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Title of Paper: AN APPROACH TO THE EVALUATION OF STRATEGIES IN INSURGENCY

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ABSTRACT

This paper presents preliminary results of research carried on at Ohio State University for the ^{U.S. Army} Engineering Topographic Laboratories at Fort Belvoir, Virginia. The objective of this research was to formulate models and techniques which could be used to evaluate insurgent activity. Work has been carried out in three major areas toward the accomplishment of this goal, using South Vietnam as the study area. Based upon the structural characteristics of the transport network within the study area three techniques are illustrated which can be used as first approximations of the insurgents potential strategy. No consideration is given to the actual movement or flows through this network of men and material. The second section utilizes a particular algorithm to suggest a means of examining actual and potential flows through the network. The final section utilizes the network and regions derived previously and the algorithm for allocating men and material to pertinent routes as input for evaluating enemy activities within a Bayesian framework.

AN APPROACH TO THE EVALUATION OF STRATEGIES IN INSURGENCY

by

Budd H. Hebert and Eugene R. Sapp

1. Introduction

The purpose of this paper is to present preliminary results which have arisen out of research sponsored by the Engineering Topographic Laboratories, Fort Belvoir, Virginia. Work was carried on by a research team located at Ohio State University. The primary objective of this research was to develop models and techniques which could be used at the field level to evaluate insurgent activity. As a result, a majority of the model output is presented in graphical or map form. The models are sufficiently flexible so as to account for rapid changes in insurgent activities. Provision is also made for weekly, daily or even hourly changes. In addition to providing the basis for graphical output, the models also suggest means of facilitating the storage and retrieval of intelligence information.

One final point must be made regarding this study. Results are tentative and the data used is sometimes tenuous in nature. It was not the principal intent of this research to improve the types of intelligence data which are collected, but rather to illustrate techniques which will

enable more efficient processing of the data presently in use. Thus, it is hoped that through procedures suggested in this study the field intelligence staff will be relieved of the arduous task of having to search through multitudinous supplies of data in order to provide a basis for a command decision. By relying more upon machine processing with instant action-reaction capabilities, the intelligence officer can effectively evaluate various types of strategies. With the capability of storing and instantly retrieving necessary intelligence data, command decisions can be tested, evaluated and retested instantly in the field offices. As an example imagine the following. Suppose a decision is made to interdict a given highway link. With the assistance of computer facilities and a cathode ray tube which would display the highway network, it would be feasible to black out a particular road by using a light pen on the cathode ray tube. The computer would instantly compile this information and display the resulting network.

The paper is divided into three major sections. The first deals with the development of the regional network. In addition, several techniques, based upon the structural characteristics of the network, are discussed in view of evaluating insurgent activities. The second section suggests methods which can be used to determine the movement of men and material over the network. The final section utilizes information from both these first two parts to formulate command decisions within a Bayesian framework.

2. Regional Network Model and Output

2.1 General Features of the Model

The general area within which insurgent strategies were evaluated was first geographically broken down into regions which were treated as nodes. To each node there was then attached a status vector representing the level of men and material supporting the activities in the region. In addition, a flow vector was also defined for each node which represented potential movement between each region. However, before this second vector could be established a system of connections among the regions had to be stated for the entire area. This network enabled interchange between all the nodes, and thus provided the basis for time dependent changes to take place.

2.2 Derivation of Regions and Their Nodal Representation

For purposes of areal delineation the system of regions and networks were restricted to an area corresponding to Allied Corps II and Corps III (Figure 2.2.1). This restricted our examination to an area within South Vietnam that is topographically dominated by mountains, plateaus and very limited amounts of beach area.

Selection of the nodal regions was based upon the type of warfare that was waged by the insurgents during the early 1960's in South Vietnam. The primary operational aspect of guerrilla warfare used to determine the location of the regions and their corresponding nodal representation

STUDY AREA

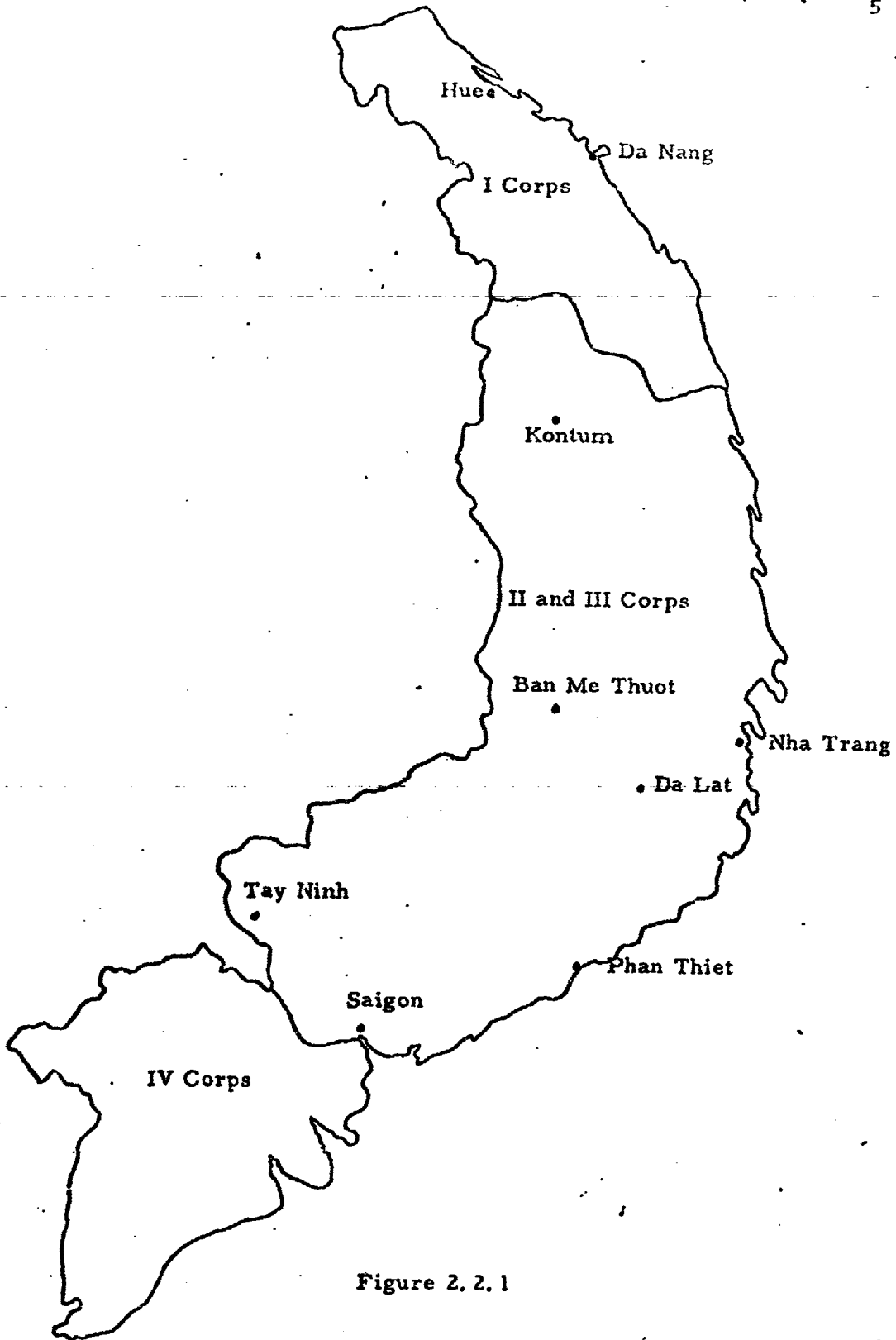


Figure 2. 2. 1

was the concept of "base areas." As originally conceived during the communist revolution, this concept was used in the absence of an urban base for political and military operations. The communists, lacking any base of operations in the cities, developed "base areas" in strategically located rural areas. With their increasing use by Mao Tse-Tung, general principles were developed in selecting the location of these base areas.¹ The most important of these factors is that political objectives override purely geographic advantages. Because of the political warfare of these insurgents it is imperative that these base areas be located close to major cities and major transport lines whether or not they happen to be located in favorable topographic locations.

2.3 Identification of the Transport Network

The system of transport movement within South Vietnam was relatively flexible. Since supplies were moved principally by a portage system, the major transport network consists of a system of paths and trails. This necessitates our considering a nonconventional transportation system when examining flows of men and material. We must assume that there are several avenues of potential movement between any two points. Thus, interdiction on a single route does not necessarily indicate that movement between two areas would be discontinued. Rather it could

¹ Robert McColl, "A Political Geography of Revolution: China, Vietnam, and Thailand," Journal of Conflict Resolution, Vol. XI, No. 2, June 1967, pp. 153-167.

be the case that movement would be either rerouted through an intermediate base area (node) or more likely that the porters would simply travel over another path in the valley, on another ridge, or only a few yards away! As a result we are not dealing with a transport system that is rigid as are conventional transport networks. Some recent work by Army intelligence does suggest, however, that even with this type of transport system there are critical points on the network.²

The network displayed in Figure 2.3.1 was derived on the assumption that movement by the insurgents within II and III Corps was accomplished primarily by porters.³ The actual location of routes was dependent upon topographic features within the study area, shortest traveling time between any two of the nodes, and location of highways and well defined paths.

One final set of input data was necessary before proceeding to the techniques illustrated in this paper. Travel time had to be computed for each of the transport links. According to Viet Minh planning factors used in this general area two travel time figures were used depending upon the type of terrain. It was assumed that a single porter could travel at the rate of 15.5 miles per one ten hour day over relatively level terrain

²Recent work under Major Teal suggests that terrain features to a great extent control the movement of the insurgents, especially in mountainous areas.

³J. Wallace Higgins, "Porterage Parameters and Tables," The RAND Corporation, Research Memorandum, RM-5292, (August, 1967), pp. 1-49.

Porterage Transport Network - South Vietnam

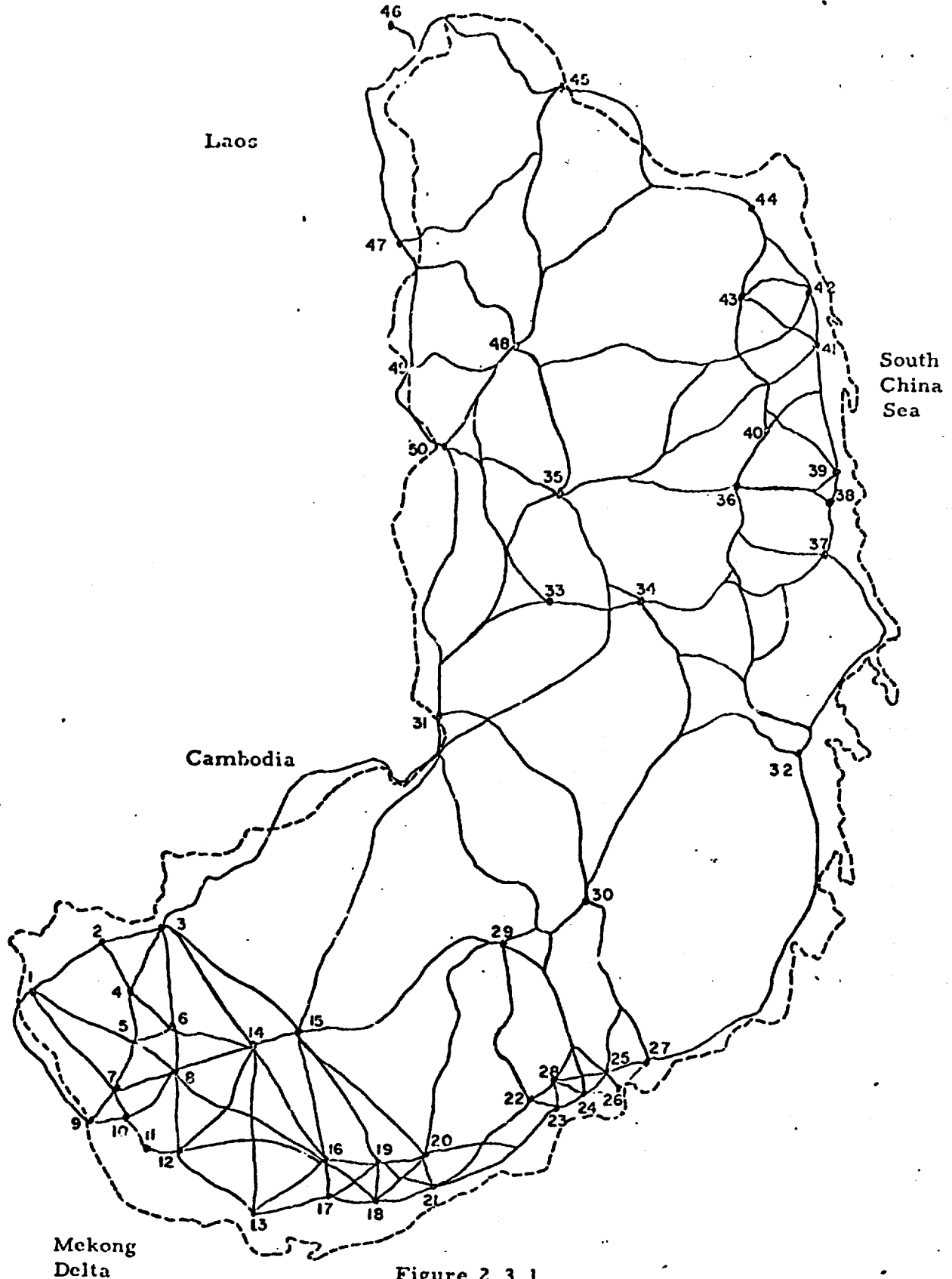


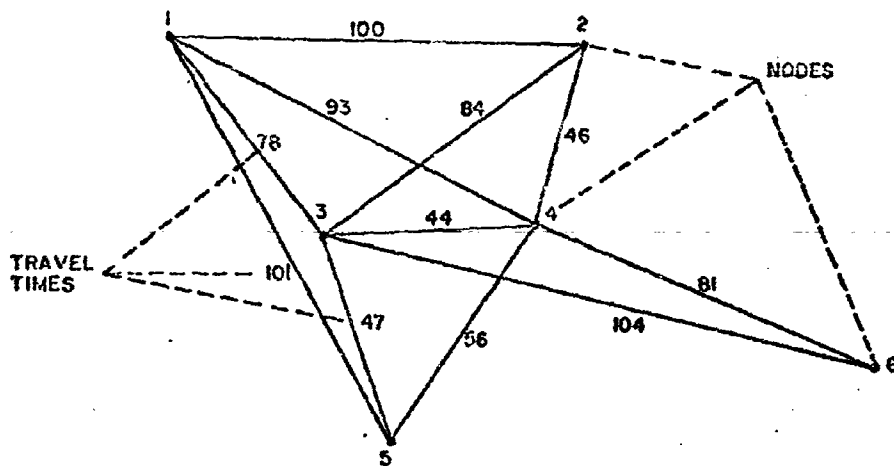
Figure 2.3.1

and at the rate of 9.3 miles per day over mountainous terrain. Using this information it was a simple task to attach a value to each link in our transport network which represented travel time between each pair of directly connected base areas.

2.4 System Accessibility

As a method of evaluating potential insurgent strategies in terms of the structural or geometrical characteristics of this transport system, we now turn our attention to a portion of the body of graph theory. As illustrated by Shimbel, an index can be derived using graph theoretic techniques which explicitly measures the accessibility of a node on a network relative to the entire system.⁴ Applying this procedure to the transport network used in this study yields a more explicit measure of the importance of individual base areas within the system. Using the network of Figure 2.4.1 as an example a connection matrix is derived, as indicated below the network. The first connection matrix is an unweighted method of representing the network, the second is weighted on the basis of travel times between each node. Whenever a direct connection or arc exists between two points on the network there is a value of one (1) in the corresponding cell of the unweighted connection matrix; otherwise all the cells contain blanks. For example, a direct connection between nodes one (1) and two (2) in the network is represented by a one (1) in

⁴Alfonso Shimbel, "Structural Parameters of Communication Networks," Bulletin of Mathematical Biophysics, Vol. XV (1953), pp. 501-507.



HYPOTHETICAL NETWORK

	Nodes					
Nodes	1	2	3	4	5	6
1	-	1	1	1	1	-
2	1	-	1	1	-	-
3	1	1	-	1	1	1
4	1	1	1	-	1	1
5	1	-	1	1	-	-
6	-	-	1	1	-	-

Unweighted

	Nodes					
Nodes	1	2	3	4	5	6
1	-	100	78	93	101	-
2	100	-	84	46	-	-
3	78	84	-	44	47	104
4	93	46	44	-	56	81
5	101	-	47	56	-	-
6	-	-	104	81	-	-

Weighted

Matrix representations of the above network.

Figure 2. 4. 1

cell (1, 2) of the unweighted matrix. Alternatively, instead of having only the binary operators one (1) or zero (0) in the connection matrix, we can weight each of the arcs. For this example they have been weighted on the basis of travel time between each node, as indicated by the numbers attached to each arc.

A second set of matrices can be derived from these connection matrices which express the network in a slightly different manner. Except for the main diagonal, all cells with blanks are replaced by the sum of the number of arcs required to reach each individual node in the network via the shortest path between any two nodes. The shortest path between any two nodes is defined as that path which contains the smallest number of arcs. In moving from node one to node six the shortest path consists of the two arcs connecting nodes one and four and node four to node six. Adding these sums to the unweighted and weighted connection matrices yields the shortest path matrices of Figure 2.4. 2. Summing across each row results in the accessibility index indicated in the far right-hand column. From this index we can note that nodes 3 and 4 are tied as the most accessible nodes in the unweighted system. Applying this same procedure to the weighted connection matrix we find that the most accessible node is number four (4). Application of this procedure with a powering of the weighted connection matrix to the insurgent transport system in South Vietnam results in the following accessibility indices for the 50 nodes (Figure 2.4.3). In this case the transport arcs have

		Nodes						Accessibility Index
		1	2	3	4	5	6	
Nodes	1	-	1	1	1	1	2	6
	2	1	-	1	1	2	2	7
	3	1	1	-	1	1	1	5
	4	1	1	1	-	1	1	5
	5	1	2	1	1	-	2	7
	6	2	2	1	1	2	-	8

Unweighted

		Nodes						
		1	2	3	4	5	6	
Nodes	1	-	100	78	93	101	174	546
	2	100	-	84	46	102	127	459
	3	78	84	-	44	47	104	357
	4	93	46	44	-	56	81	320
	5	101	102	47	56	-	137	443
	6	174	127	104	81	137	-	623

Weighted

Shortest path matrices.

Figure 2. 4. 2

**ACCESSIBILITY INDICES FOR
STUDY AREA NODES**

Rank	Percent Accessibility	Node
1	11.13	31
2	7.77	34
3	6.21	48
4	6.04	30
5	5.54	3
6	5.02	15
7	5.02	7
8	4.69	29
9	4.58	28
10	4.56	24
11	4.44	25
12	3.53	32
13	3.14	33
14	2.64	41
15	2.62	36
16	2.52	42
17	2.50	37
18	2.13	39
19	2.13	50
20	2.05	44
21	1.79	40
22	1.77	45
23	1.45	43
24	1.20	27
25	1.09	47
26	0.84	20
27	0.56	22
28	0.55	49
29	0.41	46
30	0.40	14

Figure 2.4.3

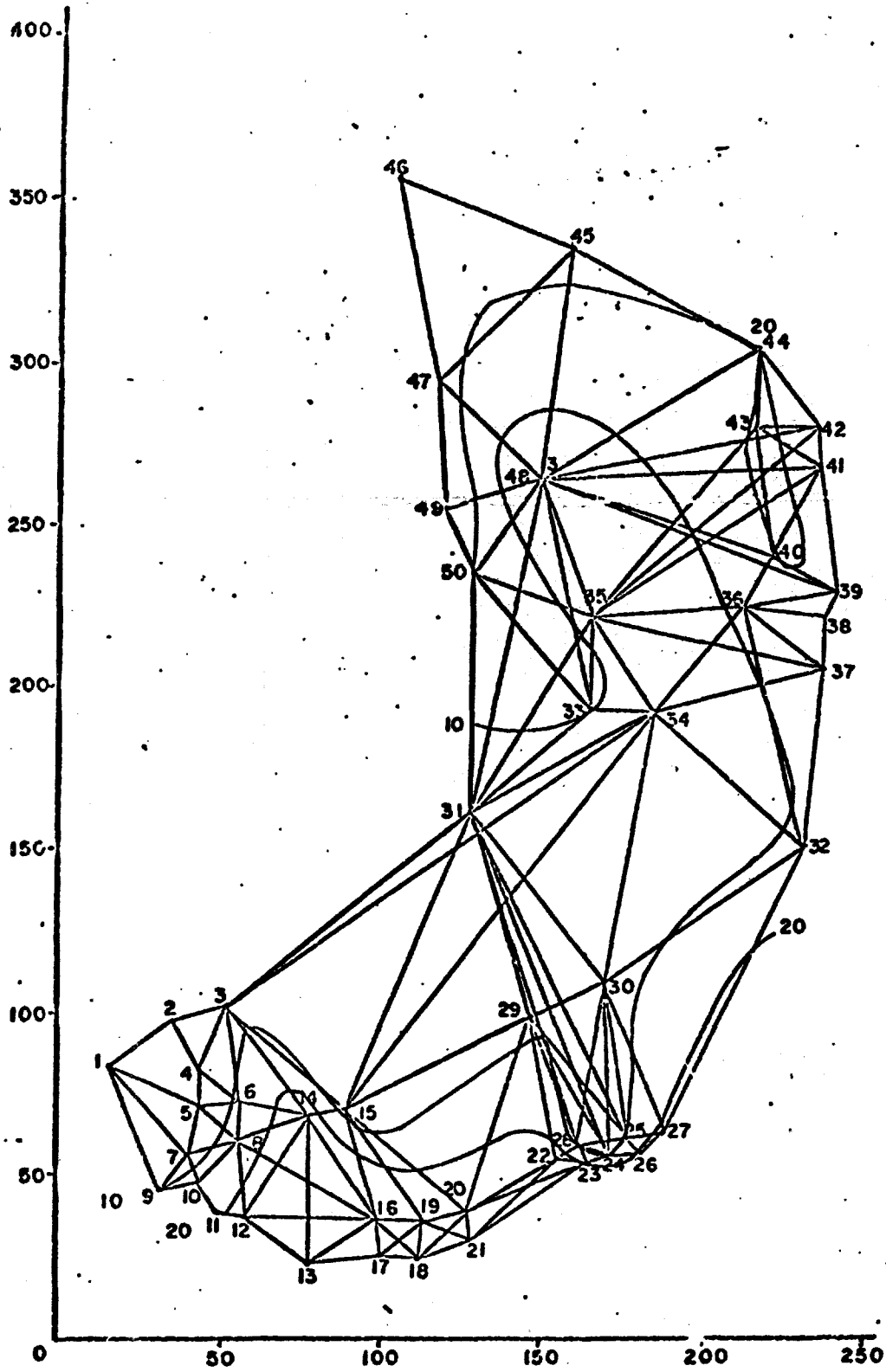


Figure 2. 4. 4

been weighted on the basis of portage travel time. This table lists the percentage of each node's accessibility to the entire system. In this case node 31 accounted for slightly more than 11% of the column sum of accessibility derived from the powered connection matrix. These percentages are ranked and plotted on the map of the abstracted transport system as indicated in Figure 2.4.4.⁵ Iso-rank lines are drawn at the 10 and 20 rank levels indicating several characteristics. First, the most accessible portion of the network focuses upon the interior highlands with fingers extending down toward the coastal areas. Two other probes extend into the iron triangle area and an area just north of Saigon.

In conclusion, this technique enables one to determine potential nodes of threat. By the fact that a node is accessible to the remaining nodes on the transport network (on the basis of travel time) we can assume that it could be a control point or supply point for the network. Based only upon the structural characteristics of the system this procedure enables determination of the relative importance of nodes on the transport system.

2.5 Minimal Spanning Trees

For purposes of this study it is assumed that the insurgents will desire to minimize some sort of cost function in transporting men and

⁵This figure presents the geometrical representation of the original transport network. Any nodes which are directly connected on the original network are also directly connected in this network; i. e., there is a 1 to 1 correspondence.

materials over the transport network. For illustrative purposes we assume that he desires to minimize travel time when moving over the system. Added constraints could also be considered such as traveling with the least amount of risk of engaging the enemy, or movement only over those paths with a certain percentage of tree coverage, etc. The output which is derived from this section enables detection of potential sources of supply once target nodes have been selected. In addition, once movement is detected over a given link we can also determine the probable direction of movement. A by-product of this approach is that once supply points are given, only certain routes are necessary in furnishing supplies to the entire network. Thus we can often deal with a highly reduced transport system.

A "tree" as used in this context has very specific properties. In the general sense it is that set of arcs which are required to just barely connect all nodes in a network. Thus, given N number of nodes in a network, $N-1$ arcs are required to furnish a tree for the system. Using a simple example, if there are five (5) nodes in a transport network then only four (4) arcs are required to just barely connect this system. That is, with four arcs it is possible to get from one node to any other node on the network.

For the network discussed in this paper we are concerned with a special type of tree. Weighting each of the arcs on the basis of travel time, we are concerned with those trees which connect a supply point to

all other nodes within a given range at a total minimum travel time.

Thus in Figure 2.5.1 the set of arcs which make up the tree are such that this particular combination of the total set of arcs minimizes total travel time from node 31 to all the other nodes within a certain range.

If we assume that only particular nodes on the original network are supply points, notably nodes 1, 2, 3, 31, 50, 49, 47, and 46, and minimal spanning trees are computed for all eight nodes, then we can combine these minimal spanning trees to form a reduced network. The reduced network is illustrated in Figure 2.5.2. Instead of having to consider 276 separate arcs of the original network we now have to consider only 107 arcs when discussing movement from the eight sources to all other nodes. Utilizing this reduced network we can now begin to determine from what supply points buildup at a particular node can occur. For instance movement over the arc connecting nodes 34 and 32 can originate at node 31, 50, 49, 47, or 46 and a probability can be attached to its originating at each of these nodes. Thus we have detected potential sources of supply for a seemingly remote activity, using a special set of selected routes.

2.6 Isochrone Analysis of Movement

This section, as in others, is concerned with taking raw intelligence data which have been collected in the field and making projections based upon these data which are indicative of future insurgent activity. The solution is graphical in nature and is based upon the regional

A MINIMAL SPANNING TREE
SOURCE NODE 31

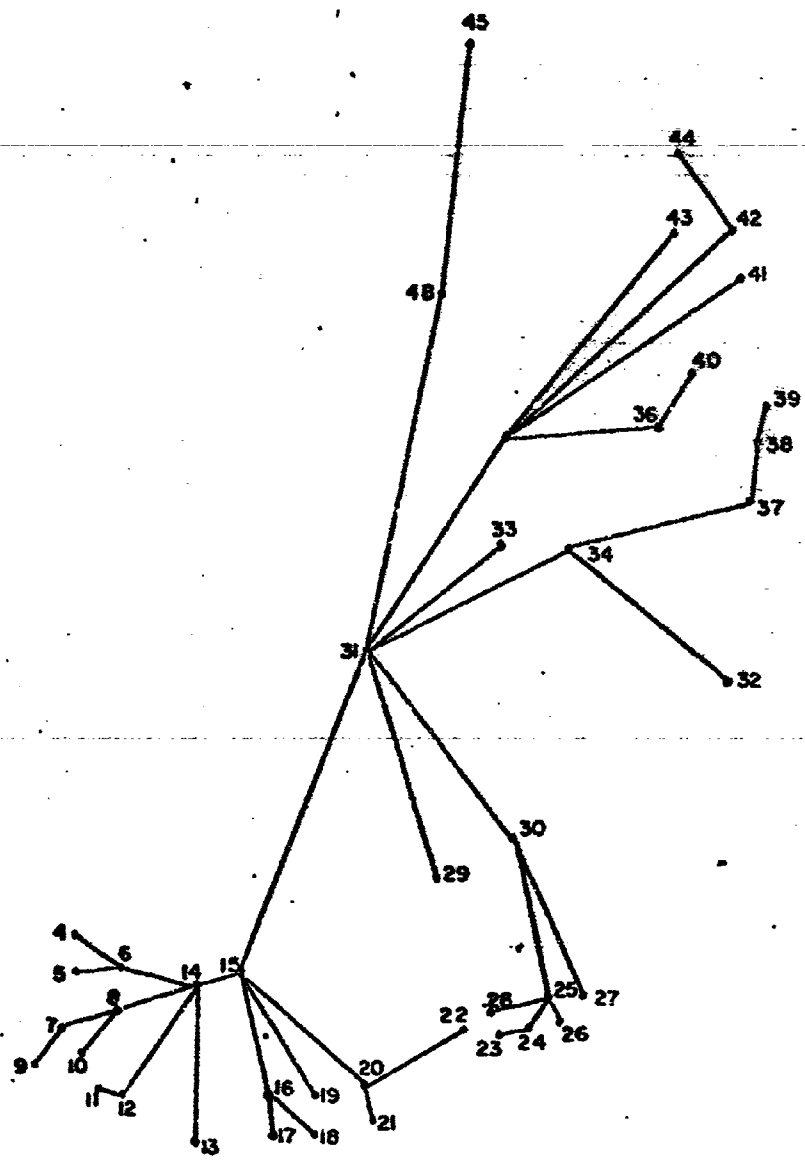


Figure 2. 5. 1

networks, minimum travel times, and isochrone lines. The procedure uses these isochronous lines and their intersections to indicate zones where a coordinated potential threat can occur at the earliest possible moment.

If we consider an isolated, but significant, troop buildup at a base area or an extraordinarily large movement of troops over a particular transport link, concern is generated as to possible future activity of such forces. We are therefore interested in the various paths which these troops might take and some sort of cost constraint for traversing the various alternatives. In an optimal sense we are interested in the minimal spanning trees that radiate from a base area or over which troops may be traveling. Utilizing the tree concept, one can define a set of time boundaries such as 1 hour, 2 hours, etc., indicating travel time from the source. If these temporal points on optimum trees are connected the result is an optimal set of isochronous lines radiating from the source. Two of these temporal lines of sufficient magnitude will eventually intersect, indicating a point of earliest combined effort. A series of such points results in a line of earliest combined effort. In addition to this optimal combination of forces we can also define zones of suboptimal combination in terms of travel time (Figure 2.6.1). In this figure the concentric circles radiating out from the two sources s_1 and s_2 are the isochrone lines. The intersection of equal valued isochrone lines from both sources defines the line of earliest combined effort, A-B.

REDUCED NETWORK

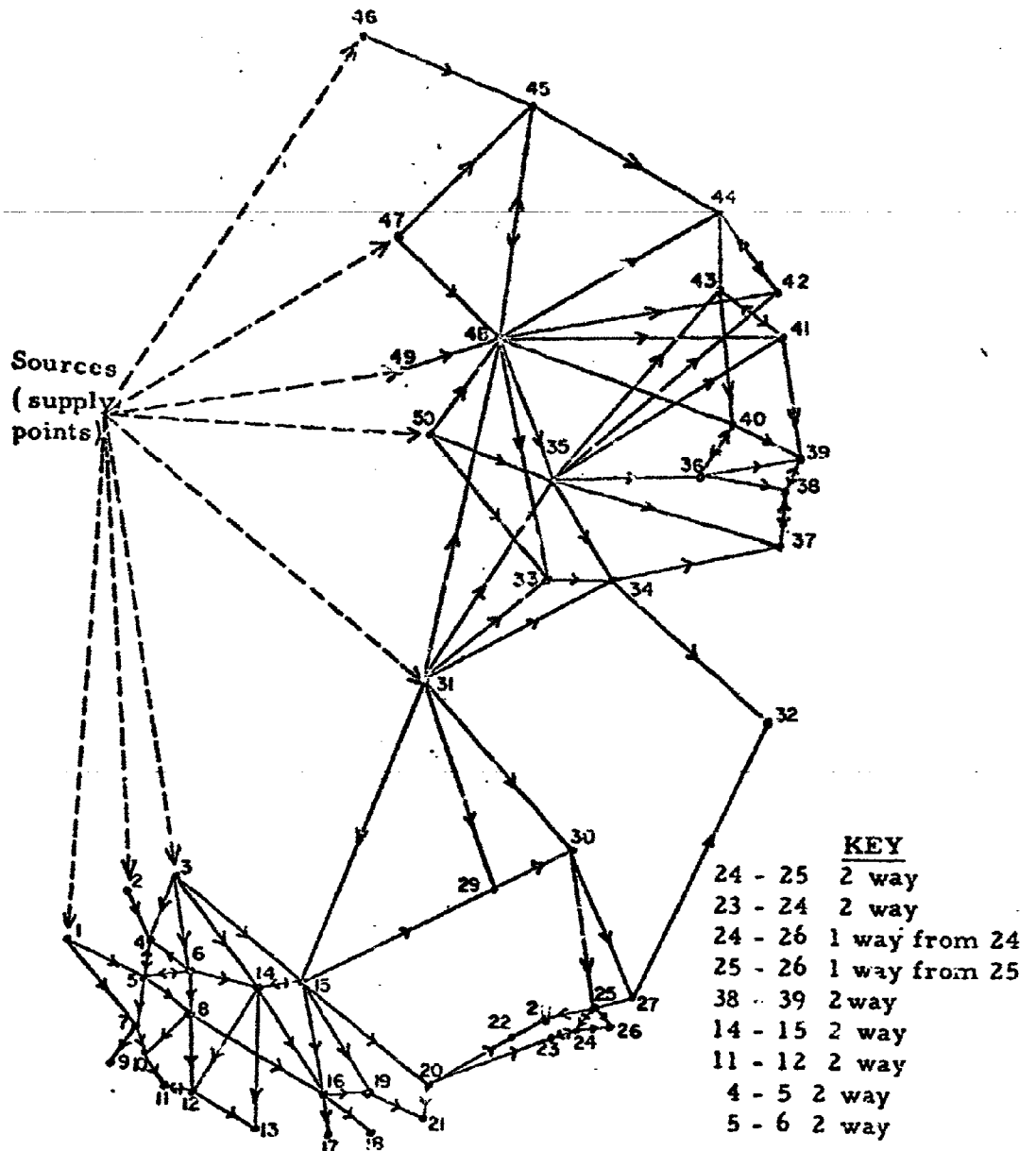


Figure 2.5.2

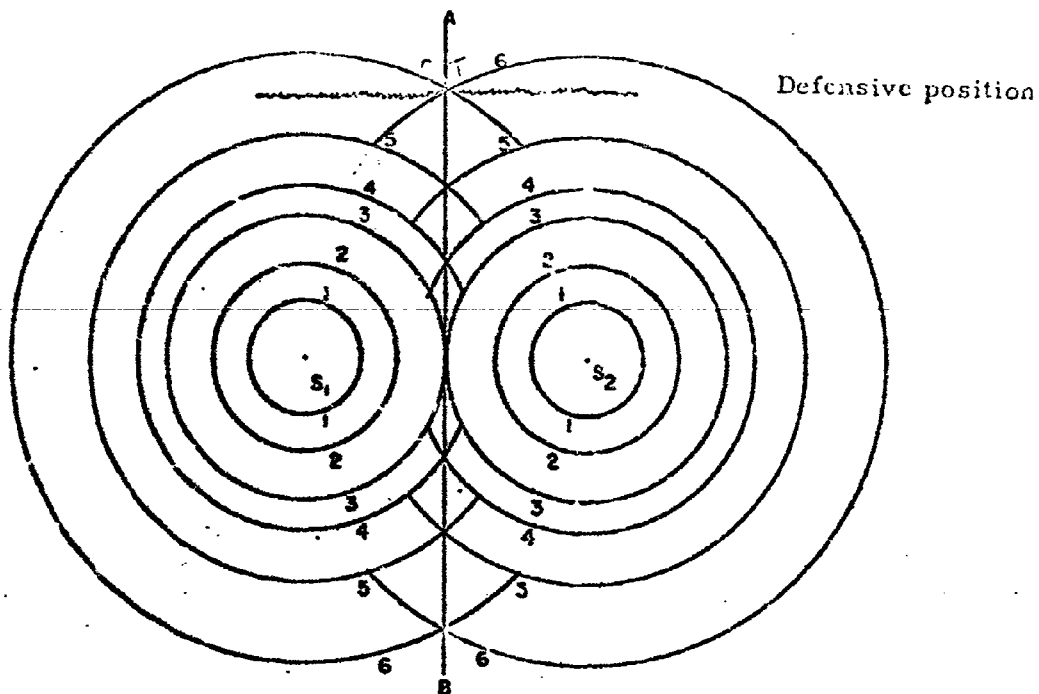


Figure 2.6.1

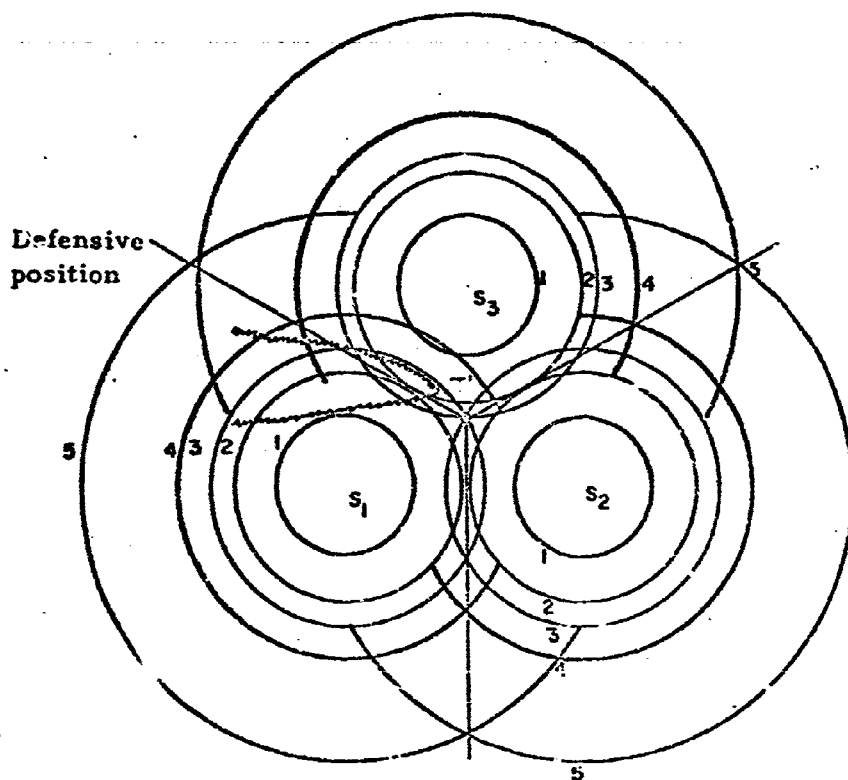


Figure 2.6.2

The shaded area represents a zone within which troops may be combined at some time greater than the earliest combined effort line. We may also note that at isochrone line six the troops combine forces at the earliest possible time against a defensive position.

In the foregoing figure we assumed that activity occurred spontaneously at each source. However, it may also be the case that observation of some activity above a certain threshold of significance at various sources may not occur at the same time. In such a case the earliest observation can be used as time zero and later ones retarded appropriately.

When three or more source points are introduced into the problem we provide for the possibility of lines of earliest combined effort intersecting (Figure 2.6.2). This establishes a space-time relationship that becomes of increasing importance to a defensive position. In the case of only two sources of supply (Figure 2.6.1) the probable location of attack could be at T. In the case of three sources of supply the probable area of attack now shifts to the focus created by the intersection of the three lines of earliest combined effort (Point T' of Figure 2.6.2). At this point the insurgents can bring to bear the greatest magnitude of striking power at the earliest possible time.

Thus far in our discussion we have assumed an homogenous region with transport facilities available in all directions and a constant velocity of movement. This has resulted in a system of concentric isochrones

radiating from each source. In reality we are not often concerned with such idealistic assumptions, and as a result movement in all directions is distorted. With the introduction of irregular topographic features such as rivers, valleys, mountains, etc., and man-made features such as bridges, roads, paths, etc., the isochrones lines are often distorted. Taking these factors into consideration we could get isochrone lines from a single source which appears as follows (Figure 2.6.3). The isochrone lines are greatly distorted along the road where large distances can be covered in relatively short periods of time. The hills and river create boundary effects where steep gradients occur in the slope of the isochronous surface broken only by the occurrence of a pass or bridge through which movement can occur.

Applying this same procedure to our example in South Vietnam yields the Figure 2.6.4. For this we use only two sources of supply (nodes 31 and 34) and the existing system of transport routes. Each of the isochrone lines represents a travel time of ten hours by a portage system. Superimposed over a map depicting the transport network for this area, we would note the influence of the routes in forming these isochrone lines. Due to the fact that the isochrone lines are distorted, we may also note that the line of earliest combined effort is also a wavy line. If three or more nodes had been used we could have noted the occurrence of several of these wavy lines of earliest combined effort. Although only rough generalizations, such techniques give a first

approximation as to where insurgents may be found at a future time.

3. Flow Analysis and Its Application to Strategy Evaluation

Evaluation of insurgent strategies within a Bayesian framework-- as will be discussed in the next section--is dependent upon some type of system which will allocate potential movement of forces. Thus, given that buildup will occur at a certain node on the system discussed previously, we would like to be able to examine the probable flows that will occur over the network in order to supply this node with the necessary men and materials. Three major elements are contained in such a study: first there must be some nodes which are staging points and which will thus require certain quantities of men and material. These are termed demand centers. Secondly, we assume that there are certain other nodes which have a surplus of men and materials, a surplus in the sense that the quantity of men and materials is greater than that required to maintain the base area. As a consequence they will have an excess of men and materials available. These centers are called supply nodes. And thirdly, there must exist some type of transport network capable of handling potential movement of these men and materials from the supply nodes to the demand nodes. In addition there is a cost and a capacity constraint associated with each of the arcs in the system. For one system the cost constraint on each arc is the amount of time it takes to traverse the arc. The central problem with which we are concerned

is moving as much men and materials over this system as is necessary to meet all demands at the buildup nodes and perform this in a minimal amount of time. Although we are concerned with minimizing travel time, other constraints could be added to each of the arcs. Thus we might think of some sort of risk figure being attached to each arc which would incorporate such items as coverage on the trail, water supply, detection by unfriendly forces, etc. The problem then becomes one of trying to fulfill all the demands at the buildup nodes with a total minimum amount of risk.

The resulting flows of men and material over the transport system can then be examined in detail and possible points of interdiction suggested. It is at this point where some type of action-reaction graphical display could be used to great advantage. Once demand and supply centers are established and the flows are moving throughout the system, it would become extremely critical to study the resulting movements when one or more arcs are removed. At the field command level this could be performed quite well by a cathode ray tube hooked up to computer facilities. In this way many different alternatives could be instantly studied by blotting out an arc with a pen light and studying what occurs to the resulting flows.

Programs are already available for handling the first problem of flows.⁶ In addition, interdiction programs are also available, which with modifications could be incorporated into this type of analysis.⁷

4. An Application of Bayesian Inference Techniques to Threat in Insurgency Evaluation

A great deal has been written about this topic by people such as Schum,⁸ Edwards,⁹ and Dodson.¹⁰ The general goal of their research efforts was to compare the performance of human beings with and without the use of Bayes' Theorem in simulated military intelligence environments. It is the intent of this paper to demonstrate the manner in which the techniques developed by the abovementioned researchers can be applied to the problem of evaluating enemy strategies.

The problem is that the assessment of the significance of military intelligence data, a task that is enormously difficult for a human analyst for at least the following reasons: (i) Intelligence data must be evaluated in terms of their impact upon a very large number of hypotheses. (ii) The number of variables or events which bear on each hypothesis is very large. (iii) The input data are not available, and the

⁶D. R. Fulkerson, "An Out-of-Kilter Method for Minimal Cost Flow Problems," Journal of the Society of Industrial and Applied Mathematics, Vol. IX, (1961), pp. 18-27.

⁷E. P. Durbin, An Interdiction Model of Highway Transportation, The RAND Corporation, Research Memorandum, RM-4945 (1966), pp. 1-27.

extent to which they are fallible is not known and may often be only fragmentary.

The Bayesian paradigm provides a way of replacing the problem of mentally aggregating the impact of a large volume of intelligence data upon each hypothesis with the much simpler task of evaluating the impact of each unit of data individually and allowing a high-speed digital computer to perform almost instantaneously the aggregation of the effects of the judgments on each datum made individually. Schum⁸ and Edwards⁹ have determined that the human can perform threat estimation significantly more effectively when he is unburdened in this manner.

For sake of example, we shall consider a very simple hypothetical case to demonstrate the manner in which this approach considers each datum individually rather than as a whole. Suppose that the intelligence analyst is trying to estimate the probability, or the likelihood, that the enemy is building up a force to try to mount an effective attack on the city of Song Cau. The accompanying map shows Song Cau as well as certain VC base areas. Although this map is old and may not be accurate or even complete, it will serve adequately for this example.

It is assumed that the enemy base areas are, for the most part, strategically located so as to serve as staging areas. A second major assumption is that the enemy order of battle in each base area is reasonably well known. The third, and final, assumption upon which this approach depends is that expertise is available within the US/SVN

military establishment which can estimate reasonably accurately the amount of men, supplies, artillery, etc., which the enemy would require in order to mount an effective attack upon Song Cau or any potential target.

It would appear that there are six base areas which must be considered as influencing the estimate of the threat to Song Cau. For each base area, there are many variables which must be considered such as medical supplies, troops, artillery, food, fuel, etc. Information concerning these variables is considered available, even if only in fragmentary and temporally separated bits. The intelligence analyst then faces the overwhelming task of estimating the enemy intentions regarding Song Cau on the basis of prohibitively large amounts of data. In mathematical form, the analyst is trying to determine

$$P(H_i/D_1 D_2 D_3 \cdots D_n) \quad (1)$$

where H_i is the hypothesis being evaluated.

H_1 may be the hypothesis that Song Cau is going to be attacked.

H_2 may be the hypothesis that the enemy intends to maintain the status quo at Song Cau.

H_3 may be the hypothesis that the enemy is reducing his strength at Song Cau (or, more precisely, at Phu Bon which should be the major staging area for an attack on Song Cau) presumably to supply another

base area for an attack elsewhere. D_1 through D_n are the basic intelligence variables which influence the potential target. For example, D_1 might be the event that 2 artillery squads were sighted moving to Kontum from Quang Tin. D_2 might be the event that 3 infantry divisions are present in the Ban Me Thot base area. The $P(H_i/D_1 D_2 D_3 \dots D_n)$ is the probability that hypothesis H_i is true given events D_1 and D_2 and D_3 and D_4 ... and D_n .

The Bayesian paradigm provides a convenient technique for evaluating Eq. (1) in terms of a prior estimates of $P(D_j/H_i)$ the probability that event D_j will occur given that hypothesis H_i is true.

SOUTH VIETNAM 1966

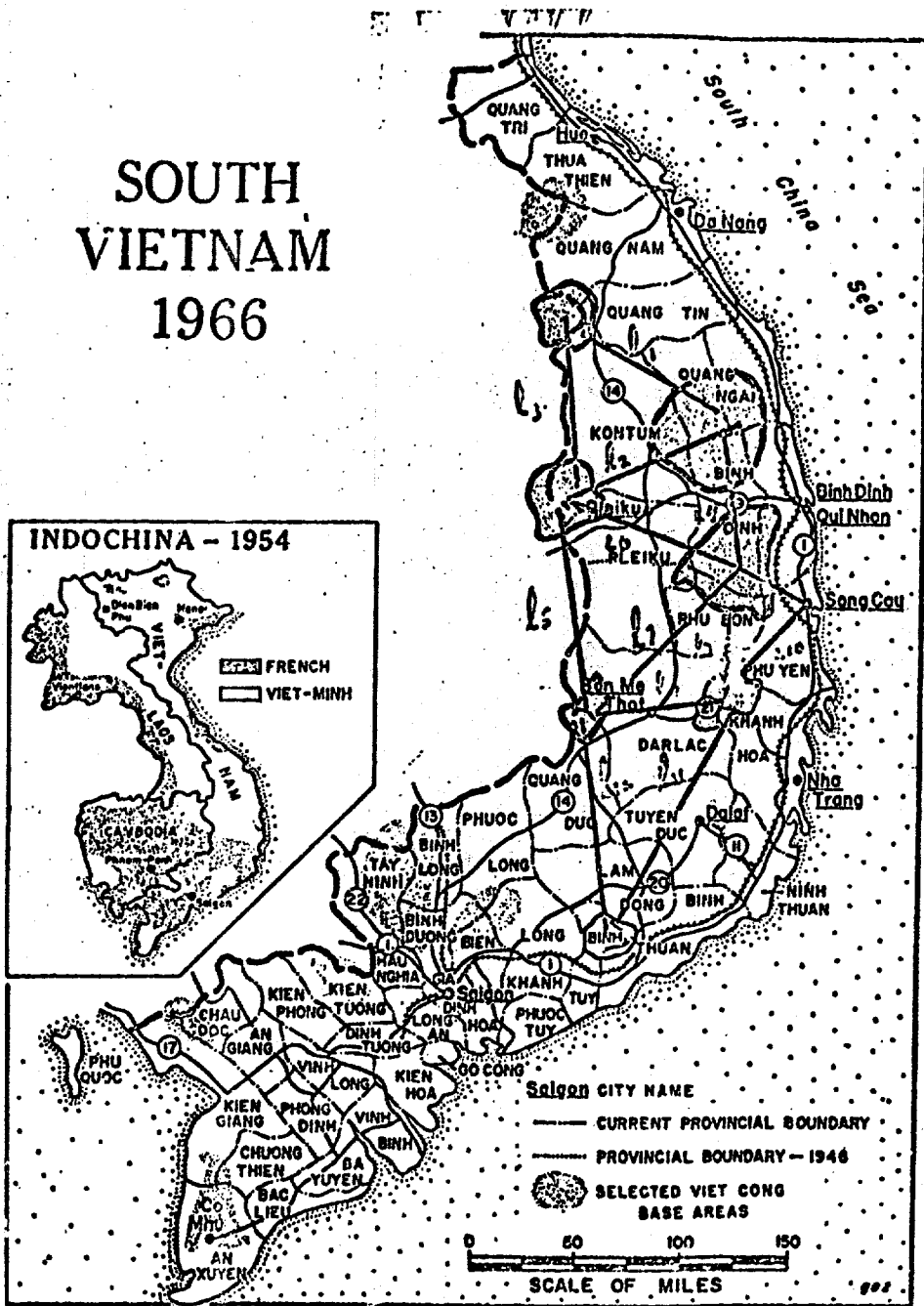


Figure 4.1.. Map showing potential target, Song Cau and surrounding enemy base areas.

In the simple example stated above,

$P(D_1/H_1)$ = probability that the enemy would move 2 artillery squads from Quang Tin to Kontum if he were going to attack Song Cau.

$P(D_1/H_2)$ = probability that he would move the 2 squads if he wanted to maintain the status quo at Song Cau.

As stated earlier, it is assumed that military experts could arrive at reasonable estimates of the probability of occurrence of the events under each hypothesis. Essentially it is an estimate on his part of what the enemy would require to take Song Cau, and where he would get it, given reasonable estimates of the enemy order of battle at each base area. As the events are observed to be occurring, or even not occurring, a digital computer aggregates the data and estimates the cumulative probability $P(H_1/D_1 D_2 \dots D_n)$ by Bayes' rule on the basis of the a priori estimate of $P(D_1/H_1)$ supplied by the military experts. Such aggregation can be accomplished by the computer almost instantaneously. The computer, incidentally, may be used in conjunction with a cathode-ray tube display or line printer to generate and display additional information to further facilitate the task of the analyst. This will be discussed in more detail throughout this paper.

In the specific example under consideration, attention must be given to five distinct base areas and their potential capability to supply the Phu Bon base area from which the attack would be staged. Other

research on this program has yielded techniques for specifying the minimal networks interconnecting the six base areas. They may be minimal in the sense of travel time, distance, or even risk. Flows over this network will be key variables in the assessment of potential threat to Song Cau. For sake of specificity, links on this network have been arbitrarily added to the map and labelled l_1 through l_{12} . After the network has been defined, variables which influence the various hypotheses are listed in a matrix format along with the corresponding a priori conditional probabilities. The basic variables will fall into 2 general classes: flow variables and status variables. For example, consider first the hypothesis that the enemy is planning to attack Song Cau. The analyst is now in the position of having to estimate in general terms what the intelligence data would be under the hypothesis, say, that the enemy is building up for an attack. Considering only a few variables, he might estimate that the enemy would need the following force to overrun Song Cau:

4 to 6 units infantry

3 to 5 units artillery

1 to 3 units medical supplies

4 to 5 units food

4 to 6 units ammunition.

From enemy OB he knows that the enemy has the following strength at the Phu Bon staging base:

2 to 3 units infantry
 2 units artillery
 1 unit medical supplies
 2 to 3 units food
 3 units ammunition

He would insert these data into the matrix of a priori probabilities as shown below. If, for example, enemy OB is not completely accurate, and he expects that the enemy probably has 2 or 3 units of food stored but that chances are slight that the enemy has 1 or 4 units, he may assign values of 0.45 to the a priori probabilities of 2 & 3 units of food and values of 0.05 to the probabilities of 1 & 4 under the status quo hypothesis.

Variables	No. of Units	Hypotheses Status Quo Probabilities	Build Up
Infantry	0		
	1		
	2		
	3		
	4		
	5		
	6		
Food	0	0	
	1	.05	
	2	.45	
	3	.45	
	4	.05	
	5	0	

A priori conditional probabilities for the other status or order of battle variables would be entered in a similar manner. Under actual operation, as recent intelligence data are introduced, the computed probability that the enemy is maintaining the status quo will remain fixed at a certain level if he is in fact maintaining the status quo. However, if he increases or decreases the level of food, say, then the computer will yield a lower value of probability that the enemy is maintaining the status quo. This should immediately clue the analyst that something is possibly happening. It might be desirable to provide for man-machine communication at such a point so that the analyst could ask the computer, "Why did the probability that the enemy is maintaining the status quo at Phu Bon decrease?" The machine would then provide him with a cathode-ray tube or typed display saying, for example, "Most recent OB estimate specified:

x units infantry
y units artillery
z units medical supplies

but most recent intelligence data show

x-2 units infantry
y units artillery
z-1 units medical supplies."

This would indicate that the enemy is decreasing his strength at Phu Bon, and the analyst would immediately try to determine possible destinations for the forces which have left. He might check the system and find that

the computer has estimated a build-up at Long Binh. He could instruct the computer to display or print-out the minimum travel time network between Phu Bon and Long Binh and to compute the earliest time at which the forces could be brought to bear on Long Binh. If, however, build-up at Long Binh or anywhere else had not been indicated, he might ask the computer some general question such as "List the possible destinations in II Corps and the corresponding travel times."

The number of tasks that could be performed by the system is virtually unlimited, and it is expected that many algorithms could be developed which could greatly enhance the efficiency of the intelligence analyst.

Considering now the hypothesis that the enemy is building-up his forces at Phu Bon, it might be beneficial to evaluate the hypothesis in two ways independently, one on the basis of the status of forces and the other on the basis of network flows in the general direction of Phu Bon.

Again, it appears that some form of man-computer communication would be extremely useful in this context. The analyst is in the process of mentally staging the logistical aspect of an hypothetical encounter. He has a fairly firm idea of what the enemy would require to capture Phu Bon and must guess just how the enemy is going to supply or build-up the Phu Bon staging area. If such a feature could be incorporated, he might at this point instruct the computer to print out or display on a cathode-ray tube the following information:

(i) Minimum travel time network linking Phu Bon to all other base areas within, say, II Corps area.

(ii) A summary of enemy order of battle at each base area arranged in vector form. For example, if the enemy had 8 units of infantry, 10 units artillery, 6 units food, etc., at Long Binh a vector would be printed next to Long Binh on the network in the form

8
10
6

·
·
·

(iii) The amount of surplus or deficit in each commodity which the enemy has at each base area relative to the amount required to hold a defensive position there, again printed out as a vector. If such information were presented in map form, the analyst could estimate what the enemy would do to supply Phu Bon under the hypothesis that Phu Bon is being built up. For example, he might see that at Ban Me Thot base area, the enemy has a surplus of 2 units of infantry. He would then say, perhaps, that under the hypothesis of build-up at Phu Bon, there is a probability of 0.5 that one unit of infantry would move along link 17

from Ban Me Thot to Phu Bon and 0.3 that two units would move along link l_7 at some future time. If enemy OB at Phu Bon should indicate increased infantry strength, the probabilities of flows would be reduced, perhaps even automatically, but probably by the analyst. Such information could be displayed for all pertinent base areas simultaneously as indicated below along with the

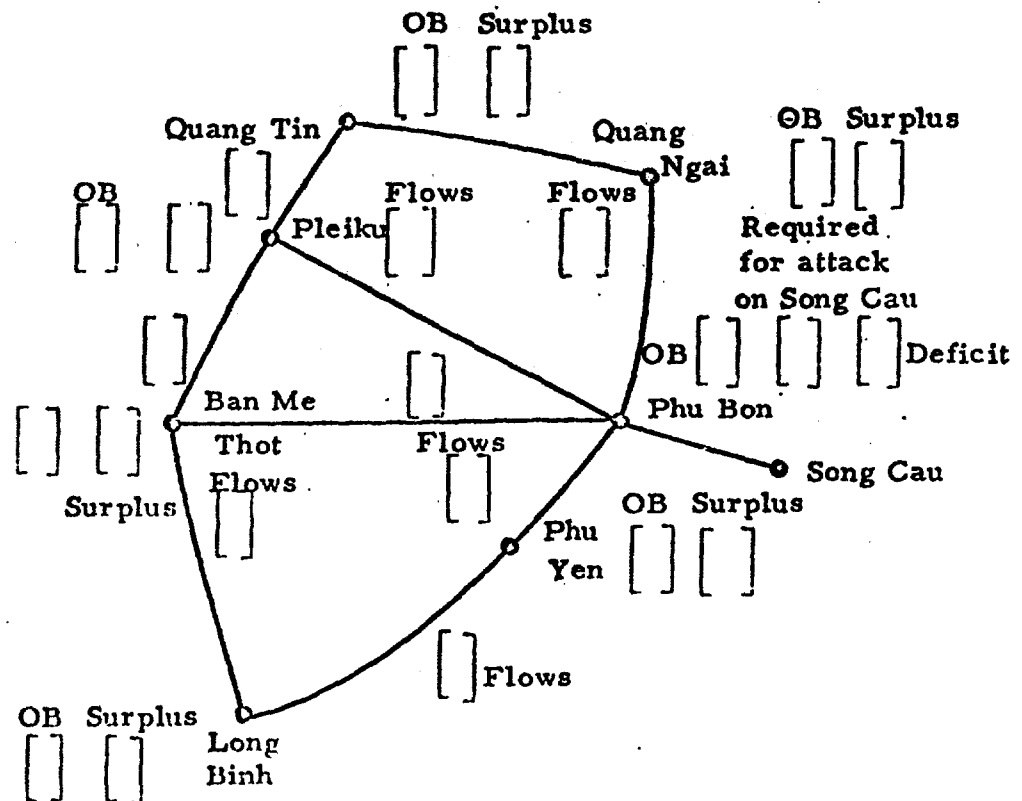


Figure 4. 2. . Computer graphical print-out of most recent enemy order of battle and movements.

network and the flows of men, materials, etc., which had been reported during, say, the last 48 hours.

Given such a display, the analyst could estimate what flows will occur if the enemy mounts an attack on Song Cau. He makes estimates of probabilities by considering a priori, prior to the hypothetical attack, one variable at a time, one link at a time. It is apparent that his task has been reduced from one of assessing the impact of a large number of events collectively after the build-up has begun to one of considering the potential impact of a large number of events individually prior to the build-up and letting the computer perform the estimation of the threat to Song Cau as the events which he had considered before-hand are reported to the intelligence establishment.

Status variables probably should be considered independently from flow variables when testing the build-up hypothesis. Again considering one variable at a time, for example infantry troops, probabilities might be assigned in the following manner for the build-up hypothesis:

If the enemy is known to have 2 units of infantry at the Phu Bon base area, and it is estimated that 6 units would be required by the enemy to take Song Cau, increasing values should be assigned to the probabilities that the enemy has 2, 3, 4, 5, or 6 units of infantry at Phu Bon. If probabilities are assigned in this manner, the computer will produce corresponding estimates of the probability of build-up as

intelligence reports are received which contain clues of actual build-up. Status variables should be normalized so that when full strength is reached at the base area, the probability of a build-up is 1.0.

The mathematical details will be presented in an appendix.

Summarizing what has been presented here, there would be at least 2 hypotheses for each potential target, build-up and status quo and a very long list of variables describing regional status and network flows. The variables would not be the same for every potential target, because for instance, flow on a link near Cu Chi obviously has no impact on the probability of threat to Khe Sanh. The following, then, is the general form of the matrix of a priori conditional probabilities:

	Variables	Units	Base Area Phu Bon H_1 : Status Quo	Build-Up
Status	Infantry			
	Artillery			
	Food			
	etc.			
Flows link				
	l_1 Infantry			
	l_1 Artillery			
	l_1 Food			
	etc.			
	l_2 Infantry			

This matrix may be considered as a representation of supply and hypothetical demand in that the status quo hypothesis constitute a representation of enemy supply in all the base areas and the build-up hypotheses represent demand upon the supply assuming a build-up is going to take place. It is an efficient and useful representation and many items of information could probably be derived from it in addition to the Bayesian estimations.

5. Conclusions

This research has been directed to the question whether or not the speed of a digital computer can be brought to bear effectively upon the complex task of performing real-time on-line inference of enemy strategy from intelligence data. It is the opinion of the authors that a computer can be structured in such a manner as to provide a great deal of assistance to the intelligence analyst who is faced with this task. The material presented here can only be considered to constitute a preliminary design, at best, but results to date seem to indicate that such a system is technically and economically feasible.

Appendix

This appendix outlines briefly the mathematical detail of Chapter 4.

For a potential target, say that there are 3 hypotheses, and that they are exhaustive. Perhaps they would be:

H_1 = heavy buildup

H_2 = maintain status quo

H_3 = decreasing strength.

For any individual variable, D_j ,

$$P(H_1/D_j) + P(H_2/D_j) + P(H_3/D_j) = 1.0 \quad (1)$$

also

$$P(H_1/D_j) = \frac{P(D_j/H_1) P(H_1)}{k} \quad (2)$$

where

$P(H_1)$ = a priori probability that H_1 is true

and $P(H_i/D_j)$ = probability that hypothesis i is true given that datum j has been observed, and k is simply a normalizing constant introduced to satisfy Equation (1).

In practice, we might start with

$$P(H_1) = P(H_2) = P(H_3).$$

We would first consider one variable, say infantry status, in a given

region and call this variable D_1 . We would evaluate $P(H_1/D_1)$, $P(H_2/D_1)$, $P(H_3/D_1)$ for the region using Equation (2). Thus we have established for the region under consideration certain levels of probability of each hypothesis being true given the variable D_1 . These values would then serve as a priori probabilities ($P(H_i)$ in Equation (2)) for evaluating each hypothesis when variable D_2 is considered. For example,

$$P(H_1/D_2) = \frac{P(D_2/H_1) P(H_1/D_1)}{k}$$

Edwards (reference 8) says that it is of little consequence how the $P(H_i)$'s are chosen initially as long as they are not close to 0 or 1.

This seems reasonable in that if there is a great deal of evidence to support one hypothesis, its probability will build up and the others will build down no matter where they started.

As this formulation stands, D_j is a binary variable, either the event occurred or it didn't. For example, presence or absence of infantry units would constitute the two values that a certain variable could assume. However, Dodson, (reference 9) has proposed a workable technique for quantizing each variable so that different levels of each variable could be considered. In addition Dodson's modified Bayes theorem (MBT) allows for the case in which the true state of the variable is not known. That is, if a sighting of infantry troops was reported as consisting of 4, 5 or 6 squads with different levels of personal probability of the actual state, the MBT can accommodate this situation easily. In

mathematical form, the MBT is

$$P(H_i/D_j) = \sum_{k=1}^{\mu} P(D_{jk}) \frac{P(H_i) P(D_{jk}/H_i)}{k}$$

where $k = 1, 2, 3 \dots \mu$ are the different states of the variable D_j can assume.