15667

Operational Effectiveness Modeling of Intelligent Systems

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ABSTRACT

As the Army pushes ahead with the development of intelligent vehicle systems, TARDEC is working to meet these challenges by developing platforms with greater autonomy. Using TRADOC's CASTFOREM model, the Army's premier ground combat simulation model, my office provides operational effectiveness analysis to quantify the battlefield effectiveness of TARDEC concepts.

This paper will first review our past efforts to provide operational effectiveness analysis to TARDEC's intelligent vehicle programs. A few years ago, our office performed a comprehensive evaluation of TARDEC's RAVE concepts, evaluating the effectiveness of semi and fully autonomous platforms.

The paper will then discuss the many challenges associated with modeling autonomous and semi-autonomous platforms. These challenges are related to the platform's behaviors and the unique threats faced by unmanned platforms.

Autonomous and semi-autonomous platforms exhibit unique behaviors which are difficult to capture in a combat simulation. Combat simulations such as CASTFOREM are unable to model the behavior of an autonomous platform moving tentatively along a path using its mobility algorithms. Similarly, acquisition and firing timelines can be different for a remotely operated sensor or weapon. Modeling of tampering by threat combatants and hostile civilians in a combat model is a daunting challenge which must be addressed.

Operational effectiveness analysis using models such as CASTFOREM have historically provided the concept designers with valuable insight by quantifying the concept's value in combat. The modeling of autonomous and semi-autonomous platforms has introduced new challenges which must be overcome to continue to support development of these systems.

Key words: Operational Effectiveness, Combat Simulation, Intelligent Systems

I. INTRODUCTION

The Army continues to look at intelligent systems for a variety of different missions. Operational effectiveness analysis is used to quantify the benefits of these technologies, and can identify which technologies provide the most effective solution for a specific mission. Since 1992, our office has used TRADOC's CASTFOREM model to perform this analysis.

II. BACKGROUND

CASTFOREM (Combined Arms Support Task FORce Evaluation Model) is a combat simulation model used to provide operational effectiveness analysis of new technologies. Developed by the Army's Training and Doctrine Command (TRADOC), CASTFOREM is used for Analysis of Alternative (AoA) studies to support key milestone decision making. Since 1992, TACOM (U.S. Army Tank-automotive and Armaments Command) has used CASTFOREM to provide operational effectiveness analysis for TARDEC (Tank-automotive Research, Development, and Engineering Center). TACOM's Cost & Systems Analysis Office has the largest CASTFOREM facility outside of TRADOC, with its own secure facility and six full time analysts. TACOM uses CASTFOREM to both evaluate weapon systems concepts and to provide parametric estimates of key design variables. CASTFOREM is used to identify the "knee in the curve" to compare what is technically feasible to its level of combat effectiveness.

CASTFOREM is a discrete, event driven force-on-force combat model developed to determine the effectiveness of ground combat systems. It is a high resolution, constructive simulation which is event driven and utilizes an embedded expert system. The model specifically simulates each combat vehicle or dismounted soldier as an individual entity, whose lines of sight and visibility to other entities are specifically modeled. The battle is simulated on digitized terrain, normally a 50 km box, which has been characterized for soil density, vegetation, contours, water features, roads, and urban areas. Atmospherics are played in detail; time of day, clarity of the ambient atmosphere, wind, temperature, etc. are all modeled. Atmospheric effects which effect sensors, from

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the effects of detonating rounds as well as man made obscurants, are all included in acquisition calculations. The model is able to play engineering services, air support, communications, and limited re-arm and refueling services. It is the Army's accepted combat model, and is fully verified, validated, and accredited (VV&A'd).

The CASTFOREM modeler is able to evaluate the effectiveness of a new technology using a variety of Measures of Effectiveness (MOEs). Force level statistics are available, such as the loss exchange ratio (LER), blue dead, red dead, either at the force level or by weapon system type. The model tracks who shot at who using what sensor, what weapon, what round, and at what range. A separate algorithm evaluates the level of damage to the target, based on the vehicle's vulnerability assessment for that specific round. For the evaluation of active protection systems, the model tracks the type of incoming round, the range at which it was fired, what type of APS round was fired in response, and the effectiveness of the counter munitions. Residual damage due to the fragmented remains of a destroyed incoming round are also evaluated.

III. PAST MODELING OF INTELLIGENT SYSTEMS

In 2002, TARDEC tasked our office to evaluate the operational effectiveness of three TARDEC designed **R**apidly reconfigur**A**ble **VE**hicle (RAVE) concepts in support of the Future Combat System (FCS) program. Three concept platforms were evaluated using four CASTFOREM vignettes.

The RAVE concept was developed as a combined two piece modular vehicle that had in-field modularity. The RAVE was envisioned operating in either combined or two piece mode depending on the mission. One of the modules would entail a common crew/mobility module with a two-person crew station that would reconfigure with various mission modules depending on the mission. The tailored mission modules have limited mobility when operating alone utilizing batteries could be operated in a semi-autonomous or in a remote controlled mode. While the combined weight of a mission module and mobility module is 20 tons, each individual module was light enough to be carried by a transport helicopter. The vignettes were designed to make use of this increased tactical and operational mobility. The one piece RAVE was played as the two modules combined.

One of the key attributes evaluated in this study was whether the module was manned, and the level of control needed to operate the platform. The three alternatives were:

1. A two module configuration, manned, which did not separate.

2. A two module configuration consisting of a manned mobility module and an unmanned remote control mission module. Line of Sight (LOS) was required for the mobility module to maintain control of the mission module. Loss of the mobility module resulted in loss of firepower and mobility for the mission module.

3. A two module configuration consisting of a manned mobility module and a semi-autonomously operated mission module. It was assumed that a 4km beyond line of sight (BLOS) control range was available. Loss of the mobility module resulted in loss of firepower only for the mission module.

In the CASTFOREM model, the logic was developed to require the mission module to successfully communicate with the mobility module before moving to its next waypoint (remote control mission module only) or to fire (semi-autonomous and remote control mission modules). This allowed the modelers to evaluate the loss of either the mission module or the mobility module. Crew casualties from the mobility modules were tracked.

The study had some serious limitations. If a mission module was destroyed, the mobility module controlling it remained in place and was unable to control other mission modules. Similarly, if a mobility module was lost, the corresponding mission module would be unable to move (remote control only), and unable to fire (both variants). No other mobility module could gain control of the mission module. These limitations were the result of decision tables in CASTFOREM, which could have been modified to address these situations. The analysts determined that adequate TTPs to model these behaviors were not available at the time, and felt that the significance in evaluating the three alternatives was probably minimal.

In addition to control issues, the combat effectiveness of an active protection system (APS) and increased mobility for these systems was quantified.

The study quantified the benefits of an unmanned, semi-autonomous mission module in the four vignettes.

IV. CURRENT MODELING ISSUES

Current efforts to model the operational effectiveness of intelligent systems focuses on five primary issues: lethality; system control; timelines; tree line movement; and anti-tamper issues.

1. Lethality

Any remote controlled or autonomous platform with a weapon would obviously have to be carefully controlled before being allowed to fire. A simulation of these conditions would have to reflect this reality. In our simple RAVE analysis, a robotic platform followed the same procedures as a manned vehicle when preparing to fire. The only additional requirement imposed was that the robotic platform had to call back to the controller and receive a reply prior to firing. This prevented the robotic platform from firing after the controller was destroyed. A realistic representation of this would be much more complicated. It is important to the modeler to quantify the time delays inherent in firing through a remote platform.

This issue also applies to the use of active protection systems (APS). If these platforms employed any type of hard kill APS systems, then the rules of engagement would need to be carefully constructed to reflect what would actually be done on the battlefield. The danger of collateral damage to both friendly troops and civilians would have to be taken into account. The rules of engagement for an APS firing to defend an unmanned vehicle would probably be quite different than that for a manned vehicle. These differences would have to be carefully modeled in the simulation.

2. Control Issues

The initial work we performed using RAVE concepts only looked at very basic control issues, basically LOS versus NLOS and semi-autonomous vs. remote control. There are many additional control issues which need to be investigated and quantified.

The method of control is the most fundamental issue. If the controller uses visual sensors (DVO or FLIR) to operate the robotic platform, significant modeling issues must be addressed. Does the controller have the same FOVs as he would have at the vehicle? Any degradation in sensor fidelity, or time delays while the images are transmitted, must be played to proper fidelity.

In some cases, the modeling of robotic vehicles may be more accurate than manned vehicles. The human factor, such as the ability to reorient sensors to respond to outside stimulus is lacking in robotic vehicles and is very difficult to model.

The loss of a controlling vehicle presents additional issues. Until TTPs are developed to address these issues, the modeler can either play a “most logical” approach, or parametrically look at a variety of responses. The first and most obvious question is how many robotic vehicles one controller can handle. This is a question of both technology and human factors. Technically, the controller must have the communication equipment available to communicate with more than one robot. The modeler needs to know the effect on communication time delays. If the robotic vehicles are sharing one communication channel with the controller, significant time delays are possible. An even more significant issue to the modeler is the human factor. If one soldier is expected to control two or more robotic platforms, there will most likely be degradation in the operational effectiveness of the affected platform. This degradation could be quite significant, but can only be characterized by quantifying the soldier's effectiveness of controlling multiple robots. Metrics to quantify this effort need to be developed.

Autonomous or semi-autonomous robotic platforms present different issues to the modelers. These platforms are controlled by a specific set of instructions and algorithms. Many of these are based on external conditions, for example a maneuvering algorithm will identify the path ahead and move down it. This is very difficult to replicate in an operational effectiveness model. The model we use, CASTFOREM, moves entities based on a series of maneuver control points (MCPs) or waypoints, following specific links. There is no way that the model can simulate the stops and starts of a platform moving tentatively down a path.

Simulating follower vehicles would pose less of a challenge. If the platform only needs to follow a manned vehicle, simulating that would not be a problem. What happens to the follower if the lead platform was disabled or destroyed would have to be addressed by the modeler.

3. Timeline Issues

To properly model a robotic platform, time delays inherent in the controlling of the platform must be accounted for. Whenever the platform reaches a decision point it cannot resolve internally, it must communicate the issue to the controller and await instruction. For some operations, such as movement, the controller may be programmed to respond immediately, and the time delay may be small. For other issues, such as firing its primary weapon, the soldier in the controlling platform may become part of the loop, increasing the time delays before the weapon is allowed to fire. Similarly, acquisitions by the robotic platform may take longer to resolve. In each of these cases, the modelers will need to quantify these time delays so that they can be properly played in the simulation. Obtaining accurate data for these time delays is the most significant issue.

4. Tree Line Movement

Some robotic platforms may be designed to be “tree huggers”, following the nearest available tree line. This reduces the platform's probability of detection, when viewed against a complex terrain background. This would not pose a major challenge to the modeler. The MCP, or waypoints, could be set up to closely follow tree lines available along the path. The platform would then follow these preplanned routes during the simulation. As with most movement in the simulation, it is pre-planned. Consequently, the robotic platform would be unable to dodge into the trees if fired upon.

5. Anti-Tamper

Anti-tamper poses a significant challenge to the modeler. In traditional combat simulations, the battlefield contains blue forces, red (threat) forces and whites (civilian non-combatants). These civilians may be killed by the combat, and those numbers can be captured. The model is not designed to allow civilian forces to become hostile, or take hostile actions against blue forces. It is unlikely that our current model, CASTFOREM, will be modified to do so. CASTFOREM assumes that blue, red, and white personnel are always distinguishable. Consequently, only a red entity would be able to shoot at, or attempt to disable, a blue platform. As soon as the red entity was identified, blue would attempt to kill it. Blue would undoubtedly disable or kill the red entity long before he could approach the platform close enough to tamper with it.

The only feasible solution would be to create a red entity with such low visual and thermal signature that he could only be identified as a threat at extremely short ranges, perhaps a few meters. At this point, blue would recognize the threat and attempt to defeat it. A non-combatant would not approach the vehicle that closely, having been warned off by anti-tamper warnings.

Once these problems have been overcome, the only remaining problem is how to model the tampering itself. For example, the threat may attempt to incapacitate the platforms sensor, or attempt to overturn or otherwise defeat the platform's mobility. Technologies would be in place on the platform to defend the platform from these threats. Some engineers have suggested that these technologies would become increasingly dangerous (and potentially lethal) to the threat as he came closer to the platform. From the modeler's perspective, each defensive technology would have an associated probability of defeating the threat. Data would need to be developed to provide the appropriate probabilities of success. These data would need to be obtained from actual experiments, which would be very difficult. This would be the equivalent of trying to estimate the probability that the threat considered this a suicide mission. A more realistic approach would be to parametrically look at different levels of success for each layer of protection, and then mathematically determine likely probabilities of defeating the threat.

V. CONCLUSION

Real challenges remain to adequately model robotic platforms in an operational effectiveness model. A past effort performed by our office provides a "first cut" at quantifying various issues inherent in playing robotic platforms. In the RAVE study, we were able to quantify the benefit of having the manned controller vehicle safely removed from the front line.

This paper identified five areas which require additional effort. For lethality, the controls needed to allow an autonomous or semi-autonomous platform to fire must be developed in adequate detail to allow the modeler to incorporate it in the simulation. A variety of control issues need to be resolved. The level of autonomy of each platform modeled must be quantified. How that platform interacts with its controller must be described in detail. The time delays and degradation of effectiveness inherent in controlling a second platform must be quantified. These delays can then be included in the simulation. Tree line movement is probably the easiest of these issues to resolve, Anti-tamper issues may be worked with some imaginative modeling, but obtaining estimates of the effectiveness of various anti-tamper defenses may be difficult.

Our office will continue to work issues related to modeling robotic platforms for operational effectiveness analysis. Working with TRADOC and other organizations which supply the necessary data, we will support TARDEC intelligent systems work for years to come.

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