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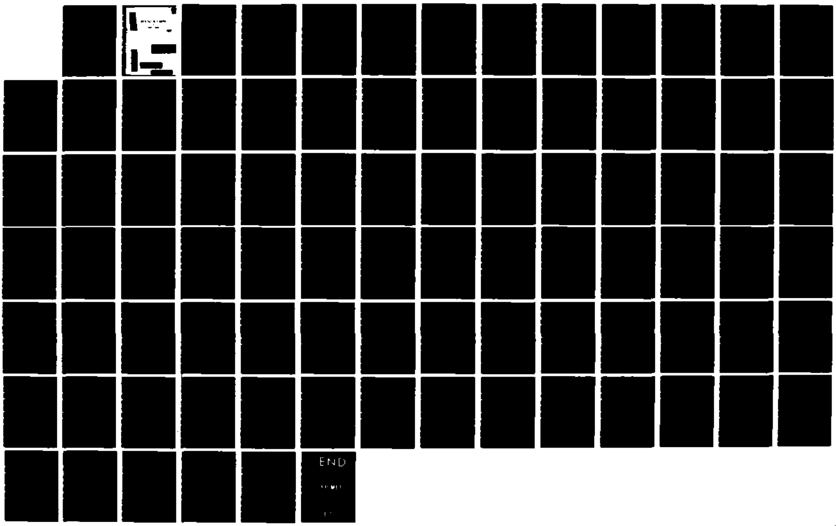

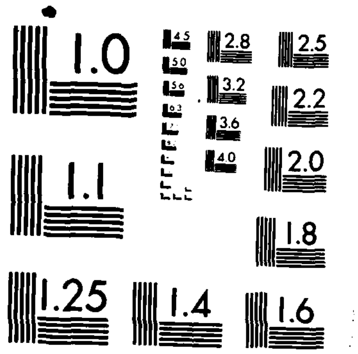

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estimates to determine the expected number of complete rounds available for combat. By assigning a numerical combat power value to each expected target by a Delphi Method and selecting the optimum munition to engage each target type, units can formulate a second linear program which optimizes overall effectiveness. The solution to this linear program, constrained by the number of complete rounds available and the number of targets acquired, gives the amount of ammunition by type which should be carried. The nature of this linear programing formulation is such that a manual solution method, which yields results identical to the linear programing solution, can be employed.

A Quantitative Method for Determining
Artillery Basic Loads of Ammunition

Daniel J. Bonney, CPT

Final Report, 6 Aug 1985

University of Utah, Salt Lake City, Utah
Master of Engineering Administration

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by

Daniel J. Bonney

Comprehensive Engineering Report

Department of Mechanical and Industrial Engineering
University of Utah

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ABSTRACT

Army artillery units stationed worldwide must determine both the types and amounts of ammunition they will carry into combat: the unit basic load (UBL). Currently each unit independently determines its UBL; the decision is based solely on the experience of the unit commander. This report recommends a quantitative method for determining the UBL which will increase the combat effectiveness of all artillery units.

Since the dimensions of all types of cannon ammunition components are virtually identical and the capacities of all vehicles are known, units can estimate the maximum amount of ammunition which can be carried by solving a series of simple linear programing problems. This amount is then reduced by applying vehicle reliability estimates to determine the expected number of complete rounds available for combat. The mixture of ammunition component types depends on munition effects, the expected target array, and the relative importance of targets. By assigning a numerical combat power value to each expected target by a Delphi Method and selecting the optimum munition to engage each target type, units can formulate a second linear program which optimizes overall effectiveness. The solution to this linear program, constrained by the number of complete rounds available and the number of targets acquired, gives the amount of ammunition by type which should be carried. The nature of this linear programing formulation is such that a manual solution

method, which yields results identical to the linear programing solution, can be employed.

Application of this method ensures that all factors influencing UBL composition are considered in detail. The solution of the optimum effectiveness problem, by either linear programing or manual means, and the analysis of the solution provide a basis for final decisions regarding exact UBL composition and loading location. The cost of applying the method is minimal, and all artillery units can apply the method to increase their combat effectiveness.

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GLOSSARY OF ABBREVIATIONS

AO -	Aerial observer
APICM -	Anti-personnel improved conventional munitions projectile
ASIC -	All source intelligence center
ASP -	Ammunition supply point
BC -	Battery commander
DPICM -	Dual purpose improved conventional munitions projectile
DS -	Direct support mission
FASCAM -	Field artillery scatterable minefield projectile
FDO -	Fire direction officer
FEBA -	Forward edge of the battle area
FO -	Forward observer
FSO -	Fire support officer
GB -	Green bag propellant charge
GS -	General support mission
GSR -	General support reinforcing mission
HE -	High explosive projectile
ILL -	Illuminating projectile
JMEM -	Joint munitions effectiveness manuals
LP -	Linear programing model
MOE -	Measure of effectiveness
MT -	Mechanical time fuze
MTBF -	Mean time between failures
M109A2 -	155 mm self-propelled howitzer
M520 -	8-ton wheeled cargo vehicle
M548 -	6-ton tracked cargo vehicle

OR -	Operational readiness percent
PD -	Point detonating fuze
Q-36 -	Counter mortar radar
Q-37 -	Counter battery radar
R -	Reinforcing mission
RAP -	Rocket assisted projectile
SMK or HC -	Smoke projectile
S-2 -	Battalion intelligence officer
S-3 -	Battalion operations officer
TACFIRE -	Digital fire direction computer
TOE -	Table of organization and equipment
UBL -	Unit basic load of ammunition
VT -	Variable time or proximity fuze
WB -	White bag propellant charge
WP -	White phosphorus projectile
Z8 -	Zone 8 propellant charge

Note: Non-standard abbreviations are used for target types which form the basis for linear programing decision variables. Target type abbreviations used in this study are listed in Appendix F.

EXECUTIVE SUMMARY

The unit basic load (UBL) is the quantity of ammunition components carried into combat by artillery units. This ammunition must sustain the combat operations of the unit during the initial stages of combat until resupply can be accomplished. Since many more targets will be acquired than can be engaged, the amount of complete rounds and the ammunition component types included in the UBL will be a primary determinant of the artillery unit's success in the initial stages of combat.

Currently each battalion commander determines the composition of the UBL based on a subjective evaluation of his unit's mission, expected target array and load carrying vehicle capabilities. This approach fails to consider several factors affecting UBL composition. More importantly, the subjective approach does not firmly establish a sound measure of UBL effectiveness upon which UBL composition decisions may be based. In practice, this results in a wide variation between supposedly optimum UBL's.

This report examines all factors affecting UBL composition, establishes a measure of effectiveness for the UBL, and recommends a quantitative approach to solving the UBL problem. The quantitative approach establishes ways to estimate:

a. Unit maximum carrying capacity

b. Ammunition vehicle reliabilities

c. Expected target types, numbers acquired and target range distributions

d. Situational relative target values

e. Effects of engagement on enemy combat power or engagements benefits

f. Ammunition amounts and types required for engagement or engagement costs.

These estimates are then included in a logical, sequential method whose ultimate objective is to maximize the decrease in enemy combat power, as quantified by the relative target values, constrained by the total amount of available ammunition and the number of targets which will be acquired. A linear programing approach to optimization is developed which leads directly to a manual heuristic solution method that yields results identical to the linear programing solution. The manual solution method can be implemented in all active artillery units with a minimum of training and requires no external computer support.

The quantitative method provides a solution which specifies which targets should be engaged in combat, the level of engagement, and the proportion of ammunition components by type which should be included in the UBL. While the limited state of the art of target value assessment precludes direct application of the solution values to the UBL, the solution values and their sensitivity to changes in relative target values gives the battalion commander a sound basis for final decisions regarding UBL composition and a thorough understanding of how UBL selection will influence his unit's effectiveness in combat. Additionally, the quantitative method requires analyses of vehicle reliabilities and target acquisition capabilities which will affect his unit's combat effectiveness and which he may not have considered separately.

Application of quantitative UBL method will:

1. Ensure that all key considerations are examined in detail
2. Provide insight into the nature of both the UBL problem and artillery combat effectiveness that will assist in the final determination of UBL composition
3. Identify possible problems in vehicle fleet reliability and target acquisition orientation that may hinder combat performance
4. Increase awareness of the importance of target selection and assessment to combat effectiveness among the junior officers who provide fire support in combat.

The only cost of implementing this method in a field unit is in the training time required to assemble data and complete the analysis. By combining data gathering with compatible regularly scheduled training, this cost is limited to an estimated 40 hours for the battalion S-3, who is in charge of the analysis, over and above current scheduled training.

While continued study of target value assessment methods may improve the accuracy of the quantitative solution, the method can be applied now with a reasonable expectation of improving both UBL composition and artillery unit effectiveness. The wide ranging benefits which accrue from implementation of this quantitative method to determine UBL composition are both substantial and relevant to every field artillery battalion. Considering the minimal costs of implementation, every artillery unit with an active combat contingency mission should apply the method to reconsider their UBL composition. Even if no change in UBL is warranted, the benefits of the method's application may prove to be the margin of success in future combat operations.

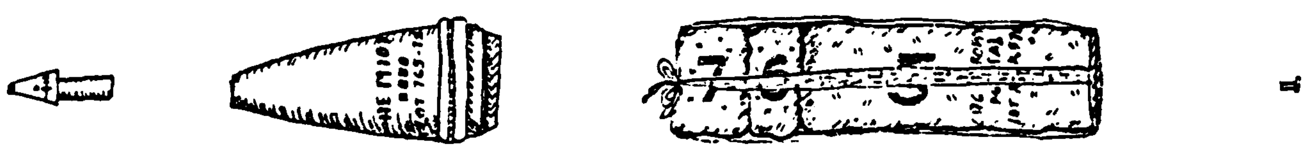
I. INTRODUCTION

I.1 Background

The mission of all field artillery units is to provide timely and accurate indirect fire support for maneuver forces. While many factors influence the ability to accomplish this mission, the type and quantity of ammunition available for expenditure is a primary determinant of artillery combat power. Without ammunition that can hit the targets which are located, and cause casualties to the wide variety of target types that are expected, no artillery unit can be effective.

When ordered into a combat situation, artillery units draw a predetermined amount of ammunition from consolidated supply points. The unit carries the ammunition forward to its initial combat positions on its assigned load carrying vehicles. This quantity of ammunition, defined as the unit basic load (UBL), must sustain the unit's combat operations until forward resupply points can be established and more ammunition can be issued.

Unlike simple rifle ammunition, artillery ammunition allows great flexibility in range, trajectory and target effects. This allows optimal use in a wide variety of tactical situations against different target types. A complete round of separate loading artillery ammunition is shown in Figure 1.



Fuze　　Projectile　　Propelling charge　　Primer

Figure 1. Components of a complete round of artillery ammunition.

In a given tactical situation, the correct combination of these components will produce the maximum amount of casualties and/or materiel damage against a specific type of target. Obviously, both the quantity and types of ammunition components that are included in the unit basic load will determine the overall effectiveness of an artillery unit during the initial stages of combat.

I.2 Problem Definition

Since the unit basic load must be stored in readiness for possible contingencies, its exact composition must be determined prior to hostilities. Currently, artillery battalions independently determine their unit basic load. The artillery battalion commander considers:

1. the battalion's mission
2. the expected distribution of enemy targets
3. the availability of cargo carrying vehicles.

Based on these factors and his experience he subjectively determines the relative amounts of each type of component that will maximize his battalion's combat power. The maximum amount of ammunition which can be loaded on the unit's assigned vehicles, while complying with the commander's guidance on its relative composition, is determined experimentally by testing various vehicle load configurations using actual ammunition components.

The inadequacy of this subjective/experimental approach is demonstrated by the wide variation of supposedly optimum UBL's determined by identical units facing similar expected enemy target arrays. A quantitative method to determine UBL's will improve the effectiveness of all artillery units by providing data on the quantity and type mixture which will optimize the battalion's combat power in a specific tactical situation. The battalion commander can then review this quantitative data, examine the sensitivity of the models to changes in estimated values, and make an informed final decision on the composition of the unit basic load. At present, the factors affecting the UBL have been discussed in the literature but no quantitative procedure which will optimize the battalion's UBL with any degree of certainty exists.

I.3 Factors Influencing Basic Load Composition

In attempting to produce a quantitative method which will lead to an optimum effectiveness UBL, the factors which influence our decisions must be examined in detail. Both the availability and accuracy of existing data will be a primary determinant of which quantitative methods can be applied and the reliability of their results. The factors affecting the UBL problem range from those which can be determined with absolute certainty (ammunition component dimensions) and situational variables that may be reasonably estimated as expected values (vehicle reliability, expected threat) to those which are truly subjective and require assumptions (requirements for special munitions). Factors which can be determined with relative certainty include:

a. Ammunition component dimensions. The physical dimensions of the variety of projectiles, fuzes and propellant charges will affect the unit's maximum carrying capacity. This data is readily available in technical manuals.

b. Load carrying vehicle characteristics. The dimensions, reliability and number of available cargo vehicles determine the maximum amount of ammunition that can be expected to be available at the initial combat locations following tactical deployment from peacetime stations. Vehicle dimensions and capacities are listed in technical manuals and the number and types of authorized vehicles for each unit are found in Tables of Organization and Equipment (TOE).

The failure of vehicles during deployment will reduce the amount of ammunition available for engagement. Fleet reliability can be estimated by application of reliability theory to experimentally determined data.

The factors influencing the type mixture of ammunition are entirely dependent on the combat situation faced by the artillery battalion. These considerations and their impact on the UBL problem include:

a. Artillery mission assignment. Field artillery battalions are assigned one of four standard missions: direct support (DS), reinforcing (R), general support (GS), general support reinforcing (GSR). Missions are assigned by higher headquarters as a method of allocating artillery combat power. Each standard mission defines the maneuver force which the artillery battalion will support in combat and consequently limits the expected target array to the enemy threat faced by the maneuver force supported.

b. Friendly situation. Logistic unit plans will specify the time required to set up forward ammunition supply points (ASP). This will determine the time during which the UBL may be expended. The plans of the maneuver force supported will influence the amount of special ammunition required to support the operation and reduce the amount of target effects ammunition available for target engagement.

c. Enemy situation. The organization, intentions and tactics of the enemy will affect the plans of friendly forces and will determine the type, amount and distribution of possible targets; the expected target array. Analysis of the expected threat is an art in its own right which far exceeds the scope and purpose of this paper. Fortunately, this analysis has been completed for a wide variety of possible contingencies and enough information to determine an expected target array for a specific situation is readily available. Since a single combination of artillery ammunition components will maximize the casualties and/or equipment damage on a particular type of target, the impact of the expected target array on the mixture of component types within the UBL is most significant.

d. Ammunition effectiveness. In addition to the importance of target type, the casualties caused by any shell/fuze combination are affected by target posture, terrain and weather. The propelling charge which will provide the best trajectory characteristics in a particular situation is solely a function of the range to the target. The casualty producing potential of various shell/fuze combinations has been determined experimentally by exhaustive testing and is tabulated in the joint munition effectiveness manuals (JMEM) and included in the tactical fire direction subroutines of the current fire direction computer (TACFIRE).

e. Target acquisition assets available. Targets which can be engaged are acquired by forward observers, indirect fire locating radars, aerial observers, and a wide range of intelligence sources. The capabilities of these assets will determine the number and type of targets that will be acquired in a given situation. The location accuracy of each target agency will influence the amount of ammunition required to achieve a specified level of casualties on a target. The expected accuracy of each target acquisition asset has been determined experimentally and is included in the TACFIRE data base. The capabilities of each system are affected by terrain, weather and enemy situation in the area of combat operations.

To provide a reasonable degree of accuracy, any UBL computation method must address each of these factors by applying the most accurate data available for the particular solution. The wide variation in current UBL's can be attributed to either inaccurate data bases or, more probably, a failure to consider one or more of the above factors. Due to the situational nature of many of the key variables to be considered, no method of computation will be foolproof. At a minimum, a quantitative method will ensure that no key considerations are overlooked.

I.4 Measures of Artillery Unit Effectiveness

The UBL that we determine will be a function of the variables discussed above and the overriding objectives which we hope an optimum UBL will accomplish. The measure of effectiveness (MOE) which we select will determine both the quantitative methods of solution available and how we will quantify the situational variables. Due to the complex nature of combat and the large number of variables which affect the ultimate outcome of any engagement, a wide variety of combat models have been developed during the last century. Each model attempts to predict the outcome of an engagement in hopes of indentifying those factors critical to success in combat. All define success in combat as accomplishment of a force's stated objective; the objectives have been stated in terms of seizure of terrain, speed of advance, destruction of enemy forces, minimization of friendly casualties, or some combination of these objectives. While this definition of success in combat is appropriate for maneuver forces, it is much too broad to apply to artillery units since all artillery units simply provide fire support to assist maneuver units in accomplishment of their objectives.

Current U.S. doctrine focuses its attention on localized force strength ratios to predict the outcome of engagements. Success is defined as accomplishment of unit objectives which are defined in terms of terrain defended or gained and destruction of enemy forces to produce favorable force ratios. Based on historical data, defenders will be successful if they are attacked by forces of less than twice their combat power. Attackers will be successful if they can concentrate six times the combat power of the defender. Figure 2 shows the relationship of force ratios to success in combat.

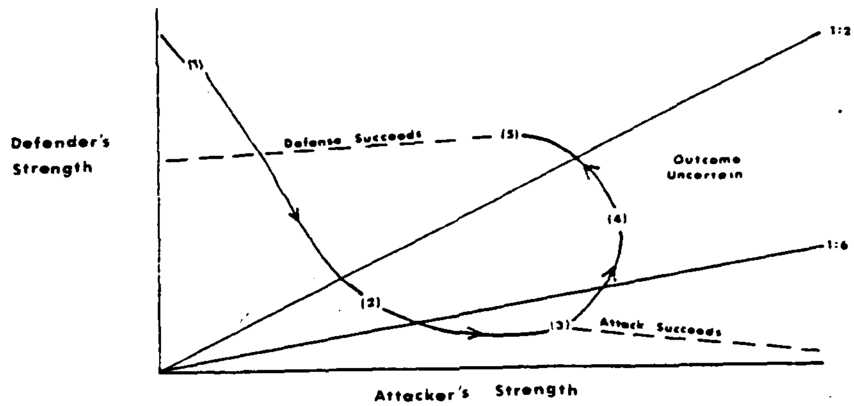


Figure 2. Force ratios and expected outcome.

Unlike some previous force ratio predictors which used detailed computations to determine exact force ratios based on the total number of units present on the battlefield, this representation is only presented to understand the current concept of battlefield dynamics. The local force ratio changes as units enter combat and casualties are inflicted. The curved line shown on Figure 2 represents a hypothetical engagement. The defender initially controls the terrain of his choice and enjoys a favorable strength ratio (1). After probing the defensive position the attacker deploys into an attack formation rapidly increasing his local strength (2). If enough combat power can be applied the attack will be successful (3). If the defender commits reserve forces sufficient to offset the attacker's arriving forces (4), given his inherent ability to inflict a higher relative amount of damage, his defense will be ultimately successful (5). Thus, the primary determinant of success in an engagement is the ability to maintain freedom of action and control the disposition of enemy forces in space and time.

While this measurement of success remains too general for our purposes, this concept formed the basis for a series of studies known as the Fire Support Mission Area Analysis. The studies, presently ongoing, attempt to determine methods to increase the combat power of artillery units by suggesting changes in artillery tactics, equipment, munitions, organization and procedures. One of the results of this study suggests that the value of various target types is situational and that in a given situation, certain key targets, if destroyed, will greatly decrease the enemy's freedom of action and consequently his ability to attain favorable local strength ratios.

Recognizing the limited current state of the art in target value assessment, our objective in combat should be to minimize the enemy's flexibility by maximizing the destruction of critical target types that are most important to the enemy's success in a particular situation. Thus the MOE for the unit basic load is the expected decrease in enemy combat power resulting from expenditure of the unit basic load. The quantification of this decrease, which we hope to maximize, will be discussed at length in Chapter III.

I.5 Solution Method Selection

The quantitative method selected to solve the UBL problem must allow incorporation of all factors affecting the problem, optimize the MOE in a specific situation, be flexible enough to allow application in a wide variety of strategic and tactical situations, and allow implementation with a minimum amount of additional resources above those already available in the field. Considering our MOE it is apparent that we will be unable to quantify the benefits of any solution in monetary terms.

Due to the large number of situational variables, simulation would at first appear to be a valid approach. However the available combat simulations and games do not consider many of the factors critical to the UBL problem. While additional rules could be developed, implementation in the field would require numerous iterations to achieve a reasonable expectation of an optimal solution. Since many of the variables are probabilistic and there are complex interrelationships between variables, non-linear programing appears potentially useful. This approach, no matter how accurate, cannot be implemented in any unit without considerable training of users and provision of computer solution methods. Linear programing appears to provide a basis for an accurate solution which can be implemented with a minimum commitment of additional resources.

We have identified a MOE which we hope to optimize and factors impacting on the problem which will serve as constraints. While the MOE and constraints must be quantified in some systematic manner, this approach appears to meet the accuracy and flexibility requirements. Linear programing computer packages, although not directly available to field units, are widely available and can be used with minimum training. The relatively straightforward formulation and solution of LP's as well as the availability of sensitivity analysis, to reconsider the coefficients determined for the key situational variables, appear to make the LP approach to the problem most appropriate. As will be shown in the analysis of the LP solution, the LP which solves the UBL problem will lead to a straightforward manual solution method whose accuracy will equal that of the LP formulation.

I.6 Application of Linear Programing Approach to the UBL Problem

While it is possible to develop a single LP formulation which will simultaneously consider all of the key factors, from an implementation standpoint it is preferable to develop a method which considers the various aspects of the problem sequentially. As long as optimum decisions are made at each stage of the process in view of the ultimate MOE, this approach should yield results approaching those of a single LP formulation.

Given the above MOE, maximizing the number of complete rounds available in the initial combat positions will contribute to attainment of our ultimate objective. This amount is constrained by the carrying capacity of the vehicle fleet and loading requirements. Since all ammunition dimensions are similar and vehicle capacities known, a straightforward LP which estimates the maximum number of complete rounds loaded can be formulated and solved. This amount will be reduced by vehicle failures that can be predicted from reliability data, and the number of complete rounds expected to arrive can be determined.

In combat the artillery battalion controls which targets, of the many available, will be engaged and how much ammunition should be expended during each engagement. They will be limited by the amount of ammunition available for target engagement and the number of targets located by the target acquisition system. Maximum effectiveness will only be attained if each target selected is engaged with the most effective munition for that target type. Since target values and ammunition effects are situational, a Delphi method to determine this information is applied. An LP can now be formulated with an objective of maximizing the decrease in the combat strength of important target types. By including the ammunition cost of each engagement in the LP, the solution will indicate:

1. which targets should be engaged
2. the level of each engagement
3. the amount of each type of ammunition component required to support the selected engagements within the ammunition amount available.

In addition to providing the solution to the UBL problem, the LP solution will provide sensitivity data that may indicate that the coefficients of the decision variables which were determined by the Delphi method may require further revision.

This general approach to the problem appears promising. However, further analysis requires explicit statement of the LP's proposed. Due to the large number of situational values that impact on the problem, the most efficient development and explanation requires the introduction of an example problem which demonstrates the basic method of solution as well as developing the analysis. The situation presented will portray a possible strategic and tactical situation but, due to classification of actual unit missions and plans, any similarity to any real unit or plan is purely coincidental.

I.7 Example Situation

The 1st Battalion, 83rd Field Artillery (1/83 FA) is a 155 mm howitzer battalion stationed in West Germany. Its authorized equipment includes:

1. Eighteen M109A2, 155 mm self-propelled howitzers
2. Eighteen M548, 6-ton tracked cargo carriers
3. Eighteen M520, 8-ton wheeled cargo carriers
4. Thirty-six 1 1/2 ton ammunition trailers, one for each M548 and M520

In the event of imminent hostilities the battalion will be ordered to execute its contingency plans. Based on intelligence estimates, this will occur a minimum of 36 hours prior to the primary Warsaw Pact forces entry into West German territory. Upon alert, the battalion loads its combat equipment and moves in convoy to an ammunition storage depot located 65 km from its peacetime location. At the depot, the battalion, assisted by the forklifts and ammunition handlers stationed at the depot, loads the UBL on its assigned cargo vehicles. Once ammunition loading is complete, the battalion moves to its initial combat locations, a distance of 225 km by its authorized route. The total time from alert to occupation of initial positions requires 26 hours. Upon arrival, the battalion will have 10 hours to prepare for combat.

At the commencement of hostilities, the battalion's mission is to provide direct support to a U.S. maneuver brigade which includes two mechanized infantry battalions and one armored battalion. The brigade defends a sector 15 kilometers wide. The terrain in the brigade's sector is hilly and approximately 60% of the area is heavily wooded. Current brigade plans call for the emplacement of six field artillery delivered minefields in all situations and eight contingent minefields. In addition, artillery smoke is required to screen the movement of one company-sized team during the brigade's defense. No major expenditure of artillery illumination is planned. Resupply of ammunition will be impossible until 72 hours after initial alert.

The brigade is expected to be opposed by a Warsaw Pact Motorized Rifle Division. The two primary avenues of approach into the brigade sector can support one regiment abreast. Intelligence indicates that the tactics and equipment of this division are typical of a Soviet division. The division is expected to conduct a movement to contact until encountering forward U.S. elements, then deploy into attack formation to conduct an attack from the march with an ultimate objective located 70 km to the rear of forward U.S. forces.

The target acquisiton assets available to 1/83 FA include:

1. One Q-36 counter mortar radar attached to 1/83 FA
2. One Q-37 counter battery radar located in the brigade sector
3. Forward observer teams attached to each maneuver company
4. Two aerial observers under 1/83 FA operational control
5. Access to all-source targeting information through the TACFIRE system.

I.8 Applicability of Demonstrated Problem Solution

The general situation presented above provides enough information to apply the proposed solution method in detail. Before continuing several cautions are in order. In addition to the conjectural nature of the situation above, classification of target value, target acquisition and ammunition effectiveness data precludes the use of actual data. Estimation of relative values will be employed so that realism of the solution method is not compromised. However, the only valid conclusions which can be drawn from this analysis are limited to the appropriateness of the solution method. Any other inferences from the basic data or the specific UBL computed for the example situation will be totally invalid. With this caution in mind, the UBL which maximizes the combat effectiveness of 1/83 FA in this particular situation will now be determined.

II. ESTIMATION OF AVAILABLE AMMUNITION

The tactical situation indicates we will acquire many more targets than we will be able to engage due to the limited amount of ammunition we can carry. Due to the slight difference in ammunition component dimensions (Appendix B) the type mixture of ammunition will affect our maximum carrying capacity. However we cannot determine which targets should be engaged without constraining the total amount of ammunition available. Since the component dimensions are similar, a reasonable approach would be to first estimate the maximum carrying capacity using the average component dimensions.

II. 1 Maximizing Use of Vehicle Capacity

Given the known characteristics of ammunition components and load carrying vehicles, a single LP formulation would maximize the total unit carrying capacity. However the solution may indicate that all of one type component be loaded on one type vehicle. Recognizing that some vehicles will fail during deployment and that the vehicles will be positioned in three distinct locations upon arrival at the front, a uniform distribution of ammunition across the vehicle fleet is desired. A series of LP formulations, one for each type of load carrying vehicle and its assigned cargo trailer will alleviate this problem.

The maximum carrying capacity of all cargo vehicles is constrained by:

1. Weight capacity
2. Volume capacity
3. Floor space

4. Vehicle loading and tiedown requirements

5. Balance requirements.

These basic constraints will apply to all vehicles with open cargo space. The M109A2 has preconfigured cargo space allowing 34 complete rounds to be carried.

The M548 and 1 1/2 ton cargo trailer system has open cargo space and a LP must be formulated to estimate its maximum capacity. Our objective is to maximize the number of complete rounds carried on the vehicle/trailer system. We control the number of each component which will be loaded. The M548 must be loaded so that all components can be tied down; ammunition components may not be stacked. Thus we are constrained by floor space. In the trailer, we are constrained by volume since the load is stabilized by the walls of the trailer and tiedowns are not required. Both the vehicle and trailer are constrained by their highway weight capacity which is 50% greater than the rated cross country capacity; i.e. the highway capacity of the 6-ton M548 is 9 tons. The LP formulations and solutions for both the M548 and M520 are included in Appendices D and E.

A cursory glance at the LP solutions shows several inaccuracies. The solution does not provide integer values for the decision variables but indicates we should load fractions of pallets and fuze boxes. While it is possible to load single rounds and fuzes this will increase the time to complete loading. Due to the irregular shape of single components we are unable to accurately portray their inclusion in the LP formulations. While other methods are available that will alleviate this problem, specifically a branch and bound approach, a search for greater accuracy at this point will not be cost effective.

Assuming we will load single components, the non-integer solution will provide an estimate of maximum carrying capacity higher than any integer solution. Multiplying the maximum capacity of each vehicle by the number of each type vehicle and summing these products yields an estimated battalion maximum carrying capacity of 5130 complete rounds. The maximum capacity determined experimentally by a unit in Germany using a mixture of component types was 4980 complete rounds. Obviously, the LP solution provides a relatively accurate representation of true capacity.

The non-integer LP provides an absolute upper limit on carrying capacity that may not be attained when we attempt to physically load the number of components in the LP solution. As long as units utilize all available space to load complete rounds of ammunition without exceeding vehicle weight capacities, their experimental maximum carrying capacity will approach the quantity determined in the LP. Consequently units may determine their maximum capacity experimentally without resorting to LP formulations.

II.2 Vehicle Reliability Estimates

Unfortunately, all the historical data needed to estimate vehicle fleet mission reliability is unavailable in existing maintenance records at unit level. Only the monthly operational readiness (OR) rate for each vehicle type is maintained on file. The operational readiness rate is computed by:

$$OR = \frac{\text{Operational days}}{\text{Operational days} + \text{Nonoperational days}}$$

The OR rate will allow us to estimate how many vehicles are avail-

The OR rate will allow us to estimate how many vehicles are available when deployment is ordered but provides no information on the number of vehicles we can expect to arrive fully loaded in the initial combat locations.

To estimate mission reliability we must assemble failure data for the vehicle fleet under conditions approximating those we will encounter during deployment. This data can be collected in conjunction with high vehicle use periods during major field exercises. The specific data requirements will depend upon how we model the failure distribution.

Since the average life of a vehicle in a unit is about five years and vehicles are replaced at mileages corresponding to an increase in the failure rate, we can reasonably assume that at the time of deployment:

1. All vehicles will have passed the initial high failure period.
2. No vehicles have entered the end of life high failure period.

We can reasonably assume that vehicle failures will be exponentially distributed. The exponential distribution is defined by only one parameter, the mean time between failures (MTBF), which can be estimated by:

$$MTBF = M \div r$$

where M is the fleet mileage and r is the number of failures. To determine the MTBF we must simply document the total fleet mileage and the number of failures during a major exercise or training period. The mission reliability is given by:

$$R(m) = \exp [- m \div MTBF]$$

where m is the required mission mileage. The number of vehicles, X, which will successfully complete deployment is binomially distributed with an expected value

$$E(X) = n \times R(m)$$

where n is the number of vehicles operational at deployment.

The number of vehicles expected to be operational at deployment can be determined using the relationship:

$$E(n) = f \times OR$$

where f is the total number of vehicles in the fleet.

Returning to the sample problem we first assemble the required data during a major training density. This data is given in Table 1.

Table 1. Fleet reliability data.

Vehicle type	Fleet Miles (M)	Failures (r)	OR
M109A2	4231	3	93%
M548	3563	5	86%
M520	2298	6	82%

Based on this data we compute the number of vehicles expected to arrive at the initial combat locations 180 miles from garrison. The results are provided in Table 2.

Table 2. Expected vehicle arrivals.

Vehicle Type	Fleet Size	Number Deployable	Mission Reliability	Number Arriving
M109A2	18	17	.880	15
M548	18	15	.777	12
M520	18	15	.625	9

Having determined the maximum capacity of each vehicle type and the number we expect to arrive at the initial combat locations we can compute the amount of ammunition expected to be available in the initial combat locations.

II.3 Expected Available Ammunition

The expected available ammunition is computed in Table 3.

Table 3. Expected available ammunition.

Vehicle Type	Max.Capacity	Number Arriving	Type Vehicle Total
M109A2	34	15	510
M548	106	12	1272
M520	192	9	1728
		Unit Total	3510

It must be emphasized that this amount is only an estimate which we will use as a constraint on our ability to engage targets. Once we have determined what targets we should engage and the amounts of ammunition required to support these engagements within the expected available amount, we must reconsider how to load the desired ammunition mixture on the available vehicles. This will be discussed in Chapter IV.

III. DETERMINATION OF OPTIMUM AMMUNITION TYPE MIXTURE

Within the total expected amount of available ammunition our ultimate objective is to maximize the decrease in enemy combat power. Our ability to accomplish this objective will be limited by:

1. The number of each type of target acquired
2. The amount of expected available ammunition.

The situational nature of the target array and the relative values of acquired target types that will allow us to quantify the decrease in enemy combat power force us to make reasonable estimates for some variables; no better information is available. The result we seek in this analysis is the proportion of each type of ammunition within the total expected available amount that yields optimum results in combat. Once we have determined these proportions we must return to the loading problem and maximize the total amount loaded constrained now by vehicle capacities and the optimum proportion of types for our combat situation.

III. 1. Expected Targets

The expected targets that will be present on the battlefield, based on the threat analysis of our area of operations, are determined directly from references which list the organization, equipment and tactics of Warsaw Pact forces. The targets which will be considered are listed in Appendix F. The number of target types considered is limited by reasonable estimates of:

1. Range
2. Acquisition probability
3. Target importance.

We want to consider engaging any target which may contribute to the enemy combat power. However, even though we know that a mobile field bakery will be on the battlefield it will probably be out of range, its probability of acquisition is practically nil, and its importance during the first 36 hours of combat is minimal. Adding this target will only confuse the analysis. The size of target depends on Soviet tactics and corresponds to the size we would expect to acquire in combat. For example, maneuver units disperse a platoon over 250 meters, artillery batteries emplace in a 300 meter line formation, and air defense artillery weapons (ZSU-23-4) are employed in pairs within a 150 meter radius. With these considerations in mind, we establish the list of target types to be considered for engagement.

Our ability to engage targets will be limited by our ability to accurately acquire targets on the battlefield. The target acquisition assets at our disposal range from forward observers equipped with binoculars to data received from the all source intelligence center (ASIC) which may be based on satellite photos and electromagnetic intercepts. The capabilities, limitations, and orientation of each source will determine the expected number of each target type acquired. In the case of the forward observer we expect to acquire most targets within 3 km of the FEBA and the probability of acquisition of the Q-36 counter battery radar is well documented. The aerial observer's (AO) and ASIC's probabilities of acquisition can only be based on estimates made by each AO and the chief of the ASIC. By multiplying the expected number of targets by the probability of acquisition, we determine the expected number of each target type acquired.

III. 2 Expected Range Distribution

The range to each target will be a function of acquisition distance and positioning of friendly artillery batteries. These data are included in Appendix G. Since our positions will be located 5-7 km behind the FEBA and Soviet doctrine predicts a disposition of forces we determine an expected range distribution or more correctly the statistical range of expected target ranges. Our objectives here are to determine what targets will be out of range, which targets must be engaged at extended range requiring RAP, and the appropriate mixture of propellant types to support engagements of all targets which will be engaged.

Assuming a normal distribution of each target type's range, the statistical range is:

$$\text{Range} = \text{Maximum Expected Range} - \text{Minimum Expected Range}$$

The standard deviation of each distribution may be estimated by:

$$\text{Standard Deviation} = \frac{\text{Range}}{6}$$

and the mean by:

$$\text{Mean} = \text{Minimum Expected Range} + \frac{\text{Range}}{2}$$

Having determined the parameters of the distribution the standard normal variable, Z, can be determined:

$$Z = \frac{X - \text{Mean}}{\text{Standard Deviation}}$$

where X is the normally distributed variable of interest, in our case the range limits of each propellant type. By referring to a standard normal table, we can determine the proportions of propellant type to support engagements of each target type.

Applying the results of these computations to the expected acquired target quantities we find that several targets will be acquired at ranges beyond our capability, and several long range targets must be engaged with rocket assisted projectiles (RAP) rather than with a more effective projectile. This information is included in Appendix H.

III. 3 Relative Target Values

Recalling that our objective is to maximize the decrease in the enemy's combat power and that the importance of each target is situational we must quantify the relative values of the available target types. Any calculation which includes only the firepower of weapons systems is clearly inappropriate since the situation is not considered and non-weapon type targets, radars, headquarters, etc., will have no value. An estimate made by one individual, no matter how skilled or experienced, will not reflect the different situations impacting on target importance across the brigade's 15 km sector. While we have no group of target value assignment experts, we do have individuals who understand both the general brigade plan of operations and are intimately familiar with a specific aspect of the threat or enemy dispositions in a small area. By designing a Delphi method to assign values to each target type, conflicting opinions can be reduced while ensuring that the most accurate reflection of target values across the brigade sector are determined.

The battalion operations officer, in charge of controlling the process, would determine the most qualified experts from each of several groups: fire support officers, forward observers, battery commanders and operations/intelligence officers. Each expert would be required to review current combat plans and threat estimates as well as the doctrinal information regarding target selection. Each expert would then be asked to assign a value to each target type under consideration relative to a common target with a fixed value; i.e. "Given the combat situation assume that the combat importance of a tank platoon is 100. Assign values to the other listed targets in the situation faced by the unit you support. Thus if you consider an artill ~y battery twice as important as a tank platoon assign it a value of 200." Additionally, the maximum possible value should be established to limit the range of responses.

While all respondents should assign values to all target types, the controller should consider responses based on his knowledge of the respondent. A company level FO cannot reliably estimate the value of an opposing force division headquarters but can assess values of maneuver targets expected in his company sector. The controller then determines the median value and the values of the quartile limits. This information is then provided to the respondents who reconsider their initial values, assign a revised value to each target type, and provide a reason for any value assigned outside the quartile limits.

The controller determines the new median and quartile values as well as summarizing any key arguments proposed during round two and returns this information to the respondents for a final revision. This process could continue until the range of values does not decrease from one round to the next. However in this case continuation beyond the third round is probably unnecessary.

In most applications the Delphi process attempts to determine an agreed upon median value. While this is true of some of the targets we are considering (division headquarters, multiple rocket launcher), some target values will vary across the brigade front. A dismounted infantry platoon in a heavily wooded sector will be a much more important target than the same platoon in an area where targets can be spotted at a distance of 3000 meters. In this case it would be more appropriate to compute and use a mean relative target value.

The importance of the controller in this procedure is obvious since he must decide which responses are valid and interpret the data to determine the accepted relative target value. While this process has not been tested in an actual unit there are no other reasonable methods of assigning values in this situation. Sample round one experiments, using a sample of three experienced Army officers, show that the relative values assigned on round one will be within $\pm$ 20 on most targets and that the relative value order of targets will be similar. Assuming that we have completed this process, the relative target values for each target type are given in Appendix I.

III. 4 Engagement Level and Target Effects

In addition to deciding which targets to engage, we control the number of rounds that will be expended on each of the acquired targets. While we can determine the expected percent of casualties and/or equipment destroyed from the JMEMS or TACFIRE, the percent casualties does not translate directly into a percent reduction in combat power. If we fire a few rounds at a target, we will obtain no casualties but the target will certainly disperse and seek cover reducing its combat power for a short time. Conversely, we need not cause 100% casualties to make a unit completely ineffective in combat. The relationship between ammunition expenditure, percent casualties and target combat power for a hypothetical target is shown in Figure 3.

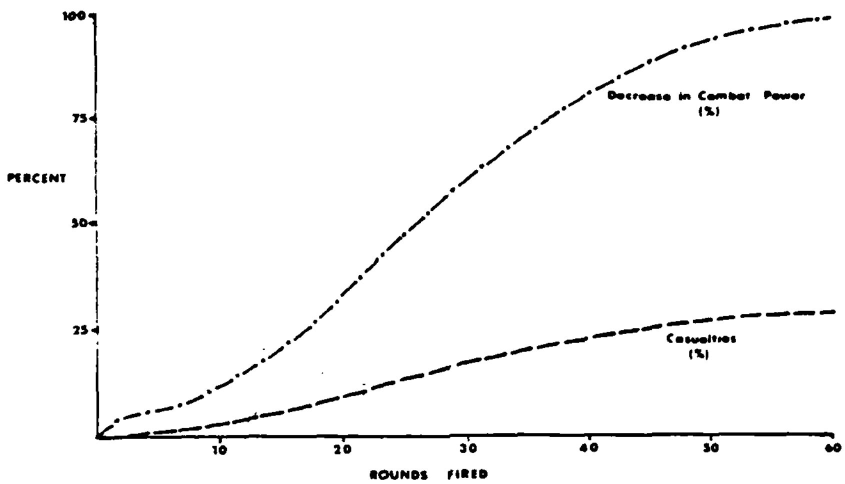


Figure 3. Relationship of casualties, combat power and ammunition expended

Since we are considering an area type target, initial rounds cause no casualties. Once sufficient coverage of the target is attained, casualties are caused but the rate of casualties decreases as vehicles and personnel disperse and take protective measures. Combat power decreases sharply as initial rounds are received. If expenditure continues, casualties and vehicle damages occur until the remaining personnel and vehicles can no longer perform a combat mission effectively.

While the inflection points on the combat power curve or its parameters cannot be determined, historical analysis of units in combat indicates that:

1. Units suffering 30% casualties will be combat ineffective over the long term.

2. Units suffering 10% casualties will be ineffective for a short period and then continue combat at a significantly reduced effectiveness estimated at 70% of their original effectiveness.

3. Units receiving low volume fires will be ineffective only while receiving fires and then continue more cautiously resulting in an estimated 5% decrease in offensive effectiveness.

III.5 Ammunition Costs

We have decided which targets should be considered for engagement and the possible levels of engagement for each target. Recognizing we will be limited by the amount of available ammunition, we will fire the most efficient shell/fuze combination at each target type. Suppression (S) of actively firing targets requires expenditure of six HEVT rounds reducing target combat power by 5%. Engagement to limit (L) produces 10% casualties and a 30% decrease in target combat power. Destruction (D) produces 30% casualties and renders the target combat ineffective. Having directly related casualties to combat power, the ammunition cost to limit or destroy a target's combat power can be determined directly from the JMEM or TACFIRE. Due to classification of actual values approximate ammunition requirements, or costs, have been assumed and are included in Appendix I.

III. 6 Maximizing Artillery Combat Effectiveness

All information required to formulate a linear programing problem which will determine the composition of the UBL which maximizes the decrease in enemy combat power described in terms of relative target values is now available. The LP formulation for our sample situation is given in Appendix J.

The decision variables in the objective function are the number of engagements that should be made against each target type at a specific level of engagement. The first letter of each decision variable indicates the level of engagement, suppress, limit, or destroy, followed by the target type code. Long range targets which must be engaged with RAP, the last eight terms in the objective function, are indicated by "L" following the target type code.

The MOE which we have specified, the decrease in enemy combat power as a result of UBL expenditure, is reflected in the objective function which is the sum of the combat power decreases resulting from engagement of each target type. The coefficients of the decision variables are determined directly from the relative target values and the analysis of target effects: suppression decreases the relative combat value by 5% or .05 x relative target value, engagements to limit degrade combat effectiveness by 30% or .3 x relative target value, and engagements to destroy eliminate the target's relative target value.

Our ability to maximize the decrease in enemy combat power is limited by the number of acquired targets of each type and the expected amount of available ammunnition. Constraints 2 through 22 and 32 state that for each target type the total number of engagements of that type must be less than the number acquired. For target types that may be engaged with RAP two constraints are necessary to ensure we do not engage targets at long range with other munitions, for example constraints 13 and 14.

Constraints 23 through 30 reflect the fact that the amount of each ammunition type required to support the selected engagements equals the sum of the products of ammunition costs times the number of each type engagement. One constraint per shell/fuze combination is required. The constants in constraints 24 and 25 reflect the shells required to support the maneuver commander's special ammunition requirements for smoke (HC) and FASCAM. Constraint 31 specifies that the total number of rounds fired must be less than the total expected amount of ammunition available. These constraints, 2 through 32, will limit the value of the objective function.

The remaining constraints will not influence the value of the objective function but are included to provide a direct solution determining the proportion of each type of component to be loaded. Constraints 33 and 34 compute the number of different propellant charge types needed to support the engagements selected based on the expected range distribution of the targets. The coefficients of the variables are determined by multiplying the ammunition cost times the charge selection percentage determined in Appendix G. Constraints 36 through 39 determine the number of fuzes by type to complete the selected engagements. Constraints 40 through 53 merely determine the percentage of each type component within the expected available amount of ammunition.

The solution to the LP will tell us:

1. Which targets should be engaged
2. The amount of ammunition by type to support these engagements

3. The proportion of each component type that should be included in the UBL.

By applying the optimal proportions to our initial attempts at maximizing the use of vehicle capacity we can determine the amount and type of components to be loaded on each vehicle.

III. 7 Analysis of Solution

As expected, the computer solution, Appendix K, provides the proportion of each type of ammunition that should be loaded to maximize the decrease in enemy combat power. Noting that we have 53 constraints in the LP formulation and only 47 non-zero variables in its solution, we realize this solution is degenerate. We know that alternative solutions exist which will yield the same value of the objective function.

An examination of the sensitivity analysis shows that any decrease in the coefficient of ST will result in a different optimal solution while any increase in the coefficients of LID or LMORT will change our solution. While we cannot predict a unique optimal solution will result if we change the values of any or all of these coefficients we can gain valuable insight into the importance of the relative target values and ammunition costs to the optimal solution. If we compute the ratio of target value to ammunition cost for engagements ST, LID, and LMORT we find that they are equal. In essence, the relative target values we have specified state that we are indifferent among the following three options:

1. Suppress 4 2/3 tank platoons with a total of 28 rounds
2. Engage to limit 1 1/6 infantry platoons with a total of 28 rounds

3. Engage to limit 1 5/9 mortar platoons with a total of 28 rounds.

Each of these alternatives will result in an equal increase in the value of the objective function. This result is consistent with the zero reduced costs specified for LMORT and LID.

Unfortunately degeneracy limits the usefulness of the sensitivity analysis. If we are truly indifferent between options involving variables with a zero allowable increase or decrease in objective coefficients the LP solution is valid. If not, we must change objective function coefficients appropriately. When a non-degenerate solution is produced the reduced costs indicate the change in coefficients required to produce a revised optimal solution which will make that variable positive. This information is invaluable in reviewing the relative target values determined via the Delphi procedure.

In any case, we have determined the optimal proportional mixture of ammunition types which should be included in our UBL. We will now reconsider the maximum use of vehicle capacity.

III. 8 Application of Proportional Requirements

Obviously, we could simply reformulate the maximum capacity LP's, Appendices D and E, using the exact dimensions for each component type with additional constraints to ensure that the desired proportions are attained. However, we will be faced once more with the fractional solution produced by a non-integer solution method. Given our desire to maintain a uniform distribution of component types across the vehicle fleet, we will be forced to distribute components based on immediate considerations which cannot be addressed in any quantitative method.

A new series of LP formulations can only provide a point of departure for determining specific vehicle loading plans. However, we already have an acceptable point of departure; the estimated maximum capacity of each vehicle type and the desired proportional mix.

By multiplying the maximum estimated capacity by the percentage mixture of each type component we can estimate the optimum load for each vehicle type. The results of these computations are given in Appendix L. To meet the equal distribution objective we must load single rounds and we still face the problem of deciding where to load fractional rounds. The exact location of loading will be determined not only by capacity but by considering how closely we must adhere to our proportion mixture desires, our desire to not load single components, as well as when we expect to fire the majority of each component type. By giving priority to loading only full pallets we can easily find a load configuration which does not exceed our vehicle capacity while approaching the desired equal distribution. Next we must load the components on each vehicle type to determine their exact location and ensure that vehicle capacities are not exceeded. Any remaining space can then be filled with single components, if we decide that is feasible, adding slightly to our total capacity and increasing our overall unit effectiveness.

IV. IMPLEMENTATION

IV. 1 Constraints on Implementation

While every unit has key personnel capable of applying this quantitative method without fully understanding the LP solution, no computerized LP solution program is readily available to field units. As explained previously, the maximum carrying capacity can be determined experimentally with acceptable accuracy. However manual solution of the LP which maximizes the decrease in enemy combat power would require additional training and its solution would be time consuming. If an alternate manual solution method can be developed, no other obstacles to implementation are expected.

IV. 2 Benefit/Cost Relation of the UBL Problem.

In the sample problem solution we found that the solution was degenerate and that one of three decision variables could be positive and result in the same value of the objective function. If we compute the ratio of the coefficient of each variable in the objective function and ammunition required for each engagement, we find that this ratio is the same for the three variables LID, LMORT, and ST. Additonally, a review of the LP solution indicates that all targets of some types are engaged completely at a single engagement level while other targets are neglected completely. By computing the ratio of the engagement coefficients or benefits and ammunition costs, shown in Appendix N, we see that the engagements selected in the LP solution are, in general, those with high benefit/cost ratios.

Consider for a moment a simple economics problem. We wish to maximize our profits or benefits constrained by our total budget. Additionally we are constrained by the maximum amount we can invest in each of several possible alternatives. Obviously to maximize profits we will:

1. Spend the total budget
2. Invest first in the alternative which provides the greatest return per unit investment up to the limit for that alternative
3. Continue to select alternatives and invest completely in them until no money remains
4. Not invest in alternatives with low returns on our investment.

The similarity of the UBL problem to this example is apparent.

IV. 3 A Heuristic Solution.

The LP is formulated in such a way that application of a few rules and computations will allow its manual solution. The manual solution will not only approach the optimal computer solution it will yield identical values for the decision variables. The manual solution to the sample UBL problem is given in Appendix O.

The target with the highest benefit/cost ratio, SBCP, is selected first, and the maximum number of engagements is conducted. The ammunition required is subtracted from the amount available and the target with the next highest benefit/cost ratio is selected. The process continues until no ammunition is available to engage more targets. If a new engagement level for a target which has previously been engaged is considered the engagement levels must be compared. In the case of DBCP, the level of engagement increases contributing more to the value of the objective function. The SBCP engagements are canceled, the ammunition for SBCP credited to the remaining total, and DBCP selected for engagement. Later in the analysis we encounter LBCP. The level of engagement here is lower than DBCP which has already been selected so we do not cancel DBCP and let LBCP be zero.

The manual solution in Appendix O does not include computation of ammunition type proportions or powder mixture. These values can easily be determined manually once the values of the decision variables have been found.

IV. 4 Summary of Solution Method

A quantitative method that provides a solution to the UBL problem which can be implemented in active duty units has now been determined. The key steps in determining an optimum UBL are:

1. Assemble basic data.
    a. Maximum capacity for each cargo vehicle in complete rounds
    b. Expected number and range distribution of each target type
    c. Average OR rate
    d. Number of failures and total fleet mileage by vehicle type during a high usage period
    e. Ammunition costs to suppress, limit and destroy each target type expected.
2. Determine relative target values for all expected targets by the Delphi method.
3. Compute the total expected amount of available ammunition.
4. Compute the target effect/ammunition cost ratio for

each expected target.

5. Select targets for engagement beginning with the highest ratio and continuing until the expected amount of available ammunition is expended.
6. Compute the proportion of each type of ammunition component required to support the engagements selected.
7. Determine the point of departure load plan for each vehicle type.
8. By experiment, finalize exact amount and loading location for the UBL.

As in all quantitative methods, a solution has been produced based on the best available information. This solution does not constitute an operational decision, but merely provides information upon which a sound decision may be based. Particularly in this situation, considering the method of assigning relative target values and their importance to the solution, sound judgement must be applied. While the manual solution does not provide a sensitivity analysis per se, the impact of the benefit/cost ratio on the solution gives a great deal of information to the decision maker. He can easily determine how much the ratio for a target not selected must increase to allow selection and what decrease will cause non-selection.

V. RESULTS AND CONCLUSIONS

V. 1 Implementation Costs

The availability of a manual heuristic solution method minimizes the cost of implementation. Vehicle and ammunition dimensions are tabulated and available, and reliability data may be determined concurrent with regularly scheduled training activities. The only cost of implementation is the training time that must be spent to 1) determine relative target values via the Delphi method 2) compute required data, ammunition costs and range distributions, and 3) analyze recommended UBL composition. The costs in training time for these activities are estimated below:

Table 4. Training time cost of implementation.

Position	Activity	Time Required
Battalion Commander	Analysis of results	6 hours
S2/S3	Data compilation, Delphi control, and computation	40 hours
FDO	Ammunition cost computations	6 hours
FSOs/FOs/BCs	Delphi method participants	3 hours each/ 108 hours total

The commander's analysis time is equivalent to the time he would spend considering the UBL problem using a less systematic approach. The activities of the FDO are easily completed concurrent with normal TACFIRE sustainment training. The effort required by the FSO's and FO's in completing the Delphi method analysis may be combined with required study and briefings on unit contingency missions which, while reducing the time cost of the UBL problem solution, will improve the accuracy of the Delphi method. The only time cost far above normal requirements is the time that must be spent by the S2/S3. Considering the benefits that will accrue from application of the method this cost is minimal.

V. 2 Implementation Benefits

It may be tempting at this point to accept the UBL mixture of ammunition types given by the LP as the optimum mixture for a specific situation. A review of the procedure shows that the key factors in selecting targets for engagement are the relative target values of different target types, how casualties are expected to affect target combat power, and the ammunition cost for engagement. While we can determine the amount of ammunition required to cause a certain percentage of casualties and equipment damage with relative certainty, we can only estimate what impact casualties will have on an enemy target and what effect each engagement will have on the outcome of combat. The state of the art of target value assessment is not sufficiently advanced to give us a great deal of confidence in the results of any procedure which relies so heavily on the relative target values. If we cannot blindly accept the results of this time consuming procedure, what are the benefits?

The quantitative approach to the UBL problem produces two primary benefits:

1. It ensures that all factors impacting on the problem and its solution are identified and examined in detail
2. It allows a greater understanding of what factors are critical to an artillery unit's success in combat, and how the UBL selection affects unit performance.

The battalion commander, who makes the final decision on the UBL composition, must consider all the factors influencing basic load selection, analyze the recommended quantitative solution and determine the mixture that will best accomplish his unit's mission in combat. By examining the benefit/cost ratios for target engagements he can readily determine the change in relative target value needed to cause a target to be selected for engagement. In addition to providing information specific to UBL selection, the quantitative method provides data on vehicle reliability and target acquisition capabilities that he may not have previously considered separately. Once the importance of these factors to his combat effectiveness is recognized, he may decide that additional analyses of those areas are required.

Obviously the UBL is not the only factor influencing artillery unit effectiveness in combat. We have assumed in this analysis that all targets will be located accurately and that the unit is capable of delivering munitions on target when acquired. The vast majority of training time in artillery units is spent to ensure that accuracy and timeliness standards can be met. However, in a combat situation where we are limited by the amount of ammunition available, target selection, munition selection and level of engagement selection are of the utmost importance to unit effectiveness. Since these factors are difficult to assess in training, very little training time is allocated to their consideration.

The quantitative method for determining the UBL places primary emphasis on these critical but often neglected considerations. Each participant in the method, particularly the FSO's, FO's and FDO, must consider relative importance of targets and the ammunition type and quantity for engagement. While the quantitative method will assist in determining the best UBL for the combat situation, the knowledge and insight gained by the participants, who must make combat decisions as to both how and which targets should be engaged, will improve combat effectiveness no matter what final UBL composition is determined.

V. 3 Areas for Continued Research

Considering the critical importance of target values to artillery effectiveness, the information available in the field is woefully inadequate. Commanders in the field are left to determine what level of casualties are desired on each target type with very little information concerning how those casualties will influence the outcome of the battle. Continued efforts in the area of target value assessment, utilizing computer assisted simulations, and the effects of casualties on unit performance based on historical analysis, are needed.

V. 4 Conclusion

While it is impossible to quantify the wide ranging benefits of applying the quantitative method for determining the unit basic load, they are indeed substantial and, more importantly, relevant to an artillery unit's success in combat. Considering the minimal cost of the method in training time, every artillery unit with an active combat contingency mission should apply the quantitative method to reconsider their basic load composition. Even if it is decided that no change in the UBL composition is warranted, the training benefits which result from application of the method may prove to be the margin of success in the event of hostilities.

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Appendix A: Characteristics and Effects of 155 mm Ammunition.

A complete round of artillery ammunition includes four interchangeable components: fuze, projectile, propelling charge and primer. To fire a round, one of each component is required. The howitzer crew threads the fuze into a machined recess in the nose of the projectile. The projectile and fuze are then rammed mechanically into the cannon bore so that the rotating band engages the rifling of the cannon. The correct type and number of powder increments are then placed in the breech behind the projectile and the breech block is closed. The primer is placed in a firing lock in the breech block. When the primer is fired it ignites the propelling charge which propels the projectile out the muzzle of the cannon.

The primer used is determined by the type firing lock of the weapon system. Only one type primer is used for any weapon system. Since each primer weighs about 2 ounces and is the size of a rifle shell its impact on the UBL is negligible.

Three types of propelling charges or powders are available for use in the 155 mm howitzer commonly referred to as green bag, white bag and Zone 8. The type powder and number of increments to be fired is determined based solely on gun target range. With computerized data computation, the charge which produces the least possible range probable error will be selected. However, except at the extreme end of a charge's range capability the increase in range probable error is minimal, resulting in an overlapping of acceptable ranges for the various charges. The optimum ranges for each powder type are:

Green bag, M3	1600 - 9,000 meters
White bag, M4	4600 - 14,000 meters
Zone 8, M1191	9800 - 18,100 meters

Targets out to 18,100 meters can be engaged with all types of shell/fuze combinations. Targets from 18,100 to 23,500 meters can be engaged only with the rocket assisted projectile described below.

The shell/fuze combination determines the effects of the round on the target. Special effects shells are those which do not primarily produce direct personnel or materiel damage. Special effects shells include: field artillery scatterable mines (FASCAM), illumination (ILL) and smoke (SMK). Each of these projectiles uses a single type of compatible fuze. Casualty producing shells include convential munitions, which are steel shells filled with an explosive element, and improved conventional munitions that release explosive submunitions.

There are three conventional munitions: high explosive (HE), rocket assisted projectile (RAP), and white phosphorus (WP). The HE and RAP projectiles are filled with TNT and may be fuzed with either a point detonating (PD) fuze causing a ground burst or a time fuze, mechanical (MT) or proximity (VT), causing an air burst. Casualties are produced by fragments of the shell casing. RAP target effects are similar to HE effects except that the RAP allows engagement of targets at extended range. WP causes materiel damage by spreading burning pieces of phosphorus on the target area igniting flammable substances. It is always fired with a PD fuze.

Improved conventional munitions include antipersonnel (APICM) and dual purpose (DPICM) rounds. APICM disperses fragmentation bomblets on the target area causing personnel casualties. DPICM disperses a combination of antipersonnel fragmentation and anti-vehicle shaped charge bomblets. Both APICM and DPICM use a mechanical time fuze only.

In addition to these standard components, a variety of other munitions are available which are not considered in the UBL computation. Nuclear and chemical projectiles are available but they are not included in the UBL due to the strict control of their employment and transport. Terminally guided projectiles are now being produced but worldwide fielding is not projected for several years.

Until fielding of terminally guided projectiles, artillery remains an area fire weapon. Target effects depend on the dispersion of fragments or submunitions on the target area. While projectiles are designed to maximize their effects, a single shell has a very low probability of causing any target effects. Consequently, a large number of shells must be fired to produce a significant level of damage, especially against armored targets.

Appendix B: Ammunition Component Dimensions

Component	Type	Weight (lbs)	Dimensions (HxLxW (inches))	Note
Propellant Charges	Green Bag M3	29.0	33.8 x 6.4 x 6.4	2 per container
	White Bag M4	30.5	27.8 x 7.4 x 7.4	1 per container
	Zone 8	70.0	29.3 x 8.3 x 8.3	1 per container
Projectiles	FASCAM	874	39.4 x 29.1 x 14.5	Pallet of 8
	ILL	782	29.1 x 32 x 13.6	
	SMK	727	27.1 x 32 x 13.6	
	HE	797	27.1 x 32 x 13.6	
	RAP	780	38.8 x 29 x 14.5	
	WP	830	27.1 x 32 x 13.6	
	APICM	804	27.1 x 32 x 13.6	
	DPICM	874	39.4 x 29.1 x 14.5	
Fuzes	All	55	9.2 x 14.6 x 12.8	Box of 16

Appendix C: Ammunition Carrying Vehicle Capacities

M109A2, 155mm Self-Propelled Howitzer:

Preconfigured internal ammunition racks
Maximum capacity: 34 complete rounds

M548, 6-Ton Tracked Cargo Carrier:

Weight Capacity (Highway)	9 tons
Cargo Width	80 in.
Cargo Length	102 in.
Floor Space	8,160 sq. in.

M520, 8-Ton Cargo Carrier:

Weight Capacity (Highway)	12 tons
Cargo Width	96 in.
Cargo Length	189 in.
Floor Space	18,144 sq. in.

1 1/2-Ton Ammunition Trailer:

Weight Capacity (Highway)	2.25 tons
Cargo Width	54 in.
Cargo Width	54 in.
Wall Height	36 in.
Cargo Volume	104,976 cu. in.

Appendix D. An LP Maximizing M548 capacity

```
MAX      PAL1 + PAL2
SUBJECT TO
   2)    810 PAL1 + 43 POW1 + 55 FUZ1 <=   18000
   3)    810 PAL2 + 43 POW2 + 55 FUZ2 <=   4500
   4)    420 PAL1 + 56 POW1 + 118 FUZ1 <=   8160
   5)    13860 PAL2 + 1688 POW2 + 628 FUZ2 <=   104976
   6)     PAL1 + PAL2 - 2 FUZ1 - 2 FUZ2 =    0
   7)    8 PAL1 + 8 PAL2 - POW1 - POW2 =    0
   8)  - 8 PAL1 - 8 PAL2 + TOTRND =    0
END
```

-Maximize number of projectiles loaded
-548 weight constraint
-Trailer weight limit
-548 floorspace limit
-Trailer volume limit
- projectiles = fuzes
- projectiles = powders

```
    LP OPTIMUM FOUND  AT STEP      8

        OBJECTIVE FUNCTION VALUE

 1)         13.2540869

VARIABLE          VALUE          REDUCED COST
     PAL1        13.254087          .000000
     PAL2          .000000          .045321
     POW1        46.308633          .000000
     FUZ1          .000000          .110615
     POW2        59.724062          .000000
     FUZ2         6.627043          .000000
   TOTRND       106.032695          .000000
```

Quantity of components to be loaded on M548, (1) and trailer (2)

Maximum capacity in complete rounds

```
ROW         SLACK OR SURPLUS      DUAL PRICES
   2)         5272.918274           .000000
   3)         1567.377930           .000000
   4)            .000000            .001138
   5)            .000000            .000038
   6)            .000000            .011859
   7)            .000000            .063751
   8)            .000000            .000000

NO. ITERATIONS=       8

   RANGES IN WHICH THE BASIS IS UNCHANGED

                        OBJ COEFFICIENT RANGES
VARIABLE        CURRENT         ALLOWABLE         ALLOWABLE
                 COEF           INCREASE          DECREASE
    PAL1        1.000000        INFINITY           .043356
    PAL2        1.000000         .045321          INFINITY
    POW1         .000000         .025781           .065595
    FUZ1         .000000         .110615          INFINITY
    POW2         .000000         .281729           .005525
    FUZ2         .000000        INFINITY           .104818
  TOTRND         .000000        INFINITY           .125000

                        RIGHTHAND SIDE RANGES
   ROW          CURRENT         ALLOWABLE         ALLOWABLE
                  RHS           INCREASE          DECREASE
     2      18000.000000        INFINITY         5272.918274
```

3	4500.000000	INFINITY	1567.377930
4	8160.000000	3986.080994	4969.240112
5	104976.000000	59799.759277	102024.110352
6	.000000	13.413152	81.338052
7	.000000	96.853080	207.903858
8	.000000	INFINITY	106.032695

Appendix E. An LP Maximizing M520 Capacity

MAX PAL3 + PAL4	-Maximize number of projectil loaded
SUBJECT TO	
2) 810 PAL3 + 43 POW3 + 55 FUZ3 <= 24000	-M520 weight limit
3) 810 PAL4 + 43 POW4 + 55 FUZ4 <= 4500	-Trailer weight limit
4) 420 PAL3 + 56 POW3 + 118 FUZ3 <= 18144	-M520 floor space
5) 13860 PAL4 + 1688 POW4 + 628 FUZ4 <= 104976	-Trailer volume limit
6) PAL3 + PAL4 - 2 FUZ3 - 2 FUZ4 = 0	-#projectiles =#fuzes
7) 8 PAL3 + 8 PAL4 - POW3 - POW4 = 0	-#projectiles =#powders
8) - 8 PAL3 - 8 PAL4 + TOTRND = 0	
END	

LP OPTIMUM FOUND AT STEP 7

OBJECTIVE FUNCTION VALUE

1) 24.1218789

Quantity of components to be loaded on M520 (3) and traile (4)

VARIABLE	VALUE	REDUCED COST
PAL3	20.652308	.000000
PAL4	3.469571	.000000
POW3	169.107691	.000000
FUZ3	.000000	.000000
POW4	23.857340	.000000
FUZ4	12.060939	.000000
TOTRND	192.975031	.000000

Maximum capacity of complete rounds

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	.000846
3)	.000000	.000846
4)	.000000	.000000
5)	9025.402554	.000000
6)	.000000	.033275
7)	.000000	.036294
8)	.000000	.000000

NO. ITERATIONS= 7

RANGES IN WHICH THE BASIS IS UNCHANGED

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
PAL3	1.000000	.000000	.412511
PAL4	1.000000	.702450	.000000
POW3	.000000	.055015	.000000
FUZ3	.000000	.000000	INFINITY
POW4	.000000	.000000	.038202
FUZ4	.000000	INFINITY	.000000
TOTRND	.000000	INFINITY	.125000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	24000.000000	432.505504	1077.[illegible]

3	4500.000000	385.270378	3524.907684
4	18144.000000	804.417740	319.452225
5	104976.000000	INFINITY	9025.402954
6	.000000	24.696707	128.178461
7	.000000	33.670760	13.259481
8	.000000	INFINITY	192.975031

Appendix F: Expected Number of Targets Acquired

Target Type	Abbreviation	Total Number	Acquisition Agency	Probability of Acquisition	Number Acquired
Tank Platoon, T-62	T	54	FO/AO	.6	32
Infantry Platoon, Mounted BTR	IBTR	54	FO	.7	38
Infantry Platoon, Mounted BMP	IBMP	27	FO	.7	19
Infantry Platoon, Dismounted	ID	6	FO	.9	5
Antitank Section, SAGGER	ATM	30	FO	.4	12
Battalion Command Post	BCP	29	FO/AO	.3	9
Regimental Command Post	RCP	6	AO/ASIC	.1	1
Division Command Post	DCP	2	AO/ASIC	.1	0
Air Defense Artillery, ZSU-23	ADA	8	AO	.2	2
Surface-Air Missile, SA-9	ADM	18	AO	.2	4
Counter Battery Radar	CBR	4	AO/ASIC	.3	1
Resupply Platoon	LOG	49	AO	.3	15
Artillery Fire Direction Center	FDC	8	AO	.2	2
Field Artillery Towed, D-30	FAT	12	CBR	.8	10
Field Artillery Self-propelled	FSP	12	CBR	.8	10
Surface-Surface Missile Plt	SSM	4	ASIC	.2	1
Multiple Rocket Launcher	MRL	6	AO	.2	1
Mortar Battery	MORT	9	CBR	.9	8
Jamming/Intercept Station	REC	7	ASIC	.1	1
Anti-tank Plt, T12, SPG-9	ATG	12	FO	.5	6

Appendix G: Expected Range Distribution

Target Type	Acquisition Distance Min	Acquisition Distance Max	Range (km) Min	Range (km) Max	Range (km) Mean	Range (km) Deviation	Charge Selection Proportion GB	WB	Z8	RAP	Out of Range
T	1.2	10	6.4	18	12.2	1.9	.05	.78	.17	0	0
IBTR	1	6	6	14	10.0	1.3	.22	.78	0	0	0
IBMP	1	6	6	14	10.0	1.3	.22	.78	0	0	0
ID	8	2	5.8	10	7.9	.7	.94	.06	0	0	0
ATM	1	3	6	11	8.5	.8	.73	.27	0	0	0
BCP	2	4	7	12	9.5	.8	.27	.73	0	0	0
RCP	3	5	8	13	10.5	.8	.03	.97	0	0	0
DCP	8	15	13	23	18.0	1.7	0	.99	.01	0	0
ADA	4	6	9	14	11.5	.8	0	1.00	0	0	0
ADM	4	20	9	28	18.5	3.2	0	.08	.36	.50	.06
CBR	2	4	7	15	11.0	1.3	.06	.93	.01	0	0
LOG	3	20	8	28	18.0	3.3	0	.11	.39	.45	.05
FDC	2	10	7	18	12.5	1.8	.03	.77	.20	0	0
FAT	4	15	9	23	16.0	2.3	0	.19	.62	.19	0
FSP	2	12	7	20	13.5	2.2	.02	.57	.39	.02	0
SSM	20	30	25	38	26.5	2.2	0	0	0	.09	.91
MRL	7	17	12	25	18.5	2.2	0	.02	.39	.58	.01
MORT	1	3	6	13	9.5	1.2	.34	.66	0	0	0
REC	3	5	8	13	10.2	.8	.07	.93	0	0	0
ATG	1	5	6	13	9.5	1.2	.34	.66	0	0	0

Appendix H: Expected Long Range/Out of Range Targets

Target Type	Number Acquired	Percent RAP	Number RAP	Percent out of Range	Number out of Range
ADM	4	.50	2	.06	0
LOG	15	.45	7	.05	1
FAT	10	.19	2	.00	0
FSP	10	.02	0	.00	0
SSM	1	.09	0	.91	1
MRL	1	.58	1	.01	0

Appendix I: Relative Target Values and Ammunition Costs

		Ammunition Costs							
		S		L		D		RAP	
Target Type	Relative Value	Type	Cost	Type	Cost	Type	Cost	L	D
T	100	HEVT	6	DPICM	130	DPICM	650	NA	NA
IBTR	70	HEVT	6	DPICM	80	DPICM	400	NA	NA
IBMP	85	HEVT	6	DPICM	95	DPICM	475	NA	NA
ID	65	HEVT	6	APICM	24	APICM	120	NA	NA
ATM	30	HEVT	6	DPICM	30	DPICM	150	NA	NA
BCP	180	HC	6	HEPD	60	HEPD	180	NA	NA
RCP	200	NA	NA	HEPD	60	HEPD	240	NA	NA
DCP	300	NA	NA	HEPD	120	HEPD	480	NA	NA
ADA	20	HEVT	6	DPICM	40	DPICM	160	NA	NA
ADM	30	HEVT	6	HEVT	60	HEVT	250	60	250
CBR	130	NA	NA	HEVT	50	HEVT	250	NA	NA
LOG	10	NA	NA	WP	36	WP	144	120	480
FDC	70	NA	NA	DPICM	60	DPICM	300	NA	NA
FAT	140	HEVT	6	DPICM	36	DPICM	144	80	320
FSP	160	HEVT	6	DPICM	95	DPICM	390	120	540
SSM	350	NA	NA	HEVT	60	HEVT	200	60	200
MRL	200	NA	NA	DPICM	36	DPICM	144	60	240
MORT	50	HEVT	6	APICM	18	APICM	72	NA	NA
REC	180	NA	NA	HEPD	50	HEPD	260	NA	NA
ATG	40	HEVT	6	DPICM	60	DPICM	230	NA	NA

NOTE: Optimum ammunition selected and quantities required are estimated. Actual data is classified.

Engagement Levels:
- S: Suppression, 0 casualties, 5% reduced effectiveness
- L: Engage to Limit, 10% casualties, 30% reduced effectiveness
- D: Engage to Destroy, 30% casualties, 100% reduced effectiveness

Reduction in relative target value

```
MAX      5 ST + 30 LT + 100 DT + 4 SIBTR + 21 LIBTR + 70 DIBTR
     + 4 SIBMP + 25 LIBMP + 85 DIBMP + 3 SID + 20 LID + 65 DID
     + 2 SATM + 9 LATM + 30 DATM + 9 SBCP + 54 LBCP + 180 DBCP
     + 60 LRCP + 200 DRCP +  SADA + 6 LADA + 20 DADA + 2 SADM
     + 9 LADM + 30 DADM + 39 LCBR + 130 DCBR + 3 LLOG + 10 DLOG
     + 21 LFDC + 70 DFDC + 7 SFAT + 42 LFAT + 140 DFAT + 8 SFSP
     + 48 LFSP + 160 DFSP + 60 LMRL + 200 DMRL + 3 SMORT + 15 LMORT
     + 50 DMORT + 54 LREC + 180 DREC + 2 SATG + 12 LATG + 40 DATG
     + 9 LADML + 30 DADML + 3 LLOGL + 10 DLOGL + 42 LFATL
     + 140 DFATL + 60 LMRLL + 200 DMRLL
SUBJECT TO
   2)      ST +  LT +  DT (=    32
   3)      SIBTR +  LIBTR +  DIBTR (=    38
   4)      SIBMP +  LIBMP +  DIBMP (=    19
   5)      SID +  LID +  DID (=    5
   6)      SATM +  LATM +  DATM (=    12
   7)      SBCP +  LBCP +  DBCP (=    9
   8)      LRCP +  DRCP (=    1
   9)      SADA +  LADA +  DADA (=    2
  10)      SADM +  LADM +  DADM (=    2
  11)      LADML +  DADML (=    2
  12)      LCBR +  DCBR (=    1
  13)      LLOG +  DLOG (=    8
  14)      LLOGL +  DLOGL (=    7
  15)      LFDC +  DFDC (=    2
  16)      SFAT +  LFAT +  DFAT (=    8
  17)      LFATL +  DFATL (=    2
  18)      SFSP +  LFSP +  DFSP (=    10
  19)      LMRLL +  DMRLL (=    1
  20)      SMORT +  LMORT +  DMORT (=    8
  21)      LREC +  DREC (=    1
  22)      SATG +  LATG +  DATG (=    6
  23)     6 ST + 6 SIBTR + 6 SIBMP + 6 SID + 6 SATM + 6 SADA
     + 6 SADM + 60 LADM + 250 DADM + 50 LCBR + 250 DCBR + 6 SFAT
     + 6 SFSP + 6 SMORT + 6 SATG -  HEVT =     0
  24)     6 SBCP -  HC =  - 150
  25)      FASCAM =     330
  26)     36 LLOG + 144 DLOG -  WP =     0
  27)     60 LBCP + 180 DBCP + 60 LRCP + 240 DRCP + 50 LREC
     + 260 DREC -  HEPD =     0
  28)     24 LID + 120 DID + 18 LMORT + 72 DMORT -  APICM =     0
  29)     130 LT + 650 DT + 80 LIBTR + 400 DIBTR + 95 LIBMP
     + 475 DIBMP + 30 LATM + 150 DATM + 40 LADA + 160 DADA
     + 60 LFDC + 300 DFDC + 36 LFAT + 144 DFAT + 95 LFSP + 390 DFSP
     + 36 LMRL + 144 DMRL + 60 LATG + 230 DATG -  DPICM =     0
  30)     60 LADML + 250 DADML + 120 LLOGL + 480 DLOGL + 80 LFATL
```

Long range target

Target type

Engagement level

Number of engagements less than number acquired

Cost x engagements selected = ammunition to support engagement

```
   - 320 DFATL + 60 LMRLL + 240 DMRLL -  RAP =     0
31)      HEVT +  HC +  FASCAM +  WP +  HEPD +  APICM +  DPICM
   +  RAP <=   3510
32)      LMRL +  DMRL =     0
33)     0.3 ST + 6.5 LT + 32.5 DT + 1.32 SIBTR + 17.6 LIBTR
   + 88 DIBTR + 1.32 SIBMP + 20.9 LIBMP + 104.5 DIBMP + 5.64 SID
   + 22.56 LID + 115.2 DID + 4.38 SATM + 21.9 LATM + 109.5 DATM
   + 1.62 SBCP + 16.2 LBCP + 64.8 DBCP + 1.8 LRCP + 7.2 DRCP
   + 3 LCBR + 15 DCBR + 1.8 LFDC + 9 DFDC + 0.12 SFSP + 1.9 LFSP
   + 7.8 DFSP + 2.04 SMORT + 6.12 LMORT + 24.46 DMORT + 3.5 LREC
   + 18.2 DREC + 2.04 SATG + 20.4 LATG + 78.2 DATG -  GB =  - 150
34)     4.68 ST + 101.4 LT + 507 DT + 4.68 SIBTR + 62.4 LIBTR
   + 312 DIBTR + 4.68 SIBMP + 74.1 LIBMP + 370.5 DIBMP + 0.36 SID
   + 1.44 LID + 7.2 DID + 1.62 SATM + 8.1 LATM + 40.5 DATM
   + 4.38 SBCP + 43.8 LBCP + 175.2 DBCP + 58.2 LRCP + 232.8 DRCP
   + 6 SADA + 40 LADA + 160 DADA + 0.48 SADM + 4.8 LADM + 20 DADM
   + 46.5 LCBR + 232.5 DCBR + 3.96 LLOG + 15.84 DLOG + 46.2 LFDC
   + 231 DFDC + 1.14 SFAT + 6.84 LFAT + 27.36 DFAT + 3.42 SFSP
   + 54.15 LFSP + 222.3 DFSP + 3.96 SMORT + 11.88 LMORT
   + 47.52 DMORT + 46.5 LREC + 241.8 DREC + 3.96 SATG + 39.6 LATG
   + 151.8 DATG -  WB =  - 330
35)      GB +  WB +  Z8 =     3510
36)      HEVT +  RAP -  VTM732 =     0
37)      HC -  MTM565 =     0
38)      FASCAM +  APICM +  DPICM -  MTM577 =     0
39)      WP +  HEPD -  PDM557 =     0
40)  -   DPICM + 3510 PDPICM =     0
41)  -   APICM + 3510 PAPICM =     0
42)  -   WP + 3510 PWP =     0
43)  -   FASCAM + 3510 PFASCAM =     0
44)  -   RAP + 3510 PRAP =     0
45)  -   HEVT -  HEPD + 3510 PHE =     0
46)  -   HC + 3510 PHC =     0
47)  -   GB + 3510 PGB =     0
48)  -   WB + 3510 PWB =     0
49)  -   Z8 + 3510 PZ8 =     0
50)  -   VTM732 + 3510 PVTM732 =     0
51)  -   MTM565 + 3510 PMTM565 =     0
52)  -   MTM577 + 3510 PMTM577 =     0
53)  -   PDM557 + 3510 PPDM557 =     0
END
```

Ammo for engagement less than available total

Powder composition

Fuze selection

Calculation of proportions

LP OPTIMUM FOUND AT STEP 64

OBJECTIVE FUNCTION VALUE

1) 3017.33331

VARIABLE	VALUE	REDUCED COST
ST	4.666667	.000000
LT	.000000	78.333332
DT	.000000	441.666656
SIBTR	.000000	1.000000
LIBTR	.000000	45.666666
DIBTR	.000000	263.333328
SIBMP	.000000	1.000000
LIBMP	.000000	54.166666
DIBMP	.000000	310.833328
SID	.000000	2.000000
LID	.000000	.000000
DID	.000000	34.999999
SATM	.000000	3.000000
LATM	.000000	16.000000
DATM	.000000	94.999999
SBCP	.000000	26.000002
LBCP	.000000	26.000001
DBCP	9.000000	.000000
LRCP	1.000000	.000000
DRCP	.000000	9.999998
SADA	.000000	4.000000
LADA	.000000	27.333333
DADA	.000000	113.333332
SADM	.000000	3.000000
LADM	.000000	41.000000
DADM	.000000	178.333332
LCBR	.000000	2.666666
DCBR	.000000	78.333332
LLCG	.000000	.000000
DLCG	.000000	2.000000
LFDC	.000000	29.000000
DFDC	.000000	179.999998
SFAT	.000000	15.000002
LFAT	.000000	6.000002
DFAT	8.000000	.000000
SFSP	10.000000	.000000
LFSP	.000000	34.166666
DFSP	.000000	167.999996
LMRL	.000000	50.000002
DMRL	.000000	.000000

Positive value for engagement variables indicates number of engagements of that type target and level of engagement

SMORT	.000000	2.000000
LMORT	.000000	.000000
DMORT	.000000	10.000000
LREC	1.000000	.000000
DREC	.000000	48.999998
SATG	.000000	3.000000
LATG	.000000	38.000000
DATG	.000000	151.666664
LADML	.000000	41.000000
DADML	.000000	178.333332
LLOGL	.000000	96.999999
DLOGL	.000000	389.999996
LFATL	.000000	24.666666
DFATL	.000000	126.666664
LMRLL	1.000000	.000000
DMRLL	.000000	9.999998
HEVT	88.000000	.000000
HC	150.000000	.000000
FASCAM	330.000000	.000000
WP	.000000	.000000
HEPD	1730.000000	.000000
APICM	.000000	.000000
DPICM	1152.000000	.000000
RAP	60.000000	.000000
GB	741.093991	.000000
WB	2286.419983	.000000
ZB	482.480019	.000000
VTM732	148.000000	.000000
MTM565	150.000000	.000000
MTM577	1482.000000	.000000
PDM557	1730.000000	.000000
PDPICM	.328205	.000000
PAPICM	.000000	.000000
PWP	.000000	2632.500000
PFASCAM	.094017	.000000
PRAP	.017094	.000000
PHE	.517949	.000000
PHC	.042735	.000000
PGB	.211140	.000000
PWB	.651402	.000000
PZB	.137459	.000000
PVTM732	.042165	.000000
PMTM565	.042735	.000000
PMTM577	.422222	.000000
PPDM557	.492877	.000000

Number of each type component to support selected engagemen

Proportion of types within total amount

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	27.333333	.000000
3)	38.000000	.000000
4)	19.000000	.000000
5)	5.000000	.000000
6)	12.000000	.000000
7)	.000000	30.000002
8)	.000000	10.000000
9)	2.000000	.000000
10)	2.000000	.000000
11)	2.000000	.000000
12)	1.000000	.000000
13)	8.000000	.000000
14)	7.000000	.000000
15)	2.000000	.000000
16)	.000000	20.000002
17)	2.000000	.000000
18)	.000000	3.000000
19)	.000000	10.000000
20)	8.000000	.000000
21)	.000000	12.333334
22)	6.000000	.000000
23)	.000000	.833333
24)	.000000	.833333
25)	.000000	-.833333
26)	.000000	.083333
27)	.000000	.833333
28)	.000000	.833333
29)	.000000	.833333
30)	.000000	.833333
31)	.000000	.833333
32)	.000000	80.000002
33)	.000000	.000000
34)	.000000	.000000
35)	.000000	.000000
36)	.000000	.000000
37)	.000000	.000000
38)	.000000	.000000
39)	.000000	.000000
40)	.000000	.000000
41)	.000000	.000000
42)	.000000	.750000
43)	.000000	.000000
44)	.000000	.000000
45)	.000000	.000000
46)	.000000	.000000
47)	.000000	.000000
48)	.000000	.000000
49)	.000000	.000000
50)	.000000	.000000
51)	.000000	.000000
52)	.000000	.000000
53)	.000000	.000000

NO. ITERATIONS= 64

RANGES IN WHICH THE BASIS IS UNCHANGED

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
ST	5.000000	.444445	.000000
LT	30.000000	78.333332	INFINITY
DT	100.000000	441.666656	INFINITY
SIBTR	4.000000	1.000000	INFINITY
LIBTR	21.000000	45.666666	INFINITY
DIBTR	70.000000	263.333328	INFINITY
SIBMP	4.000000	1.000000	INFINITY
LIBMP	25.000000	54.166666	INFINITY
DIBMP	85.000000	310.833328	INFINITY
SID	3.000000	2.000000	INFINITY
LID	20.000000	.000000	INFINITY
DID	65.000000	34.999999	INFINITY
SATM	2.000000	3.000000	INFINITY
LATM	9.000000	16.000000	INFINITY
DATM	30.000000	94.999999	INFINITY
SBCP	9.000000	26.000002	INFINITY
LBCP	54.000000	26.000001	INFINITY
DBCP	180.000000	INFINITY	26.000001
LRCP	60.000000	INFINITY	9.999998
DRCP	200.000000	9.999998	INFINITY
SADA	1.000000	4.000000	INFINITY
LADA	6.000000	27.333333	INFINITY
DADA	20.000000	113.333332	INFINITY
SADM	2.000000	3.000000	INFINITY
LADM	9.000000	41.000000	INFINITY
DADM	30.000000	178.333332	INFINITY
LCBR	39.000000	2.666666	INFINITY
DCBR	130.000000	78.333332	INFINITY
LLOG	3.000000	27.000000	.500000
DLOG	10.000000	2.000000	INFINITY
LFDC	21.000000	29.000000	INFINITY
DFDC	70.000000	179.999998	INFINITY
SFAT	7.000000	18.000002	INFINITY
LFAT	42.000000	8.000002	INFINITY
DFAT	140.000000	INFINITY	8.000002
SFSP	8.000000	INFINITY	3.000000
LFSP	48.000000	34.166666	INFINITY
DFSP	160.000000	167.999996	INFINITY

LMRL	60.000000	50.000002	INFINITY
DMRL	200.000000	INFINITY	50.000002
SMORT	3.000000	2.000000	INFINITY
LMORT	15.000000	.000000	.000000
DMORT	50.000000	10.000000	INFINITY
LREC	54.000000	INFINITY	12.333334
DREC	180.000000	48.999998	INFINITY
SATG	2.000000	3.000000	INFINITY
LATG	12.000000	38.000000	INFINITY
DATG	40.000000	151.666664	INFINITY
LADML	9.000000	41.000000	INFINITY
DADML	30.000000	178.333332	INFINITY
LLOGL	3.000000	96.999999	INFINITY
DLOGL	10.000000	389.999996	INFINITY
LFATL	42.000000	24.666666	INFINITY
DFATL	140.000000	126.666664	INFINITY
LMRLL	60.000000	INFINITY	9.999998
DMRLL	200.000000	9.999998	INFINITY
HEVT	.000000	.074074	.000000
HC	.000000	4.333334	INFINITY
FASCAM	.000000	INFINITY	INFINITY
WP	.000000	.750000	INFINITY
HEPD	.000000	.055556	.144444
APICM	.000000	.000000	INFINITY
DPICM	.000000	.359649	.074074
RAP	.000000	.055555	.166667
GB	.000000	.000000	.477239
WB	.000000	.125549	.000000
Z8	.000000	.066934	.000000
VTM732	.000000	.074074	.000000
MTM565	.000000	4.333334	INFINITY
MTM577	.000000	.000000	.074074
PDM557	.000000	.055556	.144444
PDPICM	.000000	1262.368393	260.000053
PAPICM	.000000	.000000	INFINITY
PWP	.000000	2632.500000	INFINITY
PFASCAM	.000000	INFINITY	INFINITY
PRAP	.000000	194.999964	585.000031
PHE	.000000	260.000053	.000000
PHC	.000000	15210.000854	INFINITY
PGB	.000000	-.000058	1675.110260
PWB	.000000	440.678066	-.000058
PZ8	.000000	234.939722	.000000
PVTM732	.000000	260.000053	.000000
PMTM565	.000000	15210.000854	INFINITY
PMTM577	.000000	.000000	260.000053
PPDM557	.000000	194.999964	507.000034

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	32.000000	INFINITY	27.333333
3	38.000000	INFINITY	38.000000
4	19.000000	INFINITY	19.000000
5	5.000000	INFINITY	5.000000
6	12.000000	INFINITY	12.000000
7	9.000000	.155556	.911111
8	1.000000	.466667	1.000000
9	2.000000	INFINITY	2.000000
10	2.000000	INFINITY	2.000000
11	2.000000	INFINITY	2.000000
12	1.000000	INFINITY	1.000000
13	8.000000	INFINITY	8.000000
14	7.000000	INFINITY	7.000000
15	2.000000	INFINITY	2.000000
16	8.000000	.194444	1.138889
17	2.000000	INFINITY	2.000000
18	10.000000	4.666667	10.000000
19	1.000000	.466667	1.000000
20	8.000000	INFINITY	8.000000
21	1.000000	.560000	1.000000
22	6.000000	INFINITY	6.000000
23	.000000	164.000000	28.000000
24	-150.000000	149.999998	29.000000
25	330.000000	28.000000	164.000000
26	.000000	288.000000	.000000
27	.000000	164.000000	28.000000
28	.000000	144.000000	.000000
29	.000000	164.000000	28.000000
30	.000000	60.000000	28.000000
31	3510.000000	164.000000	28.000000
32	.000000	.194444	.000000
33	-150.000000	741.099991	482.480011
34	-330.000000	2286.419952	482.480011
35	3510.000000	INFINITY	482.480011
36	.000000	147.999998	INFINITY
37	.000000	149.999998	INFINITY
38	.000000	1481.999985	INFINITY
39	.000000	1729.999985	INFINITY
40	.000000	INFINITY	1151.999985
41	.000000	INFINITY	.000000
42	.000000	.000000	28.000000
43	.000000	INFINITY	329.999996
44	.000000	INFINITY	60.000000
45	.000000	INFINITY	1817.999985
46	.000000	INFINITY	149.999998
47	.000000	INFINITY	741.099991
48	.000000	INFINITY	2286.419952
49	.000000	INFINITY	482.480011
50	.000000	INFINITY	147.999998
51	.000000	INFINITY	149.999998
52	.000000	INFINITY	1481.999985
53	.000000	INFINITY	1729.999985

Appendix L: Estimated Optimum Load

M109A2: Maximum capacity 34 complete rounds

Component	Type	Proportion	Estimated number
Projectiles	DPICM	.33	11.22
	FASCAM	.09	3.06
	RAP	.02	.68
	HE	.52	17.68
	HC	.04	1.36
Powders	GB	.21	7.14
	WB	.65	22.10
	Z8	.14	4.76

M548: Maximum capacity 106 complete rounds

Component	Type	Proportion	Estimated number
Projectiles	DPICM	.33	34.98
	FASCAM	.09	9.54
	RAP	.02	2.12
	HE	.52	55.12
	HC	.04	4.24
Powders	GB	.21	22.26
	WB	.65	68.9
	Z8	.14	14.84

M520: Maximum capacity 192 complete rounds

Components	Type	Proportion	Estimated number
Projectiles	DPICM	.33	63.36
	FASCAM	.09	17.28
	RAP	.02	3.84
	HE	.52	99.84
	HC	.04	7.68
Powders	GB	.21	40.32
	WB	.65	124.80
	Z8	.14	26.88

Appendix M: Optimum Loading Point of Departure

M109A2: 34 projectiles, 24 powders

DPICM	11
FASCAM	3
RAP	1
HE	18
HC	1
GB	8
WB	8
Z8	5

M548: 104 palletized projectiles, 106 powders

DPICM	4 pallets
FASCAM	1 pallets
RAP	0 pallets
HE	7 pallets
HC	1 pallet
GB	11 canisters
WB	69 canisters
Z8	15 canisters

M520: 192 palletized projectiles, 192 powders

DPICM	8 pallets
FASCAM	2 pallets
RAP	1 pallet
HE	12 pallets
HC	1 pallet
GB	20 canisters
WB	125 canisters
Z8	27 canisters

Appendix N: Benefit/Cost Ratio Ranking

Rank	Target Type	Benefit	Cost	B/C	Maximum # Engagements	Total Ammunition Required	Ammunition Type
1	SBCP	9	6	1.50	9	54	HC
2	SFSP	8	6	1.33	10	60	HEVT
3	SFAT	7	6	1.17	8	48	HEVT
	LFAT	42	36	1.17	8	288	DPICM
4	LREC	54	50	1.08	1	50	HEPD
5	LMRLL	60	60	1.00	1	60	RAP
	LRCP	60	60	1.00	1	60	HEPD
	DBCP	180	180	1.00	9	1620	HEPD
6	DFAT	140	144	.97	8	1152	DPICM
7	LBCP	54	60	.90	9	540	HEPD
8	DMRLL	200	240	.83	1	240	RAP
	LMORT	15	18	.83	8	144	APICM
	DRCP	200	240	.83	1	240	HEPD
	ST	5	6	.83	32	160	HEVT
	LID	20	24	.83	5	120	APICM
9	LCBR	39	50	.78	1	50	HEVT

Appendix O: Heuristic Solution

Rules for application:

1. Select target with the highest B/C ratio.
2. Engage all available targets at that level, reduce total available ammunition.
3. Continue selecting targets for engagement until no ammunition remains.
4. If the target being considered has already been engaged at a lower level, cancel the lower level engagement and engage at the higher level.
5. If the target being considered has already been engaged at a higher level do not consider engagement at the lower level.

Inital amount of available ammunition:
3510 - 150 HC - 330 FASCAM = 3030

Example Solution:

Step	Decision	Ammo calculation	Status
1	SBCP	3030	cancel
		- 54	
		2976	
2	SFSP	-60	
		2916	
3	LFAT	-288	cancel
	Reject SFAT	2628	
4	LREC	-50	
		2578	
5	LMRLL	-60	
		2518	
6	LRCP	-60	
		2458	
7	DBCP/cancel SBCP	-1620	
		+ 54	
		892	
8	DFAT/cancel LFAT	-1152	
		+ 288	
		+ 28	
9	LBCP Not considered		
10	ST (4 2/3 engaged)	- 28	
		0	

Decision Variable Values Determined

Decision Variable	Value
SFSP	10
LREC	1
LMRLL	1
LRCP	1
DBCP	9
DFAT	8
ST	4 2/3

Note: The values of these decision variables are identical to those of the LP solution. The amount of ammunition by type to conduct these engagements and the proportion of each type within the total available amount can be determined manually.

Appendix P: Resume

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EXPERIENCE:

June 1983 - May 1984 — Battalion Operations Officer
Baumholder, West Germany
Planned and supervised execution of the battalion training program, formulated unit combat operations contingency plans.

April 1982 - May 1983 — Division Artillery Duty Officer
Baumholder, West Germany
Compiled unit readiness reports, wrote annual and quarterly training guidance, controlled field artillery fires using automated fire direction computer.

August 1980 - March 1982 — Battery Commander
Baumholder, West Germany
Led and managed all activities of a howitzer battery of 105 men including personnel actions, training, maintenance and supply.

May 1978 - July 1980 — Battalion Fire Direction Officer
Ft. Lewis, WA - Baumholder, West Germany
Established gunnery system procedures which allowed timely and accurate delivery of fires.

January 1976 - April 1978 — Battery Officer
Ft. Lewis, WA
Artillery forward observer and battery fire direction officer.

EDUCATION:

Currently pursuing degree in Master of Engineering Administration.
University of Utah, 33 hours completed

Tacfire Fire Support Course
Grafenwoehr, West Germany 1982

Field Artillery Advanced Course
Ft. Sill, OK 1979

United States Military Academy
West Point, New York B.S. 1975