NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A METHODOLOGY FOR MODELING URBAN COMBAT IN ALARM

by

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September 1987

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b RESTRICTIVE MARKINGS:

2a SECURITY CLASSIFICATION AUTHORITY:

2b DECLASSIFICATION / DOWNGRADING SCHEDULE:

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; Distribution is unlimited

4 PERFORMING ORGANIZATION REPORT NUMBER(S):

5 MONITORING ORGANIZATION REPORT NUMBER(S):

6a NAME OF PERFORMING ORGANIZATION: Iaval Postgraduate School

6b OFFICE SYMBOL (If applicable): 55

7a NAME OF MONITORING ORGANIZATION: Naval Postgraduate School

6c ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000

7b ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000

8a NAME OF FUNDING / SPONSORING ORGANIZATION:

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c ADDRESS (City, State, and ZIP Code):

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

A Methodology For Modeling Urban Combat In ALARM

12 PERSONAL AUTHOR(S) PRITCHETT, Christopher S.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year Month Day)	15 PAGE COUNT
Master's Thesis	FROM ______ TO ______	1987 September	96

16 SUPPLEMENTARY NOTATION

17 COSATI CODES		
FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Urban, ALARM, Built-Up, NETWORK, Time Domain, Cartesian Space

19 ABSTRACT (Continue on reverse if necessary and identify by block number) This thesis extends the levelopment of the Advance Airland Research Model (ALARM), a research effort at the Naval Postgraduate School (NPS), in the areas of urban terrain representation and urban mission planning. The growing proportion of dismounted infantry forces in the U.S. Army and the increased urbanization of Europe requires having a means at hand for studying the use of dismounted infantry in urban combat. The feasibility of using networks to model urban terrain and sequence the activities comprising an urban mission are demonstrated. A division scenario is developed that links brigade and battalion terrain networks. A template for an urban defense mission is developed and demonstrates the use of networks for simulating mission planning in built-up areas. An outline is provided for linking multi-level terrain and mission networks into one planning model.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL: Prof. Samual H. Parry

22b TELEPHONE (Include Area Code): 408-646-2779

22c OFFICE SYMBOL: 55Py

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted

All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

Approved for public release; distribution is unlimited.

A Methodology For Modeling Urban Combat in ALARM

by

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Captain, United States Army
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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1987

ABSTRACT

This thesis extends the development of the Advanced Airland Research Model (ALARM), a research effort at the Naval Postgraduate School (NPS), in the areas of urban terrain representation and urban mission planning. The growing proportion of dismounted infantry forces in the U.S. Army and the increased urbanization of Europe requires having a means at hand for studying the use of dismounted infantry in urban combat. The feasibility of using networks to model urban terrain and sequence the activities comprising an urban mission are demonstrated. A division scenario is developed that links brigade and battalion terrain networks. A template for an urban defense mission is developed and demonstrates the use of networks for simulating mission planning in built-up areas. An outline is provided for linking multi-level terrain and mission networks into one planning model.

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I. COMBAT IN BUILT-UP AREAS

A. INTRODUCTION

When one views history and considers the make-up of today's Army within the context of Airland Battle Doctrine, urban combat is an aspect of future wars that increases in importance. Much of the study done in the last ten years has been at the tactical level where the nature of combat in cities sharply contrasts the fluid combat of mechanized/armored forces. In retrospect, battles have often been fought in urban areas because of their political, industrial and symbolic value or because they unavoidably became the focus of a battle or campaign. This implies that urban combat can have a strategic significance. The contrast in combat characteristics and the strategic importance accorded many urban areas underscores a need to understand urban combat, particularly from an operational context where strategic planning translates to tactical execution of missions.

History is repleat with examples of ground forces fighting in built-up areas. Examples are not limited to the battles of WWII, but find prominence over a wide range of scenarios in Korea, Vietnam, and the Mideast as well as the Falklands, Afganistan and Central America. Both U.S. and Soviet doctrines concerning combat in built-up areas stress avoiding urban areas unless necessary. The conditions that necessitate combat in built-up areas are important to operational planning. If anything, the increased urbanization of Europe since WWII indicates a high probability of urban combat occuring in a future European war. A brigade commander can expect to have *at least* one urban area within his sector that controls key terrain or impacts on the battle plan in some way.

The structure of today's Army and the realization that the next war in Europe will find U.S. forces outnumbered necessitates a well defined role for dismounted infantry. With the inception of the light division (and including airmobile and airborne units), non-mechanized divisions now comprise a substantial part of the active Army. Considering the quantitative superiority allowed the Soviet ground forces, this represents a considerable portion of our combat capability that must be factored into any conflict. Dismounted infantry is best suited for fighting in built-up areas. The Army's Airland Battle Doctrine states that operational planning orients on decisive objectives stressing the need to fight on terms favorable to us. The tenants of initiative, agility, depth and synchronization combine with this idea to form the framework of the doctrine. By successfully defending against the enemy's first echelon attacks, while simultaneously disrupting the efforts of his follow-on forces and those elements which sustain his effort, U.S. forces will project flexible combat power and maintain the initiative necessary to defeat the enemy in detail at the time and place of our choosing. Accomplishing these tasks implies maximizing the potential of U.S. combat assets. For example, by capitalizing on man-made and natural obstacles and using dismounted forces in depth and on restrictive terrain, mobile forces will be free to pursue the deep battle [Ref. 1].

B. PURPOSE AND OBJECTIVES

This thesis provides a methodology, from an operational planning perspective, for modeling urban combat within the conceptual design of the ALARM (Airland Advanced Research Model) model. ALARM has undergone a conceptual design process at the NPS since 1984. The purpose is to develop a systemic, variable resolution model combining the realism advantages of high resolution, interactive models with the sensitivity and alternatives analysis capabilities usually inherent in closed, aggregate models. ALARM uses three methodologies: time-domain networks, cartesian-space networks, and a generalized value system. These methodologies structure the planning and execution processes of the model. The cartesian-space and time-domain networks are particularly suited for modelling the physical representation of urban terrain and the planning functions of urban combat, respectively. Several theses have demonstrated their applicability in modelling mechanized/armored combat scenarios. The methodologies have been applied in the development of a network solver that determines the critical path through a planning network [Ref. 2]. Additionally, a terrain network analysis model is being developed simultaneously with this thesis. The model calculates avenue of approach physical characteristics [Ref. 3]. Another thesis previously developed using ALARM methodologies provides algorithms for generating avenues of approach and allocating forces to these avenues in a terrain network [Ref. 4]. Each of these models focuses on a single level of resolution. However, the ALARM concept envisions modelling these processes at different levels of resolution in order to depict multi-echelon views of the same system and to assimilate varied attributes at each level. Thus, variable level resolution networks of urban terrain can be created to support variable level planning and decision processes.

In general, once an activity level is established within the planning process (a mission is received) and a picture of the battlefield and opposing forces is determined, the primary planning task allocates forces to meet mission goals. This allocation leads to a decision process of assigning assets to targets. In turn, carrying out the allocation is the planning task of the next subordinate unit. This thesis researches the representation of variable resolution urban terrain through cartesian-space networks and the applicability of time-domain networks to modeling urban warfare mission planning. The objectives of the research are as follows:

- Demonstrate the applicability of established ALARM methodologies to modeling urban combat.
- Refine the existing mathematical inputs to the Force Planning Model to characterize combat in built-up areas.
- Demonstrate the capability of linking planning levels and their respective missions through the use of time-domain networks and cartesian-space networks.

C. DOCTRINE

In the preceding section the ALARM model was viewed in concept and considered briefly as a means for modelling combat in built-up areas. The next step is characterizing urban combat itself. This section begins, by way of background, with a comparative discussion of U.S. and Soviet urban doctrine. With these ideas, missions are developed for light/dismounted infantry. In the last section, a scenario is illustrated for use in subsequent chapters demonstrating the design aspects of ALARM.

The special significance accorded battle in an urban setting is recognized by both sides and, in general, the same doctrinal approach is taken. Towns and villages straddle lines of communication and many cities in Europe are communications centers. Built up areas pose as obstacles to maneuver and, in particular, impede or inhibit mobility, speed of execution, and momentum. Both U.S. and Soviet doctrines stress avoiding built-up areas and emphasize bypassing and isolating them when possible. However, while both doctrines recognize the defensive value of urban areas, U.S doctrine specifies including urban areas into defenses when possible. Built up areas have inherent abilities for delaying, altering or stopping an attacker. They enhance weapons effectiveness from a defensive perspective. The dominant role of mechanized and armored forces in open terrain gives way to the use of light or dismounted infantry, supported by other arms, in an urban environment. Such a situation requires a change in operational practices.

1. Soviet Defense

Generally, the Soviets emphasize defense as an economy of force operation in an overall offensively oriented doctrine. A defense is established when regrouping forces becomes necessary to continue offensive operations. The defense is used to protect LOCs (lines of communication), rear areas, or flanks. Doctrine specifies establishing a defense well forward of built-up areas and echeloning forces in depth. Typically, a security zone is established out to 40 km and allocated to a second echelon motorized rifle regiment. The purpose of this zone is delaying, deceiving, and disrupting an attacker. The main defensive positions begin 15 km out from the built-up area and is organized in two echelons. The first echelon of a division defense may consist of up to two motorized rifle regiments heavily reinforced, particularly with artillery, and organized in strong points around kill zones. The first echelon's mission is defeating an attack forward of the built-up area. The second defensive echelon organizes along the forward edges or approaches to the urban area and includes the first echelon regiments' supplemental positions. These positions are prepared, in part, by the the first echelon regiments themselves. The remainder of the preparation is done by the second echelon regiment upon its withdrawal from the security zone and into the built-up area itself. The tank regiment is used along flanks and areas where maneuver exists. A characteristic of Soviet urban combat is combining arms down to platoon level. Consequently, strong points will contain their own armor, anti-armor, artillery (in a direct fire mode), as well as logistics elements. These salient features of a Soviet defense of a built-up area are visible at levels above and below the motorized rifle division. The technique lends itself to a rapid assumption of the offense. [Ref. 5]

2. Soviet Attack

Soviet offensive doctrine concerning built-up areas parallels U.S. doctrine. A surprise attack from the march, the preferred tactic, is analogous to the hasty attack used by U.S. forces. However, reconnaissance forces assume a critical role in both the attack from the march (surprise attack) and the Soviet deliberate attack. The goal of a surprise attack against a built-up area is to pursue key LOCs or terrain, such as networks of highways, railheads, bridges and utilities. Reconnaissance elements frequently work outside the range of artillery but can be expected to have close air support, airborne and airmobile assets. Failure of a surprise attack may lead to a deliberate attack. In this situation, reconnaissance forces are responsible for seizing a foothold in the built-up area. The phases of the Soviet deliberate attack on an urban objective are isolation, reconnaissance, firing a preassault artillery prep, and assaulting. Isolating the built-up area is the mission assigned to second echelon motorized rifle regiments which do so by attacking to the flanks and rear of the objective. All attacks emphasize mounted, rapid movement versus systematic clearing of the urban area. If necessary, a massive preassault artillery barrage presages an assault on the built-up area. The assault occurs through a foothold gained by reconnaissance elements. Again, the key characteristic of this phase of operations is the Soviet propensity for combining arms - often down to platoon level where task organization with tanks and artillery is the norm. The mounted infantry attack is not necessarily abandoned in favor of dismounted infantry assaults. The reason is the importance of the APC (armored personnel carrier) to Soviet combined arms and the emphasis on rapid advance. Their doctrine stresses conducting limited visibility operations. [Ref. 5: pp. 3-1 to 3-12]

3. **U.S. Defense**

It is not surprising that a *relative* wealth of material is available on U.S. defensive doctrine. The NATO (North Atlantic Treaty Organization) posture in Western Europe makes it the most likely situation to occur at the outset of war. Use of urban terrain as a combat multiplier is a key aspect of this defense. Consistent with defensive doctrine in general, the role of urban areas is defined in terms of the covering force, main battle area, and rear area operations. The restrictive nature of built up areas assists in the hand-off within the covering force area by denying the enemy the ability to gather maneuver room and momentum. The presence of an urban area may assist in accomplishing the covering force mission of deceiving, delaying and attriting the enemy. Frequently, the main battle area will consist of mutually supporting urban areas around which the defense is organized. Defensive positions are situated well forward of critical built-up areas and may incorporate other built-up areas that are astride or dominate avenues of approach and whose retention is not necessary to the overall plan. Mechanized and armored forces prevent isolation of defended built-up areas by maximizing long range fires, channelizing the enemy, and forcing him to deploy early. In locations where maneuver is restricted, a deliberate defense by infantry or dismounted forces in cooperation with mobile forces is established on the periphery of built-up terrain integrating adjacent key terrain. The assumption is that either the urban terrain has key terrain within it or adjacent to it, or that the enemy will attempt to bypass it. Rear area operations often center around urban terrain. As such, they may require protection or defense from Soviet airmobile and airborne strikes. In these situations, the defense will take place within the built-up area itself from the outset. U.S. doctrine emphasizes task organizing combined arms down to company level but recognizes the dominance of infantry elements in conducting the defense. [Ref. 5: pp. 3-13 to 3-19]

4. U.S Attack

U.S. attacks in and around built-up areas are categorized in standard doctrinal terms: hasty and deliberate. A hasty attack against an urban objective differs from a deliberate attack in that the attacking force most likely will be required to move through a fixing force versus moving around it on a flank. This requirement exists for two reasons. First, the urban objective is an obstacle to maneuver in and of itself. Second, the attack is only undertaken if a maneuver to bypass is not possible or fails in the first place. Loss of the element of surprise, stiff opposition against a hasty attack, insufficient forces, and a congested battle area are causes for conducting a deliberate attack against a built-up area. The three phases of an attack against an urban area are isolating, assaulting, and clearing. Isolating is usually carried out on adjacent natural and/or key terrain by armored and mechanized forces. Here suppressive fires (air and ground) and ATGMs (anti-tank guided missiles) are used to their fullest extent since, their effects are diminished inside a built-up area. Assault forces are balanced, combined arms units representative of the major organization conducting the attack. The shock action, mobility , and firepower of these forces are ideal for seizing a foothold on the outskirts of the urban objective and for conducting feints or supporting attacks to alternate flanks and rear. Once in the built-up area, light infantry, dismounted infantry and engineers become the dominant forces used in clearing. In this phase, armored forces perform direct support and mobile reserve roles. Consequently, task organizing for an attack on an urban objective necessarily includes attachment of dismounted infantry. [Ref. 5: pp. 2-7 to 2-15]

D. URBAN PATTERNS AND MISSIONS

A method of categorizing missions in and around urban areas is to analyze task organizations in relation to urban patterns. While not exhaustive, this section illustrates several of the most probable missions and structures them along the lines of urban patterns. In regards to ALARM, emphasis focuses on the planning level(s) germane to the mission. A brief discussion of some relevant facts on Western European urbanization provides a framework of reference.

Since the end of WWII a significant increase in urbanization has occured in Western Europe and the FRG (Federal Republic of Germany) in particular. Urbanization is defined in four categories. Large cities contain populations in excess of 100,000 and form the center of densely built-up urban complexes. It is estimated that the roughly forty-nine large cities in the FRG account for ten percent of the land area. A corps commander can expect to have *at least* one large city in his sector. Towns and small cities, often found near large cities and along LOCs, have populations between 3,000 - 100,000. It is estimated that there are over 230 such areas. One or more divisions may simultaneously be concerned with this type of built-up area. Villages number in excess of 20,000 and contain populations under 3,000. The typical brigade sector may have an average of twenty five villages with an average interval of 3.5 km between them. Strip areas occur within most urban patterns. They are relatively small built-up areas occuring next to secondary roads and along LOCs. Strip areas are primarily the concern of battalions and below but, those in the vicinity of larger cities will naturally concern higher commands. Within any of these categories, the density and types of man-made features can be homogeneous or heterogeneous but, in general, the larger the area the more variable the densities and structure types. [Ref. 5: p. 1-2]

Patterns of urbanization are natural delimiting mechanisms for defining and task organizing missions. There are five of these patterns. They result from the combination of natural terrain features with the four categories of built-up areas. Each is described in FM 100-5 [Ref. 5: pp. 1-2 to 1-8] and briefly summarized below.

1. Hub

A hub is the central complex of any urban pattern. Regardless of its size, its effect remains constant relative to defensive and offensive missions. For the defender, the hub serves as an anchor point of the defense or a strong point for a defense in depth if adjacent terrain restricts maneuver. An attacker first attempts to bypass a hub. If not successful, it becomes a pivotal point he must overcome at considerable expense in terms of time and resources. On occasion a hub may be the objective of a deliberate attack for purely strategic reasons and the focus of corps level planning . [Ref. 5: p. 1-6]

2. Satellite

The primary aspect of the satellite pattern which distinguishes it from a hub is the mutual support of its components. Generally, satellites ring hub areas. Mutual support applies to economic, transportation and communication aspects as well as tactical, lines of communication, and weapons effects aspects. Satellite patterns receive particular attention in division and brigade planning sectors. They are further characterized as having homogeneous terrain and a primary LOC passing through the hub. Numerous routes for attacker and defender are available. [Ref. 5: p. 1-7]

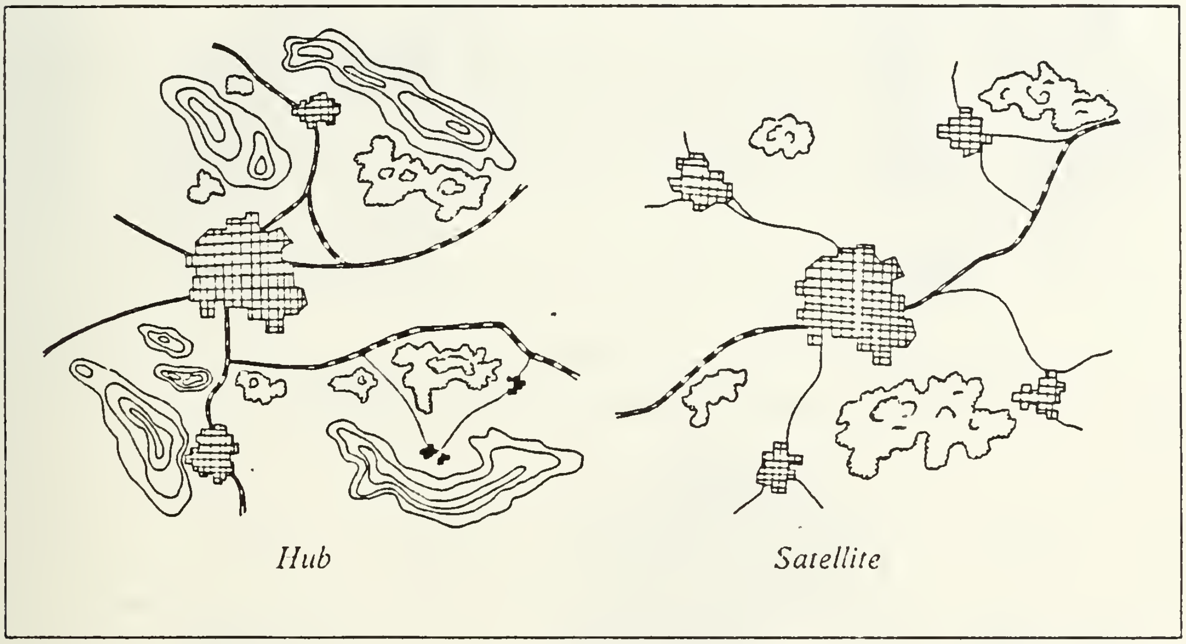


Figure 1.1 Hub and Satellite Patterns.

3. Network

The network pattern is larger than the satellite pattern, has less homogeneous terrain, and provides less mutual support between built-up areas. Most often it is composed of several satellite patterns or hub areas and appears less symmetric. Primarily the concern of divisions and corps, the network will contain numerous critical and divergent lines of communication. It is ideally suited to a defense in depth but provides an attacker with the most flexible and numerous maneuver options. [Ref. 5: p. 1-7]

4. Linear

This pattern is prevalent in the other patterns but, because of its relatively small size, does not effect planning above the battalion level. Frequently, a linear built-up area incorporates a key terrain feature such as a bridge, railhead, or power plant. For a defender it facilitates the networking of defensive positions and provides natural obstacles for channelizing an attacker. For these reasons it presents an attacker with a series of decisions that effect his task organization, avenue of approach and timing. [Ref. 5: p. 1-8]

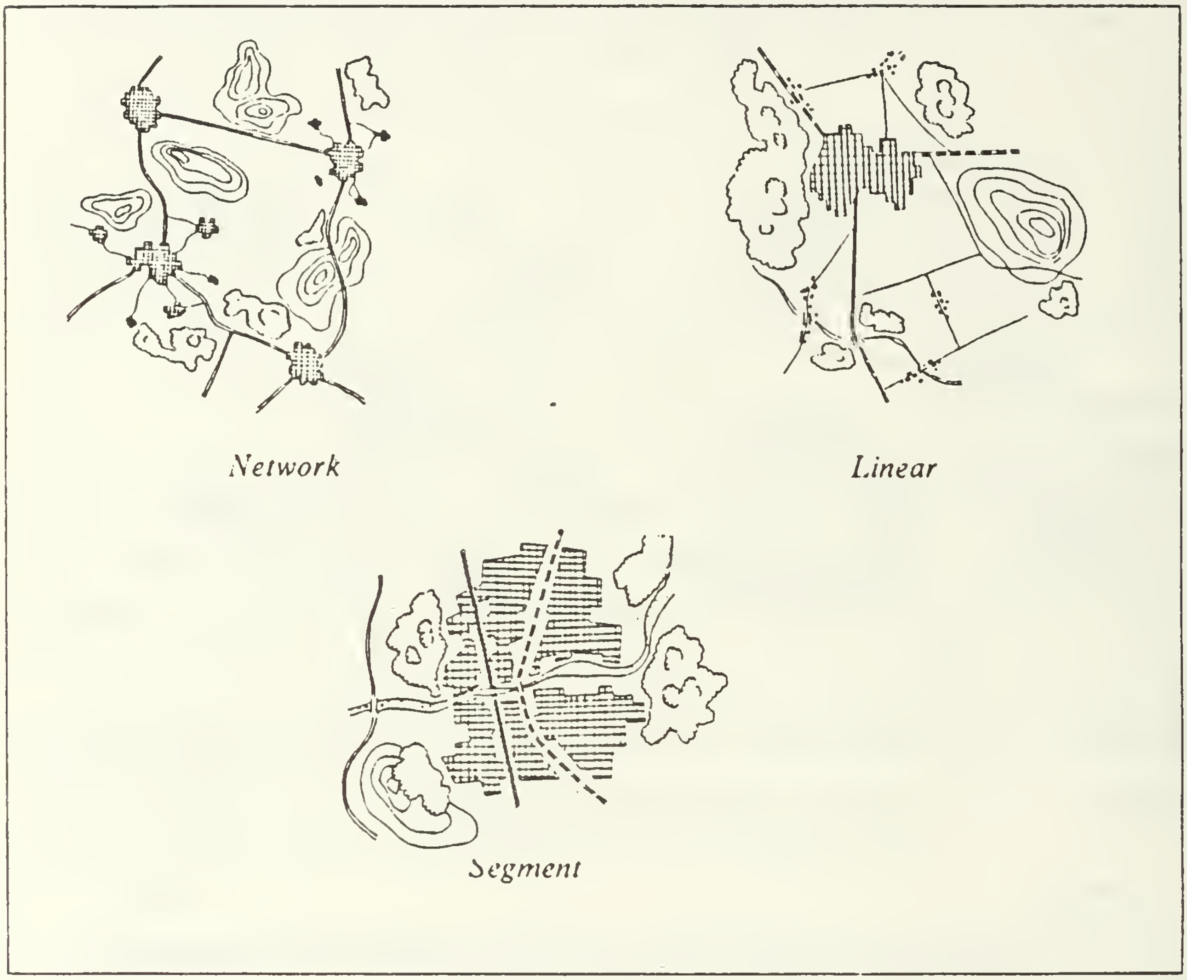


Figure 1.2 Network, Linear, and Segment Patterns.

5. **Segment**

All levels of command are confronted with this pattern. It occurs where an urban area is significantly divided by natural terrain features such as ridges, rivers, or elevated multi-lane highways. It impacts especially on boundary determination and task organization and can be to the benefit or detriment of the attacker and defender. [Ref. 5: p. 1-8]

A synthesis of these pattern characteristics leads to light infantry being task organized with armored and mechanized forces in the following situations:

- On restrictive urban terrain to maximize its use as an obstacle.

- To make an initial penetration in a built-up area.
- To seize and clear an entire built-up area.
- To control locations where LOCs pass through built-up areas.
- For controlling urban networks for use by mobile forces.

These are situations where urban terrain is to be held, systematically seized and cleared, or the mission can be enhanced by using airmobile units. A listing of light infantry missions, according to planning level, incorporates the ideas presented in this section and is shown at Table 1.

TABLE 1
MISSION LISTING BY PLANNING LEVEL

	HUB	SATELLITE	NETWORK	LINEAR	SEGMENT
CORPS	Deliberate Def. Deliberate Atk. Rear Defense		Def. in Depth Airmobile Delay Deliberate Atk. Defense of LOC		Deliberate Def. Airmobile Delay Deliberate Atk.
DIV		Deliberate Def. Deliberate Atk. Defense of LOC Airmobile Delay	Defense in Depth Defense of LOC Deliberate Atk. Airmobile Delay		Deliberate Def. Deliberate Atk. Airmobile Delay
BDE		Defense in Depth Deliberate Atk. Airmobile Delay Deliberate Def.			Deliberate Def. Deliberate Atk. Airmobile Delay
BN				Hasty Atk. Deliberate Atk. Deliberate Def. Recon	Hasty Atk. Deliberate Atk. Deliberate Def. Airmobile Delay Recon
CO/PLT				Hasty Atk. Airmobile Delay Raid Recon	Hasty Atk. Airmobile Delay Raid Recon

E. SCENARIO

1. General Scenario

The Fulda Gap is a traditional axis of attack into the south-central part of Western Europe. Assuming that an attack by the Warsaw Pact seeks use of some portion of this axis, the general scenario places a Blue light infantry division defending to the north of the gap against a flank attack whereby Red attempts to avoid Blue's strength forward and within the gap. The division sector is an urban network. In addition to the six small cities and towns and the fourteen villages, the terrain is characterized by two river obstacles, the *Eitra* and the *Haune*. Heavily wooded, hilly areas border on the north and south with elevations averaging 450 meters. The terrain restricts high speed avenues of approach to two routes which orient on bridges across the river obstacles. These crossing locations are controlled by built-up areas and if seized by Red, allow for rapid flank access into the Fulda Gap. The pictorial at Figure 1.3 depicts the sector and approaches. The map representation is from Series M745 3-DMG-1975, 1:50,000 L5324, Hunfeld (NB4717-NB5817-NB5928-NB4728).

The blue division is organized in a defense in depth. Assume that the ALARM model, at this level, determines an optimal force allocation suggesting a infantry and mechanized task organization. Pure light brigades defend the northern and southern flanks in terrain that is restrictive to mechanized forces. A mixed brigade is responsible for the central sector. A mech-heavy brigade, in reserve, defends in depth along the *Haune* which is the main river obstacle. According to the planning horizons shown at Appendix A, the Blue division plans to face at least one Red division of a Combined Arms Army.

2. Brigade Scenario

The center brigade is the focus at this level of resolution. For simplification, the only units represented in the brigade are the infantry, mechanized, armor and artillery elements. The brigade's sector is characterized as a satellite pattern with Eiterfeld as the hub. The brigade executes a deliberate defense within its sector.

Implied missions for the brigade are a defense of the *Eitra*. and a defense of Eiterfeld. The town is key terrain which blocks approach to open terrain to its southwest and access to the bridges across the *Haune*. An attempt to bypass Eiterfeld requires river crossings to the north or traversing dismounted to the south. The brigade plans to defend against Red regiments of a MRD (motorized rifle division) and is task organized as in Table 2.

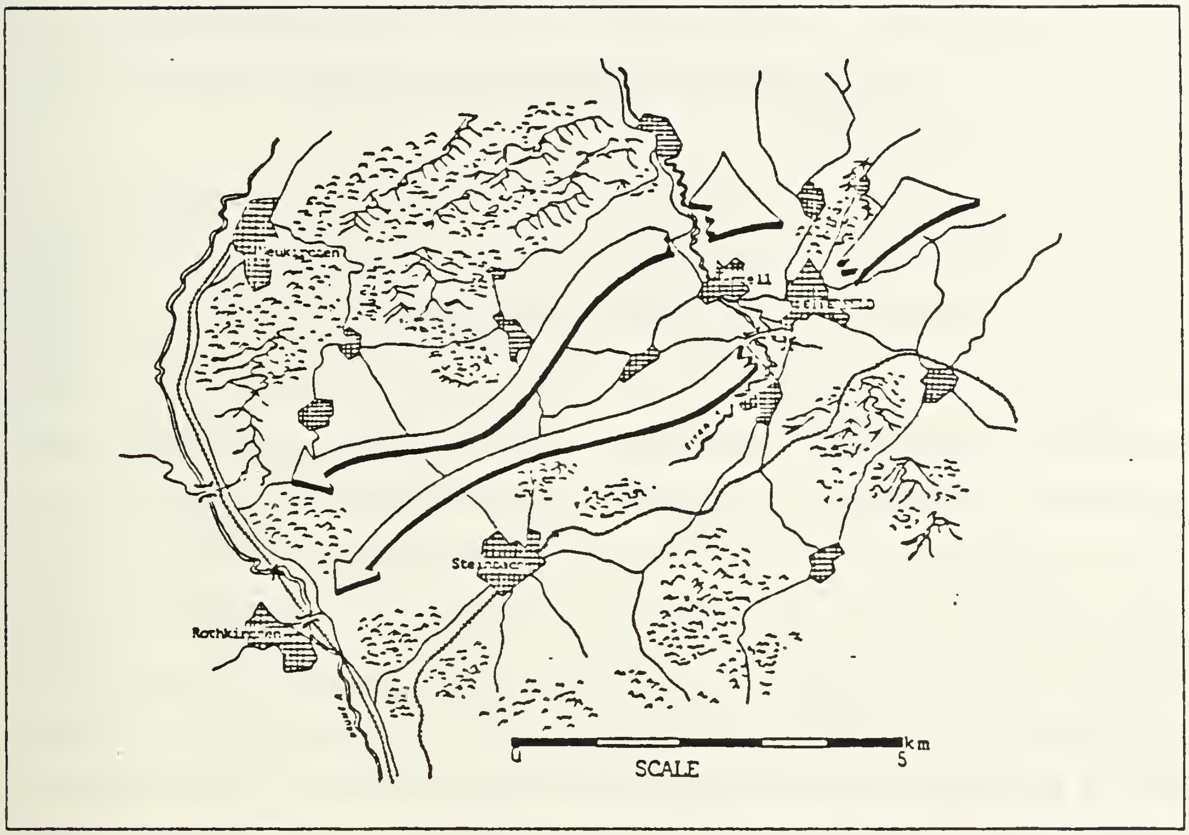


Figure 1.3 Division Sector.

TABLE 2
BRIGADE TASK ORGANIZATION

INF BN 1	TF LITE	INF BN 3	BDE CON
3 Inf Co	3 Inf Co	3 Inf Co	Mech Bn(-)
1 CSC	1 CSC	1 CSC	Armor Co(-)
Arty Btry	Mech Co	Arty Btry	Engr Bn
	Armor Plt		Mech Arty
	Arty Btry		DS Arty

3. **Battalion Task Force Scenario**

Task Force Lite, in the brigade center, defends Eiterfeld. The town's proximity to Arzell and the *Eitra* characterize the task force sector as a segmented pattern. The task force elements are located between 20 km and 50 km to the rear of

Eiterfeld and must move to the sector. The mechanized company and the armor platoon form the covering force and establish a security zone approximately 2 km forward of the town. The task organization is a light infantry battalion augmented with mechanized and armored elements.

TABLE 3
BATTALION TASK FORCE ORGANIZATION

INF CO A	INF CO B	INF CO C	TM MECH	TF CON
3 Inf PLT	3 Inf PLT	3 Inf PLT	3 Mech PLT	Btry D
			1 Armor Plt	AT Plt
				Engr Plt

Eiterfeld is four square kilometers in size with a population over 3,000. It consists of a light industrial section to the northwest, a business section in the center, and a residential area to the southeast which thins into farms and strip areas to the northeast. Four hard surface, all weather roads enter Eiterfeld from the north and exit in two roads to the south and west crossing the *Eitra*. Three hill masses are key terrain to the northeast: Hill 406, Hill 306, Hill 376, which dominate the northeastern portions of Eiterfeld and its approaches. Hill 335 on the northern outskirts of the town and Hill 324 directly south control immediate bypass avenues to the bridge locations. Within Eiterfeld, key terrain features are the factories in the industrial section, the reservoir north of the town and the central business sector which controls all routes through the town.

The remaining chapters, which develop an urban methodology, use the battalion task force scenario. The center brigade scenario and its subordinate element's missions are the basis for demonstrating the variable resolution development of ALARM planning processes.

II. CARTESIAN-SPACE NETWORKS

Cartesian space networks are used in ALARM to model the physical aspects of the battlefield. Normally the first step in planning an operation (following mission analysis) is making a terrain assessment. How a section of terrain impacts on tactical movement/unit placement, logistics and communications are generally things considered by a planning organization. While ALARM will incorporate multi-level cartesian space networks for each of these, the purpose of this chapter is to extend the development of the terrain/transportation network to built-up areas. The scenario presented in the first chapter is modeled in the candidate networks. Previous work with terrain networks is extended by identifying urban peculiar network characteristics and attributes. An additional purpose of this chapter, pursuant to a conceptual objective of ALARM, is to outline the integration of parallel subordinate networks within the network of a higher planning organization. The presentation of the candidate terrain/transportation networks emphasizes integration at the brigade and battalion levels. The division and brigade networks are first described in terms of arc/node types and attributes. Task Force Lite's sector includes Eiterfeld and forms a subordinate network within the brigade terrain/transportation network. This brigade network is also defined. A brigade subordinate unit mission paralleling the defense of Eiterfeld is defending along the *Eitre River* north of Eiterfeld. Thus, the battalion defending this sector has a river defense mission against a possible Soviet regimental crossing operation. The corresponding battalion terrain/transportation forms another portion of the brigade terrain/transportation network. A follow-on step in the ALARM design is modelling the simultaneous brigade level planning and execution of these two battalion level missions. This follow-on step is discussed further in the conclusions section of the final chapter.

A. ARC TYPES AND ATTRIBUTES

An arc in a cartesian space network represents a homogeneous strip of terrain between two points on the ground. The nodes delineate the end points of the particular terrain possessing the homogeneous characteristic. At the levels of resolution used in ALARM, *homogeneous* is defined in terms of the most prevalent type of terrain that influences movement. As the level of resolution increases, the degree of homogeneity, represented by arc types, increases since the network becomes more detailed. For terrain and transportation networks that depict built-up areas, the arc types and attributes defined by previous research are still appropriate and are shown in Appendix B. However, the proper modeling of urban areas requires additional arc type and attribute descriptors, particularly for higher resolution networks.

The only urban simulation in use today by the U.S. Army is ACABUG (American Canadian Australian British Urban Game). The model is high resolution and defines urban characteristics in terms of densities. Additionally, ACABUG categorizes attributes such as construction materials, building types, and percentage of firing apertures, to name a few. Defining urban characteristics in terms of densities is appropriate for this research. However, the list given in Appendix B need only be augmented with seven additional arc types. The first five additional arc types are defined in FM 100-5 [Ref. 5: pp. 1-4 to 1-5] and the last two originate with the author. All are estimated in terms of ratios of built-up volume to total urban volume. Using volume as the means of expressing these density types accounts for the three dimensional aspect of fighting in an urban environment. The measurements given are estimates from scaled photographic examples. A brief description with the number code of each follows. [Ref. 6]

• **Urban Dense Random (11) :** Buildings are located close together in a random arrangement. Older European cities and towns consist primarily of random dense patterns. The roads are narrow with buildings and structures buttressing against them. [Ref. 5: p. 1-4]

• **Urban Orderly Block (12) :** Typical of center sections of larger built-up areas, this density classification is closed but organized, usually in a grid pattern. Streets are wide, buildings are high and connected, with breaks occuring at intersections. Thus, compartmenting occurs and reduces observation and fields of fire. [Ref. 5: p. 1-4]

• **Urban Residential Dispersed (13) :** This type of area surrounds or borders the orderly block type. It is characterized by one to three story single dwellings with patterned open spaces such as yards or gardens. The streets can form square blocks or circular patterns. [Ref. 5: p. 1-5]

•**Urban High-Rise (14) :** A self descriptive characteristic is the height of buildings in this type of area, frequently five to twenty stories tall. These areas are contiguous to the orderly block type and exist most frequently in larger cities. It features large open spaces between buildings. There are obvious advantages to the defender in terms of observation and strength of positions. [Ref. 5: p. 1-5]

• **Urban Industrial/Transportation (15) :** The industrial and transportation pattern is usually part of large built-up area. It is characterized by moderate to large buildings of varying constructoral strength with a lot of open space between structures. Industrial areas usually include major transportation routes and railways. [Ref. 5: p. 1-5]

• **Urban Open Space (16) :** These are areas in or near built-up areas that offer increased fields of fire but are still controlled by the surrounding urban structures. Examples are parks, parking lots or sports fields.

• **Sparse Urban/Terrain Combination (17) :** Perhaps the most common type density where combat is likely to occur, urban/terrain combinations are located on the periphery of built-up areas. The major characteristic is that it includes key terrain within or adjacent to the city or town. This type has a relatively low ratio of buildings to area but the combination of key terrain and a few hardened structures makes urban/terrain areas attractive to a defender and creates good foothold areas for an attacker who can seize any portion of one.

TABLE 4
SUMMARY OF ARC TYPES AND ATTRIBUTES

ARC TYPE	*ATTRIBUTES*
Urban Dense Random (11)	Density = 40%
Urban Orderly Block (12)	Density = 60%
Urban Residnt Disp (13)	Density = 48%
Urban High-Rise (14)	Density = 30%
Urban Indust/Trans (15)	Density = 15%
Urban Open Space (16)	Density = 0%
Sparse Urban/Terrain Comb. (17)	Density = 10%

B. NODE TYPES AND ATTRIBUTES

Several additional node types require defining and addition to the list at Appendix B, further describing urban networks. The four node types described below are prominent points within any urban pattern. They either delimit the density patterns described above or are focal points in planning urban operations, especially placing troops and control measures.

- **Urban Intersection (6) :** Intersections provide easily identifiable coordination points and, when connected, can denote phase lines. Both of these control features are important to urban combat planning and mission execution. Larger intersections can control disproportionately large sections of built-up areas in all directions. They are also key points in the lateral movement and shifting of forces.

- **Key Building/Structure (7) :** This node type is used to denote the beginning and end of a particular avenue of approach. They may be placed anywhere within the network but will typically mark changes in density type.

- **Bridge End Node (8) :** Bridges are usually key terrain, as in the present scenario. Therefore, the end nodes mark a transportation arc that requires control, traversal by a unit, or is otherwise critical to the plan.

- **Urban Peripheral Opening (9) :** Frequently within built-up areas open spaces occur, as described earlier. In urban constricted areas, openings present better fields of fire and observation as well as maneuver capability. As such, the nodes that mark the peripheral points of this type of urban terrain are important to planning.

TABLE 5
SUMMARY OF NODE TYPES AND ATTRIBUTES

NODE TYPE	*ATTRIBUTES*
Urban Intersection (6)	No Additional
Key Building/Structure (7)	
Bridge End Node (8)	
Urban Peripheral Opening (9)	

C. URBAN TERRAIN NETWORKS

Much of the research already conducted for ALARM has emphasized using terrain/transportation networks in mission analysis and unit placement. The thesis by McLaughlin [Ref. 4: pp. 20 to 91] presents algorithms that calculate network flow rates and select arcs for positioning units. The flow rates indicate the allowable size and speed of a unit traversing an arc. The rates can be used to model a scheme of maneuver. From a defensive perspective, McLaughlin's work results in algorithms that model a unit's ability to select terrain most favorable to its tactical plan in terms of stopping or delaying an attacker. The arc selection process was improved upon from earlier work to the degree that now allows the use of multiple selection criteria. For example, fields of fire, cover and concealment criteria can all be used selecting a route whereas, prior to Mclaughlin's work, only one of these could be used. In essence, this allows the representation of differing tactical preferences. Additionally, and perhaps most significantly, the methodology models a unit's ability to defend or orient its combat power in several directions, which translates to exerting control over several arcs. The capability to split a unit's combat power is important to realistically representing combat in built-up areas where the ground battle typically takes on a multi-directional character.

Inherent in a unit's planning process is analyzing terrain in order to arrive at decisions about committing forces. The thesis research currently being done by Choi develops a terrain network analysis model [Ref. 3]. In general, the model accepts terrain data input represented by 100 m coded grid squares and calculates the length, width, and slope of a terrain arc. Changes between terrain types corresponding to those listed in Appendix B are measured in width along the arcs of a network. Calculating the average width along the length of an arc produces a description of an avenue of approach that can be related to flow rate. The model also determines the average slope along an arc. While the current model uses 100 m squares to code the terrain, it is fair to say that the resolution can easily be varied depending upon the available data. It should be noted that the terrain data depicting the urban scenario is available through Rolands and Associates, Monterey, Ca., in a corps sized section [Ref. 7]. The data points are coded and correspond to the six-digit grid coordinates of the map sheet referenced in the first chapter. Thus, sorting through the corps data, one can extract the division, brigade, and battalion sectors for use in Choi's terrain model.

As stated earlier, an objective of the continuing research in ALARM is to link parallel missions, at one level of resolution, within higher command level planning networks. Ultimately, the terrain analysis model and avenue of approach generation and unit placement algorithms will be tied in with this work to produce a prototype planning module for ALARM. A step in that direction, and one of the stated goals of this thesis, is modeling the urban terrain networks at various levels of resolution. The remainder of this chapter presents the candidate division, brigade and battalion networks. The map section shown in Figure 2.1 is a reproduction of the battle area. Subsequent figures depict the various level networks placed over this terrain.

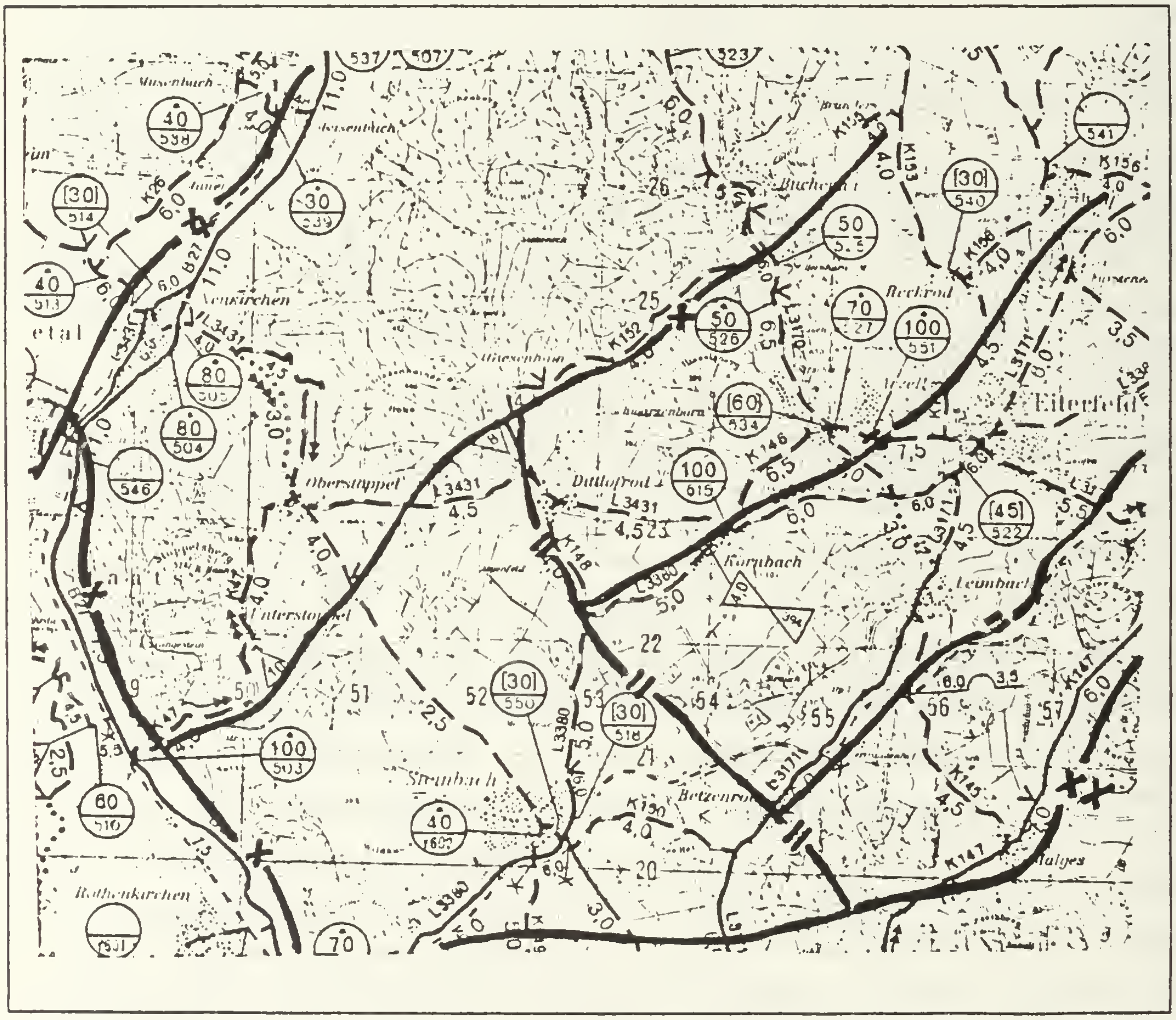


Figure 2.1 Divisional Battle Sector.

1. Division Network

The division network shown in Figure 2.2 models the two avenues of approach described in the first chapter. The arcs that support a mounted attack against Eiterfeld are limited. However, Eiterfeld dominates all of the arcs depicted. Urban nodes denote only the key points of interest within the built-up area such as bridges or intersections. In the present scenario, the divisional points of interest are the bridges and those urban features whose seizure by the enemy would necessitate a change in the friendly course of action. For example, seizure of the central intersection of Eiterfeld might render the retention of the remainder of the town untenable. The lower resolution node type, *village* (2), denotes the smaller urban areas in entirety.

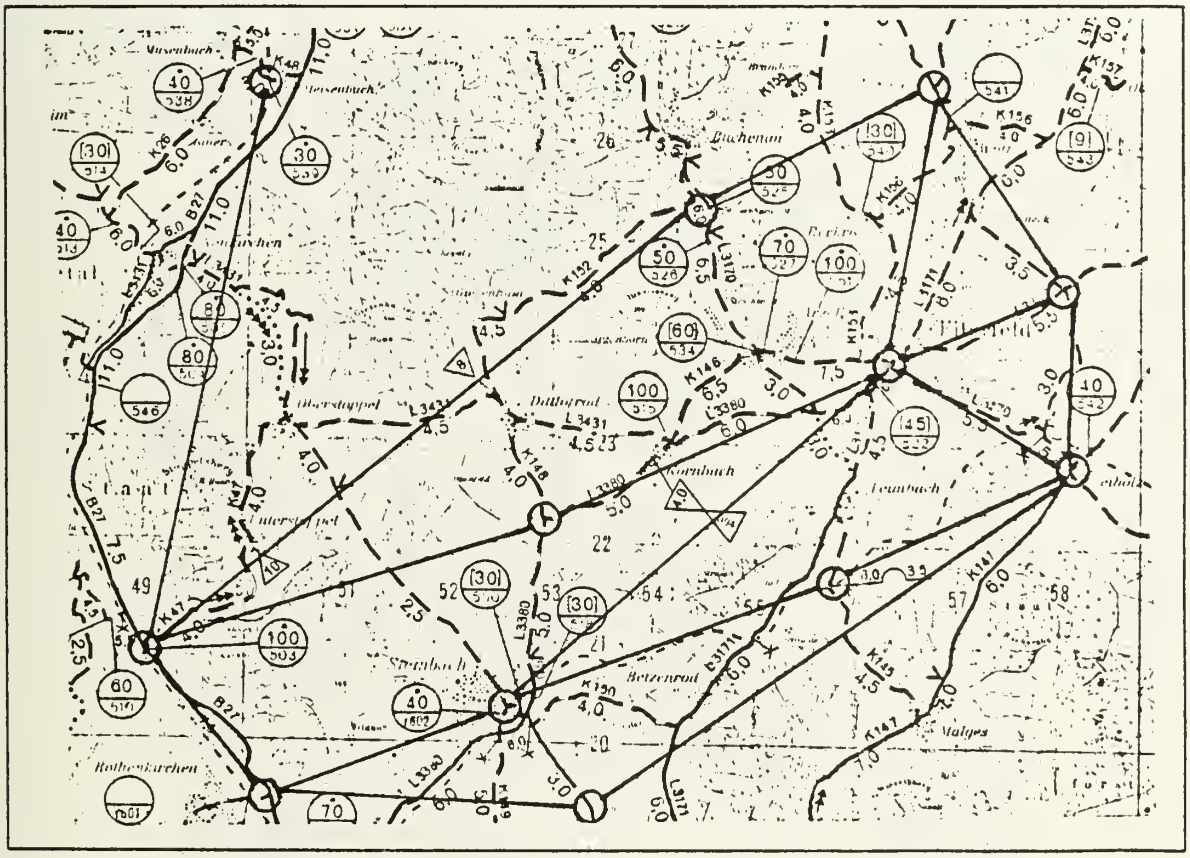


Figure 2.2 Division Network.

2. Brigade Network

Solid black nodes are nodes that are common with a higher command level and are shown in order to demonstrate how the networks link. The linking nodes of the division network are apparent in Figure 2.3. At this level of interest, only key points and features are assigned a node. Note that a larger city may contain many key urban nodes linked by their respective arcs. Eiterfeld is a relatively small town and thus requires fewer arc/node combinations. The arcs depict only those paths through the built-up area network that support enemy formations within the brigade's planning horizon. The respective arcs from the division network are, in many instances, segmented into subarcs in the brigade terrain/transportation network. This is because the brigade has a more refined view of the battlefield and is naturally concerned with specific areas for delaying and stoping the enemy.

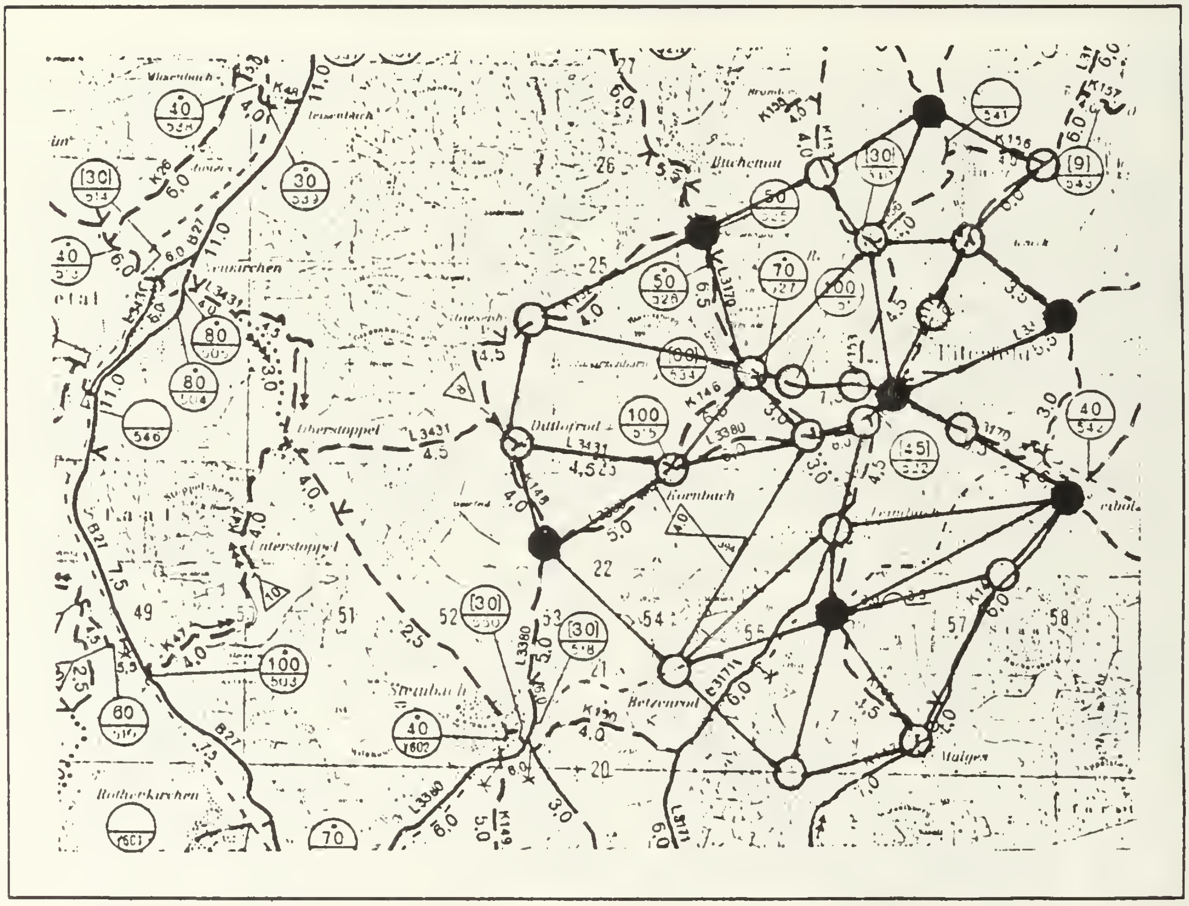


Figure 2.3 Brigade Network.

3. Battalion Network

Figure 2.4 is an enlargement of the task force sector with the urban network superimposed. At this level of resolution, all the key features of the built-up area that are of interest to the task force are depicted by nodes. The connecting arcs take on the density attributes. The key bridges are marked by a pair of end nodes which allows forces to be placed on the connecting arcs. Again, as in the brigade network, lower resolution arcs become segmented into more detailed subarcs in the battalion network. The resulting arcs are capable of supporting the movement of company sized enemy elements at a minimum. Avenues of approach that would allow an enemy force to bypass are also represented by arc/node combinations since it is assumed that the enemy would focus on these paths in his planning. Thus, the terrain surrounding and adjacent to Eiterfeld is important to the friendly plan as locations for preventing isolation of the built-up area.

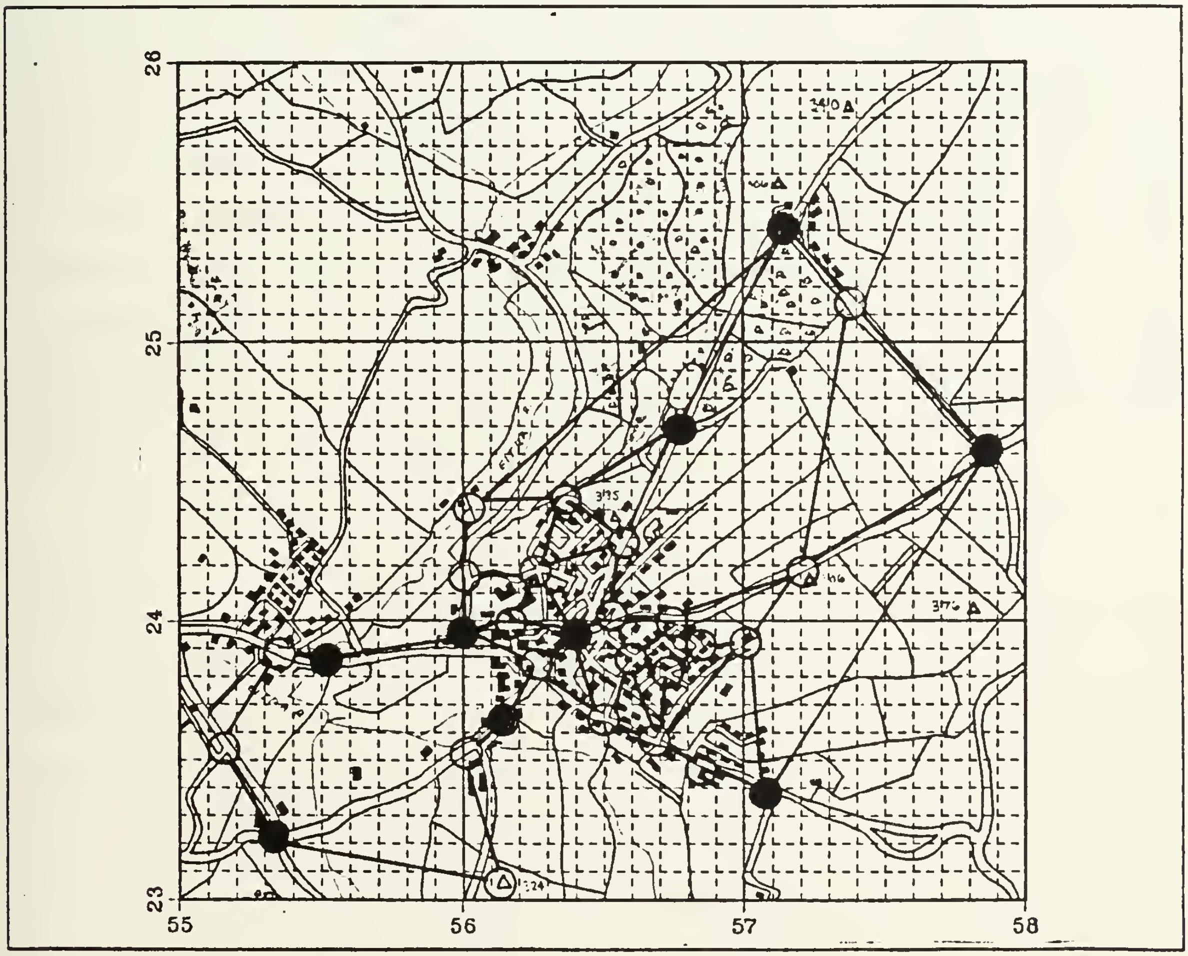


Figure 2.4 Task Force Sector.

Terrain analysis is an aspect of ALARM that is being fully developed. The networks depicted above, in combination with the defined arc and node types, present the means to extend research into the multi-resolution design concept held by the ALARM designers [Ref. 8]. In this respect, the urban terrain networks and the terrain/transportation network utilized in the prototype Soviet river crossing mission provide the foundation for linking parallel missions under a higher command planning network. Leaving this as an area for future research, emphasis in the next chapter is on urban time domain networks that will work in tandem with the urban cartesian space networks.

III. TIME DOMAIN NETWORKS

Time domain networks represent mission planning processes and are designed as planning templates. Having completed a mission statement and terrain analysis, and obtained estimates of friendly and enemy capabilities, the next step in the planning process is to analyze friendly courses of action against the enemy's probable course of action. The mission planning template, or network, serves this purpose in ALARM. It is also the mechanism whereby orders to subordinate elements are formulated. In analyzing courses of action, commanders and staffs recognize that certain factors are under their control such as task organization, movement routes and artillery allocations to name a few. Other factors cannot be controlled but still must be considered in the analysis. For example, enemy actions, terrain characteristics and enemy capabilities are factors that must be anticipated. The latter are considered from best case to worst case when analyzing friendly courses of action. By analyzing all of the various combinations of these controlled and uncontrolled factors, feasible options for accomplishing the mission result. The basis for determining feasibility is usually time, friendly casualties and/or attrition to the enemy. From the feasible options the commander selects the most favorable course of action for accomplishing the mission's objective and then generate orders to subordinates.

The Force Planning Model in ALARM is designed to find the feasible paths through a mission planning network. Whereas the model was initially built around a Soviet regimental river crossing template, this chapter provides an urban template for use in the model. The section which follows explains the structure of the Force Planning Model using time domain network terminology, with particular emphasis drawn to the relationships of the model's inputs with the actual planning process. With this in mind, the mission template for a U.S urban defense is developed and explained in detail. The central features of this type network are the mathematical submodels that characterize the particular combat. These are developed for the urban defensive scenario. The next chapter analyzes the results obtained using the urban defense template in the Force Planning Model.

A. THE FORCE PLANNING MODEL

The Force Planning Model solves time domain networks in the ALARM planning process. The arcs of a time domain network represent the passage of time, or activities, and the nodes delineate the beginning and end of these time periods and are called events. Solving the time domain network is analogous to solving a PERT (Program Evaluation and Review Technique) network for the critical path. The criteria for selecting the critical path in PERT is time. However, the critical path for the Force Planning Model is defined in terms of minimizing the time for completing the mission and friendly casualties but may also include a level of attrition to the enemy. Thus, the resulting solution is structured by the time, casualty, and mission constraints imposed by the next higher echelon. The solution also defines the mission orders of a lower echelon.

As an illustration of these ideas, Figure 3.1 depicts the mission planning template used for the Soviet regimental river crossing mission. While it is a regimental template, the sequence of activities may be equally appropriate to any Soviet planning level. On

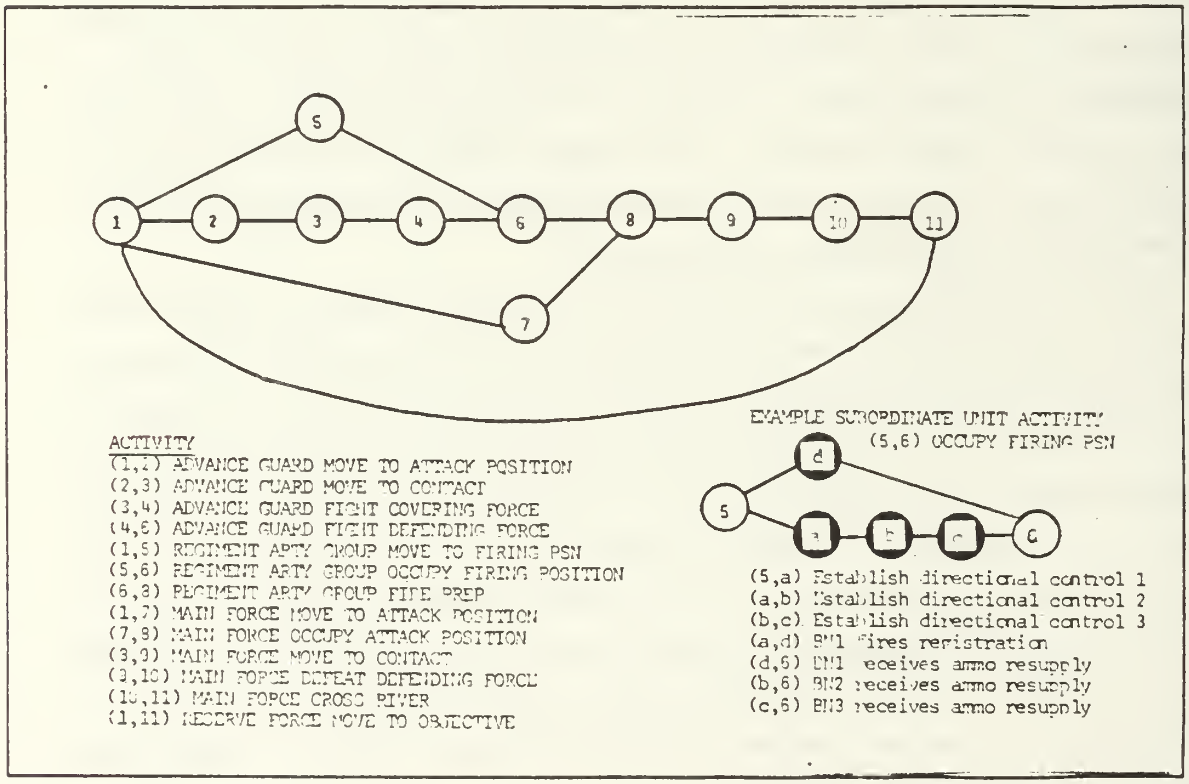


Figure 3.1 Soviet Regt. River Crossing Template.

the other hand, other templates may be necessary to categorize river crossings at other command levels. Because of the inherent simplicity of having one template apply to all levels and mission scenarios, designing a single generic template was a developmental goal for the urban defense. But, first, a brief description of the model inputs is necessary before further pursuing the network development.

1. Model Inputs

The time domain network is a generalized depiction of the sequence of events a force must plan and conduct to successfully complete a mission. Events are connected by activities, pictorially represented by arcs, and represent the passage of time. Each activity is structured within five constraints. As they pertain to combat, these constraints include a time to accomplish the activity, the makeup of the opposing forces, and the attrition to the opposing forces. In the Force Planning Model, the constraints are called *arc characteristic equations.* They may change in form, depending on the mission being modeled, but do not change in substance. They are always defined by a duration equation, friendly and enemy force makeup equations and friendly and enemy survivor equations. Figure 3.2 gives a conceptual picture of the basic Force Planning Model inputs and outputs for an activity.

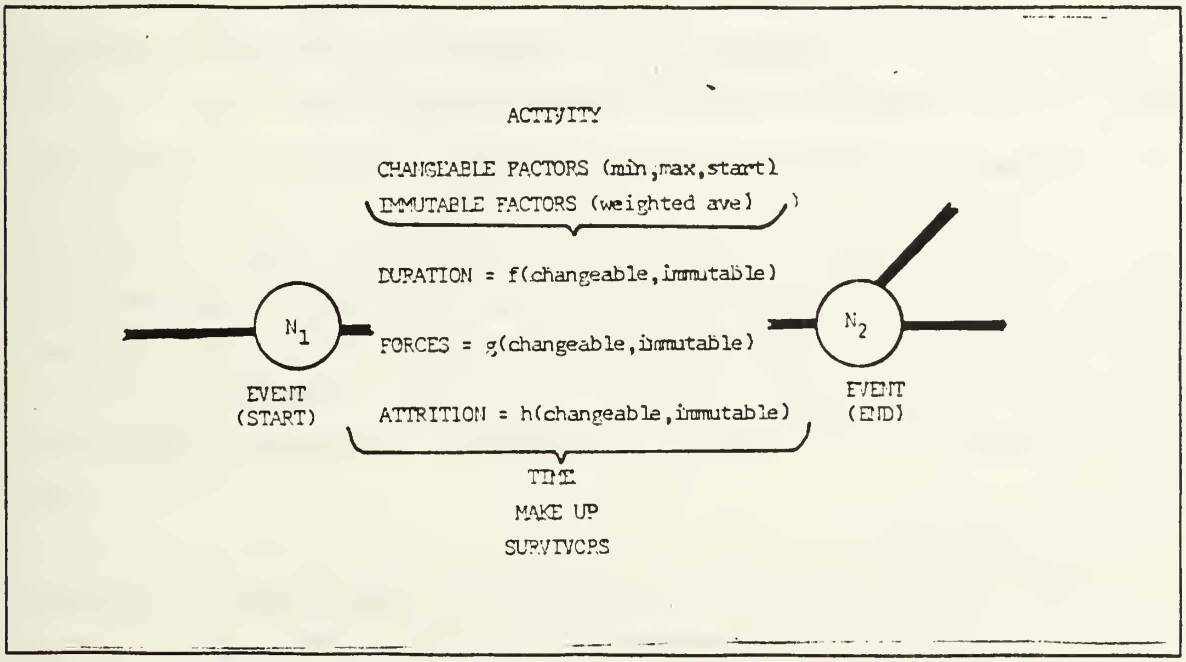


Figure 3.2 Model Inputs Defining an Activity.

The idea of arc characteristics being allowed to change form but not substance relates directly to the point made earlier of the existance of two types of planning factors: those a commander/staff can control and those that cannot be controlled. These are referred to as *changeable factors* and *immutable factors*, respectively. Both are input parameters to the Force Planning Model and are related through the characteristic equations. These parameters define the form of the arc characteristics. Since changeable factors are things that can be directly changed by a decision, they are assigned a starting and ending value and an increment of change value. To illustrate, in defending a built-up area with a combination of mechanized and light infantry forces, a commander may consider including elements of both types in the composition of the covering force. Thus, he would consider adding to or taking away from a mechanized base in increments of light infantry squads, platoons, companys etc., depending on the activity level and situation. Immutable factors, on the other hand, are those things that may be affected but not controlled by a decision. For example, the commander planning the employment of the covering force in front of an urban area can only anticipate how the enemy will organize his forces to counter the threat his covering force presents. He thus plans against several alternatives that simplify to a pessimistic, expected, and optimistic prediction of opposing force size. The model uses a weighting system to combine these three estimates with the most weight usually given to the expected value of the immutable factor to produce an enemy course of action. Equation (3.1) gives the general form of the simple weighting function.

$$\textbf{(a(Pessimistic) + b(Expected) + c(Optimistic))/ n = Value} \qquad \textbf{(eqn 3.1)}$$

The values of the coefficients can be chosen to model any number of decision situations. For example, if the extreme cases are the only contingencies of concern, the value of b is set to zero. The value of n must be the sum of the coefficients. While standard PERT methodology uses the values (1,4,1) for the coefficients, the current Force Planning Model uses the Soviet planning technique of setting the weights equal to (3,0,2).

2. Solving The Model

Central to the planning process is analysis of the courses of action. Assuming that the inputs to the decision making process are reasonable or valid, the plan results from comparing the alternatives and selecting the best option. Infeasible alternatives are discarded. If all alternatives are infeasible, the commander in effect must look to changeable factors and determine levels that will allow the mission to be successfully completed. The model simulates this analysis by comparing results given the characteristic equation for each activity, or arc, on the network (i.e., determining the duration, force makeup, and force survivors of each activity at the various changeable factor values).

Defining the changeable factor ranges allows the model to search for combinations that yield feasible solutions. This is accomplished by moving through a conceptual tree network of factor values. The vector of changeable factor starting values is used to calculate the duration, makeup, and force survivors for each activity with the combined, weighted value of the immutable factors. Violation of either the overall mission completion time or maximum friendly casualty level results in an infeasible course of action and causes the incrementing of one of the changeable factors. The procedure continues until all possible combinations are checked. The outcome with the shortest time and the minimum casualties to the friendly side is the optimal solution. At this point, the usual by-products of a network solution are generated such as the critical path arcs, slack times and sequence of critical events.

As an example, consider a company level urban activity in a planning network of clearing a building. Suppose the course of action depends only on three factors: the size of the enemy force, the size of the assault force and the amount of ammunition required for the assault. The first factor is an immutable factor. Therefore assume that the enemy is expected to occupy the objective in squad strength but at best may only use a fire team and at worst a platoon. The size of the assault force and ammunition load are changeable factors. Thus, analysis of the courses of action might start with a platoon in the assault carrying twice the basic load of ammunition. However, other possible courses of action require consideration of increasing the size of the assault force in platoon increments and decreasing the ammunition carried by half loads. One of the constraints on the mission could be as follows. First, a higher headquarters is likely to impose a time limit for completion of the mission. The actual time needed is a function of the opposing force size, the number of friendly troops sent into the assault, and the amount of ammunition they require to clear the enemy. Likewise, the constraints on force compositions and attrition levels are in some way functions of the same factors. The specific functions relating the factors are the characteristic equations.

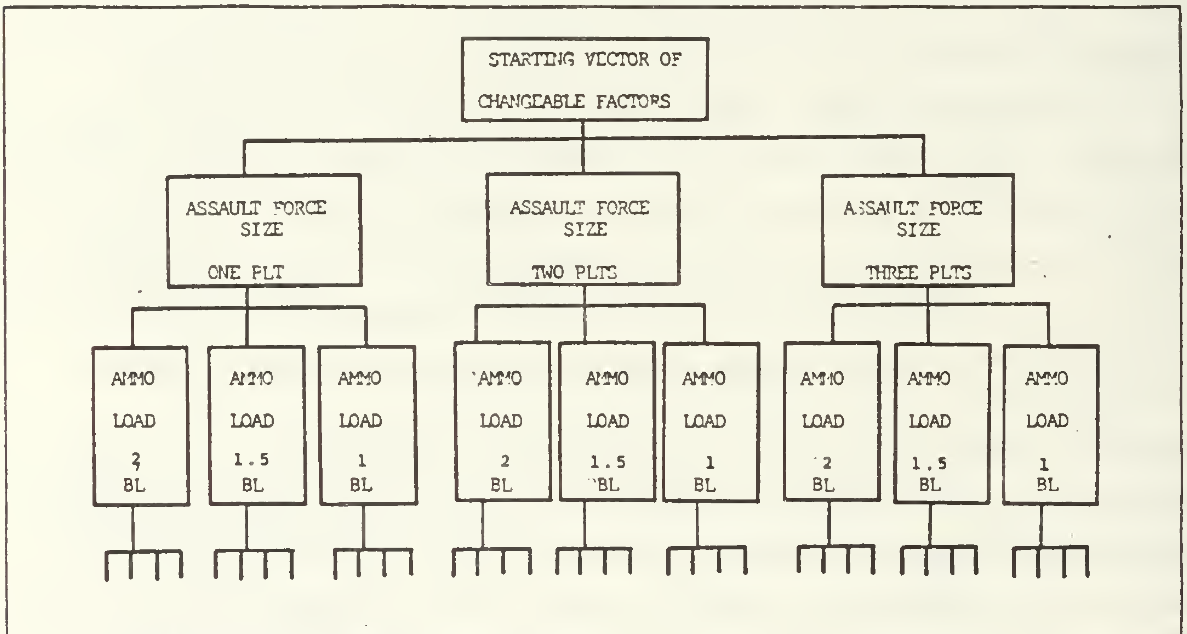
In general mathematical notation, these can be expressed as shown in Equations (3.2) through (3.4).

TIME = f(ENEMY FORCE, FRIENDLY FORCE, BASIC LOAD) **(eqn 3.2)**

FORCE = g(ENEMY FORCE,FRIENDLY FORCE,BASIC LOAD) **(eqn 3.3)**

CASUL = h(ENEMY FORCE, FRIENDLY FORCE, BASIC LOAD) **(eqn 3.4)**

First, the friendly force size is varied over a constant starting value of ammunition load to determine feasible solutions. Each time a combination fails in terms of overall time and casualties, the assault force is incremented one platoon. If all sizes of the assault force fail to produce a successful assault, in terms of time and casualty constraints, the next level of the tree network varies ammunition load over each of the force sizes. Figure 3.3 diagrams a portion of this hypothetical tree network as an illustration.



	MIN	MAX	STEP
ASSAULT FORCE SIZE	1	3	1
AMMO LOAD	1	2	.5

Figure 3.3 Example Tree Diagram.

Totaling the time and casualty results over all arcs (activities) results in a solution. The results become the time and activity constraints that describe the mission orders of the next subordinate unit. The following section logically developes the urban defense mission planning template in terms of the concepts discussed to this point.

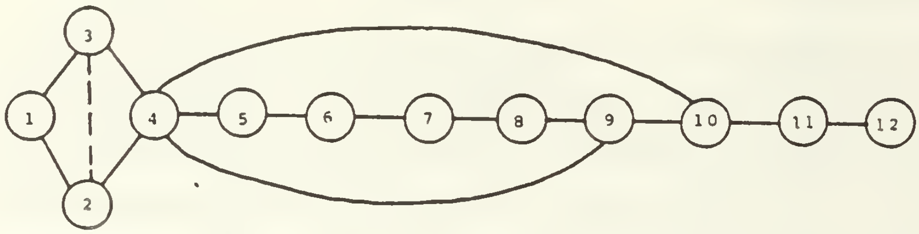
B. MISSION TEMPLATE

The mission template must be specific enough to represent the essential activities of a particular type of mission yet general enough to be applicable to variations caused by changes in the planning level or scenario. In addition, it should logically mesh with higher and lower templates of likely follow-on missions. All templates are planned from first activity to last activity as a sequence of events leading to successful mission accomplishment. In developing the following template, the scenario presented in the first chapter is used. While the specific situation has a U.S. task force defending a segment patterned built-up area, the candidate planning network is equally useful for planning the defense of any of the other patterned built-up areas. The network is also applicable at planning levels above a battalion task force. The size of the forces involved does not alter the sequence of events and, for those scenarios that omit particular activities, inputs of zero for the arc characteristic equations generally alter the outcome appropriately.

The development of the mission template is essentially a description of activities and events for an urban defense in consonance with the doctrinal ideas already discussed. However, an aspect of the Force Planning Model limiting the sequencing of activities is the fact that the current version of the model cannot simultaneously attrite two forces performing parallel activities. For example, the covering force engagement cannot be modeled simultaneously with the execution of the main defense battle. In contrast, artillery can cause attrition by either modeling fire missions as separate activities in sequence with other activities or by having artillery attrition accounted for implicitly in the attrition characteristic equations of other combat activities. This limitation occurs because, unlike PERT networks which determine critical path based on time alone, the Force Planning Model uses time as well as force make up and casualties as criteria in calculating a solution through the network. The current version of the model cannot solve a network with this degree of complexity built into parallel arcs.

1. U.S. Urban Defense Planning Template

Recalling the scenario and the task organization, note that each combat asset has a specific role in the defense that consists of one or more activities. A salient feature of a U.S. defense of a built-up area is engaging the enemy well forward of the built-up area. This is primarily the role of a mobile covering and security force. Artillery supports with fires forward of the built up area, particularly against enemy assembly and attack areas. However, artillery fire support capabilities are limited as the battle moves into the built-up area proper because of the decreased effectiveness of indirect fire in urban areas. Engineers are employed in preparing demolitions, obstacles and key positions for the defense. Successful defense of a built-up area usually predicts a counterattack as a follow-on mission for armor and mechanized forces if the enemy has been removed from the urban area or by light infantry forces if he still has a foothold. At a minimum, the counterattack has as its objective the reestablishment of the covering force and security zone. The network pictured in Figure 3.4 depicts the activities just described for successful defense of an urban area.



ACTIVITY

(1,2) COVERING FORCE MOVE TO ZONE
(1,3) ARTILLERY ECHELON TO FIRING POSITION
(2,4) DEFENSE FORCE MOVE TO URBAN AREA
(3,4) ARTILLERY COMPLET OCCUPATION OF FIRING POSITION
(4,5) DEFENSE FORCE ESTABLISH HASTY URBAN DEFENSE
(5,6) COVERING FORCE FIGHT RECON ELEMENT
(6,7) COVERING FORCE MOVE TO ALTERNATE FLANK POSITION
(7,8) MAIN DEFENSE FIGHT FOOTHOLD ASSAULT
(8,9) COVERING FORCE FIGHT ADVANCED GUARD
(4,9) PREPARE DEMOLITIONS AND KEY OBSTACLES
(4,10) PREPARE URBAN DELIBERATE DEFENSE AND ALTERNATE/SUPPLEMENTAL PSNS
(9,10) ARTILLERY FIRE AGAINST FIRST ECHELON ATTACK FORMATIONS
(10,11) MAIN DEFENSE DEFEATS ASSAULT ON URBAN AREA BY MAIN BODY
(11,12) PREPARE TO ECECUTE THE COUNTERATTACK PLAN

Figure 3.4 U.S. Urban Defense Template.

2. Sequence of Events

Consider the network as linking three phases of battle: the preparation phase, the covering force operation and the main defense phase. The events of the three phases are now briefly described in relation to the network shown in Figure 3.4.

a. Preparation Phase

This phase includes arc activities between nodes one through five and the three activities leaving node four. These activities account for the covering force establishing security forward of the built-up area and covering the occupation and preparation of a hasty defense within the built-up area. A hasty defense is established when crew served weapons are emplaced, sectors of fire established, fields of fire cleared, and communications tied in between elements. The hasty defense precedes improving positions towards establishing a deliberate defense. The dummy arc between nodes three and two is critical to the mission timing since it requires the covering force to be positioned first to screen the movement to and occupation of the built-up area by the main defense force. The direction of the arc must be specified in the input to the Force Planning Model as going from node three to node two because the solver completely services nodes from lowest numbered to highest numbered. The two long arcs leaving node four and ending in nodes nine and ten, demonstrate that these activities continue until actual battle is joined inside the urban area. The timing reflects both defensive fundamentals of continuously preparing any defense as long as time permits and the need of having key demolitions emplaced before enemy reconnaissance elements can attempt to seize key objectives.

b. Covering Force Operation

The covering force activities consist of detecting and engaging the enemy's recon element. Perhaps as important is securing the flanks against enemy attempts to isolate and bypass the built-up area. These activities are represented by arc and node combinations five through nine. Since the network presents an optimistic sequencing of activities and is modeled against Soviet attack doctrine, the covering force stops the reconnaissance element, moves to supplemental positions oriented on the flank avenue of approaches, and prevents the advanced guard from bypassing or isolating the built-up area. All of these activities are planned to occur before the main defense engages the assault by the main body. In fact, according to Soviet doctrine, bypass or isolation must fail before a deliberate assault is made on the built-up area.

c. *Main Defense Phase*

A major assumption of this portion of the network is that the covering force action is successful in preventing isolation of the built-up area and the enemy is forced to conduct an attack to clear it. Effective use is made of supporting fires to harass and disrupt the enemy's attack formations. A possible variation would add another set of arcs and nodes following node eleven depicting the intended use of reserves in stopping the assault. However, since the reserve is likely to be used and reconstituted repeatedly throughout urban combat its use is left as implied in the single activity between nodes ten and eleven. Ultimately, a reconstituted reserve is used to counterattack, evict the enemy from the urban terrain and reestablish the security zone.

Thus, the proposed planning network is a logical progression of activities which reflect current doctrine on urban defense. The network's generality allows encompassing forces at any level of planning. The network is flexible enough for modeling most urban defensive scenarios.

C. CHARACTERISTICS OF THE URBAN MODEL

To this point the structure of the Force Planning Model has been presented and a candidate urban defense planning network described. The arc characteristic equations are the elements of the model that integrate the two concepts. This section is organized in six parts. First the assumptions are stated. The remaining sections document the development of the candidate changeable and immutable factors and the three types of arc characteristic equations: duration, force makeup, and attrition. Some of these elements are developed to model urban and/or light infantry aspects of combat specifically. Others are useful in any general combat scenario under appropriate assumptions. The emphasis is on the logic behind each equation, the assumptions on which it is based, and its limitations. In most cases, numerical values for the parameters are not discussed at this point. However, Appendix C contains the data file used in running the defense planning network in the Force Planning Model. The numbers shown in the input files are discussed in the next chapter.

1. Assumptions

As stated earlier, the ground combat elements represented in the model are limited to tanks, APCs, infantry, anti-armor, artillery,and engineers for simplicity. The combat power for each is derived from Standard Units of Armament (SUA) estimates. The SUA values used are based on those used in the prototype Force Planning Model for a Soviet river crossing. A thesis by Manzo and Hughes gives alternative values and relative conversion factors based on the T-62 tank as a reference entity [Ref. 9]. The two sets of values are comparable; however, Manzo and Hughes base their estimates on weapons caliber and dispersion factors. The estimates used in the Force Planning Model are aggregate values that implicitly account for numerous factors such as armament, mobility and range. In either case, the assertion is that the values are fair representations of relative combat power. Because the model requires that SUAs be summed across the different elements, the total combat power of a conceptual unit is viewed as if it is a homogeneous force. The strength of a particular force increases or decreases in proportion to the number and type of elements in its make up.

An important set of assumptions pertaining to the attrition submodels (characteristic equations) concern the nature of the attrition rate coefficients. The majority of the submodels used are applications of Lanchester's classic combat formulations drawn from Taylor's research [Ref. 10]. In particular, urban and urban peripheral combat situations are modeled under Lanchester's square law, also known as equations of modern warfare with constant coefficients.

$$dx / dt = -ay \qquad \text{(eqn 3.5)}$$

$$dy / dt = -bx \qquad \text{(eqn 3.6)}$$

These were selected because they are simple to program and they have several associated forms with closed form solutions that express other combat results such as duration of battle and surviving force sizes.

Assume the coefficients remain constant for any particular engagement but can have differing values depending upon the force compositions and point in time of the battle. This is accomplished, as will be seen, by creating different immutable attrition factors for each change in situation. Creating these factors raises the issue of coefficient estimation. The problem with estimating attrition rate coefficients is accounting for the many factors that determine a kill rate. Certainly, at a minimum, they are functions of time and relative force sizes. Various arguments exist for rationalizing how they change. Essentially, two primary methods are available for estimating coefficients, the COMAN and the Bonder/Farrell.

COMAN depends upon a high resolution simulation that outputs a detailed casualty history over time. The data must include the time of occurance of each casualty, which force sustained the casualty, and the size of the force after the casualty.

Attrition coefficients are calculated external to the simulation through use of the high resolution data and a fitted parameter approach. In the case of COMAN, the fitted parameter is the maximum likelihood estimate of the time between casualties. The main assumption of the method is that casualties occur randomly and independently according to a memoryless Markov Process. Therefore, by the memoryless property of the exponential distribution the likelihood function becomes the product of the independent probabilities of each casualty occuring in a given time.

The Bonder/Farrell approach does not rely on a high resolution simulation. Analysis determines the acquisition time and kill time which are summed to give the total time for a firer to kill a target. The method uses a renewal or semi-Markov process and assumes that shots are independently repeated until a kill occurs. From this the probability of a single shot kill is calculated. By using the geometric distribution, the expected time for a kill to occur (first success in k trials) is calculated. This is accomplished by taking the probability a target is killed on a particular shot, multiplying by the shot number, and summing this product over the total shots fired. The inverse of the expected time to kill is the firing rate. When multiplied by the probability of a single shot kill, the attrition rate coefficient results.

The attrition coefficients used in the the urban network are in units of SUAs killed per firer per hour. They are not values obtained from either of the two methods per se but are estimates based on contemporary Force Planning Model usage. In its fully operational form, ALARM will make use of one of the formal methods for estimating.

2. Changeable Factors

The remainder of this chapter references Appendix C, the sample input for the Force Planning Model. Cross references appear in the appendix at appropriate locations and serve as examples. The changeable factors fit into one of five categories. A commander/staff can effect the battle through decisions dealing with movement of units, allocation of planning time, logistics, obstacle planning, and task organization. The five factors are in line with the tenants of Airland Battle doctrine presented in the first chapter.

The movement of units is classified as either tactical or administrative. The former is typically conducted using one of the tactical movement techniques: travelling, travelling overwatch or bounding overwatch. Administrative moves are usually in convoy. Because speed is terrain dependent, movement intervals are the only factors that are changeable. This category of factor is refered to as *spacing*.

The operations and planning category has the single changeable factor, *time to prepare for the counterattack.* Preparation time is included as a changeable factor because a commander decides how soon after defeating the enemy assault to initiate the counterattack. Depending on the plan developed and the condition of weapons and troops, the counterattack can be immediate or it can take time to reorganize and augment the reserve. If the enemy still retains small portions of the built-up area, the counterattack is conducted with the dismounted infantry reserve. If the enemy is completely evicted from the built-up area, the mechanized and armored units counterattack and pursue to reestablish the security zone and maintain contact with the enemy.

Logistics sustains operations. As stated earlier, the number of combat elements explicitly considered in the model are reduced to a manageable number. The many classes of supply that sustain this force are also reduced for simplification. Artillery ammunition is the only supply item currently represented in the model.The *percent fired in support* is the changeable factor and contributes to modeling preplanned artillery fires. Time often expresses the mission requirement in actual preplanned fires. As an illustration, an order might call for a ten minute prep on an objective. However, for the simulation, modeling the fire support mission against the enemy's attack formations uses tons of ammunition fired for expressing the mission requirement. There are several reasons for doing this. First, it builds logistics consumption into the model, which is a realistic constraint on operations. Second, the changeable factor relates to time through the firing rate (expressed in tons fired per gun per hour), another factor easily measured.

Obstacle emplacement has been modeled in several of the terrain and unit placement network algorithms already designed for ALARM. Therefore, it is natural that it should be considered pertinent to urban networks as well. The number of obstacles emplaced as part of a defensive plan impacts on overall mission completion time and is a changeable factor categorized under obstacles.

Finally, a commander can array his forces to fit a number of concepts of operation. The forces available in the urban model allows the task organization to vary within the covering force, the main defense, the flank defense, and the reserve. The changeable factors are expressed as fractions of organic units assigned to a conceptual force. The conceptual forces vary in size as well as composition. This type of changeable factor also allows artillery missions and priority of fires to be implicitly modeled. As an illustration, a priority of fire mission translates into allocating all of the artillery SUAs to a specific conceptual unit, such as the covering force. Table 6 summarizes the changeable factors.

TABLE 6
SUMMARY OF CHANGEABLE FACTORS

SPACING
vehicle interval
march interval
formation interval (mechanized)
formation interval (infantry)

PLANNING OPERATIONS
time to prepare to execute the counterattack

LOGISTICS
tons of ammunition for support
artillery mission allocation

OBSTACLES
number of obstacles to prepare

TASK ORGANIZATION
fraction of organic units assigned to conceptual units
-covering force
-main defense
-flank defense
-reserve

3. Immutable Factors

Not all immutable factors are tangible planning considerations. Some are implied in a commander's consideration of METT-T (mission, enemy, terrain, troops, and time). Those that are implicit are the truely immutable factors over which he cannot exercise control, such as attrition rates. However, in the Force Planning Model they are explicitly defined. The immutable factors for the urban planning network are categorized as either movement, attrition, opposing force organization, weapon/terrain physical characteristics, or operations related. These are briefly described below and summarized in Table 7. Again, Appendix C provides examples for cross reference.

The first category, movement, includes distance and speed factors used in planning maneuver of forces. Those factors considered explicitly in a movement plan are travel distances, the size and composition of forces, and the movement technique. The factors that are implied when formulating a plan are road and cross country speeds and the physical dimensions of the elements being moved.

TABLE 7

SUMMARY OF IMMUTABLE FACTORS

MOVEMENT
distances to travel
vehicle road speed
vehicle cross country speed (and tech factor)
pax road speed *
pax cross country speed * (and tech factor)
number of vehicles per formation
number of pax per formation
number of formations (per conceptual unit)
formation angle (terrain dependent)

ATTRITION
friendly direct fire attrition rate
enemy direct fire attrition rate
friendly indirect fire attrition rate
enemy indirect fire attrition rate
friendly urban attrition rate
enemy urban attrition rate
artillery casualties expected per ton fired
artillery probability of detection
friendly urban clearing rate

OPPOSING ORGANIZATION
fraction of origional units in conceptual units
- recon element
- advance guard
- main body

WEAPON/TERRAIN CHARACTERISTICS
firing rate for artillery (tons/hr)
built-up area volume
percentage of urbanization (density)
percent of urban area defended

OPERATION RELATED
number of positions to prepare
time for artillery to occupy
obstacle preparation time
sector preparation time
position preparation time

*NOTE: "PAX" is a term associated with the moyement of personnel and equipment, and commonly used in infantry units.

Virtually all of the immutable factors relating to attrition are factors not specifically considered when analyzing courses of action. However, a commander's consideration of placing forces in a particular position or moving along a specific route will include the expected vulnerability to casualties. Attrition rate coefficients are examples of immutable factors that are considered in general ways when comparing enemy and friendly capabilities. A unit requesting priority of fires is implicitly attempting to increase its attrition rate. Attrition rate factors are explicitly defined in the network as attrition rate coefficients for direct, indirect and urban fires. Other factors that are defined are probabilities of hit and kill for artillery fire. Immutable attrition factors are integral parts of the characteristic equations describing combat activities.

As stated earlier, a realistic method for determining the anticipated enemy course of action is weighting a pessimistic, expected and optimistic estimation of a particular capability. Immutable factors that determine enemy organization are defined in terms of fractional parts of units assigned to conceptual forces, such as the advance guard or recon element. In reality, the enemy's actual strength and composition are seldom known with certainty. Consequently, analysis of the enemy's capabilities results in planning against a likely course of action whether it be the worst case ,expected or best case. The weighting equation models the requirement to plan against some enemy course of action.

Physical characteristics of weapons and terrain are fixed factors. They impact on the length of battle and engagement outcomes. Both factors are explicitly considered in actual planning and thus, are included in the urban planning network. Examples of the factors used are artillery firing rate and the ratio of built-up area to total sector size.

Operational related immutable factors include times to execute plans, prepare positions, and emplace obstacles. Again, the pessimistic, expected, and optimistic estimates are used in the model much the same way that they are considered in actual planning situations.

4. Duration Equations

Duration equations are the characteristic equations that determine the time to complete an activity of the network. The equations used in the urban planning network are grouped into three types: duration of movements, duration of engagements, and task durations. The first group models the time required for making administrative or tactical moves. They are embellishments of the D = RxT formula. The factors that describe a convoy or road march are:

- Time - T
- A representative vehicle length - L
- A column interval - I_c
- The total number of vehicles in the column - N_c
- The distance to be traveled - D
- The speed of the column - S

They are combined to describe the movement time in Equation 3.7

(eqn 3.7)

$$T = \frac{(L + I_c)N_c - I_c + D}{S}$$

The assumptions of the model are that all vehicles are of the same length and move at a constant speed. Figure 3.5 diagrams the concept.

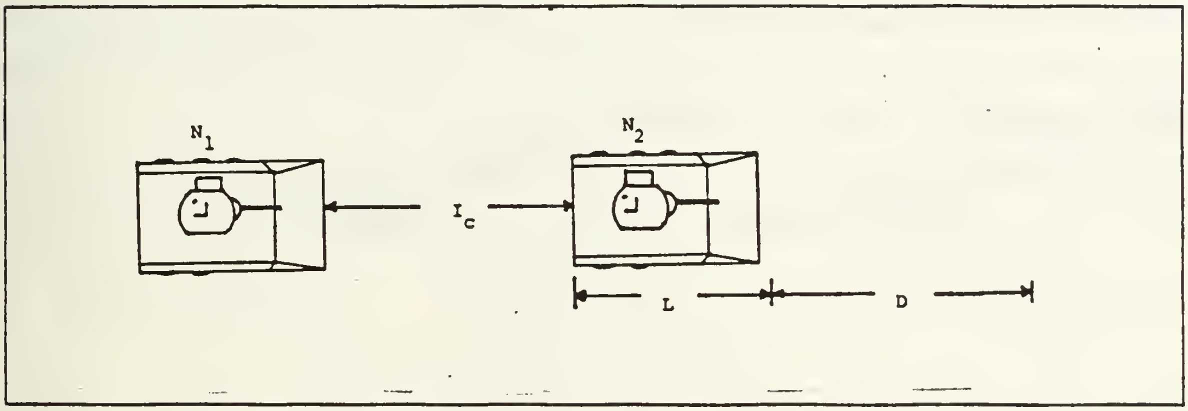


Figure 3.5 Diagram of Convoy Movement.

Tactical moves use one of the tactical movement techniques. Whereas the column moves in serial, the basic formation of a tactical move is the wedge. The wedges themselves move in serial (traveling and traveling overwatch) or in tandem (bounding overwatch) with intervals between and within formations dependent upon the terrain being traversed. The factors describing a tactical move are:

- Time - T
- The number of wedges - W
- The number of entities per wedge - N_e
- The inter-entity interval - I_e
- The inter-wedge interval - I_w
- The distance to move - D
- The wedge apex angle - θ
- A technique factor - t_f

They are combined to describe the time to move by Equation 3.8.

(eqn 3.8)

$$T = \frac{(W - 1.0)I_w + \{ [(.5N_e - 1.0)I_e] \, SIN\,\theta \} W + D}{S}$$

The model assumes constant speed, equal sized formations and that the angle θ decreases as terrain becomes more restrictive. The technique factor accounts for the slower movement of the overwatch formations. Figure 3.6 diagrams the concept.

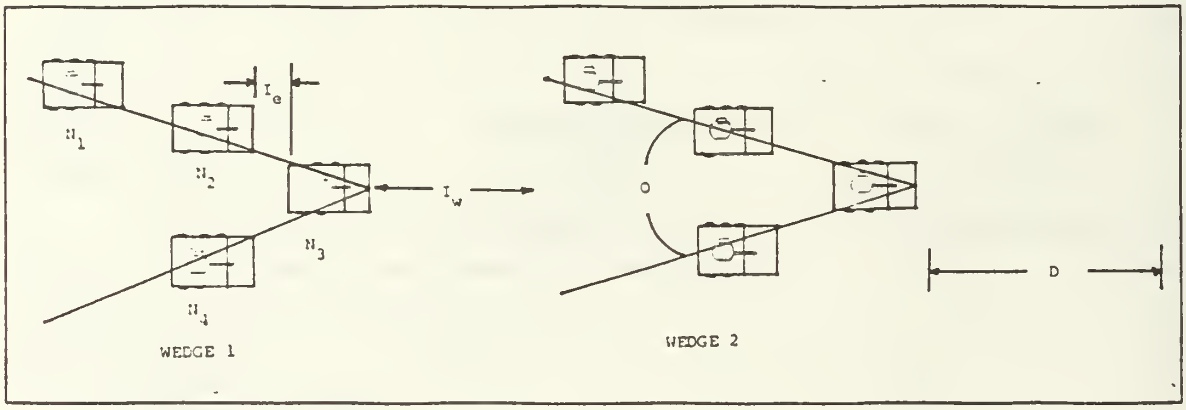


Figure 3.6 Diagram of Tactical Movement.

The duration equations which model length of engagements in the urban planning network are mostly extensions of the square law [Ref. 10: p. 129] by Lanchester. However, because of the homogeneity assumption and the different nature of fighting within built-up areas, two other equations are used that describe heterogeneous combat and combat in built-up areas, respectively. The parameters in the square law length of battle equation are:

- Time - T
- The friendly attrition rate coefficient - α
- The enemy attrition rate coefficient - β
- The starting friendly force size - Y_0
- The starting enemy force size - X_0
- The enemy fractional breakpoint - f^X_{BP}

Lanchester's equation is expressed as follows:

(eqn 3.9)

$$T = \frac{1.0}{\sqrt{\alpha \beta}} \ln \left\{ \frac{\left(\frac{X_0}{Y_0}\right) f^x{}_{BP} + \sqrt{\frac{\alpha}{\beta} - \frac{X_0{}^2}{Y_0{}^2}\{1 - (f^x{}_{BP})^2\}}}{\sqrt{\frac{\alpha}{\beta}} - \frac{X_0}{Y_0}} \right\}$$

An assumption of the model is the Y-force wins a fixed breakpoint battle against the X-force. The model yields the number of survivors for the winning side and assumes that the losing side is reduced to its breakpoint strength. Since the network principle itself assumes a successful completion of the activities by the friendly side (in this case the U.S.), the enemy is always assumed to reach his breakpoint first. Therefore, the condition expressed by Equation 3.10 must first be checked to see if it holds for the ratio of forces. A further assumption is that the attrition rate coefficients are constant.

(eqn 3.10)

$$\frac{X_0}{Y_0} < \sqrt{\frac{\alpha}{\beta} \cdot \frac{\{1 - (f^y{}_{BP})^2\}}{\{1 - (f^x{}_{BP})^2\}}}$$

A model that accounts for differing attrition effects due to direct and indirect fire is appropriate in engagements where the attrition contributions of each are able to be distinguished. For example, the covering force usually has priority of artillery fires to support its direct fires. Equation 3.11 is adopted from the prototype river crossing planning network. Its input parameters are as follows:

- Time - T
- The enemy fractional breakpoint - $f^x{}_{BP}$
- The percent casualties due to direct fire - C_d
- The percent casualties due to indirect fire - C_i
- The friendly direct fire attrition rate - α_d
- The friendly indirect fire attrition rate - β_i
- The starting enemy force size - X_0
- The starting friendly force size - Y_0

The parameters are related in Equation 3.11.

(eqn 3.11)

$$T = \frac{(f^{x}{}_{BP} - 1.0)C_d}{-\alpha_d X_0} + \frac{(f^{x}{}_{BP} - 1.0)\, C_i\, Y_0}{-\beta_i X_0}$$

Assumptions are constant and independent attrition rate coefficients and that the percentage of casualties due to each type of fire is deterministic and represented as a proportion.

Fighting in cities is a protracted form of combat. Destroying an enemy means his positions have to be physically cleared in close combat. The requirement to methodically clear each built-up structure accounts for the long engagement times. As the resistance increases, the total battle time increases, but at a faster rate. This suggests that an exponential function models the engagement time. The following equation is used in two situations. It determines the time for a defender to evict an entrenched enemy or the time for a defender attrite an attacker to breakpoint from static positions. For this latter use a defense enhancement factor is included and represents the value a defender gains by occupying defensive positions and letting the attacker attempt to clear him out. The variables describing urban physical dimensions and percentages occupied are relative to the situational use of the equation. The following variables describe the model.

- Time - T
- The total urban volume - V_u
- The percent of the total volume urbanized - U_v
- The percent of the urban volume defended - U_d
- The clearing rate - R
- The starting enemy force - X_o
- The starting friendly force - Y_o
- A defense enhancement factor - f_d

The exponential model is given by Equation 3.12.

(eqn 3.12)

$$T = \exp\left\{\frac{V_u U_v U_d X_0}{R\, Y_0 f_d}\right\}$$

Assumptions for the model are that the clearing rate is constant and inversely proportional to the size of the force being cleared. The urban volume represents the size of the built-up area seized by the enemy assault that must be cleared. The percentage of the volume that is urban terrain is the density characteristic explained in the second chapter. The diagram at Figure 3.7 is a graphical representation of the urban volume factors. Note that if the enemy does not gain a foothold prior to his assault, no urban clearing by the defending force is necessary. In this case, Lanchester's square law is used to model attrition for the main defensive battle .

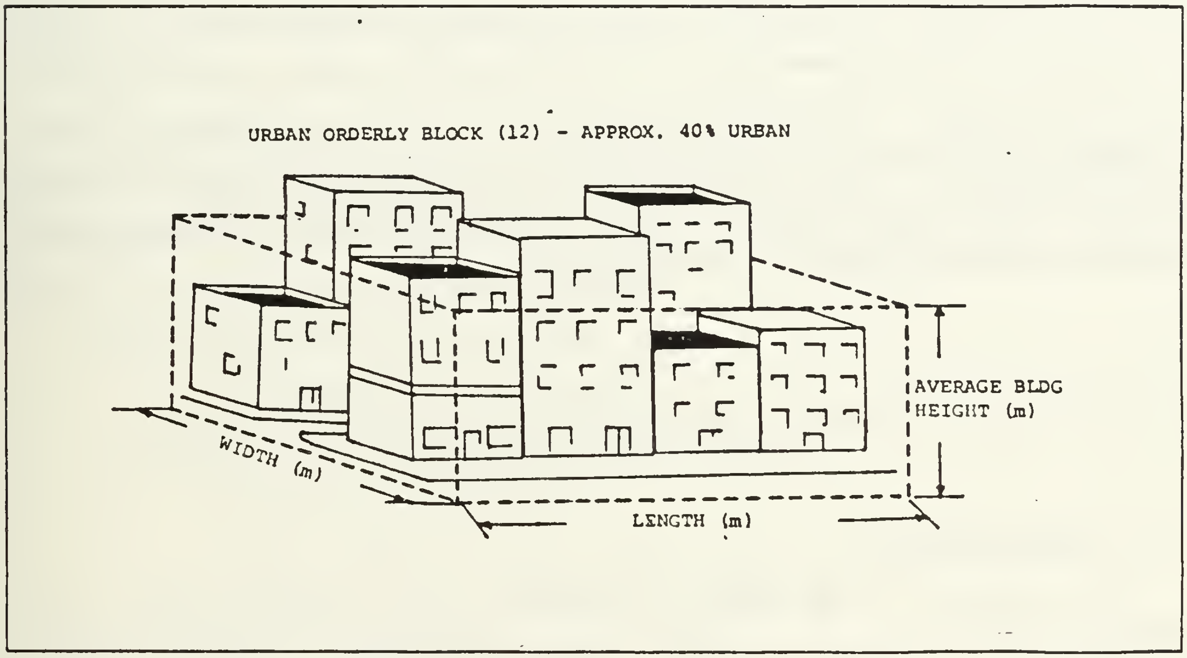


Figure 3.7 Urban Terrain Model.

The last group of duration equations concern task completion times. These are tasks that are commonly found in ARTEP (Army Training and Evaluation Program) manuals or training manuals and are stated as performance standards. In this respect, they describe discrete time events having the form of changeable or immutable factors. In the urban network, specific activities that are also considered as tasks are time spent occupying the artillery position, occupying the defense, preparing positions and demolitions, and organizing for the counterattack.

5. Force Makeup Equation

The force makeup equation keeps track of the current composition and strength of the opposing forces. The SUA, as described earlier, is the unit of measurement of an entity's combat power. All entities have a SUA and thus, total combat power is additive over the number and types of entities making up a conceptual unit. The fractions of the organic units allocated to the conceptual forces for the friendly side are changeable factors. An example is the fraction of the mechanized company or the armored platoon that comprises the covering force. The fractions of enemy original units allocated to conceptual forces are immutable factors, as pointed out earlier. An example of this is the fraction of the regimental artillery group allocated to the advanced guard. The characteristic equation used throughout the network model is shown by Equation 3.13. The Force Planning Model continuously keeps track of three values based on the starting value of a force. At any time in the sequence of activities the original and current SUA values are determined, as well as the remaining number of entities in a unit.

(eqn 3.13)

$$F_0 = \Sigma_i \text{ (fraction of organic unit}_i \text{ in conceptual units}_j\text{) (SUA}_j\text{)} \qquad \text{for all } j$$

6. Attrition Equations

An extension of the square law equation with constant attrition rate coefficients is used in conjunction with the respective equation for duration of battle. The specific form is shown by Equation 3.14. The same conditions that make the duration equation applicable are necessary for this relationship to hold. The model yields the number of survivors for the winning side and assumes that the losing side is reduced to its breakpoint strength. If the particular values of the input factors are not consistent with this assumption, the program returns an infeasibility message and the appropriate factors have to be adjusted. The logic of assuming a successful outcome of the mission is, after all, the basis from which plans are formulated.

(eqn 3.14)

$$Y_f = Y_0 \sqrt{1.0 - \frac{\alpha}{\beta} \frac{X_0^2}{Y_0^2} \{ 1 - (f^x{}_{BP})^2 \}}$$

Two other attrition equations model the effects of artillery and counterbattery fire. Attrition caused by indirect fire is modeled by first defining the following variables:

- The surviving enemy force - X_f
- The current enemy force size - X_c
- The expected casualties per ton of ammunition - C_t
- The total tons of ammunition available - T_a
- The percentage allocated to the mission - T_f

The submodel used is shown by Equation 3.15.

(eqn 3.15)

$$X_f = X_0 - C_t T_a T_f$$

Counterbattery fire is a risk run by an artillery unit actively engaged in support. The length of the fire mission, to a large extent, relates to the probability of being pinpointed for counterbattery fire. Thus, a simple model relating mission duration to casualties uses the following variables.

- The surviving friendly force - Y_f
- The current friendly unit size - Y_o
- The enemy indirect fire attrition rate - β_i
- The length of the mission - t
- The probability of being detected - P_d
- The probability of a counterbattery hit - P_h

Equation 3.16 describes the relationship of the variables.

(eqn 3.16)

$$Y_f = Y_0 - \beta t P_d P_h Y_0$$

This chapter has described the Force Planning Model and detailed the input requirements for the urban combat scenario. The candidate urban planning network has been structured for use in the Force Planning Model. Variables relevant to the network of activities and the assumptions underlying their use were defined. The mathematical submodels relating the variables and the respective simplifying assumptions were explained. The planning network is implemented in the following chapter.

IV. URBAN MODEL ANALYSIS

Planning an urban defense has been modeled using network methodologies developed for ALARM. The method sequences the activities that comprise a deliberate defense mission. Implied in the model's development is the assumption that such a methodology reasonably represents the actual execution of a plan. Specific assumptions regarding the mathematical constructs were stated in the last chapter. The explanatory variables and the dependent variables were presented as factors and characteristics. The characteristic equations express the variable interrelationships as mathematical submodels. The next step is analyzing the reasonableness the selected values for the variables and the results produced by the mathematical submodels. A sample solution of the urban template by The Force Planning Model is used as a base case. Appendix C documents the input programs and gives the values of the changeable and immutable factors used in the base case. The resulting solution is one tactical option for the defense of Eiterfeld and is expressed by these factors. The final section of the chapter analyzes several important equations: the characteristic equations drawn from the square law and the original mathematical construct that calculates the duration of the urban battle.

A. ANALYSIS OF BASE CASE INPUTS

1. Factors

The task force organizes into a covering/flank force, a main defense force, and a reserve. These are the conceptual forces that participate in the activities of the network. The force makeup equations determine the strength of the conceptual forces by summing the fractional parts (SUAs) of the organic units assigned to a conceptual force. The fractional parts are changeable factors. In the covering force, the mechanized company and the tank platoon combine to form a company team. The composition of this force varies in platoon increments. Those mechanized and armor platoons not used in the covering force may be assigned to the flank or main force. The flank position is the alternate position taken by the covering force following its engagement with the the enemy reconnaissance element. The remnants of the covering force join an established flank force composed of infantry, anti-armor, and possibly some portion of the mech or armor not used in the original covering force. Two infantry companies, the balance of the anti-armor weapons not used on the flank, and the engineer platoon form the base of the main defense. The main defense can be incremented by platoons of the third infantry company and the tank platoon. A reserve of at least one platoon from the third infantry company is required but varies upwards to an entire company. Figure 4.1 summarizes the conceptual force compositions produced for the base case of the model and indicates the range of values considered.

NAME OF FACTOR	SOLUTION VALUE	RANGE
FRACTION OF MECH IN COVERING FORCE	1.0000	.3333 - 1.0000
FRACTION OF ARMOR IN COVERING FORCE	1.0000	.0000 - 1.0000
FRACTION OF MECH IN MAIN DEFENSE	.0000	.0000 - .3333
FRACTION OF ARMOR IN MAIN DEFENSE	.0000	.0000 - 1.0000
FRACTION OF COMPANY A IN MAIN DEFENSE	1.0000	1.0000
FRACTION OF COMPANY B IN MAIN DEFENSE	1.0000	1.0000
FRACTION OF COMPANY C IN MAIN DEFENSE	.0000	.0000 - 1.0000
FRACTION OF AT ASSETS IN MAIN DEFENSE	.4444	.0000 - .8888
FRACTION OF BATTERY D IN MAIN DEFENSE	1.0000	1.0000
FRACTION OF ENGINEERS IN MAIN DEFENSE	1.0000	1.0000
FRACTION OF MECH SECURING FLANKS	.0000	.0000 - .6666
FRACTION OF ARMOR SECURING FLANKS	.0000	.0000 - 1.0000
FRACTION OF COMPANY C SECURING FLANKS	.6666	.0000 - 1.0000
FRACTION AT ASSETS ON FLANKS	.5554	.0000 - 1.0000
FRACTION CO C IN RESERVE	.3333	.3333 - 1.0000

Figure 4.1 Friendly and Enemy Force Organizations.

The Soviet regiment organizes into a standard march column configuration consisting of a reconnaissance element, advance guard, and a main body. The units in the march column are the conceptual enemy forces that participate in the network of activities. Each conceptual force is a combined arms organization. The regimental artillery group (RAG) divides between the advance guard and the main body. The recon platoon, a tank platoon from the tank battalion, and a motorized platoon from one of the motorized rifle battalions (MRB) comprise the conceptual recon force. At least one motorized rifle company, a tank platoon , and a portion of the RAG make up the advance guard. The remaining forces of the regiment organize into the main body. The portion of the reconnaissance force surviving the covering force battle becomes the force that conducts the enemy foothold assault. The fractional pessimistic estimate of the organic forces making up the conceptual forces is generally twice the standard value, and the optimistic value is generally one third the standard value. The fractional values are immutable factors. The base case enemy task organization is a weighted sum of these immutable factors. [Ref. 11]

The first file shown in Appendix C is the initialization file for the test run. A required mission completion time of 72 hours is set for completing the mission. The Force Planning Model was originally designed around an offensive mission, the Soviet regimental river crossing. In the context of an offensive mission, the time required is a maximum bound on the mission duration. Thus, the model attempts to find the best solution that is less than the specified time. A minimum time makes sense for an offensive mission order because operations orders for an attack usually specify a *no-later-than-time* for seizing the objective. Defensive mission time constraints are usually specified as lower bounds because a defending mission orders a force to hold a position *at least* for a specified time. Since the Force Planning Model currently finds a minimum time through the network, even for a defensive mission, the model's time constraint cannot always have a maximum bound interpretation. For the defensive scenario, interpret the time as describing the expected mission duration. An improved version of the model under development at Rolands and Associates will have the capability for selecting an upper or lower bound depending on the mission. Nonetheless, interpreting the 72 hours as an expected time for completing the mission is reasonable. For example, it is reasonable under the assumption that the task force organization is in effect for 72 hours or that the task force knows it will receive another mission in 72 hours. Both examples frequently occur in actual planning situations.

The conceptual friendly and enemy force breakpoints are also given in the initialization file. Define the breakpoint as that point, relative to force size, at which a unit can no longer perform its current mission. In general, assume that a force in the defense has a lower breakpoint than a force in the offense. Consequently, a value of 40 percent of original strength is used for as an average defensive breakpoint and a value of 60 percent for the offense. These values vary with the particular activity and unit.

Because some conceptual forces enter several engagements, their breakpoints are sensitive to the cumulative effects of multiple battles. As an illustration, the enemy reconnaissance force fights twice, first against the covering force and then against the main defense to gain a foothold on the built-up area. The breakpoint in the first engagement is 20 percent. Consequently, in the second engagement the reconnaissance force will accept fewer casualties and the breakpoint is set to 60 percent of the strength entering this engagement.

Recall that the changeable factor values for the friendly task organization are defined as the fractional parts of the original units used in forming the conceptual forces. Other changeable factor values deal with spacing during movement, planning operations, logistics, and obstacles. The values for the factors under these categories are now briefly addressed. The spacing values include the convoy and tactical movement intervals. The intervals reflect widely practiced tactics by most mechanized, armored and infantry units. Under the category of planning operations, *preparing for the counterattack* is the time required for implementing the counterattack plan by moving troops and effecting coordination called for in the plan. The values used in the model are the author's estimates of these changeable factors. The *tons of ammo available for support* and the *percent ammunition fired in support* changeable factors are categorized as logistics factors. The former factor is calculated in tons based on fifteen pound rounds, an average firing rate of three rounds per minute, and a required total support time of between eight and twelve hours, without resupply. The data, from standard information available on weapons, are averages taken over several similar weapons systems [Ref. 12]. One remaining changeable factor is the *number of obstacles to prepare*. For reasons of simplification the two bridges in Eiterfeld are the only planned obstacles.

The immutable factors defining enemy task organization were previously described. Of the remaining immutable factors, several are justified as easily measured values, such as vehicle and building dimensions. Others are assigned values that are found in manuals such as ARTEPs (Army Training and Evaluation Program) and SQTs (Skill Qualification Tasks), such as the time to occupy a battery firing position. Those that are not self explanatory are the rate factors. The justification for using constant attrition rate coefficients was made in the last chapter. In terms of values, assume a defender destroys between zero and three attackers in an hour and an attacker, at a natural disadvantage, destroys between zero and two defenders per hour.

Converting these rates into SUAs per hour yields the values given in Appendix C. The building clearing rate is a reasonable estimate derived from the author's small unit level experience. Assume an typical building has dimensions of 10m x 10m x 30m (LxWxH). One person can tactically clear the typical building volume in ten minutes (or $300m^3$ per minute) Therefore, a company of 160 personnel clears 2,800,000 m^3 in an hour. Define a cubic kilometer as 1000m by 1000m by the average building height, where the average building height depends on the urban density pattern as defined in Chapter II. For the purpose of this explanation, assume a height of 30m. If 20 percent of the buildings in the cubic kilometer are defended, then a clearing rate of .48 cubic kilometers per hour results. Because actual photographs of Eiterfeld are not available, the percent defended and density of buildings are estimates based on what a European town of this size probably has.

2. Characteristic Equations

The military analyst is interested in how tactics and weapons effects combine in determining the outcome of a battle. Because modern battles have not usually resulted in the annihilation of one side, one assumes that each side has a point where fighting must terminate. Just as there are many complex factors that enter into attrition rates, there are also many factors that enter into determining battle termination points. Lanchester's square law is one model that aggregates both attrition and termination factors and produces deterministic battle results that depend on force size. One of the simplest ways to define these termination points is by using relative force size. In the urban network, the square law model applies to the covering force battle, the engagement against the enemy foothold assault, and the urban battle itself. The size of friendly force surviving these engagements depends on three factors in the square law model:

- the initial force ratio - X_0/Y_0
- the ratio of the attrition coefficients - α/β
- the relative breakpoints - f^x_{BP} , f^y_{BP}

Equation 3.10 relates these three factors and states the condition that must hold to assume that one side (in this case the U.S. side) wins an engagement. [Ref. 10: pp. 128 to 131]

For analyzing how these three relative factors interact to determine the outcome of battle, a FORTRAN program was written. The program completly innumerates the solutions to Equation 3.10 for the range of values given below.

- the initial force ratio (enemy:friendly) - 1:3 to 3:1
- the attrition coefficients (SUAs/hr) - .5 to 3.0 (α) and .5 to 2.0 (β)
- breakpoints - .1 to .9 for each force

At each force ratio, over 1500 combinations of the other factors are possible, resulting in over 21,504 total battle situations for consideration. Each time a loosing condition occured at a particular force ratio, it was counted. By counting the number of loosing conditions, information about the chances of winning at each force ratio was obtained. The force ratio is used as the pivotal relationship since it most closely represents a changeable factor; that is, something a commander can control. On the other hand, attrition rate coefficients and breakpoints are more complex factors that are not necessarily controlable by anything a commander or staff can do. From the results of the analysis, some general statements can be made regarding how well the square law equation approximates reality. A basis for these statements is the adage that an attacker should have a three to one force advantage over the defender to have a reasonable chance of winning.

Another point of analysis is the assumption made earlier that a defender accepts more casualties and thus has a lower breakpoint for battle termination. The results show that a defender with a 1:3 force advantage (that is a force ratio of .3) almost always wins. His chances of winning are better than 50 percent as long as the force ratio is 1:1 or better, in favor of the defender. As the ratio of forces increases to the attackers advantage, the defender's chances of winning rapidly diminish to 15 percent at a 2:1 ratio. At the classic 3:1 ratio in favor of an attacker, the defender only wins 2 percent of the time. A closer look at the complete enumeration of battle conditions verifys the assumption that a defender can win by accepting a lower breakpoint. At the force ratios favoring the attacker, the defender still wins as long as two conditions hold. The first condition requires the defender to attrite the enemy at a substantially faster rate. For the particular values of attrition coefficients used, α has to be at its maximum value and β has to be at or near its minimum. The second condition that occurs simultaneously with the first, in nearly every instance where the defender wins against odds of 2:1 or better, is that the defender's breakpoint is less than the attacker's. At extreme force ratios favoring the attacker, the defender's breakpoint had to be at its minimum.

These results appeal to intuition and what has been learned from past battles. While recognizing that attrition rates and breakpoints represent the aggregation of numerous complex factors, most of which are beyond a commander's control, the results of this analysis correlate with steps actually used by defending units to enhance the chances of winning. For example, hardening positions and fighting from positions located on key terrain are efforts that artificially increase the force ratio to the defender's advantage. Preplanning artillery, enplacing mines, and covering obstacles by fire are all ways of artificially increasing the defender's attrition rate against an attacker.

If an attacker does not gain a foothold on a built-up area prior to initiating an assault against it, the difficulty of the attack increases. However, for a defender, preventing an attacker from gaining a foothold is also difficult because the defender can seldom secure every avenue of approach into a built-up area. Equation 3.12 models the time it takes a defending force to clear an attacker from a foothold area he is attacking through. The equation is also useful for modeling the time an attacker takes clearing a defender from urban defensive positions. For this latter use assume the defender remains stationary in his positions and thus, rather than evicting the attacker by counter assaults, defeats him from a positional defense. The sample case models the situation where the attacker gains a foothold and is evicted by counter assault. The network is also easily modified for modeling a situation where the attacker assaults without gaining a foothold by reverting to the set of square law characteristic equations for the main defense activity.

Again, as a means for determining how Equation 3.12 resolves changes in the input parameter values, a small FORTRAN program was written. The program varies the force ratio in the equation over the same range of values used in the analysis of the square law. The other parameters are held constant at the values used in the base case. The sample case situation places the attacker in control of approximately a square block of Eiterfeld and physically occupying 30 percent of the structures. Thus, as a defense technique, the defender clears the enemy from this portion of seized terrain. The actual force ratio used in the base case gives the attacker a 2:1 advantage. As the force ratio increases in favor of the defender, the time needed to evict the attacking force decreases rapidly. For example, at a 1:2 ratio in favor of the defender, the time decreases from a 17 hour battle to a 5 hour battle. The reverse holds true when the force ratio increases in favor of the attacker and, a 3:1 ratio results in a battle that takes over 72 hours for the defense to win since the attacker occupies portions of Eiterfeld (i.e., a foothold) in greater strength.

Analysis of the same equation for a situation where a defending force defends by remaining in static positions and wearing the attacker to his breakpoint involves using the defense enhancement factor in Equation 3.12. As defined in the last chapter, the defense factor represents a subjective evaluation of the strength a defender gains by virtue of being in a defensive posture. It is subjective based on the type of defense being conducted and the terrain being defended. Using the same FORTRAN program and varying the defense enhancement factor between one and three, the results show that a force defending from a strong position (a factor of three) can defeat an attacker in substantially less time than if he were in a weaker posture.

The results obtained from the urban battle duration equation, Equation 3.12, and the square law equations are reasonable and accurately approximate expected actual outcomes of engagements. The parameters can change to represent different tactical situations. The values of the changeable and immutable factors used as input parameters to these and other characteristic equations are also justified and reasonable. The urban network model remains to be implemented as a whole.

Sections of the solution to the base case situation are shown in the following series of tables. The base case resulted in the mission being completed in under the 72 hour target time. The total of all activity times shown in Table 8 was 57.9 hours. The durations of the activities agree with times one might expect occur. The covering force took 6.5 hours to make a cross country tactical move of 50 km to the covering force zone. Likewise, the dismounted infantry made a 20 km tactical cross country move in 13.2 hours. The artillery displaced by a convoy move over 15 km of hard surface road in .68 hours, or about 45 minutes. Thus the movement equations predict reasonable movement times.

The times required for completing the activities where forces engaged in combat are also shown in Table 8. Note that the covering force battle with the reconnaissance element lasted only 5 minutes. As expected, neither force is supposed to become decisively engaged. Typically, a meeting engagement occurs and an rapid assessment of the relative size and activity of the opposing force is made. This is called developing the situation, following which forces would usually disengage. Any engagement would be brief since, in this case, the covering force has considerably more combat power than the recon element. As the advanced guard moves forward to attempt to flank the defending force, the covering force moves to secure positions where the flanks can be strengthened. The activity representing the battle between these two forces takes 15 minutes. Again, considering the long range fires available to both sides, and the fact that both forces are predominatly armored and mechanized, the duration of the engagement is within the bounds of reason.

TABLE 8

SUMMARY OF BASE CASE ACTIVITY TIMES

ARC	NAME	START NODE	END NODE	NBR PATHS	DURAT	SLACK	BLUE UNIT	RED UNIT
1	CF.MV.TO.ZONE	1	2	6	6.57	0.	cover.forc	red.recon
2	ARTY.MV.TO.PSN	1	3	12	0.68	0.	btryd	red.raq
3	DUMMY.ARC	3	2	6	0.	0.	main.defe	red.recon
4	DEF.MV.TO.URBAN	2	4	12	13.26	0.	main.defen	red.rag
5	ARTY.OCC.FIRE.PSN	3	4	6	0.24	0.	btrvd	red.rag
6	MAIN.FORCE.OCC	4	5	6	3.00	0.	main.defen	red.raq
7	CF.FIGHT.RED.REC	5	6	6	0.06	0.	cover.forc	red.recon
8	CF.MOVE.TO.FLANK	6	7	6	0.88	0.	cover.forc	red.recon
9	MAIN.DEF.FIGHT	7	8	6	0.12	0.	main.defen	red.ft.hld
10	CF.DEFEAT.ADV.G	8	9	6	0.13	0.	flank.defe	adv.guard
11	ARTY.FIRE.SPT	9	10	12	1.50	0.	btryd	main.body
12	MAIN.DEF.DEFEAT	10	11	9	17.82	0.	main.defen	main.body
13	PREP.DEMO	4	9	6	14.00	0.	enq	red.rag
14	MAIN.DEF.PREP.A	4	10	6	20.52	0.	blue.reser	red.rag
15	PREP.TO.COUNTER	10	11	9	6.00	0.	tm.mech	main.body

Note from Table 9 that the casualties from this engagement, shown in units of SUAs, reflect the vulnerability of the advanced guard to the long range fires from a defender occupying key terrain. Since the heterogeneous character of a unit is lost when aggregating SUAs into the total combat power of a unit, difficulty arises when attempting to describe the casualties by element type. Since the advanced guard is composed entirely of tanks and APCs with an average SUA of 25, the covering force looses roughly twenty vehicles in this engagement. The battle between the main defense and the main body for control of the built-up area lasts 17.6 hours. Again, this represents a realistic figure for an urban engagement. While technically the time represents continuous combat, as do all the times, the aggregation of the subactivities comprising this one engagement make it difficult to attempt to describe the 17.6 hours of activity as anything beyond an overall duration. Developing a higher resolution network to model urban combat below the battalion level would allow this time to be broken down into more detail.

TABLE 9

SUMMARY OF BASE CASE CASUALTIES

FORCE	NAME	START SUA	CURRENT SUA	BREAKPOINT
1	red.rag	719.9	719.9	0.0
2	red.recon	233.3	116.7	116.7
3	adv.guard	606.6	121.3	121.3
4	main.body	2733.1	1366.6	1366.6
5	red.ft.hld	116.7	23.3	23.3
6	tm.mech	465.0	442.5	279.0
7	cover.force	465.0	442.5	279.0
8	main.defense	1596.0	937.0	186.0
9	flank.defense	991.6	873.2	396.6
10	blue.reserve	213.3	213.3	0.0

3. Results

The Force Planning Model program outputs solution statistics. The statistics for the base case are shown in Table 10. The activities along the critical path are given.

TABLE 10

SUMMARY OF BASE CASE SOLUTION STATISTICS

CRITICAL PATH IS ROW 16 OF PATH.ARC ARRAY WITH ARCS AS FOLLOWS

ARC	NAME	START NODE	END NODE
1	CF.MV.TO.ZONE	1	2
4	DEF.MV.TO.URBAN.AREA	2	4
12	MAIN.DEF.DEFEAT.MAIN.BDY	10	11
14	MAIN.DEF.PREP.ALT.PSNS	4	10

CRITICAL PATH IN SEQUENCE ORDER

DELAY IN THE COMPLETION OF ANY OF THESE ACTIVITIES WILL DELAY THE COMPLETION OF THE MISSION

NAME OF ACTIVITY	MUST BE COMPLETED NLT
CF.MV.TO.ZONE	6.567 HOURS
DEF.MV.TO.URBAN.AREA	18.829 HOURS
MAIN.DEF.PREP.ALT.PSNS	40.351 HOURS
MAIN.DEF.DEFEAT.MAIN.BODY	57.966 HOURS

The critical path for the urban defense mission reinforces what was expected. That is, one would expect the critical activities to include as a minimum, moving the forces into position on time and defeating the main assault on the built-up area. Note that the slack times given for the activities are subject to interpretation. The literal meaning of the slack time is the amount of time the activity can be delayed without affecting the total completion time for the mission. When viewed in this respect, there is 10-14 hours of slack for most of the activities not on the critical path. This type of information is valuable to a planning staff faced with the many things that go wrong in a mission once it begins.

V. URBAN MODEL VALIDATION

The urban defense planning model easily accommodates the design concepts of ALARM. An underlying motivation for simulations is the development of a means to assist decision making. Thus, in this final chapter, the urban planning network is isolated as a decision tool. Implementing the model for a few simple planning decisions demonstrates its use in this role. A point repeated throughout this thesis is recognition of those factors a commander controls that may influence the course of battle. While recognizing a commander's ability to control or change factors in the real world, the corresponding outcomes brought about by his choices remain uncertain until implementation of the plan occurs. Using the urban network model and varying the changeable factors, possible trade offs between options can be seen before hand. Analyzing three planning situations demonstrates how the network model is used as a decision tool. Within each situation, assume a single type of changeable factor category is the basis for making a decision. By running the model at various input values of the associated changeable factors, a means of analyzing activity completion times and casualties results. Time is measured in *hours* and casualties are measured in *standard units of armament* (SUAs). The casualty measurement is an aggregate SUA value that cannot distinguish between the type of entities destroyed. Therefore, view the values given as a relative loss in combat power rather than specific weapons systems destroyed.

A. FIRST SITUATION

The first case focuses at the brigade planning level. Suppose the brigade is deciding how to assign artillery missions to its supporting artillery. Specifically, under the current scenario, Task Force Lite has only its attached battery in direct support (DS). This DS capability is improved upon by giving the task force priority of fires from another battery. In terms of the model, doing so gives the task force an additional battery's worth of SUAs. In actual terms, it doubles the number of tubes the task force has in direct support. Therefore, the urban network program is changed to reflect the increased SUA total and number of entities. The changeable factor varied is *the percentage of ammunition fired in the support mission.* Assume the increased number of artillery tubes doubles the available ammunition. The amount fired varies between 0 percent and 100 percent. The results of this artillery mission assignment are contrasted with the task force's performance with only its DS battery in support when firing identical percentages of ammunition.

The time and casualty outcomes of two activities of the network are affected by varying the percentage of ammunition fired against the enemy's attack formations. Those activities affected are the fire support mission and the main defense's fight with the main body within the urban area. In the first activity, the percentage of ammunition fired determines the length of the fire mission. One expects that as the duration of the fire mission increases, the friendly casualties from counterbattery fire also increase. However, one also expects that the increased ordnance placed on the enemy increases his attrition. Attriting the enemy force before it launches its assault on the built-up area has obvious advantages for the defender. The time required to defeat the attack should decrease as the size of the attacking force decreases. These trade-offs can be analyzed by the network model.

The resulting activity time and casualties for selected values of the changeable factor are shown in Figures 5.1 and 5.2. The pie charts show the numbers resulting

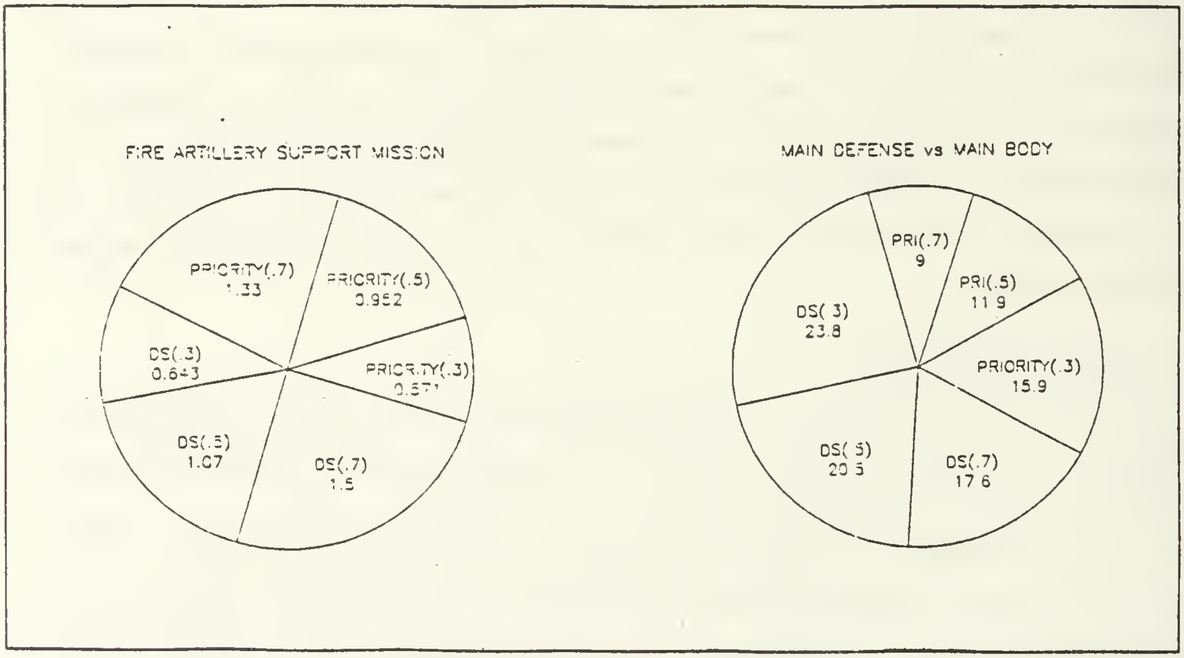


Figure 5.1 Situation 1 Activity Times.

from each trial. The pie sections are coded to reflect whether the trial performed was with priority of fires from an additional battery (PRI) or with the task force's direct support battery (DS) only. The number in parenthesis gives the value of the changeable factor (i.e., *artillery mission allocation*) used in each trial. For example, consider the appropriate pie sections, of each activity, for the PRI(.3) and DS(.3) trials in Figure 5.1. Increasing the number of tubes available to the task force does not significantly alter the time required to fire the mission. Each takes slightly over one half hour (.571 hrs and .643 hrs, respectively). The main defense, however, defeats the main body substantially faster (15.9 hrs to 23.8 hrs) when the task force can attrite the enemy with more artillery support (given priority of fires) than with less. The figures clearly demonstrate the trade-offs. Now consider the casualty diagrams in Figure 5.2

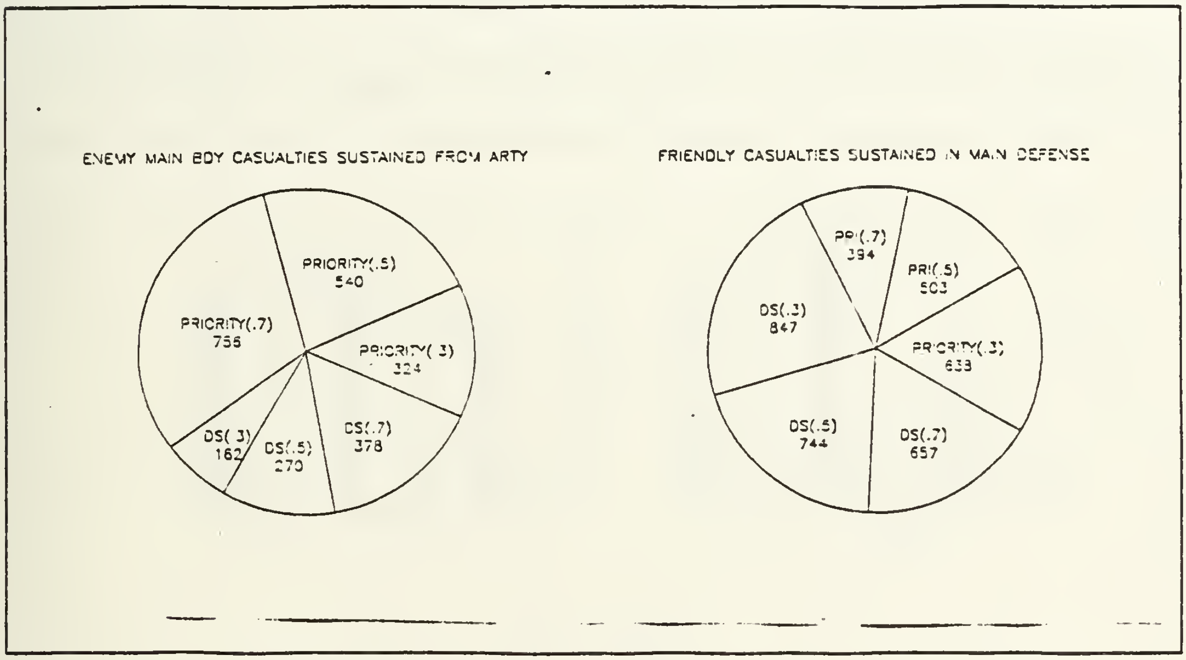


Figure 5.2 Situation 1 Casualties Per Activity.

for the same two trials. They show that the enemy suffered 324 casualties when the friendly forces had priority of fires from an additional battery but only 162 casualties when the task force had just its DS battery in support. The corresponding losses to the task force in the main defense activity are shown as 638 casualties when having priority of fires. However, without priority of fires from an additional battery the friendly casualties increase to 847 since the enemy cannot be attritted as much prior to his attack occuring. Generally, the same effect is achieved with only a DS battery firing the bulk of its ammunition as when the task force is given the additional fires of another battery and uses only one-third of the ammunition available between the two batteries.

In terms of overall mission completion time and total friendly casualties sustained, the effects of employing the various options are demonstrated by the bar charts in Figure 5.3. Note, from the bar graph on the left, the nearly ten percent increase of friendly casualties with only a DS battery firing one-third of its ammunition (DS(.3)) than when the same percentage is fired from two batterys each, with one given a priority of support mission to the task force (PRI(.3)). When reviewed from this perspective, assigning the task force priority of fires significantly decreases the percentage of casualties sustained in the operation. The total mission completion time can also be reduced, as seen from the bar graph at the right, from 70.2 hours to 60.3 hours for the respective uses of artillery units and ammunition.

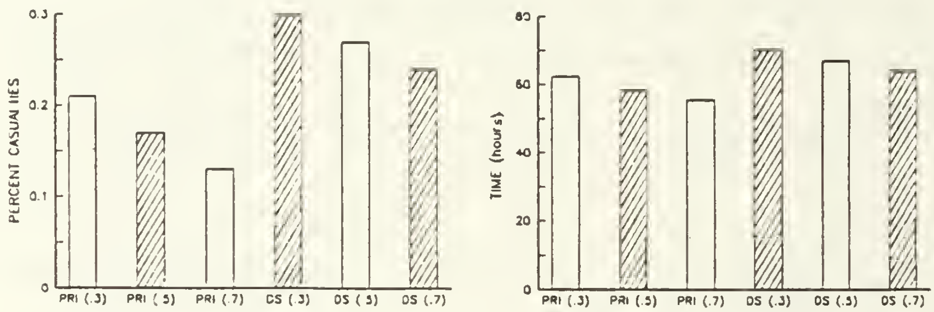


Figure 5.3 Situation 1 Total Mission Times And Casualties.

B. SECOND SITUATION

In accordance with urban defensive doctrine, the task force organizes into a covering force, flank security force, main defense force and a reserve. This organization can be accomplished in a number of ways. Allocating the mechanized and armored units to the covering force and flank security outside the built-up area is considered the best use of these assets. However, the three light infantry companies can be allocated to either the main force within the built-up area, the flank security force on favorable terrain, or the reserve. This situation analyzes the effects of varying the makeup of these three forces based on use of the dismounted infantry. As in the base case, a reserve of at least platoon strength is maintained and two full companies of infantry defend from within Eiterfeld. Therefore, in this situation the issue is allocating the platoons of the third infantry company. Assume the decision hinges upon the effects various uses of the third company have on mission completion time and attrition to the friendly force. Three activities are affected as a result of changing the disposition of the third company: engaging the advanced guard on the flanks, fighting the assault on the built-up area by the reconnaissance element, and defeating the main attack by the enemy main body.

The pie charts at Figure 5.4 depict the effects the various force configurations have on the three activity completion times. Again, each pie section is coded in order

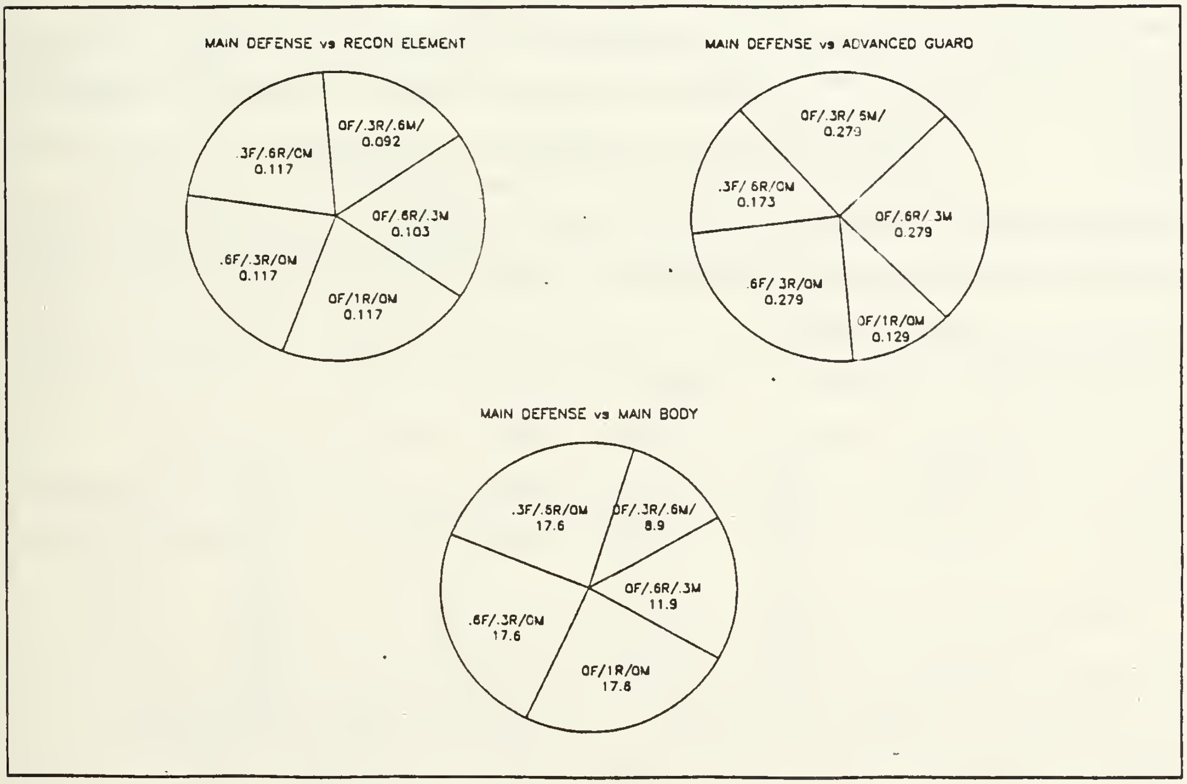


Figure 5.4 Situation 2 Activity Times.

to distinguish the configurations used. The code reflects the fraction of the third infantry company used on the flanks, as part of the reserve, and in the main defense.

For example, the pie section a the three o'clock position shows 0F/.6R/.3M and translates to using none of the platoons of the third company on the flanks, two platoons (.6 or two out of three) in the reserve, and one platoon (.3 or one out of three)in the main defense. Compare the results of this configuration with the results when one platoon is shifted from the reserve and added to the main defense (0F/.3R/.6M). The time required for the main defense to defeat the main body decreases from 11.9 hours to 8.9 hours. Comparing the remaining sections of all the pie charts charts in Figure 5.4 shows the effects on the three activity completion times for the different uses of the third infantry company. Note the lack of significant change to the length of the engagements with the recon element and advanced guard. However, when the strength of the main force is increased by one or two additional platoons the main body is defeated much faster. The shortest times of 11.9 hours and 8.9 hours result from not using the infantry on the flank positions.

Adding infantry platoons to the main defense allows the enemy to be cleared from the built-up area faster and results in fewer friendly casualties for this activity. However, this means taking forces away from the flank positions and higher casualties result to the friendly side when engaging the advanced guard. Compare the results in Figure 5.5 for two alternative cases in which two out of the three platoons are employed on the flanks with none in the the main defense (.6F/.3R/0M) and no infantry platoons are placed on the flank but two are employed in the main defense (0F/.3R/.6M). Little difference in friendly casualties is noted in the main defense fight with the recon element because in both cases the size of the main defense overwhelms the opposing force. However, not using any dismounted infantry on the flanks causes the covering force to sustain 199 casualties against only 95.8 casualties if the two platoons are positioned on the flanks. Additionally, the main defense sustains about one-third more casualties when it is not augmented with the additional infantry platoons.

The effects on overall mission completion time and total friendly casualties for each employment option are given in Figure 5.6. The bar graph on the left indicates that the mission concludes earlier with a strong main defense (0F/.6R/.3M), but casualties are slightly less with a strong flank defense (.6F/.3R/0M). Casualties in all cases are between 21 precent and 25 percent. Since casualties are in units of SUAs, the difference is not particularly significant. It does emphasize the increased intensity of battle in an the urban environment and the better protection afforded dismounted

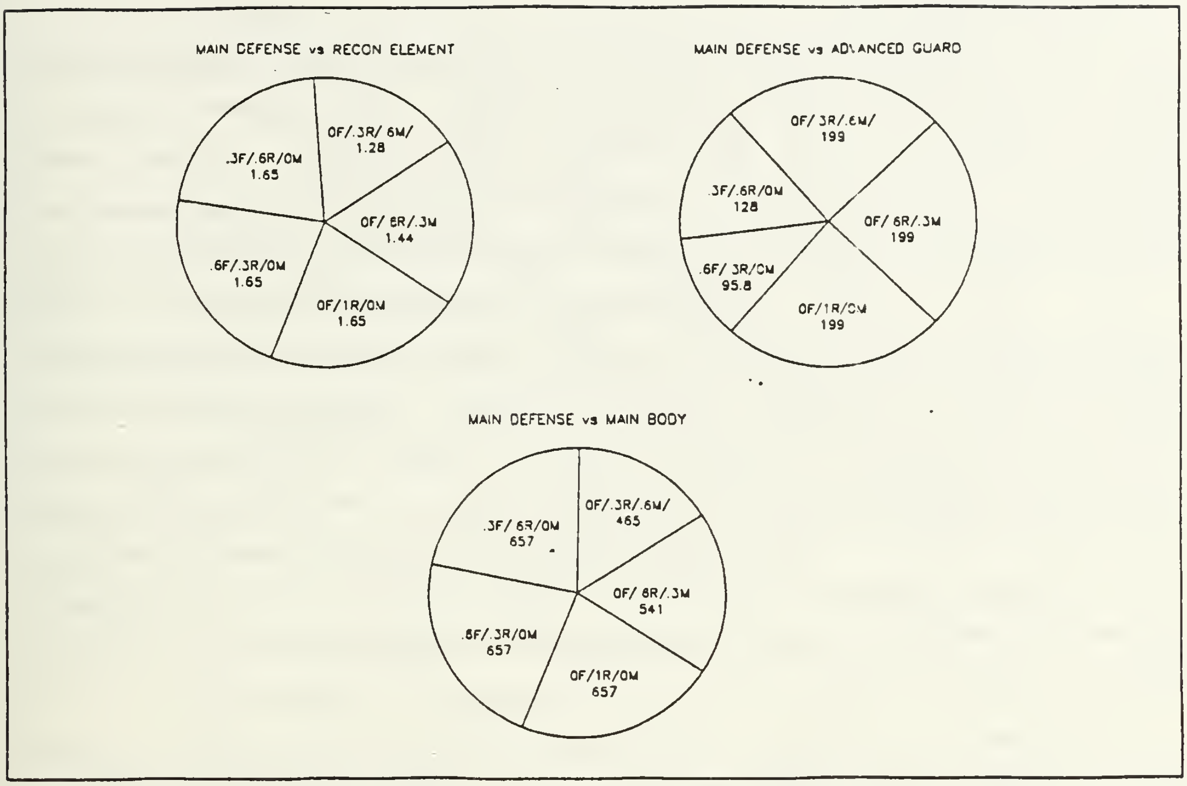


Figure 5.5 Situation 2 Casualties Per Activity.

troops on terrain adjacent to Eiterfeld where stand-off due to long range fires of the tanks and Infantry Fighting Vehicles (IFVs) lessens the direct fire attrition capability of

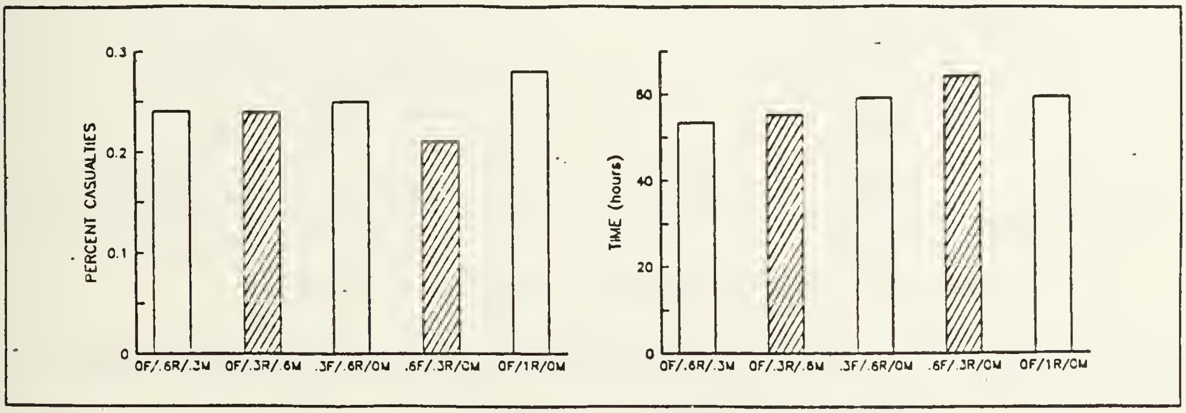


Figure 5.6 Situation 2 Total Mission Times and Casualties.

an enemy. Consequently, results point to these two courses of action as trade-off points between time and casualties. The task force commander might select either one depending upon other aspects of the mission and situation.

C. THIRD SITUATION

The final situation for analysis is similar to the previous one in that it considers the use of the battalion's organic anti-armor weapons. These weapons represent a significant contribution to the light infantry's ability to defeat a mounted attack. Therefore, how they are employed is critical to the defense plan. The mission and terrain analysis should show that the most favorable locations for employing them is on the key terrain adjacent to Eiterfeld or on the periphery of the built up area to cover high speed avenues of approach to realize maximum use of their range. While employing them on the flanks affords better range, occupying positions on the outskirts of the built-up area may force the enemy to conduct a dismounted assault on Eiterfeld. Assume that the positions are mutually exclusive; that is, the fires from each do not overlap significantly. The TOW (tube-launched, optically-tracked, wire-guided missiles) anti-tank weapons are therefore allocated between the two alternative locations. This allocation affects the covering force's engagement with the advanced guard (in its attempt to isolate the town) and the assault by the main body.

Ten options are considered that assume TOWs are used in pairs as tactics commonly dictate. The pie diagrams in Figure 5.7 record the effects the various

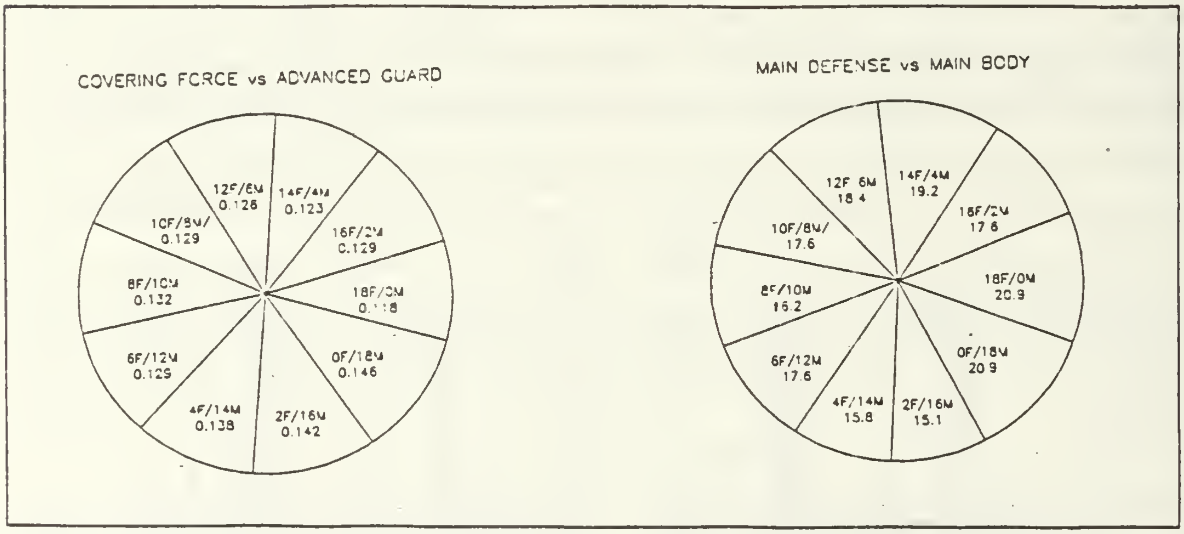


Figure 5.7 Situation 3 Activity Times.

options produce on activity completion times for the engagements against the advanced guard and the main body. The pie section code indicates the number of TOWs employed on the flanks and in the main defense. As an example, 18F/0M translates to all eighteen TOWs on the flanks and none positioned within the main defense. Viewing counterclockwise around the figures shows the effects as more TOWs are added to the main defense. Only in the case of the activity time required to defeat the main body is a significant difference noted. The best option regards to time and the main defense activity requires that the bulk of the anti-armor weapons be assigned to the main defense positions on the edge of the built-up area (i.e., 2F/16M or the pie section at the six o'clock position in the right diagram).

Again, utilizing the same type of diagrams of Figure 5.8 and considering friendly casualties, one observes that casualties increase or decrease, for each of the two affected activities, as the number of TOWs assigned to each sector increases or decreases. The more TOWs available to the flank forces, the lower their casualties, as is the case when more TOWs augment the main defense force.

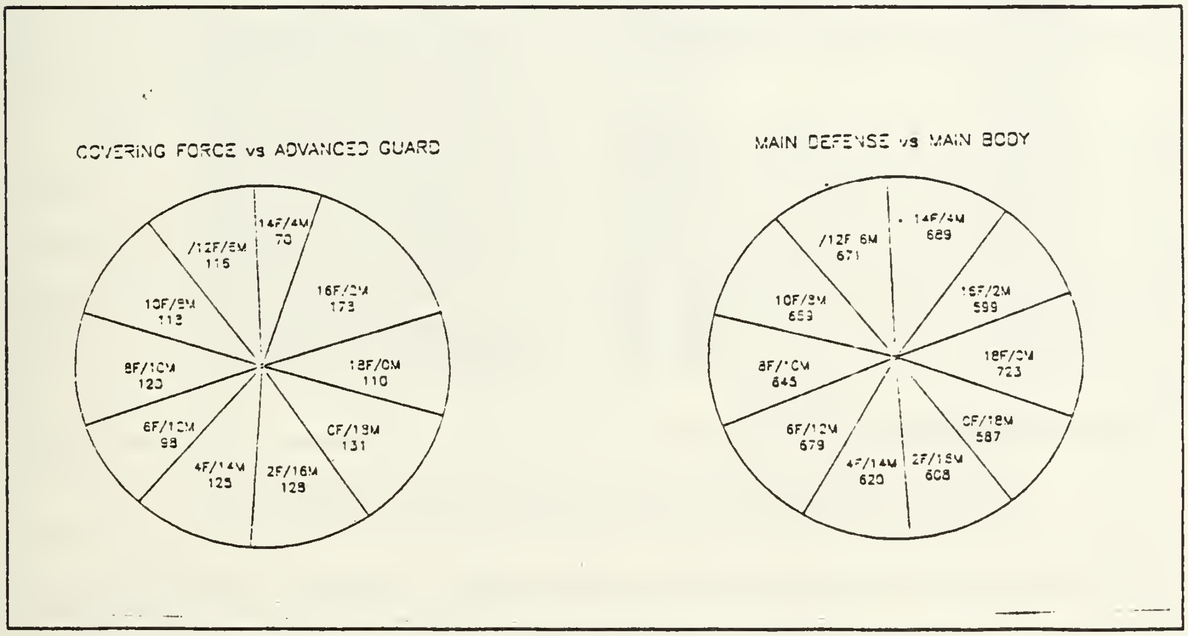
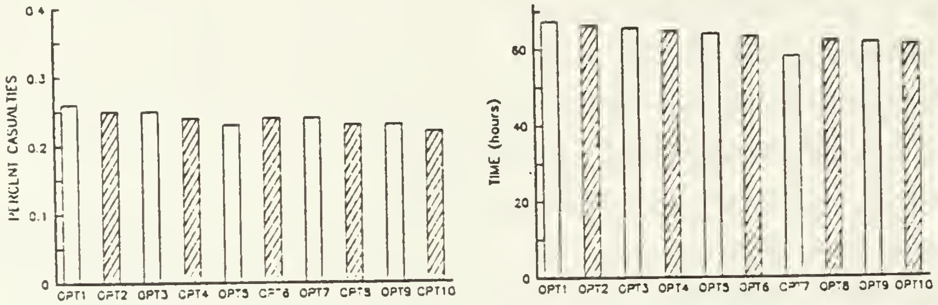


Figure 5.8 Situation 3 Casualties Per Activity.

From the perspective of the overall time and casualties on the mission, the ten options are summarized by the bar graphs in Figure 5.9 that appear on the following page. Option ten (allocating all of the TOWs to the main defense - 0F/18M) produces the fewest casualties to the friendly force and a moderate reduction in mission completion time. If minimizing time is an overiding consideration, then option seven (twelve TOWs to the main defense and eight to the flanks - 8F/12M) produces the most favorable results.



Key:

BAR GRAPH CODE	OPTION	DEFINITION
OPT 1	18F/0M	18 to Flank - 0 to Main
OPT 2	16F/2M	16 to Flank - 2 to Main
OPT 3	14F/4M	14 to Flank - 4 to Main
OPT 4	12F/6M	12 to Flank - 6 to Main
OPT 5	10F/8M	10 to Flank - 8 to Main
OPT 6	8F/10M	8 to Flank - 10 to Main
OPT 7	6F/12M	6 to Flank - 12 to Main
OPT 8	4F/14M	4 to Flank - 14 to Main
OPT 9	2F/16M	2 to Flank - 16 to Main
OPT 10	0F/18M	0 to Flank - 18 to Main

Figure 5.9 Situation 3 Total Mission Times and Casualties.

To complete the discussion of the urban modeling research, the urban network is put back into the context of ALARM and areas recommended for further study are pointed out in the final chapter.

VI. CONCLUSIONS

The objectives stated in the first chapter have been met by this research. However, several ideas arise for further research in ALARM. Chapter II extended contemporary terrain and transportation network methodology to better represent planning operations in and around urban terrain. In addition, the effort was made, in line with the third objective, to outline the linking of subordinate terrain networks within a higher element's terrain network. The outline directs future efforts for incorporating multi-echelon terrain and planning networks, generated by differing missions, into the terrain and planning network of a higher command level responsible for accomplishing each of these missions. The case-in-point would take the urban defense and river defense, at the task force level, and link them to the brigade's sector defense mission as presented in the scenario.

Within the scope of this research, additional research into a few areas will enhance the realism of the model. These areas deal primarily with improving the characteristic equations. Specifically, the duration equations for many of the non-urban specific arcs are generalized. For example, preparing demolitions is simplified to the point that it multiplies two aggregate factors together: *the number of obstacles* and *the average time to complete a typical obstacle*. Structuring the activity into more subtasks will enhance realism of the model. Tasks might include modeling movement of the engineer force between obstacles and the time spent preparing different types of obstacles. Additionally, other changeable and immutable factors could be incorporated that describe how preparation time is affected such as the size of the engineer force doing the work and the number of obstacles by type. Any of the duration equations can be enhanced by adding delays caused by hazards such as artillery fire, air interdiction and minefields. The approach recommended suggests using the probability distribution for a hazard occuring, multiplying the probability of occurance by the expected cost in time, if it occurs, and summing this product with the duration equation over all possible effects. A difficult problem caused by including hazard delays in the duration equations is modeling the resulting attrition in the attrition characteristic equations since in some instances this requires modeling attrition on parallel activities something the Force Planning Model currently does not do.

Finally, some of the attrition characteristic equations are adaptations of simple, existing combat models. While the Lanchester models used are well founded, other more complex forms exist such as stochastic models. Short of that level of complexity, one can consider heterogeneous combat models and enhancements to the basic forms, such as range dependency or battle termination with unit deterioration. Any of these additions represent an improvement over the simpler forms used for this research. The point is that this research has, in part, applied existing models by adapting them to the scenario through assumptions, and obtained reasonable results. The emphasis, however, was on demonstrating the applicability of the methodology and providing a basis for later enhancements.

This thesis has improved the capability of ALARM to accurately represent urban combat. At the same time it defines a mission for dismounted infantry forces in a European environment that can be modeled and studied. The resolution of built-up terrain is improved by identifying urban arc/node types and attributes and expanding the standing list. Identifying seven additional arc types and and four node types allows the use of key features of built-up areas in planning. The detailed study of urban doctrine and tactics led to categorizing urban missions for light infantry forces and developing a planning network that models a defensive mission. The resulting mission template accommodates the design concepts of the ALARM planning process. Not only is the network demonstrated as applicable for use in ALARM but it can be used as a stand alone model for planning the defense of a built-up area. Lastly,this research provides a well defined outline for a future direction of ALARM research, whereby multi-level terrain/transportation and planning networks can be synchronized.

APPENDIX A
PLANNING HORIZONS

The following chart defines the battle responsibilities for various planning organizations in accordance with Airland Battle Doctrine [Ref. 13].

<table>
<tr>
<td>CORPS</td>
<td colspan="2">CLOSE IN
• Fights Divisions against first echelon divisions</td>
<td>DEEP
• Attacks follow-on divisions and headquarters

• Attacks first echelon sustainers
• Provides divisions area of interest information</td>
<td>AOI
• Receives information from higher</td>
</tr>
<tr>
<td>DIVISION</td>
<td>CLOSE
• Fights brigades against first echelon regiments</td>
<td>DEEP
• Attacks follow-on regiments

•Attacks first</td>
<td>AOI
• Receives information from corps</td>
<td></td>
</tr>
</table>

			echelon sustainers • Provides brigades area of interest information		
BRIGADE	CLOSE • Ft bns against first echelon bns	DEEP • Atks follow-on bdes • Atks first echelon log Provide bns area of interest info	AOI • Receives information from division		

NOTE: AOI is Area of Interest.

APPENDIX B
ARC AND NODE TYPES AND ATTRIBUTES

The following lists are arc and node types and attributes defined by previous ALARM research [Ref. 4: .]p. 68

ARC TYPES AND ATTRIBUTES

ARC TYPE	*ARC ATTRIBUTE*
Autobahn (1)	Arc identification number
Autobahn/Railroad (2)	Ident number of end node.
Railraod (3)	No. lanes on route
Concrete Road (4)	Off route class
Asphalt Road (5)	Main route Class
Dirt Road (6)	Battle delay time of arc
Forrest (7)	Width of arc
Open Country (8)	
Road and Rail (9)	
Bridge/Tunnel (10)	

NODE TYPES AND ATTRIBUTES

NODE TYPE	*NODE ATTRIBUTE*
City (1)	Identification number
Village (2)	Latitude
Autobahn Junction (3)	Longitude
Road Junction (4)	Node Type Number
Hill Top (5)	
Other (6)	

APPENDIX C
URBAN DEFENSE INPUT PROGRAMS FOR THE FORCE PLANNING MODEL

This appendix records the input files and programs to the Force Planning Model. The notations in brackets {} are for cross reference to the text.

The following file is the Force Planning Model initialization file. (URBAN.INI). The file gives the time requirement for the mission, the breakpoint values for the conceptual forces, and the number of weapons assigned to each force. The file is created in free format as a SIMSCRIPT (simulation script programming language) file.

```
72 {p. 56}
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. .6 .4 .4 .4 0 .5 .2 .5 .2 {p.56}
btryd     0    0    0    0    6    0    0    0
aco       0    0    0    0    0    0    160  0
bco       0    0    0    0    0    0    160  0
cco       0    0    0    0    0    0    160  0
mech      0    0    0    13   0    0    0    0
arm       0    0    0    0    0    4    0    0
at        0    0    0    0    0    0    0    18
eng       0    0    0    0    0    0    41   0
bn1       31   0    0    0    0    0    0    0
bn2       31   0    0    0    0    0    0    0
bn3       31   0    0    0    0    0    0    0
recon     10   0    0    0    0    0    0    0
red.rag   0    7    0    0    0    0    0    0
tank.bn   0    0    30   0    0    0    0    0
*STOP*
*STOP*
```

This SIMSCRIPT program is the data (URBAN.DAT) describing the urban defensive planning network for the Force Planning Model simulation. In general, the program lists types of weapons represented in the organic and conceptual forces and gives their respective standard unit of armament value (SUA). Intrinsic functions recognized by the Force Planning Model main program are specified followed by the listing of changeable and immutable factors with their respective values. The activities comprising the network/planning template are listed in order of sequence with each activity's characteristic equations defined. The final portion of the data file is a series of constraint equations for checking that the sum of the fractional organic units used in the conceptual forces equals one, that is, that the simulation uses all of the organic forces available in determining a solution.

```
8
BMP 20
122/HOW-TOWED 12
T-80 30

IFV/M2 25
105/HOW-TOWED 12 {p. 65}
M-1 ABRAMS 35
RIFLE 4
HMMWV/TOW 10

3.0     0.0      2.0   {eqn. 3.1}

26
PLUS SUBT * / ABS ARCOS ARSIN ARCTAN COS EXP FRAC INT LOG.E
LOG.10 MIN MAX PERTAVG MOD SIGN SIN SQRT TAN MINUS SINH COSH
TANH

23
SPACING {p. 42}
veh.int .025 .010 .050 .005 'CONVOY INTERVAL BETWEEN VEHICLES'
SPACING
march.int .005 .005 .020 .005 'ROAD MARCH INTERVAL BETWEEN PAX,KM.'
SPACING
form.int.mech .100 .050 .200 .050 'MOVEMENT TECHNIQUE INTERVAL FOR
                                   MECH, KM'
SPACING
form.int.inf .025 .025 .100 .025 'MOVEMENT TECHNIQUE INTERVAL FOR
                                 INFANTRY,KM'
```

PLANNING.OPS {p. 43 and p. 57}

counter.attack.prep.time 6.0 6.0 12.0 1.0 'TIME ALLOCATED TO PREPARE FOR COUNTERATTACK, HRS'

LOGISTICS {p. 43 and p. 57}

tons.ammo.for spt 60 60 80 20 'TONS OF AMMO FOR FIRE SUPPORT'

LOGISTICS {p. 57}

arty.mission.allocation .7 .3 .8 .1 'AMMUNITION ALLOCATION IN TONS'

OBSTACLES {p. 43 and p. 57}

no.obstacles.to prep 2 2 2 2 'OBSTACLES AND DEMOLITIONS PLANNED'

COVER.FORCE {p. 43}

fract.mech.cf 1.0 .3333 1.0 .3333 'FRACTION OF MECH IN COVERING FORCE'

COVER.FORCE

fract.arm.cf 1.0 0.0 1.0 1.0 "FRACTION OF ARMOR IN COVERING FORCE'

MAIN.DEFENSE {p. 43}

fract.mech.main 0.0 0.0 .3333 .3333 'FRACTION OF MECH IN MAIN DEFENSE'

MAIN.DEFENSE

fract.arm.main 0.0 0.0 1.0 1.0 'FRACTION OF ARMOR IN MAIN DEFENSE'

MAIN.DEFENSE

fract.aco.main 1.0 1.0 1.0 1.0 'FRACTION OF COMPANY A IN MAIN DEFENSE'

MAIN.DEFENSE

fract.bco.main 1.0 1.0 1.0 1.0 'FRACTION OF COMPANY B IN MAIN DEFENSE'

MAIN.DEFENSE

fract.cco.main 0.0 0.0 1.0 .3333 'FRACTION OF COMPANY C IN MAIN DEFENSE' {p. 69}

MAIN.DEFENSE

fract.at.main .4444 0.0 .8888 .2222 'FRACTION OF AT ASSETS MAIN DEFENSE'

MAIN.DEFENSE

fract.btryd.main 1.0 1.0 1.0 1.0 'FRACTION OF BATTERY D IN MAIN DEFENSE'

MAIN.DEFENSE

fract.engr:main 1.0 1.0 1.0 1.0 'FRACTION OF ENGINEERS IN MAIN DEFENSE'

FLANK.DEFENSE {p. 43}

fract.mech.flank 0.0 0.0 .6666 .3333 'FRACTION OF MECH SECURING FLANKS'

FLANK.DEFENSE

fract.arm.flank 0.0 0.0 1.0 1.0 'FRACTION OF ARMOR SECURING FLANKS'

FLANK.DEFENSE

fract.cco.flank .6666 0.0 1.0 .3333 'FRACTION COMPANY C SECURING FLANKS' {p. 69}

FLANK.DEFENSE

fract.at.flank .5554 0.0 1.0 .1111 'FRACTION AT ASSETS ON FLANKS'

BLUE.RESERVE

fract.cco.blue.reserve .3333 0.0 1.0 .3333 'FRACTION CO C IN RESERVE' {p. 69}

48

dist12 50 30 10 {p. 45}

dist13 15 7 5

dist24 20 5 3

dist 67 5 3 3

veh.road.speed 15 25 30

veh.xcountry.speed 5 5 10

technique.factor.m .8 .8 .8

pax.road.speed 2 3 5

pax.xcountry.speed 1 2 3

technique.factor.i 1 1 1

towed.veh.length .015 .015 .015

vehicle.length .0075 .0075 .0075

no.veh.per.form 6 6 6

no.pax.per.form 160 160 160

no.cf.form 4 3 1

no.main.def.form 3 3 3

form.angle 1.047 1.047 1.047

arty.casualties.(sua).per.ton.fired 7.0 9.0 16.0 {p. 45}

alpha.df 1.8 1.8 1.8 {p.57}

alpha.idf .3 .3 .3

alpha.urban 1.5 1.5 1.5

beta.df .9 .9 .9

beta.idf .4 .4 .4

beta.urban .6 .6 .6

time.to.occupy.arty .33 .2 .11 {p. 46}

prob.cbtry.det .2 .05 .01

prob.cbtry.hit .3 .1 .05

built.up.area.vol 5.09 2.57 .041

per.cent.urban .5 .25 .2

blue.clear.rate .24 .48 .96 {p. 58}

per.cent.defended .3 .1 .05

obstacle.prep.time 4.0 2.5 1.5

time.per.psn.per.total.unit .3 .15 .1

number.alt.sup.psn 36 18 9

defense.factor 1.4 2.0 3.0

fract.red.recon.recon 1.0 .6666 .3333 {p. 46}

fract.red.tank.bn.recon .1111 .1111 .1111

fract.red.bn1.recon .1111 .1111 .1111

fract.rag.ag .3333 .3333 .3333

fract.red.tank.bn.ag .3333 .3333 .3333

fract.red.recon.ag 0.0 .3333 .6666

fract.red.bn2.mb 1.0 1.0 1.0

fract.red.bn3.mb 1.0 1.0 1.0

fract.red.tank.bn.mb .6666 .6666 .6666

fract.rag.mb .6666 .6666 .6666

fract.red.bn1.mb .6666 .6666 .6666

23

aco	2 fract.aco.main *STOP*
bco	2 fract.bco.main *STOP*
cco	2 fract.cco.main fract.cco.flank.fract.cco.blue.reserve *STOP*
btryd	2 fract.btryd.main *STOP*
mech	2 fract.mech.cf fract.mech.main fract.mech.flank *STOP*
arm	2 fract.arm.cf fract.arm.main fract.arm.cf *STOP*
at	2 fract.at.flank fract.at.main *STOP*
eng	2 fract.engr.main *STOP*
bn1	1 *STOP*

bn1 1*STOP*

bn3 1 *STOP*

recon 1 *STOP*

tank.bn 1 *STOP*

red.rag 1 *STOP*

tm.mech 2 fract.mech.cf fract.mech.flank fract.mech.main fract.arm.cf fract.arm.flank fract.arm.main *STOP*

cover.force 2 fract.mech.cf fract.arm.cf *STOP*

main.defense 2 fract.mech.main fract.arm.main fract.aco.main fract.bco.main fract.cco.main fract.at.main fract.engr.main fract.btryd.main *STOP*

flank.defense 2 fract.mech.flank fract.arm.flank fract.cco.flank fract.at.flank *STOP*

blue.reserve 2 fract.cco.blue.reserve *STOP*

red.recon 1 *STOP*

adv.guard 1 *STOP*

main.body 1 *STOP*

red.ft.hold 1 *STOP*

15 12

1 CF.MV.TO.ZONE 1 2 red.recon cover.force

no.cf.form 1.0 SUBT form.int.mech * no.veh.per.form .5 * 1.0 veh.int * form.angle SIN * PLUS no.cf.form * dist12 PLUS veh.xcountry.speed technique.factor.m * / *STOP* {eqn. 3.8}

fract.red.recon.recon SUA(recon) * fract.red.tank.bn.recon SUA(tank.bn) * PLUS *STOP*{eqn. 3.13}

SUA(red.recon) *STOP*

fract.mech.cf SUA(mech) * fract.arm.cf SUA(arm) * PLUS *STOP*

SUA(cover.force) *STOP*

2 ARTY.MOVE.TO.FIRE.PSN 1 3 red.rag btryd

vehicle.length veh.int PLUS VEH(btryd) * veh.int SUBT dist13 PLUS veh.road.speed / *STOP* {eqn. 3.7}

fract.rag.ag SUA(red.rag) *fract.rag.mb SUA(red.rag) * PLUS *STOP*

SUA(red.rag) *STOP*

fract.btryd.main SUA(btryd) * *STOP*

SUA(btryd) *STOP*

3 DUMMY.ARC 3 2 red.recon main.defense

0. *STOP*

SUA(red.recon) *STOP*

SUA(red.recon) *STOP*

fract.btryd.main SUA(btryd) * fract.aco.main SUA(aco) * PLUS fract.bco.main SUA(bco) * PLUS fract.cco.main SUA(cco) * PLUS fract.at.main SUA(at) * PLUS fract.engr.main SUA(engr) * PLUS fract.mech.main SUA(mech) * PLUS fract.arm.main SUA(arm) * PLUS *STOP*

SUA(main.defense) *STOP*

4 DEF.MV.TO.URBAN.AREA 2 4 red.rag main.defense

no.main.def.form 1.0 SUBT form.int.inf * no.pax.per.form .5 * 1.0 SUBT march.int * form.angle SIN * PLUS no.main.def.form * dist24 PLUS pax.xcountry.speed technique.factor.i * / *STOP*

SUA(red.rag) *STOP*

SUA(red.rag) *STOP*

SUA(main.defense) *STOP*

SUA(main.defense) *STOP*

5 ARTY.OCC.FIRE.PSN 3 4 red.rag btryd

time.to.occupy.arty *STOP*

SUA(red.rag) *STOP*

SUA(red.rag) *STOP*

SUA(btryd) *STOP*

SUA(btryd) *STOP*
6 MAIN.FORCE.OCC.HASTY.DEFENSE 4 5 red.rag main.defense

sector.prep.time *STOP*

SUA(red.rag) *STOP*

SUA(red.rag) *STOP*

SUA(main.defense) *STOP*

SUA(main.defense) *STOP*

7 CF.FIGHT.RED.RECON 5 6 red.recon cover.force

1.0 alpha.df beta.df * SQRT / ORG(red.recon) ORG(cover.force) / MINUS BRK(red.recon) * alpha.df beta.df / ORG(red.recon) ORG(red.recon) * ORG(cover.force) ORG(cover.force) * / 1.0 BRK(red.recon) BRK(red.recon) * SUBT * SUBT SQRT PLUS alpha.df beta.df / SQRT ORG(red.recon) ORG(cover.force) / SUBT / LOG.10 * *STOP* {eqn. 3.9}

SUA(red.recon)

BRK(red.recon) ORG(red.recon) * *STOP*

SUA(cover.force) *STOP*

1.0 beta.df alpha.df / ORG(red.recon) ORG(cover.force) / ORG(red.recon) ORG(cover.force) / * * 1.0 BRK(red.recon) BRK(red.recon) * SUBT * SUBT SQRT ORG(cover.force) * *STOP* {eqn. 3.14}

8 CF.MOVE.TO.FLANK 6 7 red.recon cover.force

no.cf.form 1.0 SUBT form.int.mech * VEH(cover.force) no.cf.form / .5 * 1.0 SUBT veh.int * form.angle SIN * PLUS no.cf.form * dist67 PLUS veh.xcountry.speed technique.factor.m * / *STOP*

SUA(red.recon) *STOP*

SUA(red.recon) *STOP*

SUA(cover.force) *STOP*

SUA(cover.force) *STOP*

9 MAIN.DEFENSE.FIGHT.RED.RECON 7 8 red.ft.hld main.defense

BRK(red.ft.hld) 1.0 SUBT 0.4 * alpha.df MINUS / SUA(main.defense) / BRK(red.ft.hld) 1.0 SUBT 0.6 * SUA(red.recon) * alpha.idf MINUS / SUA(main.defense) / PLUS *STOP* {eqn. 3.11}

SUA(red.recon) *STOP*

BRK(red.ft.hld) SUA(red.recon) * *STOP*

SUA(main.defense) *STOP*

1.0 beta.urban alpha.urban / SUA(red.ft.hld) SUA(main.defense) / SUA(red.ft.hld) SUA(main.defense) / * * 1.0 BRK(red.ft.hld) BRK(red.ft.hld) * SUBT * SUBT SQRT SUA(main.defense) * *STOP*

10 CF.DEFEAT.ADV.GUARD 8 9 adv.guard flank.defense

1.0 alpha.df beta.df * SQRT / ORG(adv.guard) ORG(flank.defense) / MINUS BRK(adv.guard) * alpha.df beta.df / ORG(adv.guard) ORG(adv.guard) * ORG(flank.defense) ORG(flank.defense) * / 1.0 BRK(adv.guard) BRK(adv.guard) * SUBT * SUBT SQRT PLUS alpha.df beta.df / SQRT ORG(adv.guard) ORG(flank.defense) / SUBT / LOG.10 * *STOP*

fract.rag.ag SUA(red.rag) * fract.red.tank.bn.ag SUA(tank.bn) * PLUS fracr.red.recon.ag SUA(red.recon) * PLUS *STOP*

BRK(adv.guard) ORG(adv.guard) * *STOP*
SUA(cover.force) fract.cco.flank SUA(cco) * PLUS fract.at.flank SUA(at) * PLUS *STOP*

1.0 beta.df alpha.df / ORG(adv.guard) ORG(flank.defense) / ORG(adv.guard) ORG(flank.defense) / * * 1.0 BRK(adv.guard) BRK(adv.guard) * SUBT * SUBT SQRT ORG(flank.defense) * *STOP*

11 ARTY.FIRE.SPT 9 10 main.body btryd

tons.ammo.for.spt tons.per.tube.(sua).per.hour SUA(btryd) * / arty.mission.allocation * *STOP*

fract.rag.mb SUA(red.rag) * fract.red.bn2.mb SUA(bn2) * PLUS fract.red.bn3.mb SAU(bn3) * PLUS fract.red.tank.bn.mb SUA(tank.bn) * PLUS fract.red.bn1.mb SUA(bn1) * PLUS *STOP*

SUA(main.body) arty.casualties.(sua).per.ton.fired tons.ammo.for.spt * arty.mission.allocation * SUBT *STOP* {eqn. 3.15}

SUA(btryd) *STOP*

SUA(btryd) beta.idf DURATION * prob.cbtry.det * prob.cbtry.hit * SUA(btryd) * SUBT *STOP* {eqn. 3.16}

12 MAIN.DEF.DEFEAT.MAIN.BODY 10 11 main.body main.defense

built.up.area.vol per.cent.urban * blue.clear.rate / per.cent.defended * SUA(main.body) SUA(main.defense) defense.factor * / * EXP *STOP* {eqn. 3.12}

SUA(main.body) *STOP*

SUA(main.body) ORG(main.body) * *STOP*

SUA(main.defense) *STOP*

1.0 beta.urban alpha.urban / SUA(main.body) SUA(main.defense) / SUA(main.body) SUA(main.defense) / * * 1.0 BRK(main.body) BRK(main.body) * SUBT * SUBT SQRT SUA(main.defense) * *STOP*

13 PREP.DEMO 4 9 red.rag eng

no.obstacles.to.prep obstacles.prep.time * *STOP*

SUA(red.rag) *STOP*

SUA(red.rag) *STOP*

fract.eng.main SUA(eng) * *STOP*

SUA(eng) *STOP*

14 MAIN.DEF.PREP.ALT.PSNS 4 10 red.rag blue.reserve time.per.psn.per.total.unit number.alt.sup.psn * 1.0 fract.cco.blue.reserve / * *STOP*

SUA(red.rag) *STOP*

SUA(red.rag) *STOP*

fract.cco.blue.reserve SUA(cco) * *STOP*

SUA(blue.reserve) *STOP*

15 PREP.TO.COUNTER.ATTACK 10 11 main.body tm.mech

counter.attack.prep.time *STOP*

SUA(main.body) *STOP*

SUA(main.body) *STOP*

SUA(cover.force) SUA(blue.reserve) PLUS *STOP*
SUA(cover.force) SUA(cco) PLUS *STOP*

1 12

26
fract.mech.cf *STOP* > = 0 *STOP*
fract.arm.cf *STOP* > = 0 *STOP*

fract.mech.main *STOP* > = 0 *STOP*
fract.arm.main *STOP* > = 0 *STOP*
fract.cco.main *STOP* > = 0 *STOP*
fract.at.main *STOP* > = 0 *STOP*
fract.eng.main *STOP* > = 0 *STOP*

fract.mech.flank *STOP* > = 0 *STOP*
fract.arm.flank *STOP* > = 0 *STOP*

fract.cco.flank *STOP* > = 0 *STOP*
fract.eng.flank *STOP* > = 0 *STOP*

fract.cco.blue.reserve *STOP* > = 0 *STOP*

fract.mech.cf fract.mech.main PLUS fract.mech.flank PLUS *STOP* < = 1.0 *STOP*
fract.arm.cf fract.arm.main PLUS fract.arm.flank PLUS *STOP* < = 1.0 *STOP*
fract.aco.main *STOP* < = 1.0 *STOP*
fract.bco.main *STOP* < = 1.0 *STOP*
fract.cco.main fract.cco.flank PLUS fract.cco.blue.reserve PLUS *STOP* < = 1.0 *STOP*
fract.at.main fract.at.flank PLUS *STOP* < = 1.0 *STOP*
fract.btryd.main *STOP* < = 1.0 *STOP*
fract.engr.main *STOP* < = 1.0 *STOP*

tons.ammo.for.spt *STOP* < = 0 *STOP*

fract.mech.cf fract.mech.flank PLUS fract.mech.main PLUS *STOP* > = .98 *STOP*
fract.arm.cf fract.arm.flank PLUS fract.arm.main *STOP* > = .98 *STOP*
fract.aco.main *STOP* > = .98 *STOP*
fract.bco.main *STOP* > = .98 *STOP*
fract.cco.main fract.cco.flank PLUS fract.cco.blue.reserve PLUS *STOP* > = .98 *STOP*
fract.at.main fract.at.flank *STOP* > = .98 *STOP*
fract.btryd.main *STOP* > = .98 *STOP*
fract.eng.main *STOP* > = .98 *STOP*

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