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Leon D. Chapman, Editor

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PHYSICAL PROTECTION OF NUCLEAR MATERIAL IN-TRANSIT
QUARTERLY PROGRESS REPORT
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L. D. Chapman
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PHYSICAL PROTECTION OF NUCLEAR MATERIAL IN-TRANSIT

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SUMMARY

A major in-house activity related to the Nuclear Regulatory Commission (NRC) physical protection of nuclear material in-transit program this quarter focused on further development of the SABRES combat simulation model. Subroutines which simulate movement were developed for the interactive version of SABRES and then modified and incorporated into the Monte Carlo version. A barrier penetration routine and decision logic routines were also developed. The addition to SABRES of these decision logic routines allows the user to develop a set or series of plans for each scenario to account for contingencies during combat.

Work continued this quarter on development of the Emergency Assistance Request Simulator (EARS). The addition to EARS of a commercial radiotelephone capability is in the preliminary stage; analytical work on the addition of a jamming capability was completed. Several simulations were run to demonstrate the current capability of EARS to provide statistical data. A briefing on the most recent version of EARS was provided to NRC staff members.

Science Applications, Inc. (SAI) continued to provide communication analysis support. Two final reports presenting results of tasks three and four of the five-task SAI contract were submitted to Sandia Laboratories. A briefing on these reports which covered the completed tasks three and four was given to Sandia representatives by the SAI staff.

The applicability of the Safeguards Network Analyses Procedure (SNAP) to analysis of SNM transportation systems was demonstrated. Additional capabilities which would enhance the general applicability of SNAP to the transportation problem were suggested to the NRC.

IN-HOUSE ACTIVITIES

Conflict Analysis

One of the problems in the evaluation of physical protection systems for nuclear material in-transit is the determination of factors which influence the outcome of engagements between adversary and protective forces. The principal computerized methodology being developed for such evaluations is the combat simulation model SABRES. SABRES is a stochastic, individual-resolution simulation of the combat between the protective force and an adversary force after the initial attack on a road convoy. Two versions of SABRES have been developed: (1) an interactive version, which is used to generate scenarios, and (2) a Monte Carlo version, which is used for statistical analyses.

The basic elements on the SABRES models are shown in Figure 1. The number and location of the surviving defending forces from the SOURCE model are input to SABRES along with user-supplied strategies for each side. The terrain and vegetation model computes lines-of-sight and concealment probabilities. Given line-of-sight, detections are determined as a function of the target size, contrast, range, weather, and visibility. All combatants not already involved in an activity are allocated to either fire, move, or observe according to their current battle plan and situation. Casualties are assessed for all rounds which impact during this time-step; noncasualty effects of weapons fire which may cause a temporary degradation in the performance of a combatant are assessed under combat suppression. Movement and barrier penetration are then simulated. Finally, the disengagement criteria are checked for both individuals and each side.

During this quarter, the subroutines needed to simulate movement were developed for the interactive version of SABRES and modified and incorporated into the Monte Carlo version. Decision logic routines, which control the execution of tasks, were then developed along with a barrier penetration subroutine. The decision logic routines allow the user to develop a set of plans for each scenario which accounts for contingencies during the combat.

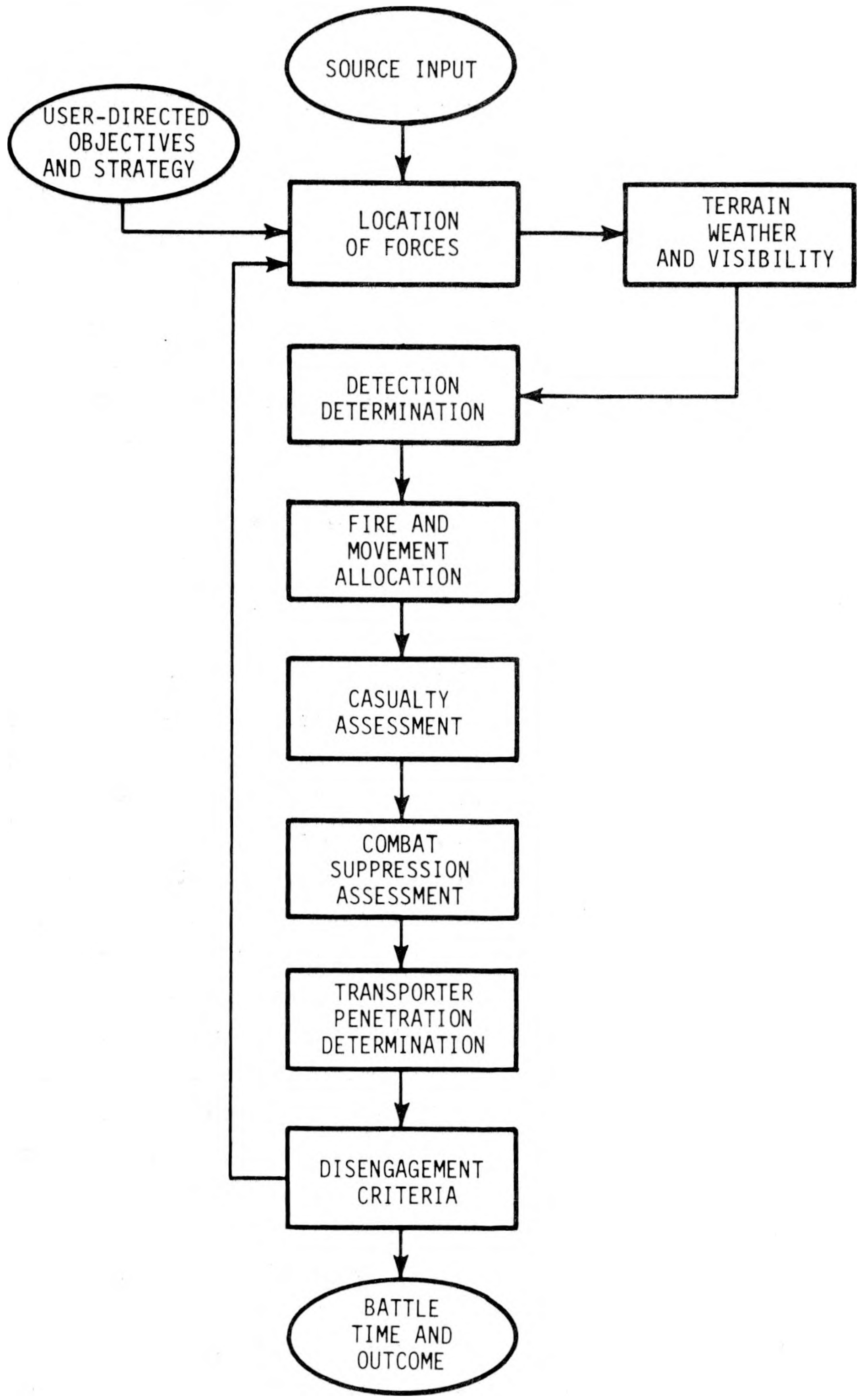

Figure 1. SABRES Schematic Diagram

A plan consists of a series of tasks or orders to be performed by each combatant. Each task has three parts: (1) the task type, (2) a completion constraint, and (3) the task objectives. The task types are the activities which are to be performed and include (1) move, (2) fire periodically, (3) fire continuously, and (4) work on the transporter barrier. The tasks are performed in series with the next task assigned upon completion of the current task. Completion constraints are used to define completion of fire events and to force the start of the next task if a movement task is not completed within a specified time. Completion constraints can be defined as (1) a specific battle time, (2) a specific time duration within the battle, or (3) the attrition of specified targets. The task objectives consist of the coordinates of a movement objective or the names or types of targets to be fired upon. Specific targets can be selected, e.g., Attacker 1 or Defender 3, or target types can be selected, e.g., barrier workers, transporter crew, etc.

During the Monte Carlo simulation of a specific battle scenario, a single plan cannot account for the contingencies which arise due to the stochastic nature of the combat. Therefore, the user must input a series of plans, each of which is designed to account for a specific contingency. The order in which each plan is enacted is shown in the plans diagrams in Figures 2 and 3. Each branch of the decision tree is a set of contingencies for which a plan must be input. During the simulation of a battle, the appropriate plans will be played.

The establishment of the battle plans for a given scenario can be accomplished by use of the interactive version of SABRES. Once the battle plans are input to the Monte Carlo version, many repetitions of the battle can be simulated and statistical results generated. Thus, the two versions of SABRES form the elements of a combat model which combines the modeling techniques of gaming and simulation. The interactive version allows the user to draw on his specific knowledge and expertise to develop a scenario and battle plans. The Monte Carlo version then generates statistical results which provide insight into the relative value of protective force characteristics.

Communication Analysis

Development of the Emergency Assistance Request Simulator (EARS) continued during this quarter with preliminary work directed toward the

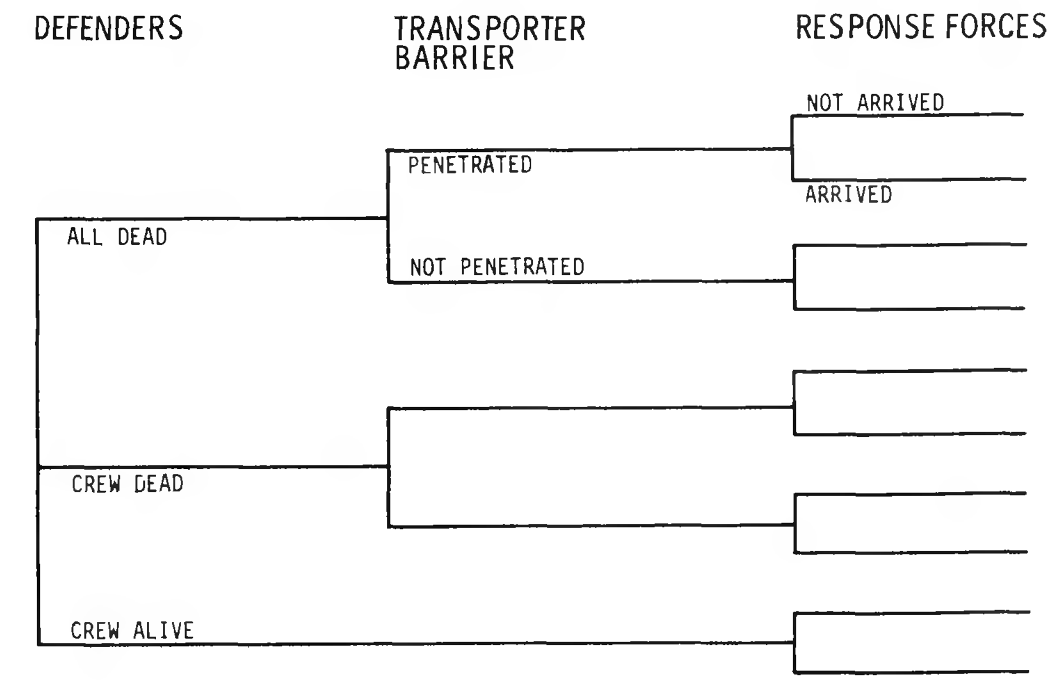

Figure 2. Adversary Plans Diagram

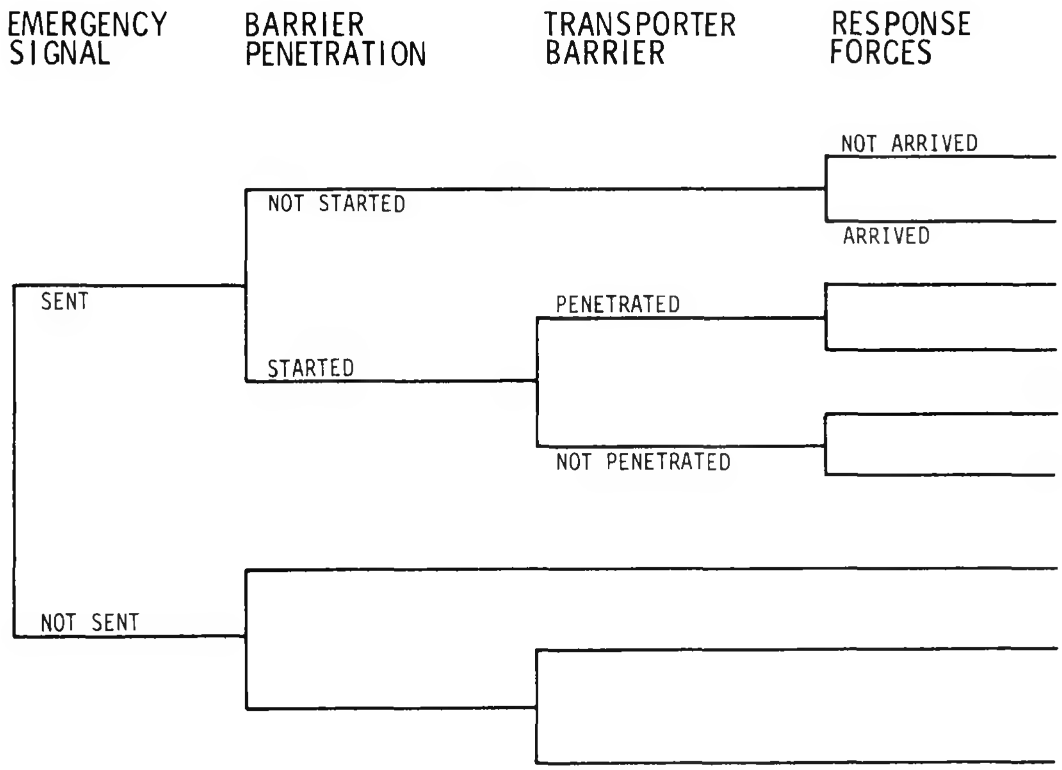

Figure 3. Defender Plans Diagram

addition of the commercial radiotelephone capability to the model. Analytical work necessary to add the jamming capability has been completed.

Several simulation runs which involved different numbers of transporters were utilized to demonstrate the capability of EARS to provide statistical data. These statistical data, which are contained in Table I, were obtained under the assumption that (1) the transporters were randomly positioned in a coordinate system which represents the United States and (2) half-hour reporting intervals were used. At the scheduled reporting time, each transporter transmitted a message twice on each of four frequencies or channels. The messages were received and acknowledged by a Central Operations Office (COO) node. The EARS model has paths through which COO can alert the statewide local law enforcement agency (LLEA) headquarters, so that emergency requests are routed to the LLEA. EARS automatically outputs the statistics of the various time differences or alert times.

TABLE I

EARS Output

	Number of Transporters							
Variables	30	40	50	60	70	80	90	100
TALERT (min.)	0.153	0.146	0.139	0.153	0.150	0.148	0.148	0.157
RETRAN	3	3	4	3	4	5	5	4
TEMERG (min.)	4.16	4.11	4.07	4.07	4.07	4.07	4.07	4.07
TCOMP (min.)	0.235	0.233	0.226	0.234	0.238	0.232	0.231	0.239
LOST	0	0	0	0	0	1	1	0
Messages	1066	1586	2093	2633	3157	3619	4157	4753

As an example, consider the data in Table I for the case in which 50 transporters were used in the EARS network. Of the 2093 messages sent for this case, none were lost (LOST = 0). Also, no messages were sent simultaneously, which would have resulted in signal interference. If an acknowledgement of the receipt of the message by COO was not received by the vehicle within 30 seconds, the vehicle automatically repeated the message (up to a maximum of five retransmissions). Failure to acknowledge the fifth retransmission results in a lost message. Note that a maximum of four retransmissions (RETRAN) was required within any single reporting interval for this case. Although not shown in Table I, a total of 17 messages (an average of 1.12 messages per reporting interval) had to be retransmitted four times.

The average time difference between the initiation of the transmission of a message and the receipt of that message at COO (TALERT) was 0.139 minute (8.34 seconds). During this time period, the receivers at each relay monitored the four channels, and a new message, which contained the original transporter message along with information related to the quality of the reception, was generated and passed to COO.

The value of the time to complete a transmission (TCOMP) is the sum of TALERT and the time difference between the receipt of the message at COO and an acknowledgement of the report from COO. The average value of TCOMP in this case was 0.226 minute (13.6 seconds). For the transmission of emergency messages, the average time required for the correct reception of the request by LLEA headquarters (TEMERG) was 4.11 minutes. The path from COO to LLEA headquarters includes an intermediate connection to the commercial Movement Control Center and, therefore, is not a direct connnection.

The variables depicted in Table I do not comprise an exhaustive list of the output available from EARS but rather are examples of the current capabilities of the model. Statistics for other variables can be easily provided. The statistical properties provided by the output for each variable designated by the user include the average value, the standard deviation, the standard deviation of the average, the minimum value, the maximum value, and the total number of observations of the variable.

A briefing on EARS was presented to NRC staff members during October. The most recent version of the EARS model was described at that briefing, and future NRC users made suggestions that will help define the final form of the model.

Future enhancements to the model will include both the implementation of the jamming capability and a modification of the code to represent the radiotelephone system. EARS can then be calibrated with the model developed by Science Applications, Inc. (SAI) to identify and investigate candidate communication systems with which to monitor the status of special nuclear materials (SNM) shipments.

CONTRACTUAL SUPPORT

Communication Analysis

SAI continued to provide support for the communication analysis effort during this quarter. In December, SAI final reports entitled "Transportation Safeguards Exemplary Candidate Communication System and Network Analysis Model II" and "Evaluation of Transportation Safeguards Exemplary Candidate Communication Systems" were received at Sandia. These reports present the results of analysis for Task II, Task III, and Task IV of the five-task SAI contract. A briefing on the Task III and Task IV results was given to Sandia representatives by the SAI staff on 15 November. At that time, a decision was made to present these results to NRC at the beginning of the next quarter.

SNAP Transportation Application

The Safeguards Network Analysis Procedure (SNAP), which was developed by Pritsker and Associates, Inc., is designed to model and analyze safeguards systems at fixed nuclear sites. A reasonable extension of SNAP capabilities is to include the analysis of SNM transportation systems within SNAP. At present, general models of some transportation systems can be constructed by the use of current capabilities. By including transportation routes in the SNAP facility model, a reasonable representation of guard and adversary actions can be developed.

The transportation route illustrated in Figure 4 can be used to demonstrate the applicability of SNAP to a hypothetical transportation problem. The route marked on Figure 4 from Hutsonville, Illinois, to Camp Atterbury, south of Indianapolis, Indiana, represents an example route that a transporter could take for the shipment of SNM. The route has been divided into seven sectors, A1 through A7. The location of a convoy is specified as one of these seven sectors; its specification within a sector is not included in the model. There is no limit to the number of sectors which can be used in the SNAP model. In the system described, LLEA forces are assumed to be available in the event the convoy is attacked. They are available from Terre Haute, Greencastle, or Indianapolis.

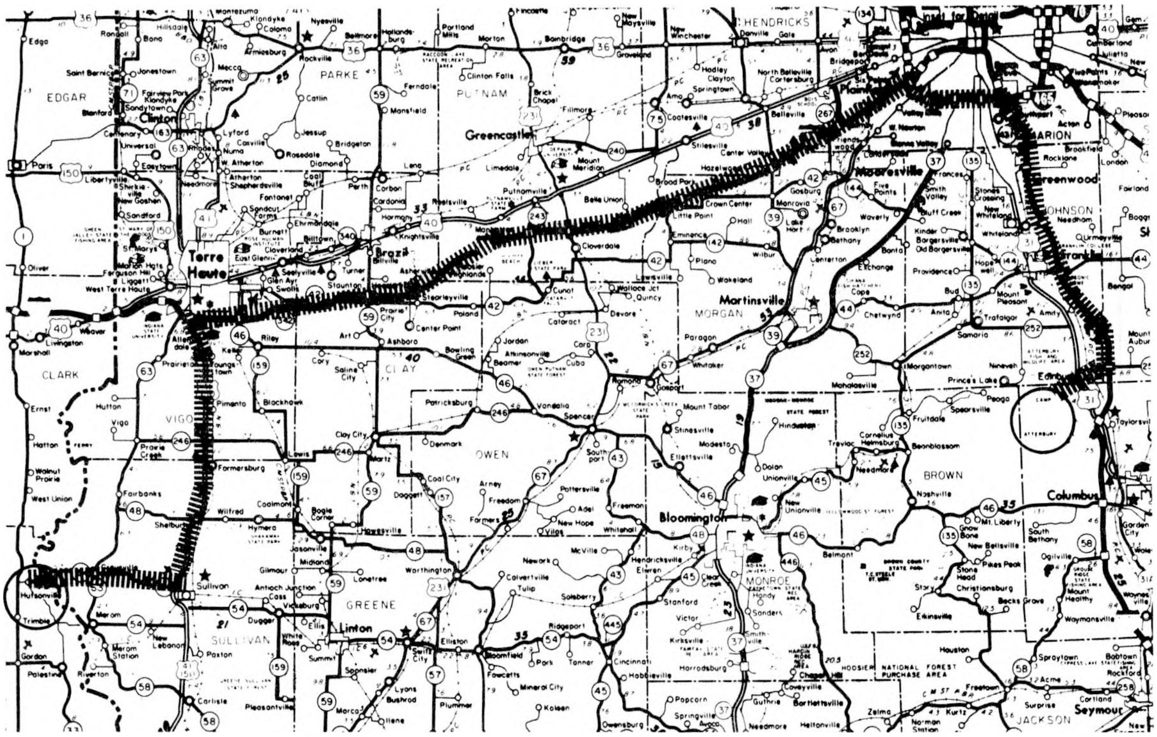

Figure 4. SNM Transport Route

The guard portion of this transportation model consists of four basic force components:

1. The convoy which transports the SNM,
2. The radio operator who monitors the convoy,
3. The small backup force which is transported by means of helicopter, and
4. The LLEA force.

The attack scenario involves an adversary attack on the convoy in one of the seven sectors along the route. The attack sector is determined probabilistically; however, the adversaries are more likely to attack sectors in the center of the route since these sectors are farthest away from substantial LLEA reinforcements. The objective of the adversaries is theft of the SNM carried by the convoy. When the transport convoy arrives at a particular sector, the attackers move into position and attack the convoy. Given that the adversaries win the engagement with the convoy, they acquire the SNM and depart. For the purpose of this example, the scenario is assumed to end when the adversaries leave the proposed target sector.

This scenario was simulated 200 times to obtain statistical information concerning the behavior of the system. General simulation results are provided in Table II. Of particular interest is the probability that the adversaries achieve their objective. For this hypothetical scenario, the model predicted the probability of adversary win as 0.40, i.e., for the 200 simulated attacks on the transport convoy, the adversaries were successful 40 percent of the time.

TABLE II

General Simulation Results

Parameter	Average Over 200 Runs
Number of guard casualties per run	2.79
Number of adversary casualties per run	1.95
Degree to which objective was satisfied	0.40
Time for each engagement	3.81 min
Total engagement time per run	4.49 min
Number of engagements per run	1.18
Time between adversary entrance and engagement	48.93 min
Scenario time	88.08 min
Scenario time given adversary succeeds	87.50 min
Scenario time given adversary fails	88.31 min
Probability adversary achieves objective	0.40

Table III contains model estimates of the probability that the adversaries will be successful given this hypothetical attack in a particular sector. For example, the model indicates the adversaries have a 47 percent chance of success if they attack sector A3. Sector A3 is located near Greencastle, which was assumed to have the smallest guard response force, and is a reasonably large distance from the helicopter base. It is likely that the delay in response time is the reason for high adversary success in this area. Note that in this hypothetical scenario the adversary will only attack a single sector in any given simulation.

TABLE III

Route Sector Statistics

Route Sector	Probability Adversary Completes Successful Attack on Sector
A1	0.44
A2	0.19
A3	0.47
A4	0.42
A5	0.37
A6	0.22
A7	0.58

This example indicates the applicability of SNAP to the SNM transportation problem. Given the current capabilities of SNAP, certain scenarios can be modeled; however, the addition of other capabilities would improve the general applicability of SNAP to the transportation problem. Some areas for development include:

1. Communications--The radio communications between various forces should be more explicitly modeled. SNAP could be extended to model limited channel access, communications networks, and radio jamming. While many communications actions can be modeled by the use of current SNAP capabilities, the addition of a specific communications element would increase the applicability of the technique.
2. Convoys--The addition of a convoy capability in SNAP would be appropriate to modeling the transportation problem. With this capability, separate vehicles would be treated as a single unit as they move along their route; however, when attacked, the convoy could separate into individual vehicles to neutralize the adversary threat.
3. Decision Modeling Capabilities--The current decision modeling capabilities applicable to forces in SNAP models were developed for the fixed-site problem. It is anticipated that these capabilities will require expansion to allow direct reference to transportation model terminology.

4. Guard and Adversary Force Location Representation--Since the "facility model" for a transportation scenario basically consists of a route or path which the guard force will traverse, it is easier to determine the location of the convoy on that path than on a path in the fixed-site problem. It is reasonable to assume that a convoy's velocity would be relatively constant throughout a sector; therefore, while the relationship of various sectors to one another can be modeled with the current SNAP facility symbology, the location of the force within a particular sector might be specified as a continuous variable. Because of the path assumption, the location of the force may be explicitly pinpointed within a particular facility node which represents a sector on its route.

Appropriate additions to the symbology could be made to take advantage of the modeling enhancements. For example, additional decisionmaking and monitoring of sectors based upon the location of a force could be included. The proposed developments are based on preliminary modeling activities and would be refined by additional SNAP analyses. Successful development of a mobile-site version of SNAP would provide users with a single methodology which is capable of analyzing and modeling both fixed-site and mobile-site systems.

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