF Fighter Command Operations Research Group has studied the chance of a pilot being shot down as a function of the number of combats the pilot has been in. This chance decreases by about a factor of 3 from the first to the sixth combat. A study made by the Operations Research Group, U. S. Army Air Forces, indicates that the chance of shooting down the enemy when once in a combat increases by 50 per cent or more with increasing experience." (bib (bi) p46)

We prefer to believe in this point of view, and so we prefer to proceed from some contagious chance mechanism. In addition, with the computing power now available, it is not inconvenient to stay with exact form of the Polya distribution rather than the limiting form -- the negative binomial distribution -- which results when the number of target kills and shooter participants is large.

Even in the exact form, the Multivariate Homogeneous Polya Distribution in equation (2) in text is derivable as a mixture. In the univariate case, bib (bh) indicates that bib (bi) was the first to show that the "negative hypergeometric" distribution could be considered as binomial mixed with a beta distribution. Similarly, equation (2) in its inhomogeneous multivariate form was shown by bib (az) to be a mixture of a multinomial (the multivariate generalization of the binomial) with a Dirichlet distribution (the multivariate generalization of the beta.)

Another point of view is that the observed warfare data, although fit well by the Polya distribution, could also be fit well by distributions of the Pareto type. The Polya distributions in warfare come naturally from the Polya Urn Scheme's application to accidents. Is there a similar model within the economic realm which: 1) could be interpreted from a warfare perspective, and 2) might lead to some Pareto type of results?

The first model of this sort which used a chance mechanism seems to be that studied in bib (bj). It followed prior results in bib (bk) the year before. According to bib (b):

"The Pareto curve fits income distribution at the extremities of the income range but provides a poor fit over the whole income range. The log-normal (or Gibrat) distribution fits reasonably will over a large part of the income range but diverges markedly at the extremities. A function suggested by [bib (bj)] appears to fit better than these and others.."

The log-normal distribution is called the Gibrat distribution by economists because of Gibrat's work in bib (bl). He found that the distribution of size for various economic units followed that distribution. He derived the distribution in bib (bm) on the basis of:

"...the law of proportionate effect, which says that in a process of growth, equal proportionate increments have the same chance of occurring in a given time-interval whatever size happens to have been reached." (bib (j), p30)

The method of analysis pursued in bib (bj) was important since it dominated models of income distribution which would follow. It says:

"In the models discussed in this paper the distribution of incomes between an enumerable infinity of income ranges is assumed to develop by means of a stochastic process ... and provided certain other conditions are satisfied, the distribution will tend towards a unique equilibrium distribution dependent upon the stochastic matrix <u>but not on the initial conditions</u>." (p318 -- underlines ours for emphasis.)

Unfortunately, warfare problems, even for large numbers of combatants, are still dominated by the initial conditions (initially deployed combatants). An equilibrium situation, even if it exists, has not had sufficient time to materialize in the existing sets of combat data. In addition, many believe any future wars will be short and intense. But models of income distribution, such as bibs (o), (w), and (bn), look toward the equilibrium situation. Thus, they do not appear directly applicable to warfare.

Bib (bj) sets up income levels, and considers transition matrices between levels. It shows that for a certain matrix the Pareto Law is the equilibrium solution. The important "boundary condition" on the matrix is that the expected income level change is negative. This keeps income levels from going to infinity while they still cannot fall below zero. On this situation, bib (j) comments:

"In fact, the proper economic justification for the stability assumption is that the growing dispersion of incomes of a given set of people is counteracted by the limited span of their lives and the predominantly low and relatively uniform income of new entrants." (p36)

Bib (o) provides precisely a model based on a birth-death process in continuous time. It starts with:

"It is well known that the negative binomial and the log series distribution can be obtained as the stationary solutions of certain stochastic processes. For example, J. H. Darwin [bib (ab)] derives these from birth and death processes with appropriate assumptions as to the birth- and death-rates and the initial conditions." p426

Simon then proceeds to generalize the considerations in bib (ab) in two directions, using word frequency in text as a metaphoric vehicle.

Simon's first stochastic model is not a steady state model, but is reminiscent of a model of bib (x) which he discusses. He defines his "states" by setting f(i,k) to count the number of different words occurring exactly i times in a text of length k. He defines his "law of proportionate effect" by allowing the next text entry: 1) to be a new word with probability p, and 2) to be a word already appearing i times with probability in proportion to $i \cdot f(i,k)$.

The warfare interpretation would consider the sequence of text as a sequence of targets, each target being tagged with the name of the shooter killing it. You generate shooters getting their first kill as the target sequence evolves at an average rate of one per 1/p targets. With constant p, Simon can show that $f(i,k+1)/(k+1) = f(i,k)/k$, so the frequencies are independent of k. We have not checked this against warfare data.

Simon's second model is a steady-state model. In the text metaphor it looks at a segment of length k sliding along the entire text. In economic terms it translates to a stream of dollars with peoples names attaching to a total of k dollars. Thus, "income producers" come into the income stream and old ones drop out, their first drop extinguishing them from the segment with their accumulated loot redistributed to the remaining names in some proportion. This model has a birth-death structure which could apply to warfare if kills were not redistributed. The usefulness of the above model to warfare is twofold: first it inspired bib (w), and second its conjecture that the right answer might be that the steady-state average fraction Y of participants with X or more things is of the form:

$$\mathbf{Y = a \cdot b^{-X} \cdot X^{-C}}.$$

Bib (w), more incisively than in bib (v), shows a relationship between the Pareto distribution and the Geometric distribution which is the limiting form of the Polya distribution for $\beta = 1$ and a large number of balls and urns. The Pareto distribution results when <u>both urns and balls</u> are distributed as follows: Empty urns are born with probability $\alpha \neq 0$ and balls are born with probability $1-\alpha$. When an urn is born it joins the existing urns. When a ball is born it is tossed according to Equation (1) in Exhibit 4, with $\beta = 1$, to the then existing urns. The steady-state limit as the process continues is a Pareto distribution: $\mathbf{a \cdot X^{-C}}$ **with** $\mathbf{C=(1-\alpha)^{-1}}$.

The Geometric distribution results when both balls and urns are tossed in accordance with Equation (1). When an urn is born with probability α and tossed into an existing urn, the new urn shares the current contents of the old urn uniformly at random. (This is like the second model of bib (o).) As before, when a ball is born with probability $1-\alpha$, it is tossed according to Equation (1) with $\beta = 1$ at the then existing urns. The limit as the process continues is a Geometric distribution $\mathbf{a \cdot b^{-X}}$ **with** $\mathbf{b=(1-\alpha)^{-1}}$.

Derivation of the Geometric distribution in this way makes no direct sense in warfare. But tossing balls and urns in the first sense, which leads to the Pareto distribution, does. In fact, it is reminiscent of the way in which attrition balls are tossed at urns in bib (f) which maintains the Geometric distribution we know to be accurate when the number of balls and urns is large. The Geometric distribution comes from the Polya Urn Scheme because the number of urns is fixed, and anytime you look for the distribution of balls in urns you can get an asymptotic <u>not steady-state</u> limiting geometric form: $\mathbf{a \cdot b^{-X}}$ **with** $\mathbf{b=(1-q)^{-1}}$ **and** $\mathbf{q}$ **= number of initial urns,** $\mathbf{n_I}$**, divided by the current number of balls tossed,** $\mathbf{r}$ **plus urns** $\mathbf{(r+n_I)}$. This q is related to α which is on average the number of urns born, $\mathbf{n_B}$, divided by the number of both urns and balls born, $\mathbf{n_B+r}$.

We conjecture, that if you toss <u>balls and urns</u> according to Equation (1), and in the sense that leads to the Pareto distribution, and keep track of the initial conditions you will get a hybrid result which looks like Simon's:

$$\mathbf{Y = a \cdot b^{-X} \cdot X^{-C}},$$

with b defined as above, but with C modified from $\mathbf{(1-\alpha)^{-1} = 1 + n_B/r}$ to perhaps something like $\mathbf{(n_B/(n_B+n_I) + n_B/r}$, to compensate for initial conditions. In this way the known limiting cases work out. Data which the Polya distribution now fits with $\beta < 1$ may be better fit by such a hybrid which directly models the process of combatants entering the war.

BIBLIOGRAPHY

(a) Cours d'Economie Politique, V.Pareto, (livre III La repar... et la consommation) Luasanne et Paris: Rouge et Cie. (1897)

(b) "The Graduation of Income Distribution", P.R.Fisk, Econometrica, 29, pp171-185, 1961.

(c) "Natural Law in the Social Sciences", M.G.Kendall, Journal of the Royal Statistical Society, 124A, pp1-19, 1961.

(d) The Economics of Vilfredo Pareto, R.Cirillo, Frank Cass and Co. Ltd., London, 1979.

(e) Human Behavior and the Principle of Least Effort, G.K.Zipf, Addison-Wesley Publishing Co., Inc, Reading MA, 1949.

(f) "Navy (and Marine Air) Non-nuclear Ordnance Requirements -- POM-85 Update, OPNAVNOTE S8000, Threat-Oriented Methodology -- Volume 4, Office of the Chief of Naval Operations, USA, 1985.

(g) "Analysis of Naval Air-to-Air Combat Kills in Southeast Asia", by J.J.Bolmarcich, G.B.Orr, & E.F.Arnold; QM 11:88, QUANTICS inc. Wayne PA, March 1988.

(h) "The Analysis of Business Concentration", P.E.Hart & J.J.Prais, Journal of the Royal Statistical Society, A119, pp 150-180, 1956.

(i) "The Size Distribution of Business Firms", H.A.Simon & C.P.Bonini, Reprint 20 of the *Graduate School of Business* Administration, Carnegie Institute of Technology, 1958.

(j) "Random Processes and the Growth of Firms", J.Steindl, Hafner Publishing Company, New York, 1965.

(k) Les Gammes Stenographiques Institut Stenographique, Paris, 1916.

(l) "On the Number of Words of any Given Frequency of Use", E.L.Thorndike, Psychol. Rec., 1, p399, 1937.

(m) Word Index to James Joyce's Ulysses, M.L.Hanley, University of Wisconsin Press, 1937.

(n) The Statistical Study of Literary Vocabulary, G.U.Yule, Cambridge University Press, 1944.

(o) "On a Class of Skew Distribution Functions", H.A.Simon, Biometrika, 42, pp425-440, 1955. Also the follow up "Some Further Notes on a Class of Skew Distribution Functions", H.A. Simon, Information and Control, 3, pp80-88, 1960.

(p) "On the Distribution of Word Frequencies", I.J.Good, Nature, 179, p595, 1957.

(q) "The Frequency Distribution of Scientific Productivity", A.J.Lotka, Journal of the Washington Academy of Science, 12, pp317-323, 1926.

(r) Documentation, S.C.Bradford, Crosby Lockwood, London, 1948.

(s) "The Bibliography of Operational Research", D.G.Kendall Operational Research Quarterly, 11, pp31-36, 1960.

(t) "On Some Modes of Population Growth Leading to R.A. Fisher's Logarithmic Series Distribution", D.G.Kendall, Biometrika, 35, pp6-15, 1948.

(u) "On the Implications of a Stationary Urban Population for the Size of Distributions of Cities", E.G.P.Haran and D.R.Vining Jr., Geogr. Anal, 5, pp296-308, 1973.

(v) "The Rank-Frequency Form of Zipf's Law", B.M.Hill, Journal of the American Statistical Association, 69, pp1017-1026, 1974.

(w) "Some Distributions Associated with Bose-Einstein Statistics", Y.Ijiri & H.A.Simon, Proceedings of the National Academy of Science USA, 72, pp1654-1657, 1975.

(x) "A Mathematical Theory of Evolution, Based on the Conclusions of Dr. J.C.Willis F.R.S", G.U.Yule, Philosophical Transactions of the Royal Society of London, B213, pp21-87, 1924.

(y) "The Commonness and Rarity of Species", F.W.Preston, Ecology, 29, pp254-283, 1948.

(z) "Experimental Evidence Concerning Contagious Distributions", D.A.Evans, Biometrika, 40, pp186-211, 1953.

(aa) "The Population Frequencies of Species and the Estimation of Population Parameter", I.J.Good, Biometrika, 40, p237, 1953.

(ab) "Population Difference Between Species Growing According to Simple Birth and Death Processes", J.H.Darwin, Biometrika, 40, p370, 1953.

(ac) "Uber die Statistik verketteter Vorgange", F.Eggenberger & G.Polya, Zeitschrift fur angeuandte Mathematik und Mechanik, 1, pp279-289, 1923.

(ad) "Sur quelques points de la theorie des probabilities", G.Polya, Annales de l'Institut Henri Poincare, 1, pp117-161, 1931.

(ae) "A Distribution Arising in the Study of Infectious Diseases", J.O.Irwin, Biometrika, 41, pp266-268, 1954.

(af) "On the Spread of Epidemic Carriers", G.H.Weiss, Biometrics, 21, pp481-490, 1965.

(ag) "On the Model of Weiss for the Spread of Epidemics by Carrier", K.Dietz, Journal of Applied Probability, 3, pp375-382, 1966. And a response: "Epidemics with Carriers: A Note on a Paper by Dietz", F.Downton, Journal of Applied Probability, 4, pp264-270, 1967

(ah) "A Note on Super Critical Carrier-Borne Epidemics", A.Abakuks, Biometrics, 61, pp 271-275, 1967.

(ai) "An Inquiry into the Nature of Frequency Distributions Representative of Multiple Happenings with Particular Biblio to the Occurence of Multiple Attacks of Disease or Repeated Accidents, M.Greenwood & G.U.Yule, Journal of the Royal Statistical Society, 83, pp255-279, 1920.

(aj) "Practical Applications of the Statistics of Repeated Events, Particularly to Industrial Accidents", E.M.Newbold, Journal of the Royal Statistical Society, 90, pp487-547, 1927.

(ak) "Die Statistik der selten-en Ereignisse", R.Luders, Biometrika, 26, pp108-128, 1934.

(al) <u>On Random Processes and Their Application to Sickness and Accident Statistics</u>, Thesis of O.Lundberg, University of Stockholm, 1940.

(am) "Theory and Observation in the Investigation of Accident Causation", E.G.Chambers & G.U.Yule, Journal of the Royal Statistical Society Supplement, 7, pp99-109, 1941 -- includes discussion with J.O.Irwin, and biblios early work by E.M. Newbold and H.M.Woods.

(an) "Accident Statistics and the Concept of Accident Proneness", A.G.Arbous & J.E.Kerrich, Biometrics, 7, pp340-432, 1951.

(ao) "Contributions to the Theory of Accident Proneness, I & II", G.E.Bates & J.Neyman, University of California Publications in Statistics, 1, pp 215-254 (I) and pp255-276 (II), 1952.

(ap) "Joint Distributions of Time Intervals for the Occurrence of Successive Accidents in a Generalized Polya Scheme", G.E.Bates, Annals of Mathematical Statistics, 26, pp705-720, 1955

(aq) "Cricket Scores and Some Skew Distributions (an Arithmetical Study)", W.P.Elderton, Journal of the Royal Statistical Society, 108, pp1-11, 1945

(ar) "A Probability Distribution of Deaths at Age X When Policies are Counted Instead of Lives", H.L.Seal, Skadivisk Aktuarietidskrift, 30, pp18-43, 1947.

(as) "A Simple Urn Model", B.Friedman, Communications on Pure and Applied Mathematics, 2, pp59-70, 1949.

(at) "The Size of Trade Unions: A Study of the Laws of Aggregation", P.E.Hart & E.H.Phelps-Brown, Economics Journal, 67, pp1-15, 1957.

(au) "The Pattern of Consumer Purchases", A.S.C.Ehrenberg, Applied Statistics, 8, pp26-41, 1959.

(av) "The Netherlands Version of the NATO Maritime Stock Pile Guidance Model", M.van Dongen & J.Bennema, Fysischen Elektronisch Laboratorium TNO, *IR 1986-33, 1986.*

(aw) An Introduction to the Theory of Probability and its Applications -- Volume II, W. Feller, John Wiley & Sons, Inc., New York, (Second Edition) 1971.

(ax) "On Discrete Multivariate Probability Functions", H.S.Steyn, Proceeding Koninklijke Nederlandse Akademie van Wetenschappen, A54, pp23-30, 1951

(ay) "On Discrete Multivariate Probability Functions of Hypergeometric Type", H.S.Steyn, Proceeding Koninklijke Nederlandse Akademie van Wetenschappen, A58, pp588-595, 1955.

(az) "On the Compound Multivariate Distribution, the Multivariate Beta Distribution, and Correlation", J.E.Mosimann, Biometrika, 49, pp65-82, 1962.

(ba) "On the Multivariate Polya Distribution: A Model of Contagion for Data with Multiple Counts", K.G.Janardin & G.P.Patil, Random Counts in Scientific Work II, Random Counts in Physical Science, Geo-science, and Business (Ed. G.P.Patil), The Pennsylvania State University Press, pp143-162, 1970.

(bb) "A Unified Approach for a Class of Multivariate Hypergeometric Models", K.G.Janardin & G.P.Patil, SANKHYA -- The Indian Journal of Mathematics, A34, pp363-376, 1972.

(bc) Discrete Distributions, N.L.Johnson & S.Kotz, Houghton Mifflin Co., Boston, 1969.

(bd) Urn Models and Their Application, N.L.Johnson & S.Kotz, John Wiley & Sons, Inc., New York, 1977.

(be) "Comparing RED BARON data to the Polya Threat Model", J.J.Bolmarcich, QTN 10:78, QUANTICS inc., Wayne PA, 1978.

(bf) "On a General Class of 'Contagious' Distributions", W.Feller, Annals of Mathematical Statistics, 14, pp389-400, 1943.

(bg) "On a New Class of 'Contagious' Distributions Applicable in Entomology and Bacteriology", J.Neyman, Annals of Mathematical Statistics, 10, pp35-57, 1939.

(bh) "Mixtures of Discrete Distributions', W.R.Blischke, Proceedings of the International Symposium on Discrete Distributions, Montreal, pp351-372, 1963.

(bi) Methods of Operations Research, P.Morse & G.Kimball, The M.I.T. Press, 1951.

(bj) "A Model of Income Distribution", D.G.Champernowne, Economic Journal, 63, 1953.

(bk) "The Graduation of Income Distribution", D.G.Champernowne Econometrica, 20, pp591-615, 1952.

(bl) Les Inegalites Economiques, R.Gibrat, Libraire du Recueil Sirey, Paris, 1931.

(bm) "Une Loi des Repartitions Economique: l'Effet Proportionnel", R.Gibrat, Bulletin de Statistique General - France, 19, p469, 1930.

(bn) "Income Distributions: a New Model", R.S.G.Rutherford, Econometrica, 23, 1955

DISCUSSION OF "ON THE DISTRIBUTION OF COMBAT HEROES"
by J. Bolmarcich

DISCUSSANT: Capt. Wayne P. Hughes, Jr., US Navy (Retired),
Naval Postgraduate School

By and large the study of leadership has been the study of what W. E Daws.n called Aces and Goats in his well researched "The U-boat Logs, 1939-1945." That is because to the descriptive historian what is interesting is what is sensational, and because to the interpretive historian what matters is the discernment of good and bad qualities of leadership in order to promote the good and suppress the bad. Largely absent from the historical record is the distribution of performance. Nothing you heard from Bolmarcich indicates that leadership is bimodel: that there are only aces and goats and nothing in between. There is such a thing as an average soldier. Before we try to improve his performance by training, motivation, or exhortation, it would be well to know what to expect as the usual characteristics. The place to start is understanding the distribution of talent before one tries to shift the mean value of it in the right direction.

There are two reasons for this. For one, a fighting man ought to know how much staunchness and such qualities to expect from average men, even if he himself is extraordinary. For another, he ought to know what the value of extraordinary performance will be worth if it is achieved. Even while one exhorts his men to "fight outnumbered and win" he must weigh in the balance the possibility that most will fight as average soldiers fight, or that if he succeeds in fostering superiority the enemy may have done the same. We can put the case simply. Given a high level of motivation and competence on our side and average performance on the enemy side, what is that worth? Should our expectations be as for Leonidas and his Spartans at Thermopylae, or should that be a last hope and not a basis for planning? It is rather important to know whether the maximum value of quality is an effectiveness multiplier of 1.5 or 15. Dupuy's work which you have seen as to ground combat suggests that on the ground, variations in Division-Corps level quality create a swing of at most two against moderately well-trained and led troops, and that the difference rarely exceeds five between the best and the worst. Jim Dunnigan, who took equipment into account, saw (in his <u>How to Make War</u>) a difference in combat value per man of as great as 29:1 between the best and the worst. He indexed U. S. forces in Europe at 87 and the forces of Iran and Tunesia at 3.

From a smattering of evidence, I once proposed (but without the courage nor facts to reduce to writing) a "theory of the expert" which has two tenets. Firstly, that when the individual ace can be isolated and be given a high level of personal control over his fighting machine, then extraordinary achievements will appear, under a measure of performance such as exchange ratio during a combat lifetime. I had in mind data from air-to-air combat and from submarine operations. Secondly, that a handful of outstanding performers achieve most of the results in combat, and to put it cynically, the rest of the men on the battlefield contribute mostly by serving as targets to dilute the efforts of the enemy.

Bolmarcich's work is the first I have seen which is scientific enough to start formulating some hypotheses such as a "theory of the expert". It seems to me his tightly drawn, dispassionate, and careful application of the Polya distribution is a giant stride toward transforming hearsay into useful statistical distributions of the empirical data.

DISCUSSION OF PAPERS PRESENTED IN SESSION IV
"COMBAT AS A DATA SOURCE"

DISCUSSANT: Robert McQuie, US Army Concepts Analysis Agency

These four papers present, at least to me, a strong and disturbing message. Since all four are carefully prepared by individuals with proven track records, let's skip the nit picking and get to the bottom line: what do they tell us about using combat data in wargames?

To answer this question, let us pose five questions about these papers and then try to summarize the results. Each question is about the findings in the paper and only the findings in the paper; those wanting a broader picture are directed to consider as well the other panels in this conference.

Usable in Wargames. The first question is, "Are the findings in the paper usable in wargames?" The Dupuy paper has presented more than two dozen findings over 25 years that bear directly on the performance of wargames and simulations. They range from evidence about rates of advance to observations about the influence of training on the outcome of battle. The Rowland paper presents the percentage of decrease of weapon lethality when moved from the proving ground to the battlefield. These findings have *been published* in the leading journals of the military and O.R. community in Great Britain and have earned for Mr. Rowland the most prestigious award the British O.R. community has to offer. Mr. Frame's work demonstrates how very chancy and expensive archival research can be, but in its present form it is a collection of data that does not appear, from his remarks, to be usable. Finally, Dr. Bolmarcich's paper bears on every game and simulation in the stable and seriously questions the forms of statistical distributions and unit effectiveness computations used by all of them.

Impact. The second question is addressed to but one specific aspect of our problems, "If the findings were used, how would they influence casualty rates?" Three of the papers describe findings from combat that would cause casualty rates in games and simulations to drop, and probably drop drastically. DuPuy's evidence describes the loss of effectiveness of units because of factors beyond the ken of the weapons designer and ordnance engineer. Roland's conclusions point to a much less intense firefight than we presently simulate as we consider only technological aspects of the weapons involved. Bolmarcich presents strong evidence that most weapons on the battlefield do not lead to casualties. He also shows that the distributions of a number of key measures of combat effectiveness are skewed strongly to the right. In such a circumstances, use of a mean as a measure of combat effectiveness results in measures of lethality that are much higher than the historical evidence will support. In the case of the Frame paper, no conclusions about impact can be drawn, because the data investigated turned out to be so incomplete.

Usability Now. The third question is addressed to the interminable delays that we see in the O.R. community in incorporating new research findings in their daily work. This is a characteristic, by the way, that we share with the big models in the econometric community, but with one difference: the econometricians write about it; we ignore it. Anyhow, the third question is, "Are the findings in these papers usable now?" For the findings of Dupuy, Rowland and Bolmarcich is a resounding "yes." None of their findings require very complicated implementation, and naturally in the case of Frame's paper no implication is possible.

Convincing. The fourth question addresses perhaps the key to the problem: "Are the results convincing?" The answer for Colonel Dupuy has to be a resounding "No;" his results have not been convincing. For more than 25 years he has produced findings of significance to the military modeling community that have been ignored. They convince many, from the mainland Chinese wargaming center to the General Staff of Egypt, but they have not been adopted here. The same situation appears to be developing with the findings of Mr. Rowland; they created great interest when first published three years ago, and there was discussion in several key places of trying them out in representative war games, but nothing has been done. Dr. Bolmarcich's findings have been published for about the same length of time, but they aren't even widely known, much less tried out. Mr. Frame's findings are convincing, it must be admitted; they convince anyone with a predisposition to the conclusion that combat data is impossible to obtain, at least in usable form.

Combat as a Data Source. Three of the papers have deomonstrated that combat can be a data source, but it is an expensive one. The fourth paper demonstrates that even a skilled practicioner can draw a blank in searching for data about real war. All four of them demonstrate, as shown by the accompanying figure, that research in this area is fraught with a good deal of heart ache.

PANEL ON COMBAT AS A DATA SOURCE

ARE THE DATA FINDINGS IN THE PAPER	DUPUY Survey	ROWLAND Small Arms	FRAME Artillery	BOLMARCICH Kill Distributions
Usable in wargames?	YES	YES	NO	YES
Likely to change casualty rates?	DOWN	DOWN	?	DOWN
Usable now?	YES	YES	NO	YES
Convincing?	?	?	NO	YES
Evidence of combat as a data source?	YES	YES	NO	YES

SESSION V: REPRESENTING HUMAN PERFORMANCE IN COMBAT MODELS AND SIMULATIONS

Session Chair: LTC Vernon M. Bettencourt Jr., TRADOC Analysis Command-Monterey

For combat modelers, the central issue is how to represent the influence of human performance on combat processes. This is a larger question than simply attempting to model how the human qualities of an individual soldier interact with a weapon. It gets at the nature of the synergism which exists between the soldiers who comprise a weapon's crew, the relationships between small groups of weapons employed to accomplish a tactical mission, and the interrelation between the decision making processes of leaders and the command and control structure which translates decisions into actions on the battlefield. Explaining and quantitatively describing the processes which underlie these relationships is a challenge facing combat modelers. Preliminary analysis by Vector Research and the Army Research Institute has started to tackle this problem based on experiences at the Army's National Training Center.

We are just beginning to understand the relationships which will provide modeling improvements. The current SIMNET effort is both a tool for training and an experimental device for exploring and measuring how current tactics and the soldiers who implement them "fight" in a simulated combat environment. We should be aware that such simulations must be tied to results in the "real world" if they are to have credible meaning. Similarly, the current effort at TRAC-Monterey to expand the representation of soldier performance in high resolution combat models must be supported by empirical data of crew combat performance if the study's results are to be truly useful. There must be a link between "real" combat performance and the results of modeling. Some powerful software tools discussed during this session will undoubtedly be aids to accomplishing this task.

The need to tie the results of simulation to credible data from combat will confront modelers even if the fundamental relationships between human performance and combat performance are well understood. Ways must be found to correlate the results of peace time operational tests and training exercises to our sparse collection of war time historical data. Mr. Jim Dunnigan's prolific use of historical human factors effects in commercial wargames serves as an excellent example in this endeavor. Efforts to improve "realism" in field exercises such as those at the National Training Center will certainly make this job easier. However, we must not overlook the possibility that future battles may not correspond to past experiences and that the ability of humans to cope with new situations in future wars may be far wider than what is seen in history or explored in training. The challenge to good modeling will be to sort through these problems and present a useful picture of the human influence on combat. To these goals, the comments of our discussant, Mr. Howard Whitley from the Army's Concepts Analysis Agency, are most important as he describes combat modeling assumptions, methodologies, and applicability. In summary, this was a stimulating session for both participants and attendees. It raised challenging issues which will serve as catalysts for MORIMOC III and for combat modelers struggling with the issue of how to best represent the effects of human factors in models.

RESEARCH INTO A CONCEPTUAL FRAMEWORK FOR REPRESENTATION OF HUMAN FACTORS IN COMBAT MODELS

W. Peter Cherry
Vector Research, Incorporated

Irving Alderman
US Army Research Institute for the Behavioral and Social Sciences

INTRODUCTION

This research was performed for the US Army Institute for the Behavioral and Social Sciences (USARI) under the terms of contract number MDA903-86-C-0248. The objectives of this research were derived from perceived shortcomings of the combat models and analyses performed in support of Army decision making. In particular, there are widely held opinions that future combat will place significantly higher levels of stress on the soldier: weapons system lethality is much higher, opportunities for recovery are much lower, and combat will go on round the clock throughout the battlefield. The technical objectives provided in the Statement of Work were "to identify human variables that are expected to influence predictions of combat effectiveness, to develop procedures for measuring these variables and collecting data, and then to estimate the nature and level of their effects".

GENERAL APPROACH

Two principal tasks were included in the research program. The first task was to develop a conceptual framework to identify the range of variables to be examined and the types of hypotheses to be investigated. The following factors were addressed:

(1) level of detail (e.g., global versus mission versus task-specific);

(2) scope (e.g., type of terrain and/or mission, nature of enemy threat); and

(3) anticipated complexity (e.g., simple "decrement" factors to adjust soldier performance under specified conditions such as fatigue versus more complex sets of relationships with multiple interacting variables).

The development of a preliminary version of the conceptual framework was based upon review of material from three sources: (1) the extensive combat, training, and command experience of a senior retired General; (2) anecdotal accounts of battle, including autobiographical and biographical literature and military history; and (3) a critical review of the behavioral science literature.

The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

The critical review of the behavioral science literature was restricted primarily to material related to fatigue and its role in combat for two reasons. First, the nature of combat envisioned by AirLand Battle Future involves continuous, high stress operations, and understanding the role of fatigue in the combat process is necessary for the estimation of human performance. Second, the extensive laboratory and field research literature offers an empirical base for refining the framework and to identifying gaps to be addressed in the second principal task.

The second principal task of the research program was the estimation of the effects of specified human variables on the combat process. It included the development of testable models and hypotheses, preparation of a research plan, development of data collection instruments and procedures, implementation of the research plan, and synthesis of the research findings. The research plan was implemented at the National Training Center (NTC) to investigate the effect of sleep-loss and fatigue on effectiveness in a simulated combat environment.

CONCEPTUAL FRAMEWORK

As noted earlier, the objectives of this research were "to identify human variables that are expected to influence predictions of combat effectiveness, to develop procedures for measuring these variables and collecting data, and to estimate the nature and level of their effects". In order to meet these objectives, a conceptual framework was developed. In developing the framework, a series of issues were considered. The framework had to provide a means for identifying and organizing tasks and activities performed by soldiers in combat. It had to provide a means of relating human factors to performance and behavior on the battlefield. Furthermore, it had to include not only static factors, for example, terrain characteristics or temperature, but also dynamic factors, for example, sleep-wake patterns, to facilitate representing changes in human performance and behavior. Finally, it had to include a means for identifying those soldier attributes which determine performance.

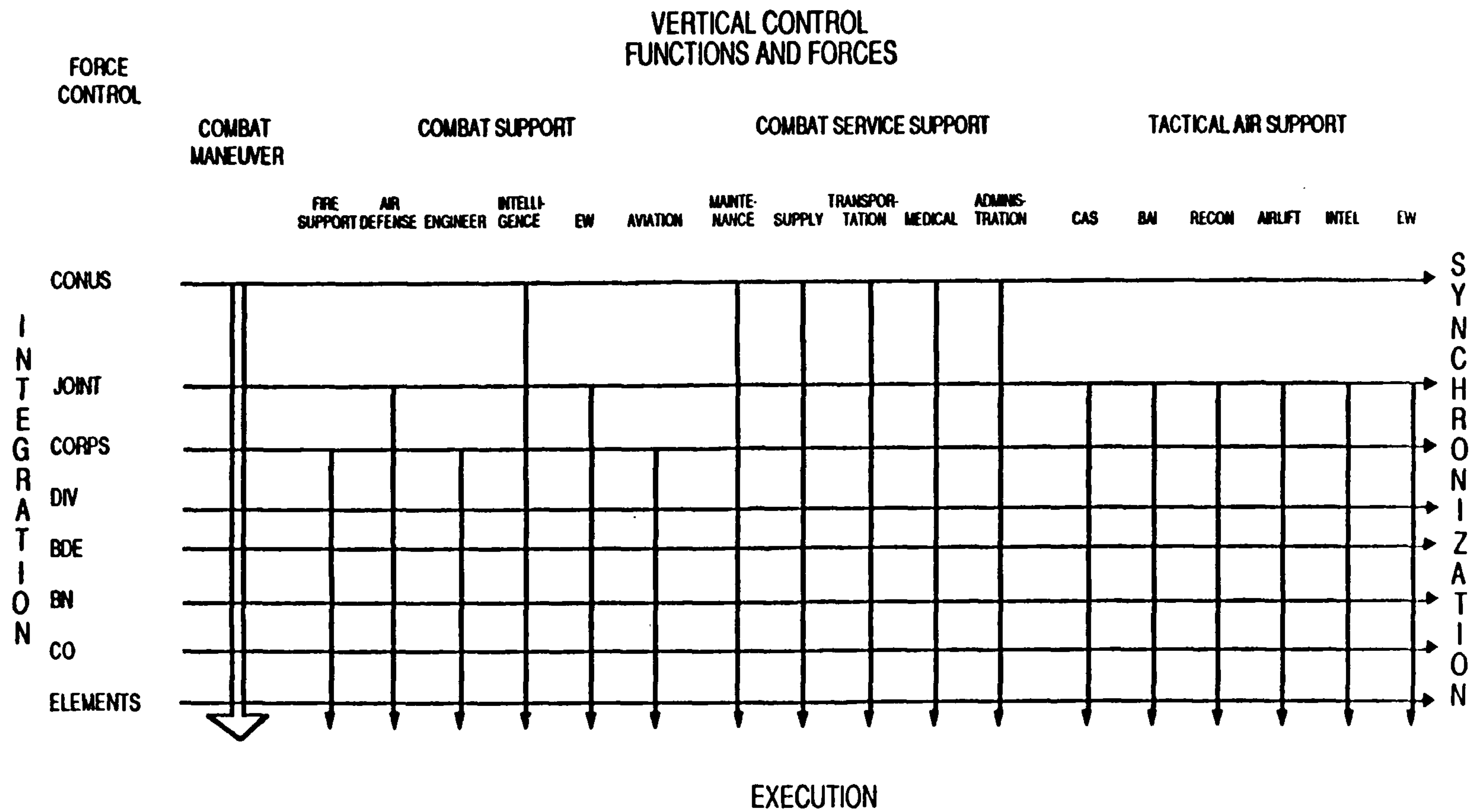
COMBAT TASKS AND ACTIVITIES

To structure and organize the tasks and activities performed on the battlefield, a concept originally developed by General William E. DePuy, (US Army, Retired) was adopted.[1] Illustrated in figure 1, DePuy's C^2 Matrix was originally intended to support analysis of command and control and specifically, tactical synchronization. For the purposes of this research, a key feature of the concept is that increments of combat power are delivered by executing elements -- the tanks of a platoon, the crew of a Forward Area Air Defense System, the repair of a system by a maintenance team, etc. The degree to which increments of combat power contribute to battle outcomes is a function of how well they are synchronized, and synchronization is the product of the activities of small teams or groups performing command and control -- planning, preparing, and supervising, at all echelons. In DePuy's concept, the horizontal functions produce synchronization in time and space. The vertical systems: stovepipes, battlefield functional subsystems, or battlefield operating systems, manage the delivery of specific increments of combat power: maneuver, fire support, intelligence, maintenance, etc.

Motivated in part by DePuy's concept, the organization of tasks and activities proposed for the conceptual framework corresponds to the tasks and

FIGURE 1: TACTICAL SYNCHRONIZATION

THE C^2 MATRIX[1]



[1]DePUY, WILLIAM, "CONCEPTS OF OPERATION: THE HEART OF COMMAND, THE TOOL OF DOCTRINE", **ARMY**, AUGUST 1988, pp. 26-40.

activities performed by executing elements. These are defined to be crews, teams, or staff elements; all are small groups. In the case of crews or teams, the tasks and activities are those of the different vertical subsystems. In the case of staff elements, the tasks and activities are those associated with horizontal and vertical command and control. Crews and teams deliver; performance of command and control elements determine when and where.

Measuring the performance of tasks and activities is for the most part straightforward. Particularly for executing elements, measures of time, accuracy and completeness are appropriate and standards and conditions can be found. However, combat has an additional dimension that the authors have categorized as behavior to distinguish it from performance. Soldiers and small groups respond to the stimuli of battle in manners which can be consistent or inconsistent with training, tactics, and doctrine. We have used behavior to describe the selection and initiation tasks and activities, both consistent and inconsistent with established norms for the situation in question. Behaviors are measured, for any given conditions and activity, in terms of probability of occurrence and, given occurrence, duration. As the focus in this research was on changes in performance, a baseline for task performance and behavior is required. We have defined this to be that performance achieved or behavior exhibited by an individual or crew, measured in a specified physical environment and characterized by values of individual and/or group attributes: physical, mental, and psychological basic abilities or capacities, levels of training and experience, and current status.

In any executing element, there are tasks and activities associated with the technical operation of a system or the technical function of the element. For example, the principal tasks of a tank crew are acquiring and engaging threat systems, i.e., delivering lethal fires while taking measures to survive. Similarly, the principal tasks of an air defense system are associated with acquiring and engaging aircraft. Those of a maintenance team include diagnosis and repair. From the perspective of the executing element, there are also secondary tasks, functionally those which tend to be associated with another battlefield function. For example, maintenance, supply/replenishment, administration, transportation/movement, are all activities performed to some degree by a tank crew, but they are secondary to engaging in real time a threat system. To reflect this situation, the framework further categorizes the tasks of an executing element as prime tasks and secondary tasks; prime tasks being those associated with the technical function of the element, i.e., operating its "system", and secondary tasks being those performed by the element but functionally associated with another battlefield operating system or vertical "stovepipe".

DYNAMIC VARIATION: CHANGES IN HUMAN PERFORMANCE

Performance, and behavior, in battle are not constant but respond to the patterns of stress imposed upon executing elements and concomitantly to the intervening periods in which recovery takes place. Certain of the stressors which establish levels of performance and propensity for behavior are essentially constant. These include the environmental conditions under which tasks are performed:

(1) thermal, including temperature, humidity, and air flow;

(2) mechanical, including vibration and g-forces;

(3) noise/auditory, including static, engine noise, gunfire, or explosions;

(4) visual, including level of illumination, contrast, glare intensity, obscuration, and field of view; and

(5) toxic, including airborne pollutants, chemical, biological, and radiation agents.

These conditions impact upon soldier performance, both in the short term, i.e., as a task is performed, and over the longer term. They are associated with the systems employed and tasks performed in a specific area of operations. They must be considered in assessing baseline task performance as well as in assessing changes in task performance. Prolonged exposure to extremes of these environments leads to degradation in capacity to perform and creates a deficit which must be overcome if ineffectiveness is to be avoided.

The combat process itself is a dynamic stressor. First, there is associated with the process a requirement to perform tasks and activities under conditions of high risk -- vulnerable to lethal fires and required to act quickly under substantial uncertainty where the consequences of error are extreme. Second, the results of combat, in particular, the presence and occurrence of casualties, generates an emotional strain which is itself a significant degrading factor in many situations.

To incorporate dynamic variation in human performance into the framework, a conceptual model of stress and recovery is proposed. It postulates, for an individual, reserves or reservoirs of capacity: physical, mental, and emotional. As illustrated in figure 2, stress is imposed and tasks or activities are undertaken, reserves are depleted, and a deficit begins to build. When opportunities for recovery occur, reserves are restored. It is postulated that there are relationships between the intensity and duration of stress intervals and corresponding intervals in which recovery is possible. In particular, prolonged stress without sufficient opportunities for full restoration of reserves eventually may create a situation in which reserves are fully depleted; in which case, full restoration is required before effective performance at any level can be undertaken. The angles in the exhibit are intended to reflect these phenomena. Angles ϕ_1, ϕ_2, and ϕ_3 are decreasing to reflect that without full restoration, reserves are depleted at a greater rate. Similarly, angle θ_1 is greater than θ_2 to reflect the possibility of a faster rate of recovery given a smaller depletion of resereves. Finally, τ_R represents the time (and resources) required to restore the reserves once the capacity to perform is completely exhausted.

The second component of the conceptual stress-recovery model is illustrated in figure 3. Key to this component is the hypothesis that levels of performance (measured by time, accuracy, and completeness) and behavior (measured by probability of action/non-action and duration) do not change gradually but instead shift between discrete levels as a function of the magnitude of the deficit in capacity described above. Baseline performance is a function of the operational environment and soldier attributes. Given a particular stress-recovery process, the time thresholds at which performance changes, are related also to soldier attributes as discussed in the following section.

FIGURE 2: STRESS/RECOVERY PROCESS

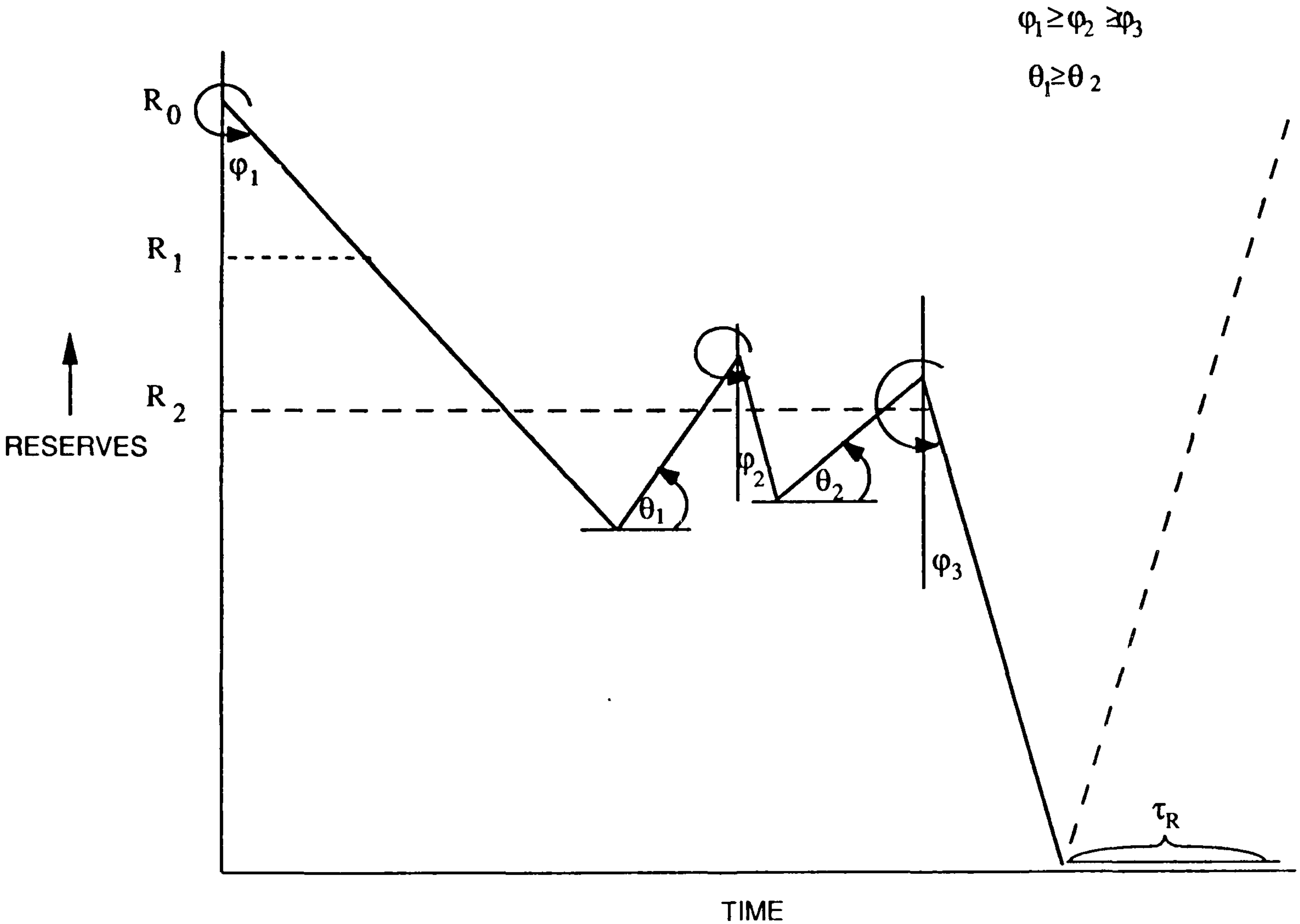
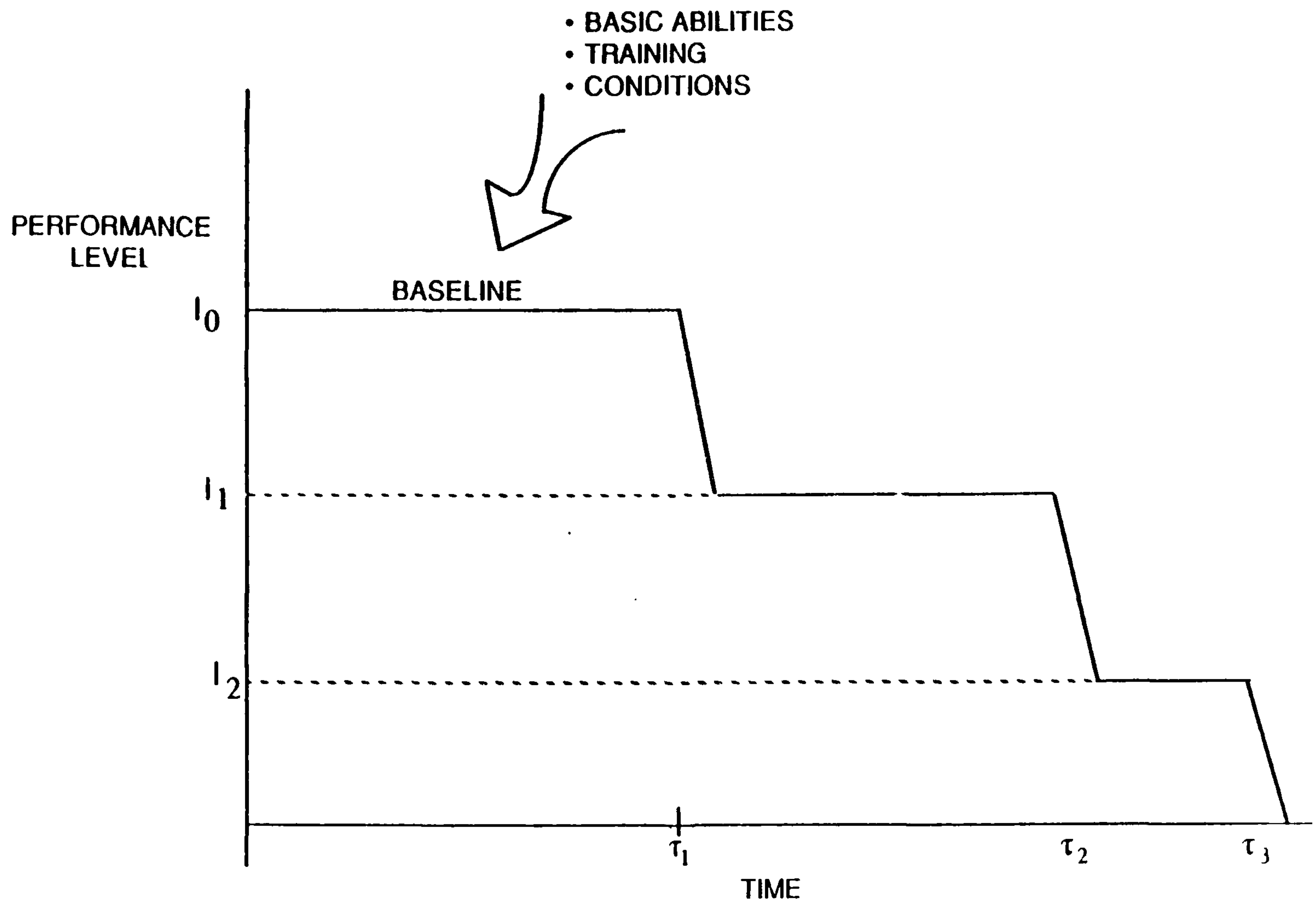


FIGURE 3: DETERIORATION OF PERFORMANCE



SOLDIER ATTRIBUTES

In characterizing the soldiers who make up the executing element of DePuy's concept, three categories of attributes can be defined. The first category represents capabilities and limitations of humans and includes anthropometric variables and basic abilities such as:

(1) vigilance;
(2) reaction time;
(3) perception;
(4) cognition;
(5) memory;
(6) psychomotor capabilities; and
(7) physiological capacity.

Baseline performance is in part determined by these attributes, as modified by the second category: training and experience. Similarly, the thresholds at which performance degrades are related to these attributes, for example, training clearly impacts upon capacity to perform under continual stress and upon recovery rates.

The so-called intangible factors:

(1) morale;
(2) motivation;
(3) cohesion;
(4) initiative; and
(5) leadership

also contribute to baseline performance and form the third category. In particular, cohesion plays a major role in establishing baseline performance for group tasks. However, for the framework it is proposed that the major impact of the intangible factor is to change the thresholds of performance associated with the depletion of reserves under stress, thus extending the length of time which a level of performance can be sustained, and to increase the rate at which reserves are restored during recovery periods.

DISCUSSION

The conceptual framework outlined above has two principal components. The first is a structure, based on the organization of a combat force into executing and command and control elements, that organizes tasks and activities according to battlefield operating systems or vertical battlefield subsystems. Tasks are associated with small groups -- teams, crews, or staff elements, and are classified as primary or secondary depending upon whether or not they relate to the principal technical function of the battlefield operating system to which the executing element belongs.

The second principal component of the framework addresses task performance and behavior. It identifies basic human attributes and assumes that baseline performance is a function of basic abilities and training and experience. It then assumes that the baseline performance is modified by operating conditions, and that it changes in a discrete fashion as a function of stress and recovery patterns. Finally, it is assumed that the major impact of so-called intangible factors -- morale, motivation, leadership, cohesion, and initiative -- is to change the time constants associated with stress and recovery patterns, in particular, the thresholds at which levels of performance can change.

From the perspective of combat modeling, application of the framework to any given set of tasks performed by an executing element or a command and control element requires that a family of stress-recovery patterns be developed for the task categories. Clearly, baseline operator abilities, training and experience, as well as intensity of task performance, are components of such patterns, as is combat results. The impact of operational environment is assumed to be first on baseline performance levels and then, for any stress-recovery pattern, on the rates at which capacity to perform is depleted or restored, represented as ϕ and θ in figure 2. The assumption of discrete levels of performance relative to capacity reserves requires that the finite number of levels be determined and that thresholds be established at which changes take place (represented as R_i and l_i in figures 2 and 3, respectively), or, equivalently, the time constants of the performance step functions be determined. The final required data relate different sets of values of human attributes to baseline performance and the above mentioned thresholds or time constants (R_0 and l_0 in exhibits 2 and 3).

HYPOTHESES AND MODELS

One of the major objectives of the research which addressed a conceptual framework was to develop procedures for measuring the impact of human variables, and then to apply these procedures in data collection and subsequent analysis. The experimental vehicle chosen was the National Training Center where data were collected during a rotation which focused on measuring sleep deprivation. The principal hypothesis addressed was that sleep deprivation would degrade performance particularly in leaders, and that the degraded performance would be evident in combat outcomes. The results of this research are summarized in this section.

HYPOTHESES

It is generally accepted that sleep deprivation results in degraded performance. The question of degree of degradation is particularly important in the context of AirLand Battle which envisions continuous operations and severe sleep deprivation. In order to address the impact of sleep deprivation, a series of hypotheses were developed related to the combat process and in particular the delivery, by executing elements, of increments of combat power:

(1) a small unit's performance in delivering its "increment" of combat power is dominated by initial conditions which determine opportunities to participate;

(2) determination of initial conditions is dominated by leadership and supervision;

(3) given opportunities to participate, the level of participation by individual systems does not vary significantly; and

(4) given a decision to participate, soldier/system contribution does not vary significantly.

In the context of sleep deprivation, data collection and analysis was performed to identify and, if possible, quantify the degradation caused by sleep loss on:

(1) performance of battalion, company and platoon leaders, and staff officers;

(2) behavior of crews and teams; and

(3) performance of primary tasks by crews and teams.

APPROACH

The data collection and analysis performed at NTC had three components. First, selected officers and soldiers (battalion commanders and staff, company commanders and executive officers, platoon leaders, and platoon sergeants) wore wrist monitors which recorded their levels of physical activity throughout the rotation. From these monitors patterns of sleep and activity could be inferred. Second, data were collected on the platoon leadership during the rotation. By relating wrist monitor data to platoon leadership, the link between sleep loss and quality of leadership could be examined. Third, an analysis of combat dynamics and results for a defend in sector mission segment was performed to relate platoon performance to combat outcomes, thus addressing the links between sleep deprivation and combat effectiveness.

RESULTS

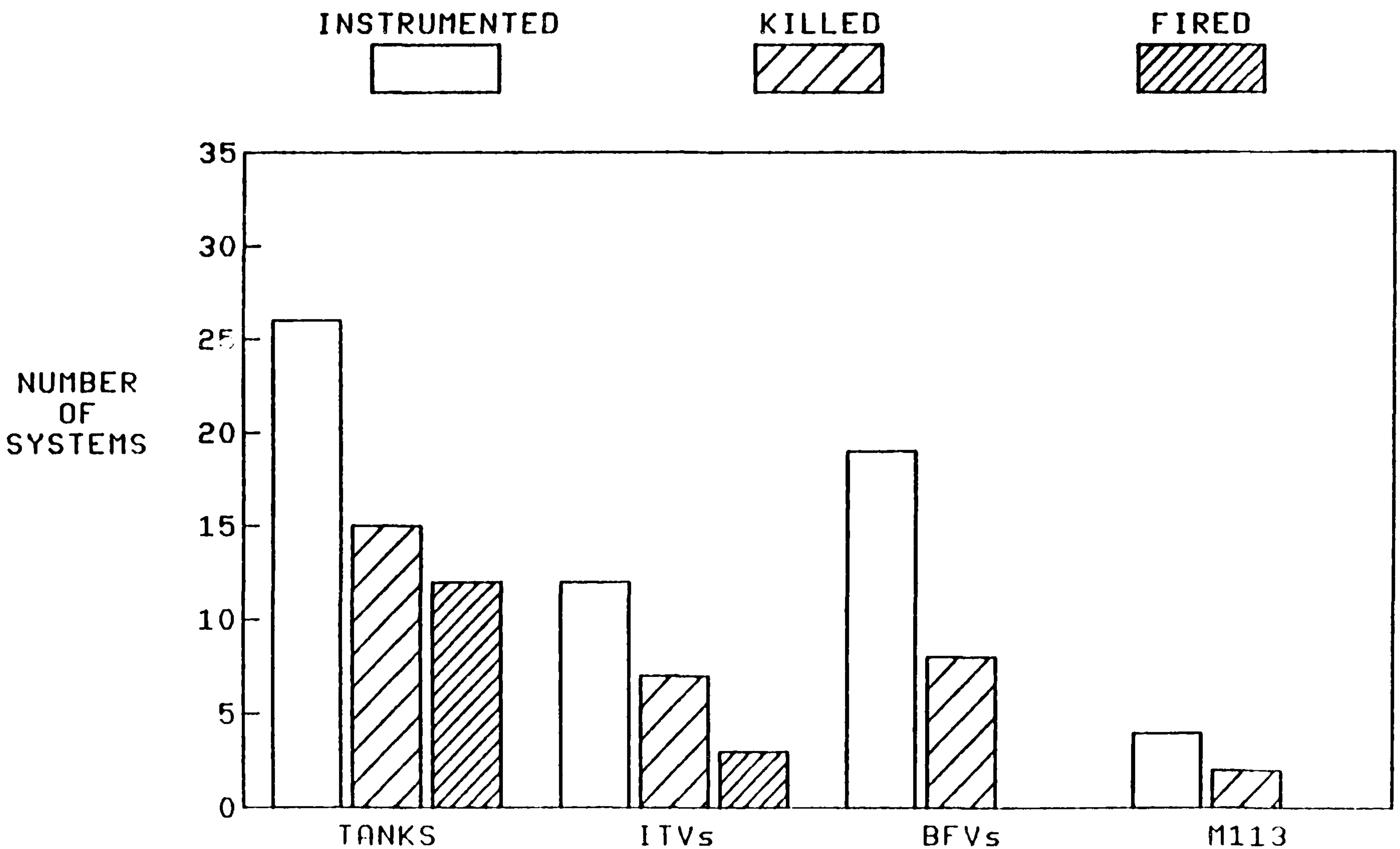
The analysis of data collected during the rotation produced mixed results. First, examination of the wrist monitor data, for those soldiers instrumented, produced no evidence of prolonged sleep deprivation. Although there were instances of activity lasting approximately 24 hours without sleep, soldiers who performed continuously over such periods then were able to sleep for four to six hours. Both the experimental literature and anecdotal material suggest that given these patterns of sleep and activity, no degradation in performance should occur. This was borne out by statistical analyses performed to relate wrist monitor data to platoon leadership performance. The nature of the data precluded establishing any statistically valid relationships between sleep deprivation and performance.

The analysis of combat dynamics focused on the four hypotheses presented above. No reason was found to reject any of the four. However, the results of the analysis appear to be pertinent. First, planning, preparation, and supervision at the battalion and company levels were the major factors in determining the number of weapon systems that had opportunities to engage. Poor command and control led to a company team counterattack against a nonexistent threat, and a faulty concept led to the ITV company being unable to contribute in a meaningful way. Thus, combat potential was not turned into combat power.

From the perspective of preparing engagement areas, failures on the part of small unit leaders to coordinate and synchronize led to poorly prepared fighting positions and thus reduced potential contributions on the part of direct fire systems. The results of the analysis of direct fire engagements were revealing. During the analysis, opportunities for engagements by individual weapon systems were determined. In fact, only a fraction of the systems present and able to fire did so, and of those firing, the distribution of rounds fired per system was biased, i.e., one or two systems expended the majority of the rounds. Figures 4, 5, and 6 illustrate these results. Exhibit 4 displays the numbers of combat systems present, the numbers that

FIGURE 4:

BLUFOR SYSTEMS INSTRUMENTED, KILLED AND FIRING DURING MISSION SEGMENT



DISTRIBUTION OF TANK FIRINGS

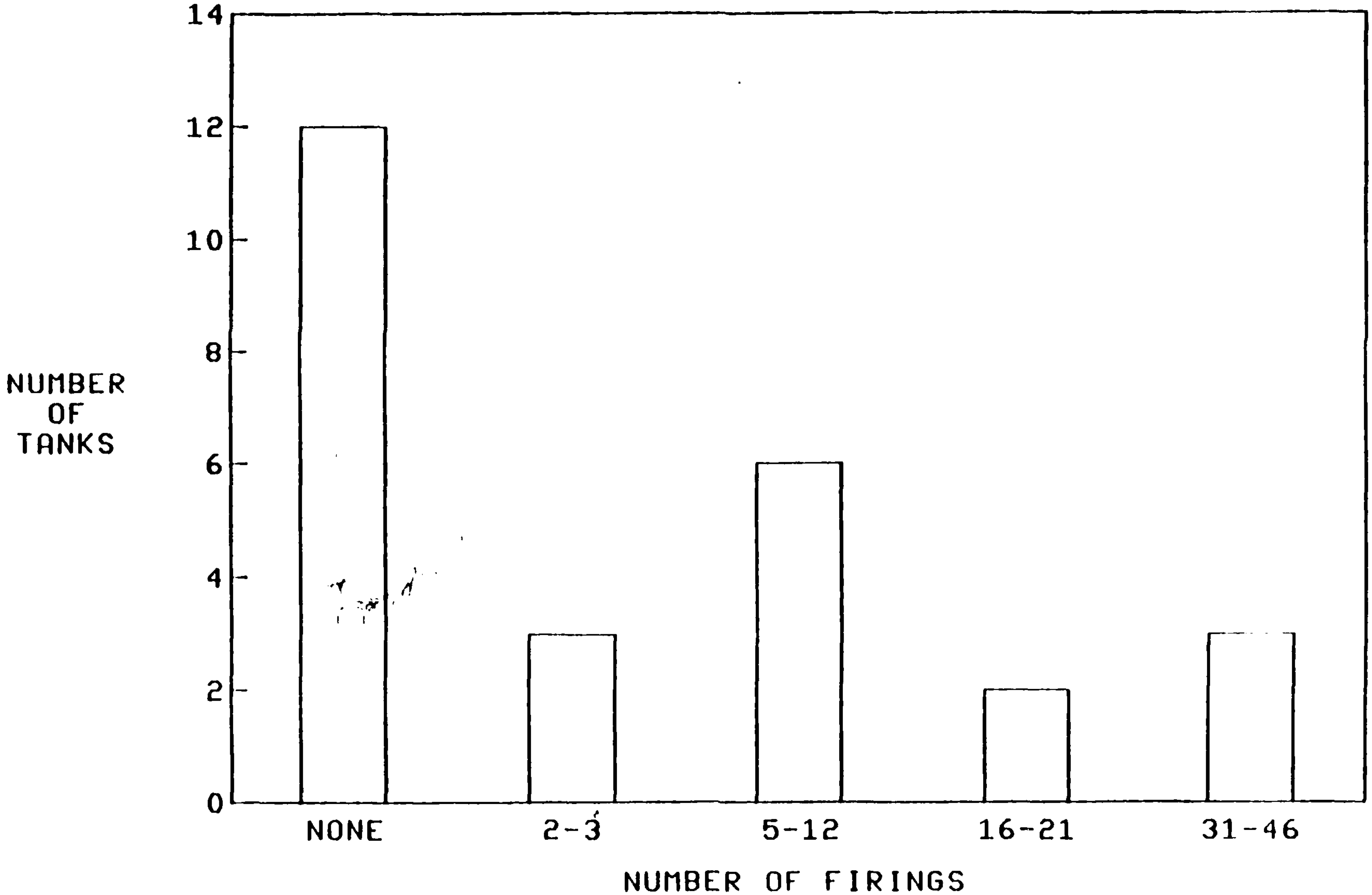
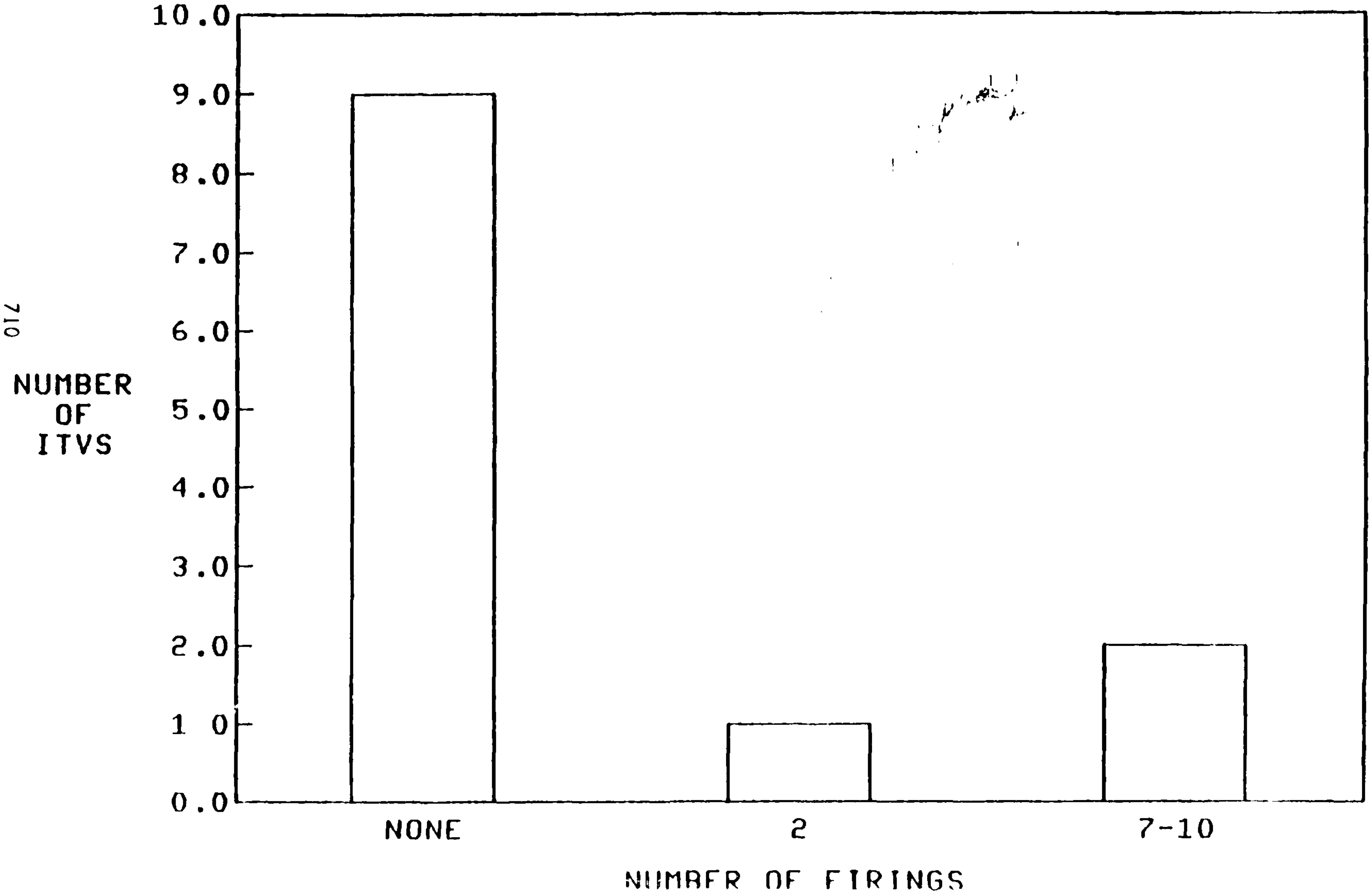


FIGURE 6:

DISTRIBUTION OF ITV FIRINGS



were killed, and the numbers that fired. Figures 5 and 6 illustrate the number of rounds fired per system for tanks and ITV's, respectively. In a sense, these results confound the first and third hypotheses, namely, those that deal with initial conditions and participation. Both factors are present; in at least one direct fire battle only three of 14 systems fired even though all 14 had opportunities. Two of these firing systems were those of unit leaders who were "too busy" to fight their units. Unfortunately, data are not available which would permit examination of the question of why the 11 systems did not engage.

For the systems that did engage, performance was sound. Weapons were sited appropriately, and system capabilities were exploited. Figure 7 provides evidence; it displays a series of measures for defensive positions and attack paths. The first opening range is the maximum range of the first opportunity of a defender to engage any attacker. The expected opening range is the expected range of first opportunity against all attackers. The actual engagement range is the range at which engagements took place. The data supports the claim that tank crews that fired did so consistent with the capabilities of their tanks and took maximum technical advantage of their positions.

OBSERVATIONS

The data collection and analysis completed in the course of this study are not sufficient to infer quantitative relationships between sleep deprivation and performance. Nonetheless, the NTC results do not support rejection of the four hypotheses concerning the delivery of increments of combat power. Not surprisingly, training and experience in leadership and command and control appear to be the major factors which determine results at NTC. This observation is based upon analysis of after action reviews and take home packages, which identify problems in time management and failures to accomplish synchronization and coordination. In fact, until the confounding effect of command and control and leadership can be isolated from overall unit performance and its impact understood, evaluating the impact of other human variables will have at least a marginal value.

CONCLUSIONS

In undertaking this research, three objectives were set:

(1) to identify human variables that are expected to influence predictions of combat effectiveness;

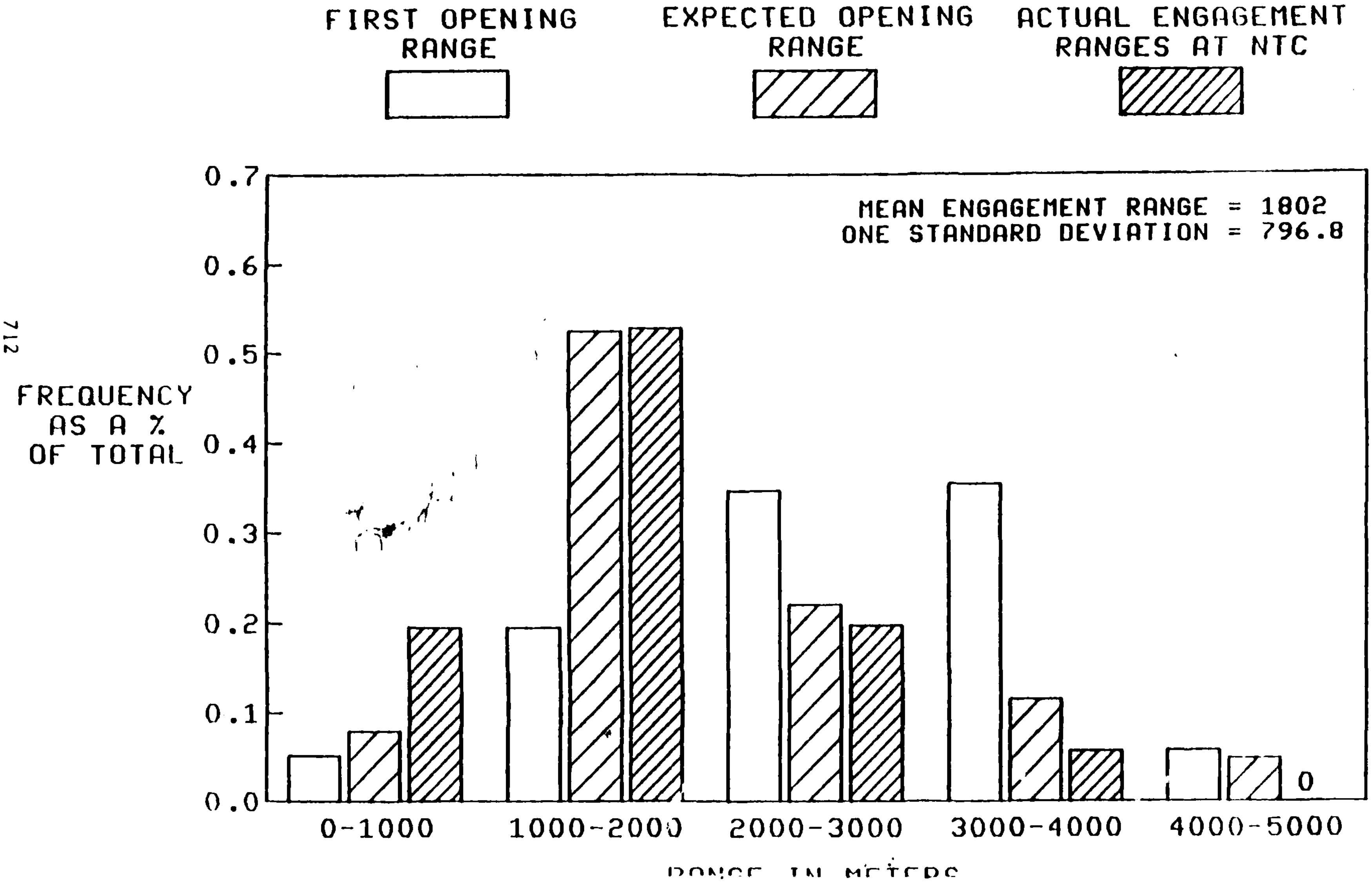
(2) to develop procedures for measuring these variables and collecting data; and

(3) to estimate the nature and level of their effects.

The conceptual framework, developed to organize and structure human variables as they influence combat, focuses attention on the tasks and activities performed by small units or groups and on tasks associated with leadership and command and control. It is the latter tasks and activities, all other things being equal, that are most important since, for example, expert tank gunnery is of no use if no targets are present in an engagement area. This suggests that human performance in leadership and command and control should receive highest priority for research addressing the impact of human variables.

FIGURE 7:

DISTRIBUTION OF FIRST AND EXPECTED OPENING RANGES AND ACTUAL TANK ENGAGEMENT RANGES AT THE NTC MINI-BATTLE 1



Baselines for such performance at levels from platoon to corps is not readily available. Until such baselines are established, it is of marginal value to investigate the changes in performance that take place as a consequence of stress and recovery. The key variables appear to be training and knowledge; their impact must be evaluated.

The National Training Center provides valuable data relative to leadership and command and control; from that data it may be possible to develop baselines for brigade, battalion, company, and platoon command and control performance. Such baselines would contribute to improvements in combat models and would provide a starting point for investigating the major role of human variables in determining combat effectiveness. The contributions of executing elements and their performance levels cannot be ignored. However, the results of this research suggest that given present knowledge, the study of human variables in executing elements should be given lower priority relative to understanding human variables which influence the execution of command and control activities. This suggestion is supported by the results available in S.L.A. Marshall.[2] Although these results have recently been called into question, our data appear to support them in kind if not in quantity. Furthermore, earlier work using high resolution combat models, and focusing on small differences in terrain and scenario[3] revealed that "only a small fraction (say 20 percent) of the total variance was caused by sampling the attrition processes"; that is in our terms, the contribution of executing elements given that they participate.

REFERENCES:

[1]DePuy, William, "Concepts of Operation: The Heart of Command, The Tool of Doctrine", **Army**, August 1988, pp. 26-40

[2]Marshall, S.L.A. (1978) Men against Fire. Gloucester, MA: Peter Smith.

[3]Personal communication from Dr. Wilbur Payne, January 1989.

Inserting The Human Factors into Combat Models

James F Dunnigan
328 West 19th St
New York, NY 10011
(212) 929-5288

3/27/89

Summary

Human factors are crucial to realistic combat modeling

Human factors have been successfully modeled, rather than simulated

Most of these models are of historical combat events

Historical models can be built using existing DoD modeling technology

These models can then be validated by reference to the historical event

Use of historical models teaches much about the nature of combat and the role and importance of human factors

History based models are useful to settle debates on how the models should work

Historical models can be easily pushed forward to the present and future

Anyone who has had to dissect and then model a historical battle, quickly realizes that human factors cannot be ignored and can be easily worked into models. The following techniques are centuries old and were made famous by the Prussians and Germans in the last century and a half. These techniques have been used in peacetime and in combat situations successfully. Having been through the combat simulation development process many times, the following techniques for expressing human factors in models have been developed.

Analyze actual event.[1]
Quantify all aspects of the event.[2]
Model Actual Events.[3]
Use these models to **Simulate** variations.[4]
Depend on **Aggregation** effect to keep you within likely range of outcomes.
Oscillate the model to test minor changes in the situation.
Human factors are but one of many elements in a model. There's no mystery or ju-ju to dealing with the human element.[5]

Discussion

After designing over a hundred combat simulations, including manual and machine driven versions, some insights have been gained about the use of human factors. Most of my models have covered past battles, so validation was straightforward and paying attention to human factors was obviously mandatory. The contemporary and future combat models were validated using a combination of extrapolation and paying close attention to how the hypothetical combat scenarios were put together. These simulations have been used extensively by military and civilian organizations.[6] This background enables me to address all five areas identified for discussion in this symposium. Below each of the areas for discussion are addressed.[7]

1-Human Factors which impact weapons and combat performance. Popular histories and AAR's provide pretty clear evidence that the effects of personal characteristic and leadership are tangible. These human elements can be quantified, as the publication of over a thousand historical games in the last quarter century has demonstrated.[8] The "Ace

Factor" applies to leaders as much as it does to pilots, infantry platoons, ship divisions, firing batteries and tank crews. [9]

Specific human factors which impact weapons and combat and performance are.

Experience- Combat experience in general and exposure to specific types of operations is arguably the human element with the most impact on combat performance.[10]

Training- Quantity and quality. Historically, this item has been honored rather more in word than deed. Once the shooting starts any corners you may have cut begin to bleed.[11]

Social Motivation- How well disposed are the troops towards the conflict they are fighting in. While troops largely fight for more immediate goals, such as survival or peer pressure, in the longer term the effects of a popular or unpopular war make themselves felt.[12]

Physical Conditioning-Troops rarely realize how important this is until they've been in combat. Most combat veterans will admit that they could have done with more PT. Getting a handle on how well prepared troops are in this department is not impossible, just difficult.

Innate abilities- Each combat job is best performed by individuals possessing specific innate abilities for it. Nations that use a lot of long term volunteers tend to place more people in jobs they have a knack for. This makes an enormous difference in combat capability.[13]

Combat Fatigue-This is a large component of the "friction" of war. People get tired and things break down.[14]

Specific examples from models and simulations the speaker has authored.

Agincourt-1415 battle between French and English. Tactical level. [15]

Leipzig 1813 Campaign in Central Europe between French and Allies. Operational level.[16]

American Revolution-1776-1781. Strategic level. [17]

The Civil War-1861-65. Strategic level.[18]

1918 German Spring offensive. Operational level.[19]

Desert War Armor battles in North Africa, 1941-43. Tactical level.[20]

Panzer Group Guderian Russian front, 1941. Operational level.[21]

Sniper Combat at the individual level in the 20th Century.[22]

Textron Tactical Model Contemporary and future anti-vehicle weapons at the vehicle/troop level. Modeled Russian execution of battle drills, reactions of troops under stress. Built on work done with *Sniper* and it's follow on game *Patrol*.

2. Human behavior/performance/combat results data bases. Data is extracted from operational data, interviews, surveys and modeling of well documented historical events.[23] The key technique is to realize that human factors *are* an integral part of any combat simulation system and any outcomes must be seen in light of human factors.

Exceptional human performance is not always the most crucial factor, it depends on the situation. Modeling of past events provides a means of identifying key factors, quantifying and validating them. These techniques have been used in several DoD combat models (MTM and derivatives). Some of the techniques and dataset types are:

Unit Histories-There are thousands of published unit histories for wars in this century. Some are better for our purposes than others, but as a body of literature they provide an adequate source of quantifiable data on human factors in combat.[24]

After Action Reports-These fill in a lot of the blanks left in unit and personal histories.[25]

Reconstruction-Data from various sources must often be rearranged into a more meaningful format in order to reconstruct what actually went on in the battle. Building a data model, or an actual combat model, is a useful way to clean up the data.[26]

Order of Battle Analysis-As much as possible, you should have the same quantity and quality of OB data for both sides. There are also minimum requirements for data in order for units to be accurately evaluated. This is the crucial dataset for a model and can be used as the core of a combat model.[27]

Leadership Analysis-The quality of the senior leadership must be analyzed. Similar to OB analysis, but more difficult because the historical record is usually pretty vague in this area.[28]

Organizational Analysis- All battalions are not equal, even if they contain the same numbers of troops and equipment. Their organization, and how effective that organization is, will eventually assert itself as a crucial factor. Historical analysis of organizational types and their combat performance can be applied to current and future situations.[29]

Terrain Analysis-There are fairly standard effects terrain (and climate) will have on troop mobility and combat effectiveness. The physical and psychological characteristics of each group of troops is often further modified by terrain effects.[30]

DoD agencies have built a number of databases in the past. Many are now unused and often difficult to locate. It will take a bit of digging to find them.[31] And you may have to fight for access. Even then, the data may have to be reorganized to be useful.

3. Representation of human behavior and performance in combat models. Humans contribute most of the uncertainty element in combat operations. People are not as predictable as we would like them to be.[32] In many historical combat situations you discover, while researching the situation, that many of the participants were basically operating in a low information environment and were making evaluations and decisions based on guesswork, hunch and luck.[33] This has been aptly modeled in commercial wargames with a literal "roll of the die." You will find that your primary tool in representing human behavior in combat models is a random number generator and probability tables of historical performance.[34]

All levels of models, from man-to-man to global can make use of a common pool of modeling techniques. These techniques are all overshadowed by the same problems combat commanders must face. The options available to participants in combat are limited and are severely constrained by fear, uncertainty and pressure. To overcome these problems, troops are trained to act in accordance with prescribed doctrine and tactics.[35] These drills can be quantified and turned into algorithms.[36] The same approach works for historical or contemporary models of combat. Look-up probability tables and algorithms are the most common technique. Examination of historical combat commander performance shows that they generally restrict their decisions to doctrine they've been taught. "Random walk" technique accurately represents irrational actions that often occur in combat.[37]

Simple AI "if/then" rules plus some randomization usually suffice to re-create an historical battles command activity. The model is then debugged using techniques similar to those found in software development. A typical AI routine for command and control is a combination of small decision trees self modified by random variation to represent commander response to FUD (Fear, Uncertainty and Doubt).

At each level of command, troop leaders have a different combination of options, resources and tasks. Platoon leaders and Army commanders are both directing the actions of troops, but do so in quite different ways.[38] While the tasks are simpler at the lower levels, there is also a greater degree of unreliability. When building a model, you show national and unit differences by varying the degree to which troops will perform their tasks as expected. Chaos Theory and Fractal users will recognize what is going on using these techniques. [39]

As you climb the chain of command you get more involved with communication and time lag. These items exist at all levels, but occupy a more central part of a commanders function as his subordinates become more dispersed. Another crucial factor at higher levels is the nature of staff and line commanders.[40] These are a higher commander's "troops" and their performance, or lack thereof, ripples down to the units and functions they control.[41]

4. Correlation of model-derived human factors effects on combat with real battlefield experience. There are a large number of factors that can be examined and measured for degree of correlation between the model and the actual event. This is done not just to satisfy an information junkies curiosity but in order to take the full measure of the event. When building a combat model you must begin with actual events and derive your model parameters from those events.[42] This technique makes it difficult for a model to wander too far from reality.[43] For situations beyond your historical data, you derive trend lines and cautiously project forward.[44]

The *Extent of Correlation* must be fairly close overall, which is not too difficult to achieve if there are a lot of entities involved.[45] The main requirement of a model to achieve credible results is its ability to replicate the historical, or postulated, event. There are a number of measures of performance that must be quantified to build the model and for use in validating against combat or exercise performance.

Casualties-These are fairly consistent for specific types of operations. Predictable losses assume you have normalized other factors like troop quality and force ratios. Each combat must produce the predicted losses after all appropriate adjustments have been made.[46]

Terrain Effects-Effects on movement are fairly well documented. The usual problem is correct analysis of terrain for the model. Tests of the model against an historical action will usually correct this. The terrain's effect on combat is less well documented.[47]

Achieve Objectives-Each side in a combat will have objectives that must be as achievable in the model as they were in the original event.

Patterns of Maneuver-The manner in which the combatants went about their business in the original battle must be reproducible in the model. You have some leeway in this area as you don't have to model every twist and turn, only those that were crucial.[48]

Resource consumption patterns- Supplies consumed. I've always been a big fan of logistics. By studying the patterns of consumption for combat you will uncover all sorts of interesting stuff.[49]

Speed of command loop- how quickly does it take leaders at various levels to become aware of combat activity and the impact of their previous orders.[50]

Accuracy of data analysis- how accurately do leaders interpret combat activity.[51]

Accuracy of decision- how efficient are decisions of leaders.[52]

Ability to implement decision- how efficient are leaders in getting their decisions carried out.[53]

And so on.[54]

There are varying degrees of friction involved and other random variables that you must be prepared to encounter and deal with.[55]

5. Requirements of various decision issues and the associated analysis and combat modeling used to support decision making, from the standpoint of the human factors needed to be included to reach valid conclusions. There are several decision issue areas that require attention to human factors.

Procurement- For many years, human factors have been recognized and addressed in the design of weapons and equipment. What has been less recognized are the human factors effect when different systems are used together and against hostile systems. Human factors extend way beyond whether the tank gunner has a comfortable and non-fatiguing view of potential targets.

Organization- It's an ongoing debate as to which military organization is the most effective.[56] This is a very touchy subject because it touches on personnel quality and ability. There is an underlying assumption that the troops and leaders are simply first rate.[57] Doubters are discouraged or ignored. It's easier to be cynical, and practical, about official human factors quality during wartime. If you have a model that allows you to dial up a range of personnel quality, you will obtain some interesting results as you run up and down the scale.[58]

Tactics- This is where lack of attention to human factors hurts you the most. NTC experience is curing many troops of bad peacetime habits, and tactics.

Training- In wartime, after you get bitten in the ass by inattention to human factors, there is generally a lot of changes made in the way training is carried out. A lot of the bad peacetime habits are abetted by models that forget how peculiar human behavior is when real bullets are flying about.

How much realism in the human factors department is required for the analysis of various issues? A fair amount. You must zero in on those key activities which account for the majority of the decision making and meaningful combat activity.[59] The key human elements encountered in all environments and levels of operations are:

*Command Control-*Command styles vary a lot, but one thing all have in common is their need to spend a lot of time with their key subordinates.[60]

Experience- Superior training can, up to a point, substitute for combat experience. NTC exposure is an example of this.

Training- Quality is more a factor than quantity. Unfortunately, quantity is easier to measure than quality.

Leadership- Another big question mark. Not only is it difficult to measure in peacetime, but is something of a hot potato even if measurement is attempted.

Fear- This is a usually underestimated and unappreciated factor in modeling. Even the best troops must contend with fear.[61] This factor is particularly acute in the opening stages of a war, when most troops and officers are green and given to quite unpredictable, or at least unwanted, behavior. Aside from the shock of combat, there is also the complications created by new weapons and tactics. Examine the opening battles of any war and you will find fear, and its impact on the troops and leaders, a tangible and substantial factor.

6. Additional Issues.

Why haven't these techniques been used more before? The game design techniques used here are noted for the use of historical models, keeping a man in the loop and extensive treatment of human factors. [62]

Leadership vs Management. A bit of both are needed in an effective armed force. Marlborough's Blenheim campaign was notable more for it's management achievements than it's purely military aspects. The Roman military system also derived most of it's continued effectiveness from sound management. Such a system was often able to overcome haphazard leadership. All the major 20th century wars were noted for the effective use of management to support the fighting troops. However, the cutting edge of combat is still dependent on a heavier dose of that ethereal quality known as combat leadership.

Do National Styles of Combat Leadership Exist? In some ways, yes. Styles in effective leadership is something of a constant across cultures. Bad leadership takes many forms, reflecting whatever particular bad habits each ill-led force is most prone to. Above the small unit level, good leadership is supported by well thought out procedures and organizational doctrine. Whether it be a Greek Phalanx or an Israeli Armored Brigade, good leaders operating in an effective structure are a formidable military force. These organizational elements can be analyzed and quantified in your model.

7. Software

I have brought with me several software times to serve as examples of how you can build human factors into models.[63] These items are free and are either Public Domain or Shareware. Doc files are included.

CROBOTS- This is a system that let's you write code, in a simplified C language, to program robots that can move, sense other robots, fire on them, detect damage to themselves and generally perform like a sentient being on the battlefield. Note that you can add the human "panic" element by having random movement or freeze-up occur under certain conditions.

Theater Combat Model-This began in 1983 as an example of how you could create a wargame within a spreadsheet program.[64] Naturally, I included human factors in the OB section. Note that two of three combat strength modifiers are human factors. These same human elements are addressed in other parts of the model.

Cost/Benefit Model-Similar to the *Theater Combat Model*, except that it evaluates weapons systems. Lot's of room for human factors. This version requires 123 2.0X, 512k, graphic adapter optional.

Both of the 123 models have also been used with Add-ins for Linear Programming and Monte Carlo analysis. The versions included here are the plain vanilla ones. I haven't tried importing either of these into Excel, but it should not be much of a chore. I've been using these spreadsheet combat models in my lectures since 1983, so you may have already come across them, or their derivatives.

If you are not able to get copies of the software at the symposium, send me a blank, formatted 1.2MB disk and a stamped, self addressed mailer and I'll send you the stuff. Address any questions on the software to me via MCIMAIL (JDUNNIGAN). If you don't have MICMAIL, try the telephone.

Notes

1. Like the weather, combat is a complex event that resists precise prediction of individual events but is predictable in more aggregated operations. The critical element is the use of a well documented actual event so that your model doesn't wander away from reality too easily.

2. The OR community has a lot of experience with this. The quantification can easily go wrong, which is why the use of an actual event is needed to maintain maximum accuracy.

3. The first model of any project should be the replication of the actual events within the model.

4. Once you have a functional historical model, you can start modifying elements of the model to reflect a non-historical event.

5. Although the human factor is a bit more slippery than something like weapons performance.

6. Ray Macedonia and I prepared a paper, which he presented at the last MORS conference, on a machine driven tactical model that I designed for him up at Textron. Ten years earlier we had worked together on planning the McLintik Theater Model. Thus while most of my models were created for the mass market, the same techniques work quite well for defense applications.

7. The verbal presentation will cover only the main points. Refer to the footnotes in this paper for more background and detail.

8. The quality of these commercially available models varies enormously. Conceptually, most are quite good. Many manage to munge their history, particularly some of the current computerized versions. None are perfect, as the concept of perfect simulation of past or present events is still only a theoretical ideal. However, even the less perfect models have proven useful. Note that the push for professional use of these "toy store" models came from within the military community. There's a lesson in there somewhere.

9. I conducted a survey of the E-4 and below of my artillery battalion in the early 1960's and the most obviously efficient platoon in the battalion also had the most positive morale and attitude indicators on the survey. The battery was led by the most respected officer in the battalion. The troops knew the battery commander was good and they knew why.

10. Throughout history, the more competent armies arranged to have their new troops exposed to combat gradually, rather than intensively. They knew that green troops had to be eased into the chaos of battle lest they be killed off before they could make any contribution. This "blooding the troops" process has some curious consequences. Green units will often be more effective after their first bout of combat, even though their strength has been significantly reduced by battle losses. One theory about this is that these losses are largely the inept. Another observation is that the troops simply learn very quickly how to do things right and which of their leaders they should pay close attention to when the shooting starts.

11. If you want a lot of examples of the impact, pro and con, of training, refer to studies of how well troops do in the opening battles of wars. Expect the unexpected.

12. This happens in most wars, World War II being one of the few exceptions. There was euphoria in 1914, but mutinies in 1917. Many post-1945 wars suffered from morale problems, in particular Korea, Algeria, Vietnam, Falklands, various Middle East conflicts and so on. This element is particularly crucial for the most likely future wars of the low intensity persuasion.

13. This has had a subtle effect on the infantry in high tech armed forces. Whereas in the past you got many of the "best and the brightest" in the trenches, now you have the technical services skimming the more capable recruits and leaving the infantry with whatever's left. This is less a problem in the West, where troops serve longer and even the lower deciles are well prepared. In Russia, you end up filling the rifle pits and gun crews with people who are barely literate or can't even speak Russian. This has an impact on combat performance, particularly in the opening battles.

14. Anyone who has participated in a few combat unit FTX's knows that after three or four days of operations a significant portion of the troops and equipment are much the worse for the wear. Yes, it does get worse if someone is also firing live munitions at you.

15. The English won this late Medieval battle because they had superior training (rigorous drills for the archers), motivation (they were trapped), physical conditioning (the French partied the night before in anticipation of their certain victory), innate abilities (English Yeoman selected for service based on ability, not noble birth) and tactics which produced excessive fatigue in French troops). The battle could not have been realistically modeled unless these human factors were were accurately shown.

16. French leaders at all levels were more experienced and were thus able to whip raw French recruits into shape quickly using superior training techniques. Napoleons exceptional staff work and procedures enabled French to make the best of their interior lines (they were surrounded by more numerous Allied forces). A particular feature of this simulation is the depiction of the effect of all senior leaders and their abilities. The players had to cope with what to do with less capable leaders. As many of these senior commanders were nobles, it was often not possible to get rid of them.

17. Modeled severe shortcomings in initiative and perception of senior British commanders. Of lesser consequence were differences in troops. Although the British were better trained in formal warfare tactics, they were caught short by the low intensity warfare tactics used by the rebels. For example, the rebel raiders in the New York City suburbs made British foraging so costly that most British food for their large garrison had to be shipped from England.

18. Significant variation in capabilities of senior commanders. Major problem of commander in chief was how to deploy command assets that varied so much in quality and often had political strings attached. Even without a nobility, many of the same problems found in **Leipzig** (above).

19. Germans developed exceptionally well selected, trained, conditioned and led assault troops. Their major motivation was a "final offensive" to end the war. These German "Stosstruppen" units made extraordinary progress, coming quite close to deciding the war. All of this had to be reflected in a simulation that used regiments and divisions as the maneuver units.

20. Had to deal with the significant differences in leadership quality and style in these battles. The Germans had worked out more effective tactics and organization for mechanized warfare in the desert. Their small unit leadership was also superior as was their command and control. All of these elements had to be represented in the game in order to accurately model the historical combats.

21. Modeled the crucial importance of key Russian leaders and the uncertain quality of untried units. Also showed the tradeoffs of pushing troops beyond their endurance in order to gain a battlefield advantage.

22. Modeled all aspects of infantry in combat, particularly the psychological. The difficulties of command and control at this most tactical level of combat were given extensive treatment. Panic and confusion were also modeled. Players with combat experience noted that this game was the most accurate they had ever encountered.

23. The model itself should function as a database because combat data is very dynamic or, if you will, "fuzzy." My experience has shown that the model is regarded by many of its users as a form of data. I first consciously discovered this while conducting focus groups of users. I then realized that I had been long using the models the same way.

24. The data you need is often buried quite deep amidst some very fuzzy piles of extraneous material. This may explain why historians come across as rather vague compared to scientists and engineers.

25. And vice versa. AAR's are at least more structured. Unfortunately, the prose is often deadly dull. Have a supply of Jolt Cola handy.

26. Once you've designed a few historical battle simulations you will naturally do this when collecting data.

27. See the **Theater Combat Model** I have brought along and pass on to you for further study. This spreadsheet based model was first developed six years ago and is derived from techniques I have been using for over twenty years.

28. Some of this analysis has been done for contemporary armed forces. Not just collected OER stats, but more hefty studies. However, acting on these studies is considered a bit too sensitive. A model is another matter. After all, it's just a game. Right?

29. The US armed forces have done a bit of this, particularly the Army. Anyway, this type of analysis is used as the justification for the various reorganizations of ground combat units.

30. Troops trained or otherwise prepared for particular climates and terrain will perform better, or worse, depending on the quality of their preparation.

31. A lot of this work was done in support of the negotiations to reduce conventional forces in Europe.

32. This may account for the lack of human factors in models. It's much easier, and seemingly more productive, to model iron and doctrine.

33. Napoleon was a great believer in luck. The Germans had another perspective. I was one of the three "debriefers" of Wehrmacht Generals Balck and von Mellenthin back in 1980. These gentlemen had seen quite a lot of combat and attributed much success to a rare quality known as "Fingerspitzengefuel" (feeling in the tips of your fingers,). Balck noted that very few combat commanders had this talent.

34. This approach has a long history. The justly famous German 19th century wargames were based on this system. Just because these concepts were picked up, or reinvented, in the 1950's and 60's doesn't make them any less valid and useful.

35. Note that the Russians are quite diligent in their use of drills, particularly at division level and below. They do this in recognition of the fear and uncertainty element.

Military history shows that success often comes from being diligent and deliberate even in the face of uncertainty.

36. The critical factor that has to be added are appropriate randomization routines to reflect the uncertain performance of troops under the pressures and uncertainties of combat. Many industrial engineers also take this into account when designing complex, high stress and labor intensive processes.

37. Confusion and lack of information cause seemingly random actions. Russian research in this area has led them to develop their norms and battle drills. Fairly simple and straightforward techniques are used to create both sides of combat operating realistically in a model (with no operator intervention).

38. A platoon leader of any army has a number of drills his troops can perform with varying degrees of efficiency Much research and observation of troops in combat proved additional lists of likely unwanted actions triggered by contact with the enemy. If the analyst is in the loop, a drill can be chosen from a menu or a new one constructed using a simple editor. The "scripts" of existing drills can be used to develop new ones. The public domain game CROBOTS is available for you to examine, and take with you if you wish. This is a practical example of how the drill "language" would work. Note that all the programmed "actor" does is sense the environment and then move or fire depending on how it is programmed to react to the situation. Experience has shown that it does not take a large number of options to accurately and realistically re-create a software driven "soldier." Equally important is the collection and organization of the information for various armed forces and levels of operations. Giving users and analysts the ability to edit this data provides a dynamic research tool.

39. You don't need anything really exotic to make a combat model act "human." Just a little chaos will usually provide the desired effect. A little chaos is also cheaper to implement.

40. The more rank your subordinates have the more problems you have with ego and the other emotional baggage that comes with seniority. Unlike squad leaders, division commanders do not personally supervise their bull colonels and often have a more difficult time uncovering and correcting bad work.

41. To put it another way, a squad leader commands the ten or so privates. The division commander deals directly with a dozen or so key commanders and staff officers who are somewhat higher up the food chain than the squad leaders grunts. Both "squad" must be represented in the proper context. The squad leader has to watch out for real bullets, the division commander has to dodge paper bullets.

42. Unless you are invested with some God like powers, you must do it this way and not the other way around.

43. Although not impossible, however. Where there's a will, there's a way.

44. Trend lines are the average trend and, as most of your are well aware, reality wanders in and around this line. Again, the aggregation effect can minimize the damaging effects of these unpredictable trend variations.

45. This is the aggregation effect. If your analysis of platoon activity has shown what the range of platoon performance in combat, a battalion's worth of platoons displaying the usual differences in performance will still produce a fairly predictable range of battalion performance. Pick apart a few historical battles, reassemble them as a model and then exercise it a bit and you'll see what I mean.

46. You have to be careful with this and just a wee bit skeptical. You are dealing with people and the psychological factors can be easily ignored. It's not so easy to ignore them during real battles. Consult the French General Staff experience in 1916-17, and so on.

47. Same old story. The messier a subject, the more reluctant many are to tackle it.

48. Deciding which is crucial and which isn't can be an interesting exercise. When researching the event, you will have to construct track charts and the like to get an idea of what tactics and drills were used. There are usually numerous variations, just keep in

mind that you'll be spending most of your time in the center of a bell shaped curve of events.

49. Among other things, you will find relationships between munitions used and casualties inflicted and prevented. Use of medical supplies and other classes of supply will be seen to have various important effects.

50. This is the classic, "Operating Within the Cycle" of an opponent. It's not so much a question of how fast ones command loop is but rather how quick is it compared to the opponents. Another problem is whether the loop is in sync with your own operations. As you dig into the historical record you will uncover numerous examples of how easily things go wrong in combat. This is why it's so much easier to model the mechanical operation of a piece of equipment while the functioning of an infantry platoon will defy the same analytical techniques.

51. There still must be a man in the loop most of the time. Someone has to interpret what is going on out there and make an appropriate decision. The Russians use a formulaic approach, at least up to the division level. Above that they depend, as most Western armies do, on the "creativity" of the commander. Not everyone is equally creative.

52. The "correct" decision may not always be the most effective one. Most leaders have a hard time hitting home runs in this department, or even getting on base most of the time.

53. Leaders are largely at the mercy of their subordinates in this area.

54. Not too so on after all this.

55. Like most things in life, you're never entirely sure what's around the corner.

56. Note, however, the numerous similarities between the organization of most infantry divisions today and the Roman Legion of two thousand years ago. We could still learn a thing or two from the Romans about troop training and officer/NCO selection.

57. This is an institutional view, perhaps justified for maintaining the institution's image. The troops know better, as did many others in, say, the 1970's.

58. I've done this in quite a number of models. You have to. For example, do you think the average crew performance of each nation using the Leopard II MBT is the same? Of course not. Even the Russians recognize this in their planning norms. It's human factors again.

59. This is the kind of broad statement that can set off endless debates. However, the use of historical combat models will quickly settle most disagreements and misunderstandings about what is relevant and to what degree.

60. Understanding them better, motivating them, promoting them, relieving them, communicating with them, etc.

61. And the associated factors of panic, disorientation and combat fatigue.

62. There are several possible reasons why this type of modeling has not been widely used. Among them are:

We live in fear of our own inventions. This should not be underestimated.

Since World War II history has fallen out of favor as a combat model research tool.

In peacetime it is difficult to "prove" the validity of your assertion using contemporary experience.

Shortage of people skilled at historical research and OR techniques.

63. Those of you who have used any of the million or so copies of my manual models have already seen some of these human factors in action.

64. This is only a force on force model, but there is a variable for tactical capabilities. This version requires 123 2.0X, 512k, graphic adapter optional.

DISCUSSION OF "RESEARCH INTO A CONCEPTUAL FRAMEWORK FOR REPRESENTATION OF HUMAN FACTORS IN COMBAT MODELS"
by W. P. Cherry and I. Alderman, and
"INSERTING THE HUMAN FACTOR INTO COMBAT MODELS"
by J. Dunnigan

DISCUSSANT: L. Ronald Speight, SHAPE Technical Centre

Similarities. Both papers produce a list of human factors affecting battle performance with much in common with each other and with others who have delivered papers (experience, training, etc, etc, ...) at this symposium.

Cherry and Alderman's paper. Introduces a 'conceptual framework'. Two types of small group : 'effectors' and those exercising command and control (vertical passage of orders and information, horizontal synchronisation and coordination). Attempt to use lack of sleep as their exemplar of stress. Factors organised in one 'base function' and three successive 'modifier' functions.

Dunnigan's paper. Lists a number of battles. Only Agincourt puts much stress on skills at the individual task level. (Note, though, one factor omitted : the shock and surprise of concerted volleys of arrows raining on the French cavalrymen). For the rest, the emphasis tends to be on high level organisation and control.

The dangers of simple aggregation. Haslam's research (which they quote) reveals a marked degradation of reasoning ability with sleep deprivation, followed by a gradual restitution of ability when the stressor is removed. But the effect on such simple well-practised skills as rifle shooting is negligible. Simple aggregation might lead one to assume undiminished small arms performance in battle conditions in aggregated models. And yet Rowland's research reveals decrements of a factor of 10 for such performance in a trials settings, and of 100 in battle. Clearly, something other than a direct effect of the stressor is involved here. Cherry and Alderman's results start to give us clues as to what these indirect effects may be : they appear to have something to do with leadership, control and cohesion in a group setting.

The Soviet approach. The Soviets pay very great attention to the human factor in battle (indoctrination; the commitment of fresh units as those exposed to intense conflict show signs of battle fatigue; etc.). Very simply, their approach appears to embrace the following:

a. At the lower levels not optimisation, but ensuring the ability to do a simple and circumscribed task with some assurance. An emphasis on predictability wherever possible.

b. Ensuring this predictability by enforcing 'norms' of expenditure; by careful calculation of what resources will be required to complete a specified task or objective successfully; by using planning aids such as 'stochastic PERT-charting' to arrange schedules of activity, etc. The total requirements are assessed by exhaustive historical analysis (rather than by _ab initio_ modelling of all the components, adjusted for modern developments.

c. The operational art is reserved for the higher echelons. Great emphasis is placed on troop control at all its different levels, meaning not just control of one's own forces but imposing control on the enemy. Rather than the Western formulation of command and control as a 'force multiplier', it would be nearer the mark to describe the Soviet conception as 'force' being a 'command and control multiplier' or 'effector'. Whole books are written and published on the theory and practice of troop control.

What are the means of 'controlling' the enemy or of disrupting his control? They include such things as:

a. 'Stunning' the opposition with artillery bombardment (in which the immediate density of fire is more important than its total weight stretched over a long period).

b. Speed above all in the offensive, thus confusing the enemy, getting within his planning cycle, and clouding perception.

c. Deception as a matter of doctrine.

d. Surprise as a paramount requirement. Reassessment in the light of the unexpected, discarding hypotheses which had governed planning, and on which all prior perceptions were based; forcing a reformulation of aims and objectives on the spur of the moment; all these should lessen cohesion and lead to poorly coordinated defenses. (Compare with Agincourt).

It is not meant to imply that the Soviet approach is all right, and that the Western approach is all wrong. Rather, that there may be some point in examining the Soviet approach, and in borrowing selectively where it may have something to offer in tackling the human dimension, or in characterising battle at the higher levels.

Questions. In the light of these two papers, their predecessors and of the Soviet approach the following general questions are posed.

a. Some decades ago, investigators such as Thurstone, Burt and Cattell had appreciable success in breaking down intellectual abilities into a number of separate factors, accounting for a fair portion of the variance of reasoning tasks. Fitts had much less success in attempting a parallel characterisation of psychomotor tasks, and a very large proportion of task-specific variation seemed to be present. What is now the accepted wisdom as regards our prospects for achieving some useful overall scheme for describing the interaction between stressors and a manageable number of 'abilities'? Is such a descriptive scheme going to account for a significant portion of battle behaviour? Or is this approach likely to lead us to an almost infinite list of fairly specific tasks, affected differently by different stressors, which in turn interact with other stressors in a way which is difficult to predict?

b. Given success in a scheme describing individual task by stressor interactions, will such predictions of task performance transfer easily to group performance? If not, should we not be concentrating our research on social and group phenomena?

c. As we increase the level of aggregation what are the factors which dominate results? Do we need great accuracy in those factors which contribute relatively little to the overall variance (such as, possibly, individual weapon performance)? Should we not now be concentrating research effort on those factors which appear to have the dominant effect, even if they appear less tractable than those on which we have concentrated hitherto?

d. Many of our aggregated models appear to be attrition driven. Forces are opposed (as a result of gross planning, but perhaps of detailed accident). Attrition occurs as a function of the opposing weapon systems. As a result of these force ratios and of this attrition all sorts of model consequences flow. Should not our models be driven more by military intentions than by mere force ratios?

e. If there is thought to be any merit in attending more to military aims and intentions, then does this not suggest that we should be building up our own theory and formulations of troop control? Might not such theories assist in the task of incorporating more operational realism at the higher levels of aggregation? And might they not be one vehicle for introducing human factors in a structured manner at such levels?

Conclusions. Whatever one's answer to all these questions, these two papers seem to me to be invaluable in focussing our attention on factors above the individual task level. It seems that these higher level factors are dominant in explaining the outcomes of battles, as opposed to duels. Huge strides have been made in collecting and organising the data pertinent to the lower levels of battle. It is time now to tackle the factors which dominate the higher levels.

SIMNET-D: COMBAT MODELING THROUGH INTERACTIVE SIMULATION

Thomas Radgowski
Richard E. Garvey, Jr.
BBN Systems and Technologies Corp.
2021 Black Horse Regiment Ave., P.O. Box 39
Ft Knox, KY 40121
(502) 942-1092

INTRODUCTION

Scientists and engineers have long used mathematical models as tools to help explain and predict events. These models have been very successful in describing occurrences in the physical world, such as the motion of planets, or the flight of an aircraft. More recently, operations research analysts (ORAs) have extended the use of these models to the sphere of military conflict. These models have proved to be of immense value in the development of military systems, because of their ability to describe and predict system performance. Recent advances in computer technology have allowed the ORA to increase both the scope and the detail of combat models, further enhancing their value to the development process. At times, however, the actual performance of the system in battle has varied from that predicted by the combat model. Often this variability has been attributed to unpredicted behavior on the part of the human operators of the system.

Mathematical modeling of human behavior has always been difficult. Human behavior is so complex, and influenced by so many factors, that it appears, at times, inexplicable and unpredictable. Nevertheless, many advances have been made in this area, particularly in the application of artificial intelligence (AI) techniques. AI has allowed the introduction of rule-based decisions into the modeling process, further enhancing the representation of human behavior. Unfortunately, even with these improvements, current computer models often fall short of adequately portraying the reaction of human beings in a combat situation. Rule-based models cannot always predict how an individual is going to react to the "fog of war", because soldiers do not always fight by the rules. Indeed, history suggests that victory often goes to the innovative, the unpredictable. The challenge remains to combine our current ability to accurately model physical events with some means of reflecting the human ability to adapt.

The Defense Advanced Research Projects Agency (DARPA) is taking a different approach to solving this problem with the SIMulator NETwork (SIMNET) project. The SIMNET approach to incorporating human behavior into combat modeling is man-in-the-loop, interactive simulation. SIMNET-Developmental (SIMNET-D) is the application of this approach to questions of battlefield (combat, training, tactics and doctrine) developments. The SIMNET-D concept is to model the key elements of the combined arms battlefield, man them with trained soldiers, then let the soldier do the fighting, while collecting and reducing data on human and system performance.

This paper will describe SIMNET-D, give examples of SIMNET-D applications in combat modeling , and discuss some issues that DARPA is addressing concerning the development of SIMNET-D as a combat model.

WHAT IS SIMNET?

SIMNET is a DARPA advanced research project into interactive simulator networking. The goal of SIMNET is to create a complete combat world that includes force-on-force combat vehicles (fully crewed simulators), a vertical slice of the chain of command (command and control), essential combat support (artillery, mortars, close air), and combat service support (refueling, rearming, maintaining).

SIMNET, now in its sixth year of development, currently simulates a variety of combat vehicles including the M1, M2/3, generic rotary and fixed wing aircraft, and the Line of Sight Forward Heavy (LOS-F-H) component of the Forward Area Air Defense System (FAADS). These simulators are now being used at sites in the United States and Germany. At present they are routinely engaging in long-distance training activities over a dedicated telecommunications line.

WHY IS SIMNET DIFFERENT?

The two key characteristics that make the SIMNET simulation different from other simulations are:

- It is a distributed simulation
- It is an interactive simulation

Distributed simulation means that there is no central computer directing the activities of the various simulation elements. Instead, each simulator has its own microcomputer, which is in continuous communication with each of the other simulation elements. One significant advantage of this approach is that, as the simulation network expands, each new simulator brings with it all of the computer resources necessary to support its computational requirements. This means that adding new simulators does not involve modifications to simulators already on the network. Further, technical problems with a single computer do not affect the overall simulation.

SIMNET is an interactive simulation that differs sharply from full crew conventional simulators, where crew members are alone in their simulated world. They can interact among themselves and control the actions of their vehicle, but other inputs into the simulation (such as the threat) are generated either by a computer or by a human controller who is not directly involved in the simulation. In SIMNET, the crew of one simulator can see and respond to the actions of other crews on the battlefield. SIMNET does not pit man against computer. In SIMNET, soldiers fight against other soldiers who are trying to fight and win on the same battlefield.

CHARACTERISTICS OF SIMNET SIMULATORS

One of the keys to SIMNET's ability to model the battlefield is the accuracy and detail with which SIMNET models combat vehicles. Simulated features of SIMNET vehicles include:

- Detailed vehicle dynamics such as engine, transmission, and drivetrain characteristics, as well as suspension, track, and soil interaction. Vehicles speed up or slow down depending on the slope and type of terrain on which they are driving. Vehicles also get stuck in unfordable rivers, and throw a track when traversing a too steep slope.

- Weapons systems dynamics such as turret and gun kinematics (azimuth/elevation) and main gun ballistics. The interaction between the laser range finder, ballistics computer, and manual inputs by the gunner affect whether or not the shell impacts the intended target.

- Damage and failure simulation for electrical, hydraulic, weapons, and other systems. SIMNET vehicles use fuel at rates representative of the actual vehicles. They use ammo at a rate determined by how frequently the crew members fire the weapons. They break down in accordance with mean time between failure rates. They can also be damaged by misuse or by enemy fire.

SEMI-AUTOMATED FORCES

In order for SIMNET to be successful, it must have the ability to mount an exercise where a unit can participate in a battle of an appropriate scale, with realistic opposing and flanking forces. One of the challenges of conducting such an exercise with man-in-the-loop is that it is difficult to provide enough qualified manpower to participate in a long-term, large-scale exercise. Indeed, the availability of troops is often a limiting factor in the scheduling of SIMNET activities. The SIMNET answer to this challenge is called Semi-Automated Forces (SAF). SAF uses artificial intelligence techniques to allow a single individual to command units of air and ground combat vehicles up to a battalion in size. The individual vehicles in an SAF unit have the same performance characteristics (vehicle and weapons dynamics, damage and failure simulation) as the manned simulators. The commander makes the tactical decisions of where, when, and how to move and shoot, and the SAF system executes the commands on the battlefield. SAF units are designed to behave so realistically that opposing forces cannot distinguish between them and a unit with combat vehicles manned by human crews. Semi-Automated Forces are regularly used in coordination with manned forces to play opposing or flanking forces in SIMNET training and developmental activities.

MANAGEMENT, COMMAND, AND CONTROL SYSTEM

Besides manned and semi-automated simulators, other devices also communicate on the network and play roles in the SIMNET simulation. The Management, Command, and Control system (MCC) performs the following functions:

- Initialize the simulation - The SIMNET Control Console initializes each simulator, giving initial conditions such as location, orientation, vehicle ID, supply status, and mileage (for modeling stochastic failures).

- Provide combat support - The MCC controls air, mortar, and artillery strikes against ground targets.

- Provide combat service support - The MCC controls the dispatching of fuel, maintenance, and ammunition trucks.

HOW SIMNET WORKS

Simulators

There are four major hardware components of a SIMNET simulator: the simulation host computer; controls, displays and the Interactive Device Controller (IDC) boards; the Computer Image Generation (CIG) system; and the sound system.

Simulation Host

The simulation host computer provides the main computing resources for the simulator. In general, it collects, processes, and distributes data to individual components of the simulator and serves as a gateway to other devices on the network. In order to provide a realistic simulation, each simulator host maintains a detailed model of its own status, including current levels of engine power, thrust, and fuel consumption; aerodynamic or terrain forces; and status of weapon system computers. To reduce network traffic, each simulator also maintains a dead reckoning model of itself and every other simulator on the network. The dead reckoning model extrapolates the current velocity and position of every other vehicle based upon that vehicle's last reported position and velocity vector. The simulation host constantly compares its own dead reckoning model with the detailed model of its status. When the difference between these models exceeds a certain threshold value (which is easily modified), the simulator broadcasts a new vehicle appearance packet onto the network. The other simulators use this message to update both their view of the vehicle and their dead reckoning model of that vehicle.

Controls, Displays and IDC Boards

The controls and displays in a SIMNET M1 tank simulator are divided into stations according to the function they perform (driver, vehicle commander, gunner, loader). These controls and displays resemble the devices in the actual vehicle. Each station is serviced by an Interactive Device Controller (IDC) board that translates analog signals from the controls into digital signals. Likewise, the IDC board interprets digital signals from the simulation host and translates them into analog signals for the displays.

Computer Image Generation System

The Computer Image Generation (CIG) system interfaces with the simulation host computer to generate the images that appear in the vision blocks of the simulator. Each CIG has a database containing information about terrain elevation and objects on the terrain, such as vehicles, houses, trees, roads, and rivers. This information allows the CIG to generate a view of the terrain for each vision block and to display images of vehicles and transient phenomena (such as shell bursts) onto this view.

Because the CIG contains the terrain database, it plays a key role in the simulation of certain functions regarding the database. For example, the CIG provides the host with regular updates on relevant features of the local terrain, such as grade and composition of the soil. This allows the host to accurately calculate the effects of the terrain on the performance of the simulated vehicle. For example, a vehicle will slow down if driven off of a paved road onto loose soil.

Knowledge of the database also allows the CIG to calculate the point of impact of a projectile. When a simulator fires a projectile, the simulation host informs the CIG of the type of ammunition fired and its initial velocity vector; the simulation host then updates the velocity vector for the entire flight. The CIG determines whether the shell hits anything on a frame-by-frame basis (each frame equals 1/15th of a second). When the CIG determines that an impact has occurred, it sends the host a message containing the type of object hit, the coordinates of the impact, and for a hit, the location of the impact on the victim.

Sound System

The sound system provides audio feedback to the crew members regarding events occurring in their vehicle and elsewhere in the simulation. Signals from the simulation (e.g., the ground impact of an artillery round) come to the simulator over the Ethernet. The simulator host determines the proximity of the burst and sends a signal to the sound system to produce the appropriate sound at the correct intensity. The sound system then produces the sound through the amplifiers and speakers.

Example

Figure 1 presents a block diagram of the simulator hardware. If the driver opens the throttle to increase the speed of the vehicle, the throttle converts the physical movement of the control grips into an analog signal. The signal proceeds to the IDC board which transforms it into a digital signal and communicates it to the simulation host computer.

The simulation host interprets the input and incorporates the change in throttle position into the detailed model of its own status, taking into account the engine, drivetrain, soil type, and grade; it constantly compares the updated detailed model with its version of its own dead reckoning model. Whenever the models differ by more than the threshold level, it broadcasts a new vehicle appearance packet over the network. Other simulators receive this message and update the position and velocity vector of the vehicle in their dead reckoning models.

For each frame (1/15th of a second), the simulation host also:

- sends the current x,y,z positions to the CIG. The CIG displays the world in the vision blocks as seen from the x,y,z position received from the simulation host. Because the driver is increasing speed, successive x,y,z positions will be farther apart each frame. These updates occur so rapidly that the visual effect for a tank crew member looking through a vision block is to see the side of the road and other terrain features move by faster and faster.

- sends current values such as RPM and speed through the IDC board to the appropriate internal displays.

- sends current values of engine noise and vibration to the sound system. As speed increases, turbine pitch and rumble of the tank's treads on the earth's surface will also increase.

SIMNET HARDWARE

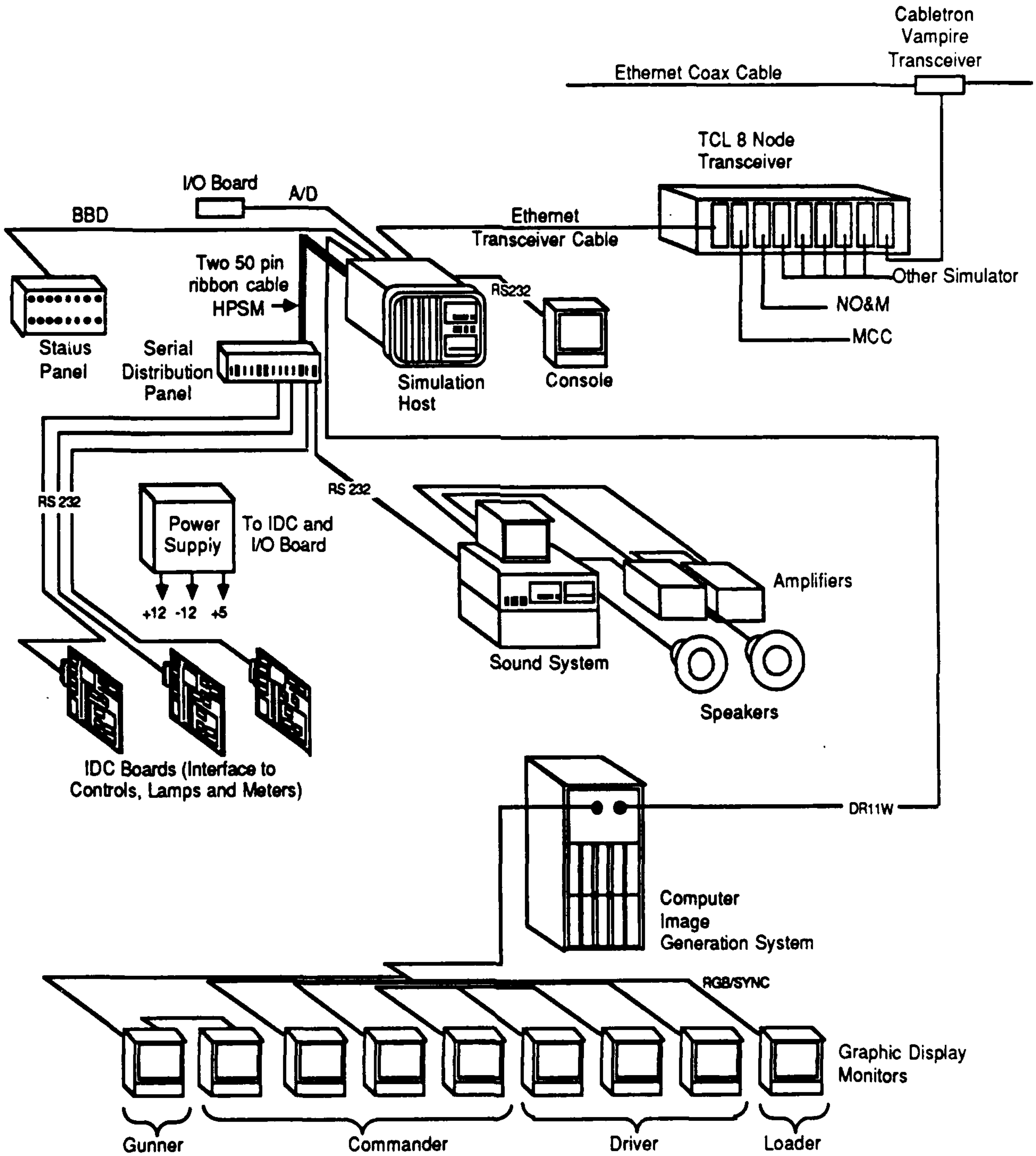


Figure 1

SIMNET PROTOCOL

A SIMNET simulator performs actions by transmitting specially formatted data packets over the network. Data packets contain information about the status of simulated vehicles (such as a Vehicle Appearance packet), or about specific events that occur on the simulated battlefield (such as a Vehicle Collision packet). Each packet contains the information necessary for the other simulators to update their views of the world. For example, a Vehicle Appearance packet for an M1 simulator contains information on the identity of that simulator, hull and turret orientation and location, velocity vector components, gun tube elevation, and gun muzzle location. Once the packet is broadcast over the network, any other simulator in the exercise can interpret this information and paint an accurate picture of the M1 in the correct location in its vision blocks.

For direct fire events, a set of packets describes the complete event. A Fire packet is transmitted at the time of fire, and contains the firer's identity, the type and velocity vector of the projectile, and the location of the muzzle. If, during the flyout, the projectile impacts the ground (misses the target), a Ground Impact packet is transmitted. Likewise, a Vehicle Impact packet is transmitted for a hit, which contains the firer's identity, the victim's identity, and the location of the impact on the victim. Finally, for a hit, the victim assesses the damage and reports it in a Status Change packet, which contains the victim's identity, the causing vehicle's identity, and the damage.

SIMNET-D DATA COLLECTION AND ANALYSIS

The SIMNET-D Data Collection and Analysis (DCA) system collects, replays, reduces, and analyzes the data packets generated by a SIMNET-D exercise. The three major components of the SIMNET-D DCA system are the Data Logger, the Plan View Display (PVD), and a data analysis subsystem.

Data Logger

The Data Logger is a mass storage device consisting of both hard disk and magnetic tape recording devices. It records all the data packets broadcast over the SIMNET-D network directly to disk or to tape. All of the appearance, firing, logistics, and other data generated during the exercise are stored for later analysis. The Data Logger can later play back this complete time history of the battle by transmitting all recorded packets from disk onto the network. The action can be viewed on the Plan View Display, which provides a birds-eye view of the battle. An additional playback capability is "time travel", i.e., the ability to play the exercise back into a simulator and allow the soldiers to drive around the battlefield and observe the exercise from ground level and from any location they choose, including locations where no vehicle was present when the data was recorded. Playback also has VCR-like capabilities such as fast-forward, freeze, or playback starting at a specified time.

Plan View Display

The Plan View Display (PVD) contains a copy of the terrain database and presents a relief map of the area on its screen. The map includes the roads, rivers, and geographic features of the terrain. Several features can be added or removed from the map including shading, contour lines, and map grids. Data can be displayed on the PVD from a currently active simulation on the SIMNET-D network, or from a recorded simulation played back from the Data Logger. The PVD interprets the data to superimpose color-coded icons representing vehicles, artillery shell impacts, and direct fire shots in the correct location on the terrain map.

The PVD also provides map manipulation and analysis tools. For example, the user can zoom in or out of any selected area of the battlefield and pan the display in any direction. Elevation and map coordinate values can be obtained for any point. Further, the user can obtain intervisibility readings between points or vehicles and examine a graphic representation of a cross section of selected terrain from one point to another. By selecting a specific vehicle, the user can obtain detailed information such as vehicle ID, location, speed, ammunition, fuel, and repair status.

Data Analysis Subsystem

The data analysis subsystem runs on a MicroVAX cluster equipped with GPX high-resolution color terminals. The recorded data from the exercise can be taken from the Data Logger and ported to this subsystem. Two analysis software programs, RS/Probe ® and RS/1® are designed to extract, organize, and analyze the data of immediate interest.

RS/Probe

RS/Probe is an interactive graphics-oriented data analysis and display software package. Its main feature is the ability to extract desired information from immense quantities of data and perform complex analysis operations on it. For example, RS/Probe can be used to extract pertinent movement and shot data from a recorded exercise and use those data to make a plot of the unit's distribution of fire during the exercise. Other output displays that RS/Probe can provide include x-y plots, time plots, spectral plots, and tabulations. Tabulations can be formatted several ways, and relayed to RS/1 for further analysis.

RS/1

The RS/1 software package combines data base management and statistical analysis features. Once tabulated, data can be rearranged, statistically analyzed, and graphically displayed. Statistical analyses include standard descriptive statistics as well as t-tests, F-tests, analysis of variance, correlations, and curve-fitting. Graphs include x-y graphs, bar graphs, three-dimensional graphs, and pie charts. Individual analysis procedures on RS/1 can be performed interactively or preprogrammed using RPL, a PL/1-like programming language. These procedures can be used to examine recorded data and provide measures such as hit rate or range distribution of hits.

RS/Probe and RS/1 are registered trademarks of BBN Software Products Corporation.

Recently SIMNET-D Research Analysts have developed real-time analysis for the SIMNET-D DCA system. With real-time analysis, the DCA system can now begin to generate standard measures as soon as the exercise begins. This permits a time savings of 80% over previous methods and can provide standard measures within two hours of the completion of the day's exercise. Measures currently available with real-time analysis include:

- Events list
  - Shots, hits, collisions, and resulting damage
  - Location, time, vehicle ID, range and ammo type
- Killer-victim and hitter-target scoreboards
- Loss Exchange Ratios
- Force Exchange Ratios
- Surviving Force Ratio Differential
- Bargraphs
  - Losses/kills over time
  - Range distribution of shots, hits, and kills
- Hit rate
- Number of rounds per kill
- Shots, hits, kills, and losses over time

These measures can be generated for individual vehicles or for different combinations of vehicles. Other test specific measures can be calculated from the basic data recorded by the Data Logger, including:

- Location and movement data
- Speed data
- Maps of vehicle motion and shots
- Logistics data
- Intervisibility
- Gunnery data (e.g., aiming and tracking errors)
- Device usage (e.g., how many times a particular button is pressed)

Most of these measures can be extracted from the data currently in the SIMNET-D protocol in about a day. Also, new data packets can be created to allow automatic collection and reduction of additional measures as required by a particular customer.

SIMNET-D CAPABILITIES

The combination of a realistic combined arms battlefield with an extensive data collection and analysis capability provides SIMNET-D with the capability to perform:

- Soldier-in-the-loop evaluation of new systems, concepts, or modifications to current systems
- Development/refinement of hardware specifications

- Evaluation/development of operational concepts, doctrine, and tactics

- Evaluation of MANPRINT issues

- Rehearsal of FDT&E or IOT&E

SIMNET-D ACTIVITIES

The SIMNET-D facility opened in November, 1987. Since that time, several organizations have conducted developmental activities at the site. A developmental activity is defined as a test, study, experiment, investigation, trial, or other examination of a battlefield development issue. While several different styles of activity have been evident, the common denominator of all these activities has been the desire to describe and predict new system performance by taking advantage of SIMNET-D's capability to perform man-in-the-loop simulation of a combined arms battlefield. This section will describe SIMNET-D activities conducted by the U.S. Army Air Defense Artillery Board and the Directorate of Combat Developments (DCD), U.S. Army Armor Center.

SIMNET LOS-F-H INNOVATIVE TEST

In March - April 1988, the U.S. Army Air Defense Artillery Board conducted an Innovative Test of SIMNET-D in support of the development of the Forward Area Air Defense System (FAADS). The goal of the test was to determine the extent to which SIMNET-D could be used to examine critical Force Development Test and Evaluation (FDT&E) and Initial Operational Test and Evaluation (IOT&E) issues. The medium for examining these issues was a battalion level, force-on-force exercise. The Red forces included a large component of fixed and rotary wing aircraft. The Blue forces included Armor and Calvary units supported by a platoon of the Line-of-Sight-Forward (LOS-F) component of the FAADS. The test began with a thirty-six hour continuous exercise with Blue in the offense. The test continued for a week, running different excursions off of the baseline exercise. The free play nature of the exercise allowed the soldiers to try novel approaches to accomplish their mission. Air defenders and rotary and fixed wing pilots experimented with many tactics and counter tactics. For example, the air defense troops became skilled in using artillery to destroy helicopters that their radar showed to be hovering behind terrain features. Task force commanders were required to innovate as well. In one excursion, the LOS-F platoon was removed from the battlefield. The Blue task force commander, realizing that he would not last long without their support, dedicated all of his air assets to an air-to-air role and attacked his objective as quickly as he could. The Red forces hesitated committing their air assets to the attack until they were certain that there were no air defense systems on the battlefield. When they did, they inflicted heavy losses on the Blue forces, but the Blue task force had already achieved its objective.

Once these battles were complete, ORAs, training analysts, and doctrine and tactics specialists examined the outcome. Even though the test was intended to be an evaluation of SIMNET-D, and was conducted using a generic version of the LOS-F, the Air Defense Artillery community reported that they learned many valuable lessons from the exercise. [1]

In particular, they recognized SIMNET-D's capability to:

- Accommodate joint integrated testing of Air Defense Artillery systems

- Evaluate system performance characteristics and identify product improvements

- Generate, collect, and reduce data to address combat developments issues

- Test the effectiveness of established and emerging tactics and doctrine

M1A1 BLOCK II TANK SIMNET EVALUATION

In June of 1988, MG Thomas Tait, Commanding General of the U.S. Army Armor Center and Ft Knox, approached the SIMNET-D Site Manager with a request to conduct an evaluation of the proposed Block II improvements to the M1A1 tank. The purpose of the evaluation was to:

- Attempt to identify measurable trends which reflect upon Block II synergistic effects on Abrams tank fightability

- Define in more detail all Block II software user requirements and address Block II MANPRINT issues

The Block II devices that were of interest were the Inter-Vehicular Information System (IVIS), the Commander's Independent Thermal Viewer (CITV), and the Position Navigation Equipment (P/NE). The suspense for this activity was short: the report had to be completed by 30 Sep 88. SIMNET-D software scientists and research analysts worked with ORAs and other subject matter experts from DCD and the Ft Knox branch of the Army Research Institute to develop both the simulation of the devices and the measures of effectiveness and measures of performance to evaluate them. By 25 July, 1988, five Block II tank simulators were available for testing by soldiers. DCD conducted three weeks of exercises during which the Block II platoon and their company commander repeatedly engaged a semi-automated Motorized Rifle Company in offensive and defensive scenarios. The IVIS, CITV, AND P/NE devices were examined both independently and in synergy, while the SIMNET-D DCA system collected objective measures on the platoon's ability to navigate, communicate and fight on the battlefield. In addition, detailed debriefings provided subjective data on these devices from what quickly became a platoon of Block II subject matter experts. While time did not permit a tightly controlled study that would yield statistically significant data (such a study is currently being conducted by the Ft Knox ARI Field Unit), this SIMNET-D exercise, combined with other parallel efforts, provided DCD with enough insight to be able to generate the required recommendations. In other words, they felt that they could confidently describe and predict how the Block II improvements would enhance soldier performance on the battlefield.

SIMNET-D AS A BATTLEFIELD DEVELOPMENTS MODEL

ACCURACY OF THE MODEL

One of the challenges for SIMNET-D is to constantly improve the detail and fidelity of the simulated battlefield, while maintaining cost effectiveness. In particular, the models of the combat vehicles must be as accurate as possible. In order to do this, the SIMNET-D approach dictates that you model only the essential elements of a system; i.e., those that are crucial to warfighting and surviving on a combined arms battlefield. This allows you to construct the simulator at a cost that permits large scale, interactive exercises. However, the task analysis first used to develop SIMNET simulators concentrated on providing simulators for training purposes. Certain compromises were permitted in this process. For example, the damage assessment model for the M1 main gun was generated using approximations of the actual dε The actual data was not used because it was classified, and it was noι seen as appropriate to include classified data in a training system. For SIMNET's role as a battlefield developments model, however, the actual data is required, and is being incorporated into the simulation at this time.

Recognizing that the performance characteristics of a SIMNET-D simulator may need to be changed from study to study , SIMNET-D software scientists are currently developing a model editor. The model editor will allow the values in the simulation to be changed to accomrr.ɔdate this need. For example, if the customer wishes to change the probability of a kill given a hit for a particular vehicle, the model editor will allow that change to be made quickly and easily.

VALIDATION OF SIMNET-D

In a simulation of this complexity, putting the correct data into the correct table of the model of a vehicle does not always guarantee that the vehicle will perform correctly. The many interactions on the SIMNET-D battlefield occasionally result in some surprises. As a result, SIMNET-D research analysts are developing a set of automated tests to determine whether or not the vehicle performs as specified. This set of tests is based on standard Army acceptance tests for real vehicles, and includes evaluations of weapons, engine, transmission, and damage simulations. The tests are conducted every time a new vehicle is introduced, or changes are made to any parameter of an old vehicle. In addition, the TRADOC System Manager (TSM)-SIMNET has contracted for an independent validation and verification of the vehicle models currently used in the SIMNET-D simulation.

Validation tests of the SIMNET system as a whole are also being conducted by the Army. Some of these focus on the use of SIMNET as a training device. These have concentrated on determining if the behavior of soldiers in the SIMNET environment is representative of that of soldiers in the field. For example, the U. S. Army Armor and Engineer Board conducted a Concept Evaluation Program of SIMNET that compared training in SIMNET with training in the field. The overall conclusion was that there was no significant difference between troops that were trained in collective tasks in the field environment versus those who were trained in SIMNET. Future efforts at training validation include a Cost and Training Effectiveness Analysis by TSM-SIMNET.

CONCLUSION

SIMNET-D has great potential as a battlefield developments model. Equipping soldiers with realistic simulations of weapon systems and allowing them to fight on a combined arms battlefield allows SIMNET-D to maximize our ability to model the physical world while incorporating man's creativity in the process. The resulting ability to explain and predict events on the battlefield holds much promise for the development of new materiel, tactics, doctrine, and training procedures. As the simulators and simulation are improved and validated, this promise will be fulfilled.

REFERENCES

1. Innovative Test of the Simulator Network (SIMNET) System, Letter Report; TRMS 88-FD-0158, RCS ATTE-3; Pate, MAJ Dennis W., Lewis, CPT Bruce D., Wolf, SFC Gary F.; U.S. Army Air Defense Artillery Board; June, 1988.

AGGREGATION ISSUES FOR COMMAND MODULES IN SIMNET

by

Dr. Alton L. Gilbert,
LTC John Robbins, USA (Ret)
Technical Solutions, Inc.

Dr. Stephen Downes-Martin
BBN Systems and Technologies Corporation

Dr. Wilbur Payne
Consultant

Abstract.

Representation of combat in SIMNET offers new challenges in the development of credible aggregation/disaggregation methodologies and a welcome opportunity to validate alternative methodologies in current use within the military operations research community. The "man-in-the-loop" nature of SIMNET provides a degree of operational realism heretofore achieved only in field exercises, with an ability to capture events and observe force interactions to a greater level of detail and at a lower cost than with such exercises. Representation of command and control through semi-automated forces makes possible the representation of force structures through echelons above Corps. This paper, while not contending that it presents all the answers, presents an approach, raises numerous questions, and makes various observations relating to the issues of representation of both aggregated forces and individual systems in SIMNET.

Introduction to Command Modules in SIMNET.

As an introduction to the program the words of one of the architects and philosophical mentors of the SIMNET (ref 4, 5, 6, 7, 8) program, Gary Bloedorn, are provided.

> *"Over the last decade, the U.S. Army has made significant advances in developing air/land battle doctrine and procuring automated Command and Control (C2), and computer-aided communication systems to support the conduct of this doctrine during war. The Army has, however, made less progress in developing a comprehensive C2 program needed to integrate this hardware and doctrine into a C2 system.*
>
> *As noted by General W. DePuy in his August 1988 article in Army Magazine, C2, '...**is a process that unifies the efforts of thousands of men performing a bewildering array of battlefield functions, each one of which is utterly essential to success. This process produces unity of effort from a diversity of means.**' DePuy goes on to note, and this is the single most important insight to be brought to the problem of developing effective C2 systems, that C2 systems may use communications and computers but that the* 'heart of the process lies in the mind of the commander'.

The Combined Arms Center (CAC) has formulated a comprehensive training program for the application of advanced automation to the battlefield requirements for C2. The synergy expected to be gained by aggressive implementation of this program has the potential to greatly enhance battlefield effectiveness by development of commanders skilled in using the hardware to develop, communicate and execute their concepts through unified application of the array of battlefield functions. Named the Battle Command Integration Program (BCIP), it is a strategy to draw together the diverse elements of C2. BCIP is to provide the mechanism to assess all aspects of the current C2 system as well and to play a dominant role in shaping the future C2.

Central to the CAC BCIP and the network technologies that allow the NSC to exercise centralized control of decentralized simulations is the development of what DARPA [Defense Agency Research Projects Agency] calls a Comprehensive Military Simulation (SIMCOMP). SIMCOMP can best be defined as an emerging national (and perhaps international) military simulation complex of which the SIMNET Command Modules at CAC will serve as a prototype for replication and rapid expansion as required, much as the Fort Knox SIMNET site now serves as a prototype for the Army. Key features of SIMCOMP are:

A centralized, world class OPposing FORces (OPFOR) (initially located at Fort Leavenworth and expanded as required to serve the JWC & SACEUR/NATO);

- *Long haul networking;*
- *Standard terrain databases; and*
- *Prototype/standardized Corps, Division, and Brigade, and equivalent JTF command posts.*

SIMCOMP incorporates both engagement level (or manned SIMNET level) simulations, characterized by their faithful, physical reality in all essential detail and more highly aggregated Operational or command level simulations wherein the power of distributed microprocessors is used to keep track of all military essential aspects of units that are directed by commanders. The commanders will direct their units by use of automated workstations similar to those now employed at Fort Knox in SIMNET-D for Semi-Automated Forces and in SIMNET-T for the TOC/ALOC. The ultimate goal expressed by DARPA is to create a distributed simulation capable of supporting a 20 Corps exercise with an OPFOR of 40 Corps-sized units. Such a simulation would network roughly 200 Divisions, 800 Brigades, and 3,000 Battalions.

Figure 1 below, depicts this SIMCOMP CAC prototype package at maturity. Notice that some elements of the BCIP simulation in Figure 1 are partially out of the SIMNET 'World', while others such as our self-contained sites at Fort Knox and Fort Benning are completely submerged in the SIMNET 'World'. This is to indicate that the BCIP elements exist in both an academic and separate *environment, and in a real world forces tactical environment using actual Army classrooms, field equipment, C2 automation and communications, as well as SIMNET networks, workstations, and simulators. The challenge is to design our command modules so that they achieve a transparent interface with the non-SIMNET elements, i.e., they can all live in the SIMNET 'World' and conduct their warfighting duties whether in the field CP complex, the college classroom, or in the SIMNET simulator (at a SIMNET site, or in a field location).*"

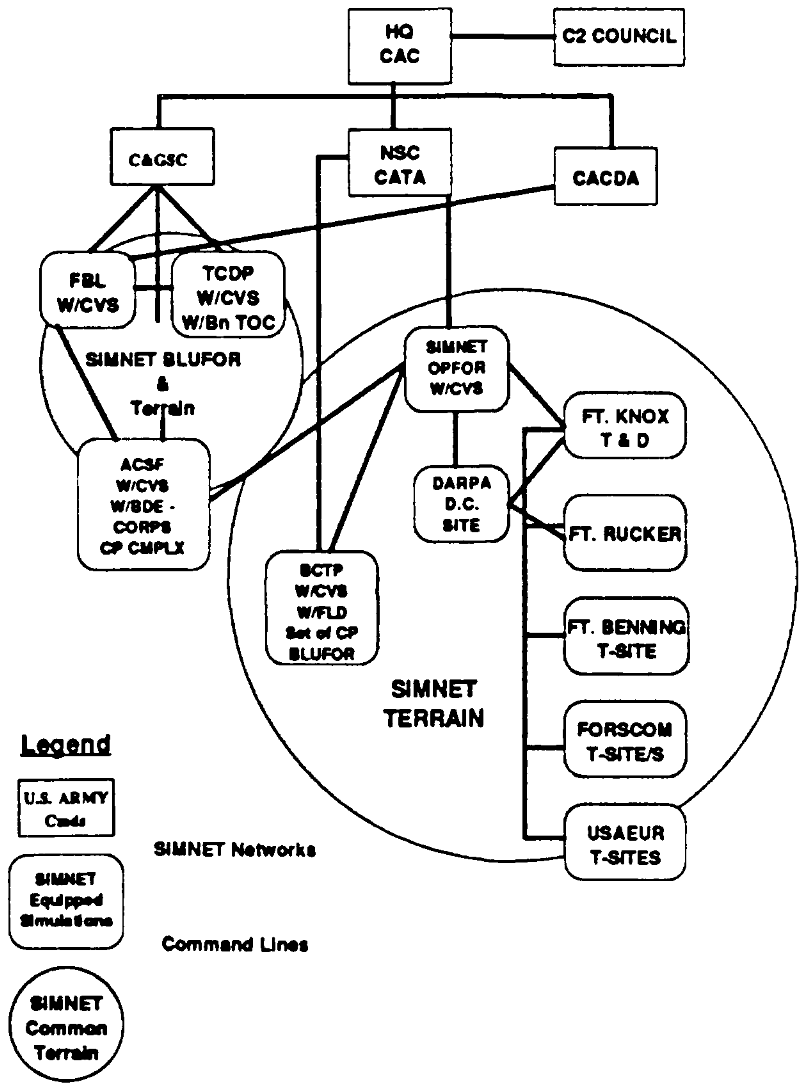


Figure 1
SIMNET BCIP Simulation

When used as a classroom training aid, or as an exercise domain for operational training, it is completely unreasonable to expect all, or a large fraction, of the units in the forces to be represented through active manned simulations. It is not even reasonable to expect most of the headquarters to be manned. The SIMNET BCIP simulation is, therefore, designed so that both headquarters and operational elements of the forces can be represented in mathematical simulations or as manned simulations. In any exercise of SIMNET BCIP, it is assumed that:

1. Only a fraction of the headquarters or operational units will be represented as manned simulations;

2. This fraction will be chosen because those force elements are the critical training subject or they have a critical impact on the causes and actions of battle; and

3. The force elements that are manned simulations will usually change during an exercise as their posture and activity changes and the critical combat action shifts to different units.

This design requires development of mathematical simulations of units and headquarters, a challenge common to typical force on force combat models. It also requires the ability to interface these mathematical models that may describe the state of a force element in an aggregated manner, with force elements represented in manned simulations, a challenge unique to SIMNET BCIP.

To illustrate this more concretely, assume that some BLUE Battalion task force is represented in manned simulation because it is soon to engage in a critical battle. Part of the RED force it will engage may already be present in the operations area and will be represented as individual vehicles or materiel items. During the course of the battle, both BLUE and RED may be reinforced. Generally, these reinforcements will come from units that are represented in mathematical simulations. Elements of BLUE and RED forces, aircraft in particular, may enter the area of operations during the battle. Whenever this occurs, it will be necessary to represent them at the same detail as any other element of a SIMNET battle.

Purpose.

The purpose of this paper is to present the status of an on-going R&D effort that is addressing the issues of aggregation and deaggregation of forces that must occur in the successful implementation of the BCIP. It can be easily understood by those experienced in such matters, and perhaps appreciated by the rest of us, that doing the "bookkeeping" on forces in combat, that may at some times be represented in highly aggregated form, such as a Division, and at other times represented by individual fighting systems, is a challenge. A need for deaggregation arises in closed simulations of combat. In nearly all models of forces larger than a single battalion, units are represented as aggregate entities. These display or move as a single element. The location and activity of the individual systems within the unit as described, at most, statistically. But occasions occur when the activity of individual systems is important. Unless these have been separately represented throughout the simulation it will then be necessary to describe them in somewhat more detail. SIMNET BCIP is much more demanding in this regard. When units are deaggregated, the individual elements must be located precisely in the SIMNET digital terrain and displayed to the manned simulations when line of sight exists.

Limitations in Modeling of Human Factors.

It is widely recognized that the representation of human factors in our combat models should be improved. An earlier MORS Mini-Symposium, MORIMOC I, included a number of general and specific recommendations to this end. It is not true, however, that human factors have been ignored in the development of combat simulations. From the earliest examples of such simulations, human factors have been represented in data, models of performance and, in a more limited sense, in the "rules of the game". What is true, and important, is that there have been very important changes in the combat models in the recent past. These demand that human factors be included as explicit, rather than implicit, elements of the model. Models that derive system performance input directly from engineering tests or peacetime crew drills give too much importance to the physical and too little to the moral factors in war. Napoleon asserted that, "The moral is to the physical as three is to one".

Figure 2 below, depicts the key steps in the evolution of models at the operational levels from Division to Theater,and it spans a period of time slightly longer than a century. There were earlier war games than Kriegspiel. Some authors argue that Chess and Go are relics abstracted from such games. None of these earlier games can be reconstructed and had no direct influence on the history outlined in the figure. Nor did earlier Japanese wargames of the World War II era, or even earlier U.S. wargames.

All of the models shown in the figure are properly described as analytic or deterministic models. None is properly described as an expected value model since only pretense supports a claim that their output is the expected value of some stochastic process. As noted in the figure, all these models can properly be described as historical models, not merely because they exist and evolved and are a part of military history. They are historical models in a more important sense because the myriad of numerical factors they employed were derived from historical sources. Usually the influence of history was indirect, relying on secondary sources such as tabulations of planning factors (for example, FM 101-10, SB38-26).

As is also noted in Figure 2, all of these models necessarily include factors related to human performance since these were present and influenced the history from which many of the numerical data used in these models derived. There is, however, an important but obvious transition from the top to the bottom of the figure with regard to the representation of human factors. Near the top, everything in the models was clearly historical. Except for computation of nuclear effects and the effects of chemical nerve agents that had never been used in war, this was very nearly true of all models down to ATLAS. Accept for the moment the simplification of arguing that human factors have and will principally influence the functions of command, control, maneuver and attrition. The influence on command was, arguably, present because all models prior to ATLAS were man-in-the-loop wargames. Because the players in these games exercised control as well as command, the same could be argued for the influence of human factors on this function. Models differed a bit in their representation of maneuver. Some dealt only with a "block time" from orders or decision to move to arrival at the destination. Others, mainly to preserve the data necessary to permit targeting, dealt with separate components, assembly, movement and deployment. In any case, the times and movement rates used had a historical basis, affected as it was by human factors. The human players in these games did not exercise control of the tactical activities during the battles that occurred in exercise of the model. Their influence was less direct, involving decisions to reinforce, to break off combat or, in fact, to maneuver to avoid battles at unfavorable odds or to improve the odds prior to accepting battle. Even so, human factors influenced the attrition estimates to the extent they influenced the historical sources of these estimates.

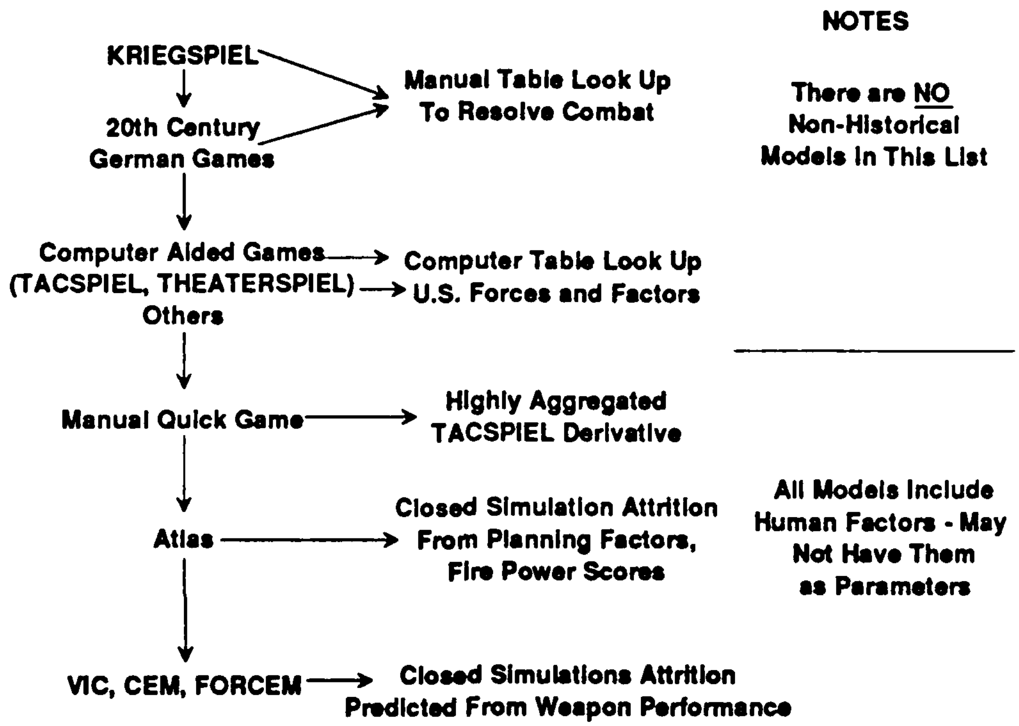


Figure 2
Operational Level Models

The causes and even the timing of the steps toward modern models should be clear. From the end of World War II until the early 1960's there were no major organizational changes, no changes to broad operational concepts and only minor changes in the weapons of the ground forces. Thus, except for nuclear weapons and the influence these exerted and chemical nerve agents, there was little reason to argue that history should not be our guide. By the end of the 1950's it was apparent that this honeymoon would soon be over. Armies of the technological nations, east and west, were on a trend toward nearly total mechanization. New weapons such as ATGM were emerging in response. The introduction of controlled fragmentation submunitions in artillery systems increased their antipersonnel effect to such a degree that they were almost different in kind. The most obvious implications of these changes were in relation to attrition and, there, in the attrition in intense small unit combat, the most basic issue in the representation of combat. Other effects were likely to flow from these and other changes to the materiel and weapons of the ground forces. But attrition presented a special problem. Of all the functions important to war it, suppression, and perhaps, command are the only ones for which we can have no direct access through peacetime experiments.

This led quite naturally to efforts to predict attrition in battle more from first principles, weapon design parameters and peacetime measurements of their performance. This makes it natural to describe as the key difference between the most recent models and all predecessors the fact that they attempt to predict attrition from weapon performance. There are many other differences. The development of internal decision logic to exercise the function of control, beginning with ATLAS, present in VIC, CEM and FORCEM and a continuing trend is at least as important. Nearly every other change could be dismissed as a natural response to increase in computing power. Calculations that could have been done in principle in earlier models can now be done in practice. Key steps in the effort to develop predictive models of attrition in battle are shown in Figure 3 below. It is a more complicated picture than Figure 2 because the path was not a simple linear sequence. It begins (in 1914) with Lanchester's Differential Equations. From there flow two branches, one to differential equations to represent attrition between forces with several different weapon types. (We call these Inhomogeneous Lanchester equations to honor F.W. Lanchester. There is no evidence that he either formulated such equations or solved them.) By 1950 stochastic versions of the Lanchester equations were derived and solved in a few simple cases. Even today, with huge computing power available, it appears that no one has tried a direct combinatorial solution to these equations. By the mid 1950's stochastic sampling solutions were obtained (more correctly, algorithms to obtain such solutions were developed) that employ the Monte Carlo algorithm. The first combat model using this approach, CARMONETTE, *is highlighted* in the figure. CARMONETTE has many daughters, only one of which, the Independent Unit Action (IUA) model, is shown.

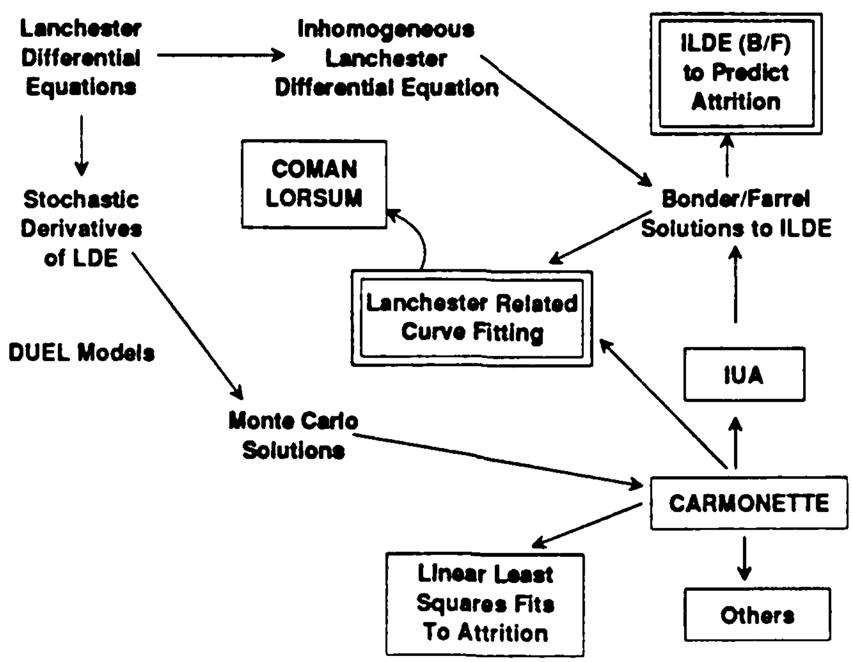


Figure 3
Battle Models

The development of such models did not, by itself, solve the problem of attrition prediction for the operational models. The resulting combat models required so much computation that they could not become on-line subroutines in these larger models. That accounts for the multiple branches extending from the CARMONETTE box in Figure 3. One of these, toward the lower left, was based on linear, least squares fits to the time dependent losses predicted in CARMONETTE battles. It was performed in association with the development of the Division Battle Model (DBM), an otherwise conventional wargame, owing more to TACSPIEL than to creativity. These least squares fits, interpreted in equations, became the attrition model in DBM. Such equations were developed for a set of typical battles. Interpolation rules were developed so that a relatively small sample of CARMONETTE battles could generate attrition estimates for the particular battle situations created in DBM.

This approach, conceptually sound and eminently practical given the available computing power, was nevertheless a dead end. The attrition curves as a function of time were not linear. Nor were they linear with respect to moderate changes in the weapon composition of the opposing forces. The use of linear least squares fits to develop predictive equations for this highly non-linear behavior demanded generation of very large samples of battles and very accurate estimates of the attrition curves for each.

The next steps initially diverge and then, partially, converge. One, perhaps the earliest, was recognition by Dr. Daniel Willard, then at ORO, that the attrition over time in CARMONETTE output was accurately fit to solutions of the Lanchester Square Law with only a few, tight clusters of attrition coefficients. In theory, this implied an underlying taxonomy of battle types that had repeatedly evolved in the many scenarios investigated with CARMONETTE. In practice, this implied that there was a more efficient computational approach to developing attrition curves for use in the operational models. If it is assumed, a priori, that the curves are approximately Lanchestrian and that assumption is not contradicted by the data, then much smaller data samples can estimate the parameters of the curves than would be needed to achieve the some precision through linear, least squares fits.

Another step, which might better be shown as parallel lines, was the development of the IUA model, a step backward to a less detailed representation than CARMONETTE in every sense except the scale of combat it represented. At the same time was the development by Bonder and Farrell of solutions to the Inhomogeneous Lanchester Equations that had weapon system performance parameters, fire allocation, and distribution rules as their direct input. After comparison of these solutions with the predictions of the IUA Monte Carlo attrition predictions it was clear that the correspondence was so strong that the deterministic methodology could replace the stochastic computations in most circumstances. That was not a dead end as might be inferred from Figure 3. Several slightly different battle models evolved using these methods. Only slightly later, operational models were developed that used these methods rather than curve fitting as the means to predict attrition in the battles that occurred in operational models. In Figure 2, VIC is such a model. It was derived from the family of models described as VECTOR (1, 2, and 3), from an Air Force model, COMMANDER, and from a Division level model FOURCE. Another approach to this same end is implied by the box containing the acronyms COMAN and LORSUM. These are formal methods used to derive the coefficients for ILDE from the outputs of Monte Carlo simulations.

There is at least one other approach to attrition methodology that must be mentioned. Trevor DuPuy has devoted many years of historical study and modeling of historical data to arrive at an understanding of the flow of combat. He has defined a concept of "relative combat effectiveness" (CEV) (ref 18) which is based upon behavioral factors as well as force size and other considerations, and asserts that the loss ratio is expressed by:

$$L_a/L_b=(CEV)^2$$

where 'a' and 'd' represent attacker and defender, respectively. This approach, based upon an empirical measure of 'quality' of the forces, has been shown by DuPuy as being in close agreement with a number of historical battles.

It is useful to note that the loss ratio given above can be reproduced almost exactly with a proper choice of coefficient for the Lanchester equations. Further, calculation of the CEV is not as straightforward or conceptually understandable as Bonder's approach to developing attntion coefficients. Finally, if the manned portion of the simulation is used to develop its own attrition coefficients, it is in a sense its own historian, and equivalently the determiner of its own CEV. Therefore, it seems that, to the extent that DuPuy is in disagreement with the Lanchester approach to attrition as he himself states, such an approach has the potential for setting things straight, but perhaps without ever settling the issues of the correct analytic model.

This evaluation puts the problem of human factors in a different and more demanding light. It might be reasonable for the earlier family of models to dismiss the concern that these factors were not present as explicit parameters. There was no potentiometer labeled "morale" or "training" or, for that matter, sloth and indolence that was connected to any of the behavioral factors that determined model output. After all, there was also no way in analysis of battles or campaigns set in the mid-range future, to determine how such potentiometers should be set had they been present. But, for the newer models there was no plausible basis to claim that these important factors were somehow invisibly, pervasively and properly present in the weapon system performance factors that formed the key input to the attrition prediction methods.

This cannot be interpreted to mean they were absent. The input to the models was not, for example, the result of engineering tests in firing at fully exposed, stationary targets at known range without distraction. Nor were the effects of suppression ignored. Firing rates in the models are limited by detection rates estimated for partially and fleetingly exposed targets. The dispersion data from which hit probabilities derive has generally but not universally been degraded by factors with some historical basis. Nevertheless, there is a long chain of inference from any historical observations to the factors that may be input to current models. The chain grows as longer and heavier as the model uses extend to combat in the five to ten year future.

The SIMNET development outlined above cannot be viewed as a complete remedy to these problems. It cannot, for example, reproduce the full stress of combat, past or future. On the other hand, its use of players in fairly detailed weapon system simulation and as small unit troop leaders has some advantages. Presumably the units represented in those simulations will be those engaged in the intense and decisive battles. The others may be represented by aggregated mathematical models. Note, however, the interplay and especially its effect over time. The journey began with a doubt that we could rely entirely on historical sources to predict attrition in future battles which were in some sense dominated by weapons not present in historical battles. It led to models that even today have a strong historical basis in every area except attrition and troop control. It included the realization that the intense, decisive battles were precisely the battles for which accurate estimates were most necessary. Even if the stress of combat introduces some human factors that SIMNET cannot capture or modifies some of those it does capture, it must be better to measure some than to guess at all. Over extended use the SIMNET derivative would seem to give an added opportunity to compare the predictions of the battle models in great detail to the results of simulations that are more directly influenced by human performance. It will not stand alone. Field experiments and some, hopefully small, sample of battle histories will still be available.

Issues In Aggregation.

The utility of analytic games in understanding the dynamics of conflict, as opposed to the results of combat, is inversely proportional to the degree of abstraction in the representation of such elements as:

Process
- attrition;
- movement;

Situation
- mission;
- logistics and resupply;
- intelligence;

Force Representation
- distribution of assets (geometry, laydown);

Human Factors
- effects of training and preparedness;
- effects of leadership and control; and
- man in the loop.

Much of the philosophical disagreement that exists in the military operations research community can be traced to differences in the perceived need for operational realism in the representation of combat. Both James Taylor and Trevor DuPuy, while perceived by many as being on opposite ends of the spectrum of attrition methodology, concede that many factors beyond simply the size of the forces affect the flow and outcome of combat. Judith Luca-Marshall (ref 10) makes an excellent point in contending that, if a model does what it is supposed to do, it is a good model; if a model is used to solve a problem that it is not capable of adequately solving, it is the poor use of the model that is at fault. While the developer of a model is often too close to it to recognize its limitations in addressing new questions that are beyond the scope of validity for the model, it is incumbent upon the architects to objectively search for conceptual approaches appropriate to this new simulation technology, without being unduly influenced by the advocates of any single approach.

For representation of combat a need exists for devising methods of variable resolution conceptually compatible with the program objectives. To integrate solely abstract, analytical methodologies would destroy the "feel" of manned simulation of combat. When a soldier is engaged in a battle, realism requires that he must "see" his environment and opponent, and he must individually be able to kill or be killed as a consequence of his actions. Yet representation of each individual system in a Corps exercise by a manned simulator is extremely costly in both dollars and manpower resources. The requirements imposed on the variable resolution, then, are as follows:

1. Wherever manned simulators exist, they must maintain a realistic interaction with their environment, including forces that may be represented in closed form;

2. In situations where no manned simulator is present, forces may be aggregated to a level appropriate to meet the objectives of the exercise; and

3. Rules of disaggregation and reaggregation must exist that are conceptually valid for the environment.

In armed conflict at echelons above Platoon, there is a decreasing percentage of the force actively engaged in combat. Based on historical studies, DuPuy (ref 18) asserts that the upper and lower bound of forces exposed to fire as a function of force size is as shown in Figure 4, below.

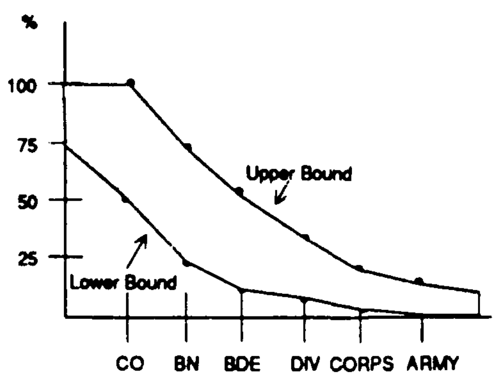


Figure 4
Percentage of Forces Exposed to Fire

Based upon these data, it can be seen that an upper bound of 25% of the systems must be manned for a Corps exercise to be "fully manned," and a more typical 10-12% would be adequate. Clearly, the manned simulators would have to be operationally reassigned as the dynamics of battle takes individual units into or out of exposure to fire, but it is clear that a high degree of operational realism can be achieved with much less than a fully manned simulation. When forces are not exposed to fire, it is reasonable to allow the bookkeeping to be maintained in aggregated form (without unacceptable loss of operational realism).

Representation of Forces. Whatever is required to be known about a force element can, in the view of simulators and developers of models of combat, be quantitatively and qualitatively defined. At any given instant, the "state" of the force can be described by a set of values that describe the present condition of each variable of interest. A model is simple or complex to the degree in which few or many variables are used to measure the behavior and situation of the force.

These values may be expressed in a vector and termed the "State Vector" that represents the units or subelements of the force at that point in time. Since the state vector will change as external and internal stimuli evoke a response, repeated sampling of the state vector over the course of a battle will provide valuable insights into the flow of combat. High resolution modeling can be said to require frequent sampling of a very detailed state vector. Highly aggregated modeling, on the other hand, may preserve only a few variables that more grossly represent the force, and may sample these as frequently or less frequently, depending upon the time sensitivity of the variables chosen.

However, in closed form combat simulation, the samples of the state vector are not samples of the state of the force, but rather samples of the **predicted** state of the force based upon the model. Therefore, only the initial state vector can be assumed to be "real". The process whereby the force responds to *stimuli* is the model. If the process is deterministic, the future state can be analytically determined from the current state and stimuli, and the model is termed a "deterministic model". If, however, for any current state and stimuli there exists multiple possible future states, the model is termed "stochastic". While there is no particular requirement that it be true, high resolution models are frequently stochastic, and highly aggregated models are typically deterministic.

In the case of a simulation with fully manned simulators, the individual system is represented explicitly. Additionally, it is stochastic because human behavior is not fully quantifiable, and certainly not repeatable. In this sense, it is a representation of "true" combat, where behavior modification occurs as a result of the learning. What should not be lost in the process of extending to Corps level exercises is that operational realism. Indeed, if the fully manned concept of the Battalion level simulation were retained through all force levels, most of the above-listed issues in aggregation would simply disappear; attrition is explicit for direct fire weapons; movement is explicit for combatants; mission is explicit and dynamically modifiable; the situation is explicit; the functional area is explicit for all types of manned simulators incorporated; the distribution of assets for combatants is explicit; the effects of training and preparedness is clearly demonstrated; and leadership and control are key elements in determining "success" in combat. There cannot be any model better than the soldier himself for operational realism, since the objective of all other models is to approximate his behavior.

Attrition Methodologies. Maneuver and attrition are the principal means whereby combat outcomes are determined. Indeed, it may be argued that much of maneuver has as its purpose forcing the opponent to fight in adverse situations or avoiding such fights. Attrition is thus a real process in battle and a virtual process in which forecasts of attrition modify behavior. Few, if any, current models base decisions on such explicit forecasts of attrition. Many base decisions on estimates of the force ratio in battle and, for example, may withdraw or reinforce to achieve more favorable conditions for battle.

The end result of this, in models as in war, is that a large fraction of the battles that occur are between forces nearly equal in capability. Some battles occur far from parity if one of the commanders errs in his estimates. Other battles far from parity occur, for example, when some part of a force is commited to battle to provide time for the rest of the force to achieve a more favorable posture. That fraction of the battles that occur near parity present a particular difficulty to deterministic methods of attrition estimation. Small unit combat models or reflection on the stochastic derivatives of the Lanchester Differential Equations demonstrates that the outcome of a replicated sample of such battles must be bimodal. Few if any of the battles in this sample follow the trajectory of the sample mean. Events early in such battles will drive them into one or the other of the sub- populations and these usually have very different outcomes in relation to attrition and other factors.

If the only purpose of a model were to forecast losses and the only role of attrition in the model were to weaken the forces in subsequent battles, then it might be argued that the sample mean gives a proper estimate in spite of the bimodality. But when, as in many current models and necessarily in SIMNET BCIP, decisions to withdraw or reinforce or call for fire support are related to the course of an ongoing battle, it is hard to argue that a deterministic model that keeps every battle near the overall sample mean can be adequate. Because the bimodality disappears in battles far from parity, these might be represented adequately with a deterministic method. But it seems inescapable that the purposes of SIMNET BCIP will require a stochastic aspect in their attrition methods.

This does not argue that the aggregated models in SIMNET BCIP must be Monte Carlo models representing individual systems, although that would resolve this dilemma. It does imply that the statistics of the sub-populations in battle outcomes must be understood and a method developed to control branching into one or the other. The challenge here is not writing algorithms to incorporate this capability into otherwise deterministic, aggregated models. The challenge is developing adequate understanding of this bimodal process and of the branching probabilities. It has been investigated in only a small sample of battles with Monte Carlo simulations. Battles using the manned simulations of SIMNET could also be used for this purpose, although the appropriate sample of battles is not likely to evolve or be replicated often in the training uses. Consistency would argue strongly that SIMNET be the source of this data for SIMNET BCIP or, as a minimum, that any model used for this be compared to some sample of SIMNET battles.

It is possible that, based upon the high degree of acceptance of the approach outlined above, one might make use of Lanchester Theory as refined over the years for attrition of aggregated forces, but use attrition coefficients that are dynamically determined based upon the attrition actually being experienced in the manned portion of the simulation. In this manner, the modeling of forces being played in closed form is closely tied to the "reality" of the forces being played with individual simulators, while preserving the credibility of the methodology for representing attrition.

It is a generally accepted premise, embodied in Low's Gaming Spectrum (ref 9) that, except for combat itself, the effect of human decisions and human factors that influence combat activity and outcome is most acutely and effectively present in military field exercises and least in abstract analytical models. The truth of this accepted view is neither apparent nor of great importance to this discussion. It is important that all models should strive for realistic representations of processes, such as attrition and maneuver, context and situation, including mission, logistical status and intelligence and the representation of the geometry and kinematics of battle. The fact that any and all of these are influenced by human factors that cannot be determined from weapons system design data nor directly from engineering tests has been discussed above.

The SIMNET derivative described above is not the ultimate solution to this need. In fact, it introduces some problems not present in the current operational models. We will discuss this problem in relation to the concept of a state vector. Not a vector in a mathematical sense, the concept of a state vector is an easy way to name the set of numbers that describes the state of units or other entities in the model. The dimensionality of this vector differs greatly in the various combat models but the easy description of it is that it identifies the elements of lowest resolution in the model and, for each, gives it location, current strength, mission, deployment geometry and other information about its status. In most operational models the deployment geometry is usually related to simple geometric figure, its location and orientation, and some description of the distribution of weapons, personnel and other sub- elements within this figure. Whether simple or elaborate, this geometric description is not always adequate for the computational purposes of the model. To illustrate, consider the simplest conceivable model that describes the deployment geometry as a point mass. That does not provide sufficient information to assess losses when the unit comes under fire or engages in combat. If this simple representation were chosen for computational convenience it would be necessary to describe its geometry and posture in more detail for damage assessment and several other purposes within the model. This process is called deaggregation in this paper.

This kind of deaggregation presents a relatively easy problem of program design. It can be and often is accomplished simply by reference to templates that describe typical deployment geometries for units in typical mission situations. It is seldom necessary to consider the detailed conformation to local terrain. The process of aggregation, implying that the deaggregated state vector will be replaced with the aggregated one, is also relatively simple in this case since in most cases the decomposition is needed for a rather short time during which only changes to strength and occasionally mission occur that affect the aggregated state vector.

Consider this same problem in relation to a model in which one or more of the small units is represented by manned simulators. For purposes of discussion assume that a Corps campaign of several days duration is represented and that one Battalion task force can be represented in simulations. It would be natural to represent a task force that is engaged in some important or decisive action within the campaign since that would maximize the value of information about human factors that might be derived. That almost certainly implies that the particular unit that is represented in simulations must change several times. In mechanized combat intense fire fights tend to last an hour or so and those which continue longer in a single area are conducted through reinforcement or commitment of reserves. Even if a single area is represented it will be necessary to represent some weapons that die early in the battle and others not present at its beginning. Many of these late arrivals will have been components of units that, at the beginning of the battle, were represented by an aggregated state vector. Moreover, the important actions of the Corps campaign are very unlikely to involve the same units or occur in the same area throughout the campaign. Given that there will be a limited number of manned simulators and that no useful data can be generated from any that are allowed to become and remain inactive as combat losses, the model must permit each to be used to represent several similar systems and must contemplate representing the activities of quite different units in different areas during a campaign. This might be done by very careful scripting of a scenario in advance. But, such scripting limits the decision options of the higher command levels and thus impacts adversely on the principal objectives of the exercise.

It should also be obvious that the decomposition required in such a model might begin with, but cannot be completed by, use of typical templates. It cannot even be done by reference to printed maps. It is well known from the use of detailed battle models with digital terrain that the weapon systems, especially those in defensive positions, must be deployed with reference to the digital map. These weapons could be described as seeking "hyper-critical" positions using very fine grained aspects of the local terrain. To illustrate, a tank in the defense might wish to deploy in hull defilade on a ridge line but in a position that ensures line-of-sight to one or more designated killing zones. An ATGM might wish to deploy in a tree line deep enough to achieve concealment but not deep enough to block its field of fire. Terrain permits this and the best combat models represent it well enough. But the x,y coordinates that accomplish this in the digital map are seldom those that would be selected from a printed map.

From this discussion we conclude that the model must be designed so that, in principle, any unit that is represented at some time can be quickly decomposed into a very detailed representation. It must be possible to do this for both enemy and friendly units. It must be possible to detach components of an aggregated unit and assign them to a unit represented in simulations. In all of these cases the state vector that represents the element represented in simulations and all elements with which it interacts must be exactly the same as that required in SIMNET for its small unit training role. In particular, since aerial platforms are included, the spatial decomposition must describe the three dimensional location of elements in relation to a digital terrain map with a precision at least as great as the finest resolution of that map.

Can this be done? The answer must be "yes" in principle. It is done today in the preparation of "scenarios" as input to battle models. That begins usually with an aggregated description of a particular battle that may have been derived as a critical battle in an operational model. The process is slow (hours to weeks) and labor intensive (four to six people). Even more important, the process relies on intuitive, cognitive processes of people who have done this many times in training exercises, in planning field experiments and in developing the input for battle models. Replacing this with a more highly, perhaps completely, automated process is the principal challenge in designing a model of the kind described above. Success would have benefits in other applications. It would, for example, present us with a solution to the problem of two way linkage in a hierarchy of models much more efficient than any presently in use. It might become an improved operational planning aid. Solutions to this problem are essential to the SIMNET BCIP model design. Furthermore, this model concept seems to be an ideal framework to support the necessary research. Many of the automated decomposition rules can be tested in simulated battles even if the final tests may require field exercises or experiments.

The corresponding problem of reaggregation seems much easier by comparison. Since in a manned simulation the decomposed units are represented for longer periods and include more changes of state than the decomposed units in typical operational models, the transformation to aggregated state vectors will be more complex. But the components of the aggregated state vector are, almost by definition, statistical abstractions of the detailed state vector.

Approach to Human Factors Modeling.

The approach taken to the problem of modeling the human factor in combat simulation by the SIMNET project is to insert humans into the combat vehicles of a network combat vehicle simulation (ref 4, 5, 6, 7, 8). The Semi-Automated Forces (SAF) component inserts a man in the loop at critical decision making command nodes of a combat unit simulation (ref 19, 20, 21). This is achieved by providing a man-machine mix in which human operators monitor the simulated decision making actions of a combat simulation, and input their decisions when the simulated humans need assistance. The SAF system, however, treats live operators as components in the combat simulation, not as controllers. They are unable to subvert battlefield reality. For example, they cannot resurrect killed units, and are subject to decision cycle delay lags in obtaining information and disseminating information and orders. They are forced to interact with the system as though that system were a fully manned military organization in combat.

The goal of the SAF project is to provide a simulation of large numbers of forces without requiring each vehicle or command post to be fully manned. Furthermore, the SAF units are required to behave with sufficient realism that an observer is unaware that the vehicles and units he sees are not fully manned. The semi-automated component makes it possible to carry out Combat Training, Command Training, and Combat Development at a low cost of materials and manpower. Furthermore, the SAF provides an upward path to large scale combat simulation integrated with vehicle-on-vehicle combat simulation. This latter will provide an arena in which integrated command level, team level, and crew level training and combat development may occur.

The SAF system provides manned commander workstations, representing the decision making command posts in the SAF task organization, interacting with and controlling semi-autonomous simulations of unit assets. The man-in-the-loop in command of a workstation is in supervisory control of his subordinate assets. These assets consist of knowledge-based simulations capable of semi-autonomously interpreting orders, planning actions, and transmitting orders to their own subordinates and information back to their superior. Combat, combat support, and service support units behave in a sufficiently intelligent manner that the SAF commander does not have to constantly micro-manage them to produce a credible behavior. The SAF commander's workstation provides a color map display showing the current state of the battle as known at that node, and provides support for transmitting and receiving orders and information so as to support the commander. Note that the SAF commander does not have perfect knowledge of the battle; a realistic simulation of battlefield communications and the possibility of mistakes by simulated SAF units introduce the fog of war.

The SAF component provides the capability to mix and match analytic models and human decision makers into a seamless real-time combat simulation, and to play that combat with and against any mix of fully manned simulators and other Semi-Automated Forces. The complete spectrum of mixed initiative is achieved by providing the human decision makers with supervisory control over their analytically driven subordinate units, and by allowing the SAF to interact with fully manned simulators. The SAF approach has been to build a hierarchy of software-based decision nodes, whose topology maps into the military command hierarchy. Human commanders interface with the hierarchy at the top level, but can monitor the military performance of the software-driven subordinate staffs and override their decision-making functions. At the lowest level of the system is a SIMNET compatible simulation of interacting vehicles and weapon systems.

Currently the highest level of the hierarchy is a Battalion level workstation, with a fully manned Regimental TOC above that. However, it is possible to insert the man in the loop at lower levels of combat (such as Company), and it is possible to mix the levels of command at which men are inserted into the SAF system. The capability to control downward to platoon level is being provided; i.e. a Battalion commander able to control individual semi-automated Companies, or even Platoons within a specified Company.

The development of an architecture to support war fighting simulation at echelons above Battalion, ultimately to that of Echelons above Corps (EaC), poses some interesting and unique challenges. It is clearly costly to run such a simulation with every vehicle a fully manned vehicle simulator, or to provide fully manned command posts at all levels of the RED and BLUE forces from EaC down. However, the traditional computer-driven combat simulations do not provide an arena for motivated human players to "fight to win." Thus, a hybrid man-machine system in which small numbers of personnel fill key decision making positions, commanding and controlling surrogate forces and staff, is being developed (ref 19, 20, 21). The Battalion level SAF system is being extended to echelons above Battalion. It will eventually provide both an OPFOR and BLUFOR in the form of Semi-Automated Forces and command posts from EaC down to individual vehicles. The success experienced with the SIMNET Battalion level SAF indicates that the development of the centralized, world class OPFOR required by the CAC BCIP is feasible .

To be truly effective as a trainer and as a combat developments tool, the Semi-Automated Forces must satisfy a number of criteria. These criteria have a major effect on the design of the Semi-Automated Forces, and so are discussed here. The Semi-Autonomous Forces must provide for:

1. Man-in-the-Loop. The system must be controllable by the human commander, with the consequential presence of human ingenuity and stupidity;

2. A Fight to Win Arena. No umpires or controllers;

3. Fog of War. The system must not provide the human commander with omniscience or omnipotence;

4. Realistic and Adaptive behavior; and

5. White Box Design. The system must not be a black box. It must be capable of being fully validated and modified by the trainers or experimenters.

The current architectural approach for SAF poses significant benefits for incorporating human factors into a large scale simulation of combat. Several important factors in representation of the human element are under careful consideration, and are an integral part of the R & D program.

Man-in-the-Loop. The war fighting simulation must exhibit all the strengths and weaknesses of human behavior. To this end the SAF system supports man-in-the-loop at any selected level of the simulation. A SAF commander and critical subsection of his staff are able to interface with the simulation at each command/decision post from Battalion down to Platoon level. These human commanders and staff communicate with each other by normal battlefield means, and are supported in their war fighting tasks by the SAF hardware and software provided at their command levels. The software support provided at each command level includes the appropriate level of battlefield monitoring, planning, and plan execution, and make up for the commanders' missing staff.

Supervisory Control. The SAF system is semi-automated with an operator in supervisory control of a large number of combat and support systems simulations on a single simulation machine. This is a contrast to the manned simulators, which have up to four crewmen in complete control of a single vehicle simulation on its own set of simulation hardware. The SAF commander is expected to input orders to the system at the appropriate level of command. For example, the system responds to orders at the Battalion commander level by automatically controlling the Battalion assets to carry out the order. The system automatically interprets those orders and generates the appropriate units and vehicle behavior, and tactics without further actions from the commander. However, the operator can, at will, drop down the command chain and take direct control of any Company and then move back up to the Battalion commander level. The operator can interrupt, modify, or override any automated system behavior so long as battlefield physics are not violated (e.g., vehicles cannot move faster than physically possible). The SAF operator is expected to be familiar with Soviet doctrine and tactics. Deviation from them must be deliberate and must be part of a planned combat developments exercise.

Fight-to-Win. The war fighting simulation supported by the SAF must provide a fight-to-win arena whose simulated lethality matches that of postulated real combat. The SAF are not controllers in the traditional sense; they fight-to-win with the assets, both manned and computer generated, at their disposal. Questions concerning which aspects of the battlefield need to be simulated to which levels of reality must take into account the requirement that the fight-to-win spirit is not compromised.

Thus, the SAF does not follow traditional protocol/rule-based approaches of providing limited lists of stereotyped behaviors from which the software or human must choose. The Semi-Automated Forces model as closely as possible the planning, monitoring, and execution abilities and difficulties of each command level and permit the man-in-the-loop to operate freely with whatever difficulties and advantages he discovers. In other words, the system models the doctrinal envelope within which the players are constrained to play the battlefield, organizational, and system realities, and allows the players full freedom within this envelope.

Omniscience and Omnipotence. A problem exists between balancing the extra tools given to a command node with most of its human staff missing, and not providing those players with a technologically derived advantage not present on the battlefield, such as an omniscient "bird's eye view" of the battlefield. The problem is grounded in two functional areas, the simulation of the combat intelligence system and the processing and presentation of information to the players. Humor concerning the ability of technology to create its own unique brand of fog of war aside, this is a real problem and must be dealt with.

A commander at Battalion level and above normally has a number of staff whose jobs include the reception, logging, collation, interpretation, summarization, and presentation of information to the commander. At the very least, the commander gets his information in the form of briefings and map displays. In a SAF system it would be totally unreasonable to expect a commander, deprived of his human staff, to carry out these staff commands and decision making. Therefore, it is necessary to provide the Semi-Automated Forces workstations map displays driven off credible simulations of the intelligence system, and to provide a simulation of his staff. The SAF system not only simulates the vehicles, crews and weapon systems of combat, it also simulates staff functions when the human commanders are not directly controlling them.

As an example of what must be done, consider a component of the intelligence system, which is embedded in and interacts with the IEW and C3I systems, and which deals with knowledge of locations and types of known and enemy forces and places such information on the situation map. In a networked simulation, it is possible to present perfect knowledge.

In order to simulate the intelligence system and deny the player omniscience and omnipotence, at least three forms of processing must be developed.

1. Strip out illegal information, determine visibility, etc.;

2. Semi-automated, and manned, forces report locations, times and types of units, including self, using a simulated C2 net, which is itself subject to battlefield degradation. Thus, the commander's situation display shows unit types, locations, times of reports, et cetera, depending on whether or not his assets actually reported, and whether or not such reports got through. In addition, the commander's requests for information and transmittal of orders uses the simulated communications net with similar transmission problems; and

3. Statistical and smart filtering processing will be applied to the raw appearance packets in order to simulate the information behavior which would exist at each command node in a combat situation, but where it is infeasible to directly simulate the multiple collection agencies, methods of information transfer, multiple combat intelligence agencies, et cetera which make up that situation.

The first two are being provided in the current stage of the SAF development, the last will be provided as the SAF project moves up the command hierarchy as part of the solution to providing Divisional and Corps level combat simulations.

Adaptive Behavior. The Semi-Automated Forces must be adaptive in its behavior, as is a real combatant. This adaptation must apply to both the man-in-the-loop, and to the semi- automated components. The man-in-the-loop becomes smarter and learns as he takes part in the combat simulation as a natural part of human behavior. However, the semi-automated components must also adapt and this can take place by two means. First, the level of competence of SAF granted to the human commanders can be settable by switches if desired. This capability is currently provided for a selection of human factors, and will be expanded as the project matures. Second, the future developments of the SAF project, such switches, controlling hit probabilities or logistic resupply times, for example, will be set to modify automatically for the survivors of combat depending on the intensity of such combat. One mechanism of adaptation which will be taken into account is a form of averaging as bloodied units are mixed with green units. Automatic adaptations and controllable competence levels make available for study by simulation the effects of human performance in combat.

Validation. All parameters, models, and rules used in the construction of the SAF system are contained in a set of modular knowledge bases with an interface provided which allows for the modification of the SAF system by the client without further computer programming. There exist three levels of simulation parameters within the SAF system. For each level of simulation, a graphical/diagrammatic editor has been developed to permit a non-programmer user to interact with these parameters. The interaction consists of examining the parameters and their values, modifying those parameter values, and creating new instances of certain parameters. These interactions by the user can take place rapidly, on the order of a few minutes. These levels of simulation and their editors (where the battle master is the person setting up the simulation, not controlling it) are:

1. The parameters which describe vehicles and weapons. The Models Editor, used by the battle master, edits the parameters associated with vehicles, weapons, simulated human performance;

2. The parameters which describe the actions carried out by vehicles and units, and their performance levels. The Tactical Action Representation Language Editor, used by the battle master, edits the basic tactical actions which vehicles, units, and humans carry out; and

3. The missions allocated by the SAF commander and by subordinate code to subordinate units. The Mission Editor, used by the SAF commander, edits and creates the mission allocated to units.

Validation of the SAF system now consists of an examination of these parameters by the military community, and modification of them if the military experts deem it necessary. A further global validation can be carried out by comparing the SAF total performance with other fully manned SIMNET battles.

Some Unique Opportunities for SIMNET.

SIMNET has shown itself to be a remarkable tool for evaluation of human performance issues in simulated combat, and the lessons learned will certainly be useful in improving the representation of human factors in the closed form modeling of combat in the future. SIMNET was designed as a training tool, and as such, was based upon paradigms and methodologies adequate for training, with little initial emphasis on the degree of validity required for the combat developments community. However, there is a commitment in the program to improving the underlying methodologies important to the combat developments community, and substantial progress has been achieved.

As SIMNET grows to the representation of forces above Battalion, it is particularly useful to the military operations research community in that growth be based upon methodologies that can be shown to have a sound foundation of consistency with historical data. In accepting the SIMNET community as a participant in the military operations research dialogue, opportunities open up to both the old hands and the newcomers. Opportunities exist for SIMNET to avail itself of the experience of years, and for the present community to better model the human factors issues that have been so difficult to capture.

Conclusions.

There are issues that have not been addressed in this paper, and indeed potentially issues not yet considered, in implementing a program of such scale with credible methodologies for representing the processes of aggregation and deaggregation. This is a research program at this point in time, funded through the Defense Advanced Research Projects Agency. Incorporation of Semi-Automated Forces into SIMNET is an active program. Some of the details of implementation are published (ref 19, 20, 21). While all issues are not resolved, a program is actively underway to incorporate the human in the modeling of combat. The authors view this as a beginning, with profound long-term implications on the military operations research community. We invite discourse, dialogue and suggestions on incorporating methodologies that are appropriate to operational realism; to add validity in aggregation to the realism of human participation in SIMNET.

References

1. "Lanchester Revisited: Progress in Modeling C2 in Combat"
Dockery, J., Santoro, T.
Signal July 1988

2. "C3I Training: The Fighting Edge"
Bonanni, P., Williams, J.
BBN Systems and Technologies Corp.
I/iTSC 1988

3. "Numbers, Predictions, and War"
DuPuy, T.N.
Hero
1985

4. "Innovative Test of the Simulator Network (SIMNET) System"
Pate, D.W., Lewis, B.D., Wolf, G.F.
U.S. Army Air Defense Artillery Board
June 1988

5. "The SIMNET Communications Protocol for Distributed Simulation"
Miller, D., Pope, A.
BBN Laboratories, Inc.
I/ITSC 1987

6. "Long Haul Networking of Simulators"
Miller, D., Pope, A., Waters, R.
BBN Laboratories, Inc.
I/ITSC 1988

7. "Data Collection and Analysis: The Keys for Interactive Training for Combat Readiness"
Garvey, R., Radgowski, T.
BBN Laboratories, Inc.
I/ITSC 1988

8. "Warfighting with SIMNET -- A Report from the Front"
Thorpe, J.
DARPA
I/ITSC 1988

9. <u>Theater-Level Gaming and Analysis Workshop for Force Planning</u>, Vol I and II
Low, Lawrance J.
SRI International
1981

10. <u>Modeling and Simulation of Land Combat</u>
Luca-Marshall, Judith
Georgia Tech Research Institute
1983

11. Aircraft in Warfare
Lanchester, Frederick W.
Constable, London
1916

12. Lanchester Models of Warfare, Vol. I and II
Taylor, James G.
Naval Postgraduate School
1980

13. Lanchester Attrition Processes and Theater-Level Combat Models
Karr, Alan F.
Institute for Defense Analysis
1981

14. A Generalized Lanchester Model to Predict Weapon Performance in Dynamic Combat, a Ph.D. Dissertation
Bonder, Seth
The Ohio State University
1965

15. "The Lanchester Attrition Rate Coefficient"
Bonder, S.
Operations Research 15
1967

16. "The Mean Lanchester Attrition Rate"
Bonder, S.
Operations Research 18
1970

17. Development of Models for Defense Systems Planning
Bonder, S., Farrell, Robert, Eds.
Systems Research Laboratory, University of Michigan
1970

18. Modeling and Simulation of Land Combat
DuPuy, Trevor N.
Georgia Tech Research Institute
1983

19. "SIMNET Semi-Automated OPFOR: A Functional Description"
Downes-Martin, S., Saffi, M.
BBN Report 6555
September 1987

20. "SIMNET Semi-Automated Forces Version 3.0: A Functional Description"
Ceranowicz, A., Downes-Martin, S., Saffi, M.
BBN Report 6939
15 November 1988

21. "SIMNET Semi-Automated Forces Version 3.0: Implementation Issues"
Ceranowicz, A., Downes-Martin, S., Saffi, M.
BBN Report 6940
27 October 1988

22. "The Soviet Army: Operations and Tactics"
FM 100-2-1
HQ Dept of the Army
16 July 1984

23. "The Soviet Army: Specialized Warfare and Rear Area Support"
FM 100-2-2
HQ Dept of the Army
16 July 1984

24. "The Soviet Army: Troops, Organization and Equipment"
FM 100-2-3
HQ Dept of the Army
16 July 1984

25. "Soviet Army Equipment, Organization, and Operations"
Report E614/8
Combined Arms and Services Staff School
February 1987

26. A Comparative Analysis of a Generalized Lanchester Equation Model and a Stochastic Computer Simulation Model, a Master's Thesis
West, Terry A.
Naval Postgraduate School
1987

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DISCUSSION OF "SIMNET-D: COMBAT MODELING THROUGH INTERACTIVE SIMULATION"
by T. Radgowski and R. Garvey
and
"AGGREGATION ISSUES FOR COMMAND MODULES IN SIMNET"
by A. Gilbert, J. Robbins, S. Downes-Martin, and W. Payne

DISCUSSANT: J. D. Fletcher, Institute for Defense Analysis

The two SIMNET papers raise a number of substantive technical questions and issues. I will address none of these. There is not time in these brief comments to do so, and the authors of the SIMNET papers are doubtless far ahead of us all in thinking through any issues that might occur to me here. Instead my intent is to place what they are doing into perspective and to cheer them on.

The perspective I have chosen is based on trade-offs and the idea of an Idea, which some of us developed at DARPA (or ARPA as it was in those days) and have tried not to forget since.

Most probably everyone here has wrestled with the trade-offs that arise to plague us in the design of systems. Basically, trade-offs remind us that there is no free lunch. In the design of programming languages, which is a topic that occasionally concerns me, we find trade-offs between security and simplicity -- a secure language is not a simple one and conversely, a simple language is seldom secure -- and between simplicity and flexibility. For that matter, programming language power may be defined as how far back the trade-off between simplicity and flexibility has been pushed.

Those of us who work with computers frequently encounter trade-offs between demands on memory and processing -- memory demands can often be reduced, but only at the cost of greater demands on processing, and vice versa. Finally, everyone must be aware of the trade-offs between cost and performance that obtain in the design of any system.

In all these systems, the quality of the resulting design is defined to some extent by how far back one or more of the necessary trade-offs has been pushed. This brings us to the idea of an Idea. What we learned to look for at DARPA were technical notions, or 'tricks,' or Ideas that were not just evolutionary, but revolutionary. That is to say, they did not just push further back some heretofore necessary trade-off in a system in an evolutionary fashion, they broke through it in the revolutionary manner of a step function or even made it unnecessary.

With these comments as background, let's take a look at the current state of tactical warfare models. Simple analytic models are transparent and understandable, but they do not account for realistic, complex battlefield relationships. In other words, we have some trade-offs here between simplicity and transparency on one side and complexity and realism on the other. Computer models can account for complex battlefield relationships and they will allow for simulation of large scale (e.g., theater-level) combat, but they are largely attrition driven and lacking in transparency -- more trade-offs.

Manned simulation approaches can include non-attrition (human performance) factors, permit many-on-many combat, and allow some transparency, but they are manpower intensive, not extendable to theater level combat, difficult to control, and make excursions and sensitivity analyses prohibitively expensive.

All I want to suggest is that we have in the combining of SIMNET with combat modeling approaches an Idea, something that is revolutionary and not evolutionary, and something that allows us to break through heretofore necessary system trade-offs. The two SIMNET papers discussed practical issues that need to be addressed to effect this combination. But the overall enterprise is, I suggest, immensely significant. If the authors of these papers and others who are working on this combination are successful, they will give us an approach that includes features of transparency -- it will be a tactical warfare model you can sit in: you will be able to see what is going on without having to work your way through a tangle of differential equations. The approach will incorporate considerable battlefield complexity -- all the issues of many on many, force on force C^3I will be present. It will permit large scale, theater-level operations -- the semi-automated forces will give us any level of aggregation we want. It will encourage the integration of non-attrition, human performance factors -- these factors can be introduced either the first time the model is run or in any replays thereafter. It will allow sensitivity analyses and excursions that are controlled at whatever level we wish. And all this will be possible at affordable cost. I suggest that all this is provided by the Idea of combining SIMNET technology with tactical warfare models, which is the topic of the two SIMNET papers I want to emphasize and place in this perspective.

An Idea of the sort discussed here is a rare and significant thing. I have suggested that we have such an Idea in hand and that it represents an opportunity and challenge for all of us. I commend it to your attention, and I urge those involved in its development to proceed with all deliberate speed. That is the perspective I suggest for the two SIMNET papers presented here.

MODELING OF SOFT FACTORS IN THE RAND STRATEGY ASSESSMENT CENTER

Paul K. Davis
Director, RAND Strategy Assessment Center
The RAND Corporation
1700 Main Street
Santa Monica, California 90406-2138

SUMMARY

Reflecting "soft factors" has been a major objective since the early design of the RAND Strategy Assessment System (RSAS) in 1982. This paper discusses how selected soft factors have been and could be represented in combat models, theater-level decision models dealing with command-control issues, and national-command-level models dealing with issues of national policy, strategy, and controls. The paper also discusses the (limited) empirical basis for the assumptions used and speculates about the degree to which the empirical and subjective basis could be improved. Finally, it notes several recent examples of policy-level analysis that have been strongly affected by assumptions about soft factors involving human and organizational issues, notably factors involving readiness, surprise, national fighting quality, the break-point phenomenon, and command-control adaptability. The paper includes references to reports describing modeling and programming methods developed for the RSAS that could be used in a broad range of other problems.involving human and organizational issues.

INTRODUCTION

Background

One of the most unsatisfactory features of most current-day military analysis is its treatment (or, rather, its nontreatment) of many so-called *soft factors*. This is not a minor consideration, one affecting only the second or third significant figure of some prediction, but rather a fundamental problem constituting, in some cases, a fatal flaw. This paper discusses several types of soft factor, argues that it is often straightforward to reflect them in analyses if merely one decides that doing so is essential, and illustrates this by drawing on experience gained in the development of the RAND Strategy Assessment System (RSAS).[1] One purpose of the paper is to convince readers that modeling soft factors can and should be a routine part of military modeling and analysis. Interestingly, when one accepts this view and begins incorporating them, the soft factors quickly become less abstract and less soft, and the very issue of soft factors slips into the background. An outside observer, however, might detect a paradigm shift having taken place.

Defining Soft Factors

Although it is common for people to talk about soft factors, usually in the context of lamenting or rationalizing their exclusion, there is no common basis for deciding what a soft factor is. Some of the more obvious definitions fail under scrutiny. For example, it is *not* the case that soft factors are identical to qualitative variables if, by that, one means variables that are not measured numerically. Many features of "hard" combat models have long been qualitative—e.g., distinctions between meeting engagements and assaults on fortified defenses. Nor is it the case that soft factors are those that have not been measured or determined accurately, since anyone familiar with combat models knows that they are stuffed with variables that would then be considered soft (e.g., the attrition rates to be expected in the next large war are probably uncertain by a factor of 4). Nor are soft factors necessarily associated with human or organizational factors, although this paper focuses primarily on examples of that type. Ultimately, factors are considered soft if they have not yet been reflected explicitly and comfortably in analysis and if they are not yet well understood. This is a disappointing definition, but it has much to recommend it.[2]

If this definition seems unreasonable, imagine how scientists in earlier centuries probably dealt with the concept of friction before there were empirical or theoretical concepts for treating it explicitly. Falling bodies were said to obey the equation $V(t) = g\,t$, where g is the constant for gravitational acceleration. If V(t) turned out not to quite obey this law in practice, especially for bodies of matter such as feathers, then it was because "there are always some complications and imperfections" (one can almost see hands waving as these "soft" matters were discussed). After a theory of friction existed, however, then one could write something like $dV/dt = g - f\,V$ and see to measure f for the body of interest. And, after the appropriate aerodynamic theories developed, one could estimate f from the size and shape of the body itself. The concept of friction was then no longer "soft" with respect to falling bodies.

In this paper we shall be discussing a particular set of soft factors determined, *at least in significant part*, by peculiarly human or organizational factors:

- The qualitative fighting capability of different forces with similar or identical equipment;

- The frictional processes in military operations such as maneuver, command and control, and the use of weapons under combat, rather than test-range, conditions; and

- The political, strategic, and operational-level decisions and decision processes that have so fundamental a role in determining the outcome of wars.

These factors are commonly regarded as annoyances and imperfections by a large part of the analytic community.[2] By contrast, many military people in the western world consider them fundamental, but use them as a basis for avoiding rigor in preference to an emphasis on the art, rather than science, of war. The Soviet approach seems to be more that of engineers, who have to cope with complications of process and people in all walks of life and who try to accomplish this by safe-siding whenever possible in their designs and construction plans over time. Western operational planners must also deal with these "engineering problems," but they must often do so without the benefit of an appropriately technical and comprehensive textbook (hence, the common emphasis on "art"). Our challenge, in a sense, is to begin defining how that textbook should deal with factors such as those above. The impression that military science can reasonably aspire to the precision and rigor of the physical sciences would be misplaced, especially when dealing with human and organizational issues, but we can surely go much farther than is customarily attempted.[3] In the following sections, I shall discuss work of the RAND Strategy Assessment Center (RSAC) in each of the above areas of so-called "soft factors." Nearly all of this work is at a relatively high level of aggregation, because we have focused on issues of policy and strategy, but the ideas and techniques should have broader application.

REPRESENTING QUALITATIVE CAPABILITIES OF UNITS

Philosophical Approach

In laying down principles for the RAND Strategy Assessment System (RSAS) in the early 1980s, my colleagues and I in the RAND Strategy Assessment Center (RSAC) decided to deviate from normal procedure and to include as many high-level qualitative factors as possible in our combat models, while recognizing that our ability to measure them might be highly limited. The reasoning on this was essentially that argued earlier and persuasively in Jay Forrester's work on Systems Dynamics at MIT: [4]

> Much of the behavior of systems rests on relationships and interactions that are believed, and probably correctly so, to be important but that for a long time will evade

quantitative measure. Unless we take our best estimates of these relationships and include them in a system model, we are in effect saying they make no difference and can be omitted. It is far more serious to omit a relationship that is believed to be important than to include it at a low level of accuracy that fits the plausible range of uncertainty.

If one believes a relationship to be important, he acts accordingly, and makes the best use he can of the information available.

If one *really* believes this, then one is comfortable using subjective inputs from experienced people, including historians and psychologists. One is also comfortable about writing down postulated relationships that *appear* right intuitively, and then asking people to help estimate the coefficients. Dealing with human and organizational realities is seen as necessary and important.

Measuring the Capability of Units

The Usual Approach: Measuring Equipment-Limited Capability

Policy-level analyses dealing with such subjects as the military balance, conventional arms control, and high-level resource allocation decisions depend heavily on highly aggregated models. At the extreme, but a very useful extreme indeed, analyses are based on the effects of proposals on the theater-level force ratio over time, ignoring attrition. Force size is usually measured in one or another variant of Armored Division Equivalents (ADEs), where a given unit's raw score is calculated by a "WEI-WUV method" or something comparable, and then ADEs are obtained by dividing by the score of a standard division (see, for example, CBO, 1988, or Posen, 1988). A modern U.S. armored division is often counted as 1.0 in such a system. It is usually assumed that these ADE scores measure force capabilities. In fact, they measure the capability of equipment, not units,[5] making no allowance for the quality of the people manning the equipment, nor for the quality of doctrine, command-control, and unit mix.

The next useful level of sophistication involves simulation models of combat. These also require measuring the capabilities of opposed forces. Some of these involve weapon-on-weapon calculations, while the more policy-oriented models often employ a dynamic version of scores comparable to ADE scores. In the past, both the weapon-on-weapon-level models and more aggregated models largely ignored human factors and depended almost entirely on equipment-limited measures of capability. To my knowledge, at least, there was no *systematic* effort to do otherwise until development of the RSAS.

Unit Capabilities in the RSAS

Consistent with the more general philosophy indicated earlier, the RSAC approach required attempting at least a first-order treatment of nonequipment issues. With this in mind, we introduced a new measure of capability into the RSAS: effective strength, as measured by effective equivalent divisions (EEDs). Effective strength (EEDs) is related to strength (EDs) by multipliers, which can be either exogenous parameters or variables:

Effective strength (EEDs) = Strength (EDs) * Multiplier 1* Multiplier 2...

The multipliers we currently use deal with (Bennett, Jones, Bullock, and Davis, 1988): [6]

- <u>Level of training</u> (roughly speaking, "readiness")

- Cohesion and effectiveness problems caused by attrition in combat (which can be offset to some degree by withdrawing the forces from combat for a rejuvenation period)[7]

- National fighting effectiveness

- Unmodeled effects of shortages in supplies or support (some effects are modeled explicitly)

- The potential benefit in morale and determination from fighting in one's homeland

- The reduced efficiency arising from interoperability problems when forces of different nationalities are operating in the same corps (or army) sector

- Certain indirect rear-area effects: reduced effectiveness of divisions at the FLOT when opponent forces are loose in the corps' rear area

- Temporary surprise effects at the tactical level (e.g., effects reflecting likely problems of disorganization)

- Temporary chemical-attack effects at the tactical level (e.g., reflecting likely problems of disorganization and reduced effectiveness due to using chemical garb)

This list is eclectic, to say the least, and the factors reflect phenomena involving a mix of human, organizational, and "physics" effects. The discerning reader will appreciate that there are numerous theoretical problems in having these multipliers. For example, having several multipliers less than 1 might overestimate the combined effects of the several problems and there are potential interdependencies. Nonetheless, having the multipliers has proven very useful: first, in reminding us to consider what are often dominant factors; second, in encouraging us to develop reasonable estimates of what the multipliers should be as a default; third, in allowing us easily to do excursions of considerable interest in both war games and analysis; and, last, in encouraging us to develop approximate models replacing exogenous parameters by dynamically calculated variables.

Readers dubious about the desirability of having such soft factors should bear in mind the following:

- It seems impossible to understand combat results in historical conflicts such as WWII and the Arab-Israeli wars without applying factors for the qualitative effectiveness of the different nations' forces. For example, German forces were more than twice as effective at the tactical level as Russian forces in WWII and Israeli forces have been at least twice as effective as Arab forces (see Dupuy, 1987, p. 281). Indeed, "everyone knows" these facts at some qualitative level. Hence, it seems downright foolish to analyze the battles of these wars without including the factors explicitly, although many statistics-oriented analysts have long and obdurately done so. It is unsurprising that they tend to find few correlations between battle outcomes and force ratio.

- "Everyone" would agree that if the ultimate simulation model existed with perfect data, then Israeli ground forces would do better on average than Arab ground forces with the same equipment, because of better tactical-level prowess by both officers and enlisted men, better support, and perhaps because of better doctrine for their theater. In the absence of such an ultimate model, we must "guess" the net effects of unmodeled considerations. The best guess would surely not be a multiplier of 1.

- If one does apply such corrections, then it is far easier to make sense out of a vast range of historical data as Dupuy has argued for some years. [8]

In practice, we ordinarily assume a multiplier of 1 for several of the variables listed above, including the national-effectiveness factor. However, doing so is clearly not a best estimate, and in some of our work we *experiment* with corrections such as reducing in some scenarios the assumed tactical effectiveness of reluctant Pact allies such as the Poles and Czechs, increasing the assumed tactical effectiveness of FRG forces and lowering the assumed effectiveness of other NATO forces that have special problems not reflected in their equipment scores. This can substantially alter one's view of where NATO's warfighting problems lie.

How Visibility Hardens Soft Variables

It is instructive to illustrate how what starts as an ad hoc multiplier for a "soft factor" can become just another "hard" variable. Consider the case of training effectiveness. So far as I know, models prior to the RSAS assumed that forces would fight as effectively as their equipment dictated, regardless of training time. Training readiness was reflected only indirectly, if *at all*—by withholding forces from the simulated battle until such time as it was deemed reasonable to assume they could be used effectively.

In any case, the first step in our procedure (1983) was to recognize the need for a multiplier. The second step was to build an analytically trivial model of how effectiveness might increase with training time. As one might expect, the equation was (Bennett et al., 1988):

$$TE = TE_O + Rate * Time$$

That is, we assumed that the training effectiveness multiplier increased linearly with time, increasing at a rate treated in the model as a parameter. However, while the analytics are trivial, the results are not. Half the Pact force structure, after all, is at a very low state of readiness. This can have a profound effect on simulation results. Also, having this issue highlighted immediately suggests that for the Soviets to achieve surprise in an attack of Europe they might have to raise their initial levels of readiness in peacetime—well before formal mobilization began. Thus, the very meaning of "surprise attack" is shifted from one akin to a bolt-from-the-blue to one better described as attack after a short-mobilization subsequent to extensive premobilization preparations to which NATO has not fully or cohesively reacted (Davis, 1988a and b).

After working with this simple model of training's effect on overall force capabilities for several years, it became necessary to extend its sophistication (Davis, 1988b) to explain qualitatively some of the major discrepancies one finds in the literature regarding the time required for Soviet Category III forces to prepare for combat (roughly 20-120 days, depending on source). The essence of the approach is simply to recognize that a given unit's effectiveness depends heavily on its mission and that the training time required for effectiveness must also depend on that mission. In particular, it is only reasonable to assume that forces can fight rather effectively when they are fighting from static defenses to protect something critical to their homeland (e.g., Soviet units defended on the outskirts of Moscow in WWII with only minimal training). By contrast, it is likely that effectiveness increases more slowly when preparing for attacks on difficult defended positions. Figure 1 illustrates these concepts with essentially notional numbers. *It remains a difficult and unsolved problem to go from such objective variables as training frequency and cadre levels during peacetime to output measures such as how quickly the unit in question can be prepared for combat once mobilization begins*. Human-factors experts surely have a role in doing better on such matters.

The example illustrates how what starts as a soft and fuzzy concept later becomes just another "hard" part of a quantitative model, although the parameter values may remain uncertain

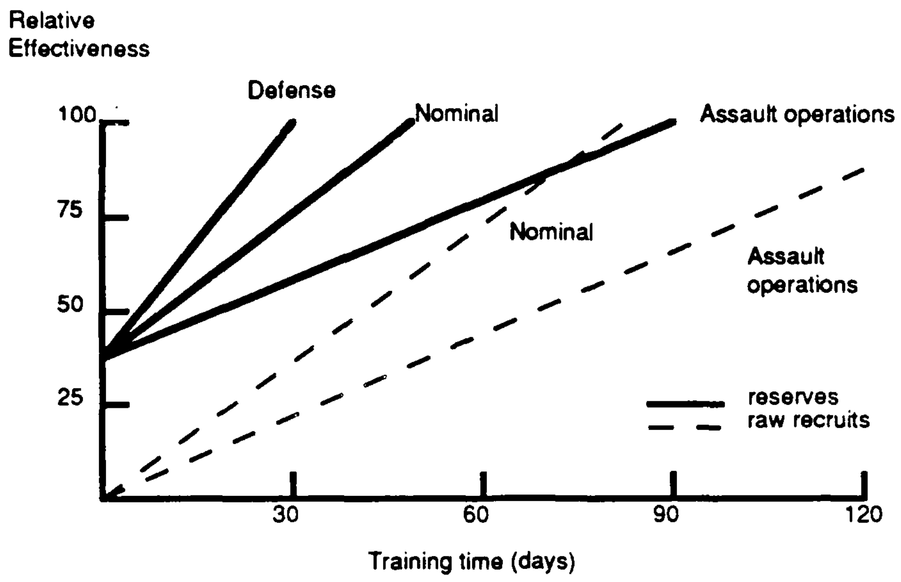

Fig. 1—Notional buildup of effectiveness with training for low-readiness reserves

and sensitivity analysis may be essential. At this stage, government sponsors and military officers with whom I have discussed these matters no longer regard the training readiness factor to be any "softer" than other variables (e.g., the terrain factors routinely applied in theater-level models on a zone-by-zone basis).[9]

Speculations

Similar strides could probably be made with respect to estimating future national-fighting effectiveness. As background here, I suspect that Israeli military leaders were not surprised when their air force quickly cleared the skies of Syrian aircraft over Lebanon (with an exchange ratio of something like 80 to 0 or 1). They *knew* they had both better pilots and a decisive advantage in command and control. Nonetheless, standard combat models would have sought to predict the results of the battle over Lebanon with complex calculations that are the rough equivalent of the Lanchester equations of ground combat or, in more detailed models, with "physics" calculations involving acquisition and kill probabilities and the like, but with acquisition probabilities calculated without fully accounting for the issues of quality and command and control. Surely we can do better. A good recipe in such situations is to focus first on itemizing the critical factors differentiating one battle from another *qualitatively*, and to then try to predict outcomes for each type of battle using *all* the objective and subjective information at one's disposal, including calculations when appropriate, but also including the currently "soft" factors such as pilot capability and command-control issues. In many instances, one will conclude that it is better to forego detailed calculations and rely on judgments and rules of thumb using techniques such as those described in Allen and Wilson, 1987. This, of course, is precisely what operational commanders have often done over the years, but without the benefit of analytic techniques designed for the purpose.

REPRESENTING FRICTIONAL EFFECTS OF MILITARY OPERATIONS

Defining what one means by "friction" is notoriously difficult. It was difficult for Clausewitz, who did not succeed, and it is difficult for us today. Indeed, the noun "friction" is used much as is the adjective "soft," in reference to factors like Murphy's Law that one currently has trouble getting a hold on.

Let us discuss three examples here, not all of which readers may agree should be referred to as frictional examples, but which are instructive nonetheless in discussing soft factors driven in significant measure (but by no means entirely) by human and organizational factors rather than laws of physics. The three examples involve: (a) the effects of air interdiction on ground-force movement, (b) the movement of large armies over long distances, and (c) effectiveness of assaults on prepared defenses.

Air Interdiction as an Enhancer of Friction

For decades, the predominant mechanism by which modelers have attempted to reflect the effects of tactical air forces on the ground war has been through direct attrition. In one common approach ground-attack aircraft fly sorties and kill, on average, some number of armored vehicles per sortie (see, for example, CBO, 1988, and Posen, 1988). A division may be assumed to lose effectiveness in proportion to its loss of armored vehicles. The image, then, is that air forces add *firepower* to the battle. Indeed, many analysts have taken the next step and translated ground-attack sorties per day into an increment of equivalent division score so that a side's total equivalent-division score is the sum of that from ground forces and air forces.[10] What happens next is interesting if one is an anthropologist observing analysts rather than someone concerned about the validity of defense planning. Because close-air-support aircraft are specifically tasked to attack ground forces and fly at a relatively heavy sortie rate, and because they can have rather significant killing potential in terms of kills per sortie, analyses often conclude that A-10s are extraordinarily cost effective with respect to both other types of aircraft and divisions—even if they have high attrition rates. Further, the analyses indicate little or no value to other tactical air missions such as battlefield interdiction and air interdiction (BAI and AI, respectively).

There are many problems with this type of analysis, but I would mention two, both of which can be regarded as involving friction in war:

1. *Virtual attrition and the pucker factor*. The kills per sortie typically ascribed to ground-attack aircraft in models are assumed independent of the air-defense environment under the reasoning that air defenses are accounted for indirectly through the attrition of ground-attack aircraft. Nothing could be farther from the truth, but those who dislike treating soft factors seem not to notice. Consider the experience of the Israeli air force in the Yom Kippur War of 1973. In the first days of that war the Israelis did not actually suffer an especially high attrition rate by the standards of simulation models, but the environment was so hostile to aircraft that the air force was ineffective initially and had to refine drastically its tactics. Anecdotes from both aircraft and helicopter pilots tell a similar story: if the environment is hostile enough, one must expect mission effectiveness to be very low even for those pilots who complete the mission alive. The conclusion I draw is that close-air-support effectiveness has been greatly exaggerated in many studies.

At a modeling level, reducing estimated effectiveness this way corresponds to effects of *virtual attrition*. Some might say it represents the *pucker factor*. In our work with the RSAS we are including a factor reducing the per-sortie effectiveness as a strong and nonlinear function of the attrition rate, using attrition rate as a measure of the environment's hostility to such missions. The parameter values we currently use in the model are highly judgmental, although historical research could probably improve on them and it seems plausible that a more detailed model could be developed that would be explicitly dependent upon the density of air defenses, their rate of fire, and the difficulty of the attacker's mission. Such a model *might* be calibratable from history and field tests or man-machine simulations that included simulated defenses and pilots with high incentive to avoid being "hit" by the simulated fire (e.g., laser beams or simulated missiles).

2. *Interdiction-induced friction.* Next, consider what anecdote and history would indicate are *important* effects of tactical air forces on the ground battle even though they have played a modest role in many analytic studies: (a) delaying and disrupting the movement of enemy tactical units while one's ground forces execute attacks on enemy forces that these units are attempting to reinforce; (b) disrupting rear-area movements generally (of supplies, support forces, and maneuver units), often in unanticipated ways; (c) slowing and disrupting the enemy's movements after he has achieved a local breakthrough, or speeding one's own movements in exploitation of a breakthrough; and (d) delaying and disrupting the movement of operational-level enemy units en route to the front. Of these, the first two have clearly been important in past wars and correspond well to both anecdotal and historical accounts, especially by army officers. Mechanism (b) is emphasized in the historical review by Dews and Kozaczka (1981), which brings home the image of tacair increasing the friction of the opponent's operations as a matter of first-order significance. Mechanism (c) is largely postulated, but is highly plausible. Mechanism (d) is at the heart of deep interdiction concepts, and is highly controversial.[11]

To summarize now, consider first that it is conventional wisdom among senior professional officers and historians that control of the air is extremely important to the ground war, and second,that there have been *no* wars as yet in which close-air support aircraft were very effective in terms of killing armored vehicles. Clearly, these people are either wrong or the *principal* effects of tactical air on the ground war have been precisely the effects that have traditionally been left out of aggregated (and some detailed) models, those dealing with the effects mentioned above.rather than close support Unfortunately, these effects are usually considered to be difficult to model accurately.

The heart of the difficulty is that we have long visualized the problem with frictionless models. Even when we try to model delays in columns caused by strafing, the mental image is often something like this: "Hmm, well, the vehicles would have to get off the road for a spell and then get back into column and start up. Let's see, how long would that take? Well, if I saw some attacking aircraft coming in then...." This type of imagery invariably leads to very short estimates of delay and disruption because it starts with individual small units and omits random and systematic complications characteristic of the whole organization rather than the part. These include human and technical command and control disruptions at the tactical level, logjams caused by damage to a particular bridge, increased timidity, the time required to shift back and forth from a relatively fast-moving posture to a defense-emphasizing posture, and the fact that equipment that could clear up problems quickly if available may be in the wrong place–i.e., a mix of human, organizational, and "physics" issues To resort to a physics analogy, one might say that there are separate coefficients of friction for static and moving bodies, and that overcoming static friction is much more difficult than one might expect from seeing the body move after it has achieved momentum. *Some* of the factors determining the coefficient of static friction here are human and organizational in character.

There are no obvious solutions for this problem as yet, but my colleagues and I have introduced some postulated relationships into the RSAS, where they can be experimented with systematically. The first cut at the most important of these was directed at mechanism (c) and asserted the following:

$$V = \max \{ (V_o - a*S/F), V_{min} \} \text{ if } V_o >= V_{min}$$

$$V = V_o \qquad \text{if } V_o <= V_{min}$$

where V_o is the movement rate one would predict based on the type of battle, force ratio, and so on, S is a CAS, BAI, and helicopter "equivalent sortie rate" against the forces in question, F is the size of the force against which the sorties are operating, a is a parameter, and V_{min} is a minimum speed that could be maintained even against heavy air attack. Thus, the image postulated was that if a breakthrough occurred and the attacker was moving at a speed of, say, 50 km/day according to standard ground-combat equations, then by applying enough sorties against the breakthrough force, it might be slowed down substantially, perhaps to a speed of 5-15 km/day.[12] Note that this effect is in addition to tacair's killing of armored vehicles, to the extent the kills in the previous time period did not change the force ratio enough to slow down the movement to V_{min}.

Movement of Large Armies

Another excellent example of frictional effects is in the movement over large distances of large armies. To a naive civilian analyst it is often very puzzling why movement rates cannot be calculated assuming that tanks should be able to move at least 20 miles per hour for at least 12 hours a day for a total of 240 miles (400 km) a day. Even sophisticated analysts often greatly overestimate likely movement rates over sparsely occupied networks subject to interdiction. They may, for example, assume that each and every "cut" can be repaired in the nominal time required for that type of repair (e.g., repair of a bridge). This, however, tends to ignore such effects as: (a) engineering equipment being in the wrong place, and having great difficulty getting to the problem area because of traffic jams; (b) resource-allocation problems and associated confusion when there are multiple problem areas; and (c) the delays and disruptions caused by attacks on support units. Again, it might be more productive to approach the problem with explicit concepts of frictional coefficients, and to then seek ways to estimate those coefficients from history and field experiments capable of demonstrating some of the human and organizational complications one sees in large-scale operations.

Effectiveness of Assaults on Prepared Defenses

As a final example of how frictional processes are both important and underappreciated, let us consider how to simulate the effectiveness of attacker and defender in Central Region scenarios that begin with the forces postured in ways constrained by arms control agreements such as withdrawal zones or thin-out zones. There are currently many proposals for such constraints being discussed in both government and academic circles throughout the United States, Western Europe, and Soviet Union. As one example, deliberately simplified to avoid going too far afield here, suppose that the Soviet Union withdrew to the Western Soviet Union fifteen divisions from the Group of Soviet Forces, Germany, and also withdrew a substantial fraction of its forward deployed ammunition. Assume no other changes occurred. If we now analyzed the significance of this change with most models, it would be difficult to see much effect at all on the results of combat, except with respect to eliminating the feasibility of extremely short-mobilization attacks, because the models would predict that the Soviets could redeploy their forces and ammunition quickly. It can be argued, however, that the effect (as measured in time required for the Soviets to restore the previous situation) would be much greater than ordinary analysis would predict. Those familiar with the complexities of assault operations, especially assaults on prepared defenses, tend to argue that orchestrating the redeployment and subsequent marshalling for the attack would be a nightmare for Pact planners if they were trying to do it quickly, especially if they feared early interdiction attacks by NATO's air forces. Their description of the attacker's problems translates naturally into friction as represented by units which can't find their sister units, communication problems, massive traffic jams, and many low-level mistakes with higher-level consequences. In any case, better progress might be made with models developed from the start from a perspective

- Such models can be built to deal with issues at any of many different levels of decisionmaking, using much the same techniques technically (e.g., knowledge-based modeling that includes such concepts as a process model for decision, hierarchies of variables, qualitatively driven tradeoff decisions in the midst of conflicting considerations, explicit treatment of perceptions and changes thereof with respect to the environment and prospects).

Interested readers may wish to see an overview report (Davis, Bankes, and Kahan, 1986). They may also wish to consider use of the RAND-ABEL® programming language, which we have now used extensively for several years in building both decision models and knowledge-based combat simulation models. This language (see Shapiro, Hall, et al., 1988) is especially suitable for work in which differentiating among situations is a large part of the challenge. Figure 3 illustrates actual code and demonstrates certain features such as the ability to use English-like variable names and the cognitively natural use of decision tables to express tradeoff issues. The language depends on a C/UNIX environment and has been used almost exclusively on Sun work stations. It is fast (only about three times slower than C), strongly typed, and part of a larger environment for modeling called the RAND-ABEL Modeling Platform (RAMP) developed by colleague H. Edward Hall. RAMP should be available to other researchers by early spring, 1989, at no or nominal cost.

Models of Nonsuperpower Decisionmaking

The RSAS also includes models to represent the behavior of nations other than the United States and Soviet Union in war games and simulations.[16] These models, collectively known as Green Agent (Scenario Agent in older publications), have outputs such as the cooperation and involvement of individual nations. For example, Green Agent will determine whether a given nation provides basing rights to a requesting superpower, or whether a NATO ally would go along with a request to authorize SACEUR to use nuclear weapons. The models are parametric to reflect fundamental uncertainties. So, for example, one specifies such input variables as the side, orientation, and temperament of each nation. The values of temperament indicate predisposition to go along with the relevant superpower's requests (e.g., values include Reliable, Reluctant, and Initially Reluctant). In addition, as with all the RSAS models written in RAND-ABEL, it is especially easy to review and change interactively even the lowest-level decision rules. Thus, the rules are very much like data in a practical sense.

Among the many reasons for having such models in RSAS work is that they are constantly reminding us of problems we would prefer to sweep under the proverbial rug. Even good allies will simply not roll over and cooperate immediately and fully with their superpower's requests, and in some cases it is nearly inconceivable that they would acquiesce at all—despite the many studies that assume otherwise. Another reason is that such models can highlight and illuminate the importance of the British and French independent strategic nuclear deterrents. Analytically, it has proven useful to study subjects such as launch under attack and flexible response theory with a combination of NCL models and Green-Agent models.

MILITARY-COMMAND-LEVEL MODELS

One of the most important features of the RSAS is that it allows and encourages analysts to make explicit their military strategies. The technique involves something called analytic war plans (Davis and Winnefeld, 1983; Davis, Bennett, and Schwabe, 1988), which can range from a mere script of orders comparable to what analysts have long put in data files at the outset of their simulations to a model of how the relevant commander might adapt his orders in response to circumstances, some of which he has anticipated with explicit branches in his plan, and others of which he must be able to respond to at any time. The analytic war plans also impose a structure forcing the analyst to confront the many dimensions of strategy. For example, in global analyses, there must be RSAS war plans for the various military theaters, as well as coordinating plans at higher levels. Even within a given theater, a truly adaptive plan must be able to cope with complications such apparent changes in the enemy's strategy (e.g., a shift of main-thrust axes or a surprising use of air forces). By forcing military officers and analysts to confront such issues as part of the modeling process, it has proven possible to inject substantially greater operational realism into both simulation and analysis. Further, discussion of military strategies has become more systematic and sophisticated and the methodology has proven useful in war-college courses dealing with operational art and combined-arms planning.

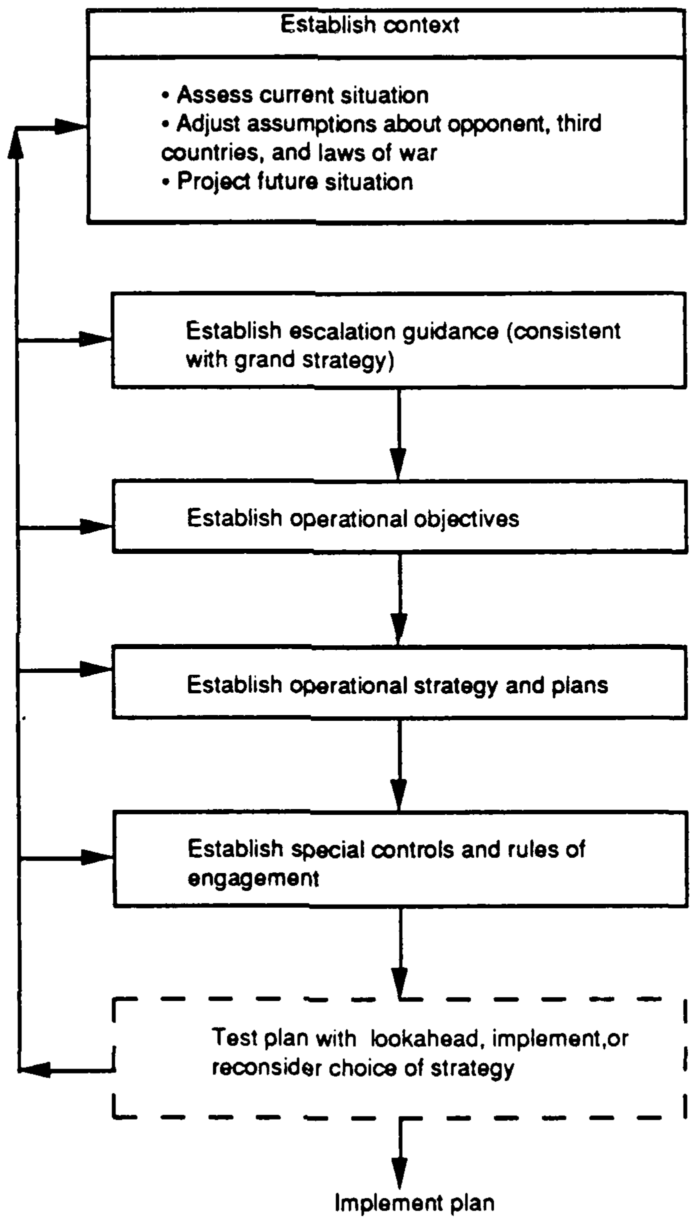

Fig. 2—Process model of original national command level models in RSAS

For some readers it may be desirable to mimic rather directly the approach we have taken in developing and using "analytic war plans." More generally, however, the technique should be understood as a mechanism for representing in simulations complex and only moderately adaptive organizational processes. This technique is for people seeking to reflect *realistic* cybernetic behavior, which may include local feedbacks and optimization, but which is seldom optimizable from the top-level viewpoint. Analogs to analytic war plans could be developed to represent mobilization, logistics, or the strategies for and operational procedures of concern at many different levels of human activity.

From NCL Models
Decision Table

Current-situation	Warning-of-escalation	Time-since D-Day(Eur)	Presume opponent	/Presumed /opponent
Eur-gen-conv	None	long	-	Blue1
Eur-gen-conv	None	short	-	Presumed-opponent
Eur-gen-conv	Eur-nuc	--	Blue-1	Blue3
Eur-gen-conv	Eur-nuc	--	>Blue1	Presumed-opponent
Eur-gen-conv	>Eur-n -		-	Blue6.

[long means greater than 10 days]

From S-Land (now called CAMPAIGN-ALT) model (Allen and Wilson, 1987)

Decision Table [Air drop lift losses]

DCA-sorties	esc-sorties	local-degree-of-surprise /	lift-loss-r	frac-lost-on-ingres
<50	>=(0.25*DCA-sorties)	High	0.02	0.30
<50	<(0.25*DCA-sortie	High	0.03	0.35
++	>=(0.25*DCA-sorties)	High	0.07	0.40
[Lines deleted for brevity]				
++	<(0.25*DC-sorties	-	0.10	0.60

Fig. 3—Examples of RAND-ABEL Computer Code

The relevance of this to a paper on soft factors in combat modeling will probably be more evident if we change vocabulary and talk about command-control rather than strategy. Command-control issues are widely considered as "soft" ("Who knows what the enemy commander would do at that point? Who knows whether the authorizations would be granted?"). Consider, for example, the problem of simulating the effects of delay and disruption on a Pact front commander being subjected to air interdiction with advanced weapons. It is easy enough in traditional models to compute attrition, and perhaps to estimate some delays that might or might not be correlated to attrition, but how do we reflect disruptive effects on the commander's entire strategy? If it means something to attack the enemy's strategy, as emphasized by Sun Tzu, then how do we see that in simulations? One way to do it is by having adaptive plans that attempt to represent explicitly the opponent's plans *and* the changes that real-world commanders would be likely to make as a function of how the war develops, rather than allowing the simulation to proceed with scripted orders. And, indeed, that is precisely what analytic war plans allow us to do, at least in principle.

In practice, we have not yet exploited this feature to the extent possible because of our focusing on other issues.

It has been especially fruitful to approach such "soft" subjects as surprise attack and deception with the method of analytic war plans. Many analysts over the years have castigated those who write about the importance of surprise and deception because there appears to be no content in the discussion. What does it *mean* to achieve either, and how can either be possible in the modern world in which the superpowers have lavish systems for warning and intelligence? In fact, however, it is straightforward to construct attack (or defense) strategies that incorporate both, and then to test them interactively or in analytic war games—primarily because the methodology forces explicitness in a comprehensible form. Surprise and deception remain as important to warfare as they have been in the past, which is very important indeed (Davis, 1988a and b).[17]

ILLUSTRATIVE IMPLICATIONS OF SOFT FACTORS IN CURRENT POLICY-LEVEL ANALYSIS

To conclude this discussion it may be useful to cite some examples demonstrating that treatment of soft issues is a matter of first-order importance, even for policymakers. My examples draw on published RAND work using the RSAS, but many more examples could readily be constructed.

1. *Assessing the threat.* The way one *views* the Central Region balance, the relative importance of short- and long-mobilization scenarios, and the value of various conventional arms control measures depend *strongly* on how one takes into account such issues as readiness, breakpoints, likely real-world force employment (rather than the more efficient optimized force employment often assumed), political-level decisions by independent nations, and the likely differences in perspective between a Pact commander contemplating invasion and a NATO-conservative U.S. analyst (Davis, 1988a,b).

2. *Tradeoffs among forces.* The tradeoffs between ground forces and air forces, or between different types of air forces, depend sensitively on how one models such soft phenomena as the pucker factor and the friction- enhancing effects of air attacks that go beyond the usual estimates of delay. Similarly, assessments of concepts such as FOFA depend on such phenomena, and also the degree to which FOFA could force changes in the operational concepts of commanders in the course of war.

3. *Crisis decisionmaking.* The issues that seem most important to deal with in improving first-strike stability involve *perceptions* and decision processes limited by aspects of human decisionmaking that are highly effective for coping with most situations in life, but potentially very ill suited for coping with life-and-death nuclear decisions in crisis (Davis, 1989). None of these are dealt with explicitly in traditional modeling and analysis. Nor are they properly reflected in today's decision aids, whether those be information displays on naval cruisers or briefing charts used in nuclear war games.

ACKNOWLEDGMENTS

Many of the concepts, models, and analyses described here were developed in collaboration with colleagues in the RAND Strategy Assessment Center, particularly Patrick Allen, Robert Howe, Carl Jones, and William Schwabe.

ANNOTATED BIBLIOGRAPHY

Allen, Patrick D., and Barry A. Wilson, 1987, *Secondary Land Theater Model,* The RAND Corporation, N-2625-NA. Describes at a simplified level combat modeling in the RAND-ABEL programming language; illustrates simple treatment of some soft factors such as surprise. Related but more complex models are used in the RSAS to describe air-land warfare in theaters other than Central Europe.

Battilega, J. A., and J. K. Grange (eds.), 1984, *The Military Applications of Modeling*, The Air Force Institute of Technology Press, Wright-Patterson Air Force Base, Ohio (available through the U.S. Government Printing Office). A survey course on combat models.

Bennett, Bruce W., Carl M. Jones, Arthur M. Bullock, and Paul K. Davis, 1988, *Main-Theater Warfare Modeling in the RAND Strategy Assessment System (3.0),* The RAND Corporation, N-2743-NA. Comprehensive high-level documentation for the RSAS model used for Europe's Central Region.

Davis, Paul K., 1988b, *Toward a Conceptual Framework for Operational Arms Control in Europe's Central Region,* The RAND Corporation, R-3704-USDP. Discusses significance of readiness and related issues to the conventional balance.

Davis, Paul K., 1988a, *The Role of Uncertainty in Assessing the NATO/Pact Central Region Balance*, The RAND Corporation, N-2839-RC. Describes the philosophical approach to military analysis being taken by the author and RSAC colleagues. Includes comparisons with alternative approaches.

Davis, Paul K., 1989, *Studying First-Strike Stability with Knowledge-Based Models of Human Decisionmaking*, The RAND Corporation, R-3689-CC. Focuses on behavioral considerations of crisis decisionmaking using an intellectual framework reflected in the RSAS' national command level models.

Davis, Paul K., Bruce W. Bennett, and William L. Schwabe, 1988, "Analytic War Gaming with Ivan and Sam," *Signal,* July issue. Provides a popular-level overview of the RSAS.

Davis, Paul K, and James A. Winnefeld, 1983, *The RAND Strategy Assessment Center: An Overview and Interim Conclusions about Utility and Development Options*, The RAND Corporation, R-2945-DNA. The original conceptual blueprint for the RSAS, somewhat obsolete but still valid at a general level.

Davis, Paul K., Steven C. Bankes, and James A. Kahan, 1986, *A New Methodology for Modeling National Command Level Decisionmaking in War Games and Simulations,* The RAND Corporation, R-3290-NA. Discusses in some detail the intellectual and technical approach taken in building political-level models sensitive to both qualitative and quantitative issues, including perceptions about the environment (including the opponent). Includes discussion of relationship to artificial intelligence research.

Dews, Edmund, and Felix Kozaczka, 1981, *Air Interdiction: Lessons from Past Campaigns*, The RAND Corporation, N-1743-PA&E. A widely read short study correcting some significant misimpressions about what air interdiction has and has not accomplished historically.

Dupuy, Trevor N., 1987, *Understanding War*, Paragon House Publishers, New York. A comprehensive account of Dupuy's theories and empirical base. Strongly recommended for all analysts willing to consider "soft factors" and their implications for combat.

Fain, Janice B., Richard C. Anderson, Trevor N. Dupuy, Gay M. Hammerman, and Charles F. Hawkins, 1988, *Forced Changes of Combat Posture,* Historical Evaluation and Research Organization (HERO), a division of Data Memory Systems, Inc., Fairfax, Virginia. A report done for the Army's Concepts Analysis Agency in Bethesda, Maryland, under Contract MDA903-87-C-0807. A recent historical study relevant to the "breakpoint" phenomenon.

Levine, Robert, 1985, *Flying in the Face of Uncertainty: Alternative Plans and Postures for Interdiction in Southwest Asia,* a Ph.D. Dissertation for the RAND Graduate School of Policy

Studies, The RAND Corporation, P-7050-RGI. Includes a thoughtful critique of common self-serving rationalizations used by military analysts, as well as providing an unusual military strategy for defense of Southwest Asia.

Posen, Barry, 1988, "Is NATO Decisively Outnumbered?" *International Security*, Spring issue. Highlights several key soft issues involving the value of support forces and a highly aggregated analysis of theater-level problems. Illustrates use of ADE methodology.

Schwabe, William, 1983, *Strategic Analysis as Though Nonsuperpowers Matter*, a Ph.D. Dissertation for the RAND Graduate School of Policy Studies, The RAND Corporation, N-1997-DNA. Describes the motivation for developing decision models of third-country behavior in crisis and conflict. Also summarizes major elements of the approach taken in the RSAS.

Schwabe, William, and Lewis M. Jamison, 1982, *A Rule-Based Policy-Level Model of Nonsuperpower Behavior in Strategic Conflicts*, The RAND Corporation, R-2962-DNA. The original documentation of the RSAS' Green Agent (then called Scenario Agent). Now obsolete in detail, but useful for its discussion.

Shapiro, Norman Z., H. Edward Hall, Robert H. Anderson, Mark LaCasse, Marrietta S. Gillogly, and Robert Weissler, 1988, *The RAND -ABEL® Programming Language: Reference Manual*, The RAND Corporation, N-2367-1-NA. Technical documentation.

Shlapak, David A., William L. Schwabe, Mark A. Lorell, and Yoav Ben-Horin, 1986, *The RAND Strategy Assessment System's Green Agent Model of Third-Country Behavior in Superpower Crises and Conflicts,* The RAND Corporation, N-2363-1-NA. Detailed documentation (including the complete computer program in RAND-ABEL) for the second-generation RSAS Green Agent.

Stoeckli, H. G., 1985, *Soviet Operational Planning: Superiority Ratios and Casualty Rates,* Soviet Studies Research Center, Sandhurst, UK. Summarizes and analyzes previously unavailable Soviet data on attrition in World War II. Interesting in part because western data have already been used to calibrate combat models, while these data are "new."

U.S. Congressional Budget Office, 1988, *U.S. Ground Forces and the Conventional Balance in Europe,* Government Printing Office, Washington, D.C. Includes technical details of a relatively typical highly aggregated air-land model of warfare developed by Joshua Epstein and modified by the CBO.

Van Creveld, Martin, 1985, *Command in War,* Harvard University Press, Cambridge, Massachusetts. Will be considered a classic discussion of the subject; includes extensive examples of how human and organizational factors have affected combat in historical campaigns.

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[1]The RSAS is a system for analytic war gaming developed by The RAND Corporation under the sponsorship of OSD's Director of Net Assessment, Mr. Andrew Marshall. It is an integrated system for studying both conventional and strategic-nuclear issues in individual theaters and on a global basis. It includes both combat models and decision models, the latter including optional political-level models. The RSAS is currently being used by about a dozen government agencies and by a sizable number of RAND projects. For a short overview, see Davis, Bennett, and Schwabe (1988).

[2]This point should not be overdone. For example, analysts have, to some extent, reflected frictional processes in terms of parameters such as decision time, reaction time, or the like. Also, the possibility of very different decisions is often treated explicitly. Nonetheless, it is unusual for analysts to take on these subjects with the diligence and enthusiasm they demonstrate in, say, the modeling of strategic mobility, Lanchesterian attrition battles, or strategic nuclear exchanges. For a survey of early-1980s models, see Battilega and Grange (1984).in which soft factors are only infrequently mentioned (one exception is the discussion in Chapter 8 of the VECTOR-2 concept, which includes explicit modeling of perceptions and intelligence).

[3]The most notable exception to the widespread tendency in the West to avoid dealing with "soft factors" was, for a long time, T. N. Dupuy, whose work strongly influenced my thinking in 1982-1983 while conceiving much of the work reviewed here. I am pleased to note the increasing number of analysts who now read, use, and refer to Dupuy's books, even if they disagree with some of his arguments and models. See Dupuy (1987), which updates his earlier *Numbers, Predictions, and War.*

[4]See, for example, J. W. Forrester, *Urban Dynamics*, The Massachusetts Institute of Technology Press, Cambridge, Massachusetts, 1969.

[5]Even the characterization of equipment-limited capability is highly controversial and there are long-standing and sometimes bitter and mindless arguments about whether such scoring systems are even useful, let alone which system to use. Those controversies are irrelevant to the current paper, but there has been considerable RSAC research devoted to understanding and improving scoring methods.

[6]In the current RSAS, the multipliers for surprise and chemical effects appear only within calculations of attrition and movement rather than in calculations of the sides' separate effective strengths. This should logically be changed in future versions of the model, but it seldom has much effect on results.

[7] As documented in a recent historical study (Fain, Anderson, Dupuy, Hammerman, and Hawkins, 1988), forces typically break off battle at much lower levels of attrition than might be expected. The reasons are many and complex, often involving maneuver issues such as the danger of being outflanked, but it is reasonable to assume that the effectiveness of a division decreases faster than linearly with increasing attrition, even if there are no absolute "break points."

[8]In unpublished work, I have shown that the attrition models used in the RSAS appear to be reasonably consistent with Eastern Front experience of the Soviet Union as described by Stoeckli (1985), if one assumes that German forces were approximately twice as effective tactically as Soviet forces.

[9]This treatment of readiness still captures only a portion of the human-factors issues, however. For example, it omits discussion of divisional leadership, which in some cases appears to have been the dominant factor in a division's performance (see discussion of the 88th Infantry Division in Dupuy, 1988, pp.114 ff., which also indicates that in retrospect "objective" indicators of that division's probable excellence could be found in its records). See also Van Creveld (1985) for much relevant discussion, unfortunately not quantitative.

[10]Using fictitious numbers merely for illustration, suppose that a standard division kills 0.10 enemy EDs in a typical day's battle and that 400 air sorties kill 100 armored vehicles. If a division has approximately 1000 armored vehicles, then it can be argued that 400 air sorties per day is equivalent to 0.10 EDs.

11. RAND Colleagues,, Ted Parker, Richard Hillestad, and Lou Wegner have developed a detailed model of interdiction effectiveness addressing some of these mechanisms assuming that unit level delays and disruptions are specified functions of attrition. Their work is especially suitable for looking at advanced munitions, but probably underestimates the value of older munitions and effects on army- or front-level strategy

[12]Using fictitious numbers merely for illustration, suppose that a standard division kills 0.10 enemy EDs in a typical day's battle and that 400 air sorties kill 100 armored vehicles. If a division has approximately 1000 armored vehicles, then it can be argued that 400 air sorties per day is equivalent to 0.10 EDs.

[13] Using fictitious numbers merely for illustration, suppose that a standard division kills 0.10 enemy EDs in a typical day's battle and that 400 air sorties kill 100 armored vehicles. If a division has approximately 1000 armored vehicles, then it can be argued that 400 air sorties per day is equivalent to 0.10 EDs.

[14] See Van Creveld (1985) for material highlighting the significance of such factors (e.g., Chapters 5 and 6).

[15] One of the difficulties in improving our understanding of these matters is that there appear to be few appropriately trained scientists working to collect relevant information about *organizational* performance in military operations. The people needed might be better served by a mix of some factory-floor experience in operations

research, business theory, and the social sciences than by knowledge of biology, psychology, or the brand of statistics that eschews theory. .

[16] The most relevant documents here are Schwabe (1983); Schwabe and Jamison (1983); and Shlapak, Schwabe, and Ben-Horin (1986

[17] At this point let me post a very large caveat. While the RSAS has all the features described in this paper, it also has many limitations and problems. Moreover, we have only begun to tap the potential of the underlying approach and many of our submodels, as described here candidly are much simpler than will eventually be desirable. As the experienced reader will have suspected, we have no panaceas yet.

HUMAN FACTORS -- IMPLICATIONS FOR HIGH RESOLUTION LAND COMBAT MODELS

CPT JAMES C. HOFFMAN
U.S. Army TRADOC Analysis Command-Monterey

I. INTRODUCTION

The use of algorithms which explicitly represent a functional form to describe the influence of human physiology and decision making processes on combat has yet to be included in any Army land combat model. Most combat simulations used in the decision making process, for analysis of tactical/doctrinal issues, and to support the acquisition system rely on engineering based models to describe the outcomes of combat processes such as target acquisition, movement, and attrition. Other models, such as the Quantitative Judgment Model developed by Trevor Dupuy, have attempted to fit historical battle outcomes to engineering based parameters. Finally, some field experiments have attempted to relate human factors to performance by obtaining quantitative measurements such as body temperature vs. time in chemical protective clothing, but this information has yet to be developed into a quantitative, step-by-step linkage from the soldier to performance parameters in combat models.

This paper describes research recently initiated by the U.S. Army Training and Doctrine (TRADOC) Analysis Command-Monterey, and sponsored by U.S. Army Deputy Chief of Staff for Personnel as approved by the Deputy Under Secretary of the Army for Operations Research, which attempts to address the issue of including measures of human performance within high resolution land combat models. The success of this effort may result in an improvement in overall modeling methodology and validity.

II. THE PROBLEM

Engineering models make little or no attempt to explicitly consider human factors. Models such as QJM are, at best, parameter fits which if correct, only apply to the specific situations from which the fitted parameter values were derived. Field experiments have collected data which have been largely unused in models. This deficiency arises from the lack of understanding on how to express measurable human factors in a functional form which adequately, in some sense, describes the influence of human performance on combat systems.

If human factors are to be considered in a meaningful way in combat models, an overall architecture for linkages between field measurable parameters and model performance parameters is required. For example, we all agree that fatigue is important and degrades performance. How do we measure fatigue (hours since sleep, BTU's per hour expended for the past X hours)? How does fatigue affect "combat" (a meaningless question)? Rather, how much is the time to detect for a Tank Commander increased as a function of the level of fatigue (as measured in units of fatigue!)? What is the reduction of hit probability by a TOW gunner as a function of fatigue? What is the probability that a commander will make a "bad" decision which results in an inappropriate deployment of forces, in the wrong place, at the wrong time? In other words, human factors degrade or enhance functions or tasks, not "combat". What we are missing is a design to take us in a quantitatively related audit trail from field tests to model function performance effects. In truth, this may oversimplify the problem since high resolution combat models use representations of combat systems such as tanks, armored fighting vehicles, air defense systems, etc., as the basic elements "attrited" during combat. Within these models there is little direct appearance of the individual[1]. Command and control processes are even less tenable, being represented by decision tables or expert human "players" who try to model "real" command and control processes within a larger model context. Thus, the audit trail of human performance within a high resolution combat model *implicitly* follows a path from understanding how the combat environment affects individual soldier performance to how weapon system performance is influenced by the effects of the combat environment on the weapon's crew and how the "quality" of command and control, as influenced by human factors, affects the ability of weapon systems to be used in combat.

The importance of crew performance over individual soldier performance is difficult to overstate when considering how to include the influence of the human within a high resolution combat model. Although it may be alluring to study how the environment of combat stresses the individual soldier and, necessarily, changes an individual's ability to accomplish any particular task, we cannot be certain how to map changes in individuals' abilities to their end effect on a given weapon system and hence the total force. The same uncertainty exist in the relationship between the decisions made by any individual commander and the effect these decisions have on the overall combat effectiveness of a tactical force. In the first case, interactions between crew members may be significant and thus allow a crew to cope in a robust way to maintain a relatively high level of weapon system performance in the face of high stress on individual crew members. Likewise, the command and control processes within a tactical force may also be similarly robust to degraded decision making. Although these are just hypotheses, they point out the difficulty of incorporating the explicit performance of the individual within a combat model and demonstrate the important implication that the study of individual soldier performance, by itself, will not be useful if the objective of research is to improve the representation of human factors within the current family of high resolution land combat models. This reasoning indicates that, for the high resolution combat model, important *real world* human factors relationships describe how weapons' *crews* interact to fight weapons systems and how *commanders* interact with the command and control process to make decisions. The consequences of these interactions, measured in terms of parameters defined in the model, are the *model's* representation of the effects of human factors on combat processes. By incorporating such model parameters, a modelling view of the influence of human factors on tactical forces can be judged in terms of the effect the inclusion of such parameters has on model output.

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[1] The SEES model which is currently under development at the Lawrence Livermore National Laboratory is a notable exception. This model, having evolved from the high resolution combat model called Janus, is primarily concerned with combat as fought by individuals, resolved at the level of the individual.

III SCOPE OF RESEARCH

Given that human factors can influence both weapon system performance and the quality of decisions resulting from a specific command and control process, one immediate problem is to determine which of these relationships, or their convolution, has the greatest influence on combat processes. The proposed research recognizes the potential importance of this question but limits the scope of research by only addressing a methodology for including a description of the effects of human factors on weapon system performance. This limitation bows to the fact that attrition processes which rely on weapon system performance parameters are significant components of current high resolution combat models while command and control process are significantly less well understood.[2]

If weapon performance is an important aspect to consider in terms of including human factors in high resolution combat models, then the distribution of weapon performance as reflected by different crews fighting identical weapons systems is a possible mapping which might permit this quantification to be useful. Current models make the implicit assumption that, for a given weapon system, all crews perform at the same level and thus have the same potential lethalities and vulnerabilities. This assumption is the logical equivalent of supposing all tanks of the same type are crewed by an identical set of solders. Although recent investigations have shown this assumption to be useful in approximating the real world performance of combat units in training[3] this is only a "first order" representation of human factors. By studying the distribution of weapon performance and then representing this distribution by an appropriate variation of model parameters, it may be possible to increase the overall level of human factors representation within high resolution combat models.

IV. PRACTICAL DIFFICULTIES

Assuming that distributions of individual weapons systems' performance which quantify the relationships between human factors and important model variables (e.g., P_k, P_h, target detection rate, etc.) are available through some reasonable experiments, then an appropriate question to ask is, "Will the inclusion of this distribution make a significant difference in model results?" Asking such a question is important for practical reasons. Namely, one would like to know, before going to the considerable expense of designing experiments and collecting data, whether or not the resulting changes in model output are significantly large enough to justify the expense. Although this may sound trivial, recent experience with the difficulties encountered during the collection of human factors data designed to measure soldier and unit performance under the stress of a chemical warfare environment (CANE studies) shows how it is possible to

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[2] Attrition process can be understood in terms of Lanchester theory. Search and detection has the advantage of the classical work of Koopman. The quantification of command and control relationships, by contrast, has yet to benefit from the development of such tools.

[3] Work by Prof. Ingber of the Naval Postgraduate School has shown that the current version of the Janus high resolution combat model can perform as a good surrogate for "combat" as portrayed at the National Training Center. [Ref. 1]

spend both time and money and not achieve the expected level of data relevance. Hopefully, investigations into model response will give an indication of how to quantify the distribution of weapon performance and thus try to insure that the measured human factors relationships are expressed in terms which are relevant to model algorithms and significant in their effect on model output. Such "front-end" analysis carries with it the assumption that the methodology (i.e., physics) of current models is essentially sound, and requires only incremental model development to significantly improve the quality of human factors representation.

The soundness of current modeling methodology is a question open to review. Rotman and Kowalczyk have shown that the Center for Night Vision and Electro-Optics (CNVEO) search model, currently the mainstay target acquisition algorithm in high resolution combat models, appears inappropriate in multiple target environments [Ref. 2]. This problem is being addressed by research efforts coordinated by the U.S. Army TRADOC Analysis Command to systematically evaluate the adequacy of current search and target acquisition algorithms in light of possible alternatives. The results of this research may produce significant changes in high resolution modeling methodology. These difficulties demonstrate that the physics of combat, as represented by model algorithms, is not free from criticism and is subject to change as knowledge of physical combat processes is increased. Should model algorithms change, then the possibility exists that those variables previously used in the measurement of the distributions of weapon performance will be incompatible with new algorithms. Thus a change in model physics may necessitate additional experiments to redescribe the effects of human factors on weapon performance using the appropriate "new" variables.

A further difficulty stems from the inherent "two-sided" nature of combat. This difficulty arises in a study of weapon performance from the simple fact that it may be difficult, if not impossible, to obtain adequate measurements of the weapon performance distributions of potential adversaries. This may lead to situations where the representation of human factors is essentially limited to friendly (Blue) forces. This difficulty points to a potential limitation on the usefulness of such models. Ideally, it is clear that the most desirable situation is where distributions of crew performance are taken into account on both sides. Failing this, the capability of the enemy (Red) force may be overstated in that it is not modified by the influence of human performance.

Although certain human factors such as fatigue can be argued as having essentially the same influence on all combatants, as explained by S. Van Nostrand [Ref. 3], it does not logically follow that such effects cancel each other during the course of combat. It may be easy to argue that since the human beings on both sides of a conflict have the same physiology, then they should fatigue at the same rate. While this may be true with respect to individual soldiers, the organizational and doctrinal differences between both sides, equipment differences, and unit cohesiveness[4] may exacerbate or mitigate the effects of

[4] Cohesion for this discussion is defined as used by Henderson and described by Johns et al. [Ref. 4] as

> the bonding together of members of an organization/unit in such a way as

fatigue in any particular situation when viewed from the level of a crew's influence on weapon performance. This possibility points out the potential danger of treating fatigue as some constant degrader of weapon system performance. Although it may degrade performance, in general, the rate of degradation may be a function of organization, tactics, and equipment.

A further point of concern is the expected increase in model complexity which is a natural consequence of the increased information content of a model which contains explicit human factors representations. The question is not that elegant, simple models are, in some sense, "better" than those of greater complexity. Certainly, one could argue that the effects of human factors on combat processes must be so complex that *any* model which faithfully represents the full spectrum of human factors is too complex to be of practical use. A counterpoint, however, is that the representation of *all* human factors may be unnecessary in that human factors relationships which produce small enough changes in model output may be judged insignificant under reasonable criterion and need not be included in models. The difficulty is that the line between "significant" and "insignificant" human factors relationships must be carefully drawn with an eye to insuring that model complexity is manageable and important human factors relationships (in terms of their effect on model output) are not omitted. How and where to draw this line in model development is obviously an issue which requires substantial thought and research.

V. PROPOSED RESEARCH

A research plan is currently under development at the U.S. Army TRADOC Analysis Command - Monterey facility to investigate the development of schemes to incorporate human factors within high resolution combat models. This research attempts to quantify the benefit of including *distributional* representations of weapons performance, as influenced by human factors, within a high resolution combat model currently used by the Army. This effort is not a simple sensitivity analysis in the sense of merely measuring the expected change in model output as seen through the main and higher order effect of a systematic variation of selected model parameters. Rather, this research will attempt to develop an audit trail from specific model variables to measures of weapon system performance which are conditionally dependent on measurable human factors. Information which represents the distribution of weapon system performance as dependent on a given set of human factors can then be used to construct a human factors dependent distribution of weapon system performance within the model.

This method may prove to be a practical way to include a distribution of weapons performance in a high resolution combat model and demonstrate a way to explore the modeling limitations which define the practical limits on the usefulness of such descriptions. The goal of this research is not to develop a new model; it is an effort to explore the limits of current modeling methodology. The results of this research will hopefully provide a measure of the importance of human factors in terms of changes in model output, giving an

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to sustain their will and commitment to each other, their unit, and the mission.

indication of which variables seem to be the important drivers of model response. This information will logically provide human factors experimenters with a guide to collecting data which can be used by modelers.

The model selected as a basis for this investigation is the JANUS model developed in its current version by the U.S Army TRADOC Analysis Command-White Sands Missile Range and used in high resolution analyses by several TRADOC Agencies. The JANUS model is described as [Ref. 5]

> ... an interactive, two sided, closed, stochastic, ground combat simulation. Interactive means that controllers or players direct, react to, and redirect certain key actions of the elements being simulated. Two sided means that there are opposing forces simultaneously being directed by two sets of players, closed means that the disposition of the opposing forces is not completely known to the player in control of friendly forces. Stochastic means that certain events such as the result of a shot or artillery volley are not predetermined but occur according to laws of probability and chance and may not occur again if the game is repeated. Ground combat means that the principal modeling focus is upon those military systems that participate in maneuver and artillery operations on land.

An advantage to using this model for this research is that the command and control aspects in any given scenario are relatively easy to control through the use of players. Additionally, the current programming and algorithmic structure is well documented and includes modestly flexible data structures which can be modified by the user without burdensome programming efforts. Furthermore, versions of this model are currently used as training models. This lends the hope that the results of research may have modestly wide applicability and utility to the Army modeling and training communities. Using JANUS also has the advantage that a measure of validity of any changes in modeling methodology can be evaluated using techniques developed to compare data collected from the "real world" training environment of the National Training Center with results from the JANUS model.

The immediate problems confronted by this research plan address the issues of: (1) How to make use of past results which quantify the distribution of weapon performance as related to crew performance? (2) How to best represent a distribution of weapon performance within JANUS as constrained by model variables and modeling constraints imposed by model architecture? (3) What are the appropriate measures of model performance with which to evaluate the significance of distributional effects? (4) What is an appropriate level of significance for measuring these effects? Reasonable answers to these questions will help address the larger issue of getting some information capable of assisting both the combat modeler and human factors data collector in determining a truly "cost effective" approach to human factors data collection and a possible path for incorporating this data into the Army's current family of high resolution land combat models.

VI. SUMMARY

This research confronts only one component of the total problem which must be addressed. Ongoing efforts to improve target acquisition algorithms[5] are essential if the goal of developing a workable strategy of incorporating human factors into high resolution combat models is to be realized. Additional research in the area of data collection is needed. Undoubtedly, the design of experiments to collect human factors data through the use of simulations such as SIMNET must be carefully thought out to insure "real world" human factors relationships are preserved in the use of such simulation. The research effort described in this paper should be seen as a small and complementary part of a larger Army program to improve the representation of human factors and human decision making processes within a useful family of combat models.

LIST OF REFERENCES

1. TRADOC Analysis Command-Monterey, *Mathematical Comparison of Computer Models to Exercise Data: Comparison of JANUS(T) to National Training Center Data*, by L. Ingber, January 1989.

2. Institute for Defense Analysis, *Extending the CNVO Search Model to the Multi-Target Environment*, by S.R. Rotman and M.L. Kowakczyk, 12 March 1987.

3. The Industrial College of the Armed Forces, *Including the Soldier in Combat Models*, by S.J. Van Nostrand, 1988.

4. Henderson, W.D., *COHESION: The Human Element in Combat*, p. 4, National Defense University Press, 1985.

5. TRADOC Analysis Command-White Sands Missile Range, *JANUS(T) Documentation*, p. 6, June 1986.

[5] TRADOC Analysis Command is currently developing a long term Search and Target Acquisition Simulation (ACQSIM) research program which will address the physics of target acquisition in terms of algorithms and develop tools for studying aspects of how military equipment and environment affect an observer's performance.

DISCUSSION OF "MODELING SOFT FACTORS IN THE RAND STRATEGY ASSESSMENT SYSTEM"
by P. Davis
and
"HUMAN FACTORS - IMPLICATIONS FOR HIGH RESOLUTION LAND COMBAT MODELS"
by J. Hoffman

DISCUSSANT: Howard G. Whitley III, US Army Concepts Analysis Agency

The main points that I feel need commenting upon as a result of these presentations relate to assumptions, methodologies, and uses of models in this particular application area. Although both are well prepared and quite timely, I become particularly concerned when I learn of existing models being considered for analysis in an area that most were not originally designed to address explicitly. As these papers discuss the application of two, JANUS and RSAS, of which my direct knowledge is somewhat limited, my comments are more of a general nature than if I had hands-on experience from which to make reference. I will comment on the above points in turn, below.

ASSUMPTIONS. Every model that I am aware of has many assumptions, either explicit or implicit, that researchers need to be aware of in the conduct of their work. Explicit assumptions stated clearly up front are the easiest to deal with in analysis, if by nothing more than recognition of potential limitations regarding specific applicability. Implicit assumptions are the most dangerous in that, as another speaker noted during the conference, if no limitation is stated up front, indirectly one could be lead to believe the un-addressed issue is of little consequence in the phenomena being represented. In these models the choice of how best to represent human factors, when humans are not explicitly detailed, could very well depend on what explicit or implicit assumptions have been made in their design and/or implementation. For example, in a situation not necessarily considered in these formulations, a properly executed deep attack can foul the decision cycle of the opposing force commander. Also, a less than timely political decision process could result in a defensive alliance being in a constant reactive mode, rather than forcing the attacker into poor decisions. In both cases, the best way to represent the human factor in the decision process may not be direct degradation of performance by some percentage, but perhaps well executed options at the wrong time. Some of these may turn out well in spite of, or as a result of, human factors, but many can result in disaster. Implementation of a delay, or transition to a reactive mode, may well be impossible in time-stepped (frame driven) simulations, however.

METHODOLOGIES. To go further into the manner of how to represent degradations, assuming that this is the correct approach, the consideration of how unrelated degradations combine into overall reduction in effectiveness needs some thought. Rather than propose a universal solution, I would like to share some functional forms I have seen used, even recently. I tried to think of clever explanations for the behavior of some, but since I could not be equally clever for all I will provide a short note on what happens in the less obvious cases. Straightforward averages and weighted averages of reductions in effectiveness appear to result in less loss of effectiveness than that determined in simple products of reduced effectiveness. The latter produces considerably lower overall effectiveness, sort of a calamity function, whereas the former might suggest that there could be order, even in disorder. One "modulation" form noted recently was computed as the n-th root of the product of n reduced effectiveness factors. An "attenuation" form noted (and actually used) resulted in slightly higher overall effectiveness than any of the components and suggesting, in a rather sly manner, that though there are problems all over, humans will find a way to overcome adversity. BG Silvasy, former CAA Deputy Director and ground commander on Grenada, tells of his troops hot wiring Russian trucks for use in moving about the island. I'm not sure how long it took for them to realize the Air Force couldn't tell the "friendlies" were using trucks of the wrong markings, but paint was found fairly quickly. Another presenter, David Rowland of DOAE in the UK, has done some excellent work in the degradation area. One of his well known papers describes the reductions in effectiveness of small arms when range test results are compared with field tests, and field tests with actual combat experience. I would add that the comparisons of laboratory or bench (engineering level) test results with range tests might reflect similar orders of magnitude differences in effectiveness levels. Humans being moved from decent, well paced, controlled environments to simulated fog-of-war situations, without fear, and then to the worst of all, total physical danger. What are the combinatorial effects?

MODEL APPLICABILITY. Researchers have a responsibility to "know their models". This need not be accomplished by building their own models. Be they stochastic (by design, not accident!), deterministic, man-in-the-loop, fully automated, time stepped, event driven, interruptible, simple, complex, item level, unit level with item level detail, ... theater level, or a global perspective, almost as many types as there are models, there can be a wrong one for any analysis. A theater level model is probably not the proper vehicle for determining the potential benefit of a new sundry pack for the soldiers' rations. It is the user's responsibility to select his model, and he will benefit from a good choice, not necessarily the most available. Now, about those models. The user, for whatever purpose, must be assured that his automated model(s) is (are) free of coding errors (a precise implementation of the designer's concept - verified, the Army term for this quality). Additionally, the model should have been validated (tested for correspondence and agreement with the reality it represents, including sensitivities, range of applicability of parameters and algorithms - and on and on, a near impossibility!). Even the most simple of models, formulas, can yield anomalies at extremes, and often this may not be discovered without testing. Surprise results typically arise at the most inconvenient of occasions. The near impossibility of totally validating large, complex models/simulations has led the Army to consider a less stringent qualification of models - accreditation (the testing and certification of its utility and validity for specific applications). In my own agency this has been done for selected models by individuals (or teams) independent of the user or developer of the models. We still do not have a formal process, with specific tasks to be performed, and even this less stringent review and qualification process is not well appreciated by users and developers. They, like many we all know, want to be left alone with "their" model to "do their thing", studies.

In summary, both Dr. Davis and Cpt Hoffman are to be commended for sharing their time and research with the mini-symposium participants. They have some good ideas that may well have applicability in the topic of the meeting. I feel Dr. Davis' emphasis on the use of parametric investigations into areas of uncertainty is worth repeating and reemphasizing. Finally, I offer my variation of Ockam's Razor (see Wayne Hughes' MORS Monograph for the original), which would implore you to "not complicate formulations unnecessarily without just cause, but don't let an incomplete understanding of a phenomena impede progress". Note that this is not the KISS principle!

Thanks for the opportunity to review these papers.

APPENDIX

TERMS OF REFERENCE
MORS MINI-SYMPOSIUM
"HUMAN BEHAVIOR AND ACTIONS AS ESSENTIAL
INGREDIENTS IN REALISTIC MODELING OF COMBAT

(MORIMOC II)

Stephen A. Murtaugh

Background

In February 1986, a MORS workshop was convened on the subject "More Operational Realism in Modeling of Combat" (MORIMOC). The participants were divided into three subgroups to examine the operations, mathematical, and physics/engineering aspects of improving combat models' realism. They examined the shortcomings and needs of combat model building and use from such standpoints as accounting for real operating conditions, creativity of opponents, and ingenuity in the use of forces. A major and unanimous finding of all three subgroups was the substantial lack of combat modeling of accounting for human actions and behavior in the combat environment; that is, the effects on battle outcome of human activity and responses, at all levels of the opposing forces. In fact, the representation of human action and behaviorial variables was cited in the workshop findings as the toughest problem in modeling and deserving of the highest priority. MORIMOC is but one of a series of recent DoD-sponsored activities which have come to a similar conclusion for all aspects of war planning, management and conduct.

Further emphasis was added by Secretary of the Air Force Edward C. Aldridge in his Keynote Address at the 55th MORS Symposium. He pointed out the need for operations analysts to account for the less quantifiable aspects of conflict, especially the people factor. He noted, however, that the people factor complicates things, for people are the least quantifiable and the least predictable element in any analysis. Yet the people factor has overriding importance - the modeled effectiveness of the most modern aircraft, ships, and tanks; the most advanced weapon systems and munitions; and the finest command and control systems, are all but a delusion if the analysis/modeling has not accounted for the people who operate these systems; plus their training and their experience and behavior in the stressful combat environment they operate their weapon systems in.

Most combat models today are driven by weapons count, weapon system effectiveness estimates, or firepower scores. However, there is substantial quantitative evidence that it is people, plus their weapons systems, rather than the weapons alone, that make the big difference in battle. Battlefield performance is not a series of isolated duels among individual weapons systems - there is a synergism of trained units interacting with each other in response to a commander's decisions, with potential degradation to the units and their effectiveness when they are under fire, losses are taken, and/or decision-making is deterred. Therefore, we need to gain greater understanding than we have of the relationships among the qualifications of combatants, their performance in various size units under combat conditions, and the combat effectiveness of man/weapon systems, units, and forces. Then this understanding must be employed in building and in making more effective use of operationally realistic combat models for support of critical planning activities such as weapon systems acquisition, force structure definition, and battle doctrine development.

Objectives

There are two objectives of this mini-symposium:

1. Develop an information base on the present status of modeling human actions and behavior and their effects on the conduct and outcome of combat. The intended scope of this information base would be provided by answers to the following:

   o Which human factors impact combat results and should be included in combat models?

   o What has been done to quantify such factors or the resulting actions and implement them in combat models?

   o What data bases have been developed of such human factors or actions and related combat results?

2. Support preparations for a MORS workshop on the same subject scheduled for Fall 1988.

Regarding the first objective, the intention is to survey, identify and critically examine (from the papers presented) analytic methodologies, implementations, and measures of effectiveness currently employed or in development to represent and integrate human behavior and actions and their effects in combat modeling. Achieving the second objective will require identification of specific developments needed in the subject area and will provide the basis for selecting people who are doing work of value in the subject area and would be meaningful contributors to the follow-on workshop. A proceedings of the symposium, composed primarily of documentation by the author(s) of each paper presented, is a critical output and will be used in the planned follow-on workshop.

Scope and Overall Planning

This mini-symposium is one in a sequence of activities designed to support the achievement of improved realism in combat modeling from the standpoints of the effects of human behavior and actions. The first step was publication in the December 1987 issue of PHALANX of an article "Of Human Behavior and Actions as Essential Ingredients for Realism in Combat Modeling". The intent of the article was to bring to the attention of the MOR community the reality and scope of this problem. The second step is a General Session at the 56th MORSS which will serve to introduce the upcoming mini-symposium to the attendees. The Chair and speakers from the sponsors of the mini-symposium will use this session to:

o discuss human factors issues and requirements in combat modeling

o identify elements of a conceptual framework for use in consideration of the mini-symposium topic, and

o define goals for a workshop planned to follow the mini-symposium.

The third step will be this mini-symposium, scheduled for late Summer, 1988. The outputs of this step will be an information base on the present status of modeling of human behaviorial effects on combat and selection of working group chairs for the follow-on workshop. The workshop, which is the fourth step, will be held in late 1988. Its goals will be defined at the 56th MORSS and they will be verified and expanded upon, as an output of the mini-symposium.

The mini-symposium will focus upon the presentation of prepared papers in specifically defined areas (see below) pertinent to the modeling of human behavior and actions in combat, critical discussion of the papers, and publication of the results so as to serve as a major part of the read-ahead package for the workshop. An important aspect of this mini-symposium/workshop series will be to identify and quantify factors which influence the actions of humans in combat enironments in either positive or negative manners. Humans will function in combat as one or more of the following:

- fighters or combatants (e.g. infantry, fighter pilots)
- operators (as of radars, weapon systems, tanks)
- decision-makers (e.g., flight leaders, unit commanders, ship's captains)

Factors which would impact their effectiveness in battle in performing these functions include:

- o training (as in weapon use and in battle group operations)
- o battle experience vs unknowns of combat
- o confidence, morale, fear, fatigue, confusion
- o leadership and decision-making

These human factors, taken in combination, influence force performance such as:

- o use of weapons so as to take full advantage of potential firepower
- o cohesion of forces under fire, especially when losses are taken
- o responsive implementation of tactics (as in reacting to opposing force's actions or in creating surprise)
- o innovation/ingenuity (as in decision-making with information missing and/or in error, or other friction of war circumstances)

Further consideration includes:

- o which factors might affect the opposing forces equally? unequally?
- o which factors might be offset by one opponent through better training, fresher forces, better intelligence, more effective communications, or more responsive logistics than the other side?

Therefore, the Call for Papers will emphasize work already completed or in progress in any of the following five areas, with priority given to work which presents results of quantitative analyses or modeling and generated data bases appropriate to the stated objectives of the symposium. The application of behavioral science in any of these areas will be especially welcome.

1. Human factors which impact combat performance

   - o What has been observed? measured? demonstrated?
   - o What is the sensitivity of combat to these factors? to the scenario?

2. *Human behavior/actions/combat* results data bases
   - o What data has been developed? is available?
   - o What are valid sources of such data? Combat? Manned simulations?
   - o What is the credibility of the data?
   - o How has the data been used in combat modeling? With what results?

3. Representation of human behavior/actions in combat models
   - o What has been accomplished? In what kinds or level of model? For what applications?
   - o How have the human factors been modeled (look-up tables, algorithms, AI technique, man-in-the-loop)?
   - o How have models constrained the ability to include human actions, including flexibility in force employment or in tactics and doctrine?
   - o Have expert systems or other AI approaches been implemented for these purposes? In what areas? With what success?

4. Correlation of model-derived human factors effects on combat with real battlefield experience.
   - o Basis of correlation (e.g., identity of appropriate measures)
   - o Extent of correlation, or lack thereof
   - o Requirements on models of combat to achieve credible results.

5. What others are doing in accounting for human effects in combat models:
   - o Approaches, progress by NATO; Japanese Defense Agency, etc.
   - o Perceptions of Soviet approaches, emphasis, progress.

Papers offered are to be unclassified. This should present no problem to authors because the great majority of the known work in this area is unclassified or can be made unclassified by sanitizing specifics such as weapon effectiveness values or details of example operations or applications. At the same time, this will greatly ease the burden of arranging for an acceptable symposium location and providing security during the meeting.

Discussants will be sought for all papers presented, so as to emphasize the symposium objective relating to performing critical examination of the methodologies, measures, and data presented by the speakers.

Because of the state-of-art survey nature of the mini-symposium, prompt and thorough documentation of all presentations and the discussant's remarks will be essential so that a proceedings can be published right after the symposium which will then serve as a reference for the follow-on workshop participants. The proceedings also would be available to the MORS sponsors and to the military operations research community.

Agenda

The chair will develop a detailed agenda which will be dependent on the response to the *Call for Papers*. *Preliminary plans include a Keynote address(es)* by one or more of the Service sponsors of the mini-symposium, and a charge to the attendees by the Chair which outlines the background and goals of the symposium plus the participation sought from each attendee.

If sufficient papers are offered in all five areas covering the intended scope of the symposium, the program will consist of five general sessions, each session covering one of the above topics. Tentatively, a program covering two days is planned, with a banquet and speaker the evening of the first day. Other arrangements will be considered, depending on the number and topics of the papers offered.

Symposium Management and Attendees

The MORS Executive Council designates Mr. Stephen A. Murtaugh, a MORS director for several terms and a former President of MORS, as mini-symposium chair. The service sponsors of the mini-symposium will recommend candidates for deputy chair and session chairs to the chair who will select the program committee. The MORS office will provide its helpful oversight and administrative support.

Attendance at the symposium will be by invitation. Invitees will include the authors of papers being presented, discussants of the papers, persons who submit acceptable statements showing that they are working in this field or are responsible for programs involving the topics being addressed, plus interested parties from the MORS Sponsors' organizations. Attendance will be controlled because the success of the symposium is in large part dependent on the attendees' contributions to the program through formal presentations, prepared discussions, and contributing commentary on the papers presented. Furthermore, the invitees for the follow-on workshop will be selected from the symposium participants, with their individual contributions being an important part of the basis for invitation.

SHAPE Technical Center at the Hague, Netherlands, has a NATO Initiative on the topic "Representation of Human Factors in Battle Models". They have expressed strong interest in this MORS mini-symposium and the workshop, and have tentatively offered to provide one or two speakers describing recent NATO studies relevant to this initiative.