A SECURITY FORCE-ADVERSARY ENGAGEMENT SIMULATION*

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ABSTRACT

A dynamic simulation of a security force-adversary engagement has been developed to obtain a better understanding of the complexities involved in security systems. Factors affecting engagement outcomes were identified and interrelated to represent an ambush of an escorted nuclear fuel truck convoy by an adversary group. Other forms of engagement such as assault and skirmish also can be simulated through suitable parameter changes.

The dynamic model can provide a relative evaluation of changes in security force levels, equipment, training, and tactics. Continued application and subsequent refinements of the model are expected to augment the understanding of component interaction within a guard based security system.

INTRODUCTION

The purpose of this paper is to report on a dynamic simulation of security force-adversary engagements developed during the U. S. Nuclear Regulatory Commission's Special Safeguards Study.

The safeguards program is concerned with providing protection measures against unauthorized use of special nuclear materials (SNM) and sabotage of nuclear facilities. The foundation of any security system is the force base provided by guards and response forces. Sensors and alarms serve only to alert forces of an overt or covert attempt at sabotage of facilities or theft of special nuclear material. Barriers, containers, vaults, etc., can only delay progress until force can be applied to prevent the success of an attempt. Such statements are meant not to detract from the vital roles of these components but to focus on the importance of the security force--the most difficult to analyze (and consequently least understood) security system component. The need for some means to quantify security force performance becomes apparent when investigating system design tradeoffs or allocating improvement funds to existing systems.

METHODOLOGY AND RESULTS

Performance Measures

Current thinking classifies security forces as either local security or response forces. Local security consists of either plant guards or convoy escorts. The purpose of local security is to provide immediate measures to oppose any adversary action. In the event an adversary has exceeded local security capabilities, the guards must delay the attempt until a more capable response force can arrive. The response force can be a dedicated regional force, alerted off-duty guards, or local law enforcement. This division of forces is based on the premise that there are economic gains to be made by sizing local security forces to delay the maximum adversary force for a specified time rather than to defeat it. For an engagement simulation to explore tradeoffs between local security and response forces, two performance measures are of interest: (1) engagement duration, and (2) engagement outcome.

Model Description

A dynamic simulation of a security force-adversary engagement was developed to obtain a better understanding of the interrelationships between factors affecting plant and transit security force performance. Factors known to play a role in force engagements were identified and interrelated as shown on the causal diagram in Figure 1. This particular diagram represents an ambush of a truck convoy. However, other forms of engagement such as assault and skirmish also can be simulated through suitable parameter changes.

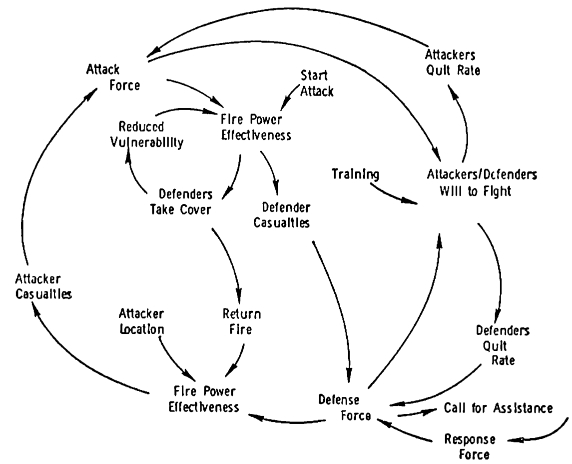

Figure 1. Ambush Causal Diagram

The following is a verbal description of the diagram:

The attack begins with a defined adversary-force level and firepower effectiveness which causes casualties in the defense force. The defenders radio for help and then take cover to reduce their vulnerability to the attackers. As the defenders take cover, they return fire which is ineffective at first but improves as attacker positions are located. The engagement continues with both sides taking casualties. After some period of time, the response force arrives to aid the defenders. An additional factor called morale also comes into play. Depending on which force is badly outnumbered that force begins to lose the will to fight; and quitters, along with sustained casualties, quickly deplete the force.

Figure 2 represents typical convoy ambush simulation results.

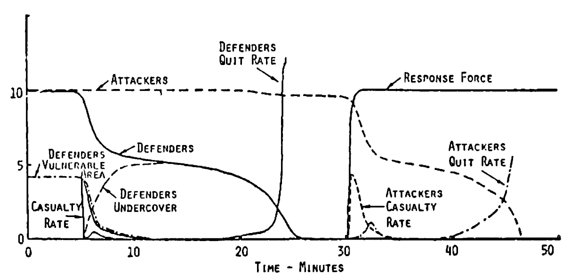

Figure 2. Typical Convoy Ambush Results

Parameter Relationships and Performance Sensitivity

Before discussing some of the functions utilized to obtain the results shown in Figure 2, it should be noted that many of the relationships are difficult to quantify and so are either based on limited experience or intuition. As such, many would be quick to discount the potential of such a model on the basis of inadequate data. However, the first purpose of a model should be to shed light on the general nature and relative importance of the variables. Such questions should be answered before expending time and money to gather data. Furthermore, since decisions will be made concerning both plant and transit security forces, the

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use of a mathematical model, even if it represents only what is believed to be the nature of the situation, can be no worse than the mental decision process. In fact, constructing the model forces one to describe openly mathematical relationships, to acknowledge inconsistencies, and to critique results. It also offers a straightforward solution to otherwise hard-to-envision multidimensional interactions.

The following equations, written in the DYNAMO simulation language, Reference 1, are those representing the defender. There is a similar set describing the attacker as each has the capability of playing either ambusher or ambushee. The equations are presented in this manner to avoid any ambiguity and to maintain the openness that is essential in exploring areas which lack a data base. Additional descriptions and illustrations are provided for those unfamiliar with DYNAMO.

An example of a 7-man adversary force ambushing a 10-man security force is maintained throughout the remainder of the discussion to indicate performance sensitivity to various parameters.

The defense force level equation is the simple difference equation:

DP.K = DP.J + (DT)*(DRS.JK - DLR.JK) (1)

where

DP - Defense force, men (10.0)**
DRS - Defense response force arrival rate, men/minute (0)**
DLR - Defense loss rate - limited, men/minute
DT - Delta time-computation interval, minutes.

The defense response force arrival rate is represented by the following expression:

DRS.KL = PULSE(RDCALL/DT, SDDEL, 1000) (2)

SDDEL = STRTF + CDDEL + RDDEL (3)

where

DRS - Defense response force arrival rate, men/minute
SDDEL - Sum of defense response force delays, minutes
STRTF - Start time of fight, minutes
CDDEL - Defense communications delay, minutes
RDDEL - Defense response force delay, minutes
RDCALL- Defense response force, men.

The function in Equation 2 simulates the arrival of the response force as a unit which has been found to be more effective than a sporadic accumulation of men.

The defense loss rate (DLR) consists of the defense quit rate (DQR) and the defense casualty rate (DCR).

The quit rate function serves to establish a point (breakpoint) in the engagement where one side decides that there is little benefit in continuing and starts to leave the engagement. Utilizing such a function provides a means of considering engagements other than those ending in annihilation of one side.

The quit rate is described by the following table function:

DQR.KL = TABHL(TQRVP, DAR.K, 0., 5., 1.) (4)
TQRVP = 0/0/1/4/9/16**

where

DQR - Mean-defense force quit rate, men/minute
TQRVP - Table function for quit rate, men/minute
DAR - Attack to defense force ratio, dimensionless.

**Base case parameter values.

The quit rate function is essentially that used by Schaffer, Reference 2. Figure 3 shows the quit rate as a function of the attack to defense force ratio.

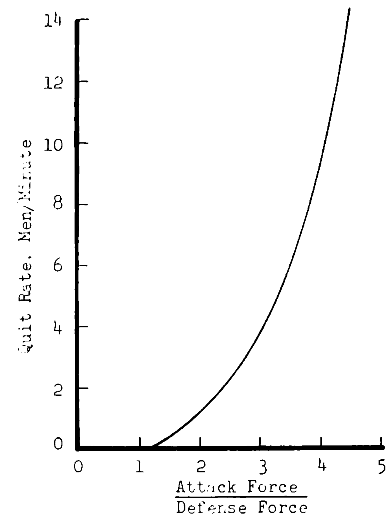

Figure 3. Quit Rate Based on Force Ratio

The attack to defense force ratio (DAR) values are multiplied by QM1 and QM2 to indicate stress and training as follows:

DAR.K = (AP.K/(DP.K + .001))* (CLIP(QM1, QM2, DCR.JK, .5) (5)
QM1 = 1.
QM2 = .5

where

DAR - Attack to defense force ratio, dimensionless
AP - Attack force, men (7.0)**
DP - Defense force, men
QM1 - Quit rate multiplier under stress conditions, dimensionless (1.0)**
QM2 - Quit rate multiplier due to training, dimensionless (0.5)**
DCR - Defense casualty rate, men/minute.

QM2 was set at 1 for low, 0.5 for medium, and 0.25 for high motivation.

Figure 4 indicates the variation in engagement duration due to changes in motivation for a change of force ratios. The win-lose transition force ratio of 0.65 is compatible with the 0.5 military rule of thumb for ambushes. As a consequence of being surprised while in an exposed posture, the ambushee initially suffers high losses. Such losses can tip the balance of forces in favor of the ambusher even when initially outnumbered nearly 2 to 1. Increasing force ratios beyond the win-lose transition point only increases the ambusher's marginal strength to shorten engagement time. The analogous situation holds for the ambushee when decreasing the force ratio below the transition point, for now the ambushee's marginal strength is increasing.

The casualty rate function is

DCR.KL = AARFC.K*AFPCH*(1 - EXP(-DPVAT.K/ (6.28*ASSRD.K*ASSRD.K))) (6)

where

DCR - Defense force casualty rate, men/minute
AARFC - Mean-attack force rate of fire, shots/minute (5.0.AP)**
AFPCH - Probability of attack force casualty given a hit, dimensionless (0.5)**
DPVAT - Mean-defender's vulnerable area, square feet
ASSRD - Mean-attack force single shot radial dispersion, feet (2.0)**.

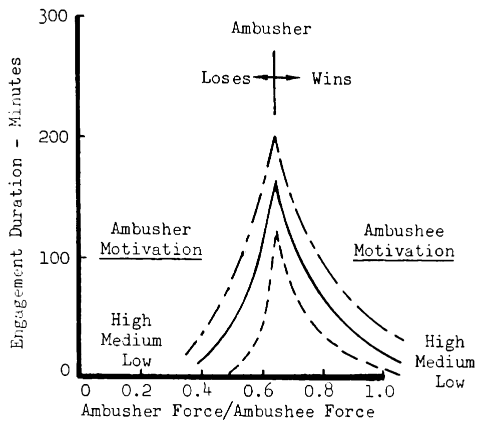

Figure 4. Effects of Motivation and Force Ratio on Engagement Duration

The first term in Equation 6 is the attack force average rate of fire, AARFC. Its counterpart in the defense force is DARFC. When the role of ambusher, AARFC is the individual rate of fire multiplied by the attack force level. As an ambushee, AARFC equals the individual fire rate multiplied by the number of attackers under cover.

For the base case engagement, Figure 5 indicates how the engagement duration changes with the individual rate of fire. The duration passes through a peak which coincides with the ambusher's win-lose transition as in Figure 4.

This peak is interesting since it is unexpected. For the base case force ratio of 0.7, a transition from ambusher win to ambusher lose could be expected since the casualty rate is a direct function of fire rate. As previously explained, the conditions for which the balance of forces tip in favor of the ambusher is determined ideally by the number of ambushee casualties that occur during the initial phase of the ambush. Reducing the fire rate would reduce these initial casualties until at some point the ambushee can survive an initial attack with sufficient force remaining to win. Any further reduction of the fire rate, however, should result in only lengthening the engagement by reducing the casualty rates on both sides throughout the engagement.

The defender's vulnerable area (DPVAT) is defined by the following table function.

DPVAT.K = TABHL(TVAVC, UCR.K, 0., 1, .2) (7)
TVAVC = 4/1.9/.9/.4/.2/.1**

where

DPVAT - Mean-defender's vulnerable area, square feet
TVAVC - Table for target vulnerable area, square feet
UCR - Under cover ratio-dimensionless.

Figure 6 represents the vulnerable area as a function of the force under cover to total force ratio.

**Base case parameter values.

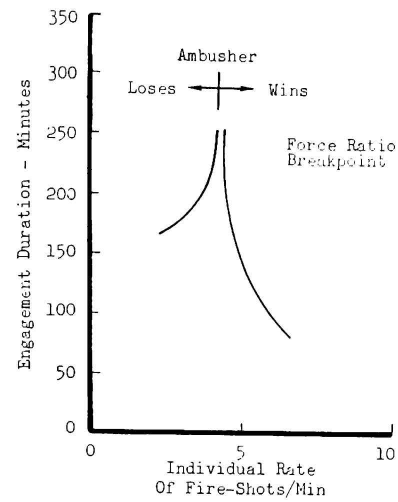

Figure 5. Influence of Fire Rate

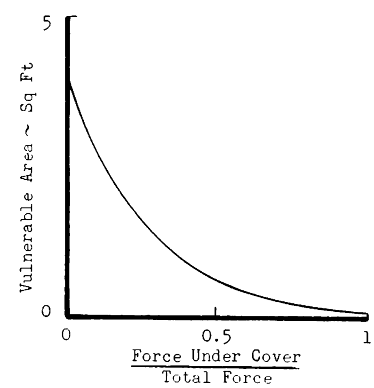

Figure 6. Target Area Reduction with under Cover Ratio

Figure 7 indicates the effect on engagement duration of changes in both the initial surprise average vulnerable area of 4 square feet and the under cover average value of 0.1 square feet. The ambusher always wins for the range of values shown in Figure 7. Accordingly, any further increase in the ambushee's initial vulnerable area can only add to the ambusher's advantage and shorten the engagement. On the other hand, most of the ambusher's advantage ends within the first few minutes of the engagement when the surviving ambushees are under cover. Therefore, one would expect prolonged engagement times to be more sensitive to the under cover vulnerable area as indicated in Figure 7.

Starting from ambush initiation, the number of defenders under cover is described by the following function:

UCD.K = SMOOTH(DPS.K, DCD.K) (8)

where

UCD - Defenders under cover, men
DPS - Defense force at start of fight, men

DCD - Defense force cover delay, minutes (3.0)**.

This is the first order exponential delay function. Once the fight is initiated, DPS is continually updated to the number of surviving defenders.

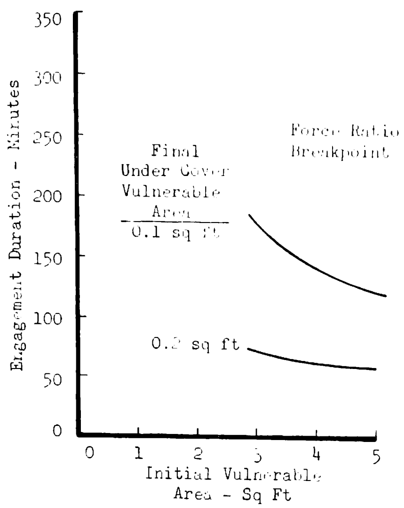

Figure 7. Effects of Initial Vulnerable Area

Since the defender's vulnerable area and the number of defenders returning fire, as indicated on the causal diagram, is determined from the results of Equation 8, the variation in engagement duration with the delay time constant, DCD, is shown in Figure 8 for an ambusher to ambushee force ratio of 0.7. Note that a rapid increase in engagement duration again coincides with the ambusher win-lose transition region just as in Figures 4 and 5.

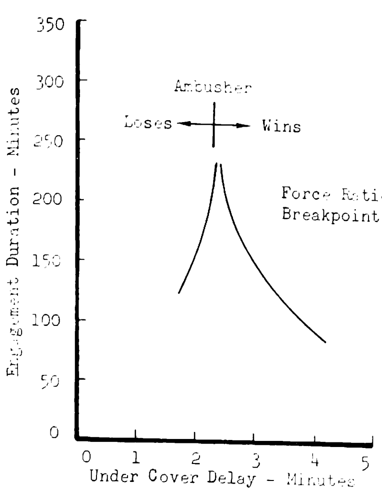

Figure 8. Under Cover Delay Effects

The accuracy of the defender's returning fire is another important effectiveness factor and is shown as a fixed value (DMIND) when the defense is ambushing or a table function when the defense is being ambushed.

DSSRD.K = CLIP(TABHL(TRDVL, ARL.K, 0, 1, .2) DMIND, .5, DREG.K) (9)

TRDVL = 50/40/30/20/10/2**

where

DSSRD - Mean-defense force single shot radial dispersion, feet
TRDVL - Table for radial dispersion of fire, feet
ARL - Ratio of attack force located, dimensionless
DREG - Defense mode switch, ambushee = 0, ambusher = 1
DMIND - Defense force minimum dispersion of fire, feet (2.0)**.

The table function is an attempt to represent changes in accuracy with attack force location. Figure 9 shows the dispersion of fire as a function of force located to total force ratio.

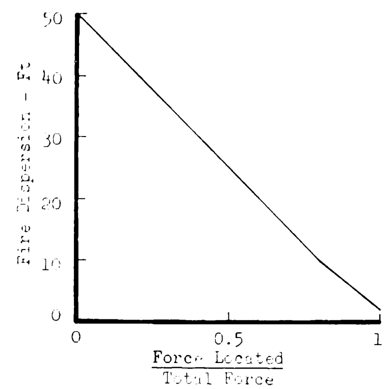

Figure 9. Accuracy As Effected by Force Location Ratio

To determine the number of attackers located, a third order information delay is used:

LOCA.K = DLINF3(APS.K, ALD) (10)

where

LOCA - Attackers located, men
APS - Attack force at start of fight, men
ALD - Attackers location delay, minutes (5.0)**.

This function which is essentially three sequential first order exponential delay functions each having the time constant ALD/3 is shown in Figure 10. The shape of this function fits intuition--a slow initial rate of location followed by a rapid rate once the situation becomes recognized and finally a low rate of locating the last few attackers.

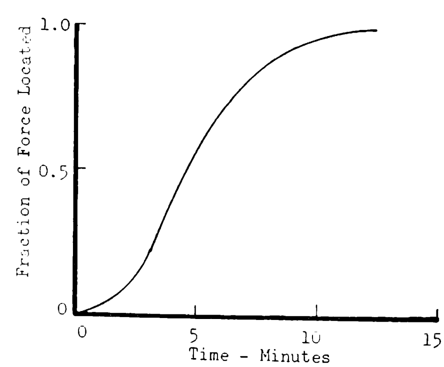

Figure 10. Rate of Force Location

** Base case parameter values.

Figure 11 shows the sensitivity of engagement duration to the attacker location delay time constant, ALD. The ambusher was the winner over the range of values plotted in Figure 11. Consequently, any increase in target location time can only degrade the ambushee's defense and so shorten the engagement.

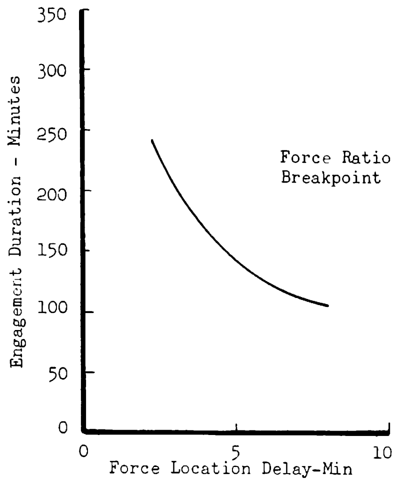

Figure 11. Duration Changes Due to Location Delay

The minimum fire dispersion contributes to the ambushers effectiveness throughout the engagement and to the ambushees effectiveness after the ambushers are located. The fact that engagement duration is very sensitive to accuracy of fire as shown in Figure 12 is not too surprising. However, the extreme peak indicated at slightly over 2 feet dispersion is unexpected. This peak also occurs at the ambusher win-lose transition.

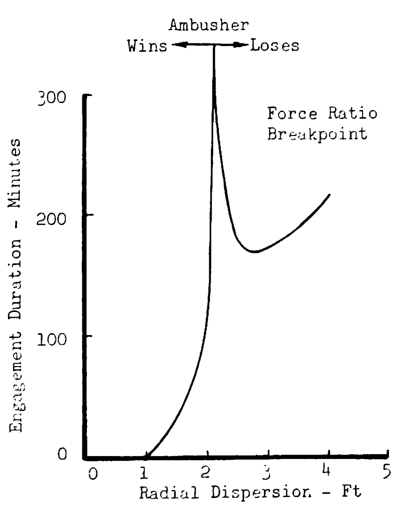

Figure 12. Influence of Fire Accuracy On Engagement Duration

Further investigation revealed that the peaks shown in Figures 5, 8, and 12 are caused by the particular engagement terminating rules used (the quit function previously discussed). At the win-lose transition point, because the model is continuous, the force ratios remain very nearly equal down to small fractional forces, neither side is outnumbered, and the engagement lasts a long time.

Subsequent research into historical battle data, References 3 and 4, indicate that large unit engagements (battalion size and greater) have a high probability of terminating by the time either side has reached approximately 30% casualties. Although it is suspected that engagements probably terminate for reasons other than casualty fraction, no supporting historical data has been found. A number of military combat simulations were found to employ casualty fraction rules to break the engagement.

Since this simulation is concerned with small numbers of participants, all actively engaged, as compared to large organization engagements, where only a fraction are actively in combat, there is an intuitive notion that casualty fractions much higher than 30% should be applicable to small engagements. While this may be true, individual groups probably differ widely as to their breakpoint.

Applying the casualty fraction approach to this simulation, with the side reaching 50% casualties first being the loser, produced marked changes as shown in Figures 13, 14, 15, 16, 17, and 18. Comparing each of these figures with their force ratio breakpoint counterparts, the following differences are noted:

- In general, utilizing the casualty fraction as a breakpoint to terminate the engagement produced shorter engagement times than obtained with the force ratio criterion. As the acceptable casualty fraction increased, engagement durations approached those obtained with the force ratio criterion.
- The sensitivity of engagement duration to model parameter changes was notably less when using the casualty fraction as a breakpoint.
- No pronounced peaks were observed at win-lose transition points when terminating engagements at a specified casualty fraction.

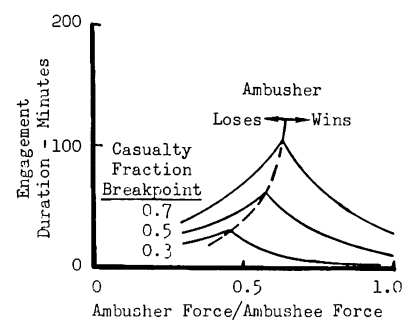

Figure 13. Force Ratio Effects

CONCLUSIONS

A relatively simple deterministic engagement model has been developed to permit the extensive parametric variations necessary for investigating the sensitivity of both engagement duration and outcome. Although limited by a paucity of data to relative evaluations of security system changes, the model has provided valuable insight into system interactions.

These results from this model thus far indicate the importance of engagement termination methods (breakpoint functions) and their impact on security performance dynamics. A method of termination based only on the ratio of surviving opposing forces is questionable. Utilizing this method causes both unrealistic peaks in engagement duration and results corresponding to very high casualty fractions (casualties/initial force).

On the other hand, determining breakpoints on the basis of casualty fractions (less than 0.7) appears acceptable in that (1) no peculiar results were observed,

(2) support can be derived from large scale battle statistics, (3) it has been utilized in military combat simulations, and (4) it could reflect the maximum price a resource limited adversary may be willing to pay for a given objective.

The experience gained from this model is being applied to a stochastic version of the model which is currently under development.

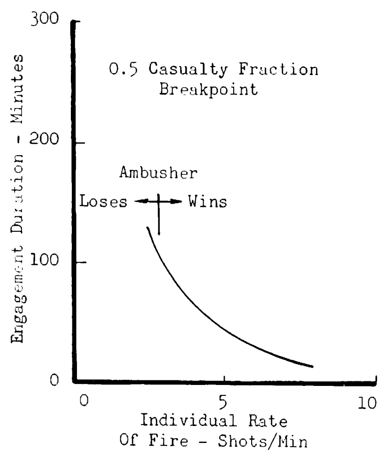

Figure 14. Influence of Fire Rate

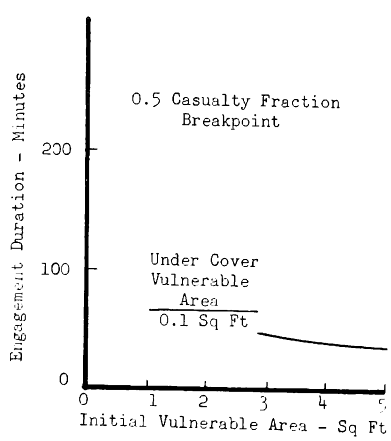

Figure 15. Effects of Initial Vulnerable Area

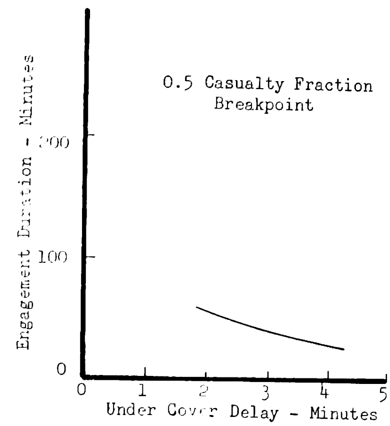

Figure 16. Under Cover Delay Effects

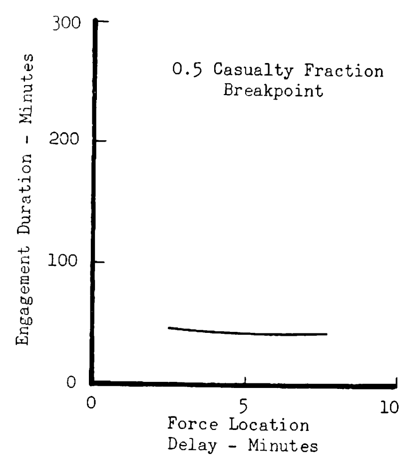

Figure 17. Duration Changes Due to Location Delay

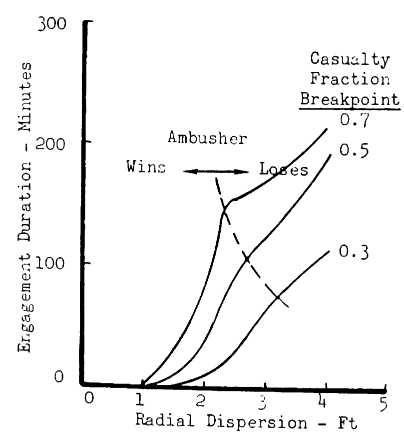

Figure 18. Fire Accuracy Effects on Engagement Duration

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