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NUREG/CR-0099
SAND78-8650
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CONF-780506--29

The Evaluation of Road-Transit Physical Protection Systems

(Presented at the 5th International Symposium on Packaging and Transportation of Radioactive Materials held May 7-12, 1978 in Las Vegas, Nevada)

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SF 2900 Q(7-73)

NUREG/CR-0099
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Date Published: May 1978

Sandia Laboratories
Livermore, California 94550
operated by
Sandia Corporation
for the
U. S. Department of Energy

Prepared for
Division of Safeguards, Fuel Cycle and Environmental Research
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555
Under NRC Order No. 60-78-096

NRC FIN No. A1173

ABSTRACT

To assess the overall effectiveness of a transportation physical protection system, computer codes which simulate armed attacks have been developed and are being used to examine a range of issues associated with road transportation systems. The paper discusses the purpose and features of three of these codes--SOURCE (which simulates the initial ambush), SABRES I (which covers the battle) and BARS (which treats the penetration of protective cargo barriers). The use of these methodologies to evaluate the value of additional vehicles, guards, armor and alternative tactics or equipment as a means of improving convoy security has recently been completed. The results which are presented demonstrate that the protection offered by the present commercial regulations for guards and vehicles is probably marginal. This could be substantially increased by the addition of armor to close escort vehicles instead of just the transporter and the use of appropriate tactics. Against the baseline threat of adversaries armed with M-16's, observation and harassment from a modest distance until re-enforcements arrive appears preferable to aggressive assault by the ambushed guard force.

THE EVALUATION OF ROAD-TRANSIT PHYSICAL PROTECTION SYSTEMS

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Introduction

The Division of Safeguards, Fuel Cycle, and Environmental Research within the Nuclear Regulatory Commission (NRC) has created a program to establish appropriate methodologies for structuring and evaluating physical protection systems. Sandia Laboratories, Livermore, is responsible for developing evaluative methodologies for transportation safeguard systems [1-4]. Many theft scenarios involving road transportation of Special Nuclear Material (SNM) result in combat between the adversaries and the transporter crew and escorts. To assist in the evaluation of transportation physical protection systems, computer codes which simulate armed attacks have been developed by Sandia. These codes can be used to examine a range of issues associated with road transportation systems.

For purposes of simulating an armed attack on a convoy, the event sequence has been subdivided into two phases (the initial ambush and the subsequent battle including the penetration of protective cargo barriers). Each of these phases is treated by a separate model described in this paper. One of the principle applications of the models is the study of the relative importance of the large number of variables which must be considered in configuring a physical protection system. The use of computerized evaluative methodologies in performing such sensitivity studies is discussed below. The results of these studies are of assistance to systems designers as well as the NRC in establishing and implementing performance-based security regulations.

Confidence in the results produced by computer models is built up through comparison with the real world or experiments. For most aspects of safeguards systems there are no real data bases. Furthermore because of the stochastic nature of many of the events involved and the tremendous impact upon the outcome of human factors no field exercises will provide a detailed verification of model results. Thus, of necessity the development of techniques to design and evaluate safeguards systems involves an evolutionary interplay of models and experiments. State-of-the-art models may be helpful in identifying critical assumptions and parameters by means of sensitivity studies. Experiments, where possible, are designed to investigate these assumptions and parameters. The results can then be used to build improved models. As both models and experiments mature user confidence is increased through the reduction in areas of uncertainty. Sandia is presently developing the definition and basic design of an experimental program to complement the modeling effort described in this paper.

Overview of Models

To address the impact of convoy configuration and tactics upon personnel survival and emergency signal generation during the initial armed attack, a computer model, SOURCE, has been developed. The SOURCE code is a time-stepped Monte Carlo model. This flexible model allows for extensive variations in the convoy configuration (number of vehicles, distributions, vulnerabilities, velocity, communications) and in adversary characterization (number of units, deployment, and weapon capabilities). In the SOURCE code, the convoy is described by the number of vehicles and their positions, vulnerable areas, observation conditions, and communications capabilities. Convoys consisting of a number of different types of vehicles can be addressed. Emergency messages can also be initiated either by a vehicle under attack or by one vehicle observing an attack on another. The conditions under which an attack is observed can be varied and the capability of sending a message depends on the condition of the crew and their equipment. The code calculates the damage to personnel and equipment and includes the cumulative effects of multiple hits.

The adversaries are described in terms of the number of attack units, their deployment, and their weapons characteristics (i.e., field of fire, rate of fire, lethality, etc.). The flexibility in the code allows a broad range of adversary attack strategies to be addressed. In the SOURCE example which follows, a pre-chosen unit initiates the attack; this unit selects its target and opens fire when the target comes within a prescribed distance. Once this unit opens fire, all other adversary units attack any vehicle which enters their field of fire. Impact points are functions of the aim point and weapon accuracy. The model limits the number of rounds fired per weapon, and includes reload time.

As the armed attack progresses through the initial attack stage, if the convoy has not escaped, the surviving guards may start to return fire and the engagement enters the battle phase. This part of the engagement is simulated by a computer code known as SABRES. Because of the complexity of this code it is being developed in stages. The basic elements of the SABRES models are shown in Figure 1. The general organizational structure and limitations of the SABRES I version have been discussed previously [4].

SABRES I uses simplified descriptions for detection and targets. It does not include movement, barrier penetration, or terrain. The next version, SABRES II, includes these elements. A comparison between SABRES I and II is given in Table I. SABRES I does include more than forty parameters which have an effect on the way a simulated engagement progresses. Some of these parameters describe pertinent characteristics of people in the battle and others apply to the weapons involved. Sensitivity studies have been conducted on many of these parameters. The effect of force size, weapons systems, time to cover for defenders, and deployment of individuals on the outcome of the engagement has been investigated.

Whenever appropriate in construction of the SABRES models existing methodologies have been used. However in many cases this was not desirable because of a need to include more recent data, differences in objectives, or the need for improved modeling approaches to properly simulate the events involved. In developing program modules existing subroutines were carefully reviewed on an individual basis. In the situations where existing models were inappropriate, improvements were added or a new model developed. For example the study of several Department of Defense weapons accuracy and personnel incapacitation subroutines in existing small unit combat codes showed that they were not sufficient for physical protection system analysis. The Department of Energy's Safeguards studies have developed a methodology for assessing the probability of incapacitation given a hit [5]. This model together with the most recent weapons data as supplied by the Army Materiel Systems Analysis Agency (AMSAA) is used in SABRES II to determine the probability of incapacitation. Figure 2 shows the differences in incapacitation probabilities as calculated by the DOD methodology developed for a

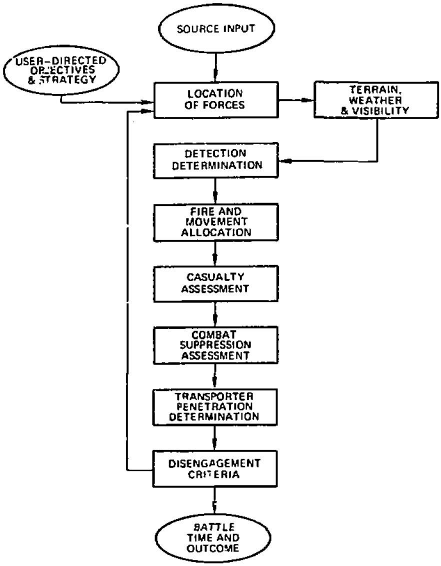


Figure 1. The SABRES Models

TABLE 1

COMPARISON BETWEEN SABRES I AND II

SABRES I	SABRES II
Flat terrain	Detailed terrain and vegetation
Rectangular targets	Target figures which account for posture and cover
Detection as a function of range	Detection as a function of contrast, range, weather, and visibility
No movement	User directed movement
Barrier penetration not included	Barrier penetration included

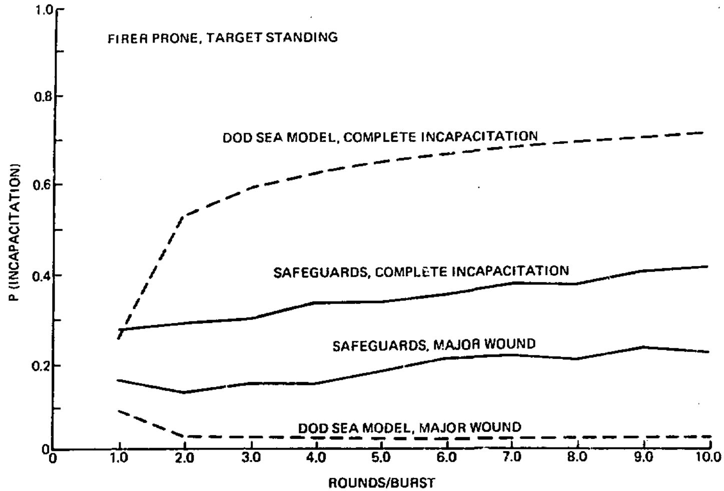


Figure 2. A Comparison of Probability of Incapacitation Assessments

model of small unit combat in South East Asia (SEA) [6]. The two methodologies principally differ in that the safeguards model offers more resolution in the treatment of posture and lethality assessment. The example shows that the differences can become large. This could significantly effect various measures of battle performance. In particular the SEA methodology could result in greatly reduced battle times.

In the later stages of the battle, it is possible that the adversary force may have taken control of the transporter and immediately surrounding area. Under these circumstances while attempting to remove the SNM from the transporter they may still have to contend with hostile fire from escort vehicle personnel and LLEA response forces. Additionally the transporter may contain armor and deterrent systems to create a barrier against forceable entry. Such barriers delay the adversary providing time for further re-enforcements to arrive. SABRES II contains a dedicated model, BARS, to simulate the penetration of the barriers and removal of the SNM. The BARS model has been used to investigate the sensitivity of the barrier penetration time to variations in the strategies which the adversary force and defending force might employ, and to the combat performance of the two forces.

In the BARS scenario, the adversaries divide their forces between the tasks of working on the barrier and providing covering fire. The defending forces divide their firepower between the barrier workers and the covering firers. The model chooses the actual allocation strategies for the adversaries and the escorts by structuring the problem as a two-person game in which the objective of the adversary force is to minimize the barrier penetration time while that of the defenders is to maximize it. The fraction of the barrier penetrated in any specific time step is calculated according to the number of adversaries allocated to the task and the level of their performance as determined from their suppression state. A state transition suppression model for the behavior of individuals under combat stress is used in BARS. It includes the degradation under fire of the combat performance or barrier penetration capability of an individual.

A major limitation in the BARS model lies in the fact that combat stress and its influence on suppression phenomena is not well understood. Extremely little information exists concerning the performance of individuals while suppressed. Thus, the principle value of BARS is in identifying the relative influence of suppression through sensitivity studies. An example of these relative performance analyses is given in the next section.

Example Analysis

The road transit evaluative methodologies developed by Sandia have been used to evaluate the impact on convoy security of changes in physical protection requirements. The SOURCE code can be used to investigate the contributions to security of alternative convoy configurations, tactics when ambushed, and equipment against a wide range of different adversary threats. For example the use of SOURCE to examine the relative benefits of light vehicle armor is shown in Table II. In this example a simulated ambush of a convoy consisting of seven guards in two escort vehicles and one transporter was examined. As soon as an attack was recognized or an emergency signal received the vehicles were under orders to either rendezvous around the transporter, stop immediately outside hostile fields of fire, or a combination of the two tactics in which the remote escort would stop and the other escort would rendezvous with the transporter as it attempted to escape. Table II contains a summary of the impact on personnel survival of armoring different combinations of convoy vehicles. The measure chosen as the basis for the comparison was either the probability of three or more guards surviving or the transporter escaping. In the example scenario the tactic of stopping outside hostile fields of fire (column 1) is preferable to a rendezvous of both escorts around the transporter (column 2). Table II indicates that with proper tactics armoring the transporter and close escort offers significant benefits while the further benefit derived from armoring the remote escort appears to be marginal. In comparing tactics the defense of the transporter after the initial attack must also be considered. Wide scattering of guards which could result from the stop tactic may or may not necessarily be beneficial depending on their tactics.

The SABRES I combat model can be used to study the relative value of alternative tactics the defenders could employ and the weapon systems they could possess. The following restrictions in SABRES I apply to the examples given below: (1) all battlefield participants are in fixed position throughout the engagement, (2) every participant detects every other participant throughout the battle, (3) there are no re-enforcements, and (4) the battle is terminated when all individuals on one side have sustained either a major wound or death. These limitations will not exist in SABRES II.

One possible defense tactic is whether or not to engage the adversary at close quarters. Figure 3a summarizes SABRES I simulations which indicate that moderate increases in the distance between defenders and adversaries might significantly increase the time duration of battles. Thus if the objective of surviving guards is to prolong the battle until reinforcements arrive, harassment from a distance may be a reasonable tactic and should be emphasized in guard training. Figure 3b shows, however, that unless additional defenders arrive, extended battle time by itself may not increase the likelihood of defender success.

The SABRES I code can be used to address the value of the weapons supplied the guard force. To demonstrate this capability the relative values of the M-16 and M-14 rifles have been examined. Both the SOURCE and the SABRES analysis showed that the M-16 was most effective when used in the single shot mode. Due to the inaccuracies and rapid expenditure of

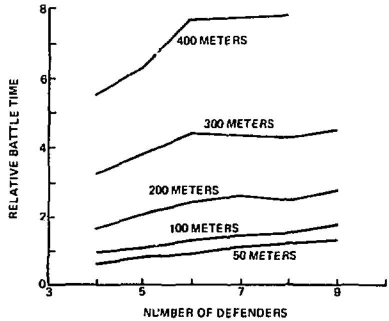
TABLE II

THE BENEFITS OF LIGHT ARMOR

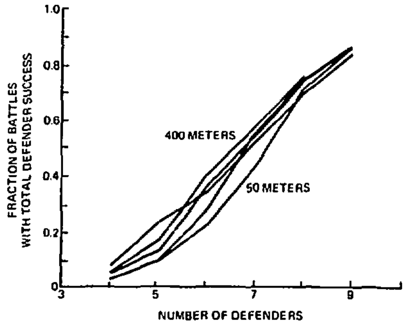
Figure of Merit: Probability of three or more guards surviving or transporter escape

Configuration: Remote escort, transporter, close escort; 3 + 2 + 2 = 7 guards

	Tactics		
Armored Vehicles	Stop	Rendezvous	Stop, Escape, Rend.
None	0.50	0.05	0.50 (0.1E)
Transporter	0.75	0.15	0.75 (0.4E)
Transporter and Close Escort	0.85	0.25	0.90 (0.4E)
All	0.90	0.45	0.90 (0.4E)



3a.

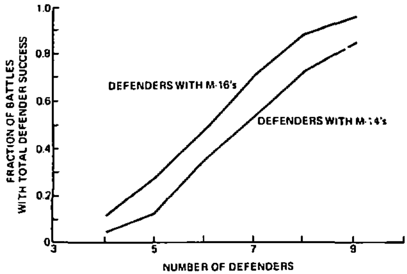


3b.

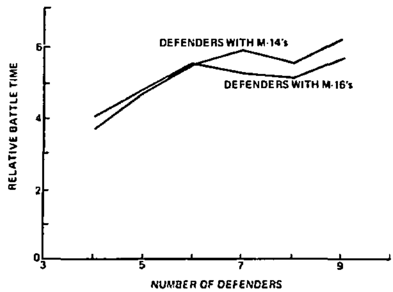
Figure 3. Sensitivity to Separation Distance

ammunition as well as legal questions automatic weapons may not be desirable. The result in Figure 4a given by the SABRES I conflict model shows that M-16's may reduce the size of the guard force required to achieve a given level of effectiveness by about one man compared to a force with M-14's. This corresponds to an uncertainty in the adversary force size of about one man. Thus, the physical protection provided by the guard force may not be highly dependent upon the rifle selected. This is further emphasized by the fact that the length of the battle as shown in Figure 4b may be fairly independent of the rifle system used.

The barrier penetration simulation model, BARS, can be used to investigate the sensitivity of the safeguards system to the performance of personnel under the stress of combat. An example of the sensitivity studies possible is shown in Figure 5. The curves represent the average fraction of the barrier penetrated at any time for 100 simulations. Shown in the figure are the curves for (1) the base case in which the group effectiveness of barrier workers is high and all escort and attacker attributes are identical, (2) the case in which the escorts perform poorly while suppressed, and (3) the case in which the barrier workers perform equally poorly while suppressed. The BARS model indicates the importance of escort suppressed performance. The attackers compensate for poor barrier worker suppressed performance by avoiding barrier work early in the battle and concentrating their force to eliminate the escorts.



4a.



4b.

Figure 4. Impact of Defender Weapon Systems

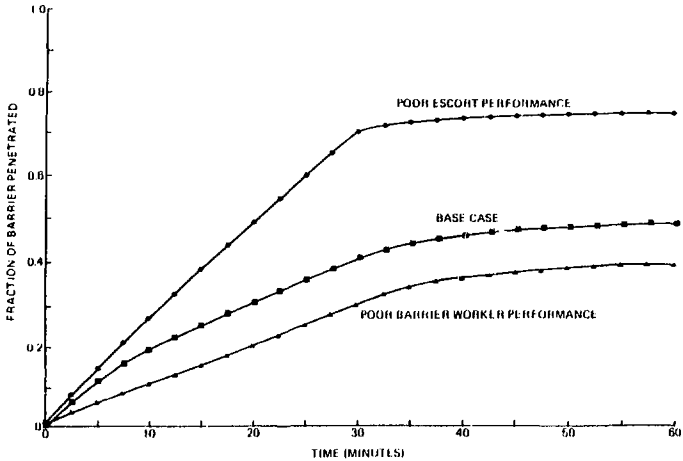


Figure 5. BARS Output

With the added features being incorporated into SABRES II it will be possible to analyze the effects of terrain on combat. The terrain model is a modification of the one originally developed for the DOD Southeast Asia combat model [6]. It includes a capability for representing general land contours as well as specific obstacles such as large boulders, etc. Vegetation can also be handled. A top view of the terrain features associated with a section of one of the contour maps used in the Sandia developed tactical board game [7] is shown in Figure 6. Items represented include rock formation, cliffs, roads, trees, and brush. The user can select the positions for the defenders and adversaries on a CRT display at a computer interactive terminal. A possible selection is shown in Figure 6. The SABRES II code will then simulate a prescribed period of combat; detection, fire allocation, casualty assessment, suppression and barrier penetration. A status report of all personnel at the end of the period as shown in Figure 7 is one possible output. The user can then update his tactics and "play" another period of combat. Thus SABRES II will not only be useful in conducting general trade-off studies but also as a protective force training tool.

Summary

A series of evaluative methodologies has been developed for analyzing the physical protection of road transportation systems. SOURCE examines the initial ambush before the protective forces can return fire. The SOURCE model has been used to investigate the relative value of alternative convoy configurations, tactics, and equipment. The SABRES series of models treat the two sided engagement that follows the surprise attack. SABRES I has been used to examine the general sensitivity of battle outcome to factors such as force size, exposure, weapon characteristics, and engagement tactics. Many of the SABRES I shortcomings are being eliminated in the second phase of development, SABRES II. The upgraded version

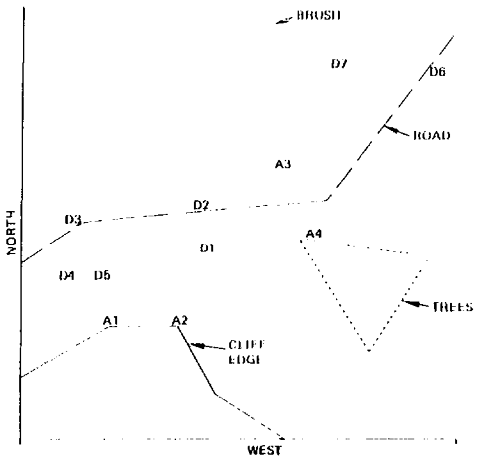


Figure 6. Vegetation, Obstacles, and Battle Participants AMBUSH Map 'A' Surface

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COMPLETED 1TH PARTIAL RUN,   TIME 60.00 SECONDS
STATUS OF ADVERSARY
  1   INCAPACITATED
  2   KILLED
  3   KILLED
  4   HEALTHY                  200 ROUNDS LEFT        10 IN MAGAZINE
      SUP STATE IS [illegible] POSTURE IS 2           FIRING STATUS IS 3
      DETECTS DEFENDER 3, 5, 6, 7
STATUS OF DEFENDER
  1   HEALTHY                  200 ROUNDS LEFT        20 IN MAGAZINE
      SUP STATE IS 1           POSTURE IS 1           FIRING STATUS IS 3
  2   HEALTHY                  200 ROUNDS LEFT        20 IN MAGAZINE
      SUP STATE IS 1           POSTURE IS 1           FIRING STATUS IS 3
  3   HEALTHY                  200 ROUNDS LEFT        10 IN MAGAZINE
      SUP STATE IS 1           POSTURE IS 2           FIRING STATUS IS 3
      DETECTS ADVERSARY 1, 3, 4
  4   KILLED
  5   HEALTHY                  200 ROUNDS LEFT        10 IN MAGAZINE
      SUP STATE IS 1           POSTURE IS 2           FIRING STATUS IS 3
      DETECTS ADVERSARY 1, 4
  6   HEALTHY                  200 ROUNDS LEFT        10 IN MAGAZINE
      SUP STATE IS 1           POSTURE IS 2           FIRING STATUS IS 3
      DETECTS ADVERSARY 1, 2, 3, 4
  7   KILLED
```

Figure 7. SARRES II Combat Status Report

accounts for terrain, detection, barrier penetration, and movement. The capability of introducing response forces into the conflict will also be added to future SABRES models. A method for approximating response force distributions has been developed by Sandia Livermore and is described in a companion paper [3].

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