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ESTIMATING MUNITION CONSUMPTION, FUEL CONSUMPTION, AND LOSSES OF MAJOR END ITEMS IN A THEATER-LEVEL CAMPAIGN (CALAPER)

MARCH 1997

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13. ABSTRACT (Maximum 200 words)

CALAPER consists of a series of programs which compute munition and fuel consumption, and equipment losses based upon information from two computer simulations, the Combat Sample Generator (COSAGE) and the Concepts Evaluation Model (CEM). Six automated methodologies are utilized to determine munition consumption. Materiel losses and fuel consumption are computed based on two different methodologies. The purpose of this publication is to document the methodologies and assumptions utilized in the process.

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ESTIMATING MUNITION CONSUMPTION, FUEL CONSUMPTION, AND LOSSES OF MAJOR END ITEMS IN A THEATER-LEVEL CAMPAIGN (CALAPER)

March 1997

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	ESTIMATING MUNITION CONSUMPTION, FUEL CONSUMPTION, AND LOSSES OF MAJOR END ITEMS IN A THEATER-LEVEL CAMPAIGN (CALAPER)	SUMMARY CAA-TP-97-1
CAA CONCEPTS ANALYSIS AGENCY UNITED STATES ARMY		

THE REASON FOR PERFORMING THE EFFORT was to document the methodologies and assumptions contained in the Calculation of Ammunition, Petroleum, and Equipment Requirements (CALAPER) process.

THE SPONSOR was the Director, US Army Concepts Analysis Agency (CAA).

THE OBJECTIVES were to:

(1) Consolidate and document the mathematical formulas contained in the process.

(2) Document the assumptions contained in the three major programs of the CALAPER process: Munitions Consumption (MCON), Equipment Loss Consolidator (ELCON), and Fuel Consumption (FCON).

THE SCOPE OF THE PAPER was based on the most recent architecture of the CALAPER process as of November 1996.

MAIN ASSUMPTIONS inherent in the methodology are:

(1) Applicable to conventional munitions only.

(2) For each shooter-vehicle/target combination, expenditures are allocated according to the same proportion as the component tactical model populations were aggregated.

(3) For each direct fire vehicle, munition expenditures are allocated to the type munitions in the same proportion the component tactical model expenditures were aggregated at a specified target.

(4) For artillery and mortar systems, munition expenditures are allocated to the type munitions in the same proportion the component tactical model expenditures were aggregated.

(5) All weapons are issued a combat load at the start of each simulation day. Reissues of combat loads are instantaneous.

(6) Artillery-delivered smoke and illumination rounds fire in the same proportion as fired in the tactical combat model Combat Sample Generator (COSAGE).

(7) Forty-two percent of damaged systems are repaired in general support (GS) maintenance pools.

(8) With regard to Class V bulk materiel, engineer units perform six type of activities: disabling bridges, creating intrabuilding barriers, cratering roads, seeding booby traps, creating abatis, and crushing rocks and stones for use in hardstands, airfields, and improved roads.

(9) Zeroing occurs when systems deploy to theater, when they are issued to combat units from maintenance pools, or when they are returned to theater stock from GS maintenance pools.

(10) Minimum activity level for any engineer unit will be 33 percent of its capability to perform barrier and denial activities.

(11) Applicable to smart munitions explicitly played in Concepts Evaluation Model (CEM) simulation.

(12) For purposes of extrapolating division level consumption, nine battalions are equivalent to one division.

THE BASIC APPROACH was to review the computer logic and translate the logic into an equivalent mathematical formula to document the inherent assumptions.

THIS EFFORT was directed by Mr. David E. Williams, Operational Capability Assessments - Southwest Asia.

COMMENTS AND QUESTIONS may be sent to the Director, US Army Concepts Analysis Agency, ATTN: CSCA-SW, 8120 Woodmont Avenue, Bethesda, Maryland 20814-2797.

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CHAPTER 1

INTRODUCTION

1-1. INTRODUCTION. This chapter provides a brief overview of the Calculation of Ammunition, Petroleum, and Equipment Requirements (CALAPER) process. The following chapters provide a more technical description of each methodology used in CALAPER. The CALAPER process consists of a series of programs and routines designed to calculate munitions (Class V), materiel (Class VII) losses, and fuel (Class III) consumption estimates for specified theater-level campaigns. It is a subsystem of the overall process for estimating wartime expenditures of munitions, fuel, and major end items in a theater-level campaign, sometimes referred to as the wartime requirements methodology.

1-2. OVERVIEW OF REQUIREMENTS METHODOLOGY

a. Input. An overview of the methodology is provided in Figure 1-1. The system uses input data such as scenario, opposing forces, and detailed information on weapons, equipment, and munitions provided by the study sponsor, typically Deputy Chief of Staff for Operations and Plans (DCSOPS, DAMO-FDL), US Army Training and Doctrine Command (TRADOC) schools and centers, and other agencies such as the Army Research Laboratory (ARL). This information is input to the division-level tactical combat simulation, Combat Sample Generator (COSAGE); the theater-level combat simulation, Concepts Evaluation Model (CEM); and the CALAPER process.
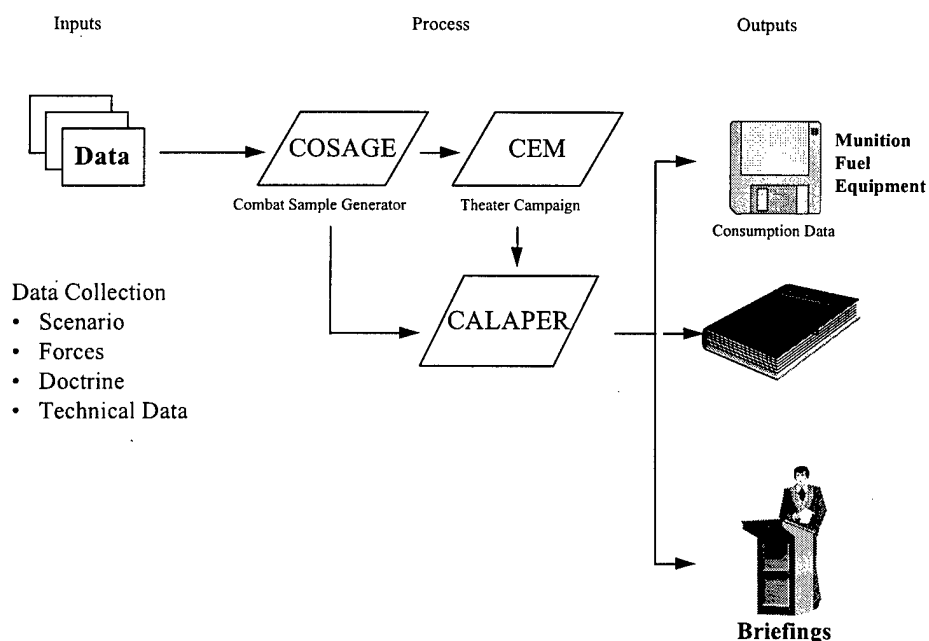

Figure 1-1. Wartime Requirements Methodology

b. Processes. The methodology consists of three automated processes. These processes consist of two combat simulations, COSAGE, and CEM, and the CALAPER system of programs which are described below.

(1) Combat Sample Generator. The COSAGE tactical simulation is a high-resolution, stochastic model that produces performance data for a friendly force of approximately division size engaged during 1 day of combat for each of several types of combat operations (postures or samples) modeled, e.g., defense intense, delay, attack, etc. These combat samples represent the expected results of an average day of conflict for that force in that particular combat operation.. COSAGE products such as weapon system expenditures and attrition, killer-victim relationships, and types and number of engagements provide statistical data to calibrate the theater-level combat simulation, CEM. It also provides data in sufficient detail to calculate equipment attrition at the line item number (LIN) level, and munition consumption at Department of Defense Ammunition Code (DODAC) level of detail.

(2) Concepts Evaluation Model. CEM is a low-resolution, two-sided, deterministic model that simulates a theaterwide campaign. It is sensitive to the force/weapon mix and the availability of resources in the theater. It provides a basis for computing theater requirements by providing information on unit availability, status, daily losses of equipment (catastrophic and repairable), daily expenditures of munitions by combat operation, and requiring theater maintenance and resupply activities.

(3) CALAPER. This system of programs processes the results from COSAGE and CEM (or Force Evaluation Model (FORCEM)) as well as other sources of data to compute munition and fuel consumption and equipment losses at the DODAC and LIN level of detail. This system consists of the Munitions Consumption (MCON) Program, the COSAGE Attrition Processor (CAP), the Equipment Loss Consolidator (ELCON) Program, and the Fuel Consumption (FCON) Program which is incorporated within the ELCON. These programs are discussed in the paragraphs which follow.

c. Output. Specific output contains information on total munition consumption by type weapon system (in rounds), losses of major end items of equipment by type (LIN), and total fuel consumption (gallons) by type equipment for each specified time period of the study. This information is used by the study sponsor to support the Army program and budget development, or special study objectives. The output from the methodology may consist of written reports, briefings, and a variety of computer output media (e.g., tapes, diskettes, etc.).

1-3. CALAPER OVERVIEW. The CALAPER process consists of three main programs as shown in Figure 1-2.

Routines   Program Execution   Outputs
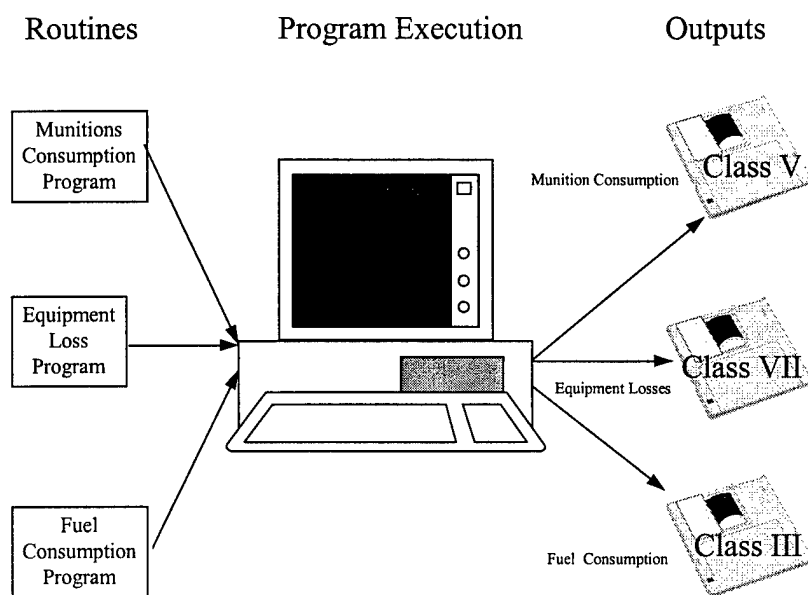
Figure 1-2. CALAPER Programs

a. Munitions Consumption Program. This program computes consumption of munitions and related items using the results from the CEM and COSAGE combat simulations. These simulated expenditures account for only a portion of the total munition consumption. Total consumption includes the addition of nonsimulated munition consumption that reflects expenditures and losses in other areas such as suspect and support unit target firings, weapon zeroing and functional checks, artillery registration, rear area security expenditures, onboard losses of munitions, and logistical losses (inter- and intratheater). Six methodologies are available to compute munition consumption. They are:

1. Modeled systems and associated munitions
2. Barrier and denial material
3. Small battle material (e.g., pyrotechnics)
4. Historical consumption rate
5. Artillery smoke and illumination munitions
6. Mines/minefields and related material

Technical descriptions of each methodology are provided in the ensuing chapters.

b. Equipment Loss Program. This program computes catastrophic loss estimates of major items of equipment due to combat using results from COSAGE and CEM for modeled systems which are explicitly simulated in both models. Nonmodeled system losses for items such as generators, radios, etc., are also generated by addressing the battlefield distribution and vulnerability of the nonmodeled equipment and by assessing the effects of enemy fires on the equipment (taken from the tactical combat model). Added to these results are historical and

logistical loss factors to account for the attrition of equipment from causes that are not simulated (such as accidents, pilferage, and enemy guerrilla actions). The methodologies in the ELCON are the topics of discussion in Chapters 8 and 9.

c. Fuel Consumption Program. This program computes fuel (Class III) consumption for selected equipment using COSAGE and CEM simulation results. Consumption estimates are generated for three types of fuel: motor vehicle gasoline (MOGAS), diesel, and JP-type aviation fuel. Similar to the equipment loss program, fuel consumption for nonmodeled items of equipment such as generators, forklifts, and recovery vehicles is calculated using historical data and logistical loss factors. The most critical item of data pertinent to fuel consumption calculations is the usage profile for each item of fuel consuming equipment. These usage profiles indicate the number of hours that an item of equipment can be expected to operate daily in a specified combat operation in one of five modes, i.e., idling, cross-country movement, travel on primary or secondary roads, or other for stationary equipment such as generators and aerial equipment such as helicopters and light aircraft. The fuel consumption methodology is discussed in detail at Chapter 10.

1-4. CEM POSTURE PROFILE. A CEM posture profile (P_p) describes the fraction of time the theater force is engaged in each type of combat operation. Viewed from the point of the entire force, the posture profile also indicates what fraction of the day the force is engaged in combat in that posture.

a. For purposes of the munition consumption methodology (chapters 2 - 7) and equipment losses methodology (chapters 8 - 9), eight postures are identified:

    (1) Friendly forces attacking threat forces in delay (BADL)
    (2) Friendly forces attacking threat forces in a prepared defense (BAPD)
    (3) Friendly forces attacking threat forces in hasty defense (BAHD)
    (4) Friendly forces in reserve (RESERVE)
    (5) Threat forces attacking friendly forces in a hasty defense (RAHD)
    (6) Threat forces attacking friendly forces in a prepared defense (RAPD)
    (7) Threat forces attacking friendly forces in delay (RADL)
    (8) Friendly force and threat forces in a static (or defense light) defense (STATIC). The percent of time is sum total of the time spent.

b. For purposes of fuel consumption (Chapter 10), five postures are identified:

(1) Attack. The percent of time is equal to the sum of time the threat force is in delaying defense, prepared defense, and hasty defense posture (i.e., sum of the first three postures listed in paragraph 1-4a above).

(2) Defense. The percent of time is equal to the sum of time the friendly force is in prepared defense, and hasty defense posture (i.e., sum of the fourth and fifth postures listed in paragraph 1-4a above.)

(3) Delay. The percent of time is the percent of time friendly force is delaying defense posture (i.e., equals the sixth posture listed in paragraph a above). Operations conducted to delay the enemy attack for the purpose of gaining time to concentrate forces, establish a new location, or to initiate offensive actions elsewhere.

(4) Static. An operation in which units are in a static posture ready to provide reinforcing support, screening, and rear area security for the force. (i.e., equals the eighth posture listed in paragraph 1-4a above.

(5) Unengaged. An operation encompassing the time that a unit is not employed in one of the four primary combat postures above. The administrative time utilized to resupply, conduct equipment maintenance, and refit for future enemy engagements.

1-5. LIMITATIONS. CALAPER was originally designed to process one COSAGE sample/ posture set for each basic CEM posture outlined in paragraph 1-4a. Recent improvements to CEM include multiple COSAGE samples/postures for the CEM static posture (i.e., less intense static, intense static). The CALAPER methodology cannot handle the multiple COSAGE sample/posture sets for the static posture. The current methodology is to process the COSAGE sample/posture set predominantly used throughout the campaign simulation. Improvements to this limitation will be made when time and resources are allowed.

1-6. SUMMARY. This chapter provided a brief overview of the overall process used in determining munition and fuel consumption, and equipment loss estimates based on simulated conflict in a theater of operations. Major elements of the methodology were described with the emphasis placed on the CALAPER process, the primary tool used to calculate the consumption and loss estimates. Chapters 2 through 7 provide detailed technical descriptions of the six munition consumption methodologies mentioned previously. Chapters 8 and 9 provide a technical description of the two methodologies used to compute losses of major end items. Chapter 10 provides the technical detail of the fuel consumption methodology.

CHAPTER 2

CALCULATING MUNITION CONSUMPTION (MODELED SYSTEMS)

2-1. INTRODUCTION. In this chapter we will provide a detailed description of the methodology for computing consumption of munitions explicitly modeled in the simulations or which can be associated with other munitions explicitly modeled in the simulations.

2-2. METHODOLOGY. The CALAPER process provides a single-point estimate for munition consumption by type. The process utilizes information from two simulations--the tactical combat model (COSAGE) and the theater campaign model (CEM).

2-3. SPECIAL MUNITIONS

a. As new munitions enter the Army inventory, the CALAPER analyst determines which of the six curent methodologies (topics of Chapters 2 through 7) to apply. CALAPER was designed to compute munition consumption for any type munition explicitly simulated in the theater campaign model.

b. The paragraphs which follow describe the input factors required for each munition using the modeled systems methodology. When a new type munition is explicitly played in CEM, updates to these input factors are required in order to represent proper tactical, doctrinal, and logistical characteristics. In the past, the Office of Secretary of Defense has addressed special concerns on the Hellfire/Longbow missiles, and Army Tactical Missile System (ATACMS). The following paragraphs address these munitions.

(1) Army Tactical Missile System. The current CALAPER methodology does not compute expenditures for the Army Tactical Missile System - brilliant antiarmor technology (BAT) and antipersonnel/antimateriel warhead (APAM). The current theater campaign methodology inputs the attrition effects (not expenditures) of BAT and APAM to the theater simulation model via a user input file (phased offline attrition (POLA) file -). CEM does not calculate munition expenditures required to accomplish the attrition effects from the POLA file. Additionally, CALAPER input data for suspect and support target factors and logistical loss factors are not immediately available for the BAT and APAM.

(2) Hellfire/Longbow Missiles. With the Hellfire and Longbow missiles the Apache helicopter can strike logistical targets deep into the enemy's rear. The support target factors were updated to reflect Hellfire expenditures based on an information paper, subject: first AH-64 mission of Operation DESERT STORM, prepared by Deputy Chief of Staff for Operations and Plans, Aviation Division (DAMO-FDV), for the Secretary of the Army. The other factors which affect expenditures are the combat load, suspect target factors, and logistical loss factors. These factors were reviewed, verified, and validated in the Ammunition Requirements Working Group (ARWG) in February 1996.

2-4. DISAGGREGATION ALGORITHM

a. Due to limitations in the number of vehicles which can be represented in the theater campaign model (CEM), many systems in the tactical model are combined. For example, in most instances, the 155mm self-propelled howitzer munition expenditures and the 155mm towed howitzer munition expenditures are combined. The method in which systems are aggregated is captured in the Reduction Attrition Calibration Model (ATCAL) Phase I (RALPH) equipment file. The information contained in this file is used by CALAPER to disaggregate the CEM expenditures.

b. The CEM records daily munition consumption. For each day, the CEM munition expenditures are recorded by posture, by shooter, by munition type (ammo pot), and by target.

c. The principal customer (DCSOPS DAMO-FDL) requires munition consumption estimates at DODAC level. A methodology was developed to apportion the theater campaign consumption to its component tactical model munition consumption (i.e., by DODAC). The assumptions necessary to apportion the expenditures accordingly are provided below.

(1) For each shooter/target combination, expenditures are allocated in the same proportion as the component tactical model populations were aggregated.

(2) For each direct fire system, munition expenditures are allocated to the type munitions in the same proportion the component tactical model expenditures were aggregated at a specified target.

(3) For artillery and mortar systems, munition expenditures are allocated to the type munitions in the same proportion the component tactical model expenditures were aggregated.

d. The fraction of shots (frac = disaggregation factor) in combat posture p by munition (weapon) w from vehicle v at target t is defined as:

$$frac_{vwpt} = \frac{CS_{vwpt}}{\sum\limits_{\forall v: v \in cemshooter} \sum\limits_{\forall w: w \in cemammo} \sum\limits_{\forall t: t \in cemt \arg et} CS_{vwpt}} \tag{2-1}$$

where CS_{vwpt} represents the number of COSAGE shots in posture p from weapon w on vehicle v at COSAGE target t.

e. The total fraction of expenditures (FOE) at CEM threat vehicle T in combat posture p allocated to COSAGE vehicle v and weapon w is defined as

$$FOE_{vwpT} = \sum\limits_{\forall t: t \in T} frac_{vwpt} \tag{2-2}$$

f. Expenditures for functional checks, zeroing, rear area security, and artillery registration are not computed by combat posture. These expenditures are allocated according to the average of

the proportion of the component tactical model populations *(disag$_v$)* where v is the COSAGE vehicle with which the vehicle is associated.

$$disag_v = \left(\frac{1}{\#postures} \right) \bullet \sum_{p=1}^{\#postures} \frac{D_{vp}}{\sum_{\forall v:v \in cemvehicle} D_{vp}}$$ (2-3)

where D_{vp} represents the population of vehicle *v* in posture *p*. The divisor represents the total population of all vehicles from the tactical combat model aggregated into the CEM vehicle slot.

g. Assuming the munition identified with COSAGE vehicle v and COSAGE weapon w, then the expenditures fired at all CEM targets are defined as

$$E_p = B_{vw} \bullet \left(\sum_{T1}^{51} FOE_{vwpt} \bullet CEM_{sqpT} \right)$$ (2-4)

where *T* represents the threat equipment where the munition is identified with COSAGE vehicle *v* and COSAGE weapon *w* and COSAGE vehicle *v* is rolled into CEM equipment *s* and COSAGE weapon *w* is rolled into CEM ammo pot *g*, and

where B_{vw} is the burst size defined in paragraph 2-5.

2-5. BURST SIZE. For direct fire weapons, in particular small caliber weapons, each CEM shot record will reflect a burst. The burst size (B_{vw}) is a function of the single shot probability of kill (Pk) data (provided by ARL) used as input to the tactical combat model. The CALAPER analyst must coordinate closely with the COSAGE Pk analyst in order that the burst size is reflected accurately in the CALAPER data base.

2-6. SUSPECT TARGETS

a. Weapon systems are expected to expend munitions against false targets (i.e., reconnaissance by fire, terrain features, etc.). These expenditures are not represented in the simulations and are estimated as a percentage increase in the rounds expended against combat targets from the CEM. Equation 2-5 represents these suspect target expenditures (T_p).

$$T_p = \alpha_p \bullet E_p$$ (2-5)

where E_p is defined by Equation 2-4, and α_p = percentage increase over theater model expenditures which represent firings at suspect targets (suspect target factors).

b. These suspect target factors are reviewed by TRADOC for each major study. Values currently in use were verified and validated by ARWG in February 1996.

2-7. SUPPORT UNIT TARGETS

a. Support units are not explicitly played in COSAGE or CEM. However, artillery units (and some aviation units--AH-64 with Longbow) can be expected to engage combat support and combat service support units. Again, multiplicative factors are introduced to represent the percent increase to the rounds fired against combat targets in CEM. Equation 2-5 represents these support unit target expenditures (U_p).

$$U_p = \beta_p \cdot E_p \qquad (2\text{-}6)$$

where E_p = is defined by Equation 2-4, and β_p = percentage increase over theater model expenditures which represent firings at support unit targets (support target factors)

b. These suspect target factors are reviewed by TRADOC for each major study. Values currently used were verified and validated by ARWG in February 1996.

2-8. ONBOARD MUNITION LOSSES

a. Consumption also includes munitions lost due to catastrophic kills or damaged weapon systems. It is assumed each system is issued a combat load at the start of each simulation day. The average number of munitions remaining on the system at the end of the day is based on the daily expenditures, inclusive of firings at suspect targets and support units. In situations where systems expend more than their combat load, the program assumes instantaneous reloading.

b. Calculation of onboard munition losses is a multistep process. The steps consists of calculating *(1) the average number of systems in combat, (2) the average system expenditures by posture, (3) number of reloads, and (4) the average remaining onboard.*

(1) Average number of systems in combat is based on the ATCAL equation.

$$A_p = \frac{losses_p}{ln\left(1.-\dfrac{losses_p}{start_p}\right)} \qquad (2\text{-}7)$$

where $losses_p$ represent the system losses which occurred in posture p for the day and $start_p$ represents the starting system population in posture p.

(2) The average expenditure per system includes firings at support target and suspect target expenditures. The average expenditure per system (AE_p) is defined as

$$AE_p = \frac{E_p \bullet \left(1.+\alpha_p + \beta_p\right)}{A_p} \qquad (2\text{-}8)$$

where E_p = is defined by Equation 2-4, and α_p = suspect target factors, β_p = support unit target factors

(3) The number of reloads (N) is defined as the ceiling of the ratio of expenditures to combat load. Recall the ceiling function always rounds up to the next integer value. For example, the ceiling of 3.01 equals 4 just as the ceiling of 3.95 equals 4

$$N = \left[\frac{AE_p}{L}\right]^{ceil} \qquad (2\text{-}9)$$

where L represents the weapon combat load.

(4) The average number of rounds remaining onboard the system (AR_p) is

$$AR_p = N \bullet L - AE_p \qquad (2\text{-}10)$$

c. The total onboard losses (O_p) are calculated according to Equation 2-10.

$$O_p = AR_p * \left[K_P + du \bullet T_P\right] \qquad (2\text{-}11)$$

where du represents the percent of the average remaining onboard load of repairable systems is damaged and unserviceable. The values currently in use were verified and validated by ARWG in February 1996.

K_p represents the number of catastrophic losses in posture p, and

T_p represents the repairable losses in posture p,

AR_p is the average number of rounds remaining from Equation 2-10.

2-9. ZEROING

a. Ammunition will be expended to zero direct fire weapons. Expenditure factors (rounds per weapon per munition) (φ) are applied to each system initially deployed to theater, issued to combat unit, or when it is returned to theater stock from the maintenance pool. Figure 2-1 demonstrates when zeroing occurs in the theater of operation.
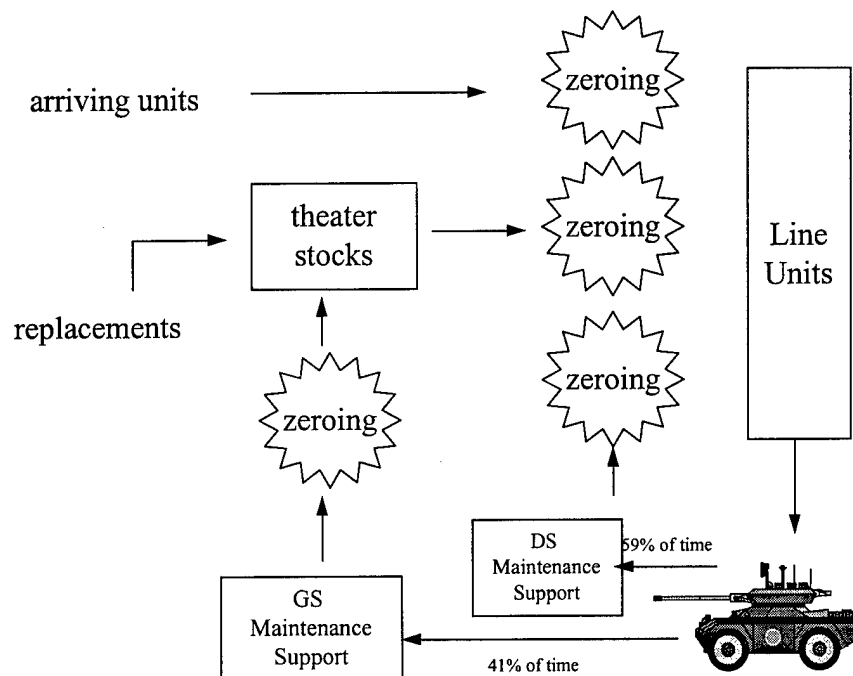
Figure 2-1. Zeroing Schematic

b. Zeroing requirements are computed according to Equation 2-12. It is assumed that 42 percent of damaged systems will be repaired in general support repair pools. However, this value is variable and can be easily modified to fit any scenario. Values currently used were verified and validated by ARWG in February 1996.

$$Z = \varphi * \left(D + (.42) * R + I \right)$$
2-12

where φ represents the zeroing factor,

D_p represents the number of systems deployed to theater in time period,

R represents the number systems returned to theater stock, and

I represents the number of systems reissued to combat units.

c. The above expenditures are allocated to specific systems according to Equation 2-3 (*tdisag*).

2-10. REAR AREA SECURITY. Rear area combat operations are not modeled in the CEM. To account for munitions expended against targets in the rear area, CALAPER includes a list of weapons which may perform rear area security and the number of rounds to be expended per weapon (ρ) deployed through the theater rear areas. Values currently used were verified and validated by ARWG in February 1996.

$$R = \sigma \cdot Q \qquad (2\text{-}13)$$

where σ = Rear area security consumption factor (rounds per weapon), and

Q = represents the number of weapons deployed in the theater rear areas.

2-11. FUNCTIONAL CHECKS. A certain number of rounds (f) will be expended by certain types of direct fire weapons on every day of conflict to ensure that they are functioning properly prior to their use in combat. This factor is multiplicative and is applied to the number of weapon systems in the combat area each day of the war. Values currently used were verified and validated by ARWG in February 1996.

$$F = f * TP \qquad (2\text{-}14)$$

where f represents the number of rounds expended daily for functional checks, and

TP represents the number of systems (or tubes) in the theater. For direct fire systems in reserve, expenditures are not included.

2-12. ARTILLERY REGISTRATION. The same formula (Equation 2-14) applies for artillery registration. However, according to doctrine, one artillery gun in a battalion registers seven high explosive (HE) rounds daily. The other tubes in the battalion calibrate their tubes base on their locations relative to the tube which performed the registration. The formula used assumes each tube in the battalion fires its share of the registration rounds. For example, assuming 21 tubes in a battalion, then a registration doctrine of 7 HE rounds per battalion equates to a 1/3 round expenditure per tube (7 rounds/21 in a battalion). This equivalent per tube registration factor (Equation 2-14) is a user-prepared input factor. Values currently used were verified and validated by ARWG in February 1996.

$$\frac{RTR}{Tubes} \qquad (2\text{-}15)$$

where RTR represents the artillery registration doctrine (i.e., & HE rounds/battalion).

Tubes represents the number of tubes in the echelon (i.e., 21 per battalion).

2-13. DAILY CONSUMPTION. Daily consumption is the sum of the component factors (as appropriate according to the weapon-munitions concerned) as described in the previous paragraphs and is defined at Equation 2-16. The total number of postures for munition consumption in CEM is eight.

$$C_{day} = \sum_{p=1}^{\#postures} \left(E_p + T_p + U_p + O_p\right) + \left(Z + R + F\right) \bullet disag_v \tag{2-16}$$

2-14. LOGISTICAL LOSSES

a. Logistical Loss Factors. Logistical loss factors are applied to the daily consumption, C_{day}, by all other causes to account for intertheater and intratheater losses not simulated in the combat models. Values currently used were verified and validated by ARWG in February 1996.

b. Intertheater Losses (SEA_{day}). Munitions not stored in theater prior to D-day must be shipped into theater and would normally be subject to sea losses based on the latest Department of Defense (DOD) sealift studies. Specific guidance must be obtained from the study sponsor regarding any intertheater losses to be used in future studies

c. Intratheater Losses. These (TLOG) represent losses that may occur from accidents, pilferage, and other causes during intratheater movement which are not simulated in the combat models. For example, if 600 green smoke grenades (signal) were consumed during a certain period of the conflict, then multiplying the 600 grenades by the factor 0.03 would result in an increased requirement of 18 green smoke grenades to account for intratheater logistical losses. A constant loss factor (LOG) is input for each type of munition.

d. Total Losses. For a specified day, the total logistical losses are computed according to Equation 2-17.

$$TLOG_{day} = \left(SEA_{day} + LOG\right) \bullet C_{day} \tag{2-17}$$

e. Total Consumption. The total day's consumption is the sum of Equations 2-16 and 2-17.

CHAPTER 3

CLASS V BULK (BARRIER AND DENIAL MATERIAL)

3-1. INTRODUCTION. Tactical units consume material to restore portions of the theater barrier and denial plan and to support corps barrier plans. The data requirements to compute consumption are the type and quantity of engineer units deployed in the theater, the number of type activities (i.e., functions) each engineer unit can perform, the material required to perform each activity, and a degradation factor which modifies the capability of the engineer unit. This chapter provides a technical description of the methodology for computing the consumption of material used in the development of the theater barrier and denial plan.

3-2. ACTIVITY TYPES. The methodology assumes six types of activities each engineer unit may be capable of performing in regard to consumption of Class V and Class V bulk material. The activity can either be for obstructive purposes or for constructive purposes. Five of the six activities are for obstructive purposes: disabling a bridge, creating intrabuilding barriers, cratering roads, setting booby traps, and creating an abatis. The constructive activity consists of crushing rocks and stones in units of 500-ton aggregates for use in hardstands, airfields, and improved roads.

3-3. ENGINEER UNIT ACTIVITY LEVEL

a. In past studies, the consumption of barrier and denial material was based on the capability of each engineer unit to perform barrier and denial activities as provided by TRADOC's Engineer Center. As the number of engineer units increases in the theater, the average portion of their assigned missions dedicated to this activity will decrease. The new methodology considers the engineer unit's activities with respect to its other missions as the theater campaign progresses.

b. The percentage of a type engineer unit capability dedicated to barrier and denial activities decreases by 3 percent for each engineer unit which arrives in theater following D-day. The minimum activity level for an engineer unit will be 33 percent of its capability to perform barrier and denial activities. The activity level is defined by Equation 3-1.

$$A_{dg} = \mathrm{maximum}\left(.33, \left(DEP_{dg} - DEP_{0g}\right) \bullet (.03)\right) \qquad \text{(3-1)}$$

where DEP_{dg} = number of engineer units of type g available for day d

DEP_{0g} = number of engineer units of type g available on D-day

3-4. ENGINEER UNIT CAPABILITY. The engineer unit capability (F_{fg}) is defined in terms of the number of type activities each unit can perform in a day. The capabilities are shown in Table 3-1. Table 3-1 also reflects the physical nature of the theater (e.g., Southeast Asia (SWA) is mostly desert; therefore, very little or no abatis will be developed).

Table 3-1. Engineer Unit Capabilities

Facility	Number performed by heavy company			Number performed by light company		
	Eur	SWA	Korea	Eur	SWA	Korea
Disable bridge	5	0.5	2	4	0	2
Intrabuilding passage	4	1	1	4	2	2
Road craters	13	3	7	11	5	9
Booby traps	5	2	4	4	4	4
Abatis	3	0	1	2	0	1
500 Tons crushed rock						

3-5. UNIT DEGRADATION FACTORS. The engineer unit capability data reflects the activity level when the type engineer unit is in a prepared defense posture. The engineer unit is likely to perform other activities when in an offensive or a light defensive posture. The unit degradation factor (DEG_p) serves to adjust the unit's capability when in other combat operations. The degradation factors are provided in Table 3-2.

Table 3-2. Unit Degradation Factors

Posture	Percent degradation for heavy company	Percent degradation for light company
Blue delay	100	100
Blue defense intense	100	100
Defense light (i.e., static)	25	25
Blue attack Red prepared Defense	25	25
Blue attack Red delay	25	25
Hasty Blue defense	100	100
Blue attack hasty Red defense	25	25
Reserve	N/A	N/A

3-6. ACTIVITY COMPONENT LIST. The activity component list (I_{if}) defines the amount of material type i required to perform activity type f. For example, an engineer company, on average, will use 34 linear shaped charges to disable a single bridge. Table 3-3 shows the quantity of materials required to perform each type activity.

Table 3-3. Activity Component List

Item	Quantity Required per Activity					
	Disable bridge	Intrbldg passage	Road crater	Booby trap	Abatis	500 tons cr rock
BRAT	2.8		2.7			
C-4, 1/4 lb	182.0		72.9	3.0	72.0	
Linear shaped charge	34.0	10.0				
Blasting cap, nonelectric	4.9	1.0	10.8	3.0	2.0	
Blasting cap, electric	4.9	1.0	10.8		2.0	
Det. cord (ft)	637.5	5.0	722.0		1800.0	
Fuze, time M700	11.4	2.5	53.4			
Igniter, fuze, M60	1.3	2.0	3.0		4.0	
Satchel chg		0.5				
Cratering chg, M180			3.6			
Cratering chg, 40 lb			12.9			
Shaped chg, 40 lb			11.1			
Firing device				3.0		

3-7. DAILY CONSUMPTION. The daily consumption of material used for developing barrier and denial facilities is provided by Equation 3-2. The total number of postures for munition consumption in CEM is eight.

$$C_{day} = \sum_{p=1}^{\#posture} \left[T_p \bullet \left[\sum_{f=1}^{\#facilities} I_{if} \bullet \sum_{g=1}^{\#typeengineerunits} F_{fg} \bullet A_{dg} \bullet DEP_{dg} \bullet DEG_{gp} \right] \right]$$ (3-2)

3-8. LOGISTICAL LOSSES. Logistical loss factors are applied to the daily consumption, C_{day}, by all other causes to account for intertheater and intratheater losses not simulated in the combat models. The same formulas defined in Chapter 2, paragraph 2-13, apply.

CHAPTER 4

CLASS V BULK (SMALL BATTLE MATERIAL)

4-1. INTRODUCTION. The scenario requirement for a number of items issued in bulk can be related to platoon, company, and battalion battles in the combat sample model. Items included in this category of munition consist of hand grenades and other pyrotechnic material. The consumption is based on a predetermined usage rate (U_{ep}) per platoon, company, and battalion engagement. This rate is multiplied by the number of platoon engagements (E_{ep}) which occurred in the combat sample.

4-2. COMBAT SAMPLE CONSUMPTION. The consumption of an item for a specified combat sample (S_p) is equal to the sum of consumption occurring in each engagement in the combat sample. This is shown at Equation 4-1.

$$S_p = \sum_{e=1}^{\#typeengagements} E_{ep} \bullet U_{ep} \tag{4-1}$$

where (U_{ep}) represents a usage rate of the item for engagement type e in posture p. The number of type engagements are limited to nine; mech battalion, mech company, mech platoon, infantry battalion, infantry company, infantry platoon, armored battalion, armored company, and armored platoon.

4-3. DIVISION EXTRAPOLATION FACTOR. The division extrapolation factor D_{dp} is used to extrapolate division combat results to the theater level. The division extrapolation factor is a function of the number of battalion engagements which occurred in CEM and represents the number of division equivalent engagements. It is assumed nine battalions are equivalent to one division. The number of division equivalent engagements is defined by Equation 4-2.

$$D_{dp} = \frac{BE_{dp}}{9} \tag{4-2}$$

where BE_{dp} = represents the number of battalion engagements in posture p on day d from the theater simulation model.

4-4. DAILY CONSUMPTION. The daily consumption (C_d), prior to logistical losses, is defined according to Equation 4-3. The total number of postures for munition consumption in CEM is eight.

$$C_d = \sum_{p=1}^{\#posture\,8} D_{dp} \bullet S_p \qquad (4\text{-}3)$$

where S_p is defined according to Equation 4-1 and D_{dp} is defined according to Equation 4-2.

4-5. LOGISTICAL LOSSES. Logistical loss factors are applied to the daily consumption, C_{day}, by all other causes to account for intertheater and intratheater losses not simulated in the combat models. The same formulas defined in Chapter 2, paragraph 2-13, apply.

CHAPTER 5

HISTORICAL RATES CONSUMPTION METHODOLOGY

5-1. INTRODUCTION. It is assumed that some weapons systems will behave in accordance with rates of consumption from historical experiences. That is to say, the change in the scenario and assumptions will not affect the rate of consumption for the duration of the campaign. The purpose of this chapter is to provide a description of the methodology for which munition consumption behaves according to historical experience.

5-2. HISTORICAL RATE METHODOLOGY

a. This methodology is the simplest of all the methodologies. The analyst merely inputs the rate of consumption for a particular munition (R_d) and the time period the rate is applicable. Using the force deployment data, the analyst inputs the quantity of weapon systems authorized (or onhand) at the start of each day of the campaign. These rates are extracted from Supply Bulletin SB-28-36, last update circa 1985.

b. Logistical loss estimates are not calculated. It is assumed the historical rate of consumption is inclusive of the logistical losses (both inter- and intratheater logistical losses).

c. Munition consumption based on history (C_d) is the product of the rate of consumption (R_d), expressed as rounds per tube per day, and the total systems deployed to the theater for a specific day.

$$C_d = R_d \cdot Q_d \qquad\qquad 5\text{-}1$$

where Q_d represents the number of weapons in the theater for day d. Period consumption is the sum of each daily consumption level in the period.

CHAPTER 6

ARTILLERY SMOKE AND ILLUMINATION MUNITION
CONSUMPTION METHODOLOGY

6-1. INTRODUCTION. The purpose of this chapter is to provide a detailed description of the munition consumption methodology pertaining to artillery-delivered and mortar smoke and illumination expenditures.

6-2. SMOKE AND ILLUMINATION CONSUMPTION RATIOS

a. Artillery-delivered smoke and illumination projectiles are explicitly played in the tactical combat model, COSAGE. The CEM merely plays the effect the artillery-delivered smoke and illumination expenditures had on the killer/victim scoreboard consumption (i.e., CEM does not explicitly play artillery-delivered smoke and illumination munitions).

b. The methodology assumes smoke and illumination expenditures are proportional to the total expenditures of other type munitions fired by the artillery tubes (e.g., high explosive, improved conventional munitions (ICM), dual purpose improved conventional munitions (DPICM)) from COSAGE. This ratio is defined by Equation 6-1.

$$\rho_p = \frac{S_p}{\sum_{\forall munitions\,(except\,smoke\,\&\,illum)} C_{ip}} \qquad (6\text{-}1)$$

where S_p represents the number of smoke (or illumination) expenditures from an artillery tube in posture p, and C_{ip} represents COSAGE expenditure of munition I in posture p.

6-3. SUSPECT TARGETS

a. Artillery systems are expected to expend smoke and illumination rounds against false targets (i.e., terrain features, etc.) for obscuration or illumination activities. These expenditures (T_p) are not represented in the simulations and represent a percentage increase in the rounds expended against combat targets from the CEM. Equation 6-2 is Equation 2-5 modified to include the smoke (or illumination) munition consumption ratio ρ_p (Equation 6-1).

$$T_p = \alpha_p \bullet E_p \bullet \rho_p \qquad (6\text{-}2)$$

where E_p = defined by equation 2-4

α_p = percentage increase over theater model expenditures which represent firings at suspect targets (suspect target factors).

b. These suspect target factors are reviewed by TRADOC for each major study.

6-4. SUPPORT UNIT TARGETS

a. Support units are not explicitly played in COSAGE or CEM. However, artillery units (and aviation units) can be expected to engage combat support and combat service support units. Artillery systems are expected to expend smoke and illumination rounds against enemy combat support and combat service support units (U_p) for obscuration or illumination activities. Again, multiplicative factors are introduced to represent the percent increase to the rounds fired against combat targets in the CEM. Equation 6-3 is Equation 2-5 modified to include the smoke (or illumination) munition consumption ratio ρ_p. (equation 6-1).

$$U_p = \beta_p \bullet E_p \bullet \rho_p \qquad (6\text{-}3)$$

where E_p = represents the expenditures for the system in posture p, and

β_p = percentage increase over theater model expenditures which represent firings at support unit targets (support target factors).

b. These suspect target factors are reviewed by TRADOC for each major study.

6-5. DAILY CONSUMPTION. Daily consumption is provided at Equation 6-4. The total number of postures for munition consumption in CEM is eight.

$$C_{day} = \sum_{p=1}^{\#postures} U_p + T_p + E_p \bullet \rho_p \qquad (6\text{-}4)$$

6-6. LOGISTICAL LOSSES. Logistical loss factors are applied to the daily consumption, C_{day}, by all other causes to account for intertheater and intratheater losses not simulated in the combat models. The same formulas defined in Chapter 2, paragraph 2-13, apply.

CHAPTER 7

MINES/MINEFIELD METHODOLOGY

7-1. PURPOSE. The purpose of this chapter is to provide a detailed description of improvements made to the mines/minefield expenditures methodology in the CALAPER process.

7-2. OVERVIEW. In the past, the minefield expenditures methodology relied heavily on the total linear frontage for each type minefield played in COSAGE and the number of battalion engagements occurring in the theater simulation model (CEM). The methodology did not realistically consider the capabilities of the engineer units which would actually be in theater. In addition, the effects of modern mines/minefields were not represented in the COSAGE Model. The methodology for defining the minefield laydown is discussed in detail in the Mines/Minefield Expenditure Methodology Update Report (CAA-MR-94-13). The updated mine/minefield expenditures methodology no longer relies on the total linear frontage of each type minefield (e.g., COSAGE SIMU47 output file). The expenditure estimates for mines/minefields is determined by a linear model based on first and second order differences from the CEM battalion report file and the user-defined battalion minefield templates. The battalion minefield templates define the number of mines/minefields emplaced based on the capability of engineer units and the type of combat operation (e.g., attacking, prepared defense, delay). Provided in the following paragraphs is a technical description of the methodology.

7-3. METHODOLOGY. The CEM produces the engagement report which contains cumulative engagements (C_{dtp}) by posture (p), by day (d), and by type terrain (t). This file is the basis for estimating the number of battalion engagements for the Munitions Consumption Program. Four steps are necessary in order to determine the estimated number of battalions moving into each posture and are outlined below.

a. Step 1. Sum the cumulative number of engagements over terrain type. CEM reports the cumulative number of engagements by terrain, by posture, and by day. The first step is to compute the daily cumulative number of engagements defined by the following equation.

$$E_{dp} = \sum_{t=1}^{3} C_{dtp} \qquad (7\text{-}1)$$

where t represents the terrain type,
d represents day,
p is the posture...

b. Step 2. Compute the battalion posture profile for each day ($B_{d,p}$). The CEM posture profile ($B_{d,p}$) is defined as the first order difference ($E_{d,p} - E_{d-1,p}$) and represents the number of battalion engagements in posture p which occurred on day d. The boundary condition ($E_{0,p}$) equals zero, since it represents the engagement activity prior to D-day (Day 1 in CEM).

c. Step 3. Compute the net gain or loss of battalions for each posture for each day ($U_{d,p}$). This is obtained by taking the difference of the results computed in Step 2 ($B_{d,p} - B_{d-1,p}$) and represents the net movement into ($U_{d,p} > 0.$) or out of ($U_{d,p} < 0.$) posture and does not necessarily represent the number of battalions actually moving. Since no combat occurs prior to D-day (i.e., Day 1), $U_{1,p} = B_{1,p}$. (Note: $U_{1p} = B_{1p} = E_{1p}$.)

d. Step 4. Consider only those postures where there was a net gain ($U_{d,p} > 0.$) of battalions. It is assumed that only battalions moving into a particular posture will lay down minefields (e.g., battalions moving from an attack operation to a defensive operation). Therefore, $U_{d,p}$ is further modified to equal the max ($0., U_{d,p}$).

e. Obstacle Template. The obstacle template (T_{ipm}) defines for each type unit i in posture p the number of mines/minefields of type m placed in a 24-hour period. For further detail on the methodology for creating the obstacle template, refer to the Mines/Minefield Update Memorandum Report published 1995.

f. Daily Mine Consumption. The total number of mines (M_{md}) of type m placed on day d is defined by Eqiatopm 7-2. The total number of postures for mine/minefield consumption in CEM is eight.

$$M_{md} = \sum_{i=1}^{3} \sum_{p=1}^{\#postures} \left(\frac{F_{id}}{\sum_{j} F_{jd}} \right) * U_{dp} * T_{ipm} \tag{7-2}$$

The fraction $\dfrac{F_{id}}{\sum_{j} F_{jd}}$ is used to apportion $U_{d,p}$ and represents the fraction of the force which is type unit i (i.e., heavy, light, or cavalry) on day d.

> F_{id} represents the number of type i units in the force on day d,
>
> $U_{d,p}$ is the number of battalions moving into posture p on day d, and
>
> T_{ipm} is the number of mines of type m placed by unit type i (e.g., light, heavy, cavalry) in posture p.

g. Reseeding. The number of mines of type m on day d, which follows the self-destruct day, required for reseeding (R_{md}) is determined by the number of the original forces which placed the mines and the self-destruct times for each type minefield. Reseeding only occurs on the day following the self-destruct date. The number of these units which will reseed cannot be accurately measured. However, it is reasonable to assume that if the posture profile ($B_{d,p}$) does not change by the self-destruct date, then some or all the original units which remained in posture

will reseed the minefields. If the number of days to self-destruct is zero; the minimum number of units avaialble for reseeding β_{dp} is zero otherwise the minimum number of units available for reseeding β_{dp} is defined according to Equation 7-3

$$\beta_{dp} = min\left(B_{dp}, \ldots, B_{kp}\right) \tag{7-3}$$

where $k = d +$ (number of days to selfdestruct)

The above equation provides a conservative estimate. The total number of reseeded mines/minefields on day d is defined by the following equation: The total number of postures for mine/minefield consumption in CEM is eight.

$$R_{md} = \sum_{i=1}^{3} \sum_{p=1}^{\#postures} \left(\frac{F_{i,d}}{\sum_{j} F_{j,d}}\right) * \beta_{dp} * T_{ipm} \tag{7-4}$$

Note: the day identifier in Equations 7-1 and 7-2 represents different days.

h. Total Consumption. The total consumption (T_m) for type mine m is defined as

$$\sum_{d \in Period} M_{md} + R_{md} \quad ,$$

where *Period* is defined in 10-day time intervals.

7-4. LOGISTICAL LOSSES. Logistical loss factors are applied to the daily consumption, C_{day}, by all other causes to account for intertheater and intratheater losses not simulated in the combat models. The same formulas defined in Chapter 2, paragraph 2-13, apply.

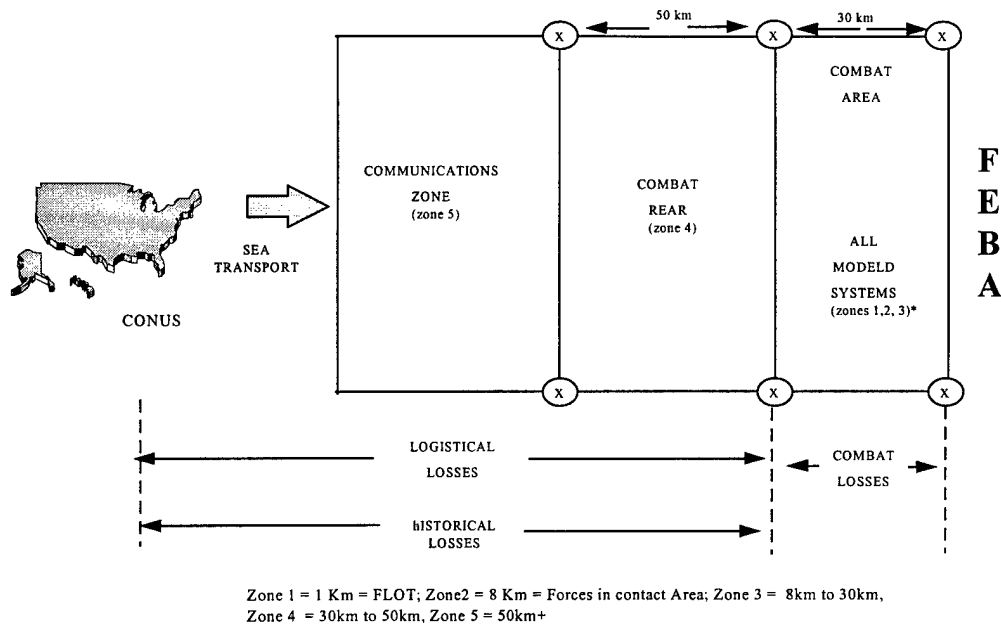**CHAPTER 8**

**EQUIPMENT LOSS METHODOLOGY
(MODELED SYSTEMS)**

8-1. INTRODUCTION

a. General. The equipment attrition program is a subsystem of the CALAPER model and is used to compute losses for major items of equipment (MIE) to support US Army forces in a given theater-level conflict. These requirements include catastrophic (permanent) losses due to combat, logistical losses, and historical losses due to accidents, pilferage, wearout, and guerrilla activity. Presently, there are over 1,700 MIE for which losses are computed. These items are categorized as either modeled or nonmodeled.

(1) Modeled Items. Modeled items of equipment are those that are simulated both in COSAGE and CEM. About 30 items of the 1,700 MIEs are modeled in COSAGE and CEM. They are the direct and indirect firing weapon systems such as tanks, artillery howitzers, attack helicopters, etc. COSAGE provides the expenditure and attrition statistics from the opposing systems (weapon-on-weapon statistics) which are extrapolated and used to calibrate the attrition algorithm used in the theater simulation. CEM replicates the intensity of combat for each day of the conflict, the deployment of opposing forces, the influence of resupply and maintenance returns, and finally, the losses of combat equipment incurred for each day of the conflict in the combat area of the battlefield.

(2) Nonmodeled Items. For these items, the process uses the COSAGE Attrition Processor subroutine that replays the enemy artillery and tactical air missions from the COSAGE simulations against these nonmodeled items, which are grouped into 22 vulnerability categories. Further detail of this methodology is highlighted in Chapter 9.

8-2. BATTLEFIELD LOSS DISTRIBUTION SCHEME. Figure 8-1 shows the battlefield loss distribution (Z_{zed}) scheme and basis for computing losses for modeled items. For modeled systems, it is assumed all systems are located in the combat area.

Zone 1 = 1 Km = FLOT; Zone2 = 8 Km = Forces in contact Area; Zone 3 = 8km to 30km,
Zone 4 = 30km to 50km, Zone 5 = 50km+

Figure 8-1. Schematic of Battlefield Loss Distribution Scheme

8-3. HISTORICAL LOSSES

a. A key element in the calculation of total equipment loss estimates is the historical loss file developed in 1971 from the Systems for Estimating Materiel Wartime Attrition and Replacement Requirements (SYMWAR) Study. SYMWAR, developed from historical data of World War II and Korean battles, provides loss rates (h_{zpch}) for each of 10 causes of loss for 4 different combat postures, in 5 theater zones for 36 classes of equipment. Losses of modeled equipment based on the historical data base are computed according the formula below.

$$H_{ed} = \sum_{z=1}^{3} \sum_{p=1}^{\#posture} \sum_{c=1}^{10} Z_{zed} * h_{zpch} * P_p \qquad (8\text{-}1)$$

where P_p is the percent of time forces are in posture p (there are eight CEM postures),

Z_{zed} is the fraction of equipment e in zone z on day d,

h_{zpch} represents the historical loss rate for historical loss category h due to cause c in posture p in zone z.

b. The 10 cause loss categories with a description are provided in Table 8-1

Table 8-1. Cause Loss Categories

Cause	Description
Direct fire	Losses that result from all shooter round "line of conflict" fire
Area fire	Losses that result from all shooter artillery or mortar fire
Mines	Losses that result from enemy-laid mines
Bombing	Losses that result from enemy bombing missions
Strafing	Losses that result from strafing by bombers at soft targets
Abandonment	Losses that result from leaving or undamaged equipment
Wearout	Losses that result from wearout of equipment
Accidents	Losses that result from serious accidents causing removal of item in power from combat activity
Pilferage	Losses of usually hand-carried small arms to stealing, etc.
Guerrilla	Losses of equipment by enemy penetrators or underground military elements

8-4. COMBAT LOSSES. As described above, combat losses (C_{ed}) are those major items of equipment simulated in the theater-level campaign and reported for each day of the conflict. It is assumed that the CEM combat losses occur within zones 1, 2, and 3. CEM represents several of the cause loss categories (direct fire, area fire, mines, bombing, and abandonment); therefore, the historical data pertaining to these cause loss categories are not added to the total loss estimate.

8-5. LOGISTICAL LOSSES. Intertheater shipping losses (sea lane losses) and intratheater losses along the theater line of communication (LOC) are normally computed as percentage add-ons to the basic theater losses developed by the simulation..

8-6. DAILY CATASTROPHIC LOSSES. The daily catastrophic losses are the sum of the combat catastrophic losses, the historical losses, and the inter- and intratheater losses.

$$\left(C_{ed} + H_{ed}\right) \bullet \left(1 + sea_d + log_d\right)$$

where sea_d represents the intertheater loss factor for day d, and

log_d represents the intratheater loss factor for day d.

CHAPTER 9

EQUIPMENT LOSS METHODOLOGY
(NONMODELED SYSTEMS)

9-1. PURPOSE. The purpose of this chapter is to provide a technical description of the process to calculate losses for systems not explicitly played in CAA's simulations (in particular, COSAGE and CEM). These systems which are not simulated in COSAGE (and CEM) are called nonmodeled systems. These nonmodeled systems are further characterized by vulnerability categories. There are 22 vulnerability categories.

9-2. DEFINITIONS. Before proceeding to discuss the nonmodeled systems methodology, several key variables need to be defined.

δ_d Effectiveness of tactical air (TACAIR) on day d. If input value δ_d is set equal to -1., it tells the program to set the value equal to ω_d; otherwise, set value to input value δ_d.

d_{pi} The number of systems for vulnerability class i that belongs to the Blue force played in COSAGE posture p.

l_{pi} Number of losses of items in vulnerability class i in posture p due to threat artillery fire missions from COSAGE and based on initial quantity d_{pi}.. Result comes from CAP, which reassesses the COSAGE fire missions against the vulnerability classes.

t_{pi} Number of losses of items in vulnerability class i in posture p due to threat TACAIR fire missions from COSAGE and based on initial quantity d_{pi} Result comes from CAP, which reassesses the COSAGE fire missions against the vulnerability classes.

f_{zd} Fraction of total quantity of a LIN in zone z on day d. The value is based on user input allocation of SRCs to the five zones.

h_{zpch} Historical loss rate for item in historical class h in posture p and in zone z due to cause c.

Q_d Quantity of LIN item for day d.

P_{pd} Percent of day d in posture p.

L_d Logistics loss factor for day d.

E_d Amount (tons) of threat artillery ammo consumed on day d in CEM.

9-3. ARTILLERY EFFECTIVENESS. Artillery effectiveness is defined as the ratio of the total threat artillery munition consumption for the day (E_d) to the maximum of each daily threat artillery consumption as occured in CEM. This factor is used to adjust daily loss rates to account for varying levels of artillery involvement in the campaign. (The underlying assumption is that the combat samples equate to the most intense day of conflict.)

$$\omega_d = \frac{E_d}{max\left[E_j : \forall j\right]} \tag{9-1}$$

9-4. TACAIR EFFECTIVENESS. The purpose of the TACAIR effectiveness factor δ_d is to modify the loss rate to account for change in air superiority. For example, a situation might start with a decided enemy air superiority, reach a point of air parity, and finally end with friendly forces having air superiority. The user can input specific values for this factor or can set it equal to ω_d above. (For the past 9 years, δ_d has equaled ω_d as calculated above.)

9-5. BATTLE LOSSES. Each LIN is associated to a vulnerability category i. Battle losses for a LIN are those losses due to the theater simulation results (does not include the historical losses data base--SYMWAR). The terms $\left(\dfrac{l_{pi}}{d_{pi}}\right)$ and $\left(\dfrac{t_{pi}}{d_{pi}}\right)$ are the loss rates by vulnerability class i and by posture p based on the reassessment of the tactical combat model (COSAGE) threat artillery and TACAIR missions, respectively. The term $\left(\sum\limits_{p=1}^{\#postures}\left(\dfrac{l_{pi}}{d_{pi}} * P_{pd}\right)\right)$ represents the average loss rate due to threat artillery on day d for vulnerability class i. Similarly, $\left(\sum\limits_{p=1}^{\#postures}\left(\dfrac{t_{pi}}{d_{pi}} * P_{pd}\right)\right)$ represents the average loss rate due to threat TACAIR missions on day d for vulnerability i. These factors are further scaled by the artillery and TACAIR effectiveness factors, respectively. The number of postures equate to the eight postures represented in CEM (refer to Chapter 1 for further clarification). The resulting loss rate will be applied to those LINs associated with vulnerability class i and located in the battle area $\left[Q_d * \sum\limits_{z=1}^{3} f_{zd}\right]$. Using the same loss rate due to threat TACAIR mission, additional losses are calculated for interdiction and other logistical targeting in the corps rear and COMMZ areas of the theater. The losses are

scaled down by the square of the TACAIR effectiveness factor. The complete equation for the battle losses for a LIN in vulnerability class i on day d is provided here.

$$B_d = \left[Q_d * \sum_{z=1}^{3} f_{zd} \right] \left[\omega_d * \sum_{p=1}^{\#postures} \left(\frac{l_{pi}}{d_{pi}} * P_{pd} \right) + \delta_d * \sum_{p=1}^{\#postures} \left(\frac{t_{pi}}{d_{pi}} * P_{pd} \right) \right] +$$

$$\delta_d^2 * \left[Q_d * \sum_{z=4}^{5} (f_{zd}) \right] * \sum_{p=1}^{\#postures} \left(\frac{t_{pi}}{d_{pi}} * P_{pd} \right) \qquad (9\text{-}2)$$

where $\displaystyle\sum_{P=1}^{\#postures} P_{pd} = 1.0$ and P_{pd} represents the percent of time in posture p on day d.

9-6. HISTORICAL LOSSES. The SYMWAR data base, also referred to as the historical losses data base, contains loss data based on World War II, the Korean War, and early Vietnam war. This data base contains losses attributed to other factors not explicitly played in the simulation. Guerrilla warfare and pilferage are examples of causes for losses which are not explicitly played in the simulation. Each LIN is associated with an historical loss class h. The LIN losses based on historical data for day d are computed according to Equation 9-3.

$$H_d = Q_d * \sum_{z=1}^{5} [f_{zd} * \left(\sum_{p=1}^{\#postures} \left[P_{pd} * \sum_{c=1}^{10} h_{zpch} \right] \right)] \qquad (9\text{-}3)$$

9-7. TOTAL LOSSES. Losses of systems can also occur in the logistics support network (i.e., supplies from CONUS to combat area, etc.). The analyst enters these loss rates (L_d) via the confelcon input file for each day of the campaign. These factors are applied to the total losses for a given day to yield losses in the logistics support network. Total losses of a nonmodeled LIN are defined here.

$$T = \sum_{d \,\in\, daysofcampaign} (B_d + H_d)(1 + L_d) \qquad (9\text{-}4)$$

CHAPTER 10

FUEL CONSUMPTION METHODOLOGY

10-1. INTRODUCTION. The purpose of this chapter is to introduce and define terminology specific to the fuel consumption methodology.

10-2. MODES OF OPERATION. A mode of operation describes the type of movement in which activity an equipment engages. There are five modes of operation, as described in Table 10-1.

Table 10-1. Description of Operation Modes

Mode of operation	Description
Idling	Time spent with the engine operating for the purpose of supporting the functional availability of the mission
Travel on cross-country roads	Travel over unimproved terrain
Travel on secondary roads	Travel on unimproved surfaces such as dirt or semiprepared surfaces, usually single lane
Travel on primary roads	Travel on prepared, hard-surfaced roads which afford maximum speeds. Generally two lanes or larger
Other	Used for all other equipment operations that are not wheeled or tracked vehicles--such as generators and helicopters

10-3. USAGE PROFILES

   a. A posture profile (P_p) describes the fraction of time the theater force is engaged in each type of combat operation. Viewed from the point of the entire force, the posture profile also indicates what fraction of the day the force is engaged in combat in that posture. For purposes of fuel consumption, five postures are identified.

      (1) Attack - offensive operations with the objective to seize terrain and/or destroy enemy forces through concentration of assets, maximum mobility, and firepower. This is the sum total of time when the threat is in a delaying posture, prepared defense posture, and a hasty defense posture.

      (2) Defense - defensive operations committed to countering an enemy attack for the purpose of destroying enemy forces, holding terrain, or gaining time in which to prepare for the

attack. This represents the total time when the friendly force is in a hasty defense and a prepared defense.

(3) **Delay** - operations conducted to delay the enemy attack for the purpose of gaining time to concentrate forces, establish a new location, or to initiate offensive actions elsewhere.

(4) **Static** - an operation in which units are in a static posture ready to provide reinforcing support, screening, and rear area security for the force.

(5) **Unengaged** - an operation encompassing the time that a unit is not employed in one of the four primary combat postures above. The administrative time utilized to resupply, conduct equipment maintenance, and refit for future enemy engagements.

b. The fuel usage profile (up_{pm}) indicates, on average, the number of hours the type equipment will be operating in mode m if the theater force were engaged in combat posture p for the whole day. A sample of a usage profile is provided in Table 10-2.

Table 10-2. Usage Profile

Posture	Usage profile				
	Idling	cross-country	Secondary roads	Primary roads	Other
Attack	6.3	4.1	2.3	1.9	0.0
Prepared defense	7.4	4.0	1.8	1.6	0.0
Delay	4.8	5.8	1.5	2.3	0.0
Static	4.9	2.9	2.6	2.3	0.0
Unengaged	4.9	2.9	2.1	2.0	0.0
Consumption (gal/hr)	6.0	18.8	18.8	12.0	0.0

c. The importance of usage profiles will become clearer when we discuss the formulation of the fuel consumption algorithms.

d. Associated with the usage profile is a fuel consumption rate (fcr_{em}) expressed as gallons per hour in each mode of operation.

10-4. BATTLEFIELD DISTRIBUTION. For purposes of fuel usage and loss computations, the battlefield is divided into two zones--the combat zone and the combat rear zone.

a. **Combat zone** - extends to 30 kilometers (km) back from the forward line of own troops (FLOT).

b. **Combat rear zone** - extends for another 50 km from the back of the combat zone.

10-5. COMBAT LOSSES. Equipment in combat suffer two types of losses--mobility firepower losses and catastrophic losses (K-kills).

    a. Mobility firepower losses occur when, as a result of a hit, an item of equipment suffers loss of mobility or firepower or both. The equipment is repairable. It will recycle into combat after repair.

    b. Catastrophic losses occur when an equipment is either totally destroyed or is not considered cost effective to repair. For these type losses, the unused fuel in its tank is also lost and is identified as onboard losses.

10-6. METHODOLOGY

    a. Combat Fuel Consumption. The number of equipment systems in combat the entire day is equal to the amount authorized less the catastrophic and repairable losses which occurred during the day. This difference is then factored with the fuel consumption rate, the usage profile, and the posture profile to yield the fuel consumed for the day. Equation 10-1 defines this relationship.

$$fuel_{1ed} = \left[auth_{ed} - ncpl_{ed} - cpl_{ed} - ctl_{ed}\right] \bullet \left[\sum_{m=1}^{5} fcr_{em} \bullet \sum_{p=1}^{5} up_{emp} \bullet P_{pd}\right] \quad (10\text{-}1)$$

where P_{pd} represents the percent of time CEM force is in posture p on day d,

       fcr_{em} is the fuel consumption rate for equipment e in mode of operation m,

       $auth_{ed}$ is the authorized level of equipment e on day d,

       cpl_{ed} is the number of combat permanent losses of equipment e on day d,

       $ncpl_{ed}$ is the number of noncombat permanent losses of equipment e on day d, and

       ctl_{ed} is the number of combat temporary losses of equipment e on day d, and

The factor $\displaystyle\sum_{p=1}^{5} up_{epm} \bullet P_{pd}$ represents the number of hours equipment e operates in mode m when "fighting" in all postures p for day d.

    b. Fuel Consumption for Combat Catastrophic Losses. The fuel consumed for combat systems which are catastrophically lost during the day is defined according to Equation 10-2. It is assumed the losses occur at midday.

$$fuel_{2ed} = cpl_{ed} \bullet \frac{1}{2}\left[\sum_{m=1}^{5} fcr_{em} \bullet \sum_{p=1}^{5} up_{emp} \bullet P_{p}\right] \quad (10\text{-}2)$$

c. Onboard Loss of Fuel. This refers to the loss of fuel remaining in the fuel tank of an equipment system when it suffers a catastrophic loss. The onboard loss is the remainder of fuel in the fuel tank after a half a day's usage in combat and is defined according to Equation 10-3.

$$fuel_{3ed} = cpl_{ed} \bullet tank_e - fuel_{2ed} \qquad (10\text{-}3)$$

where $tank_e$ is the tank size for equipment system e

d. Maintenance Fuel Usage. This term refers to fuel consumed during diagnostic and field testing operations while combat and noncombat equipment system are repaired.

$$fuel_{4ed} = (nctl_{ed} + ctl_{ed}) \left[\sum_{m=5} fcr_{em} \bullet \sum_{p=1}^{5} up_{epm} \bullet P_p \right] \qquad (10\text{-}4)$$

where $nctl_{ed}$ is the number of noncombat temporary losses of equipment e on day d,

ctl_{ed} is the number of combat temporary losses of equipment e on day d, and

fcr_{em} is the fuel consumption rate for equipment e in mode of operation m,

The factor $\sum_{p=1}^{5} up_{epm} \bullet P_{pd}$ represents the number of hours equipment e operates in mode m when "fighting" in all postures p for day d.

e. Fuel Consumption for Combat Repairable Losses. The fuel consumed for combat systems which suffer mobility and firepower damage is defined according to Equation 10-5. It is assumed, on average, the loss occurs after a half a day of combat.

$$fuel_{5ed} = ctl_{ed} \bullet \frac{1}{2} \left[\sum_{m=1}^{5} fcr_{em} \bullet \sum_{p=1}^{5} up_{epm} P_p \right] \qquad (10\text{-}5)$$

f. Total Fuel Consumption. Total fuel consumption for the day is defined according to Equation 10-6.

$$total = \left((1 + sea_d) \bullet \left((1 + loc_d) \bullet \sum_{i=1}^{5} fuel_{ied} \right) \right) \qquad (10\text{-}6)$$

where sea_d represents the percentage amount of losses to occur when shipped by sea on day d, and

loc_d represents the percentage amount of losses to occur when moving within the theater area of operation (i.e., moving to front line from port of entry)

APPENDIX A

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APPENDIX B

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GLOSSARY

1. ABBREVIATIONS, ACRONYMS, AND SHORT TERMS

APAM   antipersonnel/antimateriel (warhead)

ARL   Army Research Laboratory

ATACMS   Army Tactical Missile System

ATCAL   Attrition Calibration Model

AT/M   antitank/mortar

ARWG   Ammunition Requirements Working Group

BADL   Blue attack Red delay

BAHD   Blue attack Red hasty defense

BAPD   Blue attack Red prepared defense

BAT   brilliant antitank

CALAPER   Calculation of Ammunition, Petroleum, and Equipment Requirements

CAP   COSAGE Attrition Processor

CEM   Concepts Evaluation Model

COMMZ   communications zone

CONUS   continental United States

COSAGE   Combat Sample Generator (model)

COSCON   COSAGE Consolidator (program)

DCSOPS   Deputy Chief of Staff for Operations and Plans

DESCOM   Depot System Command

DOD   Department of Defense

DODAC   Department of Defense Ammunition Code

DPICM	dual purpose improved conventional munition
ECL	engineer class
ELCON	Equipment Loss Consolidator (program)
FASCAM	family of scatterable mines
FCON	Fuel Consumption (program)
FLOT	forward line of own troops
FOE	fraction of expenditures
FORCEM	Force Evaluation Model
GS	general support
HE	high explosive
ICM	improved conventional munition
K-kill	catastrophic kill
LIN	line item number
LOC	line of communication
MCON	Munitions Consumption (program)
MIE	major item of equipment
MOGAS	motor vehicle gasoline
PD	point detonating
POLA	phased offline attrition
PULIN	line item number system will pull from (a weapon system on a piece of equipment, i.e., a .50 caliber machinegun on an M1A1 tank - M1A1 tank LIN is PULIN)
RADL	Red attack Blue delay
RAHD	Red attack Blue hasty defense

RALPH   Reduction ATCAL Phase 1

RAPD   Red attack Blue prepared defense

SSN   standard stockage number (RDAISA)

STAT   static

STATIC   Blue and Red in defense light

TACAIR   tactical air

TRADOC   US Army Training and Doctrine Command

WARRAMP   Wartime Requirements for Ammunition, Materiel, and Petroleum

WARREQ   wartime requirements

2. MATHEMATICAL TERMS AND SYMBOLS

A_p Average number of systems in combat in posture p

AE_p Average expenditure per system in posture p

AE_p Average number of munitions remaining onboard system in posture p

$auth_{ed}$ Authorized level of equipment e on day d

B_{vw} Burst size of munitions from weapon w mounted on vehicle v. Burst size must reflect the single shot probability of kill data uses as input to the tactical combat model.

BE_{dp} Number of battalion engagements in posture p on day d

C_d Total number of munitions consumed on day d

cpl_{ed} Number of combat permanent losses of equipment e on day d

ctl_{ed} Number of combat temporary losses of equipment e on day d

d_{pi} — The number of systems for vulnerability class i that belongs to the Blue force played in COSAGE posture p.

DEG_p — Unit degradation factor

$dirag_v$ — Theater disaggragation for COSAGE vehicle v for which the munition is associated

E_d — Amount (tons) of threat artillery ammo consumed on day d in CEM

fcr_{em} — Fuel consumption rate for vehicle e during mode of travel m

$frac_{vwpt}$ — Fraction of shots in combat posture p by munition w from vehicle v at target t

FOE_{vwTt} — Total fraction of expenditures at CEM threat vehicle T in combat posture p

f_{zd} — Fraction of total quantity of a LIN in zone z on day d.
The value is based on user input allocation of (SRCs) to the five zones

h_{zpch} — Historical loss rate for item in historical class h in posture p and in zone z due to cause c

K_p — Number of catastrophic loss in posture p

I_{if} — Amount of material type i required to perform engineer activity type f (activity component list)

l_{pi} — Number of losses of items in vulnerability class i in posture p due to threat artillery fire missions from COSAGE and based on initial quantity d_{pi}.
Result comes from CAP, which reassesses the COSAGE fire missions against the vulnerability classes.

LOG — Logistics loss factor

$ncpl_{ed}$ — Number of noncombat permanent losses of equipment e on day d

$nctl_{ed}$ — Number of noncombat temporary losses of equipment e on day d

O_p — Total number of onboard losses in posutre p

P_{pd} — Percent of day d in posture p

Q_d — Quantity of LIN item for day d

QD — Number of vehicles deployed in the theater rear areas

L_d — Logistics loss factor for day d

R — Total number rounds expended due to rear area security

S_p — Combat sample consumption (applicible to pyrotechniques only)

SEA_d — Sea loss factor for day d

t_{pi} — Number of losses of items in vulnerability class i in posture p due to threat TACAIR fire missions from COSAGE and based on initial quantity d_{pi}
Result comes from CAP, which reassesses the COSAGE fire missions against the vulnerability classes.

T_p — Number of temporary (repairable) losses in posture p

$tan k_e$ — Capacity, in gallons, of tank size for equipment e

TP — Number of systems (or tubes) in the theater

up_{pm} — Fuel usage profile in posture p for mode of travel m. Represents average number of hours the type equipment will be operating in travel mode m in combat posture p.

Z — Total number rounds expended due to zeroing

α_p — Suspect target factor for item in posture p

β_p — Support unit target factor for item in posture p

δ_d — Effectiveness of TACAIR on day d. If input value δ_d is set equal to -1., it tells the program to set the value equal to ω_d; otherwise, set value to input value δ_d

φ — Zeroing expenditure factor

ρ_p — Ratio of smoke (or illumination) munition expenditure to total munition expenditures from artillery system in posture p

σ — Rear area security factor

ω_p — Artillery effectiveness ratio

3. OTHER MATHEMATICAL NOTATIONS

$\forall_x$ — for ever item x

$\in$ — is element of set

$\ni$ — such that

$\{\forall_x : x \in S\}$ — for all elements x in set S