Embedded Simulation to Prevent Tactical Surprise and Improve Soldier Performance

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ABSTRACT

The U.S. Army Science and Technology (S&T) Advisory Group created the Technology Enabled Capability Demonstration (TECD) concept in order to demonstrate and measure progress towards meeting the Army's top ten science and technology challenges. One of the designated challenges is the prevention of tactical surprise at the small unit level. Operating under the premise that soldiers at the squad level lack sufficient situational awareness to prevent tactical surprise, the TECD 3 effort was created to increase small unit situational awareness through the fusion of various planning and intelligence systems into a small unit framework. The Linguistic Geometry Real-time Adversarial Intelligence & Decision-making (LG-RAID) simulation is a lightweight course of action (COA) planning tool that employs innovative algorithms to predict enemy activity in a highly reliable and efficient manner. As such, LG-RAID was selected as a participating application in the TECD 3 federation and was embedded on both individual soldiers and tactical vehicles in a lightweight mission command system. In this paper, we discuss how the LG-RAID simulation improved soldier effectiveness, situational awareness and facilitated the prevention of tactical surprise during the execution of four tactical situational training exercises (STXs) held at Fort Dix, NJ and executed by the Army's Experiment Force (EXFOR). Furthermore, we discuss the integration of LG-RAID into the TECD 3 framework and technical challenges that were overcome. Results of this integration and exercise, presented in this paper, highlight the potential value of embedded simulation at the tactical level.

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INTRODUCTION

The Technology Enabled Capability Demonstration (TECD) Concept

Senior U.S. Army leadership identified and prioritized the Army's top ten science and technology challenges in 2011 in response to a rapidly changing operational environment (Buschmann & Pellicano, 2014). In order to demonstrate that these challenges were being adequately addressed and progress subsequently measured, the U.S. Army Science and Technology (S&T) Advisory Group created the Technology Enabled Capability Demonstration (TECD) concept. For each of the top ten challenges, a TECD was established to demonstrate and rapidly deliver high-impact, innovative technological solutions to complex problem sets. One of the top ten challenges designated by Army leadership was the prevention of tactical surprise at the small unit level. In order to address this particular designated challenge, the TECD 3 effort was created.

Specific Challenge: Tactical Surprise

In the current operational environment, the rifle squad has been designated as the foundation of the decisive force by Army leadership (Association of the United States Army, 2011; Maneuver Center of Excellence, 2012). In the future battle space, squads will operate at far greater distances from their adjacent and higher units (Mundwell, 2013) and thus will require access to technologies that provide overmatch. However, squads still lack access to these overmatch technologies that higher echelons possess (Brown, 2012; Anderson, Burk, Miles, & Tobin, 2014) and thus fight in much the same manner as in previous conflicts. As such, the literature contains recent examples of small U.S. units surprised by both enemy contact (Biddle, 2003) as well as friendly fire (Wilson, Salas, Priest, & Andrews, 2007; Peck, 2015) due to lack of advanced situational awareness capabilities.

Recent efforts have attempted to provide squads with advanced situational awareness capabilities (Young & Ishii, 2012) but have been largely unsuccessful due to their reliance on still-emerging technologies (Bonds, et al., 2012) that are both cumbersome to the individual soldier and unreliable. Due to the above, Army leadership identified this as a critical technological gap and applied resources towards overcoming these challenges. In this manner, TECD 3 was created.

TECD 3 and Linguistic Geometry Real-time Adversarial Intelligence & Decision-making (LG-RAID)

TECD 3's purpose was to rapidly develop, integrate and demonstrate potentially game-changing technologies in a newly created framework in order to prevent tactical surprise at the small unit level. This envisioned framework would fuse various planning and intelligence systems into a lightweight architecture that provided squads at the tactical edge with advanced situational awareness tools. Technologies that provided Course of Action (COA) planning, terrain analysis and near real-time tips and cues to squads were actively pursued.

As a result of the above, the Linguistic Geometry Real-time Adversarial Intelligence & Decision-making (LG-RAID) simulation was selected as a potential candidate for development and integration into the TECD 3 framework. The LG-RAID simulation is a light-weight course of action (COA) planning tool that predicts enemy activity in a highly reliable and efficient manner. Additionally, the simulation is capable of complex terrain analysis and, under this effort, a real-time tips and cues capability was created to facilitate the prevention of squad surprise. In this instantiation, LG-RAID, as part of the TECD 3 federation, was embedded on both individual soldiers and tactical vehicles in a lightweight mission command system.

In this paper, we discuss how the LG-RAID simulation improved soldier effectiveness, situational awareness and contributed to the prevention of tactical surprise during the execution of four tactical situational training exercises (STXs) held at Fort Dix, NJ and executed by the Army's Experiment Force (EXFOR). Furthermore, we discuss the integration of LG-RAID into the TECD 3 framework and technical challenges that were overcome. Results of this integration and exercise, presented in this paper, highlight the potential value of embedded simulation at the tactical level.

BACKGROUND

LG RAID Background

LG-RAID is based on solid theoretical and experimental foundations (Stilman, Yakhnis, & Umanskiy, 2010; Stilman, Yakhnis, & Umanskiy, 2007; Stilman, 2000). The LG-RAID theoretical foundation employs Linguistic Geometry (LG), a type of Game Theory developed over the last 40 years within research in Artificial Intelligence (AI) (Stilman, 2000; Stilman, Yakhnis, & Umanskiy, 2007). Contrary to other gaming approaches, LG is scalable to the level of real world systems. This scalability is based on solving Abstract Board Games by “projecting” their state space onto the Abstract Board, generating strategies in the form of certain projections and “elevating” those projections back into the game state space. This approach permits the avoidance of tree-based searches typical to other gaming systems and, consequently, avoids combinatorial explosion that prevents scalability of those systems.

LG-RAID is designed to target tactical echelons with little computational support, such as Company and below, to provide low-overhead COA Analysis and war gaming capability as part of mission planning, rehearsal, and execution. It can estimate likely and dangerous enemy locations, intents, and actions, as well as provide recommendations on specific friendly tactics. This analysis is based on domain information, e.g., detailed terrain data, platform, weapon and sensor capabilities, as well as specific mission information provided by the user through an intuitive web-based or Android User Interface. The mission data includes task-organized friendly forces (e.g., units, equipment, ammunition loads, and positions), scheme of maneuver as an execution matrix, command and control (C2), mobility and fire control graphics, and any known information about the enemy forces or plans. LG-RAID functions as an automated light-weight simulator that executes a faster than real-time game based on the above inputs. The LG algorithms are utilized to generate tactically valid actions for both friendly and enemy forces for the entire mission duration, without additional input from human operators or detailed scripting. After every such simulation run, the user is then provided with an animated movie of the likely sequence of movements, engagements, and other actions for all entities over the desired time horizon. This animated presentation is intended to stimulate thinking of the tactical situation and improve visualization of the battlefield dynamics. Typically, the user would execute multiple simulations or “what ifs” by varying the mission plan or enemy information to consider alternative COAs or prepare for any contingencies. Such COA analysis can also be repeated during the mission based on live data, e.g., actual movement of friendly forces, enemy SPOT reports, or changes in commander’s intent.

TECD 3 & E14 Demonstration Background

TECD 3 was created to address a major tactical challenge the Army currently faces, namely its squads are too often surprised in tactical situations. Soldiers in these small echelons lack sufficient timely mission command and tactical intelligence to understand where their assets are, who and where the enemy is and who and where noncombatants are. They also lack the ability to communicate this information to each other and higher echelons in near real-time. Thus, the focus of TECD 3 was to demonstrate and deliver measurably relevant, innovative and game-changing capabilities that could be rapidly transitioned and fielded to the force. The TECD 3 concept is illustrated in Figure 1.

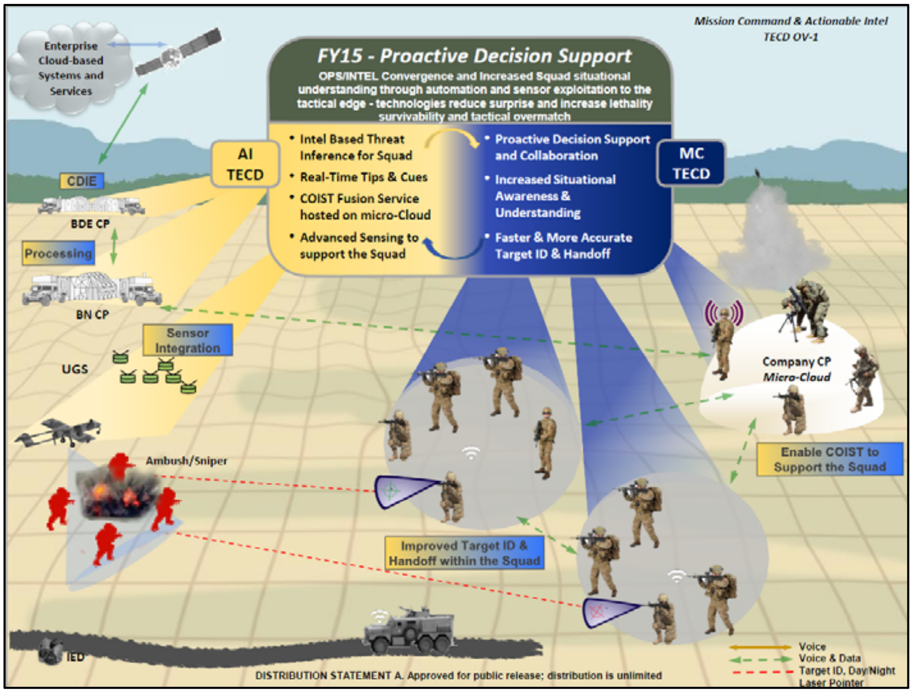

Figure 1: TECD 3 Concept (Buschmann & Pellicano, 2014)

The TECD 3 vision was to create a lightweight mission command framework that provided soldiers at the squad level with rapid COA planning, enhanced terrain analysis and information exchange capabilities to prevent tactical surprise and improve small unit performance. Proactive notifications, delivered to individual soldiers, would improve soldier's Situational Awareness (SA). Decision aids, in the form of real-time tips and cues, would identify potential threat activities to the squad operating on the tactical edge. Figure 2 below illustrates the capabilities within the TECD 3 vision applied within an operational vignette.

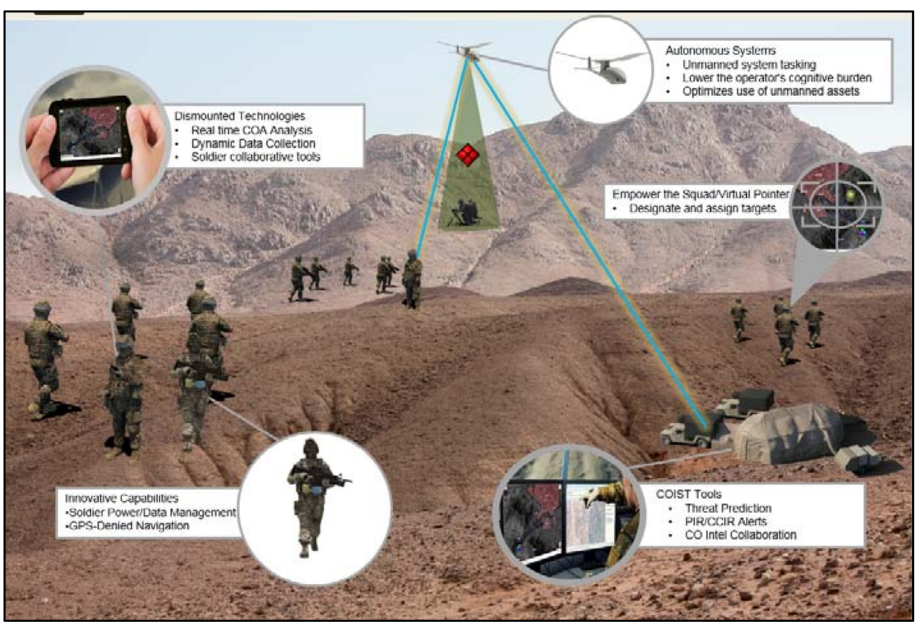

Figure 2: TECD 3 Operational Vignette (Buschmann & Pellicano, 2014)

The TECD is a three year effort with iteratively increasing capabilities demonstrated at an annual demonstration held at Fort Dix, NJ. The first year's demonstration (hereafter referred to as E13) demonstrated an austere squad capability. The second year's demonstration (hereafter referred to as E14) added additional capabilities to demonstrate a networked platoon. The purpose of E14 was to execute a system-of-systems integration test in an operational setting in order to demonstrate the effort's developed capabilities. In order to create a realistic operational environment, E14 utilized soldiers from the Fort Benning-based experimental Force (EXFOR) to operate the TECD's framework. The EXFOR provided crucial technological feedback of the framework in an operational setting.

METHOD

Integration of LG-RAID into TECD 3 Framework

LG-RAID software was installed at three different levels within the TECD 3 framework. One LG-RAID node (LG-RAID CP) was installed at the Command Post to allow the Commander and Staff to perform pre-mission COA analysis. The user was able to iterate over several alternative schemes of maneuver for the friendly forces and rapidly war game them against likely enemy tactics. Terrain analysis and route analysis was also performed to identify the preferred BLUFOR mission plan. Some of these generated COAs could then be chosen to be sent over the network to the second LG-RAID node (LG-RAID Mounted), located in the Company Commander or Platoon Leader's vehicle. The LG-RAID Mounted node exchanged data with the Command Post node whenever the network was available. The Commander was then able to use the same user interface as the LG-RAID CP node to adjust the chosen COA, or perform additional analysis while on the move during the mission. In addition to these two full LG-RAID nodes, Android client software was also installed on several Nett Warrior Android handheld devices carried by the platoon leader, platoon sergeant, and squad leaders. These nodes were not capable of performing full COA Analysis by themselves; however, they received and visualized running estimates computed by either the LG-RAID CP node or the LG-RAID Mounted node. Additionally, the user was able to modify the current mission plan on the handheld device using the Android LG-RAID application (app) and send requests for re-computation of the current mission analysis to the higher echelon node. Extending the reach of the COA Analysis capability to the dismounted small unit leaders was a key objective of this experiment.

All of the LG-RAID nodes were also interfaced with the Mission Command software. This experiment utilized Joint Battle Command-Platform (JBC-P) at the Command Post and in the vehicles, while Nett Warrior (NW) software was used by the dismounted soldiers. During mission execution, JBC-P and NW instances transmitted various types of data, such as Position Location Information (PLI) of friendly units and enemy SPOT reports, employing Joint Variable Message Format (JVMF) over the tactical network. Mounted and Command Post LG-RAID nodes listened to this message traffic in order to continuously track the current state of all friendly forces and any new information about enemy activities. Based on such up-to-date state information, COA Analysis was periodically updated and distributed to all dismounted LG-RAID-enabled devices.

Based on such up-to-date COA Analysis information, the LG-RAID Android app provided timely upcoming threat warnings to the dismounted leaders, with the goal to minimize surprise. Integration with Nett Warrior software on the same handheld device allowed the app to track current positions of the user, as well as any other platoon and squad members. These positions were then cross-referenced with estimated likely enemy threat areas in the current COA Analysis. Based on proximity threshold, a warning was generated for the user when any subordinate friendly soldiers approached one of these locations. Warning messages were presented to the small unit leader through the Android Proactive Mission Monitor (PMM) application that prioritized, organized, and notified the user of any key events. When a warning was clicked, the upcoming threat was displayed on the map highlighting anticipated enemy location and recommendations for friendly actions to counter the threat.

One of the key challenges to integrating LG-RAID into the TECD 3 Mission Command framework was the reliability of communication over the tactical network using Soldier Radio Waveform (SRW) radios. Due to high latencies and low bandwidth, reliable connectivity using standard higher level protocols, such as Transmission Control Protocol (TCP), was not feasible. Only low level User Datagram Protocol (UDP) was available. Custom UDP-Reliable (UDPR) protocol was developed in order to enable reliable communications between LG-RAID at the Command Post, on board of vehicles, and on handheld devices. UDPR was designed to minimize message traffic and to support throttling of the transmission rate, critical to minimizing traffic interference with mission critical communications.

Situational Training Exercises (STX) Lanes

During the E14 demonstration the EXFOR performed product assessment by executing four STX missions. Each STX mission was decomposed into a number of procedures with outlined detailed execution steps. The exercise performed over five days utilized mission command orders (i.e. Operations Orders and Fragmentary Orders). In addition, great care was taken to ensure the demonstration was performed in as tactical a manner as possible. STX missions were executed with a small footprint of engineers that observed both the Soldiers and the technologies, providing assistance only when required. Live actors served as the exercise's Opposing Forces (OPFOR) and civilians on the battlefield (COBs) and were also augmented by constructive simulation entities. The four STX missions executed during E14 for TECD 3 are depicted in Table 1.

Table 1: STX Missions

STX Mission	STX Mission Title	STX Mission Description
1	Reconnaissance	EXFOR conducted reconnaissance in zone to locate enemy forces
2	Attack	EXFOR conducted attack to destroy enemy forces
3	Hasty Defense	EXFOR conducted hasty defense to repel enemy forces
4	Route Security	EXFOR secured route to prevent enemy forces from interdicting supply lines

As previously discussed, during the conduct of those missions, LG-RAID was utilized in both a mounted and dismounted fashion. The simulation was deployed in a vehicular configuration, operating at the company and platoon echelon of the TECD's mission command framework. The simulation was also employed in a dismounted mode, operating off a soldier's handheld computing environment (Nett Warrior). Employment methods are depicted in Figure 3 and EXFOR feedback was collected for both configurations.

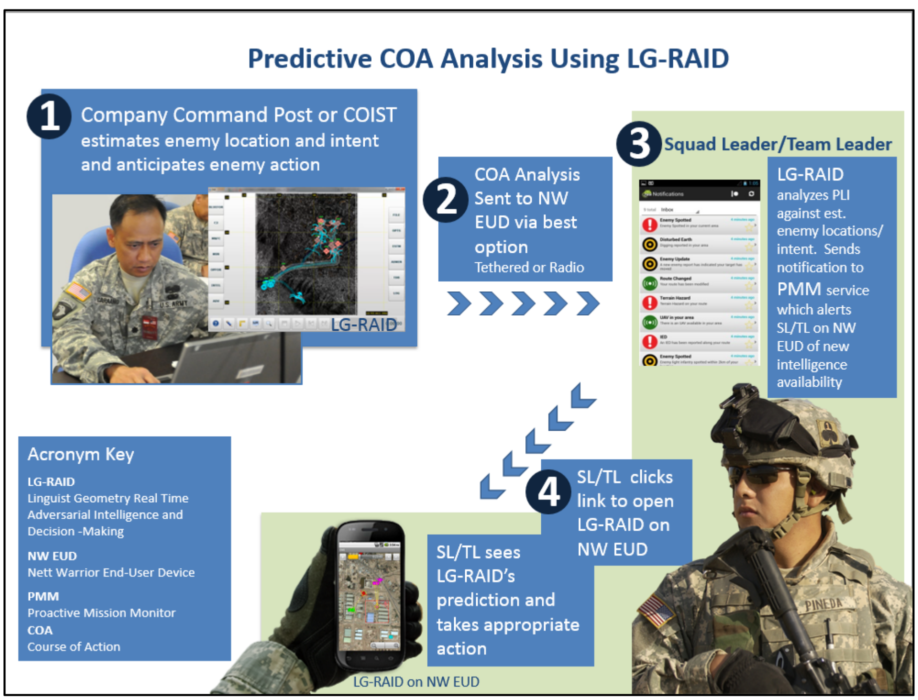

Figure 3: LG-RAID Employment Methods

RESULTS

Technical Performance of LG-RAID in TECD 3 Framework

During experimental runs, the LG-RAID software did not suffer any crashes or other critical failures. The software started automatically as the handheld devices, vehicles, and Command Post computers were powered on in the morning and continuously ran until post-mission shutdown. Pre-mission COA Analysis was successfully performed both at the CP and on-board the Commander's Vehicle. Data was successfully sent between the LG-RAID nodes when they were within radio contact range. During the mission execution, LG-RAID on the Commander's vehicle was able to receive JVMF messages, track positions of the dismounted forces, update the COA Analysis based on mission progress, and distribute this information to the dismounted handheld devices. The LG-RAID Android app demonstrated tracking of the users' positions and notified them of approaching anticipated threat locations.

The main technical difficulties were centered on radio network capabilities. Reliable connectivity was not possible between the EXFOR performing the missions at remote training ranges and the Command Post. As a result, the LG-RAID at the Command Post was unable to reliably track mission progress. This deficiency caused the dismounted soldiers to periodically lose LG-RAID guidance in situations when contact with the Commander's vehicle was lost, generally as a result of soldiers moving deeper into the woodline during the mission execution. These network limitations were expected and accounted for by the overall system design. After initial planning using the LG-RAID CP, all calculations during the mission were performed using the LG-RAID node onboard the Commander's vehicle to take advantage of its proximity to the target mission area. Similarly, the LG-RAID Android app was found capable of continuing to operate even when the connectivity to the vehicle was lost, by using a cached last-known COA Analysis until a new update was received.

Another technical challenge were the infrequent hardware failures of both tactical radios as well as the Android devices. These events did cause additional difficulty in tracking the current state of the mission, resulting in a periodic conflicted system state which reduced the accuracy of the COA Analysis. While this did not adversely impact the ability to provide timely threat alerts during this experiment, the future versions of the software should be designed to account for such contingencies.

Finally, the experiment confirmed that LG-RAID messaging traffic did not interfere with network performance of the overall Mission Command system. The UDPR protocol was employed to shape the traffic to approximately one packet per second (PPS) for the mounted system and 0.25 PPS for the handheld. Due to small message sizes, such throttling did not affect user perception of the amount of time required to send analysis between various nodes, indicating that the traffic can be slowed down even further, if needed, without compromising system performance.

Soldier Feedback

Soldier feedback (n = 11) was collected via questionnaire administered by testing personnel after each STX mission. The E14 questionnaire was a four-question survey (5-point scale) that measured participants' assessment of whether or not the LG-RAID simulation, when embedded in a tactical situation, improved soldier effectiveness, situational awareness and facilitated the prevention of tactical surprise. Mean feedback results are depicted in Table 2.

Table 2: Mean Feedback Results

	Soldier Effectiveness	**Situational Awareness**	**Prevention of Tactical Surprise**
Average	3.82	3.91	4.27
Standard Deviation	0.75	0.94	0.47

Soldier effectiveness was self-reported via survey using the following question: "You utilized/would utilize LG-RAID as an analysis tool for mission planning and preparation?" Situational awareness was measured, via self-administered survey, with the following question: "You utilized/would utilize LG-RAID as a mission rehearsal tool and/or help brief the mission plan?" Finally, the prevention of tactical surprise was measured via self-reported survey through the use of this question: "Was the location of the estimated threat relative to your position, planned routes and terrain easy to understand?"

Soldiers rated the LG-RAID simulation as effective when embedded in a tactical situation. Using the survey midpoint as an anchor value, a series of Student's t-Tests were performed to compare soldier assessments of the technology to the survey midpoint. There were significant differences found for Soldier Effectiveness [$t(10) = 3.61$, $p = 0.01$], Situational Awareness [$t(10) = 3.19$, $p = 0.01$] and Prevention of Tactical Surprise [$t(10) = 9.03$, $p < 0.0001$] indicating positive assessment of the technology. Student T-tests were conducted at $\alpha = 0.05$.

DISCUSSION

Conclusions

The purpose of this experiment was to assess the value of embedding simulation at the small unit echelon. Specifically, we examined whether or not the integration of a light-weight simulation into a mission command framework improved soldier effectiveness, situational awareness and facilitated the prevention of tactical surprise during the conduct of multiple training missions executed in an operational environment. In order to support our research objective, and one of the Army's top ten science and technology challenges, we integrated the LG-RAID simulation into the TECD 3 mission command framework and conducted human-in-the-loop experimentation.

The results of our experimentation are promising. Technically, we successfully integrated the LG-RAID light-weight constructive simulation into the TECD 3 mission command framework. During both mission planning, as well as during mission execution, the simulation was able to overcome periodic network failures and still update and synchronize its current COA analysis and estimates to various nodes operating in the training exercise. The simulation successfully performed its mission in three separate configurations, or nodes: at the Command Post, in the Commander's vehicle and at the individual dismounted soldier echelon. The simulation was able to perform its intended purpose without adding to the network's load, as result of the efficient UDPR protocol we developed for the TECD 3 framework.

Functionally, we demonstrated that embedded simulation may offer potential benefits to Soldiers at the small unit echelon. Using obtained Soldier feedback, we determined that the LG-RAID simulation was effective when embedded in a tactical situation. Soldiers rated the technology as improving both their performance and situational awareness as well as reducing the likelihood of surprise by the enemy. These results were collected over the conduct of four tactical training exercises, which utilized experienced soldiers performing various tactical missions in an operational setting.

Lessons Learned

The primary lesson learned was the effect that hardware (i.e. tactical radios and handheld devices) failures had on the simulation's ability to successfully synchronize itself between the three nodes employed for this experiment. While the Command Post environment was relatively robust with redundant systems, a hardware failure at the dismounted squad echelon represented a significant technical challenge, as this was a single point of failure. To address this contingency, future software versions of the simulation will help mitigate this situation by enabling faster re-synchronization once the hardware failure has been corrected. The immediate fix to this challenge however is to increase the density of handheld platforms at the squad level so that the loss of one device has much less of an impact to squad situational awareness.

Another lesson learned is that future software development of the simulation is required in order to more fully meet the needs of TECD 3. As previously mentioned, the simulation must be further developed to enable faster synchronization in the event of a hardware failure or loss of connectivity attributed to thick vegetation, etc. This effort is currently underway. Similarly, analysis of the custom UDP-Reliable (UDPR) protocol has been conducted and improvement opportunities identified whereby asynchronous communication can be conducted more effectively between the three modes of employment outlined in this paper.

Recommendations for Future Research

Results of this study will be used to guide future design of experiment decisions for the next exercise, to be held again at Fort Dix, NJ. In that scheduled experiment, we intend to examine and explore new network topology techniques to decrease the amount of asynchronous activities between the three nodes outlined in this paper. Additionally, we will create a collective performance rubric whereby we can better objectively measure Soldier performance and effectiveness and thus quantify performance gains made through the use of embedded simulation at the small unit echelon. Also, we plan on obtaining more detailed human-computer interface feedback from soldiers for the next exercise, so as to improve the interaction between the LG-RAID Android app and dismounted leaders. This may potentially improve soldiers' responses to various identified threat activity. Finally, the analysis of potential cyber vulnerabilities to the TECD framework represents another potential future research area.

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