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The Feasibility of Estimating the Contribution of Artificial Obstacles to Force Performance

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This thesis focuses on the study of the contribution which artificial barriers make to the combat process. This problem area has been of particular concern in force structure analyses at the Department of the Army level. The U.S. Army has acknowledged its commitment to barrier operations by stated doctrine, significant stockpiles of barrier materials and war plans which allocate significant portions of deployed forces to the execution of barrier plans. In the environment created by reduced force levels and inflationary budgets the high level decision maker faces the continual dilemma of deciding where to accept force reductions and how to adjust mission requirements. To be competitive in that environment the barrier mission must be assessed on the basis of its contribution to the force mission. An acceptable analytic method has not been developed which will provide that assessment.

The intent of this thesis was to prove the feasibility of a technique for studying the barrier problem. The conclusion that the particular technique recommended by this thesis is feasible, does not appear to be invalidated by the difficulties encountered in structuring the model. Recommendations for a second generation model with a more flexible representation of possible Red strategies and a concentrated effort to develop Blue decisions which accurately reflect the impact of the simulated time period continue to be appropriate.

THE FEASIBILITY OF MEASURING THE CONTRIBUTION OF ARTIFICIAL OBSTACLE SYSTEMS TO FORCE PERFORMANCE

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements of the degree

MASTER OF MILITARY ART AND SCIENCE

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1975

ABSTRACT

This thesis focuses on the study of the contribution which artificial barriers make to the combat process. This problem area has been of particular concern in force structure analyses at the Department of the Army level. The U.S. Army has acknowledged its commitment to barrier operations by stated doctrine, significant stockpiles of barrier materials and war plans which allocate significant portions of deployed forces to the execution of barrier plans. In the environment created by reduced force levels and inflationary budgets the high level decision maker faces the continual dilemma of deciding where to accept force reductions and how to adjust mission requirements. To be competitive in that environment the barrier mission must be assessed on the basis of its contribution to the force mission. An acceptable analytic method has not been developed which will provide that assessment.

The military community has generally accepted three qualitative descriptors as representative of the barrier contribution—direct attrition, target enhancement and delay. Direct attrition refers to opponent losses inflicted by landmines. Target enhancement is defined as any improvement which accrues to the defender's weapons as a result of the employment of artificial obstacles. The supporting research for this thesis indicates that improved methods for assessing these two impacts either exist or are under development. The impact of delay is then the appropriate target for additional analytic effort.

Existing historical data and analyses were assessed in an attempt to define qualitatively the impact of barrier delay. That research indicates that the use of artificial obstacles contributed to several important combat capabilities. Among these were the capability to exercise economy of force, break or maintain contact, prepare subsequent positions and develop intelligence. Unfortunately the employment of a barrier did not guarantee these capabilities. Thus delay is significant only if the commander has the freedom to employ other force assets in a manner which makes the delay useful. The resulting conclusion is that any attempt to assess the barrier impact by explicitly measuring delay would not provide adequate representation of the barrier function.

To provide a useful method for assessment, the analytic effort was then directed to the development of a model which could portray freedom of action. Freedom of action in this case is being defined as the capability to select alternative courses of action, one of which is the artificial barrier, for accomplishing the force mission. The creation of that environment required a modeling technique dissimilar to those currently used in production modes to support force structure analysis.

The technique selected to support this thes's was a computer simulation war game developed on an experimental basis at the Research Analysis Corporation. The war game uses a basic dynamic programming algorithm to represent defensive combat in an environment where the defender is permitted to select courses of action from an admissable decision list in an attempt to maximize his Forward Edge of the Battle Area (FEBA) position. This technique was adapted for the barrier problem in a prototype model called the Barrier Effectiveness Analysis Revision (BEAR).

The initial construction of the BEAR model was subsequently invalidated by the discovery of a coding error in the computer program. The correction of that error led to a major revision of the model. The results presented in Chapter IV cannot, therefore, be considered valid. That discussion does provide key insights for structuring an analysis using this model.

The appendix to this thesis includes sample coding and output for both the original model and the revised version. A discussion of the salient differences and their 'mpact is also included. Generally, the barrier option appears less attractive when compared to other firepower options than indicated by the original results. The capability of the modeling technique to represent the barrier in a freedom of action environment is, however, maintained.

The intent of this thesis was to prove the feasibility of a technique for studying the barrier problem. The conclusion that the particular technique recommended by this thesis is feasible, does not appear to be invalidated by the difficulties encountered in structuring the model. Recommendations for a second generation model with a more flexible representation of possible Red strategies and a concentrated effort to develop Blue decisions which accurately reflect the impact of the simulated time period continue to be appropriate.

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CHAPTER I

THE PROBLEM

In U.S. Army doctrine a fundamental consideration for defensive operations is defense in depth. "The defender achieves depth to the defense by proper deployment; maneuver of forces; use of blocking positions, field fortifications, and barriers; and proper employment of fires and reserves."[1] Thus the barrier is one of the tools used by the tactical commander to achieve an adequate posture for defense. The U.S. Army's commitment to this doctrine in Europe is demonstrated by stockpiles containing several hundred thousand mines and tens of thousands of tons of other barrier materials. In addition, U.S. Army Europe plans for the use of a significant portion of the deployed force to execute extensive barrier plans in the event of a Warsaw Pact attack on NATO forces in Central Europe.[2]

With such a significant resource commitment to barrier operations it would appear obvious that high level military decision makers should have some definite insight into the contribution of barriers to force effectiveness—a simple answer to the question, "How much barrier is enough?" The answer to that question becomes more critical when considering the future prospects of Mutual Balanced Force Reduction or U.S. Army Europe unilateral force withdrawals for economic reasons. In this environment total force resources are further constrained forcing the decision maker to accept trade-offs of various force elements which contribute to the accomplishment of the force mission. In the area of barrier operations the staff officer or military analyst cannot provide meaningful data to aid the decision maker in effectively weighing the barrier contribution as a basis for comparison with other combat components.

"There exists practically no open literature on the minefield emplacement problem, what a minefield accomplishes, and the cost effectiveness of a minefield or other types of barrier systems."[3] This statement by Mr. Sidney Sobelman, Scientific Advisor to the Deputy Chief of Staff for Military Operations, demonstrates the void faced by the analyst or staff officer when he attempts to support any force recommendation tied to barrier operations. The discussion of obstacles often centers on minefields. The minefield, however, is only one of a possible series of artificial obstructions that includes demolished bridges or culverts, road craters, and abatis. In U.S. Army doctrine, "Mines are used as an obstacle, or as a supporting obstacle in a system."[4] Thus by intent, minefields are no different than other obstacle types. The minefield is different, however, in that its components are active munitions. The minefield can directly and independently inflict casualties on an opponent. Since the minefield is the only obstruction which can provide a direct casualty producing effect, the intent of obstacle and barrier operations must go beyond that influence.

"A barrier according to the definition in AR 310-25, is 'a coordinated series of obstacles designed or employed to canalize, direct, restrict, delay or stop the movement of an opposing force, and to impose additional losses in personnel, time, and equipment on the opposing force.' In the same publication an obstacle is defined as 'any obstruction that stops, delays, or diverts movement.' Obstacles are, and barriers may be, components of a defensive position, which is, broadly speaking, 'any area occupied and more or less organized for defense.'"[5] The definition of an obstacle is general enough to include both natural and artificial obstructions to movement. It is logical to site artificial obstructions to insure that maximum advantage is accrued from the natural obstructions of terrain. A critical aspect of U.S. Army doctrine for employing obstacles is the requirement to cover the obstacle by fire.[6] Without covering fire the value of the obstacle is limited because modern technological developments such as vehicle launched bridges and mine plows will permit rapid breaching.

A discussion of the doctrinal intent of obstacles leads to defining three functional impacts that the obstacle will have on the combat process. First the minefield will directly inflict casualties. The magnitude of those casualties will naturally be a function of the type of action the opposing force chooses to either breach or bypass the minefield. Second the combination of obstructing the opponent's movement and using covering fires should tend to increase the effectiveness of those covering fires. This increase is logically derived from the target being exposed to the defender at the obstacle, and the fact that the attacker cannot close to the defender in order to gain an advantage from weapon systems that have increased capability as range to target decreases. For the sake of simplicity this particular impact of the obstacle will be referred to as "target enhancement." The third impact may be simply referred to as "delay." The obstruction forces the attacker to use more time to move from one point to another. This delay is a function of the attacker choosing to breach the obstacle or moving to an alternate route. In summary, the three obstacle impacts are direct target kills, target enhancement and delay.[7]

The barrier by definition is a coordinated series of obstacles. The barrier is then a set of obstructions accomplishing the purposes of inflicting casualties, enhancing targets, and delaying the opponent. The term "coordinated" reflects the planning intent of the defender and there is some question as to the importance of the term when attempting to gauge the impact of the barrier on the combat process. In its study, Historical Evaluation of Barrier Effectiveness, the Historical Evaluation and Research Organization of Dunn Loring, Virginia, indicates that "In the one example in which a planned barrier system did not exist, there is evidence that a series of obstacles, not actually related in any conceptual sense, tended to grow into barriers in terms of effects."[8] Thus the key to defining the impact of the barrier on the combat process would appear to be the effect on the attacker rather than the intent of the defender. The logical question at this point is whether the three effects established for the obstacle directly carry over to a discussion of barriers. In the definition of a barrier the terms canalize, direct, restrict and stop are used. Stop is obviously the extreme value of delay. The terms canalize, direct, and restrict are rather tenuous, but appear to imply at a minimum, forcing the opponent to take some action he might otherwise not consider. Since he is altering his action delay may be implicit. Additionally it is unrealistic to consider an impenetrable barrier. Any feasible barrier system can be breached given the attacker's willingness to spend sufficient resources and time.

Therefore, canalization, direction and restriction cannot be guaranteed. Since some additional physical action is required to overcome the barrier either by breaching or altered route, delay appears to be the most appropriate measure for the impact of the barrier with respect to the attacker's movement. The other portion of the definition of a barrier which refers to additional losses in personnel and equipment can be adequately accounted for by the obstacle impacts of inflicting casualties and enhancing the target. It would then appear that although some difficulty exists in defining when a barrier exists, the impact of the barrier on the combat process is much the same as that of the individual obstacle but larger in scale.

The inadequacy of barrier assessment using existing staff-oriented tools was further demonstrated in a December 1973 letter from the Assistant Chief of Staff for Force Development (ACSFOR) to the Chief of Engineers.[9] This letter admitted the failure of the Concept Design for the Army in the Field (CONAF) study in representing barrier effectiveness and requested any possible aid in improving the CONAF methodology in this functional area. The CONAF study is key to understanding the particular problem of how much barrier is enough. That study provides the state-of-the-art tools for supporting the high level decision maker in force design and resource allocation. The stated purpose of the study was to "develop a conceptual design for the Army in the field which will provide the best Army capabilities attainable within projected levels of resources available during the mid-range period. Through development of a method for formulating type forces and analyses of the costs and capabilities of alternative mixes of organizations and attainable materiel systems, a preferred type force will be designed and related goals and priorities identified to guide the force development and combat development processes.[10] The Study Directive further stated, "CONAF is the initial effort in a continuous requirement for USACDC (U.S. Army Combat Developments Command) to support the annual planning activities of the DA staff."[11] CONAF was subsequently transferred to the U.S. Army Concepts Analysis Agency (USACAA) when USACDC was dissolved in an Army reorganization. As indicated by the stated purpose, CONAF was designed to provide a method for allocating resources to provide forces with the best possible capabilities. The ACSFOR, in essence, admitted that method failed when appropriate decisions were required concerning the barrier mission.

A critique of the barrier play in CONAF provides the basis for properly defining the problem areas in modeling barriers. Key to the CONAF study was the system used to assess the effectiveness of various force mixes. "The heart of the system is the CONAF Evaluation Model (CEM), a fully automated combat simulation that can simulate months of theater land and air combat activity in just hours on a computer. The CEM is capable of finer distinctions among force units down to battalion size than any other existing model of comparable scope and speed. A unique feature of the CEM is the simulation and automation of the commander's decision processes and allocation of resources at all levels from division through theater.[12] This description of CEM has been generally used to justify the position that CONAF does provide the state-of-the-art tools for force analysis. The outputs from the model are functions of the results of brigade-level engagements. "The assessment of each brigade-level engagement results in supply expenditure, casualties, major weapon losses, and FEBA (Forward Edge of the Battle Area) displacement....Casualties, major weapon losses and FEBA displacement are heavily dependent on the amount and type of firepower generated by the two sides."[13] CEM can be generally termed a firepower model. To provide some significant influence on the battle outcome the impact of a given element of the combat process must, in some fashion, alter relative firepowers.

Two other descriptive terms for CEM are deterministic and mean expectation. The model is deterministic in the sense that outputs are constant for a given set of inputs. This constancy is a function of the fact that each time the model assesses a variable such as casualties it assigns a single value which would be the average result that could be expected under the particular circumstances of that moment. It is these average assessments which support the term mean expectation. Altering the results from the model requires a change in mean rather than influencing the variance of a particular variable.

The effects of adding a barrier in the brigade-level engagement are "1) modification of firepower with the resultant change in losses and 2) the lessened advance made by the attacker across the barrier."[14] The barrier effects previously established were direct casualties and target enhancement both of which would change the attacker and defender engagement losses; and delay which would lessen advance. It would then appear that CEM can, in fact, adequately account for the barrier impact. Since subsequent output proved otherwise, it is necessary to isolate some of the detailed aspects of the CEM methodology in order to define the problems inherent in assessing barrier impact.

For each CEM engagement a firepower array is constructed. The array is completed by summing the firepower of shooters available to engage the three target types. Hard, medium, and soft shooters directly correspond to tanks, light armor, and personnel (includes all ground mounted weapons) respectively. Before the results from the firepower array are applied to an engagement certain modifications are required to provide for more realistic engagement outcomes. A sample modification is to insure that a sufficient proportion of target types exist for a given type of firepower. The key modification influencing barrier portrayal is the effects of different types of terrain.

TABLE 1.1

FIREPOWER ARRAY

		Shooter					
		Hard	Medium	Soft	Helicopter	Artillery	Close Air Support
Target	Tanks						
	Light Armor						
	Personnel						

Four types of terrain are portrayed in CEM. Each type is considered to have a different impact on the mobility of ground forces. "The first three types reflect the general nature of the terrain. They are:

Type A - This terrain is flat to gently rolling with a minimum of timber. It is excellent tank country.

Type B - This terrain is marginal for tanks and wheeled vehicles because of topography, soil conditions, or vegetation.

Type C - On this terrain tanks and wheeled vehicles must remain on the roads because of steep slopes and/or dense forestation or swamps.

The fourth type of terrain, Type D, is intended to represent some major obstacle that would normally require extra or special effort for the forces to negotiate or pass through."[15] The barrier which is a coordination of artificial obstacles and naturally difficult terrain is represented by Type D terrain in CEM. As a class of terrain the barrier is an input to the model at fixed locations.

The firepower array values are modified for terrain by multiplying by a factor "f" ($.67 \geq f \geq 1$).[16] The value of "f" selected is a function of the terrain type and the category of shooter. For the three normal terrain types the value of "f" for hard and medium shooters decreases as the terrain becomes more difficult. This decrease is supported logically by the fact that maneuver difficulty would increase and line of sight for these longer range weapons would occur less often. For soft shooters the value of "f" increases as terrain becomes more difficult since ground forces would tend to gain advantage as mobility and line of sight decrease. The value of "f" is the same under these circumstances for both attacker and defender. "The introduction of a barrier would appear to have the effect of reducing the attacker's capability vis-a-vis the defender. Therefore the terrain factors for the defender on Type D terrain (natural barriers) were taken to be average terrain (Category B)...For the attacker the terrain factors were taken to be 0.8 of these values."[17]

The difficulty in modifying firepower in this fashion to represent a barrier is the lack of justification for the modifier value chosen. It is a judgmental guess unsupported by any analytic base, but chosen based on the generally accepted notion that the defender must gain some advantage. Logically if the defender could improve his posture he would create the most unfavorable terrain for the attacker—Type D in this case. Since firepower is modified, an improved posture implies inflicting greater casualties. If maximizing casualties is the objective, the analyst is faced with two key issues. First, is there an alternative to obstacle and barrier employment which will permit the defender to inflict greater casualties on the attacker at less cost? If no alternative exists then the analyst may attempt to establish an acceptable and supportable methodology for altering the firepower representation in CEM to reflect the gains accrued by barrier employment.

The delay which results from a barrier is simply represented in CEM by a 12 hour delay before crossing designated Type D terrain.[18] This delay corresponds to one division period in the model. "Once each period an estimate of the situation is made at the corresponding echelon, leading to mission selection, allocation of fire support, and commitment or reconstitution of reserves."[19] Thus by employing the barrier the defender gains the supporting actions of an additional 12 hours before mission selection and subsequent evaluation. In CEM that 12 hours is of no particular significance. FEBA displacement is a deterministic function of firepower. Delay could influence the outcome only if the defender was able to add significant firepower and the attacker either remained unchanged or was decremented. The model does not permit that occurrence. This phenomenon can be demonstrated by a simplified example. At time "T" immediately following a conflict assessment a Blue force with combat power "B" and a Red force with combat power "R" exist. "R" has been greater than "B" so the FEBA has been steadily moving to Red's advantage. The clock is advanced 12 hours to permit the next assessment at T+12 hours. During that period

Blue adds combat power "dB" and Red adds "dR." If Red does not encounter the barrier the FEBA will be moved to location "L_1" for the next assessment. If Red is delayed the next engagement will occur at location "L_2" which would be at a lesser distance from the initial engagement. Whether the engagement occurs at "L_1" or "L_2" the outcome will be based on a comparison of B+dB with R+dR. Thus the model has added delay but that delay is not significant in terms of the subsequent outcome, except that the battle is fought at L_2 instead of L_1.

This brief survey of some aspects of current doctrine and the difficulties encountered in the CONAF study has highlighted several problem areas in assessing barrier contribution to force performance. First, there is the problem of determining when a set of obstacles is coordinated—the defined requirement for a barrier. A better statement of the problem is how many obstacles of what type must be employed to yield the effect of a barrier? The answer to that question would enable the planner to determine what resources are required to perform the function. A review of the CONAF study exposes some of the other problems inherent in attempting to postulate the effect of the barrier. One problem was determining the increase in casualties sustained by the attacker when the defender employs a barrier. The attempt in CEM to alter the firepower scores when a barrier was present is a recognition of the importance of this factor. The method used was judgmental and not considered particularly valid. The CEM methodology did not attempt to assess casualties directly caused by mines, another key problem. Finally, CEM attempted to represent the delay imposed by a barrier. In application that delay did not significantly alter the outcomes in the model which leads to the problem of determining what impact delay should have.

Based on these problem areas it would appear that an analyst seeking to improve the capability to assess barrier effectiveness in CEM or any other force planning method would attempt to answer three basic questions. They are:

1) When does a barrier exist?

2) What relative improvement to inflict casualties accrues to the defender?

3) What value accrues to the defender from delaying the attacker?

Initially the first question is least important. As previously indicated the answer would be the basis for determining the resource cost of a barrier. Obviously the second two questions indicate some question on the value of the barrier. If those questions cannot be satisfactorily answered there is no particular need for computing the cost for something whose value is not known. The second and third questions may be somewhat interrelated. One value of delay may be a relative improvement in the capability to inflict casualties. On the other hand the attacker may choose to ignore the existence of a minefield. There would then be no delay but a logical expectation of higher casualties. Third, it is important to remember that the attacker can choose delay at any point. With the exception of U.S. experience in Vietnam, historical evidence indicates that personnel casualties from mines have been proportionally low.[20] As an example data from North Africa between November 1942 and May 1943 indicate only two percent of U.S. casualties were caused by mines despite extensive

German employment of mined obstacles.[21] "An explanation for the phenomenon of low casualties from mines is not readily apparent especially in view of the reduction of mobility and vehicular damage from mines noted in studies of the Tunisian campaign....The hypothesis that emerges is that mines are effective barriers to movement, but relatively less effective as casualty-producing agents especially under conditions of conventional war."[22] Since mines are the only artificial obstacle which directly inflicts casualties, this hypothesis becomes even more meaningful. It would then appear that the third question—what is the value of delay—would be the most significant. The answer to that question is the objective of this thesis.

This thesis will be structured as a test of the hypothesis: It is feasible to estimate the value of barrier delay at engagement levels appropriate to theater modeling using simulation modeling techniques. This test will be accomplished by reviewing available literature, selecting an appropriate framework for the model, designing and testing the model, and reporting the results. It is important to note the concentration of the study on the feasibility of estimation rather than providing a mathematical value. This study is unclassified, hence all data inputs are either unclassified or estimates which enable a test of the model.

CHAPTER I

FOOTNOTES

[1]Department of the Army, FM 61-100, The Division, (November 1968), p. 7-2.

[2]Specific numerical references are not supplied because of security classification. Information is based on author's experience working with USAREUR Barrier and War Plans.

[3]Department of the Army, Office of the Deputy Chief of Staff for Operations, Probabilities of Mine Fields and Cost Effectiveness of Barriers, by Mr. Sidney Sobelman (Washington, D.C., Undated), p. 1.

[4]Department of the Army, FM 5-1, Engineer Troop Organizations and Operations, (July 1971), p. 4-4.

[5]Department of the Army, U.S. Army Concepts Analysis Agency, Employment of Obstacles in Combat in Europe in World War II, (Contract No. DAAG 39-74-C-0033, Historical Evaluation and Research Orgnnization (HERO), Dunn Loring, Virginia, March 1974), p. 4.

[6]Department of the Army, FM 23-3, Tactics, Techniques, and Concepts of AntiArmor Warfare, (August 1972), p. 15.

[7]The three indicated functional impacts of the barrier and obstacle are cited based on general acceptance within the appropriate military community. They were presented to the Chief of Engineers, U.S. Army Concepts Analysis Agency (USACAA), and Mobility, Equipment Research and Development Center (MERDC) in late 1973-early 1974 by the author. They were accepted as being generally descriptive of the barrier and obstacle contribution to combat.

[8]Employment of Obstacles in Combat in Europe in World War II, HERO, op. cit., p. 1.

[9]Letter, Assistant Chief of Staff for Force Development to Chief of Engineers, SUBJECT: Barrier Analysis, 7 December 1973.

[10]Department of the Army, Theater Force Performance in CONAF II (Conceptual Design for Army in the Field) Volume I - Methodology, (General Research Corporation, Westgate Research Park, McLean, Virginia 22101, May 1973), p. 1.

[11]Ibid.

[12]Theater Force Performance in CONAF II, op. cit., frontispiece.

[13]Ibid., p. 24.

[14]Ibid.

[15]Ibid., p. 11.

[16]Ibid., p. 165.

[17]Ibid., p. 164.

[18]This fact is not supported in the methodology volume on CONAF. It was obtained by the author in direct contact with analysts at USACAA.

[19]Theater Force Performance in CONAF II, op. cit., p. 15.

[20]Data presented to students enrolled in U.S. Army Command and General Staff College Course 3651—Mine/Countermine Warfare—in December 1974 in classified lectures.

[21]U.S. Army Aberdeen Research and Development Center, Ballistic Research Laboratories, Mine and Countermine Warfare in Recent History, 1914-1970, by Russel H. Stolfi (Aberdeen Proving Ground, Maryland, April 1972), p. 48.

[22]Ibid., pp. 48-49.

CHAPTER II

THE LITERATURE SEARCH

The literature search to support this thesis concentrated on satisfying two objectives: developing a qualitative assessment of the impact of the barrier on the combat process; and, reviewing existing analytical assessments of obstacle functions in combat. The first objective could be viewed as determining whether or not a definition of "delay" can be developed. That definition is important because "delay" is the barrier effect which has been injected into current force analyses. The second objective is critical in addressing the relationship between delay and the barrier functions of inflicting casualties and enhancing targets.

The logical bases for beginning an investigation of the impact of the barrier on combat are the historical experiences from World War II to the present. World War II provided the first wide-scale application of barriers in terms of the types of hardware and doctrine that are familiar today. If sufficient experience exists to indicate the impact, then some foundation for defining the factors of delay should exist. Three principal sources have been used in this investigation. In 1972 Dr. Russel Stolfi of the Naval Postgraduate School provided the Ballistics Research Laboratory a report entitled: Mine and Countermine Warfare in Recent History, 1914-1970. The purpose of the report was to provide "a pragmatic approach towards the understanding of this problem [mine and countermine combat effectiveness] from a historical point of view."[1] The report cites specific campaigns and battles as a basis for discussing the importance of mines and minewarfare. The second principal source was the 15 volume work, Landmine and Countermine Warfare, prepared by the Engineer Agency for Resources Inventory (EARI) and published in 1972. "These eight textual volumes and seven appendix volumes bring together a broad scope of information contained in archival references and technical literature. These include military histories; unit records and monthly action reports of infantry, armor, and engineer units; field manuals, and operational plans."[2] This EARI publication is a very detailed compilation of data without significant analysis. Only three volumes will be cited in this thesis. Those volumes provide the textual information on mine warfare operations in North Africa, Italy and Korea. The 1974 Historical Evaluation Research Organization (HERO) study on obstacle employment in World War II which was cited in Chapter I is the third principal source. The purpose of this study was to provide "data to permit tentative development of quantitative inputs for combat models with respect to efforts to create or improve obstacles and barriers...."[3] The HERO study concentrates on examples which include use of all types of artificial obstacles. Four case studies from World War II were used as the inputs for the study: the Battle of Kursk (Russia-1943); Nikopol Bridgehead (Russia-1944); Il Giogo Pass (Italy-1944), and the Battle of the Bulge. "With only four case studies, this exploration could not possibly produce definitive values for any of the effects sought."[4] This statement indicates that the study did not achieve its stated objective. The primary cause for this failure was the fact that hypothesized quantitative assessments were useful only in the context of HERO's mathematical representation of combat which has not received wide acceptance in the analytic community. That failure does not, however, diminish the qualitative value of the case studies which were developed from excellent primary source material.

Unfortunately the report by Dr. Stolfi and the HERO study do not agree on the principal impact of the barrier on the combat process. The HERO study concludes "it is clear that the principal military value of obstacles and of barrier systems is to permit Economy of Force (and, of course, indirectly to permit mass elsewhere as a result of such economy)."[5] In contrast, Dr. Stolfi states: "Analysis of the use of mines in North Africa shows that the crucial effects of mines were to reduce the mobility of the forces against which they were employed."[6] Although this statement is restricted to actions in North Africa, the general conclusion is appropriate to Dr. Stolfi's entire assessment. It appears that these two sources present two distinct contradictory arguments neither one addressing delay. The requirement then exists to examine each argument in some detail.

In each of the four case studies the HERO study provides some convincing logic to support the case for economy of force. For example, at the Nikopol Bridgehead, "The obstacles and field fortifications of the 335th Division [German] permitted the detachment of at least one-fourth of the division to reinforce hard-pressed units to the north, while still retaining a substantial combat power superiority over the opposing Soviet units."[7] In the Battle of the Bulge, "The hasty defenses, blocks, and minefields installed along the entire front of the 4th Division [U.S.] beginning on 17 December facilitated the use of Economy of Force along the southern four-fifths of the Division sector, and the massing of about half the division in about one-fifth of the sector, opposite the only serious German threat."[8] In both examples there was no intent on the part of the defender to delay. The barrier was designed as an aid in defeating the attacker and was used to increase the combat power of the defender. In all of these cases certain aspects of delay were implicit. It was necessary to delay German elements in some sectors of the 4th Division to enable the massing of most of the division's combat power opposite the primary threat. In other areas of the Bulge road blocks and blown bridges extensively delayed key German armor thrusts.[9] In fact some engineer reports can be used as a basis for declaring that certain German armor elements ran out of fuel because the barriers existed.[10] The delay implicit in these examples would not have been significant had forces not been preparing positions in the rear or moving to counterattack. It would then appear that the key factor is the capability of the defender to allocate his forces to meet a developing situation at the critical points. To support that allocation other areas must be defended by reduced elements (economy of force) or the attacker must be significantly delayed.

In the cited examples the barrier did appear to increase the combat power of the defender and as a result the attacker was delayed. This result appears to be the outcome regardless of the intent of the defender. At the Nikopol Bridgehead the German mission was to hold that particular terrain against superior Russian forces to enable control of the lower Dnieper river. The bridgehead was abandoned because of a threat of envelopment but the Soviets were delayed and

German forces were able to withdraw.[11] It would appear that it is ultimately the freedom of action that the barrier buys which is key to the significance of the barrier in the combat process.

How then does Dr. Stolfi's view that the crucial effect of the barrier is the reduction of attacker's mobility contrast with the HERO study? In the introduction to the report it is stated that "the effectiveness of mines as barriers to ground movement will be considered in terms of their impact on the mobility of the forces encountering them."[12] This statement indicates a predilection for this specific factor, and it would be natural to find the report expressed in those terms. This possible bias does not, however, discount the fact that Dr. Stolfi may be correct in his assessment.

One of the primary examples used for the report is the World War II conflicts in North Africa where the use of mines reached such an extent that barrier operations became one of the primary concerns of commanders.[13] Principal concentration is directed to two battles: Gazala—May and June 1942—and Second El Alamein—October and November 1942. Of Gazala Stolfi summarizes:

> . . . the German mobile force was almost immobilized due to lack of fuel and ammunition after the first 15 hours of combat. . . . The British, in effect, had fixed the Germans against and among the deep minefields and were in a position for several days to reduce the German bridgehead. The British minefields had reduced German mobility below that of the British and allowed the Eighth Army to regain the initiative temporarily.[14]

Although in trouble, Rommel did finally force the Gazala line and subsequently captured the port of Tobruk. It has been argued that the British were ultimately defeated by failing to mass resources to react to the battle as it developed.[15] The barrier preparations for the battle were effective, but the British failed to apply the economy of force the barrier operations might have permitted. Summarizing the barrier impact at Second Alamein the report states:

> The German mines near Alamein almost balanced for the Italo-German Panzerarmee the immense British superiority in tanks, artillery, and aircraft. German mines turned what could have been a swift penetration and collapse of the Italo-German positions into a grinding 12 day battle of attrition which Montgomery came startlingly close to calling off.[16]

In gaining this conclusion Stolfi argues that Rommel's employment of half a million mines reduced British mobility to the extent that the attrition battle was necessary since the terrain prevented the mass flanking movement prevalent in other major battles in North Africa. If the German dispositions for the defense[17] are examined an argument can be made for Rommel attempting to use the barrier as an economy of force measure. Dr. Stolfi alludes to this in discussing Rommel's flair for arrangement of limited firepower.[18] He does not, however, set the barrier in the concrete terms of Economy of Force. The Germans were defeated at Alamein. Rommel did not direct the defense in the first two days and much of the German difficulties were attributed to lack of supplies.[19]

The Stolfi report does provide evidence that barriers have in fact reduced the mobility of participants to the extent of significantly influencing the conduct of combat. In contrast the HERO study provides positive evidence to support the case for economy of force. There is a possibility of a logical link between the two arguments. Implicit in the argument for economy of force is the necessity for the barrier to increase the defender's combat power. If the barrier does increase the combat power and that increase can be related to reduced mobility then a bridge will exist between the two positions. To pursue this particular logic it is useful to examine the historical evidence in terms of the previously defined barrier functions of direct casualties and target enhancement.

The historical summaries provide many specific examples of the target enhancement effect. In discussing the June 1941 British offensive in North Africa, Operation Battleaxe, Dr. Stolfi comments: "At several important junctures in the summer battle, the powerful British Infantry tanks were immobilised in the frontier minefields with relatively minor damage and then 'shot to pieces' by the German Antiaircraft guns."[20] Similar experiences were encountered in Operation Crusader in November of 1941 where one unit lost 35 of 42 tanks in similar circumstances.[21] In U.S. experience in Italy in attacking the GUSTAV line in December 1943, an Armor element of 16 tanks lost 12 in a single day at one location to the combined effects of mines and fire support.[22] These three samples certainly indicate that artificial obstacles improve the defender's capability to employ other weapons because of reduced mobility. This point is driven home by an example of a small action in Tunisia in early 1943. Four German tanks stopped at the wire marking a dummy minefield and all four were destroyed. "They had taken the wire at its face value and had become sitting shots for anti-tank guns waiting for them."[23]

The point was made in Chapter I that experience generally indicated personnel casualties from mines were proportionally low. The Stolfi report was further quoted to indicate that if the vehicular damage was considered for the same period one would not have expected the minimal personnel casualties. This statement would indicate that direct kills of vehicles by mines might be a significant factor. Data samples from Okinawa, Europe and Korea indicate that from 25 to 40 percent of U.S. tank losses resulted from mines during periods when combat conditions dictated use of obstacles.[24] During the pursuit of North Korean forces in October of 1950, mines accounted for 70 percent of UN tank casualties.[25] Obviously the mine appears to be much more effective in terms of casualty production to vehicles than personnel. This phenomenon is one characteristic which Dr. Stolfi uses to support the contention of reduced mobility. In contrast, significant materiel destruction also supports the idea that mines improve combat power.

The historical experience that has been discussed does support the argument that there is a relationship between reducing the enemy's mobility with obstacles and economy of force. That relationship is generally confirmed by evidence that obstacle employment does provide a positive target enhancement and create significant vehicular casualties. Despite this evidence, economy of force may be an inappropriate term to describe the barrier impact. Economy of force implies an intent for reduced commitment at one point to enable mass at another. Historical experience indicates that the barrier can be an aid in achieving these conditions. In contrast the historical evidence is not sufficient to indicate that the barrier guarantees economy of force. The barrier may exist, reduce the attacker's mobility, and increase the defender's combat power without the defender being in a position to apply economy of force. In the Gazala and El Alamein examples the defenders did employ effective barrier systems and lost. In the first case it was established that the

British did not attempt to apply economy of force. In the second, Rommel was severely limited by logistical shortages. The logical definition of the barrier effect to this point would then be reduced attacker mobility and increased defender combat power.

The concept of delay has not made a significant impact on the discussion to this point. The reason is simple. With one exception, the historical examples that have been presented in detail have dealt with defenders who did not intend to delay. The exception was a portion of the obstacle employment in the Battle of the Bulge. In that case the obstacles were not a portion of a planned barrier, but were executed on a decentralized basis.[26] Since the objective of the search is to define the factors of delay it can be argued at this point that reduced mobility is delay. If attacker's mobility is reduced, it will require more time to move a given amount of combat power; hence delay. Also historical experience indicates that this delay promotes higher attacker casualties so the increased defender combat power should be considered a factor of this barrier delay. That argument cannot be conclusive without considering some of the other demonstrated impacts of the barrier on the combat process.

One key aspect to be considered is the effect of barrier operations when the intent is delay. A factor which gave impetus to U.S. concentration on minewarfare early in 1940 was evidence that "mines gave real protection to troops in retreat."[27] That protection would appear to be a function of being able to break contact with main force units. The aftermath of the El Alamein battle provides an excellent example of such an action. At the end of the battle in three plus German divisions Rommel was left with 11 tanks.[28] Once the

German forces began the retreat all remaining elements were withdrawn virtually intact. There is considerable argument as to whether or not Montgomery conducted a pursuit—a quite logical discourse considering it was a failure. In the pursuit that did take place there was considerable difficulty in organizing and moving British units out of the Alamein position because of extensive minefields. As they began to move, elements of two divisions were significantly delayed by dummy minefields, and heavy rains further restricted vehicular traffic. Montgomery's apparent excuse for the failure of the pursuit was the rain.[29] Whatever the historical verdict on Montgomery's pursuit, two factors were much in evidence. First the rain had equal effect on both sides. Second the minefields worked only against the British after the Germans abandoned the Alamein position. For the remainder of the retreat of several hundred miles to El Agheila mining was so extensive a British Engineer Company was able to clear only 12 miles of road per day.[30] German elements were never decisively engaged in that withdrawal. In this circumstance the impact of delay was the ability to break contact.

In the Italian theater a planned delay for an entire campaign was demonstrated. "In the overall concept of military strategy, the Germans were masters in defensive tactics of delay based upon mines and demolitions which were integrated along the routes of withdrawal and into the successive lines and points of defense—Salerno Beachhead, Volturno River, Barbara Line, Bernhard Line and Gustav Line."[31] Gen. Kesselring's purpose in the defense was to preclude the fall of Rome as long as possible, apparently hoping to stalemate the war.[32] It took the Allies approximately nine months to seize Rome after landing at Salerno. This "delay" included keeping six allied divisions bottled up in the Anzio Beachhead for approximately five months. The stalemate did not result; however, there is a definite sense of delay in the German actions. The extensive use of barriers boosted the combat power of the Germans and permitted them to break contact in order to occupy subsequent positions. In a larger sense the delay bought more extensive preparations of subsequent positions because more time permitted more construction.

In these two examples the intent of delay enabled two very important functions of combat: breaking contact and preparing subsequent positions. These are the completely defensive oriented aspect of barrier operations. The HERO study establishes an offensive corollary for delay. In this instance instead of the defender intending to break contact, he plans to use barriers to insure that the attacker maintains continual contact. The result of that contact is "exhausting the attacker's capacity for sustained combat before he can reach objectives."[33]

The HERO study uses the Battle of Kursk to demonstrate this barrier function. "The Soviet barrier plan at Kursk was conceived as part of the major defense to be offered to a German attempt to reduce the large salient which the Russians had established around Kursk in their winter offensive of 1942-43. It was thought that a strong position, with great depth, would wear out the Germans, destroy their tanks and then make it possible for Soviet forces to introduce fresh troops in a general offensive and to inflict a major defeat on the main German Forces."[34] The report details the many frustrations, delays, and altered attack plans of German elements in response to the barriers and fortified positions. The progressive reduction in rate of advance for German units on a daily basis is also detailed. The battle was ultimately won, however, by the delivery of the massive Russian counterattack.

Logically considered, the possible "wearing down" influence of the barrier in some depth cannot be ignored. Regardless of how efficient units are supported, they are not completely reconstituted in contact; hence, they sacrifice some of their combat potential in each engagement. Maintaining constant contact is an intelligent way to maximize that phenomenon. There is a considerable similarity of the initial barrier influence on operations in the eight days of Kursk and the 12 days of Alamein. The difference in outcome was that the Soviets could deliver the counterstroke—Rommel could not.

There are two aspects of the impact of barriers in combat which are not specifically addressed in the available historical analyses but should be considered as significant in this discussion. First, the more extensive the barrier the more resources that must be dedicated to negating the effect. This effect may continue its influence after the barrier or obstacle has been breached and is no longer a direct factor in the combat outcome. For example, in Italy, "as the fighting continued northward, allied mobility continued to be restricted in the rear zone of operations due to uncleared minefields around Salerno and Naples."[35] Units which could have performed other functions or been used in other locations were tied down by requirements for clearing the extensive obstacle systems. Obviously this effect can be a two-edged sword, but it demonstrates the necessity for the attacker to plan and allocate resources to overcome the barrier. It also highlights the fact that combat service support operations may prove more difficult when the obstacles continue to have an influence in the attacker's rear.

The second important aspect is the fact that the barrier delay provides a positive intelligence enhancement. As the attacker's mobility is restricted, the defender can better identify the location and size of attacking elements. Delay is an enhancement in the sense that the defender has more time to react to a particular threat. Although the existence of this aspect of barrier influence cannot be specifically supported from the historical analyses, it is certainly implied by the successful applications of economy of force which were previously discussed.

The historical summaries have provided sufficient evidence of several factors which can be identified as impacts of the use of obstacles and barriers in combat. Evidence exists to support the contention that expected armored vehicle kills by minefields are significant and that obstacles do tend to provide a target enhancement effect for the defender. On a larger scale evidence exists to support barrier influences of economy of force, and permitting the defender to successfully break or maintain contact and prepare subsequent positions. In addition extensive obstacles tend to constrict the attacker's combat service support capability and permit the defender to gain intelligence in an environment where his capability to react to that intelligence may be increased. It appears obvious that an attempt to include all of these factors under an umbrella called "delay" may prove fruitless. Before such an attempt is exhausted, however, it is logical to review any additional analytical work which may impact on the results of the historical analyses.

The historical assessments of the influence of obstacles and barriers on combat have not been supported to any significant extent by other analytic work. The one major exception has been attempts to describe the capability of minefields to cause armored vehicle casualties. That work is obviously of some importance, since the historical assessments have indicated that significant vehicular losses can be attributed to minefields.

Four principal sources provide the basis for discussion of antiarmor minefields in this thesis. In 1972 the Research Analysis Corporation published a study entitled: Operational Effectiveness of Scatterable Land Mines which was performed under contract to the Advanced Research Projects Agency (ARPA). This study was performed to analyze the many factors important to defining the cost, employment methods, and combat impact of scatterable mines. One of the factors included was the capability of the minefield to inflict direct armor losses. The second source is the Mobility Equipment Research and Development Center (MERDC) study: Antitank Effectiveness of the U.S. Army Standard Minefield Pattern. This study concentrated on predicting tank and armored personnel carrier losses using the M-15 mine and standard U.S. Army minefield doctrine. Tests were performed using both a miniature physical environmental simulation and field tests using existing hardware. The final two sources actually provide the same data. FM 20-32, Landmine Warfare includes casualty prediction curves for mechanized vehicles which have been adopted by the U.S. Army Engineer School in its Mine-Countermine Operations Manuscript of January 1973.

Data drawn from these sources are portrayed in Figure 2-1.[36] The vertical axis is labeled "Effectiveness" which is defined as the probability that a vehicle will encounter a mine. The horizontal axis represents mine density. "Density is defined as the average number of mines of a specific type per meter of minefield front."[37] The concept of density is key to the analysis of minefield effects because it permits examination with respect to only one dimension—the frontage of the minefield. Thus, a minefield of 100 meters frontage which is 40 meters deep with a density of one mine per meter is equivalent for analytic purposes to a minefield of 100 meters frontage by 20 meters deep with the same density. The density measure has apparently been used for some time. Its applicability is generally substantiated by the MERDC tests which concluded that "minefield pattern has no noticeable effect on antitank effectiveness."[38]

The obvious question is why do the three prediction curves in the figure differ? Answering that question is complicated by the fact that the data presented in FM 20-32 is not substantiated.[39] Sufficient evidence exists, however, to permit the discussion of a general theory for this method of representing minefield performance. The effectiveness curves can be basically fit to the form $E=1.-e^{kd}$ where

E = effectiveness

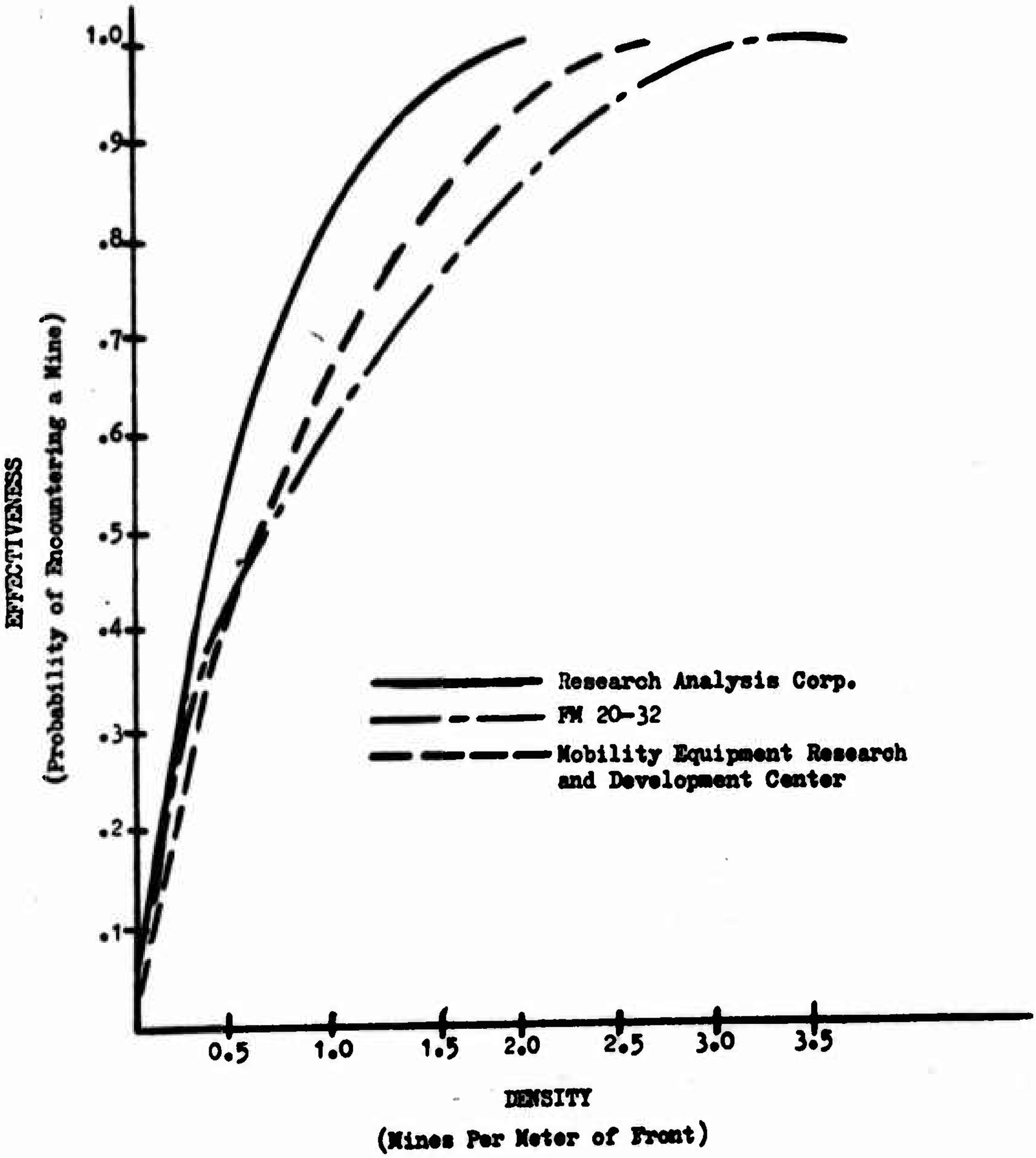
d = density

k = fit parameter

The value of "k" is a function of the area of the tank which will cause detonation of the mine. If the mine is fused for pressure activation then contact with one of the tracks is required for detonation. In contrast, a tilt rod fusing will have a much greater

FIGURE 2.1

MINEFIELD PERFORMANCE



possibility of activation since the entire frontage of the tank is, in effect, a target area. In the latter case "k" would be greater and the effectiveness curve would be pushed to the left. Realistically a family of curves exists, each a function of the type target, mine, and fuzing system. The test and simulation results are available to support the MERDC predictor so its use as a base case can be supported with some degree of confidence.

To use this data without correction two assumptions must be made. First 100% reliability of mine detonation must be assumed. If the mines do not fulfill that requirement some reduction in density should be computed. Second it must be assumed that the detonation guarantees an appropriate level of damage. Since some mines only disable the movement capability of a tank, that vehicle can continue to perform the function of delivering fire. The definition of effectiveness, therefore, must be matched with the effect that is desired.

Even if those two assumptions are accepted, there are two other major factors which will influence the casualty producing capability of the minefield. Those two factors are the attacker choice of a tactical formation to cross the minefield and the countermine technique employed to neutralize the field. In considering the impact of the tactical formation, the MERDC test provides a conclusion which somewhat simplifies the possible approach.[40] The test indicated that if tanks are in column in a minefield of effectiveness "P_E" and the first tank detonates a mine, the effectiveness of the field is not reduced for the second tank. This example can be carried out to "n" tanks. The probability of the first tank encountering a mine is P_E; the probability of the second tank encountering a mine is P_E given that the first tank encountered a mine (P_E); and the probability for the n^{th} tank is P_E given that n-1 tanks had encountered mines (P_E^{n-1}). The expected number of tank casualties is then the sum: $\sum_{i=1}^{n} P_E^i$. The other extreme for tactical formation would be all tanks in a row or simply each tank entering the field independently. In this case the destruction of the tanks would be distributed binomially with the expected number of tank casualties to be nP_E. A formation could be some combination of the two extremes and the expected number of tank casualties could be calculated by

$$EC = \sum_{i=1}^{L} T_i P_E^i$$

where: T_i = number of tanks in a row (columns)

L = number of rows

P_E = probability of an encounter

Although this logic may be useful in computing minefield effects, it has neglected the significant impact of countermine actions. The difficulty which surfaces in attempting to structure an analysis which includes countermine actions is the possible range of methods that may be chosen to neutralize the effect of the minefield. The best representation found in this research effort was the countermine adaptation used in the Division Wargame (DIVWAG) analysis which supported the fourth phase of the Family of Scatterable Mines (FASCAM) study conducted by the War Games Division of the Combined Arms Combat Development Agency (CACDA).[41] The discussion of this technique will be general because of the classification level of the report. The technique used to determine countermine actions is based on the logic that the attacker chooses a countermine method based on the effectiveness level of the covering fire imposed by defender. Various levels of effectiveness for both direct and indirect fires can be considered. For each level, combining both direct and indirect fire, the logical corresponding breach activity is chosen. For example, if the direct fire is considered "devastating" combined with effective indirect fire the attacker would choose to bypass the minefield. In contrast, if the direct fire is only moderately effective and indirect fire is ineffective, then the attacker logically chooses to breach with mine plows mounted on armored vehicles. These examples are not necessarily the realistic expectations for the given circumstances, but were chosen to demonstrate the technique employed. The major difficulty with this method is determining the conditions which will yield the threshold values for the various levels of fire effectiveness.

Obviously this technique for considering countermine significance is not immediately compatible with the technique for predicting mine casualties. A simplified alternative is to assume various proportional levels of attacker neutralization capability. For example, assume the attacker has a 60 percent countermine capability. The impact of such an assumption is to reduce proportionally the expected casualty production of the minefield. In the calculation sense EC would now be equal to $1-C\sum_{i=1}^{L} T_i P_E^i$ where C is equal to the assumed .6 countermine capability. A range of values for C from 0 to 1 would produce a family of curves for each assumed tactical formation and probability of encounter.

In discussing the impact of obstacles, particularly minefields, it is impossible to escape the universally accepted, previously discussed notion that the obstacle has no value without covering fire.

Obviously without covering fire the attacker can always choose the value of C to be 1 and the expected casualties from a minefield are then 0. The aspects of covering fire include not only the desire to maximize the direct casualty producing effect of a minefield, but also to maximize the target enhancement value gained from the obstacle. The available research necessary to define the dynamics of the obstacle influence in the target engagement process is extremely limited. Only recently has work begun at MERDC and the Engineer Studies Group (ESG) [formerly the Engineer Strategic Studies Group (ESSG)], Washington, D.C., which is specifically aimed at determining the predicted increase in defender weapon effectiveness when the obstacle is added to the combat process. Complete results of these analyses are not yet available; however, the author of this thesis initiated a study at ESG in January 1974 which addressed this particular problem. That study was based on the design of a "m x n" computerized war game, the Fortification Obstacle Effects Simulator (FOES). An interim report was prepared in June 1974 and the results presented in that report will be the basis for discussion of the dynamics of obstacle target enhancement in this thesis.

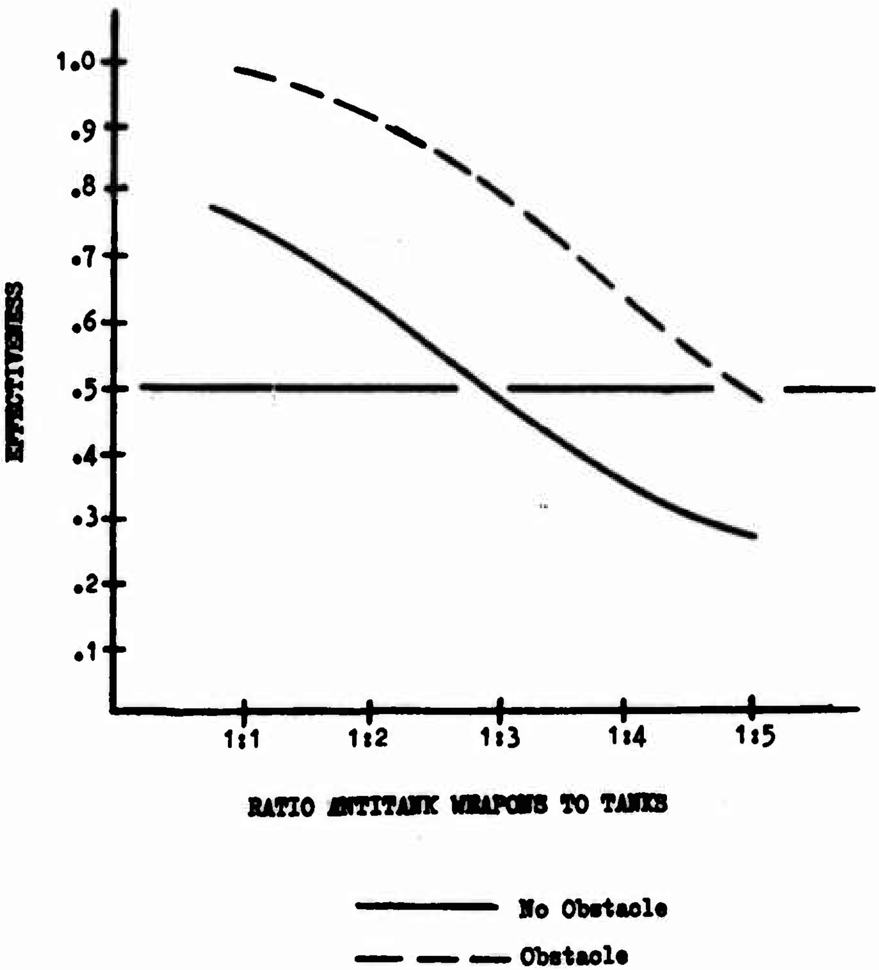
"The FOES development concentrated on simplified representations of important aspects of the combat process while attempting to maintain sufficient variability in the process to permit an adequate study of obstacle and fortification effects."[42] Three primary events were chosen to represent the combat process at the lowest level: movement, detection, and firing. The movement event was represented by assigning the attacker a random speed within each simulation cycle. Detection for the defender was based on the published results of field experiments conducted in Europe and at Ft. Ord.[43] The specific intent of these experiments was to define the dynamics of representing terrain and resulting line-of-sight dependencies to provide a basis for studying antiarmor weapon effectiveness. Two key phenomena were indicated by these experiments. First, detection appears to be a function of range. The closer the target moves to the defender the more likely a detection by the defender. Once detected, however, the length of time that the target is exposed appears to be independent of range. Thus the visible "windows" in terrain which favor the defender appear to be randomly distributed. The attacker detection event was based on information provided in RAC's Operational Effectiveness of Scatterable Mines study. The original concept was developed from field experiments conducted at Camp Stewart, Georgia, in 1955.[44] The significant observation provided by that study was that the attacker's capability to detect the defender is solely a function of the number of rounds fired by the defender independent of range and the time between firings. Simply stated this phenomenon is detection by weapon signature. The final event of the combat process in FOES was the firing event.[45] Range dependent distributions of kill probabilities were used to represent this event. In the case of newer anti-tank weapons these distributions were sanitized in order to maintain the unclassified character of the study. The obstacle was represented in this process by two distinct alterations in activity. When the obstacle was reached the attacker movement terminated for a specific period of time (delay). The defender then gained a limited increase in probability of kill which corresponded to firing at a stationary target. Defender was assigned the stationary target kill probability for every other round fired in the delay period to account for possible attacker movement to bypass the obstacle.

Figure 2-2 demonstrates a sample result for the P(Pseudo)-Dragon and P-T55 tank.[46] The measure of effectiveness (MOE) represented by the vertical axis is an equal weighting of the proportion of kills and survivals for the antitank weapon. The proportion of kills is the number of kills divided by the total number of attackers that could have been killed in the number of conflicts simulated. The survival proportion was one minus the number of attacker kills of the defender divided by the number that could have been killed in the total conflicts simulated. Defender survival in this case is not equal to the defender kill proportion since a draw was a feasible outcome for a given simulation cycle. Anytime this defined MOE has a value greater than .5 the defender possesses a kill exchange ratio that is greater than the opponent's mass ratio. For example, in Figure 2-2, the base run for one P-Dragon versus two P-T55 tanks has an MOE value of about .65. Since this MOE value is greater than .5 more than two P-T55 tanks are being killed for each P-Dragon which is lost. The logical extrapolation is that in a battle to annihilation under these circumstances the supply of P-T55 tanks would be exhausted before the supply of P-Dragons. If the MOE were exactly equal to .5, the opponents would theoretically exhaust each other simultaneously—a true draw.

Figure 2-2 provides a sample of the impact of the obstacle in terms of increasing weapon effectiveness. In this particular case the impact is dramatic in that by using the obstacle the P-Dragon can maintain a MOE level of .5 even when opposed by five P-T55 tanks. Unfortunately there is a considerable variance in the impact of the

FIGURE 2.2

P-DRAGON VERSUS P-T55 TANK



obstacle for antitank weapons of different characteristics. Only four AT weapons were portrayed initially in FOES: P-90mm AT Gun, P-106mm RR, P-Dragon, and P-TOW. The first two weapons possess range dependent kill probability distributions, so they are sensitive to the range from the weapon to the obstacle. As a result there is not only variance between weapons but in these cases variance within weapons. Table 2.1 shows some results for all four weapons expressed in terms of the number of P-T55 tanks required to achieve an MOE value of .5 in the no-obstacle and obstacle cases.

TABLE 2.1

P-T55's NECESSARY TO ACHIEVE MOE .5[47]

WEAPON	NO OBSTACLE A	OBSTACLE B	ENHANCEMENT B÷A
P-90mm	1.4	1.8	1.28
P-106mm	1.3	3.4	2.61
P-Dragon	3.0	5.0	1.67
P-TOW	4.5	5.3	1.18

The no-obstacle values give some indication of the relative effectiveness of the various weapons. Although the P-90mm and P-106mm appear equal in the no-obstacle case, the obstacle provides greater enhancement for the latter because of the significantly longer range at which the P-106 can engage. At different ranges the result for the P-106 would be less. The P-TOW is such an effective weapon at a range before the P-T55 can effectively engage that the obstacle has less impact on the P-TOW case than on the P-Dragon case.

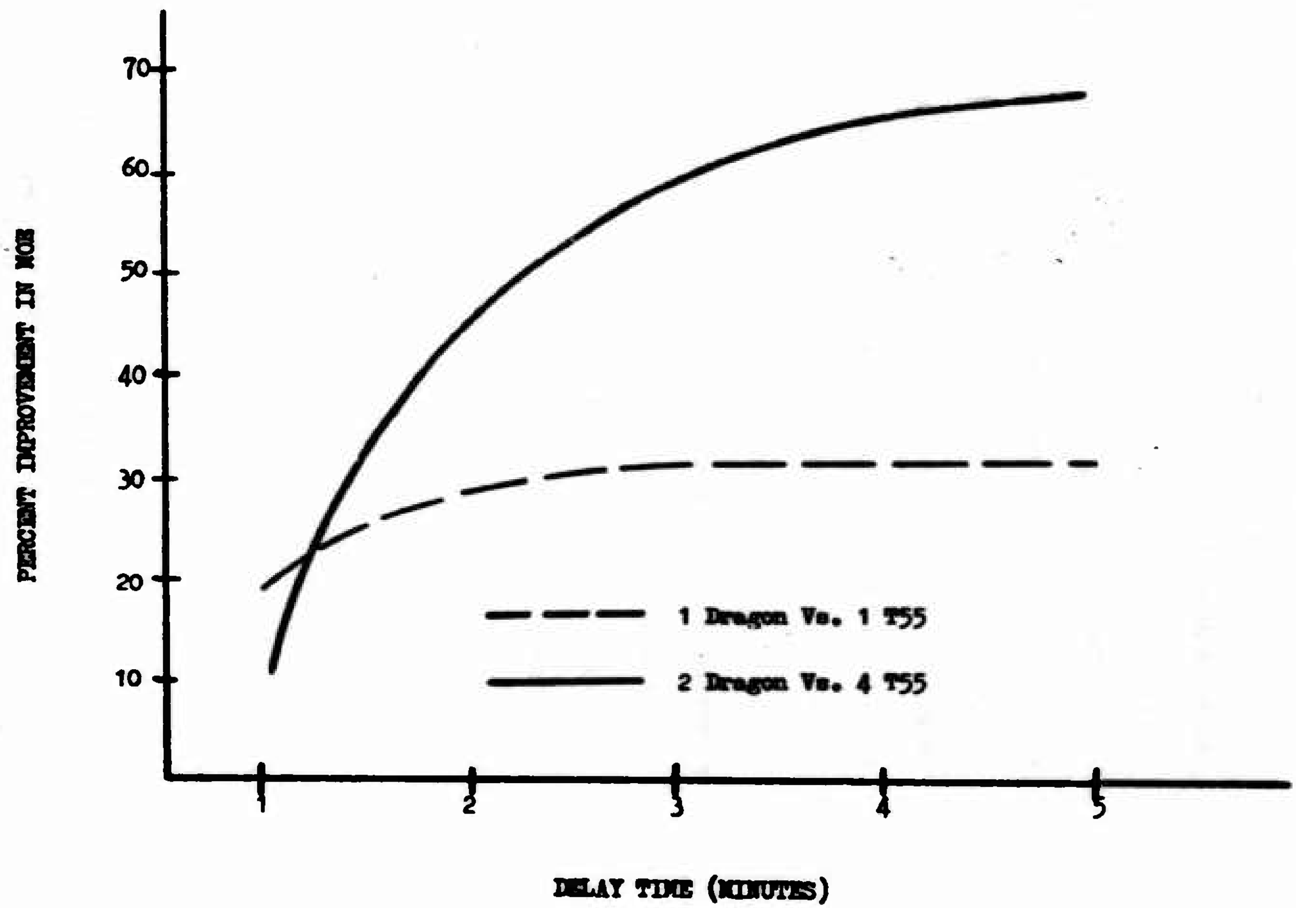
The FOES work is admittedly crude and preliminary and as a result has some significant shortcomings. One major failing was the inability to gauge the impact of indirect fire weapons. This aspect was neglected because of the inherent complexities of simulating indirect fires. A significant unresolved problem surfaced in attempting to represent AT weapons in a firepower concentration. MOE values for two AT weapons versus four tanks tended to be somewhat lower than the one on two case. This anomaly appears to be a function of the method used to represent the attacker detection event which may have given the attacker more than a realistic expectation of detection.

In spite of its rather obvious shortcomings the preliminary FOES work indicates some logical general insights on the dynamics of obstacle impact in the combat process. The only source willing to this point to even guess at the quantitative aspect of obstacles on the combat process is the HERO study which would postulate that use of mines, demolitions, and constructed obstacles would provide a combat power enhancement of 1.3, assuming the HERO definition of combat power.[48] In Table 2-1 the enhancement factors varied from 1.18 to 1.67 if the value for the P-106mm is discounted. It is logical to discount that particular value since the obstacle was sited at a near optimal range and the resulting enhancement is greater than could be expected under most circumstances. Preliminary results would indicate, however, that an expectation of increased combat power of 30 to 50 percent when the obstacle is employed is not unreasonable, especially considering the effectiveness of newer AT weapons.

One surprise in the FOES work was the lack of significance of delay. Figure 2-3 provides an example of outcomes when the intent was to determine the sensitivity of results to the length of delay time. The vertical axis represents the percent improvement in the MOE value

FIGURE 2.3

SENSITIVITY TO DELAY



when compared to the no obstacle or base case. The general tendency for additional effectiveness to rapidly peak and additional delay time lose meaning was true throughout the course of the analysis. Comparative weapon capabilities are apparently quickly maximized and increased delay times do not significantly increase the defender's additional combat power enhancement.

The preliminary conclusion that is derived from the analytic work is that vehicular destruction by mines and enhanced combat power is generally independent of delay time. In contrast, both the historical evidence and the analytic work indicate that the two phenomena of casualties and target enhancement may be significant add-ons to defender's combat power.

The logic structure formed by reviewing both the historical assessments and the available analytical results support the position that attempting to study the influence of the barrier on combat by defining a parameter called "delay" is infeasible. The effects of significant armored vehicle damage by mines and positive target enhancement when obstacles are covered by fire might be classed as the guaranteed influences when a barrier is employed. These effects, for the most part, are independent of delay time. The other influences that the barrier has had on combat such as economy of force, aiding in breaking and maintaining contact, permitting the defender to prepare subsequent positions, constricting combat service support, and developing intelligence are not guaranteed outcomes. Delaying the attacker certainly aids the defender in achieving these functions; however, the combat environment must have characteristics other than barriers which permit the defender to accomplish these actions. Delay is only one factor which might be useful in defining the defender's capability to exercise freedom of action.

On the basis of the literature search it appears that the hypothesis should be restructured to state: It is feasible to estimate the value of a barrier at engagement levels appropriate to theater modeling using simulation modeling techniques. To test this hypothesis a modeling technique must be chosen which will permit sufficient freedom of action to study the broader effects such as economy of force and breaking contact. If these effects cannot be studied the choice of employing a barrier collapses to comparing the resource cost of implementing a barrier with the cost of adding 30 to 50 percent more combat power.

CHAPTER II

FOOTNOTES

[1]U.S. Army Aberdeen Research and Development Center, Ballistic Research Laboratories, Mine and Countermine Warfare in Recent History, 1914-1970, by Russel H. Stolfi (Aberdeen Proving Ground, Maryland, April 1972), p. 2.

[2]Department of the Army, Office, Chief of Engineers, Engineer Agency for Resources Inventories (EARI), Landmine and Countermine Warfare—North Africa, 1940-1943, (Washington, D.C., June 1972), frontispiece.

[3]Department of the Army, U.S. Army Concepts Analysis Agency, Employment of Obstacles in Combat in Europe in World War II, (Contract No. DAAG 39-74-C-0033, Historical Evaluation and Research Organization (HERO), Dunn Loring, Virginia, March 1974), p. 1.

[4]Ibid., p. 166.

[5]Ibid., p. 129.

[6]Stolfi, op. cit., p. 38.

[7]HERO, op. cit., p. 129.

[8]Ibid.

[9]Ibid., p. 83.

[10]Ibid., p. 124.

[11]Ibid., p. 126.

[12]Stolfi, op. cit., p. 7.

[13]Ibid., p. 28.

[14]Ibid., p. 38.

[15]Strawson, John, The Battle for North Africa, (Ace Books, New York, New York, 1969), p. 111.

[16]Stolfi, op. cit., p. 38.

[17]EARI, North Africa 1940-1943, op. cit., p. 83.

[18]Stolfi, op. cit., p. 37.

[19]Lewin, Ronald, Montgomery As Military Commander, (Stein and Day, New York, New York, 1971), pp. 98-115.

[20]Stolfi, op. cit., p. 26

[21]EARI, North Africa 1940-1943, op. cit., p. 44.

[22]Department of the Army, Office, Chief of Engineers, Engineer Agency for Resources Inventory (EARI), Landmine and Countermine Warfare—Italy 1943-1944, (Washington, D.C., June 1972) p. 55.

[23]EARI, North Africa 1940-1943, op. cit., p. 173.

[24]Stolfi, op. cit., p. 83, 98, 102.

[25]Department of the Army, Office, Chief of Engineers, Engineer Agency for Resources Inventory (EARI), Landmine and Countermine Warfare—Korea 1950-1954, (Washington, D.C., June 1972) p. viii.

[26]HERO, op. cit., p. 1.

[27]Stolfi, op. cit., p. 20.

[28]Lewin, op. cit., p. 130.

[29]Ibid., pp. 117-130.

[30]EARI, North Africa 1940-1943, op. cit., p. 144.

[31]EARI, Italy 1943-1944, op. cit., p. xv.

[32]Ibid.

[33]HERO, op. cit., p. 4.

[34]Ibid., p. 102.

[35]EARI, Italy 1943-1944, op. cit., p. xix.

[36]Data for the Research Analysis Curve were taken from a briefing presented to the Chief of Engineers, 20 December 1973. Other sources were as indicated in the text.

[37]U.S. Army Engineer School, Mine-Countermine Operations, (Fort Belvoir, Virginia, January, 1973), p. 3-3.

[38]U.S. Army Mobility Equipment Research and Development Center, Antitank Effectiveness of the U.S. Army Standard Minefield Pattern, by William C. Comeyne (Fort Belvoir, Virginia, April 1970), p. ii.

[39]Ibid., p. 2.

[40]Ibid., p. ii.

[41] Information presented by LCOL Velverton, War Game Division of Combined Arms Combat Development Agency to Command and General Staff College Students enrolled in Course 3651—Mine/Countermine Warfare on 14 January 1975.

[42] Department of the Army, Office, Chief of Engineers, Engineer Strategic Studies Group, Unpublished Paper, "Interim Results—Fortification Obstacle Effects Simulation (FOES)," by Major Howard E. Boone (Washington, D.C., June 1974), p. 1.

[43] Ibid., pp. 4-9.

[44] Ibid., p. 10.

[45] Ibid., pp. 10-12.

[46] The weapons discussed in the analysis will be preceeded by a "P" to indicate they are a pseudo representation of the actual weapon since the true firing distributions were not represented in the model.

[47] "FOES," op. cit., p. 53.

[48] HERO, op. cit., pp. 116-169.

[49] "FOES," op. cit., p. 69.

CHAPTER III

—THE MODEL—

The logical conclusions which resulted from the literature search suggest the environment that must be created to provide a conclusive study of the impact of the barrier on the combat process. The critical requirement is to represent "freedom of action." "Freedom of action" implies a process where alternatives may be chosen for accomplishing the intended purpose. It would appear that four key factors define the capability to choose alternatives: the requirement or mission; the existing situation; resource constraints; and projected outcomes. The logical process of combining these four factors should produce a list of admissable decisions or alternative choices.

The requirement or mission is a simple statement of what must be accomplished. The existing situation is the decision maker's visualization of the important aspects of the environment in which he must accomplish the requirement. This environment is influenced by two distinct kinds of impacts: those the decision maker can control and those he cannot. In the military environment examples of the latter are terrain, weather, enemy size, and enemy dispositions. Examples of the former are allocation of fire support, location of reserves, and requirements assigned to subordinate elements. The decision maker's control is constrained by the available resources and the appropriate "cost" of a particular action in terms of those resources. Finally, the decision maker must estimate the result or outcome; logically choosing that course which provides the best chance for success within the resource limitations.

A concept for decision making was included in the CONAF Evaluation Model (CEM). In CEM, "at the beginning of each period, several tactical decisions are made at division level, based on the division estimate of the situation. These decisions include allocation of fire support to brigades, assignment of brigade mission, and commitment or reconstitution of a division reserve."[1] Obviously including any kind of a decision algorithm in combat modeling is a forward step. There are, however, some distinct disadvantages in the CEM system. "Best" outcomes are chosen, but the decisions are controlled by threshold of comparative firepower. Each is actually a "go no-go" action and some may occur concurrently. They are "no cost" decisions since the simulated decision maker is not required to spend resources. Thus this system only provides for a logical sequence for changing activity based on the current situation. The short fall is the fact that there is no comparison of alternative choices for accomplishing the same objective. As in other phases of CEM, the outcome is deterministic with this decision algorithm simply providing some additional flexibility.

An objective of this thesis is to establish a modeling technique capable of evaluating the influence of barriers. It is logical, therefore, to consider alternatives to the deterministic type model represented by CEM. One alternative is the Monte Carlo or probabilistic technique which "consists of determining a sample outcome which is dependent upon other variables, by randomly sampling from the distribution of these variables."[2] The Fortification Cbstacle Effects

Simulation (FOES) discussed in Chapter II is an example of such a model. Conflict has long existed in the military-oriented operations research community over the choice of a "deterministic" or "probabilistic" formulation of combat.[3] This thesis will not attempt to detail the various aspects of the arguments, but some brief discussion is necessary to support the subsequent selection of a modeling technique.

One key factor in the argument is whether or not the "added difficulty of solution of the probabilistic model leads to improved realism."[4] One significant analysis supports the position that the choice, in a real sense, is irrelevant because "there exists very little difference between probabilistic flow of the solution and deterministic results for forces involving more than a few dozen men."[5] Although this conclusion may be valid, it is tempered by one very significant factor. Both the deterministic and probabilistic techniques considered within the limits of the argument are oriented toward an almost complete dependency on relative mass, usually in the form of firepower scores or force ratio, to determine outcome. Any technique that claims to improve the representation of freedom of action must, therefore, consider how freedom of action should be balanced against the influence of mass. That requirement will be discussed at some length throughout this chapter; however, the initial problem remains the general choice of technique. If the solutions from deterministic and probabilistic representations of combat do, in fact, converge and the decision making process in CEM inadequately portrays freedom of action then some other representation of combat should be considered.

At this point it is helpful to forget the analyst and his concern for deterministic versus probabilistic and return to the decision maker and the four factors that influence his capability to choose alternatives. The decision maker's requirement and resources are deterministic, as are those aspects of the current situation which he can control such as the size, composition, and location of his reserve. Those aspects of the current situation which he cannot control such as weather and enemy dispositions may be classed as probabilistic. The existence of uncertainty in these areas supports intelligence as a function of combat with the purpose of reducing that uncertainty. The fourth factor, projected outcome, is significantly probabilistic. The nature of combat is such that the best plan may fail and the worst succeed; thus, the decision maker faces considerable uncertainty in this area. To reduce that uncertainty he exercises dynamic control of his resources. For example, he moves units to support, chooses to defend on the best terrain, or reallocates fire support at any time. In the perspective of the analyst a modeling technique for this process should provide the characteristics of uncertainty in outcome, alternative choices, and a dynamic control of resources.

The second major problem is to provide those characteristics for the model and maintain a useful perspective on the influence of mass on combat outcomes. Again the military-oriented operations research community provides two distinct opposing positions. On one hand an argument to support mass having the dominant influence on combat outcome is the conclusion that "'Since the year 1600 the size of the winning army has, on the average, been larger than the loser.'"[6] In contrast, another analysis of a similar period states that "Generally, initial force ratio, . . ., had little effect on the outcome of the battles studied."[7] The first position supports the widely accepted Lanchester theory of combat which portrays individual force elements as maintaining constant effectiveness with the exchange rate then favoring the larger force. The alternative position is supported by the fact that "historical data for infantry, armor, and air show consistently the more outnumbered a force is the better its exchange rate will be."[8] These two extreme positions provide ample space for compromise.

Using these arguments to gain an acceptable perspective on the influence of mass on combat outcome, it is useful to consider the various facets of the two extremes in a qualitative sense. First, if mass is not critical, in a pure sense, it would be logical to choose to fight all battles with smaller forces. That position is obviously counter-intuitive. A military tactician advocating a smaller army because it had a higher likelihood of winning would soon be seeking other employment. It would, therefore, be unreasonable not to desire a preponderance of force in the long run. At the same time it is reasonable to assume that the outnumbered opponent realizes his disadvantage and takes appropriate action to minimize its effect. This phenomenon probably accounts for the higher exchange ratios for greater disparities in force size. A combination of the historical data and logical argument would then prescribe that mass is dominant over time but must be viewed in a different perspective at a specific point in time.

The modeling concept selected to meet the various characteristics discussed in the preceding paragraphs was first developed in 1970 by Mr. Gerald E. Cooper then a senior analyst with the Force Structure

Department of the Research Analysis Corporation of McLean, Virginia. His proposal was termed experimental and there is no indication that the technique has been applied in any formal study in support of Department of the Army. As a result, information used to support this thesis was drawn from an unpublished report dated January 1971 and a sample computer test run. The short title of the report is "The VGATES (Visible Graded Approach to Theater Effectiveness) Notebook." The following comment establishes the general character of VGATES:

> VGATES is a prototype computer program that represents defensive combat in the abstract and in aggregate. A single run produces tabular and graphic summaries of combat over a range of available and committed resources.
>
> Combat is assumed to consist of a succession of single period trials. Before each trial, the defending commander reviews a list of admissable choices of what to do next. Subject to limitation on resources, the commander (algorithm) selects a single action from the list to maximize his forward (expected) FEBA position for the current period. The commander is permitted second thoughts about previous periods and can make a current choice as though many (but not all) preceding choices can be remade. The commander's decision process is repeated for each time period and each quantity of resource consumed.[9]

Briefly, this process may be described as theater conflict represented by a dynamic programming algorithm where the defending commander optimizes his strategy at a particular time and resource level.

VGATES visualizes the battle field as a series of intersections of sectors and defense lines. Sectors are widths of terrain generally parallel to the expected movement of the opponents. Logically, sectors are chosen to correspond to a specific unit type of frontage such as division sectors or brigade sectors. Defense lines are perpendicular to the expected movement of opponents and must be the same in each sector. The intersection of a sector and defense line provides a point at which an engagement may be assessed.

The algorithm which represents the defending commander uses the following objective function at period "t":[10]

$$OBJ(t) = \max_{NXT} \min_{L} \sum_{i=1}^{N4} Q(i,L) \times DIST(i,L)$$

where NXT is the decision index
L is the sector index
Q is the holding probability
DIST is the distance of a specified defense line in a specified sector
i is the defense line index
N4 is the number of defense lines

The holding probability "Q" is the probability that the defender will retain a specific defense line in a specific sector under the conditions that exist in period "t." "DIST" may be simply viewed as a weighting factor which defines the relative importance of a specific defense line. "DIST" is normalized based on a reference line so the range of possible values is $0 \leq DIST \leq 1$. Given three defense lines, sample values for "DIST" might be (1., .5, .33). Thus the defender is completely successful if he holds the first line. The territory gained by the attacker in moving to the third line is defined in this particular example to be of such criticality that the value of retaining defense line three is worth only one-third that of retaining defense line one. "The combat objective may be to retain a region. If holding any defense line in the region is a complete success, it is appropriate to regard all defense lines as having the same 'distance = 1.0."[11]

Qualitatively, the objective function is the choice of that admissable decision which maximizes the lowest sector holding probability considering all defense lines within the sector. Simply stated this "max-min" criterion is an attempt to strengthen to the maximum extent possible the weakest defender sector. A sample admissable decision list for a problem where the defending force consists of a single force type which may be either committed to combat in one of two sectors or added to the combat reserve might be:[12]

NXT

1 - Add no force
2 - Add one unit of force from CONUS to theater combat reserve
3 - Transfer one unit of force from combat reserve to sector 1
4 - Transfer one unit of force from combat reserve to sector 2
5 - Transfer one unit of force from sector 1 to combat reserve
6 - Transfer one unit of force from sector 2 to combat reserve

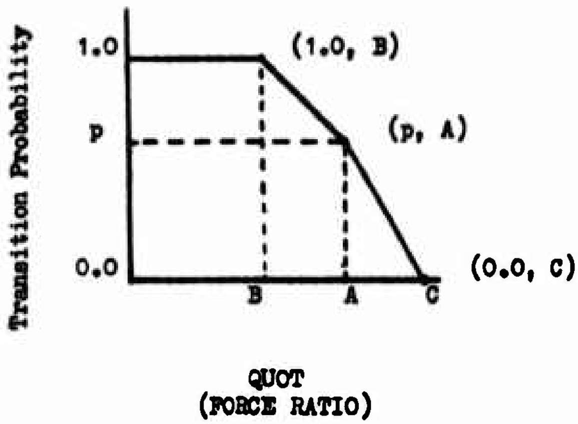
VGATES operates best in an environment where decisions cost either nothing or a unit cost. An example of a "no-cost" decision might be add no force, or if committed forces are considered to be completely controlled by the commander shifting a force from one sector to another. For other decisions the decision list is structured to reflect the unit cost equivalency. For example, assume the requirement to compare reinforcing with artillery versus committing tank unit reserves. Rather than selecting the unit sizes and then attempting to cost the alternatives, the unit sizes are selected in a manner which defines the alternatives to be about equal in cost.

The semi-probabilistic nature of VGATES is reflected in the transition probability ("T") concept. This device is a reflection of the fact that the commander is faced with an uncertain outcome. The transition probability is assumed a function of strength or force ratio (QUOT). Figure 3.1 displays the geometry of this method.[13] The vertical axis is the transition probability and the horizontal axis the force ratio. For a value $QUOT \leq B$ the defender is assumed to retain the engagement point with probability 1.. At the other extreme, for

$QUOT \geq C$ the defender is certain not to retain the point of engagement.

FIGURE 3.1

TRANSITION PROBABILITIES
IN VGATES



When the force ratio (QUOT) is in the interval B to A the transition probability is defined by a linear function determined by the two given pairs of transition probability and force ratio values (1.0, B) and (p, A). Likewise the values in the interval A to C will be defined by a linear function determined by the pairs (p, A) and (0.0, C). For any given force ratio the function then provides a corresponding probability for defender success.[13]

VGATES is not necessarily the ultimate in combat modeling, nor is it in a state of development, as introduced in the previous paragraphs, appropriate to direct application for the particular problem of analyzing barrier effectiveness. One significant attraction is the concept of a decision process which is significantly unconstrained in comparing alternatives. The formulation of an admissable decision list is limited only by the analyst's ingenuity and the necessity for maintaining a reasonable computer run time. An additional attraction is the aspect of uncertainty in the combat outcome. There is a price to pay for this particular advantage. VGATES was designed "to provide a means to relax some but hardly all of the GO and NO-GO conditions and data applied in some forms of combat simulation to partial GO and partial NO-GO rules. Partiality or distribution of results is realistic and, in a sense, should present more credible though non-unique conclusions."[14] The cost of uncertainty would appear to be the sacrifice of a unique quantitative answer for the sake of better qualitative solutions. It could be argued that the uncertainty aspects of VGATES do not truly escape the dominance of relative mass, since the transition probabilities are a function of relative force ratio. That argument will be considered in detail as the technique is modified to address the particular problem of barrier effectiveness.

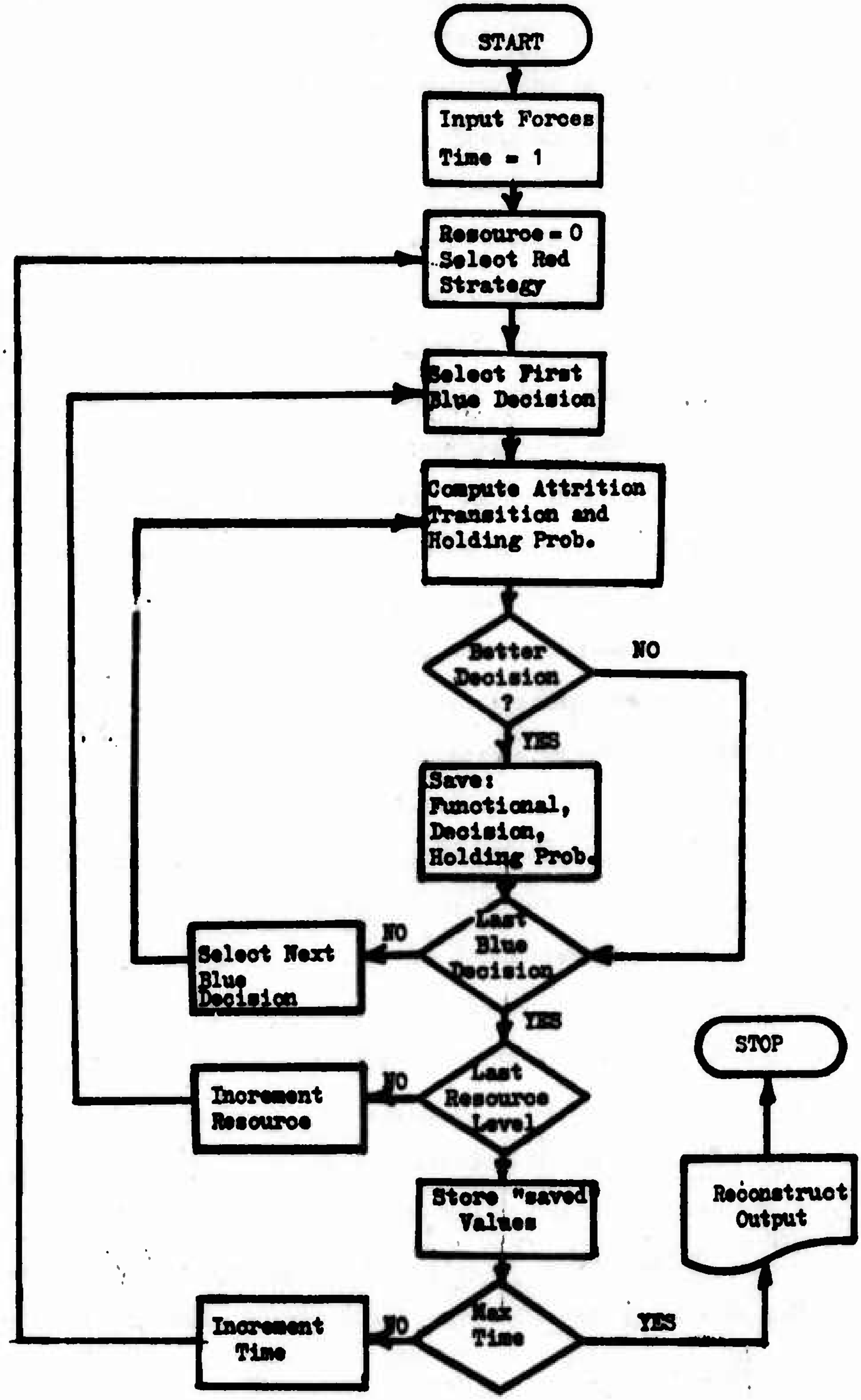
Internal and external modifications of VGATES were required to structure the technique for the barrier problem. The prototype model which resulted from those modifications will be referred to as the Barrier Effectiveness Analysis Revision (BEAR). The first modification addresses the general perspective of the type problem to be addressed. VGATES was designed in an environment where force structure decisions are concerned with theater and multi-theater strategy. In that environment factors such as basing decisions, inter-theater lift, and multi-service configuration (new aircraft carrier versus new main battle tank) must be considered. The obstacle system or barrier impacts at a lower echelon—appropriately that echelon where the commander makes the decision to employ the barrier as one of the alternative tools for accomplishing his mission. For BEAR the Division was chosen as the level for analysis. This choice was influenced by the fact that CEM resolves combat at the Brigade level. The barrier is basically a combat multiplier and should impact at the level where combat is played. Finally, the Division directs and controls those resources which support the Brigade. This altered perspective does not evoke massive changes in technique, but sets the stage for a different set of problems.

The basic logic sequence for the BEAR algorithm is displayed in the flow chart shown in Figure 3.2. After appropriate inputs are cataloged and the time counter is initialized, the process is controlled by three basic logic loops. The initialization sequence sets the beginning force levels in each sector, and sets the first combat engagement on the first defense line. Next, a Red strategy is chosen for that time period and the available Blue resource level is set to zero. The algorithm then executes the inner-most loop which corresponds to the selection of the best decision that Blue can make within the established resource level. This selection is based on Red and Blue attrition and the resulting transition and holding probabilities. Given that the decision currently being considered is equivalent to a previously selected decision, the current decision will be selected. It will be subsequently established in the discussion of the Blue decision list that this procedure for treating indifference will gain some analytic significance by the selection of sequence for the Blue decisions. When a Blue decision is selected as better, appropriate output values are saved.

The inner-most loop is exhausted by considering all feasible Blue decisions. The algorithm then checks to determine if all feasible

FIGURE 3.2

FLOWCHART OF LOGIC FOR BEAR ALGORITHM



resource levels have been considered. If not, the resource value is incremented; the first Blue decision is selected; and the process of selecting the best Blue decision is repeated. After all feasible resource levels have been considered, the selected decisions, and objective function values are stored for future reference. The algorithm then checks to determine whether or not all time periods have been considered. If not, the next time period is selected; necessary values are re-initialized; Red chooses a new strategy; and the processes of the two inner loops are repeated. After all time periods have been considered the desired output is reconstructed for analysis.

BEAR is structured so that only two major inputs are required from a read file: initial forces and terrain designations. All other information required for initialization is provided in internal data statements. The model is structured with two sectors to correspond to two Blue brigade frontages, and a maximum of six defense lines. A maximum of 31 resource levels and 30 days of combat is permitted. Terrain at the intersection of a sector and defense line may be designated as one of three classes (easy, moderate, difficult) which correspond to the three general classes of terrain used in CEM as discussed in Chapter I. The influence of terrain in the modeling process will be detailed in subsequent discussion of transition and holding probability sequences.

One difference between VGATES and BEAR is the method for inputting the initial forces. VGATES was structured to input Blue and Red forces as types of firepower. BEAR is designed for inputting unit types and then converting them to a representation of firepower. Unit organizations for Blue forces were based on data provided in <u>USACGSC</u>.

RB 101-1 Organizational Data for the Army in the Field. Red force organization was adopted from FM 30-102 Handbook on Aggressor. The unit types acceptable in BEAR are as follows:

BLUE (BUNIT)
1 Armor Battalion, 17-35H
2 Mechanized Infantry Battalion, 7-45H
3 Armored Cavalry Squadron, 17-105H
4 Artillery Battalion (155mm HOW)
5 Artillery Battalion (8in HOW)

RED (RUNIT)
1 Heavy Tank Regiment
2 Medium Tank Regiment
3 Motorized Rifle Regiment
4 Division Artillery (Tank Division)
5 Reconnaissance Battalion
6 Division Artillery (Motorized Division)
7 Anti-Tank Regiment
8 Mixed Artillery Brigade

Units input to BEAR are converted to five firepower types. Where there is possible conflict of assignment such as the case of BMP mounted Saggers, the assignment was based on the primary weapon type—anti-tank in this particular example.

TABLE 3.1

FIREPOWER TYPES

I. Light Weapons (Individual and Crew Served)
II. Armor (Tanks)
III. Light Armor Mechanized Vehicles (APC, BMP)
IV. Anti Tank Weapons (TOW, SAGGER)
V. Artillery and Mortars

The resulting combat power representations of particular unit types are shown in Tables 3.2 and 3.3. For each force the combat power representations are assigned to either one of the two sectors or placed in the reserve as designated in the input data. The first engagement is set on the first defense line by assigning a holding probability value of 1.0 for that line at the beginning of D-day. The algorithm can then begin by selecting a Red strategy.

TABLE 3.2

BLUE COMBAT POWER

(BUNIT) Unit Types	Firepower Types (MBTYPE) I	II	III	IV	V
1 Armor Battalion	277	54	18	0	4
2 Mechanized Battalion	714	0	63	36	13
3 Armored Cavalry Sqdn	643	27	75	9	0
4 Artillery Battalion (155)	0	0	0	0	18
5 Artillery Battalion (8")	0	0	0	0	12

TABLE 3.3

RED COMBAT POWER

(RUNIT) Unit Types	Firepower Types (NRTYPE) I	II	III	IV	V
1 Heavy Tank Regiment	5	98	15	0	0
2 Medium Tank Regiment	5	98	15	0	0
3 Motorized Rifle Regiment	1490	34	170	21	24
4 Division Artillery (Tank)	20	0	21	6	50
5 Reconnaissance Battalion	23	7	12	0	0
6 Division Artillery (Motorized)	32	0	21	18	74
7 Anti Tank Regiment	16	0	8	34	0
8 Mixed Artillery Brigade	20	0	0	0	72

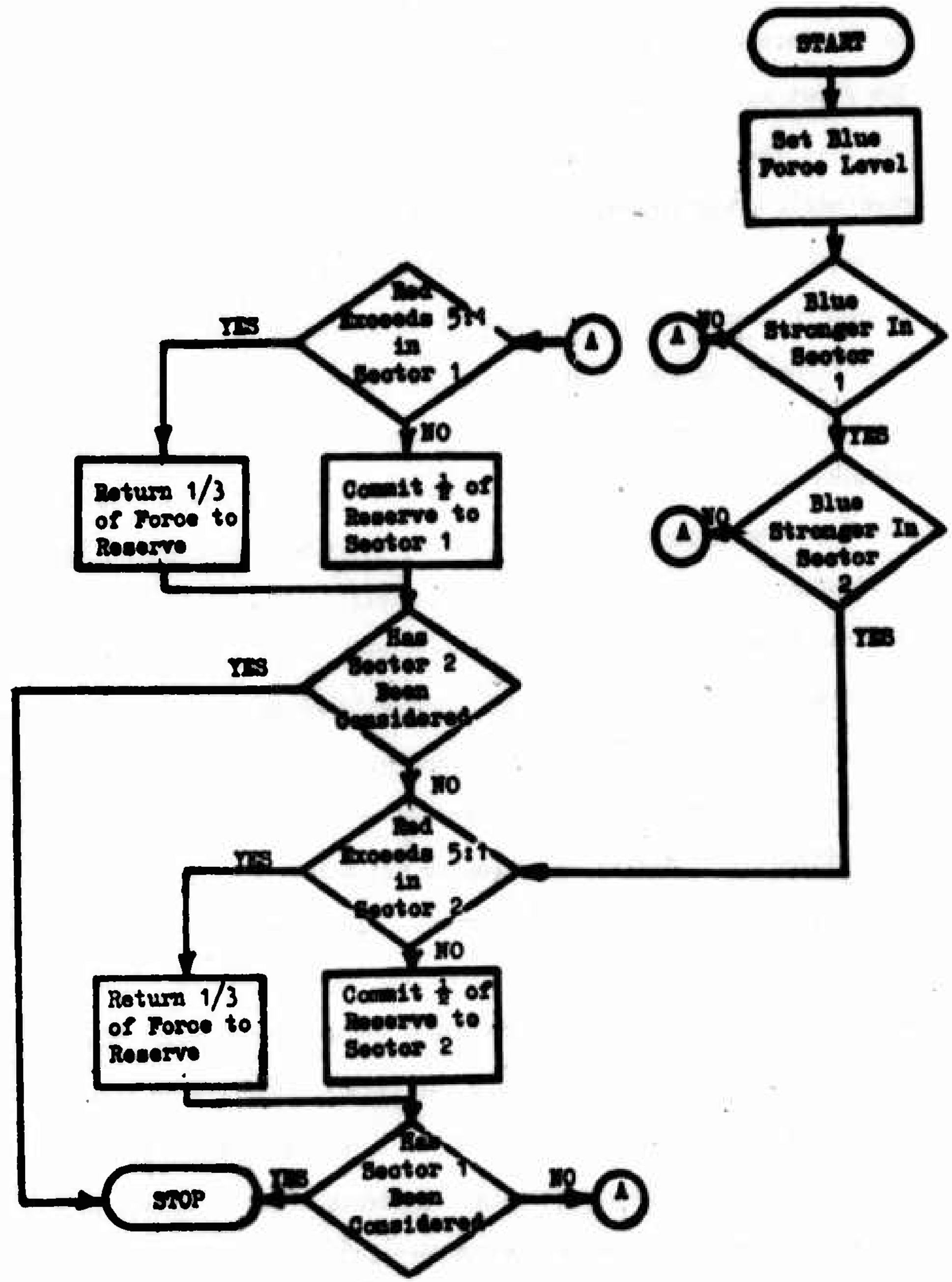
One major structuring problem for BEAR was the choice of an appropriate list of admissable decisions. The fact that only the Blue commander had decision power in VGATES was unacceptable. The best solution to this problem would be to provide the simulated Red commander with a similar algorithm which enables him to take an optimal course of action in each period. That course of action was considered infeasible in view of the time requirements and analyst capability supporting this paper. The alternative was to provide the

Red force a structured GO NO-GO decision process similar to that used in CEM. The relative force status is examined by Red at the start of each period, before Blue makes a decision. The weaker Blue sector is always chosen for the first action. If Red has less than 5:1 superiority in that sector he immediately commits one-half of his reserve to that sector. If Red forces in the stronger sector also have less than a 5:1 advantage, Red commits one-half of the remaining reserve to that sector. At the beginning of any period should the superiority exceed 5:1 in any sector, one-third of the committed element will be returned to the reserve. The threshold value 5:1 is an arbitrary choice; however, it does correspond to the logical construction of other components of the model. In the development of the transition probability sequence it will be demonstrated that a 5:1 Red superiority will restrict Blue to less than a 10 percent chance of retaining a specific defense line. By adding forces at less than 5:1 Red is attempting to achieve the "near certain" win condition. By withdrawing some elements at greater than 5:1, Red is attempting to reconstitute his force in contact under the most favorable conditions. This process is shown in detail in the flowchart in Figure 3.3.

This Red decision process may seem rather limited and arbitrary. One objective was to keep it simple. The other was to represent two actions which could have a major impact on Blue's strategy. The first is a Red tendency to operate by unit replacement. If the force ratio exceeds the 5:1 ratio in a period, the one-third withdrawal would approximate a unit size. The withdrawal of those forces will probably take the force ratio below 5:1 which forces a reinforcement the next period, accomplishing the replacement within the force's current

FIGURE 3.3

FLOWCHART FOR RED DECISION PROCESS



capability. The larger commitment of reserves to the weakest Blue sector is an attempt to represent the doctrine of concentrating at the weakest point.

The selection of the initial decision space for Blue was limited to 13 admissable actions. These actions are detailed in Table 3.4. The first seven decisions are "no cost." They are selected based on the idea that the commander can institute the action within his existing resources. They essentially provide him control of his organic forces by doing nothing, moving them laterally or moving them front to rear, or rear to front. The sequencing of these seven decisions was selected to provide an inherent priority in those cases where the algorithm might be indifferent to a choice between two decisions. As previously established should indifference be encountered, the current decision is selected. Assuming this indifference, the sequencing dictates that it is least attractive to shift forces laterally. Logically if forces are required forward the more likely alternative would be to commit from the reserve. Given that circumstances could exist where the algorithm would be indifferent between committing more forces and reconstituting a reserve, the latter would be preferred to permit rehabilitation and rest. Finally, if taking no action is equivalent to any other "no cost" decision, no action would be preferred. This choice logically permits the Blue commander to hold the current status and not rearrange forces in a manner that in future periods might prove inadvisable. The six additional decisions permit Blue to buy added capability for one sector. That capability may be ground forces, artillery support, or the barrier. The barrier initially represents only the effect of a force multiplier with a maximum value of 1.3. This additional 30

TABLE 3.4

BLUE DECISION TABLE

COST	NXT	
(0)	1	Transfer one-third combat power from Sector 1 to Sector 2
(0)	2	Transfer one-third combat power from Sector 2 to Sector 1
(0)	3	Add one-half of reserve to Sector 1
(0)	4	Add one-half of reserve to Sector 2
(0)	5	Transfer one-third of Sector 1 to reserve
(0)	6	Transfer one-third of Sector 2 to reserve
(0)	7	Do nothing
(1)	8	Add one tank company to Sector 1
(1)	9	Add one tank company to Sector 2
(1)	10	Add one battery artillery support to Sector 1
(1)	11	Add one battery artillery support to Sector 2
(1)	12	Add Barrier Multiplier increment (.05) to one defense line in Sector 1 (Max 1.3)
(1)	13	Add Barrier Multiplier increment (.05) to one defense line in Sector 2

percent can be gained only by .05 increments in each time period on only one defense line. The model is structured so that when the barrier exists Blue attrits with the enhanced capability. Blue losses, however, are assessed only against existing units. The sequencing of these decisions was selected to force the choice of the barrier should the algorithm be indifferent.

The choice of a method for computing attrition in BEAR was a major problem because of the necessity to establish a relationship between the influence of mass and the effect of a combat multiplier. "The VGATES Notebook" provides a generalized theory of attrition based on the scalar notion:[15]

$$DR/Dt = -(g \times B^{M1} + d) \times R^{M2} \qquad (1)$$

$$DB/Dt = -(h \times R^{N1} + e) \times B^{N2} \qquad (2)$$

where
R is the Red Force representation
B is the Blue Force representation
g is an effectiveness factor for Blue Forces against Red Forces
h is an effectiveness factor for Red Forces against Blue Forces
M1, M2, N1 and N2 are exponents whose values determine a particular attrition theory

The parameters "d" and "e" are called auto attrition factors. Their value will be assumed to be zero and as such they will be deleted from subsequent discussion without comment. If the values M1=N1=1 and M2=N2=0 are chosen for equations (1) and (2), the result is a statement of the Lanchester Square Law for attrition. This law is the most widely used in combat modeling,[16] so it provides the best basis for discussion. The scalar representation of the Square Law is:

$$DR/Dt = -E_B B \qquad (3)$$

$$DB/Dt = -E_R R \qquad (4)$$

where E_B and E_R have been substituted for "g" and "h" in equations (1) and (2). Dividing equation (3) by (4) the result is:

$$\frac{DR}{DB} = \frac{E_B B}{E_R R} \qquad (5)$$

It could then be argued that, under Square Law conditions, for Blue to gain an equivalent exchange (DR/DB=1) at a specific point in time, the relative effectiveness must be the reciprocal of the relative mass. Therefore, if Blue is outnumbered 3 to 1, each Blue must be three times as effective as each Red. Intuitively this particular representation of attrition is not unappealing.

The extension of the Square Law to the differential case negates some of that appeal. In derivative form equations (3) and (4) become:

$$dR/dt = -E_B BG(t) \qquad (6)$$

$$dB/dt = -E_R RG(t) \qquad (7)$$

where G(t) is some function of time. Dividing equation (6) by (7) yields:

$$\frac{dR}{dB} = \frac{E_B B}{E_R R} \qquad (8)$$

If equation (8) is integrated:

$$R_t^2 - R_o^2 = E_B/E_R \, (B_t^2 - B_o^2) \qquad (9)$$

On this basis Blue can achieve a proportionally equal exchange in the long run only if $E_B/E_R = (R_o/B_o)^2$. Now, if Blue is outnumbered 3 to 1 at the start, each Blue must be nine times as effective as each Red to achieve parity. As a result even though Blue could gain a reasonable exchange at a specific time, the manner in which the forces decay negates that effect.

In CEM the attrition equations are not direct applications of the Square Law, but the characteristics are similar. After some manipulation the CEM representation for armor losses could be written:[17]

$$DR/Dt = -R(1-e^{-\frac{C_1B}{R}}) \qquad (10)$$

$$DB/Dt = -B(1-e^{-\frac{C_2R}{B}}) \qquad (11)$$

where C1 and C2 are combinations of appropriate effectiveness and vulnerability parameters. To gain some insight into these equations assume that at a specific time C1=C2=1 and Blue is outnumbered 3 to 1.

$$DR = -R(1-e^{-1/3}) = -R(.281) \qquad (12)$$

$$DB = -B(1-e^{-3}) = -B(.950) \qquad (13)$$

$$DR/DB = \frac{(3)(.281)}{.950} = .887 \qquad (14)$$

In this scalar notion it would appear that the exchange rate would be most favorable to Blue, since the proportional exchange for equal effectiveness is near one even though Blue is outnumbered 3 to 1. It is obvious, however, from a comparison of the proportional losses that decay immediately favors Red. Figure 3.4 shows a sample force decay using parameter values that actually correspond to those used in CEM. This particular theory has even less dependence on force ratio at a specific time than the Lanchester Square Law, but there is a significant dominance of mass over time.

A possible alternative method for calculating attrition is the application of the $(1+p)^{th}$ law.[18] This law may be discussed by first returning to the generalized scalar notion of attrition:

$$DR/Dt = -E_B B^{M1} R^{M2} \qquad (15)$$

$$DB/Dt = -E_R R^{N1} B^{N2} \qquad (16)$$

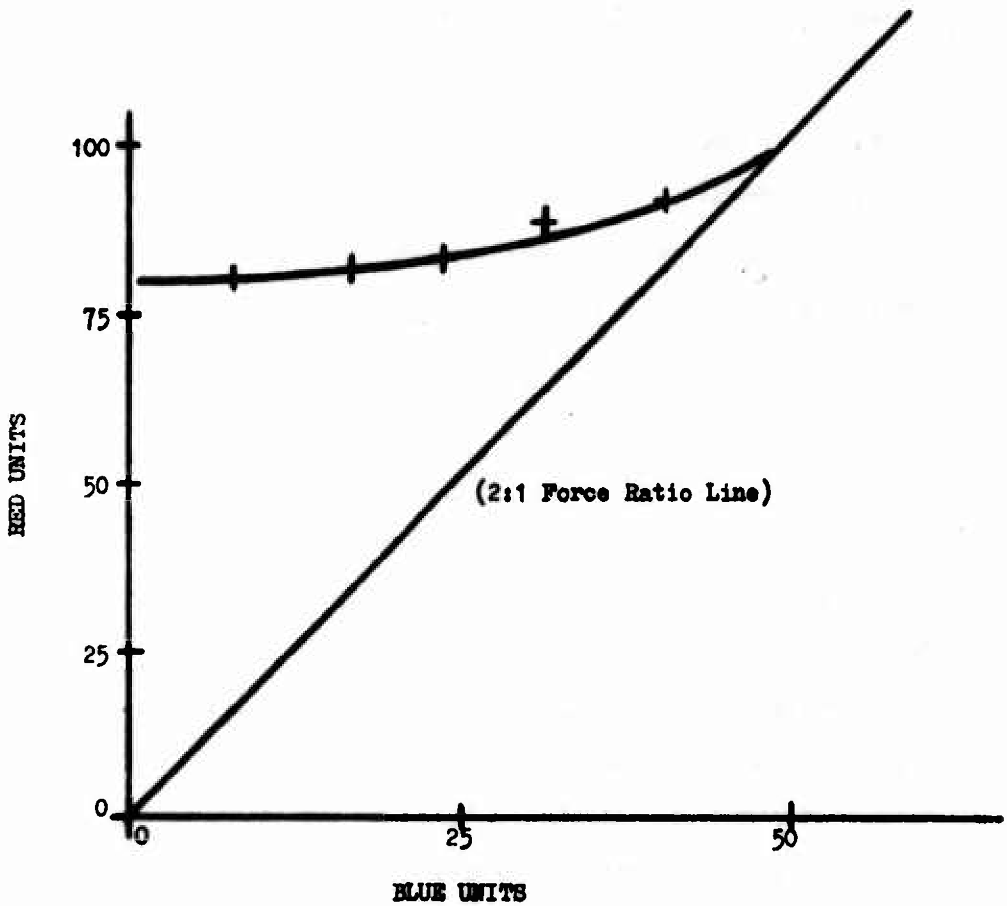
If M2=N2=n and M1=N1=n+p the equations become:

$$DR/Dt = -E_B B^{n+p} R^{n} \qquad (17)$$

$$DB/Dt = -E_R R^{n+p} B^{n} \qquad (18)$$

FIGURE 3.4

FORCE DECAY IN CONAF EVALUATION MODEL



Dividing equation (17) by (18) the result is:

$$\frac{DR}{DB} = \frac{E_B B^p}{E_R R^p} \qquad (19)$$

which is not dependent on the value of "n." A transfer to the differential operators and subsequent integration will yield a function with force sizes raised to the (1+p) power which supports the nomenclature of the $(1+p)^{th}$ law.

To indicate the effect of this particular approach assume values of p=1 and n=-.2. Under this circumstance equation (19) becomes:

$$DR/DB = \frac{E_B E}{E_R R} \qquad (20)$$

which is the same as the scalar position associated with the Square Law. There is, however, a fundamental change in the total influence of attrition. By appropriate substitutions equations (17) and (18) are now:

$$DR/Dt = \frac{E_B B^{.8}}{R^{.2}} \qquad (21)$$

$$DB/Dt = \frac{E_R R^{.8}}{B^{.2}} \qquad (22)$$

The value of "n" has no influence on the exchange rate (DR/DB), but there is a significant influence on the magnitude of attrition. In essence, "n" is controlling the speed of decay of Red and Blue forces which would be considerably slower for the specific values of "p" and "n" chosen in this example.

For HEAR the attrition scheme with p=1 and n=-.2 was adopted through a trial and error procedure. The adoption of this particular attrition theory for HEAR had some distinct advantages. The numerically inferior opponent is best served by attempting to increase his per force unit effectiveness to a level at least equivalent to his proportional mass inferiority. Mass is rewarded, but in a much expanded time frame. It could then be argued that mass is portrayed as less significant to a series of battles, but intuitively its probable impact on the war is retained.

The next problem was to examine this particular attrition theory in the context of the barrier providing the function of a combat multiplier. Accepting the fact that the barrier is a combat multiplier, one must address the question, what does it multiply? There are three possible approaches:

(1) The number of Blues that may effect attrition;

(2) The effectiveness of each Blue;

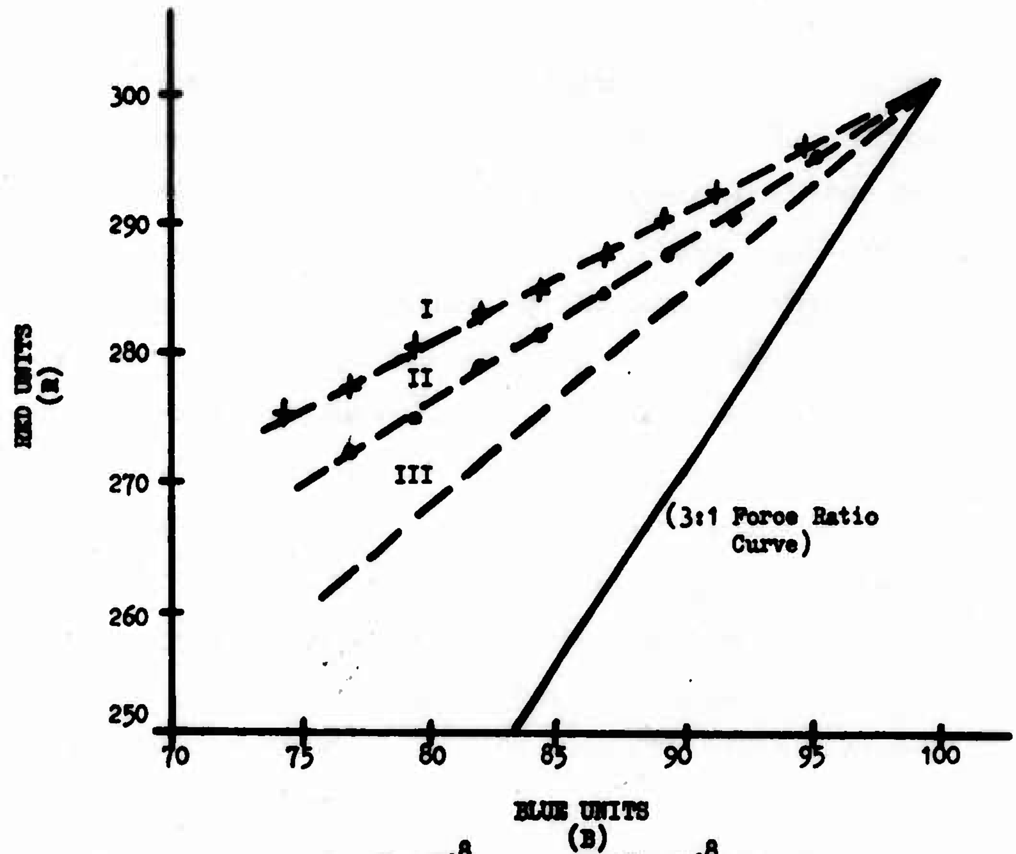
(3) The number of Blues that may both attrit and be attrited.

The third approach is to change the true force ratio by virtue of a combat multiplier. In an analytic sense that theory cannot be accepted. Given a combat multiplier of two, one weapon would equal two weapons with a combat multiplier of one. In the first case loss of one weapon would result in capability zero. In the second case the loss of one weapon only halves the capability. Logically the two conditions are not equivalent. For this reason it was determined that the combat multiplier should not affect the true force ratio. Analysis of the other two approaches provided some interesting results. Figure 3.5 shows force decays for a starting force ratio of 3:1 with no replacement using the attrition sequence in BEAR. The results indicate that the greater impact of the combat multiplier would be in altering the per unit effectiveness.

If the Lanchester theory is examined this phenomenon is not true. Recalling the basic Lanchester attrition equations:

FIGURE 3.5

FORCE DECAY IN HEAR USING COMBAT MULTIPLIER



I Base Case— $\frac{DR}{Dt} = \frac{E_B\ B_1^{.8}}{R^{.2}}$; $\frac{DB}{Dt} = \frac{E_R\ R^{.8}}{B_2^{.2}}$; $B_1 = B_2 = B$.

II Increased number of Blues for Attrition—

$$\frac{DR}{Dt} = \frac{E_B\ B_1^{.8}}{R^{.2}} ; \quad \frac{DB}{Dt} = \frac{E_R\ R^{.8}}{B_2^{.2}} ; \quad B_2 = B;\ B_1 = 1.3 \times B$$

III Increased per unit effectiveness—

$$\frac{DR}{Dt} = \frac{E'_B\ B_1^{.8}}{R^{.2}} ; \quad \frac{DB}{Dt} = \frac{E_R\ R^{.8}}{B_2^{.2}} ; \quad B_1 = B_2 = B;$$

$$E'_B = 1.3 \times E_B$$

$$DR/Dt = E_B B \qquad (1)$$

$$DB/Dt = E_R R \qquad (2)$$

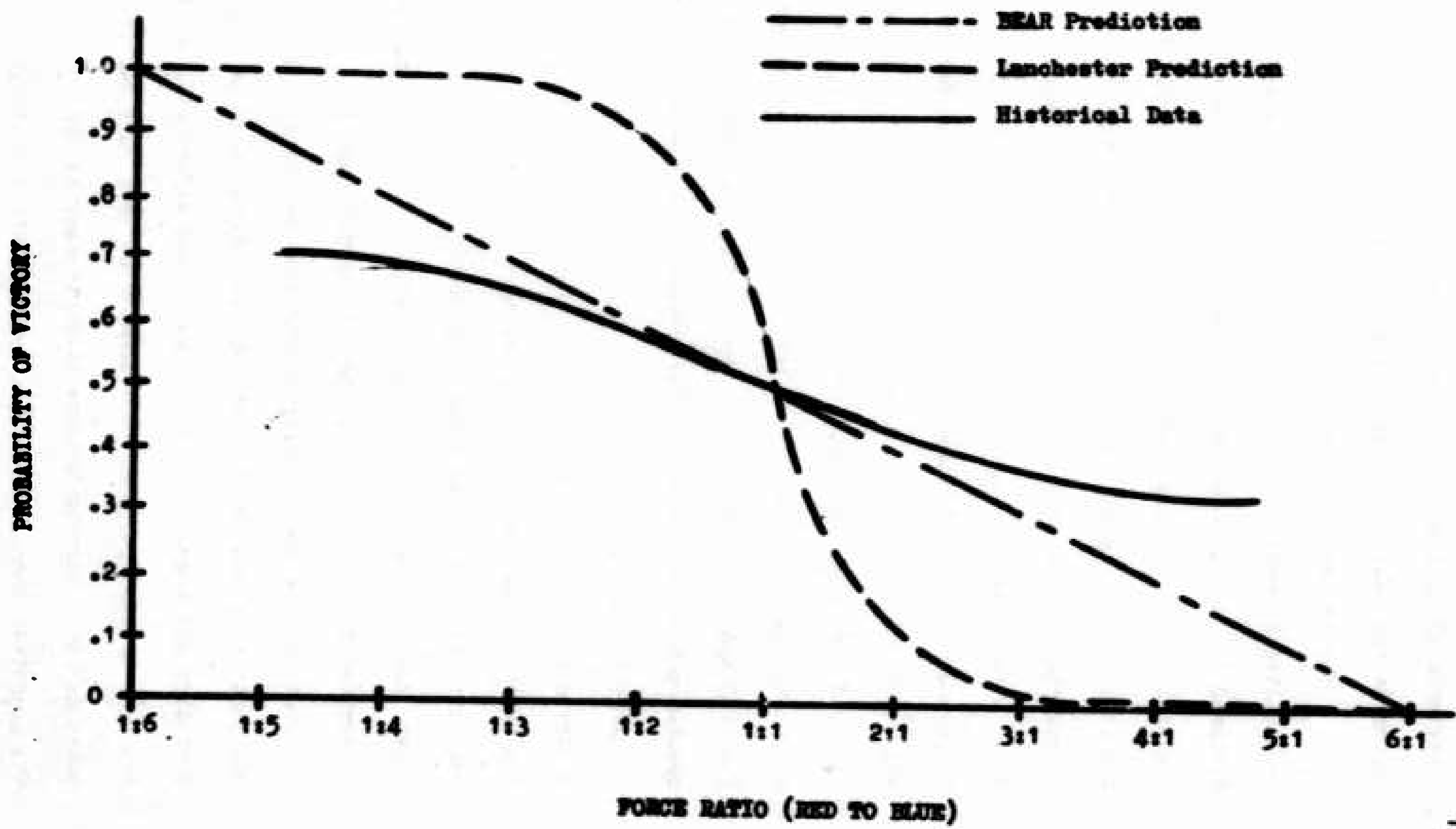
These equations indicate that attrition in the Lanchester theory is independent of the size force being attrited. It would, therefore, make no difference whether the combat multiplier was applied as $E_B' = 1.3 \times E_B$ or $B' = 1.3 \times B$. As previously discussed the force decay using the Lanchester Square Law will follow the same path for the base case (curve I in Figure 3.5) as in the method selected for BEAR, only in using the square law the speed of decay will be greater. Using the combat multiplier in the Lanchester formulation the decay will follow curve II in Figure 3.5 regardless of whether the combat multiplier is viewed as multiplying the effectiveness of each Blue or multiplying the number of Blues effecting attrition. The attrition method adopted for BEAR is a Lanchester type formulation of combat which does not change the relationship of attrition and comparative effectiveness at a specific point in time. At the same time a combat multiplier effect can be applied which will produce a significant impact on outcome without distorting the fact that a 3:1 force ratio means that one side has 300 tanks and the other 100.

To this point in the discussion no effort has been directed to distinguishing between transition probabilities and holding probabilities. The transition probability is merely the probability that Blue retains a specific engagement point at the current force ratio value developed from the type function displayed in Figure 3.1. The holding probability is the probability that Blue retains a specific engagement point given the probabilities that Blue still occupies engagement points forward of that point. Therefore, in a problem with one defense line the holding probability equals the transition probability. The holding probability concept will be further detailed later in this chapter.

Two major problems were encountered in adjusting the transition probability concept for BEAR. The first problem was determining an acceptable function to represent the relationship of transition probability to force ratio. In mass oriented tools such as CEM a look-up table was provided where the combination of force ratio and type engagement (attack of prepared position, meeting engagement, etc.) indicates a distance the FEBA will move as a result of each engagement.[19] A relatively insignificant difference in force between two opponents will cause the FEBA to advance in favor of the larger force. Intuitively this alteration in FEBA location has been associated with the condition of "win-lose." The basic foundation for the orientation to mass in determining the "win-lose" outcome of combat is found in the Lanchester theory of combat, which postulates the constant effectiveness of individual combat elements as previously discussed. Figure 3.6 demonstrates how the Lanchester type theory would predict the outcome of combat based on force ratios. The figure also indicates that the Lanchester type prediction appears unsatisfactory when compared with the actual outcomes of a significant number of historical battles.[20] The third curve is a compromise position which was used as the base function to define the relationship of force ratio and transition probability in BEAR. The aspect of "win-lose" is directly transferable to the concept of a transition probability which defines the Blue force's capability to retain terrain—a "win" condition. In terms of values the compromise position retains some aspect of the

FIGURE 3.6

COMPARATIVE METHODS FOR ASSESSING IMPACT OF MASS[20]



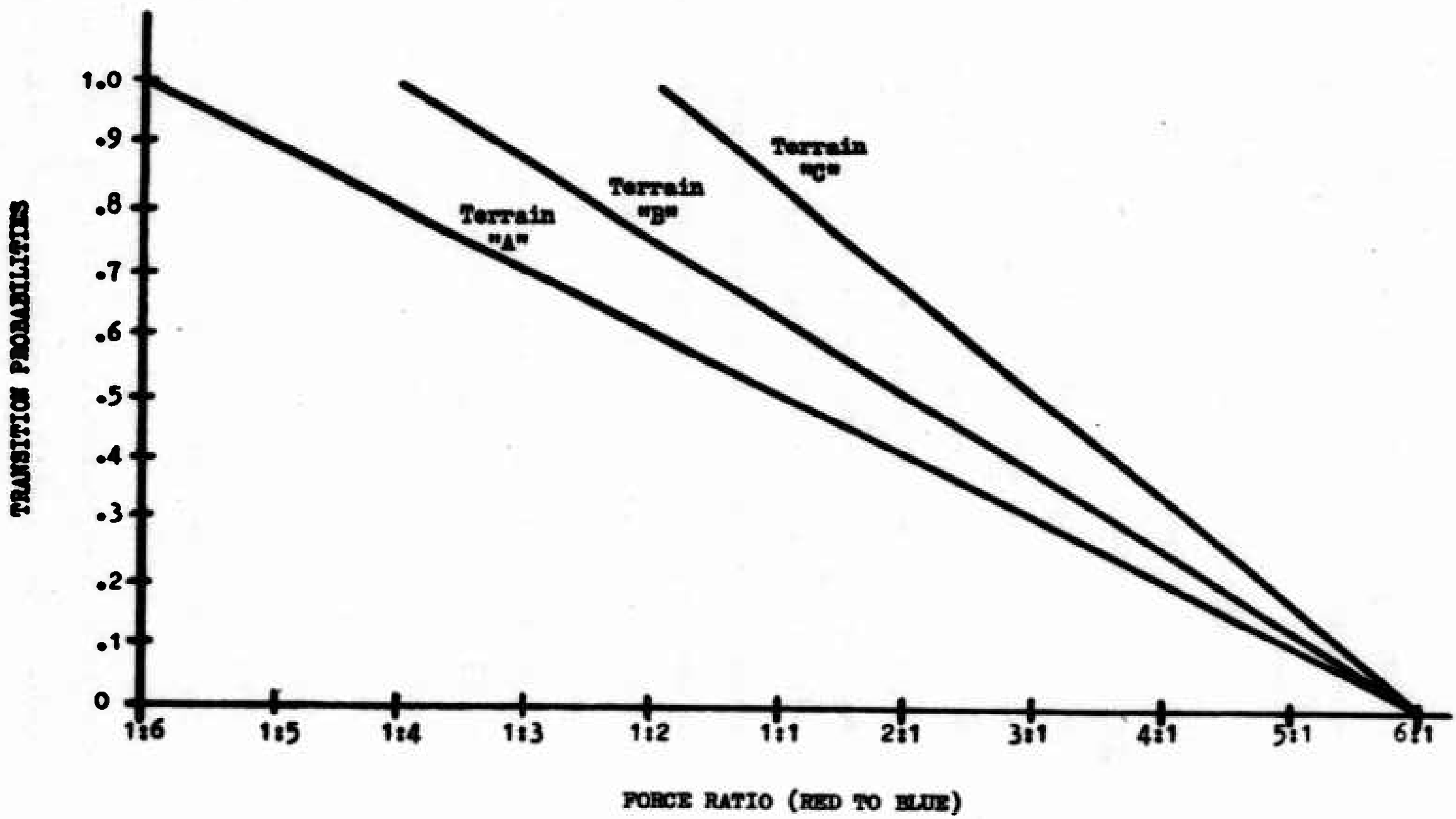
importance of mass postulated by Lanchester and, at the same time, moves closer to the reality of the historical data.

The second major problem encountered in adjusting the transition probability concept was the impact of terrain. Since VCATES was designed for higher echelon considerations terrain was not played. At division level, terrain becomes very important and the logical place for it to impact is the combat outcome. In CEM the "win" condition is associated with FEBA movement, and the barrier impacts by delaying. In an attack against hasty defenses with a 3:1 ratio the FEBA movement rates would be 3.1, 2.7 and 1.1 kilometers per hour for terrain A, B, and C respectively. A two hour delay would "buy" the defenders .52, .45, and .18 kilometers less advance by the attackers. If those values are normalized based on type C terrain the resulting values would be 2.8, 2.5 and 1. Thus it would appear that the barrier has considerably greater value in A terrain. The historical research supporting this thesis indicated that the barrier tends to have the same value, whatever that may be, regardless of where you put it. In this example the delay is two hours. If the defender can accomplish a useful purpose with two additional hours then that value accrues to him independent of the terrain. One logical argument is that terrain determines the cost of achieving the barrier function. In A terrain the cost will be considerably higher because there is little obstruction to the mobility of vehicles; hence more artificial obstacles are required. In C terrain less effort will be required to achieve the same purpose. The barrier is then more valuable to the commander in C terrain because it costs less to achieve the effect. The objective then is to seek a representation of terrain which reflects the value of terrain in the general combat outcome and permits representing the barrier in terms of the cost of achieving that influence.

The technique selected for BEAR is shown in Figure 3.7. Terrain is categorized in three classes similar to the classification used in CEM which was discussed in Chapter I. Easy terrain is represented by the basic function developed from a compromise of the Lanchester predictions and historical data. The representations for the other classes of terrain (moderate and difficult) can be supported only by the judgment of the analyst based on the general insights developed from the historical research which supported Chapter II. Intuitively, the immediate hypothesis for adoption would be that if terrain is more difficult the attacking force must be larger to achieve the same level of success. The curves in Figure 3.7 reflect that rather appealing notion in part, but consider terrain in a broader sense. The advantage of the preponderant force in easy terrain goes beyond the simple application of mass. Where maneuver is permissive the larger force can fix elements of the smaller force and use the additional forces to achieve a defender loss by maneuvering. As the terrain increases in difficulty the advantage of maneuver decreases and the force superiority becomes more prominent for engagement purposes. In BEAR, therefore, the closer the relative force sizes move to parity the greater the advantage of terrain to the defender. As the attacker increases in relative size the advantage of terrain for the defender decreases until at some point the force level completely dominates. The fact that 6:1 was chosen for this particular analysis is defensible only in the sense that no better value was

FIGURE 3.7

TRANSITION PROBABILITIES FOR DIFFERENT TERRAIN CLASSES



available. Obviously, in employing this technique over time many force ratio to transition probability distributions could be studied.

This technique for representing terrain has the impact of making the attacker's job more difficult as the maneuver difficulty increases. Within the model the barrier impacts by altering attrition, and attrition is independent of terrain. The level of attrition does, however, influence the "win" condition indirectly. If Red attrition is greater when the barrier is employed, the next engagement will occur at a force ratio more favorable to Blue. As seen in Figure 3.7 the slope of the curve, which represents the relationship of force ratio to transition probability, increases as the terrain becomes more difficult. As a result reducing the Red superiority in type C terrain will result in a greater increase in transition probability than an equivalent reduction in type A terrain. The comparative slopes can then be viewed as a comparison of the relative value of placing the barrier in a given type terrain. That relationship normalized on type C terrain is .613, .797, and 1.0 for terrain types A, B, and C respectively. A unit force ratio reduction in type A terrain will be worth about 61 percent of a similar reduction in C terrain. With this method placing a barrier in C terrain which will logically cost less is made more attractive by a representative influence on the combat outcome.

An additional requirement to enable computation of force ratio and attrition was to determine values for relative weapon effectiveness (E_B and E_R in the attrition equations) and relative weight of the various types of firepower. Relative weapon effectiveness is normally represented by one of two alternative methods. The first method is to utilize a firepower potential or score to represent a particular weapon. This alternative provides a single value for each weapon the magnitude of which implies its relative effectiveness against the score of the opponent's weapons. The obvious disadvantage of such a system is the inability to control the resolution of certain firer-target relationships. As an example, the tank and artillery piece would have relatively high firepower scores. Yet, the tank seldom, if ever, engages artillery and artillery is relatively ineffective against tanks. The second alternative is to input effectiveness matrices which provide an index for each firer-target relationship. This method was adopted for engagement sequences in BEAR with the values which were used shown in tables below.[21] The values were taken from a paper entitled "A Theory of Ideal Linear Weights for Heterogeneous Combat Forces," by David R. Howes and Robert M. Thrall. The purpose of the paper was to discuss the method and its impact. The effectiveness values were not defended as being valid in that paper, nor will they be defended here. It is sufficient to indicate that they are based on a detailed combat simulation and are representative of the type input that would be used in classified analyses. The actual values shown in the tables must be adjusted ($x\ 10^{-1}$) for use in the BEAR attrition equations.

TABLE 3.5

BLUE EFFECTIVENESS [$x\ 10^{-1}$]

		Blue Firepower Types (Firer)				
		I	II	III	IV	V
Red	I	.0034	.6485	.1170	0	10.8950
Firepower	II	.0145	1.1165	.0556	1.9150	.0588
Types	III	.0028	1.5000	.0940	2.8300	.0610
(Target)	IV	.0004	.0369	.0045	.1860	.1380
	V	0	0	0	.0970	.1193

TABLE 3.6

RED EFFECTIVENESS [x 10^{-1}]

		Red Firepower Types (Firer)				
		I	II	III	IV	V
Blue	I	.0145	.2750	.0510	0	13.5800
Firepower	II	.0115	.3470	.0319	.5070	.0880
Types	III	.0012	.3410	.0326	.1370	.1160
(Target)	IV	.0004	.0378	.0012	.0137	.0785
	V	0	.0129	.0024	0	.0690

The relative weights of the various types of firepower are required to properly define the contribution of weapon types to the force ratio. Since BEAR represents firepower types by weapon count, a transformation is required to maintain the true perspective of one rifleman versus one tank. The weights were also adapted from the Howes and Thrall paper and are displayed in the table below.[22] These weights are appropriate because they are derived from the output which determined the effectiveness indices. The weights for Blue and Red may differ for a given firepower type based on different weapon characteristics or deployment doctrine.

TABLE 3.7

FIREPOWER WEIGHTS

			Blue Weight	Red Weight
	I	(Light Weapons)	.00082	.00052
	II	(Tanks)	.40000	.33515
Firepower Types	III	(Light Armor)	.00443	.00198
	IV	(Anti Tank)	.42710	.48015
	V	(Artillery and Mortars)	.16765	.18221

BEAR possesses the capability for two output sequences. In both instances the program is designed to select various cases designated by resource levels. The first routine examines each of the daily output reports which were stored during execution of the algorithm. The objective function values on the final day of battle at the maximum resource level for each of the selected cases is returned to the program. The Blue decisions for that resource level for every day of battle are also returned to the program. The output sequence then displays, for each case the final functional value, the selected decision by period, the total number of times each decision was selected, and the slack resources available at the termination of the battle.

The second output sequence takes the decision list produced in the first sequence for each resource level and deterministically reconstructs all periods of the battle restricting the Blue commander to that particular resource level. The outputs are by period values of the functional, holding probabilities by line, and Red and Blue strengths by firepower type. The program coding and a sample output are included as Appendix A to this thesis.

The scope of the model may be briefly summarized by sketching the relationship of the Blue commander's decision space and the objective function used to select the best decision. After the Red force level in each sector is determined, the Blue force level is determined based on deletions or additions of forces that the current decision requires. The algorithm then computes the attrition for Red and Blue and calculates the force ratio (QUOT) for each sector and defense line using the surviving forces. Using these force ratios a transition probability (T) is calculated for each defense line in each sector (see Figure 3.7). The holding probability ($QNEW_1$) for the first defense line in a sector is calculated by multiplying the transition probability by the value of the holding probability ($QOLD_1$) in the last period.

$$QNEW_1 = T_1 \times QOLD_1$$

This basic procedure applies to the other defense lines with one exception. The holding probability for subsequent defense lines must account for the possibility that Blue holds forward of that line. The computation of the holding probability for Defense Line 2 would be:

$$QNEW_2 = [(1. - T_1) \times QOLD_1] + [T_2 \times QOLD_2]$$

The calculation $(1. - T_1)$ is the probability that Defense Line 1 is lost in this period. The probability that the battle moves from Defense Line 1 to Defense Line 2 in this period is the product of losing Defense Line 1 in this period and the probability that Defense Line 1 was held at the beginning of this period. The holding probability for Defense Line 2 is then the sum of the probability of the battle getting to Defense Line 2 and the probability that it can be held $(T_2 \times QOLD_2)$ if the battle is there. Similarly the holding probability for Defense Line 3 would be:

$$QNEW_3 = [(1. - T_2) \times QOLD_2] + [T_3 \times QOLD_3]$$

After the holding probability is calculated for each defense line a test value for the functional is calculated for each sector. The test value is the sum of the defense line holding probabilities multiplied by the defense line weighting factor (DIST).

$$TEST_{sector} = \sum_{i=1}^{N4} Q_i \times DIST_i$$

The minimum sector TEST value is chosen as the measure of performance for this particular Blue decision. This minimum TEST value is then compared to the functional value (F) for the last selected decision. If the value of TEST is larger than the functional value (TEST F), the decision currently being considered is better than the previously selected decision because the sum of the holding probabilities is greater. Blue is, therefore, more likely to hold in the weakest sector. In this case the current Blue decision is saved and F is set equal to TEST. The algorithm then considers the next Blue decision. After all Blue decisions have been considered the value of the functional represents the maximum probability of holding in the weakest sector considering the priorities assigned to the various defense lines. The decision which determined this outcome is saved for later reference.

The model can obviously be subjected to the question of validity. There are several impediments to answering that question in the affirmative. In general the technique deviates from the accepted methods for wargaming division level or higher conflict. Thus there is no way to compare the output results to establish similarity. Specifically most of the component aspects of the game start with concepts which have been widely accepted in the gaming community. The rationale for modifying those concepts has been detailed in this chapter. This chapter also establishes the fact that some numerical data used in the model cannot be validated. The data were selected, however, to be representative in both magnitude and form to data actually used in existing combat simulations. The important aspect of validity is the intended use of the model. The intent is to study and analyze a range of phenomena; not establish a quantitative value which can be defended in support of a specific force structure decision. On that basis this chapter should provide sufficient supporting logic to validate the model as a useful tool for its intended purpose.

CHAPTER III

FOOTNOTES

[1] Department of the Army, Theater Force Performance in CONAF II (Conceptual Design for the Army in the Field) Volume I—Methodology (General Research Corporation, Westgate Research Park, McLean, Virginia 22101, May 1973), p. 42.

[2] U.S. Army Engineer School, Student Reference—Operations Research/Systems Analysis (Ft. Belvoir, Virginia, November 1967), p. 75.

[3] Bonder, Seth Dr., "Mathematical Models of Combat" Student Reference—Operations Research/Systems Analysis (U.S. Army Engineer School, Ft. Belvoir, Virginia, November 1967), p. 345.

[4] Ibid.

[5] Ibid.

[6] Ibid., p. 348.

[7] Ibid.

[8] Merrit, Jack N. and Sprey, Pierre M., "Quality, Quantity or Training," (Student Reference—Nature and Characteristics of Ground Combat, U.S. Army Command and General Staff College, Ft. Leavenworth, Kansas, 1974), p. P12-6.

[9] Research Analysis Corporation, Unpublished Paper, "VGATES—A Semi-Probabilistic Treatment of FEBA Movement," by Gerald E. Cooper, (McLean, Virginia, January 1971), p. 1.

[10] Ibid., p. 14.

[11] Ibid.

[12] Ibid., p. 11.

[13] Ibid., p. 16.

[14] Ibid., p. 8.

15VGATES, op. cit., p. 20.

[16] Merrit and Sprey, op. cit., p. 12-5.

[17] Department of the Army, Office, Chief of Engineers, Engineer Strategic Studies Group, Unpublished Paper, "Interim Results—Fortification Obstacle Effects Simulation," by Major Howard E. Boone (Washington, D.C., June 1974) p.

[18]VGATES, op. cit., p. 20.

[19]Theater Force Performance in CONAF II, op. cit., p. 158.

[20]Merrit and Sprey, op. cit., p. P12-6.

[21]Department of the Army, Office Chief of Research and Development, "A Theory of Ideal Linear Weights for Heterogeneous Combat Forces," by David R. Howes and Robert M. Thrall, (Proceedings of the U.S. Army Operations Research Symposium 15-18 May 1972, Durham, North Carolina, May 1972), p. 106-107.

[22]Ibid., p. 107.

CHAPTER IV

RESULTS

The Barrier Effectiveness Analysis Revision (BEAR) prototype model requires between 800 and 860 seconds of central processing time to conduct 15 days of battle with a maximum of 16 resource levels. As days of battle and resource levels increase, run time is not additive. A central processing time of 2400 seconds is insufficient to conduct a 30 day battle with 31 resource levels. Under those circumstances, it was determined that utilization of the model to support this thesis would be based on a selection of a 15 day battle with 16 resource levels. That decision permits examination of a multiple number of cases without being subject to lengthy computer program turn around time. The multiplicity of cases was produced by alterations in five basic parameter categories:

A. Replacement Rates
B. Weight of Defense Lines
C. Data Inputs—Force Levels and Terrain
D. Speed of Erecting Barrier
E. Size of Alternative Blue Reinforcement—Tank Companies and Artillery

Despite the selection of an attrition routine designed to slow the speed of force decay, the model is sensitive to replacement rates. This phenomenon is compounded by the preponderance of contribution of tank and anti-tank weapons to the weighted force ratio. These two weapon types account for 81.5 percent of the total Red contribution and 82.7 percent of the total Blue contribution. At the same time the actual number of such weapons will be comparatively low. In such a case proportional losses are higher. The three options which were chosen for replacement rate (A) are shown in Table 4.1. The model has the capability to accept different replacement rates for Red and Blue, but that capability was not exercised in any of the cases that will be included in subsequent discussion. The terms high, mid, and low which have been applied to the different rates are expressive only of their relative relationships. Such rates were not compared to any existing standard.

TABLE 4.1

A. REPLACEMENT RATES (PER DAY)

	Firepower Types				
	I	II	III	IV	V
Option 1 - High	50.	5.	10.	10.	5.
Option 2 - Mid	25.	2.	4.	4.	1.
Option 3 - Low	10.	2.	2.	2.	0.5

The selected options for the second category of parameters, defense line weights (B) are displayed in Table 4.2. The values shown in the Table are those assigned to the DIST matrix which provides a weighting to the holding probabilities in the objective function $F = \sum_{i=1}^{NLines} Q(Sector,i) \times DIST(i)$. The magnitude of the values chosen has no particular significance other than providing a general rank ordering of defense lines. Option 1 provides values front to rear weighting the lines to indicate that it is most desirable to hold as far forward as possible. The third option is a complete reversal of outlook implying that it is most important to hold the final defense line. Option 2 describes the indifference position by equally weighting all six defense lines.

TABLE 4.2

B. DEFENSE LINE WEIGHTS
(DIST)

	Defense Lines					
	1	2	3	4	5	6
Option 1	1.0	.95	.90	.85	.80	.75
Option 2	1.0	1.0	1.0	1.0	1.0	1.0
Option 3	.75	.80	.85	.90	.95	1.0

The data inputs to the model provide the third category (C) of parameter. The force levels, sector assignment and terrain values are determined from the input file. The basic scenario selected for this thesis was a standard U.S. Armor Division versus an agressor Combined Arms Army (CAA). The CAA is composed of two motorized rifle divisions, one tank division, an anti-tank regiment and a mixed artillery brigade. The basic disposition for this scenario is shown in Figure 4.1. Initially the two sectors are balanced with each Blue brigade facing a motorized rifle division reinforced with additional artillery and anti-tank weapons. The Red decision process is constructed such that even though the tank division is designated as a reserve, elements can be immediately employed. This scenario with defense lines (one through six) designated as A, B, C, A, B, C terrain respectively constitutes the first data option. The second option alters the scenario by deleting the tank division. It is assumed for this scenario that the tank division will be committed after D+15. The defender has a smaller reserve and weights his defense to Sector 2. Initial force dispositions are as shown in Figure 4.2. The terrain assignments for this option are the same as for Option 1. The other two data options use the basic scenario from

FIGURE 4.1

BASIC BEAR SCENARIO

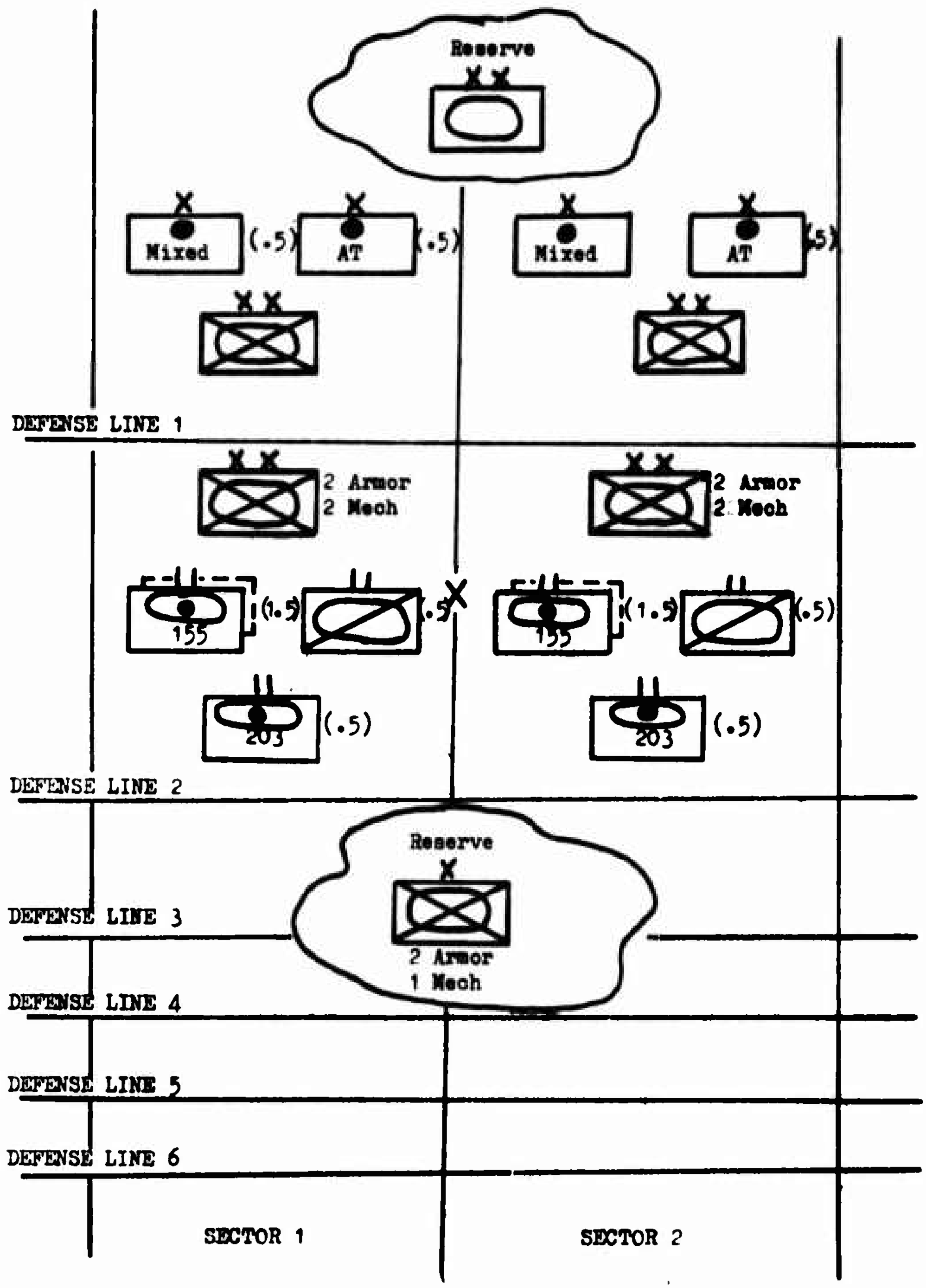
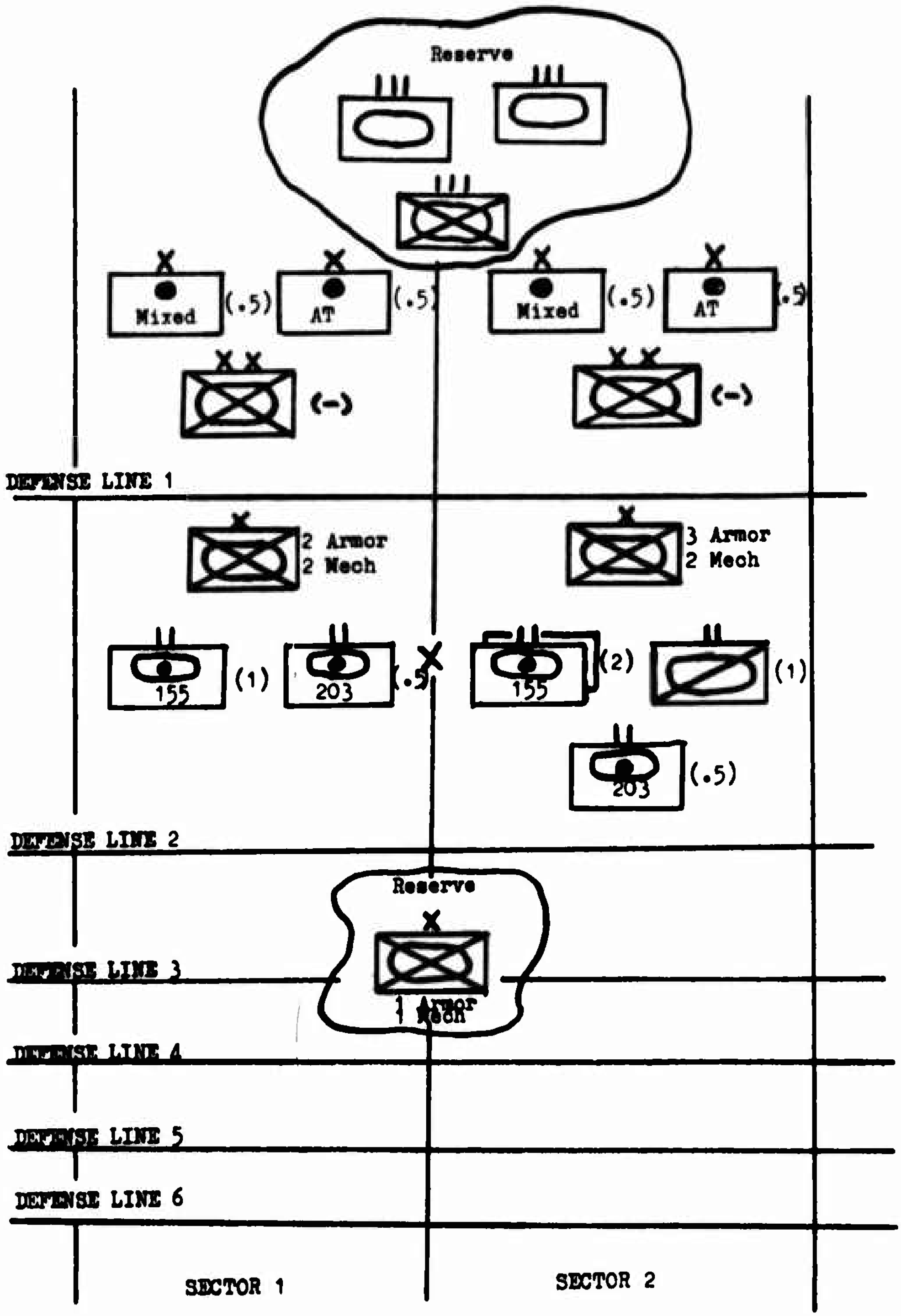


FIGURE 4.2

ALTERNATE SCENARIO



Option 1 and alter the terrain assignment. Option 3 uses all A type terrain and Option 4 all C type terrain. The fifth option was actually provided by an internal program adjustment which prevented commitment of the tank division until D+8. These options are summarized in Table 4.3.

TABLE 4.3

C. DATA INPUTS

	FORCES		TERRAIN
	RED	BLUE	
Option 1	CAA (1) Balanced Initial Dispositions (2) Tank Division Reserve	ARMOR DIV (1) Balanced Defense (2) 2 Armor Bn, 1 Mech Bn Reserve	A,B,C,A,B,C
Option 2	CAA (1) Minus Tank Division (2) 2 Med. Tank Regt, 1 Mtrzd Regt Reserve	ARMOR DIV (1) Defense Weighted to Sector 2 (2) 1 Armor Bn, 1 Mech Bn Reserve	A,B,C,A,B,C
Option 3	CAA (Same as Option 1)	ARMOR DIV	A,A,A,A,A,A
Option 4	CAA (Same as Option 1)	ARMOR DIV	C,C,C,C,C,C
Option 5	CAA (Same as Option 1, except Tank Division held until D+8)	ARMOR DIV	A,B,C,A,B,C

The fourth category of parameter (D) was the speed at which the barrier function could be added to a given defense line. BEAR was designed arbitrarily such that .05 of an increment could be added to the combat multiplier (initial value is 1.) in one sector when the barrier was employed. The maximum combat multiplier for the barrier was assumed to be 1.3. Thus it would require six days to complete the barrier for one defense line in one sector. This design routine was considered Option 1 for the barrier function. The second option was based on increasing the daily increment to .15. This change permitted the completion of the barrier on one defense line in two days instead of six. These were the only two options played in the selected cases. The magnitude of firepower which could be purchased as an alternative to the barrier function was the fifth parameter category (E). The selected options are shown in Table 4.4. These particular options were chosen in an attempt to provide successively more attractive alternatives to the barrier function.

TABLE 4.4

ALTERNATIVES TO BARRIER

Option 1	1 Tank Company or 1 Artillery Battery
Option 2	2 Tank Companies or 2 Artillery Batteries
Option 3	3 Tank Companies or 3 Artillery Batteries

Thirteen cases have been selected for discussion. The particular options selected for each case are displayed in Table 4.5. Four resource levels (0,4,8,12) have been selected for discussion for each of the individual cases. The Blue decisions selected for each case at each resource level are displayed in Tables 4.6 to 4.9. Table 4.6 also shows the D+15 functional value. A major shortcoming of the tables is the timing of a particular decision. As appropriate, this information will be provided in the discussion.

The first three cases orient on the high replacement rate option. Cases I and II both use the front to rear decreasing weight for the defense lines, and Case III weights all defense lines as 1.

TABLE 4.5

PARAMETER OPTIONS FOR CASE RUNS

PARAMETER

CASES	Replacement Rates			Defense Line Weights			Force and Terrain Inputs					Barrier Building Rate		Firepower Alternatives		
	OPTION			OPTION			OPTION					OPTION		OPTION		
	1	2	3	1	2	3	1	2	3	4	5	1	2	1	2	3
I	*			*			*					*		*		
II	*			*				*				*		*		
III	*				*		*					*		*		
IV		*		*			*					*		*		
V		*			*		*					*		*		
VI		*			*		*					*			*	
VII		*		*			*					*				*
VIII		*		*					*			*		*		
IX		*		*						*		*		*		
X		*			*		*						*	*		
XI			*			*	*					*		*		
XII			*	*			*					*		*		
XIII		*		*							*	*		*		

TABLE 4.6

BLUE DECISION SELECTIONS

RESOURCE LEVEL = 0

CASE	DECISION							FUNCT
	1	2	3	4	5	6	7	
I	1	–	1	–	–	1	12	.9720
II	–	–	1	–	1	–	13	.9765
III	1	–	–	2	–	1	11	1.0
IV	1	1	1	–	–	1	11	0
V	–	–	–	2	–	–	13	0
VI	1	–	–	2	–	1	11	0
VII	1	1	1	–	–	1	11	0
VIII	1	1	1	–	–	1	11	0
IX	–	–	1	–	–	–	14	0
X	–	–	–	2	–	–	13	0
XI	3	–	–	–	–	3	9	0
XII	2	–	1	1	–	2	9	0
XIII	–	–	–	–	–	1	14	0

TABLE 4.7

BLUE DECISION SELECTION

RESOURCE LEVEL = 4

CASES	DECISION													SLACK
	1	2	3	4	5	6	7	8	9	10	11	12	13	
I	–	–	–	–	1	–	12	–	–	–	–	–	2	2
II	–	–	1	–	1	–	13	–	–	–	–	–	–	4
III	1	–	–	1	–	1	8	–	–	–	1	–	3	
IV	1	1	1	–	–	1	7	–	–	–	–	–	4	
V	–	–	–	2	–	–	9	–	–	–	–	–	4	
VI	1	–	–	2	–	1	7	–	–	–	–	–	4	
VII	1	1	1	–	–	1	7	–	–	–	–	–	4	
VIII	1	1	1	–	–	1	7	–	–	–	–	–	4	
IX	–	–	1	–	–	–	10	–	–	–	–	–	4	
X	–	–	–	2	–	–	9	–	–	–	–	–	4	
XI	3	–	–	–	–	3	5	–	–	–	–	–	4	
XII	2	–	1	1	–	2	5	–	–	–	–	–	4	
XIII	–	–	–	–	–	1	10	–	–	–	–	–	4	

TABLE 4.8

BLUE DECISION SELECTION

RESOURCE LEVEL = 8

CASE	DECISION													SLACK
	1	2	3	4	5	6	7	8	9	10	11	12	13	
I	–	–	–	–	1	–	13	–	–	1	–	–	–	7
II	–	–	1	–	1	–	13	–	–	–	–	–	–	8
III	1	–	–	1	–	1	4	–	–	–	2	–	6	
IV	1	1	1	–	–	1	3	–	–	–	–	–	8	
V	–	–	–	1	–	3	4	–	–	–	1	–	6	1
VI	1	–	–	1	–	1	4	–	1	–	–	–	7	
VII	1	1	1	–	–	1	3	–	–	–	–	–	8	
VIII	–	–	–	–	–	1	7	–	–	–	–	–	7	1
IX	–	–	1	–	–	–	5	–	–	–	–	–	8	
X	–	–	–	1	–	1	5	–	1	–	2	–	5	
XI	3	–	–	–	–	3	1	–	–	–	–	–	8	
XII	2	–	1	1	–	–	3	–	–	–	–	–	8	
XIII	–	–	–	–	–	1	6	–	–	–	–	–	8	

TABLE 4.9

BLUE DECISION SELECTION

RESOURCE LEVEL = 12

CASE	DECISION													SLACK
	1	2	3	4	5	6	7	8	9	10	11	12	13	
I	–	–	–	–	1	–	9	–	–	1	–	–	4	7
II	–	–	1	–	1	–	9	–	–	–	–	–	4	8
III	1	–	–	1	–	–	1	–	1	–	2	–	9	
IV	–	–	–	–	–	1	4	–	–	–	–	–	10	2
V	2	–	–	–	–	–	3	–	–	–	1	–	9	1
VI	–	–	–	1	–	–	2	–	–	–	–	–	12	
VII	–	–	–	–	–	1	4	–	–	–	–	–	10	2
VIII	–	–	–	–	–	1	4	–	–	–	–	–	10	2
IX	–	–	–	–	–	1	4	–	–	–	–	–	10	2
X	–	–	–	1	–	1	1	–	1	–	2	–	9	
XI	–	–	–	–	–	2	1	–	–	–	–	1	11	
XII	1	–	–	1	–	2	2	–	–	1	–	–	8	3
XIII	–	–	–	–	–	1	4	–	–	–	–	–	10	2

All three cases use the normal barrier function and the least attractive resource cost alternatives to the barrier. The values of the functional indicate that the selected replacement rate is highly favorable to Blue. The functional value for Case II is higher than Case I because Case II uses the scenario which does not employ the aggressor tank division. Both cases generate significant slack resources because the replacement rate is so favorable to Blue that the additional combat power does not provide an attractive alternative. Slack resources are not generated in Case III. The equal weighting of all defense lines indicates greater advantage can be gained from additional resources.

The scenario in Case I begins with a balanced defense. Red immediately commits one-half of the tank division to Sector 1. With no resources Blue commits half his reserve to Sector 1 (Decision 3) on the first day and transfers elements from Sector 1 to Sector 2 (Decision 1) on the second day. No action is taken until force is added to the reserve from Sector 2 (Decision 6) on the fifteenth day. At resource level 4 the barrier function is added to Sector 2 (Decision 13) on the first and fourteenth day and the reserve is supplemented from Sector 1 (Decision 5) on the fifteenth day. Equal functionals and equal slack are generated at resource levels 8 and 12 by purchasing a tank company for Sector 1 (Decision 10) on the first day, and reconstituting the reserve from Sector 1 (Decision 5) on the fifteenth day. The barrier function (Decision 13) is employed from D+11 to D+14 in the latter case.

Case II is similar to Case I except the aggressor force is smaller. At all resource levels one-half the reserve is committed to Sector 1 (Decision 3) on the first day. The reserve is reconstituted earlier (D+7 or D+8) than in Case I. At resource level 12 the barrier function (Decision 13) is used to bolster Sector 2 in the period D+12 to D+15. In Case III with all defense lines equally weighted the battle shifts to Sector 2 early. At the lower resource levels the reserve is committed to Sector 2 (Decision 4) on the second day. After the initial commitment of additional combat power, the barrier function is selected 75 percent of the time interspersed with buys of additional tank companies and artillery.

For Cases IV through XIII the mid and low replacement rates force the functional value to zero. Blue cannot win. In these cases it was a general rule that the selection of Option 1 for the defense line weighting function (front to rear decreasing weights) forced an early commitment of the reserve to Sector 1 (Decision 3) and subsequent lateral transfer of forces to Sector 2 (Decision 1) at the lower resource levels. In contrast, Option 2 for defense line weighting (equal weights) tended to force Blue to develop the situation in early periods and commit the reserve to Sector 2 (Decision 4) after D+5. The blatant exception to this rule was Case XII which was one of two cases which used the low replacement rate. In this case elements of the reserve were committed to both sectors and additional lateral transfers of forces from Sector 1 to Sector 2 were required to overcome the rapid force deterioration. In all cases at some resource level the reserve was reconstituted. Of particular note was Case XI which used the defense line weighting function which increased moving front to rear. In early time periods the reserve was strengthened, a logical decision since the most weight is thrown to rearmost defense lines.

All of Cases IV to XIII utilized the barrier function completely at resource level 4 mostly in the period D+12 to D+15. This phenomenon is not surprising considering the construction of the algorithm. At limited resource levels the combat multiplier would be of most value in the later time periods when the force decay has stabilized. This process can be compared to the realistic expectation of preparing subsequent positions, such that as a force withdraws it can occupy stronger positions.

At resource level 8 Cases VI and X show choices of resource cost alternatives to the barrier (Table 4.8) without slack resources. Case VI offers the alternatives of two tank companies or two artillery batteries so the alternative choice is not surprising. Case X includes the option for multiplying the speed of inputting the barrier function by three. It is logical to anticipate more freedom to choose alternative decisions in that case.

The special scenario, Case XIII, where the tank division was held to D+8, can be compared to Case IV for other equivalent options. The resource expenditure was equivalent in both cases. In Case XIII, however, the early decisions to commit the reserves and laterally transfer forces are not taken. In this case the Blue commander has the tendency to take no action (Decision 7) and let the situation develop.

At resource level 12 many cases reflect an economy of force action. The barrier function is employed in the first period and the reserve is strengthened in the second. In all cases the tendency to use the barrier function in earlier periods increased as the resource level increased. The general process of the algorithm is to push those decisions which cost from D+15 to D+1.

Summary data is provided in Table 4.10. As resources increase there is a decrease in the percentage of no-action decisions. There is also a decrease in the proportion of no cost decisions. Both of these trends should be anticipated. Of those decisions which incur a resource cost the barrier function was chosen approximately 93 percent of the time.

At this point it is helpful to examine a specific case in some detail in an attempt to clarify the relationship of the output to the construction of the algorithm. Case IV was selected for this discussion. This case used the mid replacement rate and defense lines weighted front to rear (see Table 4.5). The resulting decision sequences for this case are displayed in Table 4.11. For the first three resource levels the reserve is committed to Sector 1 on the first day. Forces are transferred from Sector 1 to Sector 2 on the second day and that process is reversed on the fourth day. Part of the committed forces in Sector 2 are returned to the reserve on the sixth day. The battle then stabilizes until the termination of the conflict. The time sequence of the force ratio (Red to Blue) for each sector at resource level zero is shown in Figure 4.3. There is no difference in the Sector 1 results for resource levels 4 and 8, and a slight difference in the Sector 2 results. By employing the barrier in Sector 2 the rate of decrease of the force ratio is greater once the steady state condition is achieved. The D+15 force ratio values are 3.17, 3.16, and 3.14 for resource levels 0, 4, and 8 respectively. Figure 4.4 shows the force ratio trends for resource level 12. In this case the barrier function is employed in the first period; the battle quickly stabilizes, and the trend favoring Blue continues until the

TABLE 4.10

DECISION SUMMARY DATA

DECISION	RESOURCE LEVEL							
	0		4		8		12	
	Number	%	Number	%	Number	%	Number	%
1	14	6.7	13	6.2	12	5.7	9	4.3
2	3	1.4	3	1.4	2	1.0	-	-
3	8	3.8	7	3.3	6	2.9	1	.5
4	10	4.7	9	4.3	6	2.9	4	1.9
5	1	.5	2	1.0	2	1.0	3	1.4
6	13	6.2	12	5.7	14	6.7	10	4.7
7	161	76.7	114	54.3	72	34.3	50	23.8
8	-	-	-	-	1	.5	1	.5
9	-	-	-	-	2	1.0	2	1.0
10	-	-	-	-	1	.5	2	1.0
11	-	-	1	.5	5	2.4	5	2.4
12	-	-	-	-	-	-	1	.5
13	-	-	49	23.3	87	41.4	122	58.1
Slack			6	1.1	17	15.2	34	20.2

TABLE 4.11

DECISION SEQUENCE IN CASE IV

	Resource Level			
DAY	0	4	8	12
1	3	3	3	13
2	1	1	1	6
3	7	7	7	7
4	2	2	2	7
5	7	7	7	7
6	6	6	6	7
7	7	7	7	13
8	7	7	13	13
9	7	7	13	13
10	7	7	13	13
11	7	7	13	13
12	7	13	13	13
13	7	13	13	13
14	7	13	13	13
15	7	13	13	13

FIGURE 4.3

FORCE RATIO BY SECTOR FOR CASE IV

(RESOURCE LEVELS 0, 4, AND 8)

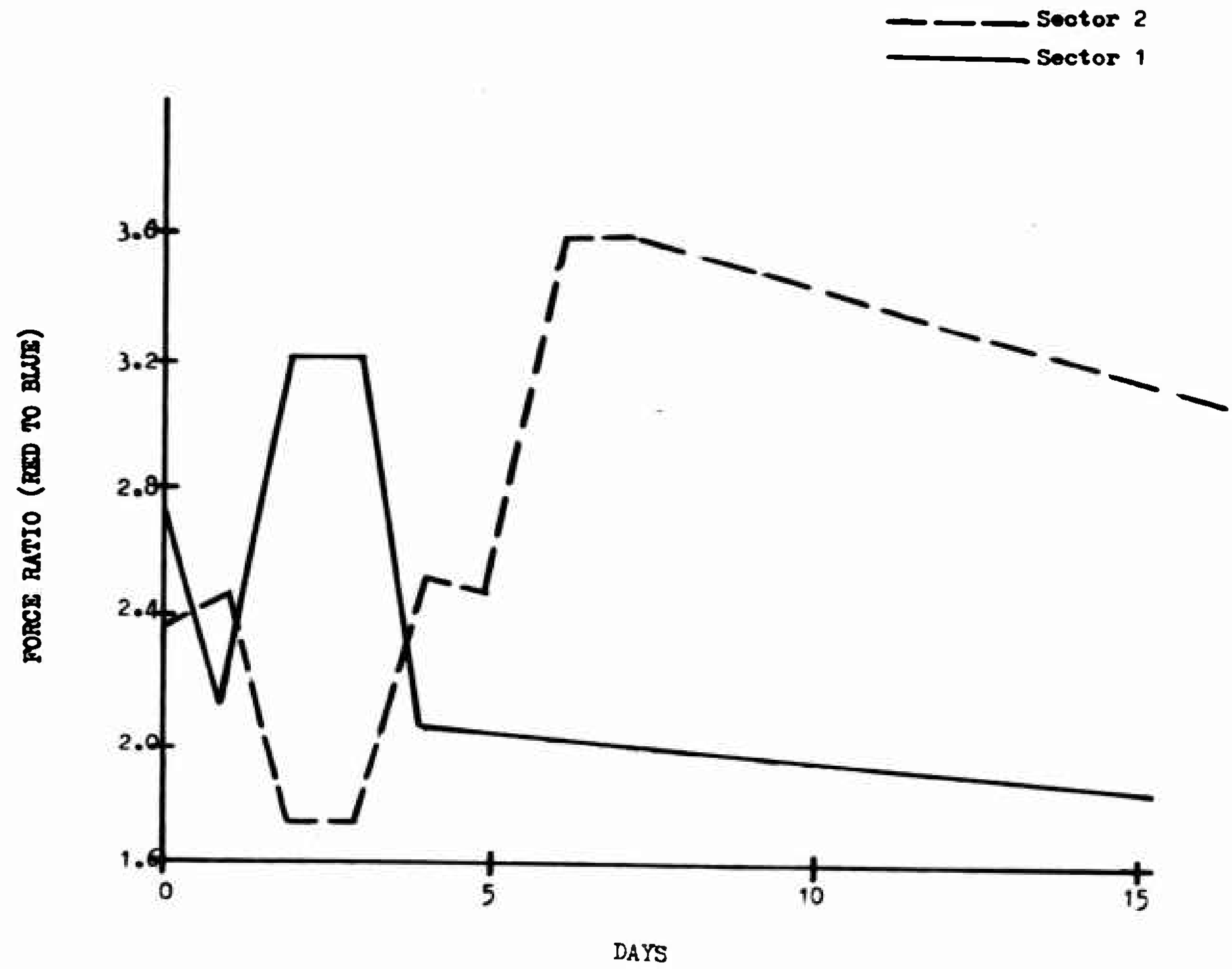
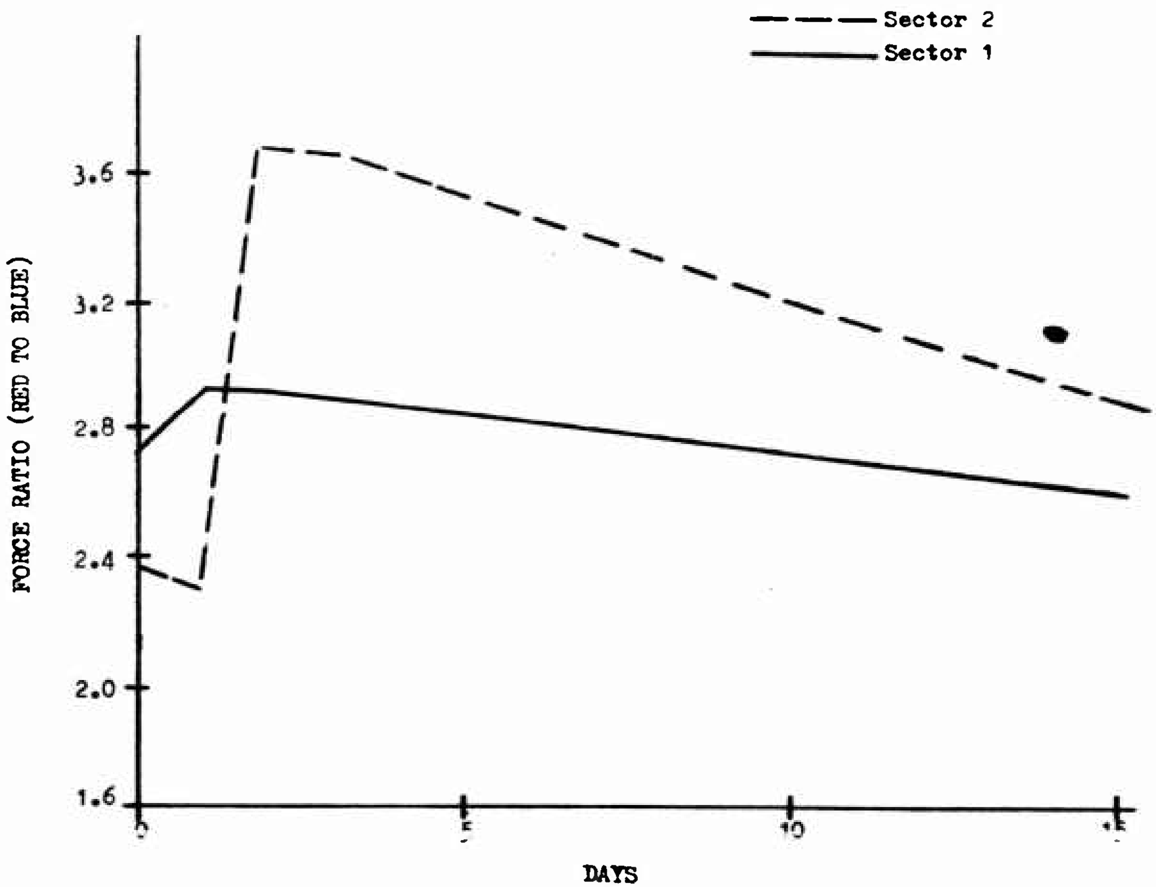


FIGURE 4.4

FORCE RATIO BY SECTOR FOR CASE IV

(RESOURCE LEVEL 12)



battle is terminated. At all resource levels Blue obviously employs economy of force by using less forces in the Sector with the barrier.

One of the apparent anomalies in the model is the fact that the barrier function is chosen but the functional value is not significantly influenced. This phenomenon is a design shortfall in the model. When the technique was discussed in Chapter III the point was made that there was only a limited capability to look back at previous decisions as the resource levels increase. At the lower resource levels Blue is unable to influence the earliest periods. The barrier function was designed to force the barrier to be input front to rear. As a result by the time the incentive for using the barrier is realized the holding probability for the first defense line has become zero. The barrier then has a significant influence on attrition with only a limited influence on the objective function.

There are two alternatives for correcting this deficiency. The first alternative is to consider the barrier function by defense line as an additional decision. This alternative would increase the decision list from 13 to 23 with a resulting significant increase in computer run time. The other alternative is to simplify the current program by considering the barrier function to be equally distributed over all defense lines.

Some criticism might be directed to the alternatives to the barrier function. Table 4.12 portrays the comparison of adding a tank company to the weighted firepower in one sector on three successive days with the increase in the barrier function on three successive days. Zero attrition was assumed for this example. The range of values indicate that the alternatives to the barrier function are reasonable from a firepower standpoint.

TABLE 4.12

COMPARISON OF TANK COMPANY ALTERNATIVE WITH BARRIER FUNCTION

DAY	ADDED TANK COMPANIES(CUM)	WEIGHTED FIREPOWER	BARRIER MULTIPLIER	WEIGHTED FIREPOWER
D	0	95.27	1.00	95.27
D+1	1	102.18	1.05	100.03
D+2	2	109.08	1.10	104.80
D+3	3	115.98	1.15	109.56

Chapter II concluded by stating that available historical data indicated that the influence of the barrier was to aid in economy of force, breaking and maintaining combat, permitting the defender to prepare subsequent positions, constricting combat service support and developing intelligence. The only one of these functions explicitly discussed in this general presentation of results was economy of force. The results have also provided indications that some of the other functions may be studied in some detail by employing this technique. The alteration of the barrier function to enable considering each defense line as an independent action should permit freedom to prepare subsequent positions. The aspect of breaking and maintaining contact is implicit in the holding probability concept. This factor can be controlled by the weighting assigned to the separate defense lines. As the Blue force is forced to hold forward, it is advantageous to maintain contact. As the weights are reversed, it is advantageous to reduce contact. The model contains no projected capability to relate to constricting combat service support. Although this function should not be dismissed summarily, there does not appear to be a feasible way to represent it in a useful fashion. The model does not presently include the capability to study the aspect of developing intelligence. As currently structured each side has significant intelligence on committed forces. Blue does have an advantage in that he chooses his decision after Red so Red's basis for action is actually one period behind. If other problems can be successfully resolved, the addition of a useful intelligence routine should not be difficult.

CHAPTER V

CONCLUSIONS, SUMMARY AND RECOMMENDATIONS

The initial major conclusion indicated by this research effort is the inadvisability of attempting to represent the value of the artificial obstacle system in combat by explicit delay. Additional time is of no value to the commander unless he is free to exercise his resources to accrue some advantage within that time. There are indications both in current analyses and existing historical summaries that the combat multiplier effect, independent of delay time, which can be realized from the employment of artificial obstacles is significant. That fact, however, is of little value to the force structure decision process until some analytic basis is created which will permit a comparison of resource costs for alternatives to achieving that function. The historical research also provided considerable insight into the possible effects of the artificial obstacle system beyond multiplying firepower. Those effects included aiding in economy of force, breaking and maintaining contact, preparing subsequent positions, and developing intelligence.

The hypothesis for this research effort, as amended in Chapter II, stated: It is feasible to estimate the value of a barrier at engagement levels appropriate to theater modeling using simulation modeling techniques. The literature search provided some definition to the barrier contributions in a qualitative sense. These contributions were summarized in the requirement to represent freedom of action.

That representation was defined as the simulation of the commander's decision process in a manner which permitted a dynamic control of resources. The creation of that environment required a modeling technique dissimilar to those currently used in production modes to support force structure analysis.

The tecnhique selected to support this thesis was a computer simulation war game developed on an experimental basis at the Research Analysis Corporation. The war game uses a basic dynamic programming algorithm to represent defensive combat in an environment where the defender is permitted to select courses of action from an admissable decision list in an attempt to maximize his FEBA position. This technique was adapted in a prototype model called the Barrier Effectiveness Analysis Revision (BEAR) for the purpose of studying the barrier contribution to combat.

Results produced by constructing and operating the first generation BEAR do indicate the capability to produce sufficient freedom of action. That characteristic provides a basis for studying the qualitative aspects of the barrier contribution to force performance in addition to the firepower multiplier capability. The term "first generation" has been applied to BEAR because the results also indicate some significant shortfalls in the model.

As currently structured the model quickly produces a steady state condition. There are several factors which appear to contribute to that outcome. One major aspect that must be considered in discussing these factors is the nature of the basic dynamic programming algorithm. The algorithm seeks a local optimum. In the case of this particular model that optimum is selected at the intersection of a time period and resource level. Although there is some capability to look back and alter a previous decision, that capability is limited. Thus at a particular time the available decisions must provide a significant impact under the existing conditions to produce a radical change in output.

A major contributor to the steady state environment is the limited Red strategy. Although Red begins with a large reserve, that reserve is quickly committed. The force thresholds which control subsequent Red movements are so great that Red is unable to take a significantly altered action after the third day. Facing this steady state opponent, it is logical for Blue to also achieve a steady state condition as long as the selected decisions do improve his posture in each time period.

Another restrictive factor in this particular analysis was the selection of time period. The decision space was chosen to correspond to those actions which might logically occur in one day. An expanded time period would foster decisions that would have a greater impact on outcome. In the case which permitted the barrier to be input at three times the original rate, the Blue commander was able to expand the scope of actions which he could select to impact on the outcome. This result demonstrated the necessity to review the scope of the decision space.

The weaknesses in the representation of the barrier function were discussed at some length in Chapter IV. With the compressed time frame and the speed at which the barrier can be constructed, the possible impact is not accurately represented when the Blue commander is restricted to a policy of completing the barrier from front to rear.

This shortfall did not, however, restrict the barrier function from being an attractive alternative within the available decision space.

The hypothesis stressed feasibility. The results from the first generation BEAR do support feasibility. The model is not yet capable of providing a practical result. The results do support a recommendation for developing a second generation BEAR capable of studying the barrier function in greater depth. Recommended alterations to the model are a more flexible representation of Red strategy, an extended time frame with appropriately altered decisions, and an improved representation of the barrier function.

The particular technique adapted to produce the BEAR model demonstrates characteristics which may be useful in other force structuring analyses. The decision space concept provides the opportunity to examine any number of alternative firepower oriented concepts. A unique analytic flexibility is also provided by the geometric representation of the battlefield using sector widths and defense lines. Rather than being tied to sector widths of specific distances, the analyst can examine several distinct conceptual combat environments by controlling the units input to a given sector. For example, assume the choice of three sectors which might correspond to Blue's anticipated use of three reinforced brigades. The concept of a concentrated attack on a narrow front might be examined by inputting two Red divisions in one sector and a reinforced regiment in each of the other two. Another possible environment that might be examined using three sectors is an open flank. Blue forces might be input with only a screening type force in one sector. To be useful these scenarios must include selected terrain values and decision spaces that would provide for logical alternative courses of action.

This thesis has provided definite indications that the experimental technique of war gaming based on the dynamic programming algorithm developed at the Research Analysis Corporation can be applied to existing force structuring problems. Consideration must be given to computer storage and run time. The comparative complexity of other war games, however, supports a recommendation for continuing the development of this technique. The barrier problem is not yet solved. This research effort does provide a starting point for that solution.

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APPENDIX

THE TWO SETS OF COMPUTER CODING AND OUTPUT IN ORIGINAL THESIS ONLY.

AVAILABLE UPON REQUEST.

This appendix includes two sets of computer coding and output. The first set provides a sample program listing and output for the Barrier Effectiveness Analysis Revision (BEAR) model as it was structured to produce the various cases which were discussed in Chapter IV. Subsequent evaluation of the model indicated that a coding error had existed in the dynamic programming sequence (Subroutine DP). That error is shown at Line Number 5850. The primary effect of the error was to base all decisions after the first period on only one firepower type for Red—artillery. The barrier function was then competing with other resource cost alternatives which did not actually impact on the objective function. The subsequent results from that output cannot be considered valid. The value of the information in Chapter IV must, therefore, be restricted to a demonstration of a method for structuring an analysis using this modeling technique. That structure includes the identification of key input variables and some of the possible methods for considering the output data.

The correction of the coding error in the original model exposed faulty logic constructions in the methods used to control the Blue reserve and the barrier function. The correction of these logic structures required a major revision in the program. The second set of program listings and output data in this appendix are from a sample run of that revised program (BEAR2). Limited available time prevented a lengthy analysis of the type presented in Chapter IV using the modified program. Some output data are available, however, to provide a basis for comparing BEAR and BEAR2.

The alteration in method for controlling the Blue reserve apparently has little impact on the best time periods or locations for committing the reserve. The reconstitution of the reserve is considerably reduced, however, since the full effect of Red tank and antitank weapons is now included. A major change in concept for BEAR2 was the implementation of one of the alternative methods for representing the barrier function recommended in Chapter IV. To enable a rapid restructuring of the model, the barrier function was simplified by representing the barrier effect as being equally applied within a sector rather than considering each defense line separately. With the altered representation of the barrier, BEAR2 output tends to predict that the barrier is not nearly as attractive compared to the other firepower options as the BEAR results had indicated. The sample output from BEAR2 does follow the trend to use the barrier in Sector 2 (decision 13) in the first time period as an economy of force measure until after the reserve is committed to Sector 2 (decision 3) in the second time period. The principal difference is that the barrier function in BEAR2 is not attractive in the later time periods. The decision algorithm now frequently selects the option of buying additional tank companies.

A special case was constructed using BEAR2 as a basis for extending the discussion on the representation of the barrier. In this case the resource cost alternatives to the barrier were set to zero capability. The resulting decision sequence is displayed in Table A.1. Red is stronger in Sector 1. Blue, therefore, uses the barrier to bolster Sector 2 before and after the reserve is committed to Sector 1. Subsequently the barrier is used to strengthen Sector 2 after forces have been transferred to Sector 1. The conclusion is that although the results are not as favorable to the barrier function as originally indicated, the modeling technique does demonstrate the capability to represent the barrier function as more than a firepower multiplier. It must be admitted, however, that with limited output data the hypothesis of feasibility is not at this point as strongly substantiated as the body of the thesis might indicate.

TABLE A.1

SPECIAL CASE USING BEAR2
(No Alternatives to Barrier Selection)

Time Period	Resource Level 0	4	8	12
D-Day	3	13	13	13
+1	4	3	3	3
+2	7	13	13	13
+3	7	13	13	13
+4	7	1	1	1
+5	7	2	2	2
+6	7	7	13	13
+7	7	1	1	1
+8	7	2	2	2
+9	7	1	1	1
+10	7	2	2	2
+11	7	1	13	13
+12	7	2	1	1
+13	7	7	2	2
+14	7	1	1	1

Decision 1 - Transfer From Sector 1 to Sector 2
Decision 2 - Transfer From Sector 2 to Sector 1
Decision 3 - Reserve to Sector 1
Decision 4 - Reserve to Sector 2
Decision 7 - Do Nothing
Decision 13 - Barrier Sector 2

BEAR2 should not be visualized as the second generation model recommended for development in Chapter V. The critical aspect of driving to a steady state solution because of the Red force limited flexibility still exists. The major conclusions and recommendations developed from this analysis do not appear to be severely weakened by the necessity for including this addendum.