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Training Adaptive Decision-Making: Laboratory Directed Research and Development Final Report

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Adaptive Thinking: Laboratory Directed Research and Development Final Report

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Abstract

Adaptive Thinking has been defined here as the capacity to recognize when a course of action that may have previously been effective is no longer effective and there is need to adjust strategy. Research was undertaken with human test subjects to identify the factors that contribute to adaptive thinking. It was discovered that those most effective in settings that call for adaptive thinking tend to possess a superior capacity to quickly and effectively generate possible courses of action, as measured using the Category Generation test. Software developed for this research has been applied to develop capabilities enabling analysts to identify crucial factors that are predictive of outcomes in fore-on-force simulation exercises.

ACKNOWLEDGMENTS

The authors acknowledge Dr. Gabriel A. Radvansky of the Psychology Department at the University of Notre Dame and students working under his direction for data collection and analysis presented within the current report.

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NOMENCLATURE

ACT	American College Testing
DANTE	Design and Assessment of Neutralization Technologies Evaluator
DOE	Department of Energy
SAT	Scholastic Aptitude Test
SNL	Sandia National Laboratories

1. INTRODUCTION

The capacity for adaptive thinking has been identified as critical to the success of personnel within military and other domains (Joung, Hesketh & Neal, 2006; Mueller-Hanson et al., 2009). Yet as illustrated by the following statement from a report by Mueller-Hanson et al. (2009) to the Army Research Institute, the ability to objectively measure and train adaptive thinking is uncertain, "The need for self-aware and adaptive leaders in the Army has been widely documented; however, the study of adaptability and how it is developed is still relatively new."

Studies conducted to assess adaptive thinking have generally relied on definitions of adaptive thinking that reflect the capacity to make effective decisions within the context of changing environmental circumstances. For example, Joung et al. (2006) defined adaptive thinking as the "capacity to cope with changing work requirements, or novel or unusual situations." Research suggests that adaptive thinking may involve a composite of various factors that include: cue recognition, sensemaking, planning and forecasting, and metacognition (Lazzara et al., 2010). Furthermore, adaptive thinking may manifest differently in operational and training settings (Tucker & Gunther, 2009).

The current report summarizes the findings and accomplishments of a three-year Laboratory Directed Research and Development project focused on adaptive thinking. The objective has been to develop techniques to measure adaptive thinking within a training environment. Such techniques would allow individuals and teams to be assessed, enabling trainers to intervene to provide direction and guidance to improve adaptive thinking performance. Much of this research has leveraged previous technical achievements which have provided capabilities for automated performance assessment (Stevens et al., 2009; 2010). These capabilities have been applied to transition the research accomplished through this project to extend the current capabilities of Sandia National Laboratories to conduct simulation-based assessments of facility physical security.

2. MEASUREMENT OF ADAPTIVE THINKING

We have defined adaptive thinking as "the capacity to recognize when the environment has changed such that strategies that had previously been successful may no longer be successful." This definition emphasizes an individual's awareness of their environment and capacity to map behavioral options onto environmental contingencies. For example, a negotiator may recognize that their counterpart is growing eager to close a sale and use this opportunity to accept the current price on the condition that their counterpart throws something extra into the deal.

There are several key implications of this definition:

> 1. What is adaptive may depend on one's knowledge or skill. For example, a conservative course of action may be appropriate for someone lacking the skills necessary to take advantage of certain opportunities, yet inappropriate for a more skilled performer.
>
> 2. Adaptive thinking implies a changing environment and consequently, behavioral decisions resulting from adaptive thinking may be distinguished from those occurring within a relative constant environment as a product of performance monitoring and associated actions to improve or correct performance.
>
> 3. Adaptive thinking is distinct from divergent or creative thinking since the behavioral decision does not necessarily involve a novel solution, although success may sometimes hinge on some degree of divergent thinking.
>
> 4. Adaptive thinking should generally correlate with outcome measures, although the correlation may be weak since good outcomes may sometimes occur in the absence of adaptive thinking (e.g., a successful outcome may be achieved, yet at the expense of an undue amount of effort).

For the current project, adaptive thinking was assessed within the context of maritime operations. Subjects were tasked with piloting a vessel while applying the U.S. Coast Guard Rules of the Road to respond to changing environmental conditions. Test scenarios were presented using SubSkillsNet, a desktop simulation that presents students with realistic controls and displays for an array of tasks associated with submarine command center operations. For each scenario, performance was assessed on the basis of whether or not subjects altered their course of action within specified time windows. Thus, the assessment of adaptive thinking was based on a decision matrix (See Figure 1) that took into account that a given change in the environment may or may not prompt a change in strategy.

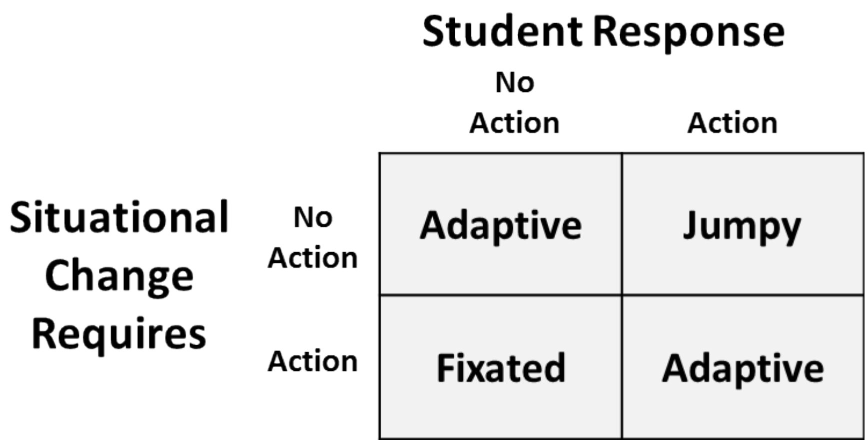


Figure 1. Decision matrix for assessing performance with respect to adaptive thinking.

A second objective of the current project was to identify cognitive aptitude measures that are predictive of adaptive thinking. As shown in Figure 2, a conceptual model was developed that encompassed cognitive processes believed to be key to adaptive thinking, with cognitive aptitude measures identified for each component of this model.

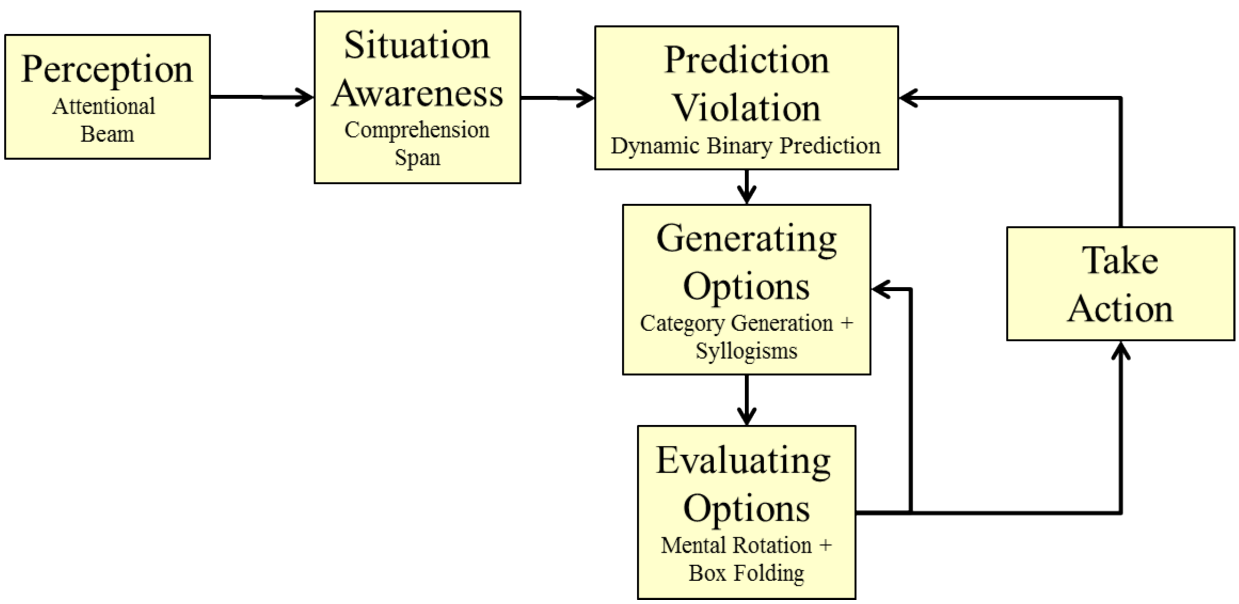


Figure 2. Notional model of cognitive processes underlying adaptive thinking.

The following sections describe the experimental paradigm that was developed to assess adaptive thinking within the context of maritime navigation and data collection undertaken at the University of Notre Dame using this experimental paradigm.

2.1. Subjects

Subjects consisted of 30 undergraduates recruited from the student population of the University of Notre Dame.

2.2. Materials

Scenarios used to assess adaptive thinking were implemented and presented using SubSkillsNet. Figure 3 provides an illustration of one of these scenarios. There were six scenarios designated as "active" based on their being a change in the environment that should have prompted subjects to adjust their course of action. The following describes each of these scenarios:

Fog Bank: As the subject follows a line of buoys, there is a gradual decrease in visibility requiring a reduction in speed.

Navigate Channel: The subject is instructed to follow a lead vessel that makes an unannounced turn.

Traffic Lanes: The subject must recognize and respond to a sailboat that crosses their path.

Follow the Leader: The subject is instructed to maintain a constant distance from a lead vessel which unexpectedly slows down.

Port Entry: After turning to head into port, the subject must recognize and respond to a vessel that crosses their path.

Port Exit: The subject must adjust coarse to avoid a slow-moving vessel in its path.

There were two additional scenarios in which there was a change in the environment, however there was no need to change course, and actually, a change in course was disadvantageous. These scenarios were referred to as *passive* and are described as follows:

Shoreline: The student is instructed to proceed along the coast. There is a vessel in the distance that slowly moves out of the way.

Fishing Activity: There are several fishing boats in the immediate path, but they are all on a course to move out of the way.

Figure 3. In this scenario, the subject must recognize and avoid a sailboat that crosses their path.

The cognitive aptitude measures included the following:

Attentional Beam. This is a measure of visual attention. Participants first gazed at a fixation point for 600ms. Then they viewed a rotary array of dots, one of which was colored, for 30ms. Afterward, a visual mask of random lines was presented for 600ms. Next, they indicated in which of the eight directions the darkened circle appeared.

Comprehension Span. This is a measure of working memory. Participants were given two sentences to read. Their task was to indicate whether each sentence was sensible. After both sentences had been presented, participants were asked to recall the last word from each of the sentences.

Dynamic Binary Prediction. This task is a variant on the binary decision making task used to assess decision making and learning. Over a series of trials, participants were shown two lights and asked to pick which light they thought would be illuminated. Unbeknownst to the participants, there was a fixed probability with which the lights were illuminated. During a series of trials, the participants should have learned this probability and picked the light that had the greater chance of being illuminated. However, in the dynamic version of this task, at a given point during a series of trials, the probability for the two lights was reversed.

Category Generation: This task assesses the ability to recall options from memory. Subjects were given a category (e.g. animals that walk on four legs) and asked to generate as many exemplars as they could within a period of two minutes.

Mental Rotation. This is a general measure of visual-spatial processing. Participants were presented with a series of pairs of figures and asked to indicate whether the two figures corresponded to the same object or not.

Box-Folding. This is also a general measure of visual-spatial processing Participants were shown a diagram of a box that had been unfolded into a flat surface. Two edges were marked and the participants indicated whether those two edges would meet if the object were folded into a box again.

Additionally, subjects were asked to report their score on the SAT or ACT college entrance exams as a general measure of their scholastic aptitude.

2.3 Procedure

Subjects first completed the battery of cognitive aptitude measures. Afterward, they were given a brief tutorial on the Coast Guard Rules of the Road that addressed only those facets with direct bearing on the scenarios used to assess adaptive thinking. Additionally, they were allowed to review a written summary of these sections of the Rules of the Road and keep this summary at their side. Next, subjects were presented with the eight SubSkillsNet scenarios.

2.4 Results

Initial analysis considered the relationship between measures of adaptive thinking and outcome measures for each scenario. As previously discussed, for adaptive thinking performance, each scenario was scored in relation to specified time windows consistent with the cells depicted in Figure 1. With regard to outcome measures, a trial was scored as a success if the subject managed to avoid collision with buoys or other vessels, and generally stayed on the appropriate course. The results are shown in Table 1. There were statistically significant correlations between adaptive thinking and outcome measures for three of the six active scenarios (i.e. Follow the Leader, Traffic Lanes and Port Entry). This correlation is believed to reflect the fact that in each of these scenarios, a failure to respond appropriately made a collision with another vessel likely. In contrast, with both the Fog Bank and Port Exit scenarios, a successful outcome was achievable without responding within the designated time windows, although the resulting solutions were generally risky or inefficient.

Table 1. Correlations between adaptive thinking measures and outcome measures for each adaptive thinking scenario.

Scenario	Measure	Success	Correlation Adaptive and Outcome
Active Response Scenarios			
Fog Bank	Adaptive	23%	$r = 0.058$ NS
	Outcome	57%	
Follow the Leader	Adaptive	17%	**$r = 0.876$ $p = 0.0001$**
	Outcome	14%	
Port Exit	Adaptive	97%	$r = 0.064$ NS
	Outcome	90%	
Traffic Lanes	Adaptive	52%	**$r = 0.739$ $p = 0.0001$**
	Outcome	36%	
Port Entry	Adaptive	50%	**$r = 0.714$ $p = 0.004$**
	Outcome	73%	
Navigate Channel	Adaptive	20%	All Outcomes Successful
	Outcome	100%	
Passive Response Scenarios			
Fishing Activity	Adaptive	7%	$r = 0.161$ NS
	Outcome	73%	
Shoreline	Adaptive	14%	All Outcomes Successful
	Outcome	100%	

Correlation analysis of scenarios based on adaptive thinking performance revealed only one statistically significant relationship between the Fishing Activity and Port Exit scenarios, with this being a negative relationship (r=-0.694; p<0.001). This is not surprising given that the scenarios were similar in that there were several vessels in the immediate path. However, these scenarios required the opposite response in that there was no need to adjust course in the Fishing Activity scenario and it was necessary to change course in the Port Exit scenario. It may be noted that although the relationship was marginal (p<0.15), adaptive thinking performance for Fishing Activity was negatively related to that for the Traffic Lanes and Port Entry scenarios, which both required a dynamic response to a vessel on a collision course.

Next, correlations were calculated between performance on the adaptive thinking measures and the cognitive aptitude measures. These results appear in Table 2. It is immediately apparent that the Category Generation task showed the strongest relationship with performance on the adaptive thinking measures. It may also be noted that this relationship was positive for the active scenarios and negative for one of the two passive scenarios. This suggests that performance in the active scenarios where changes in the environment necessitated that subjects adjust their strategy may have largely been a function of the subject's capacity to successfully retrieve from memory the options available to them in a timely manner.

Table 2. Correlations between adaptive thinking measures and cognitive aptitude measures.

			Individual Cognitive Aptitude Measures							
		Scenarios	Attention	CSpan Memory	Mental Rotate	Box Folding	Syllogism	Binary Decision	Category Generate	SAT/ACT
Adaptive Measure	Adaptive Response	Fog Bank	NS	NS	NS	NS	NS	r =-0.294 p < 0.16	NS	NS
		Follow Leader	r =-0.351 p < 0.08	NS	NS	NS	NS	r =-0.292 p < 0.14	r =0.341 p < 0.07	NS
		Port Exit	NS	NS	NS	r =-0.257 p < 0.196	NS	NS	r =0.259 p < 0.17	NS
		Traffic Lanes	r =-0.320 p < 0.12	**r = 0.379 p < 0.05**	NS	NS	NS	**r = -0.379 p < 0.05**	r = 0.257 p < 0.19	NS
		Port Entry	NS	NS	NS	NS	NS	NS	r = 0.505 p < 0.07	r =0.367 p < 0.19
		Navigate Channel	r=-0.282 p < 0.15	NS	NS	NS	NS	NS	NS	NS
	Passive Response	Fishing Activity	NS	NS	NS	NS	NS	NS	r =-352 p < 0.06	NS
		Shoreline	NS	**r = -0.428 p < 0.03**	NS	**r = -0.495 p < 0.01**	NS	NS	NS	r = -0.291 p < 0.15

In three cases (i.e., Fog Bank, Follow the Leader and Traffic Lanes), there was a negative relationship between adaptive thinking performance and performance on the dynamic binary decision making task. Successful performance on each of these scenarios required that the subject take action in response to an impending threat. Detailed analysis of the results of the Dynamic Binary Decision Making task revealed that those subjects who minimized their strategy shifts (i.e., favoring one option over the other), generally performed better than those that exhibited more exploratory behavior. Thus, it would appear that the negative correlation may be attributable to a generalized bias to respond either actively or passively to environmental contingencies.

None of the perceptual measures were positively correlated with adaptive thinking performance. In fact, there was a negative correlation between performance on the attentional beam task and performance in the Traffic Lanes scenario. This scenario required the subject be attentive to events within their peripheral vision and recognize and respond to a fast moving sailboat that intercepted the path of the subject's own vessel. It may be conjectured that the attentional focus that enables one to do well with the attentional beam task may be counterproductive if that same aptitude comes at the expense of the subject being able to monitor and respond to significant events in the periphery.

Finally, there was a significant positive relationship between performance on the CSpan and adaptive thinking performance for the Traffic Lanes scenario. CSpan provides a indication of an individual's capacity for short term memory. It may be conjectured that an aptitude for short term memory was advantageous in mentally keeping traffic of the relative location and courses of the vessels within the scenario.

2.5 Summary of Results

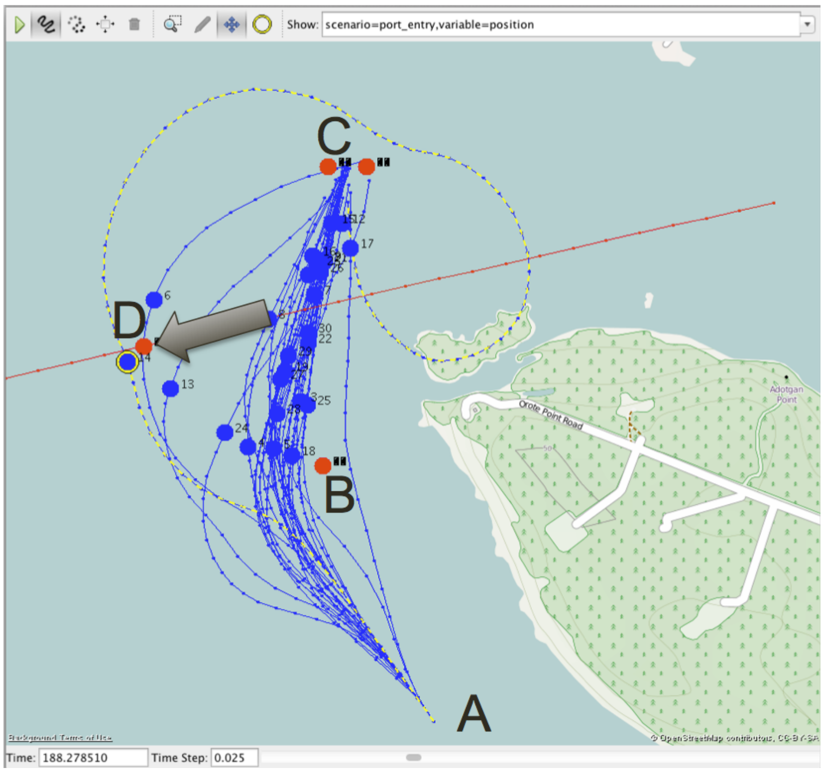
A key objective of the study had been to gain insight into the cognitive processes that underlie adaptive thinking. It was notable that the Category Generation task showed the strongest relationship to measures of adaptive thinking. Most definitions of adaptive thinking emphasize two components: (1) recognition of changing environmental factors and (2) making appropriate adjustments in strategy (Joung, Hesketh & Neal, 2006). The results of the Category Generation task clearly correspond to the latter. These results suggests that while a capacity to recognize changing environmental circumstances may be essential to adaptive thinking performance, it is the capacity to quickly recall available options that differentiates individuals with respect to their adaptive thinking performance.

The scenarios used to assess adaptive thinking performance differed with respect to their dependence on adaptive thinking for achieving an overall successful outcome. In scenarios where adaptive thinking was necessary to a successful outcome, adaptive thinking performance correlated with outcome measures. In contrast, for the remaining scenarios, the results demonstrate that success is often attainable in the absence of adaptive thinking. However, this success may require undue effort and produce somewhat inelegant outcomes.

Interestingly, there was little relationship between the scenarios with regard to adaptive thinking performance. From the onset, it had been assumed that adaptive thinking represented a somewhat singular skill, with each scenario assessing a different facet of this skill. Whereas scenarios conformed to the selected definition of adaptive thinking (i.e. the capacity to recognize when the environment has changed such that strategies that had previously been successful may no longer be successful), it is apparent that scenarios placed different demands upon the subjects. This poses a potential challenge for those seeking to measure and train adaptive thinking in that assuming adaptive thinking is broadly manifested in situations that impose diverse cognitive demands upon the decision maker, it may be difficult to identify generalizable measures and training protocol.

The current study utilized a fairly small number of subjects (i.e. N=30) and adaptive thinking performance was scored as a binary dependent measure (i.e. success=1; failure=0), resulting in a small number of data points per subject. It is acknowledged that the current method for scoring adaptive thinking performance is less than optimal and that a more continuous measure is desirable. Further research will focus on exploring techniques that assess adaptive thinking performance on a continuous scale.

The current study examined techniques for objectively measuring adaptive thinking within the context of a realistic simulation training environment. Whereas performance in the current study was assessed manually, ideally, there should be mechanisms that allow metrics to be incorporated into simulation-based training that provide an automated assessment of a student's performance relative to adaptive thinking. To accomplish this objective, it is essential that the measures accommodate student-to-student variability in the strategies adopted and specifics of the actions taken. We believe that this is achievable using the time window, and potentially, also spatial windows, approach demonstrated here. This approach provides designated points at which actions should or should not be taken and performance hinges on recognizing this contingency, as opposed to the specific actions selected and their respective outcomes. This approach also accommodates the student who adopts a strategy that does not place them within the designated time, or spatial, window, and therefore, alters the scenario in a way that makes the events that would ordinarily prompt adaptive thinking unnecessary. Further efforts are needed to develop generalizable techniques that allow this approach to be implemented across diverse training conditions, without the need to develop detailed models of specific training scenarios.



The trajectories of 30 subjects (blue dots) as they nagivate from starting point (A), past bouy (B), through the "goalpost" bouys (C). Near point (B), a crossing ship (D) comes into view on an unsafe course. Veering to the left (into the course of the other ship) is a maladaptive response.

3. APPLICATION OF ADAPTIVE THINKING

The objective for the final project year was to identify and implement a practical application of the research and associated capabilities developed during the project. An opportunity was identified in the domain of force-on-force simulations, and specifically, the use of force-on-force simulations in conducting facility security assessments. In this domain, a facility is modeled and its security assessed through a series of simulation runs in which agents representing facility security forces combat other agents representing attacking forces. The objective is to determine if the physical security of a facility is sufficient to withstand a threat consisting of a specified number of attackers with certain capabilities (e.g., weaponry) and to identify associated vulnerabilities in a facility's physical security.

For analysis of the maritime scenarios discussed in the preceding section, variables predictive of the eventual outcome of a scenario were identified and software capabilities developed to predict the outcome of a scenario based on these variables. Thus, given a set of parameters, the eventual outcome of a scenario could be predicted, given a sustained course and speed. From this analysis, for scenarios in which the subject failed to achieve a successful outcome, points in time and space may be identified in which a change in behavior (adaptation) should have occurred. This analysis does not speak to the appropriate course of action, but reveals when a change in course would have been advised.

Software capabilities developed through the current project were implemented within the context of the DANTE (Design and Assessment of Neutralization Technologies Evaluator) framework. Assessments utilizing DANTE may involve a large number of stochastic simulation runs and it is often difficult for the analyst to ascertain the factors contributing to failures of protective forces to repel attacks by the adversary forces. The capabilities developed through the Adaptive Thinking LDRD have been applied to provide near-real-time root cause analysis during execution of a series of simulation runs.

Figure 4 shows data from DANTE imported into the tools developed under this project. Note that this is a notional scenario and does not depict actual defenses or anticipated attack plans. The figure depicts simulated shots fired over the course of 100 simulation runs. Actual site assessments can analyze the runs in a variety of ways to help protective forces gain familiarity with a wide range of possible threats and responses.

A capability has been implemented that is referred to as *Dynamic Outcome Prediction*. For this capability, a user first identifies a variable of interest (e.g., attackers reach a high-value asset). As DANTE executes simulation runs, at each time step, data is extracted for a set of variables that are believed to be predictive of the simulation outcome (e.g., Defender is at Point X). Next, for each time step, a classifier is developed that predicts the outcome of the run based on the current state of the predictors. Finally, factors are identified that correspond to key shifts in outcome probability (e.g., when Defender at Point X dies, the adversary almost always reaches their objective).

Using the results, an analyst may quickly hone in on factors that are predictive of the outcome of a series of simulation runs. This can be extremely valuable when employed in real-time. For instance, it may be recognized after a small number of runs that there is a significant vulnerability and without addressing this variability, there is no need to execute the hundreds of runs that would otherwise be necessary. Furthermore, it provides analysts with insights into why they received certain results that otherwise, would have only been available through detailed manual evaluation of the results.

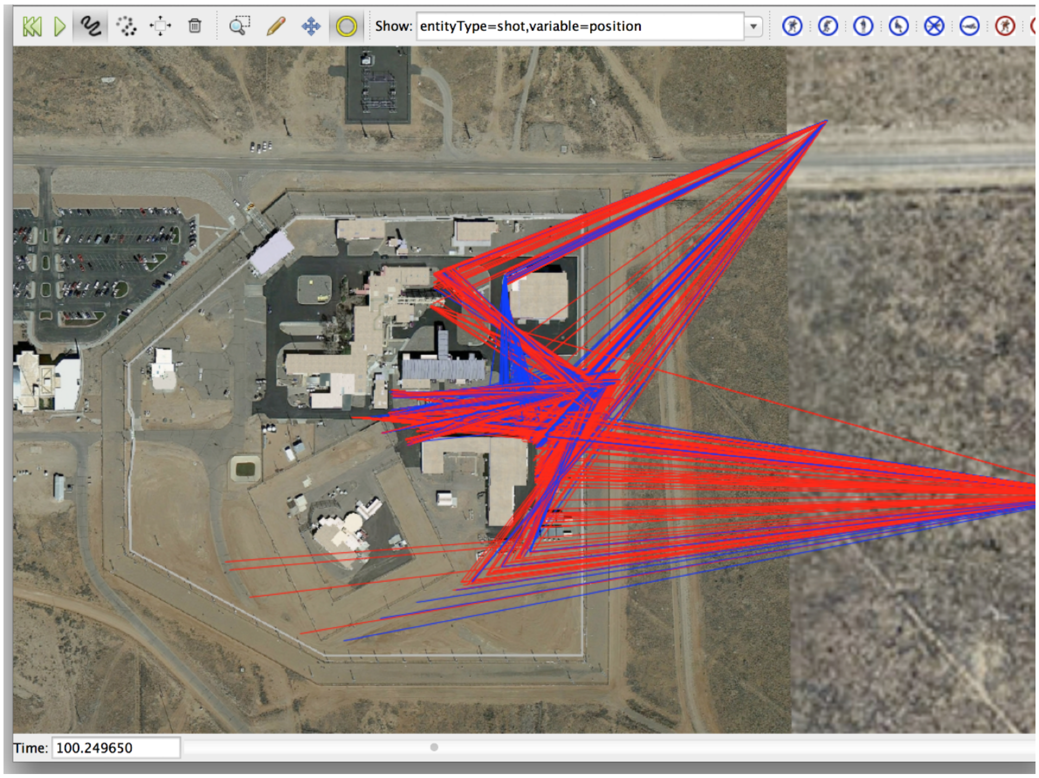


Figure 4: Visualization of shots fired during 100 simulation runs on a hypothetical physical security simulation in DANTE, showing lines of fire that could be studied in the preparation of protective forces.

4. CONCLUSIONS

The Adaptive Thinking LDRD has served to clarify and define adaptive thinking in a manner that is measurable and can provide a basis for automated assessment of performance. Using this definition, research has been conducted that highlights factors that contribute to effective adaptive decision making with human decision makers. Notably, a primary factor involves the capacity of an individual to quickly and effectively generate possible courses of action, as measured using the Category Generation task.

In analyzing data concerning human adaptive thinking, capabilities were developed that allowed the outcome of simulation scenarios to be forecasted based on the state of certain predictive variables. These software capabilities have been applied to the domain of force-on-force simulation-based assessments of facility physical security. These capabilities allow analysts to identify in near-real time the specific points in an attack that are most crucial in predicting the ultimate outcome of simulation runs. With this knowledge, the efficiency of simulation analysis is improved while providing greater insights concerning the strengths and weaknesses of a facility's physical security.

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