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MEDICAL RESOURCE PLANNING FOR COMBAT OPERATIONS: UTILIZING PERCENTILE ESTIMATES AS AN ALTERNATIVE TO THE MEAN

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Summary

Problem

Estimates based on average patient loads are traditionally used to determine the medical resources needed to support a combat deployment. However, these estimates can lead to an undersupply of the resources needed to treat casualties during certain periods of an operation due to large fluctuations in daily casualty incidence.

Objective

This present study provides medical planners with a method of assessing the variability that may be observed during short temporal slices of an operation for wounded-in-action (WIA) and disease and non-battle injury (DNBI) incidence. The Temporal Slice Casualty Projection System (SLICECAS) has been developed to examine the expected patient loads for short periods of combat operations in which there may be considerable variability in casualty incidence.

Approach

The SLICECAS model generates 400 random variates for each admission type (WIA, DNBI). Four different baseline rates and two underlying distributions, with associated times series attributes, are used to generate these variates. A moving average function is incorporated into the model that allows computation of the casualty rate averages for the user defined periods of time.

Results

The model provides eight percentile estimates (99th, 95th, 90th, 80th, 70th, 60th, 50th, 30th) of WIA and DNBI casualty rate occurrence. Additionally, an oversupply ratio is calculated for each percentile by dividing the percentile estimate by the overall mean rate.

Conclusions

Combat casualties result from many factors that can yield dramatic fluctuations in the numbers of daily medical admissions. Medical planners should be provided a range of casualty rate estimates to assist in determining the appropriate resources and supplies, rather than have to rely on a single measure of central tendency.

MEDICAL RESOURCE PLANNING FOR COMBAT OPERATIONS: UTILIZING PERCENTILE ESTIMATES AS AN ALTERNATIVE TO THE MEAN

Accurate forecasting of medical resource requirements for combat operations is dependent upon reliable projections of the anticipated patient loads. Traditionally, a measure of central tendency, such as the mean, is used to estimate daily casualty incidence for resource planning purposes. For many planning objectives, utilizing the mean to estimate daily patient loads will allow planners to reliably gauge the resources needed to medically support the deployment. For instance, in estimating consumable medical supplies, such as gauze or sutures, so long as there are sufficient numbers of that particular supply to last throughout the engagement, it is inconsequential whether more or less than the daily mean is needed on any given day.

However, when estimating resource requirements such as beds or health care personnel, utilization of a daily mean can lead to shortfalls at critical times. This is because the nature of combat yields dramatic fluctuations in casualties sustained from day to day — on many days there may be no casualties, and on others there may be large numbers of wounded. Thus, when planning for resources such as medical personnel or beds, there are no "bankable" credits associated with days of light usage, as there are with supplies such as sutures or gauze. The days in which there are few or no casualties suppress the overall daily casualty average, but beds that were empty a week earlier provide no additional benefit in a later mass casualty situation. Consequently, using the mean for estimating some medical resources may at times be inappropriate and risky to the medical success of the mission.

The present investigation examines an alternative to using mean patient load, as the appropriate statistic for projecting some needed medical resources. Specifically, the alternative put forth is a model that computes percentile distributions associated with temporal slices of the proposed operation. The model was developed in part by using the algorithms underlying the FORECAS ground casualty forecasting system.[1] Like the FORECAS system, the new model provides projections based on empirical data from previous combat operations that have been adjusted for differences associated with potential adversaries.[2] This new model, the Temporal Slice Casualty Projection System (SLICECAS), may be used by medical planners to examine the expected patient loads for temporal slices of a combat operation in which there may be considerable variability in medical admission incidence due to fluctuations in combat tempo.

The wounded-in-action (WIA) and disease and non-battle injury (DNBI) baseline rates underlying SLICECAS are based on Marine deployments to Okinawa, Korea, and Vietnam, as well as the United Kingdom amphibious force deployment during the Falklands Operation.[3,4] The baseline rates were then adjusted to account for weapon and human factors parity between the United States and potential adversaries, and for the terrain and climate of the potential operational theater.[1,2]

Goodness-of-fit tests were applied to the distributions of the WIA and DNBI casualty admission rates to determine their appropriate probability distribution functions.[1,5] This research showed that WIA rates for infantry troops under intense and heavy battle tempos are best represented by an exponential distribution.[1,5] For moderate or light battle intensities, however, the empirical WIA data of infantry troops were best represented by a lognormal distribution. Similarly, support troop WIA rates were best represented by lognormal distributions. Analyses of the DNBI data from historical combat operations indicate that the underlying data distributions were best represented by lognormal distributions for all troop types.[1] Additionally, there was a significant cross-correlation between DNBI and WIA incidence observed among infantry troops, and to a lesser extent, among support troops. Further, serial correlations between one day's WIA incidence and the subsequent days' casualty incidence were similarly observed, quantified, and incorporated into the SLICECAS model.[5]

As previously mentioned, using a fixed casualty rate to project medical resources could possibly lead to shortfalls at critical junctures of the operation. By way of example, Table 1 shows that during the 3-month period of the Okinawa operation the mean WIA casualty rate was 6.57 per 1000 strength per day — a value that represents only the 55th percentile in casualty sustainment across that operation. This implies that if medical planning were based strictly on the mean casualty rate, then on 45% of the days there would be a resource shortfall. For instance, if there were a deployment of 10,000 personnel, there would be an average of 65 casualties per day with the WIA rate of 6.57 given above. Medical planners might think they were being conservative by planning for 100 beds per day when an average of only 65 was needed. However, as can further be seen in Table 1, on 5% of the days of that operation (95th percentile) the WIA rate exceeded 21.16, which would have required 211 beds to accommodate the casualty load. The point is, that not only must daily averages be considered in resource planning but also the entire range of casualty incidence. Especially as pertains to WIA, there may be great deviations between the average daily casualty rates and maximum daily casualty rates. Table 2 shows that the deviations between the mean DNBI rates and the higher percentile values are not nearly as great as with the WIA incidence rates.

Table 1. Wounded-in-Action Rates and Selected Percentile Rates From Combat Operations

Combat Operations	**Mean WIA Rate**	**Percentile of Mean Rate**		**75th Percentile Rate**	**95th Percentile Rate**
Okinawa	6.57	54.9th		10.29	21.16
Korea	2.75	81.5th		1.96	12.97
Vietnam	2.50	66.8th		3.19	10.63
Falklands	1.86	80.1st		0.97	6.99

Table 2. Disease/Nonbattle Rates and Selected Percentile Rates From Combat Operations

Combat Operations	**Mean DNBI Rate**	**Percentile of Mean Rate**		**75th Percentile Rate**	**95th Percentile Rate**
Okinawa	4.56	55.0th		6.57	11.57
Korea	3.31	59.7th		4.53	8.21
Vietnam	1.78	58.1st		2.47	3.93
Falklands	1.28	48.8th		1.60	2.70

The Department of Defense has developed the Medical Analysis Tool (MAT)[6] to assist in projecting the needed medical resources to support a military deployment. The MAT software requires the planner to enter the expected casualty rate for each day of the operation. Because forecasting an expected casualty rate for any given day is difficult at best, the alternative is for the user to enter constant rates for various segments of the operation in which the planner has been provided guidance as to the expected combat activities and battle tempo. However, this strategy still requires the planner to be able to project the casualty rates expected for segments of the operation with a reasonable degree of accuracy. The SLICECAS tool, thus, was developed to provide the planner with percentile estimates of casualty incidence for varying temporal slices of the operation. The user enters the parameters of the operation, and designates the lengths of the time segments for which estimates are requested. These time slices may be for 1, 3, 5, 7, or 10 days. The model then uses the trends and rates gleaned from previous combat operations and provides casualty estimates corresponding to the following percentiles: 99th, 95th, 90th, 80th, 70th, 60th, 50th, and 30th.

The preceding overview provides a general description of the SLICECAS model. The following sections of this report provide user documentation for the SLICECAS model, and a detailed description of the algorithms underlying the generation of the casualty rates.

PART I — USE OF THE SLICECAS MODEL

SLICECAS INPUT

The SLICECAS model provides casualty estimates based on operational factors specified by the medical planner. The model prompts the user for the data needed via five input screens. The first input screen, seen in Figure 1, prompts the user to select the admission type(s) that is(are) to be simulated. The three options are DNBI, WIA, and DNBI & WIA. Users select one of the casualty types by clicking on the corresponding button. To change the entry, the user simply clicks on another selection, and the last selection will override the preceding entry. To proceed to the next screen, the user selects an admission type, and presses the ENTER key.

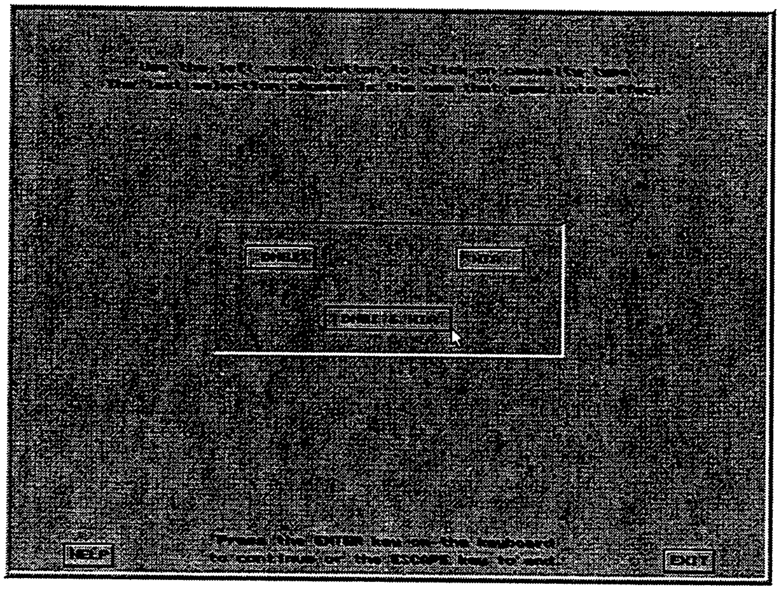

Press the ENTER key on the keyboard
to continue or the ESCAPE key to end.

Figure 1. Admission Type Selection Screen

The second input screen (Figure 2) prompts the user to select the types of troops as well as the length of the time segments of interest. The user may select from three categories of troop types: INFANTRY, SUPPORT, and SERVICE SUPPORT. The infantry troop selection represents ground combat troops. The support troop selection represents intradivisional support units, such as tank, artillery, and combat engineer units. The service support selection represents extradivisional support personnel, such as the Force Service Support Group (FSSG) and Surveillance, Reconnaissance, Intelligence Group (SRIG). The user may select one, two, or all three troop categories. After the troop types are selected, the user then selects the temporal slice that is to be simulated. The user can choose from five selections of temporal slices: 1 day, 3 day, 5 day, 7 day or 10 day. After all troop categories and a day slice have been selected, the user presses ENTER to proceed to the next screen.

The third input screen (Figure 3) prompts the user to select the adversary of the US forces for the potential scenario. Underlying each adversary selection are weapon and societal/cultural parity factors that are used to adjust the baseline projections.[3] The user makes the selection by clicking on one of the adversaries displayed on the screen. Only one adversary may be selected at a time. If more than one adversary is selected the last chosen selection overrides the previously selected one. To proceed to the next screen an adversary must be selected, followed by pressing the ENTER key.

The next input screen (Figure 4) prompts the user to select the type of terrain for the proposed scenario. The user may select from 17 types of terrain and may choose as many as are relevant. For each terrain selection, an associated percentage must also be entered. After each percentage is entered, the user presses the ENTER key and proceeds to enter another terrain factor if needed. The sum of the terrain factors must total to 100% or an error message will be displayed. Also included is an "UNKNOWN" terrain factor button to be used when the planner is uncertain of the terrain of a specific adversary. In this case, the terrain factor is then automatically based on the topography of the overall country.

The final input screen (Figure 5) prompts the user to select the type of climate for the proposed scenario. This screen operates in the same manner as the terrain factor screen. There are 12 climate types from which to choose, and the user may select as many as are appropriate. Also, included is an "UNKNOWN" climate factor button to be used when the planner is uncertain of the climate of a specific adversary.

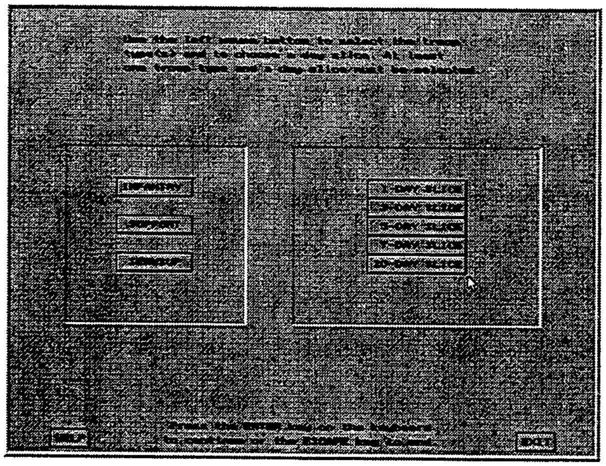


Figure 2. Troop and Day Slice Selection Screen

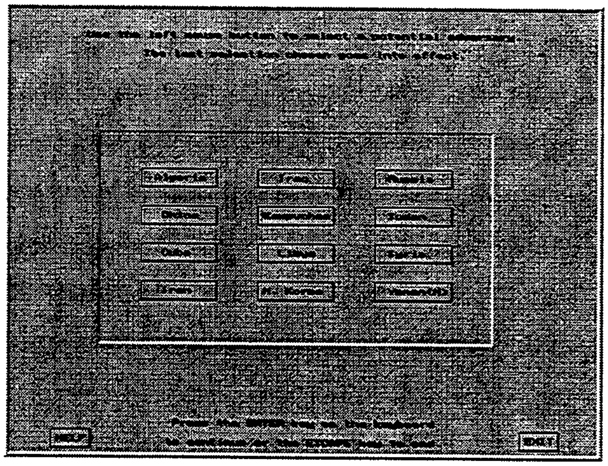


Figure 3. Opposition Force Selection Screen

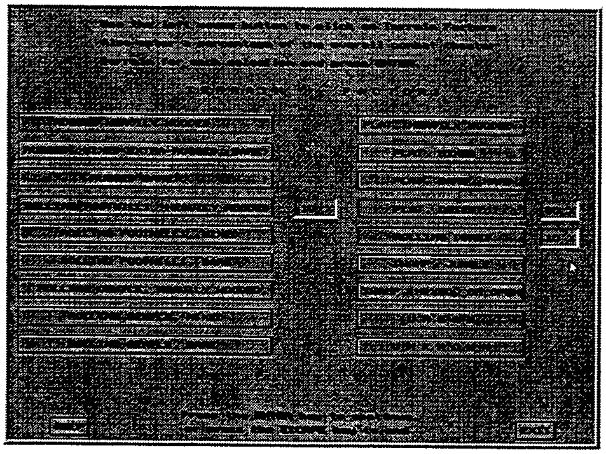


Figure 4. Climate Factor Selection Screen

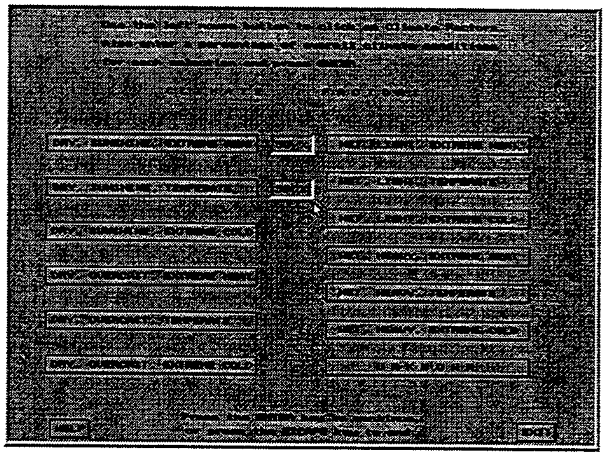
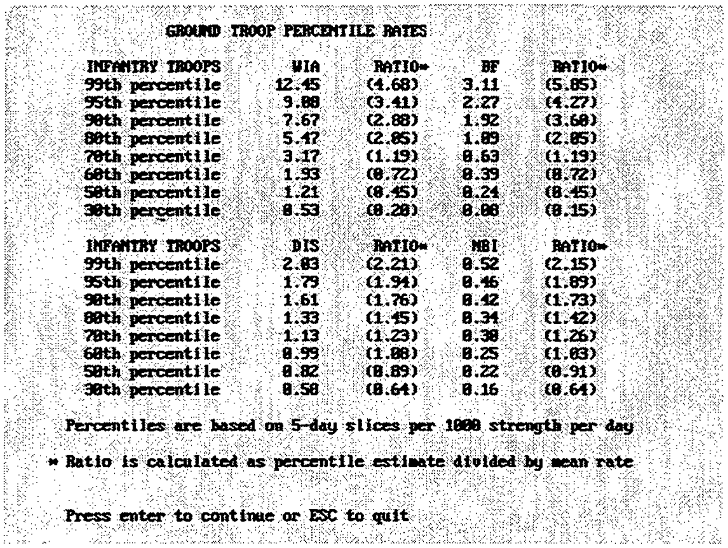


Figure 5. Terrain Factor Selection Screen

The adjustments for the impact of topography and climate on the expected casualty incidence are calculated as set forth by Dupuy.[7] If, for instance, an adversary had terrain that was 60% 'rugged, heavily wooded' and 40% 'rolling foothills bare,' the overall terrain casualty impact score would be obtained by multiplying these proportions by the Dupuy adjustment factors for those terrains and summing.

SLICECAS OUTPUT

After the user has entered all the required input parameters, SLICECAS generates output screen(s) depicting the various percentile casualty rate estimates. Eight different percentile estimates are displayed for each troop type and admission type, which range from the 99th percentile to the 30th. The rates are computed per 1000 troops per day. In addition, for each percentile rate the ratio of that percentile to the mean is also shown. Figure 6 shows the percentile estimates for an infantry troop selection. As seen, the 90th percentile of the WIA rates is 7.67 per 1000 strength per day, which represents a value 2.43 times the average (mean) among all 5-day slices for this simulation. The ratio statistic is provided to indicate to the user the potential degree of shortfall that might be incurred by using the mean for inappropriate resource planning purposes. The estimated percentile rates and ratios for battle fatigue (BF), disease, (DIS), and nonbattle injury (NBI) are also displayed as output.



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              GROUND TROOP PERCENTILE RATES

   INFANTRY TROOPS       WIA     RATIO*     BF     RATIO*
   99th percentile      12.45    (4.68)    3.11    (5.85)
   95th percentile       9.08    (3.41)    2.27    (4.27)
   90th percentile       7.67    (2.88)    1.92    (3.60)
   80th percentile       5.47    (2.05)    1.09    (2.05)
   70th percentile       3.17    (1.19)    0.63    (1.19)
   60th percentile       1.93    (0.72)    0.39    (0.72)
   50th percentile       1.21    (0.45)    0.24    (0.45)
   30th percentile       0.53    (0.20)    0.08    (0.15)

   INFANTRY TROOPS       DIS     RATIO*    NBI     RATIO*
   99th percentile       2.03    (2.21)    0.52    (2.15)
   95th percentile       1.79    (1.94)    0.46    (1.89)
   90th percentile       1.61    (1.76)    0.42    (1.73)
   80th percentile       1.33    (1.45)    0.34    (1.42)
   70th percentile       1.13    (1.23)    0.30    (1.26)
   60th percentile       0.99    (1.08)    0.25    (1.03)
   50th percentile       0.82    (0.89)    0.22    (0.91)
   30th percentile       0.58    (0.64)    0.16    (0.64)

  Percentiles are based on 5-day slices per 1000 strength per day

* Ratio is calculated as percentile estimate divided by mean rate


  Press enter to continue or ESC to quit
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Figure 6. Output Screen of Infantry Troop Percentile Estimates

PART II — STATISTICAL UNDERPINNINGS FOR SLICECAS

The percentile rate estimates are simulated using randomly generated variates for each casualty type (WIA, DNBI) in the user-defined operation. Four hundred variates, representing 100 consecutive days of casualty rates at four different levels of battle intensity, are generated using mean rates observed in previous combat operations[3,4] in conjunction with the appropriate underlying distribution. One hundred variates per level of battle intensity were chosen to ensure that the standard error for each estimate does not exceed 5%.[8] By combining simulated daily rates for the four different battle intensity levels, SLICECAS yields percentile statistics across the entire spectrum of combat tempos that are applicable even when the intensity of the hypothesized operation is indeterminable.

The random variates are derived using the baseline casualty rates, appropriate adversary-adjustments and underlying distribution functions. The adversary-specific adjustments (ADJ) are based on terrain and climate factors,[1,7] as well as the weapons and personnel factors documented in an earlier report.[2]

Infantry troops *WIA Variates*	*1-100* *Low Battle Intensity*	*101-200* *Moderate Battle Intensity*	*201-300* *Heavy Battle Intensity*	*301-400* *Intense Combat Tempo*
Product of baseline rates and adversary-adjustment	1.33 * ADJ	2.75 * ADJ	5.77 * ADJ	7.64 * ADJ
Distribution function	Lognormal	Lognormal	Exponential	Exponential

Support troops *WIA Variates*	*1-100* *Low Battle Intensity*	*101-200* *Moderate Battle Intensity*	*201-300* *Heavy Battle Intensity*	*301-400* *Intense Combat Tempo*
Product of baseline rates and adversary-adjustment	0.34 * ADJ	0.80 * ADJ	1.62 * ADJ	2.64 * ADJ
Distribution function	Lognormal	Lognormal	Lognormal	Lognormal

Service support troops WIA Variates	*1-100 Low Battle Intensity*	*101-200 Moderate Battle Intensity*	*201-300 Heavy Battle Intensity*	*301-400 Intense Combat Tempo*
Product of baseline rates and adversary-adjustment	0.01 * ADJ	0.15 * ADJ	0.23 * ADJ	0.97 * ADJ
Distribution function	Lognormal	Lognormal	Lognormal	Lognormal

After generating the 400 variates, SLICECAS then computes moving averages based upon the length of the temporal slice designated by the user. If the user has designated 3-day slices, the model computes the average rate for each 3-day period (i.e., Days 1,2,3; Days 2,3,4; Days 3,4,5) yielding 398 sequences. SLICECAS then orders the 3-day averages sequentially and determines the rates corresponding to specific percentiles (99th, 95th, 90th, 80th, 70th, 60th, 50th, 30th). This provides the user with the rates for the specific percentiles, as well as the ratio between those percentile rates and the mean derived from all of the moving averages. It is noted that the same procedure for deriving WIA percentile rates is also used for computing DNBI rates.

CONCLUSION

The SLICECAS planning tool was designed to assist medical planners and logisticians in determining the resource needs of specific ground combat operations. By providing the range of expected casualty rates for various temporal slices of an operation, SLICECAS gives the planner an alternative to using the mean daily casualty load for determining resource needs. For projecting certain resource needs, such as beds or surgeons, where there may be dramatic fluctuations in the daily demands, planning should be based on the percentile rate thought to most optimally balance considerations of oversupply with the need to ensure adequate coverage during periods of mass patient loads.

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13. ABSTRACT ***(Maximum 200 words)A***

Forecasting medical resource requirements during combat operations is dependent upon reliable estimates of the anticipated patient load. Traditionally, mean patient load estimations are used to determine the medical resources and supplies. However, these approximations can underestimate the resources needed to treat casualties during certain peak periods of an operation. This paper discusses the use of percentile estimates in forecasting patient loads as an alternative to using measures of central tendency. To assist in providing alternative estimates of ground casualty rates, the SLICECAS model has been developed to compute the varying percentile estimates. Design and construction of the model is based on data and trends observed during previous combat operations.

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