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**A FRAMEWORK FOR INCORPORATING
BATTLEFIELD PURPOSE AND
INTELLIGENCE**

by

James A. Bonomo

September 1992

Thesis Advisor:

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A Framework for Incorporating
Battlefield Purpose and
Intelligence

by

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Submitted in partial fulfillment
of the requirements for the degree of

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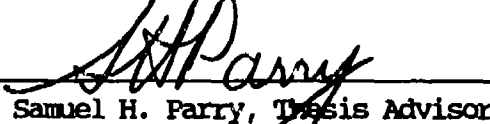
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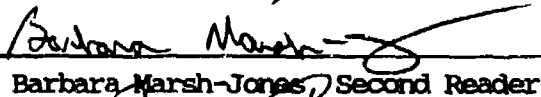
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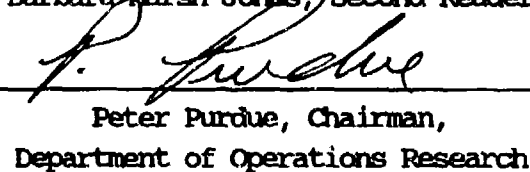
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ABSTRACT

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The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

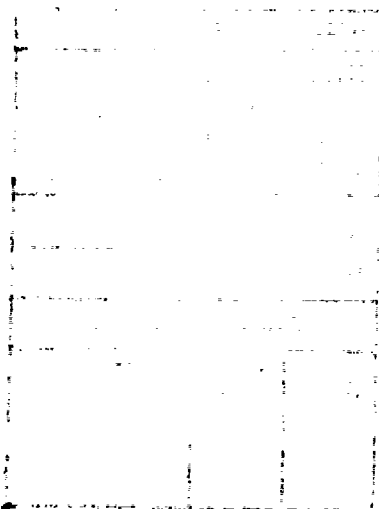


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I. INTRODUCTION

A. PURPOSE

This thesis focuses on a proposed framework for the development of stand-alone artificial intelligence (AI) programs for inclusion in a yet to be developed theatre level wargame. These AI programs will steer the wargame towards making intelligent strategic decisions. This thesis uniquely addresses some of the limitations observed in TACWAR (Tactical Warfare), a theatre level model currently in use in the Pentagon.

B. METHODOLOGY

Specifically, the goal of this thesis is to introduce a framework and discuss proposed AI submodules that simulate the decision-making processes one might expect from a theatre level commander based on his perception of incomplete and possibly incorrect information. Additionally, the mechanics of data flow, troop movements, detections, and engagement results as well as structure of the theatre environment shall be addressed and strategies discussed.

C. SCOPE OF THESIS

The proposed artificial intelligence programs are required not only to function in the presence of incomplete

information, but also to determine if they are infected with incorrect information. To pursue this, three AI modules are anticipated. The first AI module considers the problem of how a commander should best utilize his forces. He must attack plausible targets for definite politico-military goals, yet keep enough in reserve for unexpected events. A stand-alone nonlinear integer assignment program delegates specific mission objectives to specific theatre level units according to the goals of the theatre level commander. The second AI module addresses the problem of acquiring information and confirming or qualifying existing information. The assignment program allocates specific reconnaissance assets to specific operating areas to gain intelligence against targets or objectives. The last AI module is a network analysis program identifying the optimal route of march for the individual units based on three brigade level concerns.

A brief discussion of TACWAR and some of the problems which motivated this thesis are presented in Chapter II. Additional background on the origins of present day US strategy is given in Appendix A. The battlefield, reconnaissance, intelligence, and command, control, and communications factors for the proposed framework are discussed in Chapter III. Also included in this chapter are proposed models for the commander's decision processes, allocation of reconnaissance assets, and route of march determination. Methodology demonstrations of these models,

including analysis of numerical examples, are provided in Chapter IV. Finally, conclusions and areas of further study are presented in Chapter V.

II. BACKGROUND

A. THE TACTICAL WARFARE (TACWAR) THEATRE-LEVEL MODEL

The TACWAR simulation is a stand-alone, theatre level combat model currently utilized by the Conventional Forces Analysis Division (CFAD) of the Force Structure, Resources, and Assessment Directorate (J-8) of the Joint Staff located in the Pentagon.

TACWAR is one of the most comprehensive current models involving engagements on a theatre level basis using conventional, chemical, and nuclear assets. Its development comes from a long line of other theatre level models.

One of the earliest was ATLAS (A Tactical Logistical Air Simulation), which used a firepower-driven representation to simulate ground combat. In order to incorporate more sophisticated warfare systems, GACAM (Ground Air Combat Attrition Model) simplified the ground combat representations and included comprehensive air-ground and air-air combat activities. The development of increased computer memory without a significant increase in simulation running time allowed much larger models with higher degrees of detail. The Institute of Defense Analysis Ground Air Model (IDAGAM) used this advantage and improved upon GACAM by increasing its resolution to include explicit interactions among ground

weapons and an increased data base of aircraft, weapon, and munitions types. TACWAR is virtually the same as IDAGAM with the addition of a supply network and additional submodules incorporating nuclear and chemical activities to include a target acquisition subroutine [Ref. 1].

TACWAR displays data in map and table format for analysis of the comparative significance of various force sizes, structures, and mixes. Its output aids in the assessment of new concepts, doctrine, and theatre policy in the European, Korean, and the Southwest Asian theatres. The most striking display is the location of the FEBA (forward edge of the battle area) on the map supplied at the termination of the simulation run. This one bit of information holds the greatest amount of significance in the analysis of the particular theatre conflict studied. The tables created at the end of each run display the level and time (within a twelve hour window of resolution) of the attrition incurred by each side, the force size and relative efficiency of armies, as well as the exact geographical movement of the FEBA. After a number of 15-20 minute runs, including various environmental situations, an operator can perform sensitivity analysis on the findings and create a detailed report on warfare for a particular theatre and starting conditions.

The TACWAR environment includes conventional, nuclear, and chemical munitions which can be employed theatre-wide. Delivery systems include artillery, rocket launchers,

missiles, rockets, and tactical aircraft which can engage various targets including combat subunits (both first and second echelon), air bases, supply points, and SAM (surface to air missiles) and SSM (surface to surface missiles) sites. Tactical air missions include CAS (close air support), air base attack, interdiction strikes, SAM suppression air defense and escort missions. Attrition in the form of destruction and chemical contamination can be directed towards ground weapons, personnel, supplies, aircraft, facilities and shelters. The model even includes the degradation of personnel and unit efficiency resulting from the use of chemical protection equipment [Ref. 1].

A number of limitations or concerns exist with TACWAR. Foremost is that the model contains no stochastic processes to simulate the uncertainties of war; it is a completely deterministic algorithm. Although this is an excellent feature that allows for replication of runs, it can bring about false results, especially when decisions are resolved close to their thresholds. During a simulated conflict, one side is allowed the advantage of being the attacker only if the force ratio is in its favor and this meets or exceeds a predetermined and never changing threshold (unless by outside operator intervention). Should one side outweigh the other by only a few troops, thus gaining the advantage, the deterministic approach places an extremely high value on the

addition of a small number of troops. In this situation, the addition of a platoon could turn the entire tide of the war.

A conflict is initialized with the decision of the identity of the attacker. This decision is based on a force ratio of one side's offensive combat power versus the other's defensive combat power and vice versa. Provided the calculated force ratio meets or exceeds its particular threshold, the designated attacker from the previous cycle retains the offensive. Another limitation is that these force ratios are computed with the actual (ground truth) numbers and not the theatre level commanders' perceptions of their force compositions and strength nor their perceptions of the enemy. Either intelligence and deception are not a factor in the game, or all decisions are based on perfect intelligence with a perfect ability to defeat the enemy's counterintelligence efforts.

Another limitation is that the geography of the theatre is divided into long corridors called regions along the most common axis of movement. Movement on the battlefield is constrained by these artificial corridors to uni-dimensional avenues and can be pictured as rolling marbles toward each other in a trough. There is no ability to flank unless the operator intervenes. What occurs in one corridor is unknown and does not affect the actions of a neighboring corridor, though it may only be a few miles away. It is possible in the simulation that during a Communist advance on Central Europe,

a particular regiment could become hung up in a small German town, while its companion regiment only miles to the north marches completely unopposed to Spain. Additionally, the model is oriented around the concept of the FEBA. Since weapons have extreme range and can reach deep into enemy territory, the idea of a FEBA is giving way to the notion of mass and location.

The primary MOE (measure of effectiveness) that motivates the commanders' decisions in the model is restricted solely to personnel and equipment destruction; the gaining of territory is, in reality, a byproduct of conflict and not a motivator. Clausewitz, in his study of warfare, listed three measures of strategic effectiveness required for consideration in all decisions. First, attack the will of the state and destroy the government infrastructure and its ability to engage in hostilities. Next, attack the will of the army and destroy its military power and its ability to conduct war. Finally, attack the will of the people and destroy their morale and ability to support war. These concepts are further amplified in Appendix A. Additionally, it is imperative to view the acquisition of theatre territory as a MOE unto itself.

Lastly, in TACWAR there is no ready termination criterion to the wargame. It simply continues indefinitely for as long as the operator desires. A theatre level model, especially in light of today's limited theatre level conflicts, requires the

capability to declare defeat or surrender whether based on Lanchester attrition equations or political considerations.

TACWAR provides a representation of theatre level conflict and assists in many of the studies and preparations for conflict in certain areas of the world. As a model, it has various advantages as well as disadvantages and can provide an excellent source for more advanced conflict simulations.

III. THE MODEL FRAMEWORK

A. INTRODUCTION

This chapter addresses a proposed framework for developing major components of the artificial intelligence programs. The environment of the battlefield is examined and a data structure introduced on which the AI subroutines can function. The processes of reconnaissance and intelligence, maneuver, and strategic theatre level decision making are discussed and formulated. In Chapter IV, a model is presented to demonstrate the reconnaissance allocation module and the maneuver algorithm.

B. THE BATTLEFIELD

1. Representation of the Geography

The battlefield is divided into numerous hexagons similar to a modern day board game. The major geographic features of theatre level concern must be adjusted to fit the hexagons. The geographic area defined by this shape would equal the area required by the smallest theatre level unit. Depending on the resolution required by the user, the definition of the smallest theatre level unit can change. For this framework, the basic unit is at the brigade level and aggregated to form divisions. The advantage of hexagons is twofold. First, they allow two-dimensional movement, an improvement over

conventional one-dimensional models which utilized piston-like corridors. Second, they shift from the idea of a FEBA to the notion of mass and location, where the front and rear areas are no longer used as reference points.

The battlefield, for all practical purposes, exists as a network in a data base. The nodes represent the center of each hexagon and the arcs indicate the routes of possible movement from one hexagon into the adjacent six hexagons. The hexagons are oriented such that they are consistent with the main axis of movement in the theatre.

The data required at a node are stored in vector form and consist of

- node identification number.
- latitude of node.
- longitude of node.
- fixed defendability (difficulty for the attacker to maintain offense due to solely terrain attributes): a numeric scale that sets attrition values.
- variable defendability.
- fixed visibility: a numeric scale that sets detection values (in ocean situations, it simulates depth for ASW scenarios).
- variable visibility.
- current controlling force (blue, red, or neutral).
- blue perception of controlling force.
- red perception of controlling force.
- specific identification of unit.

- blue perception of unit identification.
- red perception of unit identification.

The information required for an arc is also stored in vector form. Since all arcs are of equal distance, this bit of information does not have to be stored, only implied in the movement equations. The data base maintained for each arc consists of

- arc identification number.
- fixed terrain type to affect rate of movement.
- variable terrain type to simulate weather effects.

Terrain types are divided into either heavy or light transport roads, good, fair, or bad off-road terrain, obstacle, and light or heavy seas.

Note that in order to maintain a sense of consistency in the model, the variable values of defendability, visibility, and terrain type must be compatible. This is accomplished using a weather subroutine which coordinates the impact of these three values. In the data structure, every node is accessible to every other node. Units may experience difficulty traversing arcs depending on the type of arc and unit; however, innovation and determination in actual warfare means there is always a way.

2. Identification of Unit Types

Units are classified as ground, air or naval. A unit identification number is assigned to a specific entity and is recorded at the node of its present location. The unit identification number refers to a data base file recording such attributes as

- type of unit.
- force level (current number of personnel).
- level of aggregation.
- identification of units in the aggregation.
- current node identification number.
- current mission assignment (objective identification).

Units can be aggregated to form more powerful entities such as brigades coming together to form divisions. Separation limitations between units are determined using latitude, longitude and simple trigonometry.

Military units are generalized into categories based on their capabilities. For example, instead of F-14s, A-6s, and F-117s, there are integrated strike packages and "lone wolf" surgical strike aircraft.

Ground units are divided into four basic categories:

- combat.
- support.
- theatre missiles.

- coastal batteries.

Combat units are further classified as mechanized infantry, (armor), light forces (infantry, airborne or airmobile), or Special-Warfare units.

Air units are divided into three basic categories characterized as fixed-wing jet, fixed-wing propeller, or rotary wing to account for range, payload, and speed:

- early warning detection aircraft.
- air combat aircraft.
- transport.

Early warning detection aircraft are subdivided into seven categories:

- forward air control (FAC).
- photographic reconnaissance.
- signals intelligence (SIGINT).
- early airborne warning (EAW).
- low altitude unmanned airborne vehicles (UAV).
- high altitude UAV.
- overhead satellite.

Combat aircraft include such categories as integrated strike packages, surgical strike aircraft, combat air patrol (CAP), and area bombardment aircraft.

Naval units are aggregated into five basic categories:

- carrier battle group.
- surface action group.
- submarine units.
- amphibious assault group.
- naval transport.

3. The Missions

Strategic or theatre level objectives are defined by Clausewitz as

1. destruction of the government's ability to engage in hostilities.
2. destruction of the military's ability to conduct war.
3. destruction of the people's will to support war.
4. physical control of theatre territory.

Sufficient attainment of these mission objectives will lead to a victory condition in the simulation. Strategies supporting this include

- isolation or destruction of control structure and logistical base.
- destruction of lines of communication and foreign trade, supply lines, and their intelligence network.
- denying enemy use of airspace, sea lanes, highways, bridges and other transportation media.
- deception.
- psychological warfare.
- attrition of enemy warmaking capability and enemy personnel.

The theatre level commander executes these general strategies through use of specific missions by air, ground, or naval units. A discussion of the development of present day US strategy (1980-2000) is offered in Appendix A.

There are four categories for ground combat units:

- ground-ground combat.
- amphibious assault.
- ground-air combat.
- ground-naval combat.

Six specific missions involve ground-ground combat:

- attack.
- guard.
- advance to contact.
- withdrawal and destroy resources.
- enter reserve status.
- Spec-War harassment strikes.

There are nine categories for air combat units:

- combat air patrol.
- anti-ship missile strike.
- surgical strike.
- area bombardment.
- close air support (CAS).
- anti-submarine warfare (ASW).

- escort.
- reconnaissance/early warning.
- psychological warfare.

There are nine categories for naval combat units:

- naval gun fire support (NGFS).
- naval Tomahawk Land Attack Missile (TLAM) strike.
- anti-air warfare (AAW).
- naval blockade.
- anti-surface warfare (ASUW).
- amphibious assault.
- carrier operations.
- mine counter measures.
- ASW.

C. RECONNAISSANCE AND INTELLIGENCE

1. Reconnaissance, Detection, And Intelligence

Reconnaissance is the stochastic process involving detection of one unit by another. Detection is the determination of the location of a unit and the resolution of its identity and strength. Intelligence is the process of relaying the information gained through reconnaissance to a theatre level commander so that he/she can assign mission objectives and priorities.

In this framework, reconnaissance is channeled through eight media:

- ground detects air.
- ground detects ground.
- ground detects naval.
- air detects air.
- air detects ground.
- air detects naval.
- naval detects air.
- naval detects naval.

Strategic reconnaissance is obtained primarily as a result of airborne reconnaissance. This type of reconnaissance is most valuable to the theatre level commander as it reveals location, identification, and relative strength of enemy units over a large portion of the geography. In some cases, it extrapolates intent by revealing course and speed of movement and possible strategic locations towards which the movement is directed.

2. Reconnaissance Assets

There are seven categories classifying reconnaissance assets that differ only in three particular characteristics: the probability of detection, the probability of identification given a detection has occurred, and the speed at which it can disseminate the information.

- Forward Air Controllers are small aircraft, normally single seat propeller driven planes. Used primarily to spot for artillery fire, they have both a high probability of detection and identification but are restricted by short range. They have short information dissemination time.
- Photographic Reconnaissance is conducted by low flying very fast single seat jets to minimize the time over target. They have a high probability of detection over a long range, but their high probability of identification is restricted to a short range. They have long dissemination time, since the film must be developed and interpreted by experts.
- SIGINT, or signals intelligence aircraft, search the electronic spectrum for intelligence. They have a low probability of detection; however, it extends for a long range. Their probability to identify is high and enjoys the same long range. They have a short dissemination time.
- Early warning aircraft such as the Navy's E-2 or the Air Force's AWACS aircraft carry a large airborne radar and have a high probability of identification over a long range, but a low probability of identification. They have short information dissemination time.
- Low altitude unmanned airborne vehicles (UAV) are remote controlled drones with cameras that can survey a small area with a high probability of detection and identification. They have short information dissemination time.
- High altitude UAVs can survey much larger areas than the low altitude drones but suffer a much lower probability of identification. They too have short information dissemination time.
- Overhead satellite reconnaissance has a medium probability of detection over theatre range and a high probability of identification. However, like the photographic reconnaissance asset, it requires a lot of work and has a long information dissemination time. An additional note concerning satellite reconnaissance: due to the nature of their orbit, it cannot be directed or maneuvered as easily as other assets. Its coverage of an area is restricted to those times the satellites are actually overhead.

3. Reconnaissance Operating Areas

During reconnaissance operations, assets "hunt" or "orbit" in specific reconnaissance operating areas with specific geographic boundaries. The detection coverage area for a given platform is determined from a template revealing the affected hexagons; in reality, the template only needs to define the required nodes. Different templates are required to differentiate the various track profiles of platforms. FAC or SIGINT platforms utilize an orbit which is relatively circular, and accordingly, the shape of detection coverage is uniform (see Figure 1). A platform whose track traverses a great distance such as a photographic run (see Figure 1) requires a template covering a great distance in the direction of movement but limited in its lateral view.

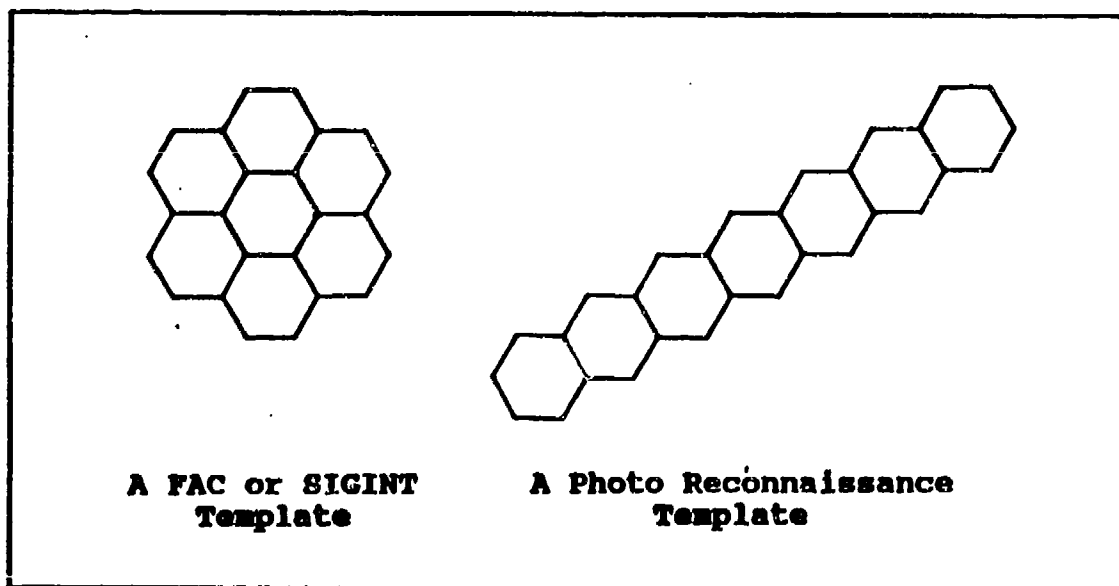


Figure 1 Various Reconnaissance Templates.

Each of the seven types of reconnaissance platforms has a specific type of template. Theatre territory is overlaid with numerous templates of each of the seven types displaying all of the possible areas of reconnaissance operations. There is no limit to the number of templates that can cover a particular geographic area which represents the various reconnaissance platforms that can search an area.

Reconnaissance by ground or naval units is more tactical, since the detection equipment of these units does not offer the same capabilities or characteristics as airborne units. Templates are created to give uniform coverage around the unit. Units which are aggregated with other units enjoy enhanced ranges centered on each of the aggregated units. Overlap of detection coverage areas is expected in this situation.

Reconnaissance by Special-Warfare units is characterized by high probability of location, identification, strength, and intent for strategic purposes; however, they are limited by short range.

4. Scheduling Reconnaissance Assets

In this framework, scheduling reconnaissance assets is accomplished through a simple ranking scheme of reconnaissance operating areas. As no reconnaissance asset can search in another category's operating area, there is only the need to determine which of its own operating areas should be scheduled

for search. Each of the operating areas is ranked according to six specific MOEs:

- **Probability of detection:** an overall probability of detection computed from the average of the individual probabilities of detection for each hexagon. The node values of fixed and variable visibility translate directly to the probability of detection; a high value of visibility relates a high probability of detection. The higher the probability of detection for the operating area, the more desirable it is to search there.
- **Reconnaissance cycles since last glimpse:** designed to keep uniform coverage over all the operating areas. The longer an area has gone unsearched, the more desirable it is to gain an update from that area.
- **Distance the operating area is from friendly units.** It is extremely important to have a confident picture of areas close to friendly forces and the bulk of the reconnaissance operations should be directed here. This value is derived using simple trigonometry and the latitude and longitude of the mid-point of the operating area and forward friendly units. It is then multiplied by -1 to give the notion of decreasing utility over distance.
- **Distance the operating area is from main strategic avenue of advance.** As the theatre commander maneuvers his forces through the battlefield, reconnaissance operations clear the path. It is important to have a confident picture of the regions close to this path. This value is computed using the closest point of approach (CPA) of the midpoint of the operating area to the proposed avenue of advance. Again, it is multiplied by -1 to give the notion of decreasing utility over distance.
- **Variance in the estimated force sizes and components in an area arising from recurring reconnaissance operations.** As detection and identification are stochastic processes, different interpretations can occur. The larger the variance in these interpretations, the more desirable it is to search an area again to confirm the intelligence picture.
- **Probability of survival within an operating area** determines how liberal a theatre commander is when assigning an asset to an area. A commander is hesitant to send a reconnaissance platform to an area where there exists a strong possibility of destruction. The value is

based on the perception of what types of enemy units are in an area and their inherent capabilities to shoot down reconnaissance aircraft.

There are various methods that can be used to aggregate the MOEs into an overall MOE; however there is currently no universally accepted choice. For this model, the suggested method is called normalization [Ref.7], where the overall MOE is defined mathematically as

$$DESIRE_{area} = \sum WEIGHT_i \times \left(\frac{MOE_i - \mu_{MOE_i}}{\sigma_{MOE_i}} \right)$$

where μ is the mean of an MOE over all operating areas, σ is the standard deviation and i is a counter for the six MOEs. A MOE whose standard deviation equals zero is assigned a default value of zero. WEIGHT is a six element vector that, when multiplied by the MOE values, emphasizes the importance of one MOE over another.

The above method provides a number of beneficial features. First, dimensionless values are created through division by the standard deviation, allowing the combination of diverse MOEs. Second, subtraction of the mean exposes the level of deviation a particular operating area has above or below the average over all the areas. A linear combination summed over the MOEs for each operating area reveals how much a particular area dominates or falls behind with respect to the average of all the MOEs. Weighting the MOEs prior to summation imparts varying levels of importance inherent to each MOE through a

multiplicative transformation of the values. For example, if MOE A were given a weight twice as large as that for MOE B, then the importance of MOE A would be deemed twice that of MOE B and have twice the impact during summation. Aggregated into one MOE, the new values are easily ranked to determine the best reconnaissance operating areas.

Though the values lose their ratio relationship, they still maintain their interval definition. For example, if areas one, two, and three received scores of four, two, and one, respectively, it would be incorrect to say area one had twice the utility of area two. All that could be said is that area one exceeded areas two and three, and that the amount area one exceeded two was twice that which area two exceeded area three.

Constraints exist to protect reconnaissance crews from too exhausting a schedule, keep the skies above an operating area from getting overly crowded, and maintain a suitable reserve force. This is performed by simply restricting or limiting the number of reconnaissance operating areas the algorithm can choose. The amount of restriction can vary depending on the constantly changing environment the theatre commander faces as asset availability changes and areas of importance shift.

A numerical example is presented in Appendix D using the results of a program run described in Chapter IV.

5. The Stochastic Process of Detection and Identification within Operating Areas

The stochastic process of determining if detection has occurred, given that the target is located within the reconnaissance platform's operating area, is a function of the individual probabilities of detection for each hexagon. A systematic counting function explores each hexagon and a random number generator is used to determine if a true detection, false detection, or no detection occurred. The probabilities of detection are based on variable and fixed visibility as well as the perception of threat to the reconnaissance platform. A hexagon with a high threat associated with it has a lower detection probability since the reconnaissance platform would be hesitant to approach within harm's reach.

The process of identification given detection involves identifying not only the unit type but also its size. Two normal distributions are required. One is centered with the mean at the true identity, surrounded by other unit types with which it could be confused; categories farther out on the tail are less likely to be confused with the detected unit. The standard deviation defines the degree of misidentification.

The other normal distribution is centered with mean equal to the true force size of the true unit or an equivalent true force size of the misidentified unit. The standard deviation defines the amount of error in determining the force size.

Following this process, enemy units are categorized with two attributes:

- perceived type of unit.
- perceived strength of unit (number of personnel).

The perceived type and strength of the enemy unit further determines the perceived importance of the unit to the enemy logistical base, and command, control, and communications structure, as well as the threat to reconnaissance operations within an operating area.

6. The Process of Intelligence Validation

Intelligence validation is the process of looking for variance in the estimated force sizes and compositions of detected enemy units. The mean and variance for each detected enemy unit is computed from the numerous estimates from reconnaissance operations. The mean reflects the current perception of the enemy and the variance determines the degree of uncertainty in this perception. A small variance is evidence that the perception of the enemy equates closely to ground truth. A large variance increases the desirability to search an area again to substantiate and confirm the intelligence picture.

A simple search algorithm can determine in which reconnaissance operating area an enemy unit is located and its associated variance of force size and composition. A unit

that has not been detected or detected only once is assigned a default value of zero. For force sizes, the variance is divided by the true force size to lessen the impact of large numbers. The average of this value over all the units in an area is used as the area's MOE.

D. THE THEATRE LEVEL COMMANDER'S DECISION

1. The Strategic Action Model

The modern strategist of a theatre level engagement must function within the guidelines of the limited and just war (see Appendix A). Still, his thinking must be in keeping with that of Clausewitz; that war is an extension of politics by other means. Continually interested in the destruction of his opponent's military force, populace will and political might, the commander will deploy forces to obtain the greatest impact. Unlike his counterpart engaged in a protracted war, the commander does not enjoy a surplus of time or supply and must use a more Jominian approach of bringing the maximum possible force to bear against the decisive point in the theatre of operations. By denying his enemy strength and operating upon interior lines of communication, he achieves a decisive concentration of force. The limited war commander does not have the ability to maneuver and must drive the forces directly toward the objective, keeping close to a preplanned axis of approach. All routes, whether singular or multiple, terminate at the grand objective or the location of

the decisive point. An engagement here, Clausewitz and Jomini agree, brings victory.

A model of this strategy requires five modules and two data bases:

- reconnaissance.
- distance from centerline.
- distance from objective.
- MOE development.
- strategic action assignment.

The reconnaissance module is the assignment program discussed in the preceding section that controls the operations, actions, and efforts of the detection process. Outputs of the reconnaissance module provide detection data in two data bases: the list of indices and the strategic area overlays to the map.

The first data base, the list of indices, is input for the strategic action assignment module. Initially, all possible objectives are assigned an index; there are four types:

1. terrain.
2. enemy units.
3. friendly units under siege from stronger enemy forces.
4. slack.

Terrain objectives require an outside operator to perform a map study of the theatre and to initialize the system with

all terrain features that have the potential to impact or affect the outcome. Such features include hills, crossroads, towns, permanent supply depots, natural chokepoints or containment points, etc. Some terrain features are always considered an objective such as a large power station, while others require a specific set of conditions. An example of the latter is a bridge. Far away from the engagement it has no real value; however, if a large portion of enemy supply or reinforcements require that bridge, it takes on new significance.

In reality, both sides have a fairly clear view of each other's fighting forces and what units comprise these forces. To initialize a wargame with each side having a list of all possible units they may face is not unreasonable. Neither side initially knows the strength or location of these units; that is the job of the reconnaissance module. As a reconnaissance asset detects an enemy unit, the second type of index (the enemy unit index) is activated and becomes an input to the strategic action assignment module. If undetected or incorrectly identified, the index will remain inactive or another index will become active. Again, an outside operator must initialize the system and load into the data base a list of all enemy units along with a larger and more generalized list representing degraded intelligence.

The third type of objective takes into account the scenario of a unit becoming ambushed or overrun during an

engagement. They cease to be an asset and become an objective requiring other friendly units to reinforce them. Every friendly unit has the potential of being in this situation.

The final type of index, the slack index, is used when none of the above apply. This option allows a unit not to engage any secondary targets and just maintain its route of march along the axis of approach. Also, this index is used for those units which are either under siege or have been heavily damaged. These units enter into reserve status, adopt a strong defensive posture without movement, and wait until reinforcements and supplies arrive.

The second data base contains the strategic overlays. Similar to the templates for reconnaissance operating areas, they determine the proximity of an enemy unit to prominent terrain features implying intent towards that terrain feature, enhancing the importance of the feature. If a detection asset determines that an enemy unit is located within one of these overlays, it activates a terrain objective index. Not only is the size of the overlay important, but also the shape of the overlay showing various routes of march or other accesses to the terrain objective. A terrain objective can have multiple overlays revealing a distribution of importance as the location of the enemy unit changes in relation to the feature.

The next three modules perform simple but necessary computations. The first module determines the CPA or lateral distance an intermediate objective is from the centerline of

the unit's avenue towards the grand objective. An outside operator determines the grand objective of the theatre commander; for instance, the invasion and conquest of an enemy's capital or the relocation of the FEBA behind a politically determined boundary as seen during the War in the Gulf when the US grand objective was to force Iraqi forces north behind the Kuwait border. Geographically, there will be a natural avenue of approach toward the grand objective. Secondary or intermediate objectives are also assigned; however, a unit which pursues them and loses sight of the grand objective violates Jomini's principle of concentration on the decisive point. Distance away from the avenue of approach is an important consideration for the theatre level commander and information can be generated using simple geometry and the latitude and longitude of the unit's hexagon.

The second module determines the distance between all perceived objectives and all available assets. This information is needed to ensure that assets engage objectives closest to them. Again, simple geometry using the latitude and longitude of the two hexagons is adequate.

The proposed strategic action assignment module is a nonlinear integer assignment program. The objective function is maximized to obtain the most benefit from the assignments of assets to objectives. The nonlinear characteristic represents the marginally decreasing returns expected from multiple assignments to a particular objective. Putting three

units on an objective does not constitute the firepower of the three separate units as they interact in an environment of limited space and aggregate to form a single larger unit.

The theatre level commander is constrained from allocating assets beyond his resources. The formulation of this program is as follows:

MAXIMIZE:

$$\sum_i (\sum_j [BENEFIT_{ij} \times ASSIGN_{ij}]^s)$$

subject to:

$$\sum_i ASSIGN_{ij} \leq TOTAL_i \quad \forall j$$

where: i =assets, j =objectives, and the exponent s is a shaping parameter on the interval $(0,1)$. $ASSIGN$ is a matrix where 0 signifies no assignment and 1 defines an assignment. $TOTAL$ refers to resources and is normally a vector of ones, indicating that a unit can only be assigned one objective; however, some units such as strike aircraft can be assigned to multiple sorties.

The benefit matrix ($BENEFIT$) is a conglomeration of nine MOEs combined using the normalization technique into a two dimensional matrix mapping friendly assets to objectives. The MOEs consist of

- probability of success of an asset against an objective; a scale determining the likelihood of success of a unit against an objective. It is composed of three attributes. First, a data base contains the expected success rate of

a type of asset against a type of objective. Second, the expectation is altered to reflect the current strength of the unit (number of personnel) above or below that of the generic unit in the data base. Third, the same is performed for the perceived strength of the objective.

- distance an objective is from the centerline of the avenue of advance is determined from the CPA module.
- distance between an asset and an objective.
- perceived amount of enemy logistical attrition determined from the perceived importance of the enemy unit and the probability of success.
- perceived amount of enemy command and control attrition.
- perceived amount of enemy personnel attrition.
- perceived amount of gained territory is derived from how far friendly forces have advanced given victory for the engagement.

Maximization here reveals the force mix where the greatest number of objectives are engaged by the commander's primary choice of units.

2. Procedure and the Mechanics of Military Engagements

The mechanics of military engagements is steeped in procedure and doctrine. Once active units have been identified and assignments given, the closest and strongest closes in and engages while the remaining assets act in a supporting role.

In this framework, the concept of attrition applies to enemy systems and depots as well as enemy personnel. After an engagement at time (t), a force at time (t+1) is divided into three distinct groups:

- functional forces: these forces have the capability to maintain hostilities in time $(t+1)$.
- nonfunctional forces: these forces have been wounded either physically or psychologically and cannot function in time $(t+1)$. Additionally, they detract from the speed of advance and the offensive capability of the functional forces as they require constant medical attention.
- casualties: these are the forces that either have been killed in the action or have left their forces to join the opposing side. This second group is the main target of psychological missions. They do not add to the offensive capability of the force to whom they surrender. As more personnel surrender, they induce others to follow suit or at least become nonfunctional and detract from offensive capability.

The force strength in time $(t+1)$ is computed from the functional forces minus a percentage of the nonfunctional forces and the surrender forces.

E. COMMAND, CONTROL, AND COMMUNICATIONS

Command, control, and communications refer to who is in charge of the command; his sphere of influence (who he/she controls and how); and the medium through which he conveys his ideas and information (his communications net). Attacking the command structure, as Clausewitz recommends, is an attack on both the government and its military forces since it isolates the forces by removing any coordination between them or direction to them. Separated from any form of guidance, they enter a more defensive posture and movement becomes stagnant. The greatest impact of degraded communications occurs where a unit encounters overwhelming enemy forces and requires

assistance. In a state of degraded command and control, the wrong reinforcements may be sent, or the unit may be completely cut off and no reinforcements sent.

In this proposed framework, command, control, and communications are not directly modeled, but rather the effects are portrayed as a degradation of information flow. In the strategic action assignment module, indices can be assigned correctly, indicating perfect command and control. They can be misidentified to a more general category depicting a loss in communications; the greater the error, the greater the loss. Additionally, the assignment can be delayed until the next decision cycle. A complete breakdown occurs where no indices are assigned, thus the fighting forces are isolated from their command structure and remain static.

Specific aircraft and brigades are designated for command and control functions. These units are primarily susceptible to detection through SIGINT, overhead satellite, and photographic reconnaissance platforms. Attrition of these units temporarily stagnates the elements aggregated with them until another command and control facility establishes communications. A random number generator based on a normal distribution about the correct index performs the assignments. The greater the attrition, the farther out on the tails of the distribution (a more general category) an assignment is taken. Once attrition has attained a preset level, no further assignments are made.

F. DETERMINATION OF ROUTE OF MARCH

1. The Route of March Module

Movement through the simulated battlefield is accomplished using a network of nodes and arcs created for the theatre and variations of shortest path algorithms. Single-source, shortest path algorithms are that family of heuristics used to determine the path through a network and offers the minimal cost of travel from a unique starting point to any other point. All the arcs in this model have nonnegative costs attached to them and are numbered for identification. The nodes have no value assigned to them and serve to join various arcs. The single-source shortest path algorithm uses a "greedy" technique in its quest for the optimal path.

"The algorithm works by maintaining a set S of vertices whose shortest distance from the source is already known. Initially, S contains only the source vertex. At each step, we add to S a remaining vertex v whose distance from the source is as short as possible. Assuming all arcs have nonnegative costs, we can always find a shortest path from the source to v that passes only through vertices in S. Call such a path special. At each step of the algorithm, we use an array D to record the length of the shortest special path to each vertex. Once S includes all vertices, all paths are 'special,' so D will hold the shortest distance from the source to each vertex." [Ref. 5]

A subset of the single-source shortest path algorithms deals strictly with undirected graphs in which there is no directional restriction on the arcs. Movement on an arc in an undirected graph can be in both directions, while in a directed graph, movement is restricted to one direction. An undirected graph is the data structure used to represent the

geography of the simulated battlefield in this framework. A spanning tree is a path which connects all the nodes in a graph so that any node is accessible from any other node. The only restriction is the graph must be acyclic (it cannot contain any loops). Figure 2 displays graphically the difference between a cyclic and an acyclic graph. A minimum-

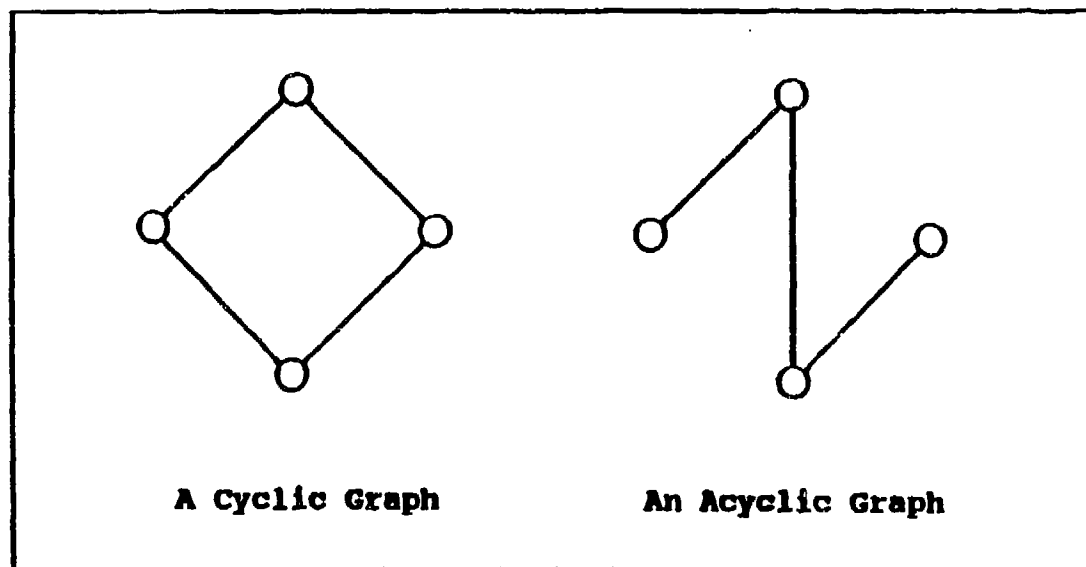


Figure 2. Examples of Various Graphs.

cost spanning tree seeks out the path in this graph which offers the minimal cost of the combined arcs. For this framework, Kruskal's algorithm (order $e \log e$) is preferred.

Kruskal's algorithm begins with a graph containing only nodes. Systematically, the arcs are introduced into the graph. The process starts with the arcs of least cost and continues with those of increasing cost such that a loop or cycle is never constructed. The process continues until every

node is included in the graph. An example is offered in Figure 3.

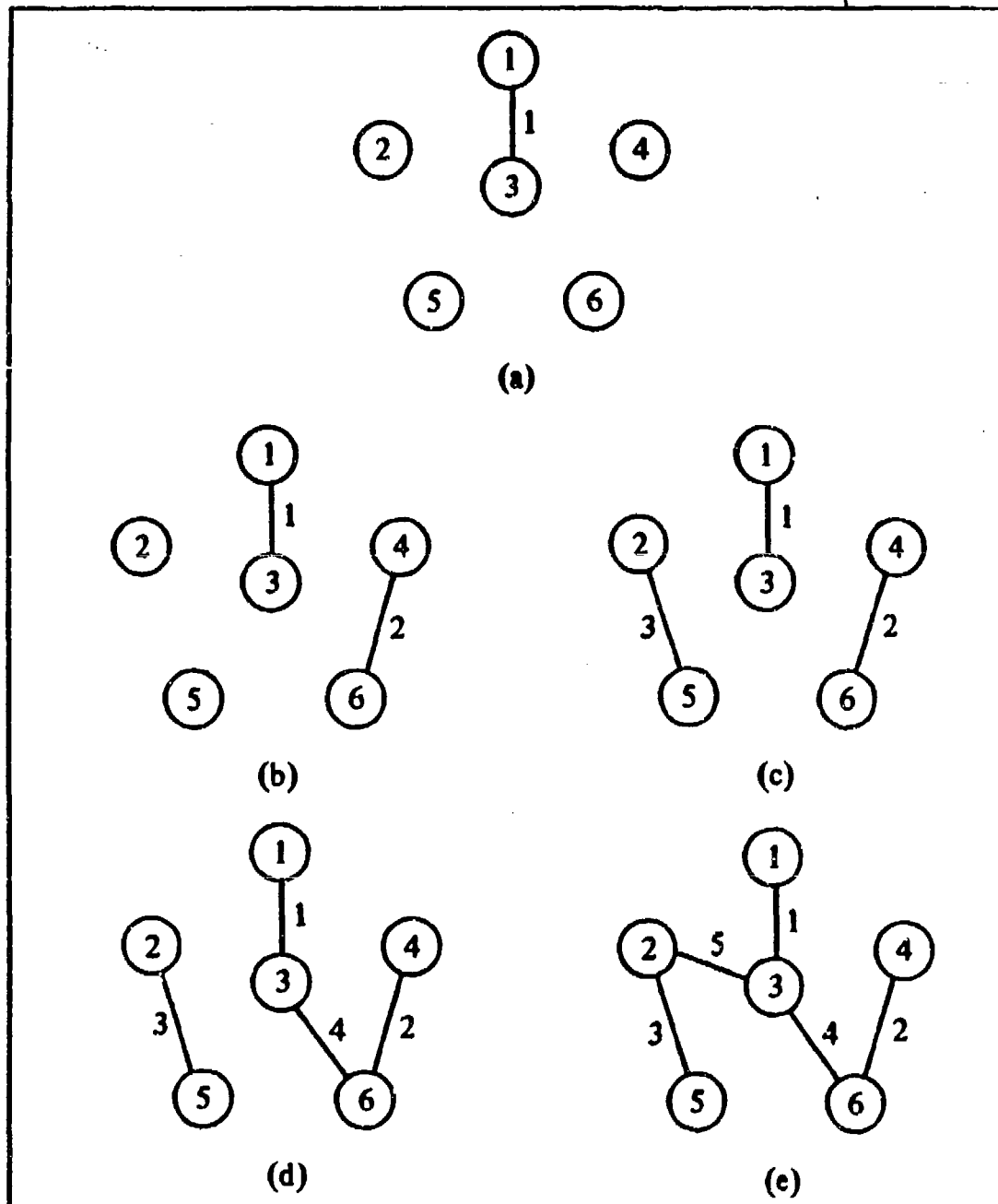


Figure 3. Sequence of Edges Added by Kruskal's Algorithm [Ref. 5].

2. Tactical Concerns

Having received orders from the theatre level commander (simulated by the strategic action assignment module), a brigade commander is faced with maneuvering his forces to achieve the assigned objective. Kruskal's minimal-cost spanning tree algorithm simulates this decision-making process.

The most expedient route is strictly a map study and seeks to minimize the time required for travel. Contact with the enemy will cause both a loss of personnel and time, and this must be weighed against the increased time of maneuver.

The route offering the greatest degree of stealth is the one where the smallest probability of detection exists. A path on which the variable and fixed values of visibility are minimized is such a route.

The most secure route is the path on which the unit does not make contact with the enemy. Nodes where enemy units are detected are temporarily removed from the network. Kruskal's algorithm determines the shortest path to the objective without travelling through these nodes or on any of the associated arcs.

This chapter introduced and discussed a proposed framework for the development of AI modules for a future theatre level simulation. A demonstration of the reconnaissance allocation module and the maneuver algorithm is presented in the next chapter.

IV. METHODOLOGY DEMONSTRATION

A. THE SCENARIO

Demonstration of the methodology used in this proposed framework is limited to the reconnaissance allocation module and the movement module. For this demonstration, it is assumed the combat unit has already been assigned its objective. The scenario consists of a field of eleven hexagons with two reserved for the objective and the initial location of the combat unit (see Figure 4). The combat unit has to cross the three by three grid to reach its objective in the minimal amount of time using one of two movement profiles; most secure where enemy contact is not permitted or most expedient where enemy contact is permitted but must be compared to the increased travel time of maneuver. Possible enemy units are located in some of the hexagons; however, their number and disposition are unknown. The combat unit has three similar reconnaissance assets to explore any of the nine hexagons. The unit must determine which three areas it must explore and then resolve the route of march.

B. THE PROCEDURE

The initial runs of this model were performed using the most secure path. The network and probability distribution over the hexagons appear in Figure 5. Nodes in the network

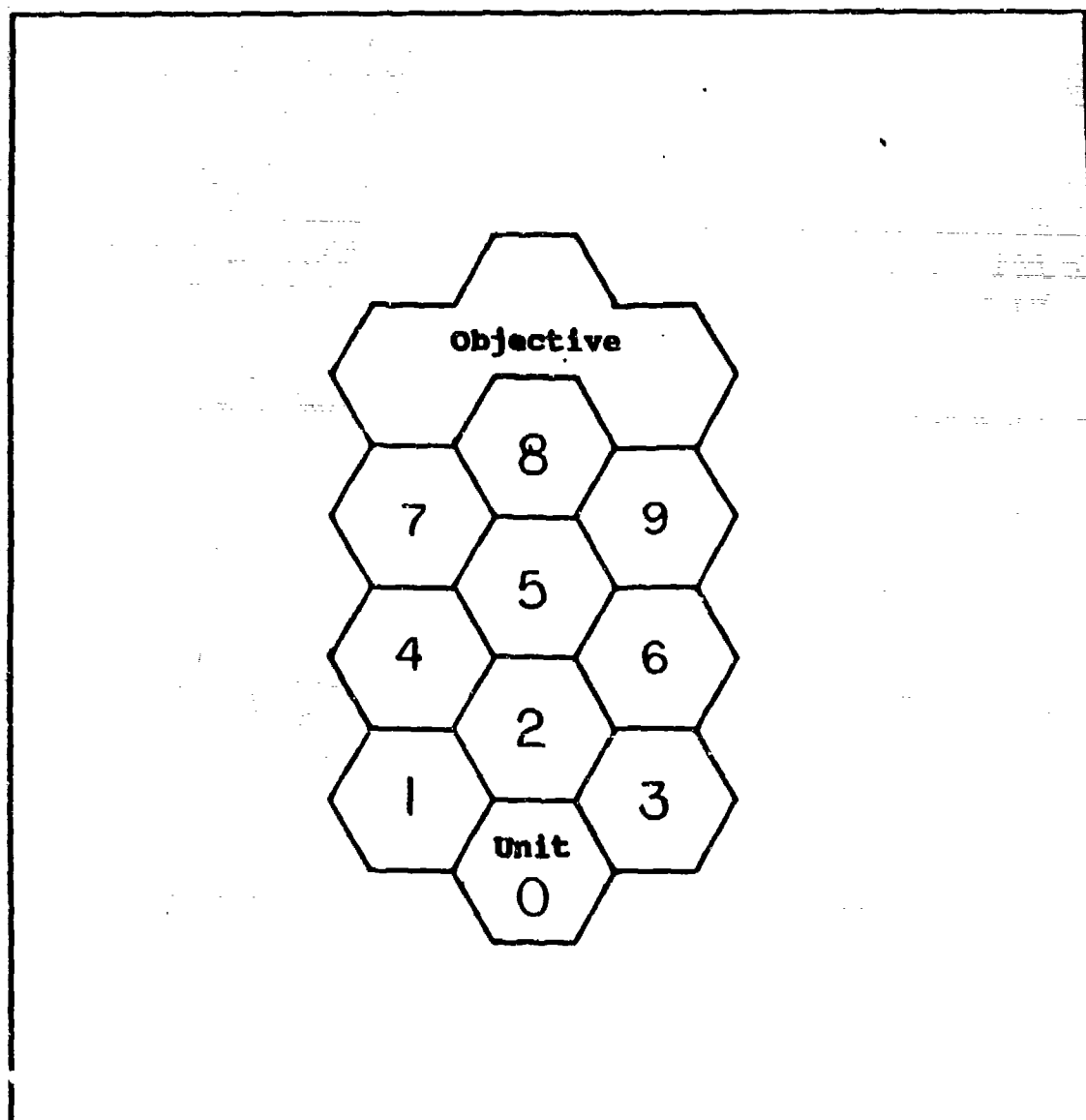


Figure 4. The Battlefield.

are considered geographically equidistant from each other. The values displayed in the network represent the amount of travel time due to terrain the combat unit encounters moving over specific arcs. The most secure path considers and minimizes the total amount of time from the current node to the destination node using Kruskal's algorithm. When an enemy

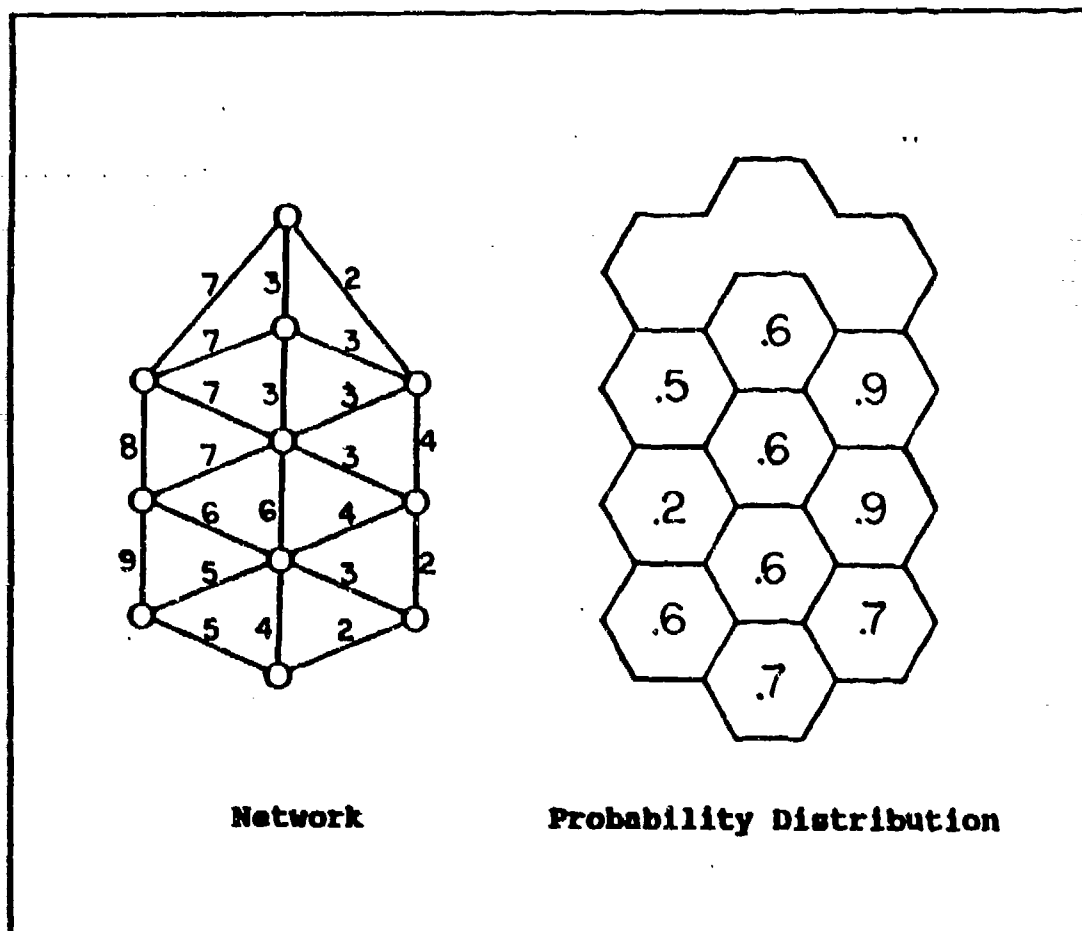


Figure 5. Network and Probability Distribution.

unit is detected, that node and the six associated arcs are removed from the system and the algorithm is run again to find the new shortest path. The most expedient path assumes that any enemy engagement incurs a time penalty of one unit. This is added to the arc or arcs immediately following the node where the engagement occurred. For this demonstration, the penalty for personnel lost is calculated from a one to one loss ratio with the enemy. For example, if an enemy force of 200 is detected, the perceived loss is 200 friendly casualties

as well as 200 for the enemy. The penalty for friendly personnel lost is transformed from personnel units to time units by multiplying by 1 time unit per 200 personnel units. This value is also added to the arc or arcs immediately following the affected node.

The probability distribution displays the probability that a reconnaissance asset detects an enemy unit in a particular hexagon. An assumption is made that the three reconnaissance assets and all the enemy units are of the same type. The probability distribution strictly refers to the probability of detection due to terrain. For this demonstration, the ability of the reconnaissance platform to identify unit strength given a detection is assumed independent of terrain and thus is equal over all hexagons. It is normally distributed with mean equal to the true force size of the enemy and a standard deviation of 20 percent of the true force size. The standard deviation refers to the amount of error inherent to this platform and is representative of many true reconnaissance platforms.

Six MOEs described in Chapter III are used in the reconnaissance allocation module:

1. The ability of a reconnaissance asset to detect an enemy unit within a hexagon; that is, the probability of detection of the enemy.
2. The number of reconnaissance cycles since the last glimpse. This is a counter which increases by one for each reconnaissance cycle. For those hexagons where a reconnaissance asset was sent or the combat unit had

occupied during the previously cycle, the counter is reset to zero.

3. The geographic distance a hexagon is from the current location of the combat unit, computed by counting the number of hexagons from the current location of the combat unit to the particular hexagon.
4. The geographic distance a hexagon is from the intended path of the combat unit, computed by counting the number of hexagons from the particular hexagon to the CPA of the intended path.
5. Variance of the estimated force size detected within a hexagon. The variance of perceived force size is computed for each hexagon. A default value of zero is given to those hexagons that either have not been searched or searched once. The larger the variance, the more desirable it is to search that hexagon.
6. The perception of a reconnaissance asset's ability to operate within a hexagon and not be destroyed by enemy fire is simply the perception of what type of enemy unit is located there. A default value of 0.7 is assigned to all hexagons prior to search reflecting an assumption made in total uncertainty that in each hexagon there is a 30 percent chance that the reconnaissance platform will be lost to hostilities. When an enemy unit is detected the value drops to 0.5; conversely, if no enemy units are detected this value jumps to 0.9; a ten percent chance that the asset will still be lost to a previously undetected enemy unit. These values slowly return to 0.7 at a rate of 0.1 per two cycles. This represents the reduced confidence of the intelligence picture as enemy units may move from one hexagon to another. The values are representative of values used in the real planning and scheduling of reconnaissance assets.

A program written in APL (see Appendix C) performed the normalization process, reducing the six MOEs for each of the nine reconnaissance areas (54 total) to one MOE for each of the areas. From the nine resulting values, the algorithm is restricted to choosing the three largest for the three reconnaissance assets and these are the primary three choices

for reconnaissance operations. A numerical example of cycle two from program run two is given in Appendix D to further illustrate the normalization process.

For the example used to demonstrate the methodology, the system was initialized with the friendly combat unit at node zero and stationary enemy units permanently located at nodes eight and nine (see Figure 4). Both enemy units have a force size of 1000. The initial shortest path runs along the right side of the field through nodes three, six, and nine.

For analysis, tables are supplied in Appendix B. The first row shows the hexagons involved in the reconnaissance decision. The last row reveals the desirability of sending a reconnaissance asset into a particular hexagon; the largest three values depict the hexagons where reconnaissance operations are directed. The middle six rows show the raw MOE data.

Four runs were conducted with this scenario. The first used unweighted MOEs, directed movement along the most secure path, and operated in an environment of perfect command and control where reconnaissance information arrived before movement into another hexagon. The second run differed from the first in that weighted MOEs exhibited the varying degrees of importance inherent to each MOE. The third run explored the effects of degraded command and control as information arrived at a much slower rate: the combat unit traversed two hexagons before receiving any updated information. The final

run was a shift in mission profiles. Instead of moving along the most secure path where the enemy was to be avoided at all times, movement was directed along the most expedient path where enemy contact was permitted.

C. ANALYSIS

Prior to any reconnaissance action, the initial optimal path ran along the right side of the field through areas three, six, and nine. The number of cycles since the last glimpse equaled zero for each hexagon, there were obviously no inconsistencies and the perception of a reconnaissance asset's ability to operate safely within each hexagon was initialized to 0.7.

1. Program Run One

Program Run One consisted of unweighted MOEs, used the most secure path, and reconnaissance occurred before each hexagon movement.

Cycle one, shown in Table B.1, directed reconnaissance operations to areas three, six, and nine. Areas three and six were identified as the most desirable with areas nine and two being the next most desirable. All of these choices were logical as they intently explored those areas near the combat unit and along its intended path. An enemy force perceived to be of size 1300 was detected in area nine shifting the optimal path to (3, 6, 5, 8, objective) from the original (3, 6, 9, objective). The combat unit moved to area three.

Cycle two, displayed in Table B.2, directed reconnaissance to areas two, five, and six. Area six was the only clear numerical favorite. These choices still concentrated reconnaissance in the immediate area and close to the intended route of march; however, area zero was considered more desirable than eight. Rather than search area zero which appears behind the combat unit, area eight would have been a better choice since it was closer to the intended path. Area zero was preferred primarily because of its close proximity to the combat unit. The model did not recognize this hexagon as being behind the unit; however, had the unit needed to retreat, this hexagon would have been required and in reality be in front. A characteristic of multi-dimensional movement is an alteration to the concept of "in front" or "behind". "In front" does not necessarily refer to the geographical direction towards the objective. In the undirected graph proposed for this framework where movement is restricted to the optimal path, "in front" refers to the next node in line towards the objective. "Behind" is the node on the exact opposite side. No detections occurred and thus there was no change to the optimal path (6, 5, 8, objective). The combat unit moved to area six.

Cycle three, displayed in Table B.3, directed reconnaissance to areas two, three and five. Area five and two, the only numerically prominent choices, were logical; area three was far from the intended path and search there did

no good. Area eight was tied in desirability with area three and a random draw chose between the two. In this scenario, areas seven, eight or nine were better choices than three; however, area three was chosen solely for its high sense of safety (probability of survival within hexagon three equaled 0.9). A weighting scheme could have expressed the increased importance of search along the intended route of march and directed operations towards those areas. A weighting scheme emphasizing proximity to the intended path was introduced in the next program run with a noticeable improvement. In cycle three, no detections occurred and there was no change to the optimal path. The combat unit moved to area five, now one hexagon away from area eight and an undetected enemy force.

Cycle four, shown in Table B.4, directed reconnaissance to areas six, eight, and nine. A better allocation would have been to choose area seven over area six. Reconnaissance operations were never directed to area seven due primarily to a low probability of detection (0.5). Again, a weighting scheme could reinforce the importance of area seven's proximity to the intended path. An enemy force of 700 was discovered in area eight and 1100 in area nine. The optimal path changed to a route from area five to seven and then to the objective.

2. Program Run Two

Program Run Two consisted of a weighting scheme for the MOEs, used the most secure path and reconnaissance still occurred before each hexagon movement. A vector (1, 4, 2, 5, 1, 2) was multiplied against each column in the matrix of normalized values before they were summed. This weighting scheme emphasized the importance of searching those areas along the intended route of march (MOE 4) and attempting an equal amount of coverage over all areas (MOE 2).

No change occurred between cycle one of this program run (Table B.5) and that of program run one (Table B.1). A force size of 900 was detected in area nine.

Cycles two, three, and four (Tables B.6-B.8) showed a marked improvement in reconnaissance allocation. In cycle two, reconnaissance was directed to areas five, six, and eight. An enemy force perceived to be 1200 was detected in area eight, shifting the optimal path to (6, 5, 7, objective).

Reconnaissance operations in cycle three were directed to areas two, five, and seven. Now the allocation algorithm had completed its search of the hexagons along the optimal path. The weighting scheme directed the focus of the allocation algorithm towards sweeping a safe path to the objective. This was an improvement over the last program run where area seven was never searched.

Cycle four directed reconnaissance toward keeping equal coverage of hexagons near the intended route. Areas four,

seven, and nine were searched. The reconnaissance asset reacquired the enemy force in area nine; however, it now perceived the force size to be 1100. Before this inconsistency could become an influence, the combat unit had achieved its objective.

3. Program Run Three

Program Run Three (Tables B.9 and B.10) consisted of the same weighting scheme for the MOEs, used the most secure path, and to simulate degraded command, control, and communications, reconnaissance occurred once for every two hexagons of movement.

A degradation of command, control, and communications cannot be planned; it must simply be accepted and the directives of the unit commander followed. In this scenario, the combat unit expected reconnaissance information at each hexagon before further advancing. When it did not arrive, the unit had to operate on its best information and make the advance based on old information. The reconnaissance platform performed its duties, supplying information the combat unit required before advancing only one hexagon.

Again, cycle one was the same and an enemy force of perceived to be 1100 was detected in area nine. As in the other two program runs, the optimal path became (3, 6, 5, 8, objective). Because of the unit's inability to gain intelligence at each juncture, the combat unit advanced

through area three to area six. The reconnaissance allocation module identified two, five, and eight as the next series of hexagons. This was an appropriate choice assuming, as the model did, that reconnaissance information would arrive before movement into the next hexagon. The unit now advanced two hexagons; it outran the intelligence coverage and ultimately moved through an unexplored area seven.

Though the team of the reconnaissance platform and the combat unit was able to achieve the objective, it is clear that the performance was not equal to that of program run two where they operated in an environment of perfect command, control, and communications.

4. Program Run Four

Program Run Four (Tables B.11-B.14) consisted of the same weighting scheme for the MOEs, perfect command, control, and communications where reconnaissance occurred before each hexagon movement, and switched mission profiles to the most expedient path.

Perception of enemy strength had a heavy impact in this program run. Enemy contact was permitted and Kruskal's algorithm had to weigh the perceived benefits of making contact or outmaneuvering the enemy. As perception of force size changed, so did perception of the optimal path. Because Kruskal's algorithm minimizes the time required to reach the objective, a multiplicative transformation was used to convert

the units of personnel to time with a ratio of one time unit to 200 people. In essence, a sacrifice of 199 people was viewed as better than the sacrifice of one time unit. It was assumed that an engagement of any size would cost an additional time unit.

Cycle one directed reconnaissance to areas three, six, and nine, as in all the previous program runs. A force size of 1500 was detected in area nine and travel through the area incurred an additional 8.5 time units. Kruskal's algorithm, using the most expedient path, minimized the time required and chose to transit through area eight.

Cycle two directed reconnaissance to areas five, six, and eight, where a force of 800 was found in area eight. The additional penalty of 5.0 time units for travel through area eight did not outweigh that of area nine, nor was travel through area seven any better, so there were no changes to the optimal path. The combat unit moved into area six.

Reconnaissance in cycle three was directed to areas two, five, and seven and no detections occurred. Consequently there were no changes to the optimal path, and the combat unit moved to area five.

Cycle four directed reconnaissance to areas four, eight, and nine. The force in area eight was now perceived at 1400 while in area nine it was estimated to be only 700. The penalty for area eight was 8.0 which outweighed the penalty of

4.5 for area nine. Kruskal's algorithm changed the optimal path to travel through area nine and then to the objective.

Perception of the environment played a heavy role in the decision making process. The unit commander maneuvered forces, constantly attempting to minimize the amount of time required to reach the objective. As reconnaissance information changed the commander's perceptions of the enemy forces, the perceived benefit of making enemy contact also changed.

V. SUMMARY

A. CONCLUSIONS

It is not appropriate to aggregate all the styles and environments of war into the one, all-inclusive theatre level warfare simulation. In order to sufficiently portray all of the conditions, artificial intelligence programs for each style of commander in each state of war are required. It is adequate to house the simulation in a singular data structure representing the battlefield, and then activate a particular AI algorithm as the situation unfolds.

There is more involved with a theatre level decision than just a comparative analysis of attrition, as performed by most theatre level simulations. Other measures of effectiveness are equally important, such as the impact of an action on the enemy's logistical base or command structure. A proper theatre level simulation must quantify and include these other MOEs along with the traditional MOE of attrition.

The state and condition of the theatre environment impacts heavily on the importance of MOEs in their relation with each other. Enemy attrition is not an important MOE in a climate of guerrilla warfare, where the desire is, rather than to make contact, to tax the enemy's logistical reserves into exhaustion. A theatre level simulation should allow for these

various climates and adapt MOE use to support proper decisions.

A theatre or unit commander is never able to make decisions based on perfect ground truth; it is always on his perception of the environment. He must utilize his intelligence gathering assets to build an accurate depiction of the surroundings. Perceptions impact heavily on his decisions. During the final program run in Chapter IV, the constantly changing perception of force size between two areas caused Kruskal's algorithm to constantly switch between two paths. This variability accurately reflects a commander "fine-tuning" operational plans as newly arriving intelligence updates his perception of the environment.

Two dimensional movement better represents reality in the maneuvering of forces over ground. Maneuver is an integral part of theatre level warfare and cannot be ignored. The program runs in Chapter IV displayed clearly the importance of two dimensional freedom of movement as the combat unit maneuvered its way around the two enemy units in order to achieve its objective. Kruskal's algorithm identifies the shortest path that the unit commander would obviously elect to maneuver forces and is adaptable to reflect changing mission profiles or tactical concerns.

Command, control, and communications are important elements to the decision making process. Degradation causes information to become "trapped" at various locations along the

information flow creating either a poor decision based on incomplete or faulty reconnaissance or a misexecution of plans because orders never arrive. Complete isolation of the command structure from receiving intelligence or directing its forces can halt any ability to effectively prosecute the war. The effects of command and control must be included in a theatre level model if it is to properly simulate the theatre level decision process.

B. AREAS FOR FURTHER STUDY

There are numerous areas for further study. First and foremost is study of different styles and states of warfare from some of the other classical strategists in various theatres of operations. Significant effort has to be put into proper MOE identification and development to satisfactorily reflect the desires of a particular commander.

A possible problem with any shortest path algorithm is that it optimizes the entire network. Kruskal's algorithm needs to be limited to optimizing only the local area to reduce the amount of computational effort.

A working copy of the Joint Theatre Level Simulation (JTLS) is in the War Lab in Ingersoll Hall, NPS, Monterey California. It is written in SIMSCRIPT, based on hexagons overlaid on a network, and operates on the theatre level; however, it requires two people to operate; one to be the blue commander and one to be the red. Incorporating AI into this

model may save time and effort as most of the required structure already exists, and the model is highly distributed.

APPENDIX A

ORIGINS OF PRESENT DAY US STRATEGY (1980-2000)

A. WHAT IS STRATEGY?

"Strategy," as interpreted by Dennis Hart Mahan (USMA 1824), is the art of "directing masses on decisive points, or the hostile movements of armies beyond the range of each other's cannon" [Ref. 2]. Written during the infancy of US policy, he reflected many of the ideals of strategy from Antione Henri, Baron of Jomini (1790), who proposed that "the basic tenet of strategy is a simple one, the necessity to bring the maximum possible force to bear against the decisive point in the theatre of operations while the enemy can muster only an inferior part of his strength there" [Ref. 2]. Jomini's emphasis on the decisive point, permitting domination of the theatre, changed the focus of the then modern concept of warfare from destruction of the enemy's armies in a Napoleonic style to the more conventional eighteenth century style of a contest for control of geographic locations. "Napoleon," Jomini referred, "seemed convinced that the first means of effecting great results was to concentrate above all on cutting up and destroying the enemy army, being certain that states or provinces fall of themselves when they no

longer have organized forces to defend them" [Ref 2]. His interpretation was fairly accurate, for in Napoleon's own words, "There are in Europe many good generals, but they see too many things at once. I see only one thing, namely the enemy's main body. I try to crush it, confident that secondary matters will then settle themselves" [Ref. 2].

When one discusses modern strategy, three names stand out: Napoleon, Jomini, and Clausewitz. In this model, the teachings of these three are employed in the development of the strategic policies of the simulated theatre level commander.

Napoleon emphasized numerical strength, deep strategic penetration, and rapid concentration of force. His perception of effectiveness was to strike "at the core of his opponent's power. Once the enemy's main armies were defeated, and perhaps also once his administrative and economic centers were occupied, all else was likely to follow" [Ref. 3].

Jomini prescribed offensive action to mass force against weaker enemy forces at some decisive point "whose attack or capture would imperil or seriously weaken the enemy" [Ref 3].

Clausewitz viewed war as "merely the continuation of policy by other means" [Ref 3]. To him, war was composed of three elements: "violence and passion; uncertainty, chance, and probability; and political purpose and effect" [Ref 3]. The first element concerns mainly the people and their will, the second the commander and his military forces and the last

"is the business of government alone" [Ref 3]. To attack these embodiments would be to gain victory through a concentration of the elements.

Many theories of strategy exist and can be interpreted for any number of hostile situations, but a question still remains: what is strategy? Concisely put, strategy is the art or science of hostile action and how one uses assets to achieve victory during action.

B. ORIGINS OF US STRATEGY

General George Washington was the first to create a US strategy during the War for Independence in the mid to late 1700's. His style of warfare and options for strategy were greatly limited and thus heavily shaped by the environment of military poverty, which was the state of the colonies. Greatly outnumbered by the British in manpower, training, and technology, and forced to fight one of the first total wars of the modern age, Washington opted for a strategy of attrition over time. The revolutionary war was a new style of war as compared to eighteenth century Europe. Conventionally, most wars between states or countries were limited, for if the European states had "waged economic war against each other by destroying each other's resources [they] would have endangered excessively the whole precarious financial and economic stability of early modern Europe and thus would have imperiled everybody..." [Ref.2]. In the new world, this threat did not

exist, so the British were free to embark on a strategy of annihilation attempting to extinguish the very existence of the colonies. This forced the colonists into a new style of warfare: the total war. Washington's hopes were to adopt a strategy of guerrilla warfare and thus test the endurance of the British. Washington proved successful, and the prevailing national strategy of this newly recognized country was to rely on its distance from all other possible invaders to deter advances strictly for logistical reasons, and if invaded, a war of attrition instead of direct confrontation would push the invaders beyond their endurance and thus into defeat. This strategy proved successful throughout the next century; however, it still emphasized the rationale that America would never be involved in a limited engagement as in eighteenth century Europe, and that all its hostilities would be total in nature.

America's introduction to a limited war came during the mid 1800's when Winfield Scott and Zachary Taylor invaded Mexico for the express purpose of the annexation of Texas. Scott's strategy was a political one which did not include the complete destruction of the Mexican army. He gave strict instructions for the conduct of the campaign, such as to respect the rights of the Mexican territory, people, and culture, and to confine the bloodshed and suffering strictly to the armed forces and away from the civilian populace. Scott did not seek to involve all of the Mexican population or

its destruction as demanded by the doctrine of total war, but sought only to capture Mexico City and convince the government of the futility of protracted war. The concept of limited war was forgotten as a part of US strategy for the next hundred years as America was involved in the Civil War, and two global wars, World War One and World War Two.

The 1950's saw a new emphasis towards the adoption of a strategy based on limited warfare. The environment of the post World War Two world was the primary source of this interest. World War Two was a total war subject to open-ended goals accomplished through unrestricted means. Society as a whole had been mobilized, and the normal economic structures altered. Total war leaves only options of no-war/total-war, where war is to be avoided at all costs, but if unavoidable it is to be pursued with a vengeance. The concept of a limited war with the mobilization of a limited amount of assets for limited objectives sought to bridge the gap between the no-war and total-war positions. The advent of the nuclear age allowed the atomic weapon to wreak havoc as never before seen. It became clear that a style of warfare had to be developed that would not require the use of such destruction. Limited warfare, now viewed as strictly an extension or continuation of politics by other means does not permit the loss of control of hostile implements or operations and thus would not advocate the extreme destruction of the enemy's forces unless it was found politically desirable.

The Korean War was the first war of the twentieth century to be fought within the doctrine of limited warfare. Its motivation was a simple strategy stemming from the US containment policy. In defense of the "Free World," the US directed its military force not towards a direct confrontation or entry into the Communist World, but towards limiting the expansion of communism into surrounding areas. A policy of hostile engagement for the acquisition of limited goals allowed the US containment policy to function without forcing entry into total war.

Just and limited war, as proposed by Jomini two hundred years ago, is the closest theory of strategy from the classic thinkers that resembles that of present day US policy. It is understandable that present day goals, results, and concerns of warfare reflect closely those of Jomini's Europe, the only difference being one of scale.

C. PRESENT DAY US STRATEGY (1980-2000)

US strategy today conforms to the guidelines for conduct of just and limited warfare. Of primary concern is that "the application of armed coercion is permissible only insofar as it advances the political purposes of war. A limited war, then, is a war in which political ends always determine military means" [Ref 4]. The impact of these two statements is great. First, it implies that military action shall be restricted to the amount believed necessary by a political

controlling force. Economy of force, or the use of force which contributes to the ultimate objective of defeating the enemy's armed forces, is to be pursued to the greatest extent possible. Military objectives shall be limited to only those which serve to achieve the overall political goal. These objectives shall be pursued in the most expedient means possible to guard against protracted hostilities. Open channels of communications between belligerent nations must be maintained. As limited warfare has a large political component, political bargaining and discussion play a key role in limited hostilities. Direct confrontation between superpowers and first use of nuclear weapons are to be avoided at all cost since they would surely escalate the limited war to total war with all its destructive potential.

Great pains must be taken to ensure that the US, in pursuing its limited warfare policy, has great flexibility in both its political and military capabilities to allow for a measured response. In short, present day US strategic policy is for direct and immediate action beginning with political gestures and escalating to a measured military response focused on Clausewitz's goals and Jomini's decisive point to gain domination of the theatre of operations.

APPENDIX B

DATA USED IN METHODOLOGY DEMONSTRATION

This appendix contains, in table format, the data used for the methodology demonstration in Chapter IV. The first row of each table shows the hexagons involved in the reconnaissance decision for that cycle. The last row reveals the desirability of sending a reconnaissance asset into a particular hexagon as computed by the normalization technique. The largest three values depict those hexagons that were searched that cycle. The middle six rows contain the raw MOE data.

Nodes involved in the reconnaissance decision
Ability of reconnaissance asset to detect in a node $P(\text{det})$
Cycles since last glimpse
Distance from current location of combat unit
Distance from intended path
Inconsistencies between detections within a node
Perception of reconnaissance asset's ability to survive while in a node
Relative ranks of each hexagon

TABLE B.1
PROGRAM RUN ONE, CYCLE ONE

1	2	3	4	5	6	7	8	9
.6	.6	.7	.2	.6	.9	.5	.6	.9
0	0	0	0	0	0	0	0	0
-1	-1	-1	-2	-2	-2	-3	-3	-3
-2	-1	0	-2	-1	0	-2	-1	0
0	0	0	0	0	0	0	0	0
.7	.7	.7	.7	.7	.7	.7	.7	.7
0	1.1	2.7	-3.1	0	2.6	-2.7	-1.1	1.5

TABLE B.2
PROGRAM RUN ONE, CYCLE TWO

0	1	2	4	5	6	7	8	9
.7	.6	.6	.2	.6	.9	.5	.6	.9
0	1	1	1	1	0	1	1	0
-1	-2	-1	-2	-2	-1	-3	-3	-2
-2	-2	-1	-2	0	0	-1	0	-1
0	0	0	0	0	0	0	0	0
.9	.7	.7	.7	.7	.9	.7	.7	.5
1.1	-.6	1.7	-2.6	1.6	4.3	-1.3	.3	-2

TABLE B.3
PROGRAM RUN ONE, CYCLE THREE

0	1	2	3	4	5	7	8	9
.7	.6	.6	.7	.2	.6	.5	.6	.9
1	2	0	0	2	0	2	2	1
-2	-2	-1	-1	-2	-1	-2	-2	-1
-2	-2	-1	-2	-1	0	-1	0	-1
0	0	0	0	0	0	0	0	0
.9	.7	.9	.9	.7	.9	.7	.7	.5
-.5	-1.9	1.1	.6	-2.7	2.4	-1.2	.6	-.3

TABLE B.4
PROGRAM RUN ONE, CYCLE FOUR

0	1	2	3	4	6	7	8	9
.7	.6	.6	.7	.2	.9	.5	.6	.9
2	3	0	0	3	0	3	3	2
-2	-2	-2	-1	-1	-1	-1	-1	-1
-3	-3	-2	-3	-2	-2	-1	0	-1
0	0	0	0	0	0	0	0	0
.8	.7	.9	.9	.7	.9	.7	.7	.6
-1.8	-2.5	-1.8	-.2	-1.6	1.7	.8	2.2	1.0

TABLE B.5
PROGRAM RUN TWO, CYCLE ONE

1	2	3	4	5	6	7	8	9
.6	.6	.7	.2	.6	.9	.5	.6	.9
0	0	0	0	0	0	0	0	0
-1	-1	-1	-2	-2	-2	-3	-3	-3
-2	-1	0	-2	-1	0	-2	-1	0
0	0	0	0	0	0	0	0	0
.7	.7	.7	.7	.7	.7	.7	.7	.7
-3.3	2.2	8.2	-7.5	0	7	-8.2	-2.2	4.8

TABLE B.6
PROGRAM RUN TWO, CYCLE TWO

0	1	2	4	5	6	7	8	9
.7	.6	.6	.2	.6	.9	.5	.6	.9
0	1	1	1	1	0	1	1	0
-1	-2	-1	-2	-2	-1	-3	-3	-2
-2	-2	-1	-2	0	0	-1	0	-1
0	0	0	0	0	0	0	0	0
.9	.7	.7	.7	.7	.9	.7	.7	.5
-7.5	-3.3	4.6	-5.3	7.7	7.6	-.9	5.1	-8.3

TABLE B.7
PROGRAM RUN TWO, CYCLE THREE

0	1	2	3	4	5	7	8	9
.7	.6	.6	.7	.2	.6	.5	.6	.9
1	2	2	0	2	0	2	0	1
-2	-2	-1	-1	-2	-1	-2	-2	-1
-2	-2	-1	-2	-1	0	0	-1	-1
0	0	0	0	0	0	0	0	0
.9	.7	.7	.9	.7	.9	.7	.5	.5
-5	-3.1	6.9	-5.4	.9	6.6	8.9	-7.9	2

TABLE B.8
PROGRAM RUN TWO, CYCLE FOUR

0	1	2	3	4	6	7	8	9
.7	.6	.6	.7	.2	.9	.5	.6	.9
2	3	0	1	3	0	0	1	2
-2	-2	-1	-2	-1	-1	-1	-1	-1
-3	-2	-2	-3	-1	-3	0	-1	-2
0	0	0	0	0	0	0	0	0
.8	.7	.9	.9	.7	.9	.9	.5	.6
-4.9	1.3	-2.7	-7.5	7.8	-5.7	5.8	1	2.6

TABLE B.9
PROGRAM RUN THREE, CYCLE ONE

1	2	3	4	5	6	7	8	9
.6	.6	.7	.2	.6	.9	.5	.6	.9
0	0	0	0	0	0	0	0	0
-1	-1	-1	-2	-2	-2	-3	-3	-3
-2	-1	0	-2	-1	0	-2	-1	0
0	0	0	0	0	0	0	0	0
.7	.7	.7	.7	.7	.7	.7	.7	.7
-3.3	2.2	8.2	-7.5	0	7	-8.2	-2.2	4.8

TABLE B.10
PROGRAM RUN THREE, CYCLE TWO

0	1	2	3	4	5	7	8	9
.7	.6	.6	.7	.2	.6	.5	.6	.9
0	1	1	0	1	1	1	1	0
-2	-2	-1	-1	-2	-1	-2	-2	-1
-2	-2	-1	-2	-1	0	-1	0	-1
0	0	0	0	0	0	0	0	0
.9	.7	.7	.9	.7	.7	.7	.7	.5
-8.2	-4.7	5.3	-4.2	-.7	11.8	.8	7.8	-5.2

TABLE B.11
PROGRAM RUN FOUR, CYCLE ONE

1	2	3	4	5	6	7	8	9
.6	.6	.7	.2	.6	.9	.5	.6	.9
0	0	0	0	0	0	0	0	0
-1	-1	-1	-2	-2	-2	-3	-3	-3
-2	-1	0	-2	-1	0	-2	-1	0
0	0	0	0	0	0	0	0	0
.7	.7	.7	.7	.7	.7	.7	.7	.7
-3.3	2.2	8.2	-7.5	0	7	-8.2	-2.2	4.8

TABLE B.12
PROGRAM RUN FOUR, CYCLE TWO

0	1	2	4	5	6	7	8	9
.7	.6	.6	.2	.6	.9	.5	.6	.9
0	1	1	1	1	0	1	1	0
-1	-2	-1	-2	-2	-1	-3	-3	-2
-2	-2	-1	-2	0	0	-1	0	-1
0	0	0	0	0	0	0	0	0
.9	.7	.7	.7	.7	.9	.7	.7	.5
-4.4	-3.3	4.6	-5.3	7.7	7.6	-9	5.1	-8.3

TABLE B.13
PROGRAM RUN FOUR, CYCLE THREE

0	1	2	3	4	5	7	8	9
.7	.6	.6	.7	.2	.6	.5	.6	.9
1	2	2	0	2	0	2	0	1
-2	-2	-1	-1	-2	-1	-2	-2	-1
-2	-2	-1	-2	-1	0	-1	0	-1
0	0	0	0	0	0	0	0	0
.9	.7	.7	.9	.7	.9	.7	.5	.5
-5	-3.1	6.9	-5.4	.9	6.6	2.4	-1.4	2

TABLE B.14
PROGRAM RUN FOUR, CYCLE FOUR

0	1	2	3	4	6	7	8	9
.7	.6	.6	.7	.2	.9	.5	.6	.9
2	3	0	1	3	0	0	1	2
-2	-2	-1	-2	-1	-1	-1	-1	-1
-3	-3	-2	-3	-2	-2	-1	0	-1
0	0	0	0	0	0	0	0	0
.8	.7	.9	.9	.7	.9	.9	.5	.6
-4.9	-3.2	-2.7	-7.5	3.3	-1.2	1.3	5.5	7.1

APPENDIX C

NORMALIZATION PROGRAM IN APL [REF. 6]

This appendix contains the computer code used to perform the normalization technique in Chapter IV. The inputs consist of the six by nine MOE matrix and a six element vector representing the weighting scheme. The output is a nine element vector revealing the utility of reconnaissance in each operating area.

Input: initial input of the 54 MOEs (INPUTM) and the MOE weighting scheme (INPUTW)

```
[ 1] MOE-INPUTM
[ 2] WEIGHT-INPUTW
[ 3]
[ 4] ROWS-⍴MOE[ ;1]
[ 5] COLUMNS-⍴MOE[ ;2]
[ 6]
[ 7] ROW-1
[ 8] MEAN-(+/MOE[ROW, ])+COLUMNS
[ 9] STANDEV-((+/(MOE[ROW; ]-MEAN)*2)+-1+COLUMNS)*0.5
[10]
[11] -12+2×STANDEV=0
[12] NORMAL[ROW; ]-0
[13] -16
[14] NORMAL[ROW; ]-(MOE[ROW; ]-MEAN)÷STANDEV
[15]
[16] ROW-ROW+1
[17] -8+11×ROW>ROWS
[18]
[19] COLUMN-1
[20] SUM[ ;COLUMN]-+/(NORMAL[ ;COLUMN]×WEIGHT)
[21]
[22] COLUMN-COLUMN+1
[23] -20×COLUMN>COLUMNS
```

APPENDIX D

NUMERICAL EXAMPLE OF NORMALIZATION

Cycle two of program run two is used to demonstrate the mathematics involved in the normalization process. The first row of each table shows the nine areas available for reconnaissance operations. Underneath each operating area are listed the six rows for each MOE. The values in the first table show the raw MOEs. The second table shows the normalized MOEs after subtracting the mean and dividing by the standard deviation. These two values are supplied in the tenth and eleventh columns. The third table shows these values after multiplication by the weighting scheme in the form of a column vector with the values (1, 4, 2, 5, 1, 2). The final table is the vector showing the utility of directing reconnaissance operations to each of the operating areas. In order from highest to lowest, they area ranked: (5, 6, 8, 2, 7, 1, 4, 0, 9).

TABLE D.1
RAW MOEs

0	1	2	4	5	6	7	8	9	μ	σ
.7	.6	.6	.2	.6	.9	.5	.6	.9	.6	.2
0	1	1	1	1	0	1	1	0	.7	.5
-1	-2	-1	-2	-2	-1	-3	-3	-2	-1.9	.8
-2	-2	-1	-2	0	0	-1	0	-1	-1.0	.9
0	0	0	0	0	0	0	0	0	0	0
.9	.7	.7	.7	.7	.9	.7	.7	.5	.7	.1

TABLE D.2
NORMALIZED VALUES

0	1	2	4	5	6	7	8	9
.5	0	0	-2	0	1.5	-.5	0	1.5
-1.4	.6	.6	.6	.6	-1.4	.6	.6	-1.4
1.1	-.1	1.1	-.1	-.1	1.1	-1.4	-1.4	-.1
-1.1	-1.1	0	-1.1	1.1	1.1	0	1.1	0
0	0	0	0	0	0	0	0	0
2	0	0	0	0	2	0	0	-2

TABLE D.3
IMPACT OF WEIGHTING SCHEME

0	1	2	4	5	6	7	8	9
.5	0	0	-2	0	1.5	-.5	0	1.5
-5.6	2.4	2.4	2.4	2.4	-5.6	2.4	2.4	-5.6
1.1	-.2	2.2	-.2	-.2	2.2	-2.8	-2.8	-.2
-5.5	-5.5	0	-5.5	5.5	5.5	0	5.5	0
0	0	0	0	0	0	0	0	0
2	0	0	0	0	4	0	0	-4

TABLE D.4
COMPUTED UTILITY FOR EACH AREA

0	1	2	4	5	6	7	8	9
-7.5	-3.3	4.6	-5.3	7.7	7.6	-.9	5.1	-8.3

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