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SYSTEMS ANALYSIS OF SENSE AND STRIKE CAPABILITIES WITHIN AN ARMORED COMBAT UNIT IN AN OFFENSIVE URBAN OPERATION

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THESIS

SYSTEMS ANALYSIS OF SENSE AND STRIKE CAPABILITIES WITHIN AN ARMORED COMBAT UNIT IN AN OFFENSIVE URBAN OPERATION

by

Wei Kang Jhovanie Tang

September 2022

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This thesis analyzes the impact of deploying loitering munitions and tactical drones with a company-level armored combat team in an offensive urban operation, using Map Aware Non-Uniform Automata (MANA) as the simulation tool. An armored combat team of the Armored Brigade Combat Team (ABCT) was modelled as part of an offensive urban operation, as a baseline to understand the impacts of Raven RQ-11 and M109A6 Howitzer, subsequently replacing them with the loitering munitions and tactical drones. The design of experiment incorporates a total of seven performance parameters of loitering munitions and tactical drones, and utilized the Nearly Orthogonal and Balanced (NOB) method to generate a total of 256 design points with 350 replications each. JMP Pro 16 software was utilized to analyze the operational effectiveness of the loitering munitions and tactical drones, and assess the key performance parameters of the loitering munitions and tactical drones. It was observed that the significant factors in order of significance were loitering munition's force structure, loitering munition's classification range and tactical drone's endurance, and indicated that the employment of loitering munitions and tactical drones enhanced the operational effectiveness of the armored company. This analysis would aid capability analysts in considering the procurement and deployment of sense and strike capabilities, with respect to potential inter-system interaction and key performance parameters.

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This thesis analyzes the impact of deploying loitering munitions and tactical drones with a company-level armored combat team in an offensive urban operation, using Map Aware Non-Uniform Automata (MANA) as the simulation tool. An armored combat team of the Armored Brigade Combat Team (ABCT) was modelled as part of an offensive urban operation, as a baseline to understand the impacts of Raven RQ-11 and M109A6 Howitzer, subsequently replacing them with the loitering munitions and tactical drones. The design of experiment incorporates a total of seven performance parameters of loitering munitions and tactical drones, and utilized the Nearly Orthogonal and Balanced (NOB) method to generate a total of 256 design points with 350 replications each. JMP Pro 16 software was utilized to analyze the operational effectiveness of the loitering munitions and tactical drones, and assess the key performance parameters of the loitering munitions and tactical drones. It was observed that the significant factors in order of significance were loitering munition's force structure, loitering munition's classification range and tactical drone's endurance, and indicated that the employment of loitering munitions and tactical drones enhanced the operational effectiveness of the armored company. This analysis would aid capability analysts in considering the procurement and deployment of sense and strike capabilities, with respect to potential inter-system interaction and key performance parameters.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABCT	Armored Brigade Combat Team
AFV	Armored Fighting Vehicle
APS	Active Protection System
ATGM	Anti-Tank Guided Missile
CAB	Combined Arms Battalion
DOD	Department of Defense
DOE	Design of Experiment
EFP	Explosive Formed Projectile
GCV	Ground Combat Vehicle
HEAT	High Explosive Anti Tank
ICV	Infantry Carrier Vehicle
IED	Improvised Explosive Device
IFV	Infantry Fighting Vehicle
ISR	Intelligence, Surveillance and Reconnaissance
LER	Loss Exchange Ratio
M/CM/S	Mobility, Counter-mobility, and Survivability
MANA	Map Aware Non-Uniform Automata
MBT	Main Battle Tank
MOE	Measure of Effectiveness
MOUT	Military Operations in Urban Terrain
NLOS	Non Line-of-sight
NOB	Nearly Orthogonal and Balanced
NOLH	Nearly Orthogonal Latin Hypercube
RCP	Relative Combat Power
SACLOS	Semi-automatic Command to Line-of-sight
SBS	Solder Borne System
SE	Systems Engineering
TOW	Tube-Launched, Optically Tracked, Wireless-Guided
UAS	Umanned Aerial System
UAV	Unmanned Aerial Vehicle

VTOL	Vertical Take-off and Landing
VUCA	Volatile, Uncertain, Complex, Ambiguous

EXECUTIVE SUMMARY

The proliferation and increasing frequency of urban operations broadens the spectrum of operational challenges for modern armored combat units like the Combined Arms Battalion (CAB) within the Armored Brigade Combat Team (ABCT) (Department of the Army and Department of the Marine Corps 2017). The CAB consists of main battle tanks (MBT) such as the M1A2 Abrams and Infantry Fighting Vehicles (IFV) such as the M2 Bradley, which are equipped with higher firepower, mobility, and protection (U.S. Department of the Army 2021b; 2016a). Despite their superior capabilities, these units face operational challenges like: irregular tactics, limited situational awareness, and restricted mobility within urban terrain.

Recent conflicts have suggested potential for Unmanned Aerial Vehicles (UAV) to supplement some of the firepower, mobility, and protection capabilities traditionally provided by MBTs and IFVs. Recent conflicts such as the one between Armenia and Azerbaijan have highlighted the effectiveness of loitering munitions in providing the Azerbaijan military with the capability to destroy armored vehicles from a stand-off distance (Shaikh and Rumbaugh 2020; Bhattacharya and Fernando 2021). In addition, drones have enabled the ability to perform Intelligence, Surveillance and Reconnaissance (ISR) operations, enhancing situational awareness of the area of operation (Crouch 2005). Therefore, newer sense and strike capabilities are enabled by such assets and could be considered complementary for the ABCT in achieving higher operational effectiveness in urban terrain. Hence, this thesis studied the prioritization of technological development or procurement of loitering munitions and tactical drones, and their effects when deployed with armored units in an offensive urban operation.

This thesis utilized a systems engineering approach to analyze the CAB and a company-level armored combat team. The boundaries, stakeholders' needs, and functional analysis of the CAB were presented to develop the following Measures of Effectiveness (MOE): (1) Blue and Red Force Casualties; (2) Loss Exchange Ratio (LER); (3) Time Steps; and (4) Probability of Mission Success.

Map Aware Non-Uniform Automata (MANA), an agent-based simulation software, was used in this analysis to develop a simulation model. A simulation model of the armored combat team with existing assets was developed, along with an enhanced simulation model that included loitering munitions and tactical drones (Williams 2014). A Nearly Orthogonal and Balanced (NOB) design of experiment (DOE) was developed to vary the performance parameters of the loitering munitions and tactical drones, to enable efficient and effective exploration of the design space (Vieira, Jr. et al. 2011; Vieira Jr. 2012).

Thereafter, descriptive statistics, stepwise regression, and partition trees were applied to the dataset using JMP Pro 16 statistical software. The analysis provided three insights:

1. Sense and strike assets should be deployed in unison for higher operational effectiveness.
2. The most significant performance parameters of the simulation model are the Loitering Munitions' Force Structure, Loitering Munitions' Classification Range, and Tactical Drone's Endurance.
3. Analysis of newer capabilities should be approached from a system of systems perspective to account for any possible inter-system interactions.

Analysis showed that interactions between the following inputs had a statistically significant impact on performance: (1) Loitering Munitions' Force Structure, (2) Loitering Munitions' Classification Range, and (3) Tactical Drone's Endurance. In the scenario where more loitering munitions were deployed, it was observed that the performance parameters of loitering munitions and tactical drones did not significantly impact operational effectiveness of the armored combat team. Conversely, should lesser loitering munitions be deployed, performance parameters of loitering munitions and tactical drones significantly impacted the operational effectiveness of the armored combat team.

These operational insights can aid capability analysts and military planners in considering the procurement and deployment of sense and strike capabilities, with respect to potential inter-system interaction and key performance parameters.

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I. INTRODUCTION

A. BACKGROUND

With the potential for military operations in urban terrain increasing, urban operations will become more significant for militaries and future operations. Recent major conflicts, from the Iraq War in 2003 to the ongoing Russia-Ukraine war in 2022, have shown the significance and frequency of urban operations (Wahlman and Drinkwine 2014; Baker 2019; O’Keefe 2020; Davies 2022). Urban operations provide a spectrum of operational challenges such as increased military casualties and vulnerabilities (Department of the Army and Department of the Marine Corps 2017). One of the essential concepts of warfare is combined arms, which was defined by the U.S Army in the *Army Doctrine Publication (ADP) 3–90 – Offense and Defense* as involving the synchronization and deployment of different military elements to achieve a larger effect than employing a single element in solitary and was highlighted by the U.S. Army Asymmetric Warfare Group as essential in urban operations (U.S. Department of the Army 2019b). To tackle such challenges, emphasis on improving the operational effectiveness of the combined arms units is essential for improving the probability of success in urban operations.

In a combined arms unit like the Armored Brigade Combat Team (ABCT), multiple elements such as armored vehicles, infantry, artillery, combat engineers, and reconnaissance are integrated as a unit (U.S. Department of the Army 2021a). Accordingly, there are multiple ways to improve the operational effectiveness of combined arms units, either by improving and upgrading individual elements of the combined arms unit or introducing newer elements and capabilities into the combined arms unit. The idea of introducing capabilities to improve operational effectiveness was reinforced by a report on lessons learnt from urban operations, where specialized equipment unique to militaries’ inventory and intelligence capabilities may enhance the operational effectiveness in urban operations (A. W. G. Department of the Army 2016). Given that the options available to enhance the military unit are endless, it is imperative to rigorously examine each potential option to improve future military capabilities.

One key example of enhancing military capabilities was observed from the Armenia-Azerbaijan conflict, where the Azerbaijan military showed the effect of leveraging both sensing and striking assets to deliver high firepower to the battlefield. Developments and changes to operational concepts highlighted the effectiveness of long-range reconnaissance and targeting technology, where it played a key role in the Azerbaijan's success, showing that the conventional means of warfare may no longer be relevant (Bhattacharya and Fernando 2021). With the deployment of drone attacks and loitering munitions, main battle tanks (MBT) like the T-70 were destroyed from longer stand-off ranges (Shaikh and Rumbaugh 2020). In lieu of air power, these sense and strike capabilities and concepts of operations have rendered armored vehicles ineffective in certain combat scenarios (Wahlman and Drinkwine 2014).

B. PROBLEM DEFINITION

The understanding of the environment's and military unit's limitations would facilitate the development of problem definition and research questions.

1. Urban Terrain

Military operations are occurring more frequently in urban areas due to the rapid urbanization and relocation of populations (Department of the Army and Department of the Marine Corps 2017). As such, militaries must adapt to performing operations within such terrain and exploit opportunities to enhance their effectiveness in an urban environment.

The proliferation of urban operations introduces a different spectrum of operational challenges to combined arms units like the Combined Arms Battalion (CAB). According to the techniques publication on Urban Operations by the U.S Army and Marine Corps, urban operations are known to bring about highly complex scenarios and engagements due to the presence and interaction of infrastructure, terrain, and population. This level of complexity is known to cause higher attrition both to personnel as well as equipment or systems (Baker 2019).

With urban areas primarily housing civilians in peacetime, the urban battlefield may incorporate both adversaries and innocent civilians, increasing the complexity for military units in detecting and classifying adversarial assets (Spencer 2021). Urban terrain also houses critical infrastructure and assets like power grids, water supply, and medical facilities, which adds to the consideration of minimizing collateral damage within the battlefield. Due to the presence of multiple layers of infrastructures, the relative technological superiority of firepower, protection, and mobility of one military force over another is often negated (Department of the Army and Department of the Marine Corps 2017).

2. Combined Arms Unit

As the U.S Army's armored force, the ABCT consists of CABs equipped with ground combat vehicles (GCV) such as the M1A2 Abrams MBT and M2 Bradley infantry fighting vehicles (IFV) (U.S. Department of the Army 2021b). The GCVs, as the main maneuver forces within the CABs, close in with and destroy adversary military assets (U.S. Department of the Army 2021b). The GCVs were designed to offer high protection and mobility to their friendly forces while having the capability of bringing higher firepower to the battlefield. Nevertheless, there are inherent limitations to these GCVs, especially in the urban terrain.

a. Firepower

GCVs have the capability to deliver high-caliber firepower on the battlefield. These vehicles are equipped with weapon systems such as the 25 mm to 120 mm cannons which are meant to destroy armored and unarmored vehicles from long ranges (Salter 2001; U.S. Department of the Army n.d.). However, the GCVs' weapons are line-of-sight weapons, and consequently, this firepower is negated due to the density and layers of buildings impeding line-of-sight acquisition and engagement of targets (Harris 1998).

In the case of MBTs, due to their higher caliber and longer cannon of the main guns with which they are fitted, they are usually limited in elevation and thus require a longer firing distance to engage targets at a higher height (Öğünç 2021). Table 1 provides an overview of the main gun elevation angles for 11 modern MBTs.

Table 1. Elevation of Tanks’ Main Guns. Adapted from Öğünç (2021).

Types of Tanks	**Main Gun Elevation**
Leopard 2A4	$-9^{\circ} to\ 18^{\circ}$
Challenger 2	$-10^{\circ} to\ 20^{\circ}$
Leclerc	$-8^{\circ} to\ 15^{\circ}$
M60A2	$-10^{\circ} to\ 20^{\circ}$
M1 Abrams	$-9^{\circ} to\ 20^{\circ}$
T55	$-5^{\circ} to\ 18^{\circ}$
T62	$-5^{\circ} to\ 18^{\circ}$
T72	$-6^{\circ} to\ 14^{\circ}$
T80	$-4^{\circ} to\ 18^{\circ}$
T90	$-6^{\circ} to\ 14^{\circ}$
K1A1	$-10^{\circ} to\ 20^{\circ}$

b. Protection

The GCVs’ survivability can be increased through susceptibility and vulnerability reduction methods, e.g, passive armor, active protection system, and signature management (Foo 2014; Goh 2014). As GCVs’ threats such as anti-tank guided missiles (ATGM) continue to improve and become more complex, there are inherent trade-offs between the GCVs’ characteristics and parameters such as mobility and cost (Pinder 1999). The increment and addition of susceptibility and vulnerability reduction methods, for instance, would cause a decrease in the GCVs’ mobility due to the additional weight (Goh 2014). Therefore, it is not recommended to continuously increase the armor and protection system of the GCVs to adapt to the evolving threats they face.

c. Situational Awareness/Sensors

In urban terrain, among the critical limitations GCVs confront are decreased situational awareness and peripheral vision. Due the placement of armor and lack of windows, GCVs’ crew members have limited visibility around and above the vehicle (U.S. Department of the Army 2011; Öğünç 2021). As such, the GCVs are more susceptible to attacks from the top, thereby decreasing the survivability and operational effectiveness of the vehicles.

d. Limitation to System Enhancement

Despite efforts to enhance the existing GCVs, there is a limit to the addition of firepower, protection, mobility, and sensor systems. Militaries like the U.S Army recognize the importance of balancing the trinity of mobility, protection, and firepower for armored units' characteristics (Haight, Laughlin, and Bergner 2012). It is also recognized that there are some trade-offs when trying to improve mobility, protection, or firepower. For example, the increment of armored vehicles' passive armor would result in a trade-off with mobility due to the additional weight, as well as firepower due to space constraints (Foo 2014).

C. RESEARCH QUESTIONS

As militaries look to modernize and adapt to a full spectrum of operations and tackle future operational challenges, capabilities such as long-range precision fires and next-generation combat vehicles have been identified as priorities for development (Feickert and McGarry 2020). Unmanned technologies such as loitering munitions and tactical drones might be able to fulfill those priorities, given their ability to sense and strike adversary assets from long range as well as to enhance situational awareness of military forces (Michel and Gettinger 2017).

This thesis aims to determine various performance parameters of loitering munitions and tactical drones which can significantly impact the operational effectiveness of a combined arms unit within an offensive urban operation.

To meet this objective, the study answers the following research questions:

1. How does the incorporation of loitering munitions and drones as a sense and strike capability affect the probability of combined arms units with GCVs achieving mission success in an offensive military operation in urban terrain (MOUT)?
2. What are the key performance parameters of loitering munitions and drones as sense and strike capabilities that should prioritized during development?

D. PURPOSE OF STUDY

The results of this study provides systems and military analysts with a system engineering framework, a modeling and simulation tool, and a statistical analysis of loitering munitions and tactical drones deployed in a combined arms unit's offensive operation in urban terrain. Evidence-based analysis provides operational insights on the potential impacts that newer platforms like loitering munitions and tactical drones could provide to improve the operational effectiveness of a combined arms unit.

E. RESEARCH METHODOLOGY

A research methodology must be identified to guide this study to ensure a systematic approach and effective use of frameworks and tools available.

1. Systems Engineering

The research method identified for this thesis is a tailored Systems Engineering (SE) approach, coupled with modelling and simulation for the systems analysis phase. The SE approach entails the analysis of (1) Boundaries; (2) Stakeholders; (3) Functions; and (4) Requirements. From the functions and requirements analysis, the Measures of Effectiveness (MOE) can be identified and utilized to measure the effectiveness of the identified system.

The tailored systems engineering methodology was adapted from a waterfall model defined by Blanchard and Fabrycky (2014) to define the SE phases. Table 2 shows the different phases of SE methodology and the deliverables from each phase.

Table 2. Tailored Systems Engineering Process. Adapted from Blanchard and Fabrycky (2014).

Systems Engineering Phase	Deliverables
Problem Definition	• Stakeholders Analysis • Boundaries • Operational Concept • Scenario
Functional Analysis	• Functional Decomposition • Requirements Engineering • Measures of Effectiveness
Systems Analysis	• Modeling and Simulation • Statistical Analysis

2. Systems Analysis

The systems analysis methodology was applied through agent-based modeling and simulation. The simulation model was conceptualized through the problem definition phase of the SE methodology and translated into an actual operational scenario. The outputs from the simulation model were then compared to the identified MOEs and analyzed in terms of trade-offs and the impact of the various components and attributes.

Agent-based simulation, specifically software developed by the New Zealand Defense Force known as Map Aware Non-Uniform Automata (MANA), was used for the analysis phase. A design of experiments is conducted to provide a comprehensive design space for the simulation runs.

Statistical analysis was applied to the data collected from the simulation runs to study the changes to MOEs caused by varying different design factors that capture lethality and situational awareness.

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II. LITERATURE REVIEW

The literature review aims to provide a summary of relevant past work performed on similar military assets.

Several prior studies have employed a systems engineering approach to understand a combined arms unit's requirements, and thereafter, researchers have utilized agent-based modeling software to model the combined arms units within a specific scenario (Capstone Cohort 311–114G 2013; Treml 2013; Soh 2013; Foo 2014; Goh 2014). By varying the performance parameters of assets such as the combined arms unit's GCVs and drones within the model using a design of experiment (DOE), these studies applied statistical analysis to the model's outputs to identify and understand the key performance parameters that enhance a combined arms unit's operational effectiveness. The literature review also examined research on newer operational developments and capabilities such as loitering munitions and drones, as well as ongoing research that complements this thesis.

A. METHODOLOGY OF PAST WORK

Recent SE studies have analyzed military assets such as GCVs through a system of systems approach coupled with SE methodology (Capstone Cohort 311–114G 2013; Treml 2013; Soh 2013; Foo 2014; Goh 2014). The system of systems approach was introduced by the Institute of Electrical and Electronics Engineers (IEEE) as the integration of systems and capabilities within a larger system to provide more functionality and performance collectively than possible with the sum of the system and its individual capability (IEEE Reliability Society 2014). Systems engineering was defined to enable the development, implementation, and transition of engineered systems (International Council on Systems Engineering n.d.) Recent SE scholars have utilized a combined arms unit as a form of system of systems to identify the unit's functions and requirements according to systems engineering methodology (Capstone Cohort 311–114G 2013; Treml 2013; Soh 2013; Foo 2014; Goh 2014). Thereafter, these scholars translated the functions and requirements into measurable parameters. Modeling and simulation was subsequently utilized to develop a relevant model for data generation, facilitating the analysis of measurable parameters to determine the studied system's effectiveness.

Capstone Cohort 311–114G (2013), for example, analyzed the various components, functions, and relationships of design factors to enhance the survivability of GCVs (see Appendix A for more information). Through an analysis, critical functions and measures of suitability were identified and compiled into a "Survivability Factor List," showing the different factors that affect the survivability of a GCV. As shown in Table 3, "Lethality" and "Situational Awareness" were decomposed into sub-functions, providing insights into the necessary functions of GCVs for analysis.

Table 3. Survivability Factor List. Adapted from Capstone Cohort 311–114G (2013) and Treml (2013).

Lethality	Situational Awareness
• Prioritize Threats • Select Threats • Acquire Threat • Track Threat • Engage Threat • Guide Ammunition to Target • Deliver Ammunition to Weapons • Track Ammunition Status • Control Weapons • Host Weapons • Manage Weapon Recoil/Impact • Manage Weapon Biproducts	• Enable Common Situational Understanding • Enable Vision • 360° Situational Awareness • Detect Objects • Identify Objects

Leveraging Capstone Cohort 311–114G's (2013) "Survivability Factor List," Tobias Treml (2013) developed a "dashboard" to study and visualize the tradeoffs and impacts of varying the GCVs' performance parameters on a combined arms unit's operational effectiveness. A simulation model was developed by Treml (2013) to include a reinforced mechanized infantry company as the combined arms unit in an offensive operation against parts of a mechanized battalion. A Design of Experiment (DOE) was conducted to vary the performance parameters of an IFV and MBT to understand the significant performance parameters affecting the operational effectiveness of the reinforced mechanized infantry company (Treml 2013).

Ceying Foo (2014) and Wei Jun Goh (2014) utilized a methodology similar to Treml's (2013) approach of modeling a combined arms unit and its GCVs, thereafter varying the GCVs' performance parameters to analyze the impact on the combined arms unit's operational effectiveness. Nonetheless, Foo (2014) and Goh (2014) focused on developing an urban warfare scenario involving a combined arms unit to analyze how the survivability of GCVs was affected by varying the performance parameters of the GCVs. Although Foo (2014) performed a similar approach of modeling the operational effectiveness of the combined arms unit, he chose offensive urban warfare as the operational context while Goh (2014) focused on defensive urban operations.

As shown in Figures 1 and 2, these previous researchers developed functional decompositions of an armored unit's offensive and defensive operations to understand an armored unit's requirements and functions in different types of urban operations (Foo 2014; Goh 2014).

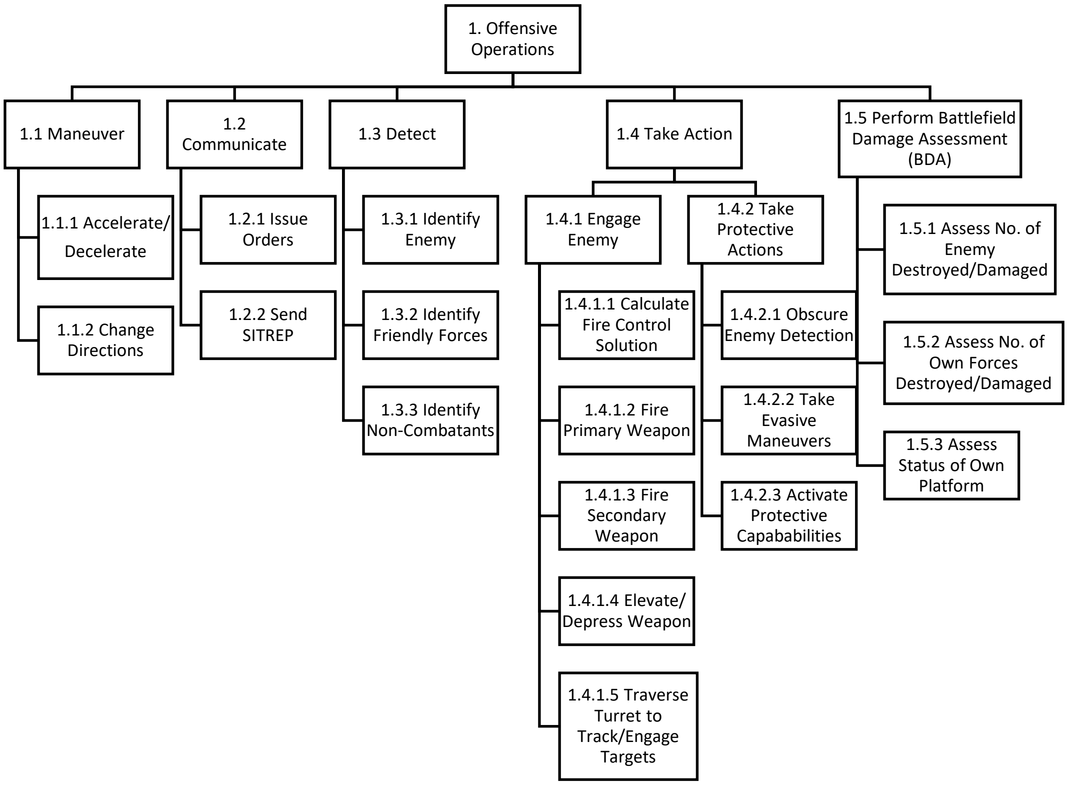

Figure 1. Functional Decomposition of an Armored Company Team. Adapted from Foo (2014).

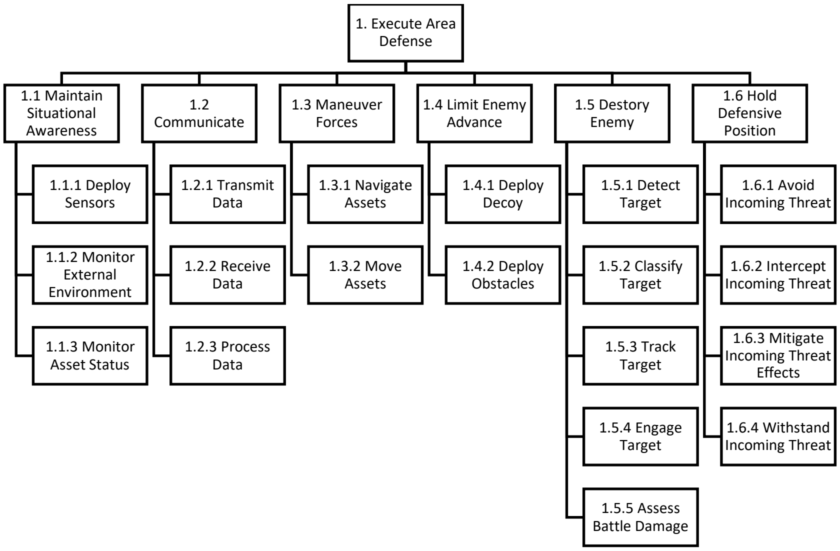

Figure 2. Functional Decomposition of an Area Defense in Urban Terrain. Adapted from Goh (2014).

As shown in Table 4, Goh (2014) identified a GCV's potential performance parameters most applicable for analyzing a combined arms unit's operational effectiveness: passive armor, Active Protection System (APS) equipping, sensor classification range, and speed. The performance parameters were then varied to identify the significance of their impact to operational effectiveness within a DOE and simulation model. A baseline model was developed to generate the initial operational effectiveness results of the combined arms unit, subsequently varying the factors shown in Table 4 to identify the significance of each factor affecting the operational effectiveness results of the combined arms unit (Goh 2014).

Table 4. Performance Parameters to Analyze Survivability in Defensive Urban Operations. Adapted from Goh (2014).

Category	**Performance Parameters**	**Baseline Model**	**Varying of Parameters**
Vulnerability Reduction	Passive armor thickness	M1 Abrams: 1,000 mm M2 Bradley: 500 mm Stryker: 250 mm	All platforms: 70% to 130% of baseline model platform inherent armor
	APS equipping	Not equipped. Number of hits to kill M1 Abrams = 1	Equipped or not: Number of hits to kill the M1 Abrams agent increases to 3
Susceptibility Reduction	Sensor classification range	M1 Abrams: 4,000 m M2 Bradley: 3,500 m Stryker: 2,000 m	All platforms: 100% to 200% of baseline model platform classification range
Mobility	Speed	M1 Abrams: 25 mph M2 Bradley: 25 mph Stryker: 36 mph	All platforms: 70% to 130% of baseline model platform speed

Similar to Goh (2014), Table 5 shows the performance parameters of the GCVs identified by Foo (2014) to analyze a combined arms unit's operational effectiveness. One of the key differences between Goh (2014) and Foo (2014) was the inclusion of an additional unmanned aerial vehicle (UAV) as a sensor within the latter's DOE and simulation model. Beyond the susceptibility reduction, vulnerability reduction, and mobility measures, Foo (2014) also varied the GCVs' force structure to analyze the effects of different combinations of GCVs within an armored unit. As shown in Table 6, Foo (2014) varied combinations of the M1 Abrams MBT, M2 Bradley IFV, and Stryker Infantry Carrier Vehicle (ICV) within the DOE.

Table 5. Performance Parameters to Analyze Survivability in Offensive Urban Operations. Adapted from Goh (2014).

Category	Performance Parameters	Varying of Parameters
Vulnerability Reduction	Passive armor	All platforms: 100% to 140% of baseline model platform inherent armor
	APS equipping	Equipped or not: Hit probability reduced by 50%
	Explosive Reactive Armor (ERA) equipping	Equipped or not: Number of hits to kill GCV agent increases from 1 to 3
Susceptibility Reduction	Presence of additional UAV as sensor	Present or not: Improve situational awareness of other assets
	Speed	All platforms: 60% to 100% of platform speed
	Signature measurement measures	Equipped or not: Probability of being detected reduced by 30%
	Force structure	Different configurations of MBT, IFV and ICV.

Table 6. Force Structure Configuration. Adapted from Foo (2014).

Force Structure (Number of Platoons)	Number of Vehicles
3 M1A2 MBT	12
2 M1A2 MBT + 1 Bradley IFV	11
2 M1A2 MBT + 1 Stryker ICV	11
1 M1A2 MBT + 2 Bradley IFV	10
3 Bradley IFV	9
1 M1A2 MBT + 1 Bradley IFV + 1 Stryker ICV	10
1 M1A2 MBT + 2 Stryker ICV	10
2 Bradley IFV + 1 Stryker ICV	9

Sze Shiang Soh (2013) also built on the studies by both the Capstone Cohort 311–114G (2013) and Treml (2013) by analyzing the impact of ISR performance parameters on the GCV's survivability. Soh (2013) also utilized a modeling and simulation approach by adapting Treml's (2013) scenario of a combined arms unit. While Capstone Cohort 311–114G (2013) identified "Provide Situational Awareness" as a critical function that impacts the survivability of GCVs, Soh (2013) expanded on how situational awareness was related to ISR framework and architecture. Soh's (2013) simulation model focused on studying the impact of ISR, using a DOE to vary the performance parameters of UAVs and GCVs, as shown in Table 7.

Table 7. Performance Parameters Variation. Adapted from Soh (2013).

Performance Parameters
• Sensor Detection and Classification Accuracy of UAV and GCV • Outgoing Communication Links Accuracy of UAV and GCV
• Persistence of UAV • Number of UAVs • Latency of Information of UAV and GCV

B. INSIGHTS FROM PAST WORK

By applying statistical analysis on the results of the simulation model developed by Soh (2013), Goh (2014), and Foo (2014), it was possible to identify the significant performance parameters of GCVs or drones to generate operational insights for the enhancement of operational effectiveness of the combined arms unit. The statistical analysis provided two key insights.

The first notable insight was the results indicating that the equipping of the APS and MBT's passive armor were significant in affecting the MOEs, while improvement in sensor classification was not significant due to the limited line-of-sight within such enclosed terrain (Goh 2014). Thus, this analysis highlighted the need to find methods to improve the situational awareness of GCVs within urban terrain, which could be mitigated by deploying newer capabilities like tactical drones to perform ISR functions for combined arms units.

The second insight was a difference in the operational insights of Soh (2013) and Foo (2014). Soh (2013) highlighted that deploying a higher number of UAVs in an offensive conventional operation increases operational effectiveness of a combined arms unit. On the other hand, Foo (2014) highlighted that despite the addition of sensors like UAVs in an offensive urban operation, the operational effectiveness of a combined arms unit was not enhanced, due to the limitation of ground units to engage adversaries from a further distance. Despite Foo’s (2014) insight that the addition of UAVs as sensors within an urban offensive operation was limited by the ground units’ ability to engage adversaries from a distance, the limitation could be mitigated by deploying newer capabilities like loitering munitions to perform the engagement from the air domain.

C. CONCLUSIONS FROM PAST WORKS

Essentially, the past works have highlighted the feasibility of utilizing an SE approach to analyze the requirements of a combined arms unit in conventional or urban warfare, both in offensive and defensive operations (Capstone Cohort 311–114G 2013; Treml 2013; Soh 2013; Foo 2014; Goh 2014). Thereafter, agent-based modeling was used to model combined arms units and vary the performance parameters of the individual assets like GCVs and drones to analyze the effects and impacts of the modified performance parameters on operational effectiveness.

D. RECENT OPERATIONAL DEVELOPMENTS

As part the U.S Army’s modernization efforts, there lies a possibility of deploying newer combat capabilities like precision strikes, potentially able to emulate the effects of GCVs or artillery from the air domain (Scales 2019). In the conflict between Ukraine and Russia in 2014, UAVs were deployed in conjunction with artillery strikes and were reported to increase the speed of engagement by artillery strikes (Angevine et al. 2019). Thus, sense and strike capabilities, like tactical drones and loitering munitions, are considered in this thesis to analyze the effects of these assets on operational effectiveness.

1. Sensing Capabilities

As situational awareness of GCVs is limited within urban terrains, unmanned systems could be deployed as a solution because they provide the ability to perform ISR operations and transfer information to the relevant parties without endangering the manned assets (Glade 2000; Farrow 2016). With sensors deployed in support of GCVs, the situational awareness of GCVs would be enhanced, thus improving operational effectiveness and survivability of GCVs within urban terrain (Soh 2013; Öğünç 2021).

As demonstrated by the Solider Borne System (SBS), smaller unmanned systems with lower specifications could be deployed directly to tactical units to obtain real-time information and battlefield intelligence (U.S. Department of the Army n.d.). These systems can also be scaled easily due to the availability of commercial-off-the-shelf (COTS) unmanned systems as well as the technology to develop smaller sized unmanned systems, which are expendable as compared to larger class unmanned systems (Crouch 2005).

2. Striking Capabilities

Strike assets provide the capability to strike targets over an extended range. However, such assets are key to operational success and usually reside at the strategic or operational levels, like the U.S. Army's Corps consisting of only one rocket artillery brigade each (Morgan 2018). To enable responsive strike capabilities, strike assets could be deployed or attached inorganically to the tactical levels. Ukrainian soldiers experienced artillery strikes often shortly after spotting a UAV, and this efficiency was attributed to Russia's task organization of deploying strike assets organically to each Battalion Tactical Group (BTG) (Angevine et al. 2019). This task organization could be also enabled by deploying emerging technologies such as armed drones or loitering munitions from a longer stand-off range to search, detect, and destroy targets. As seen in the Armenia-Azerbaijan conflict, assets like loitering munitions were utilized to destroy key installations like air defense systems, achieving a large operational advantage to then target other key assets like tanks (Atherton 2021).

E. RESEARCH OPPORTUNITIES

The research by Treml (2013) provided a baseline model and analysis on the survivability of future ground combat vehicles, while Soh (2013), Foo (2014), and Goh (2014) expanded the scope of research to include and analyze various performance factors of GCVs and drones within different operational scenarios. Specifically, their research focused on vulnerability and situation awareness aspects. Despite the varying of a UAV's performance parameters by Soh (2013) and the addition of a UAV by Foo (2014), the concept of loitering munitions deployed in conjunction with tactical level drones has not been analyzed. Therefore, this thesis concentrates on enhancing the operational effectiveness of an armored combat team through the deployment of sense and strike capabilities provided by loitering munitions and tactical drones.

F. CONCURRENT RESEARCH

Military operations have always been conducted as part of a combined arms unit and require different assets to augment the operations in different phases and terrain. As militaries prepare and design for the future battlefield, they must study other capabilities and assets to enhance collective operational effectiveness.

As such, there are two other theses being developed at the Naval Postgraduate School in parallel with the present one: “An Operational Effectiveness Analysis on Manned Unmanned Teaming Using Weaponized Unmanned Vehicles in Urban Terrain” (Phua 2022) and “An Operational Effectiveness Analysis on Small Arms Shooting Precision in Close Quarters Battle” (Teo 2022). The combination of these analyses can provide future analysts and capability development personnel with the estimated benefits and design considerations needed for the improvement of militaries for the urbanized battlefield.

III. SYSTEMS ENGINEERING PROCESS

The research for this thesis uses an SE process to (1) determine boundaries; (2) analyze stakeholders; (3) analyze functions; and (4) analyze requirements. This analysis determined the relevant MOEs, which were critical for the analysis phase.

A. BOUNDARIES

To study the boundaries, an Operational View 2 (OV-2) of the system is developed, as the purpose of the OV-2 is to "define capability requirements within an operational context" (Department of Defense n.d.). It describes the flow of resources like information, which is essential to study the relationships between operational units and assets and how it interacts on the battlefield.

The system of interest was defined to be a CAB, and its operations and operational effectiveness would be analyzed. The CAB is a combined arms unit comprising multiple assets, such as: (1) Command Unit; (2) Intelligence Unit; (3) Strike Unit; (4) Combat Support Unit; and (5) Maneuver Unit, where the GCVs reside. The CAB also serves as the boundary for the system of interest, and additional elements outside of the CAB are considered as external inputs. Figure 3 shows the flow of information within the unit, where the operational information is consolidated at the Headquarters (HQ) level and disseminated to the other units.

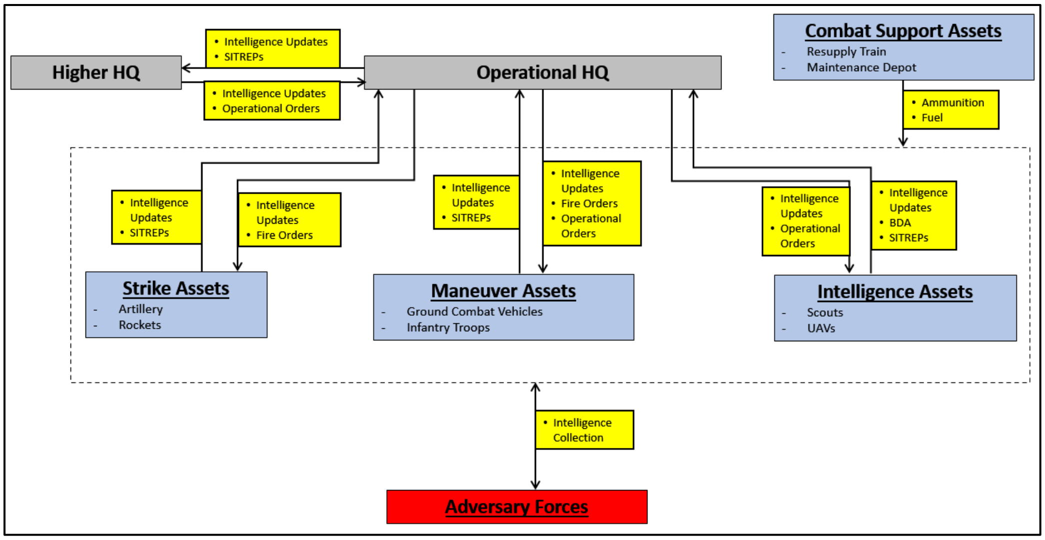

Figure 3. OV-2 of Combined Arms Battalion (CAB)

Given the envisaged organic detection, classification, and engagement capabilities for a CAB to execute its operation effectively, the OV-2 in Figure 3 can be further compressed to portray the envisaged operational view of the maneuver assets within, which represents the CAB shown in Figure 4.

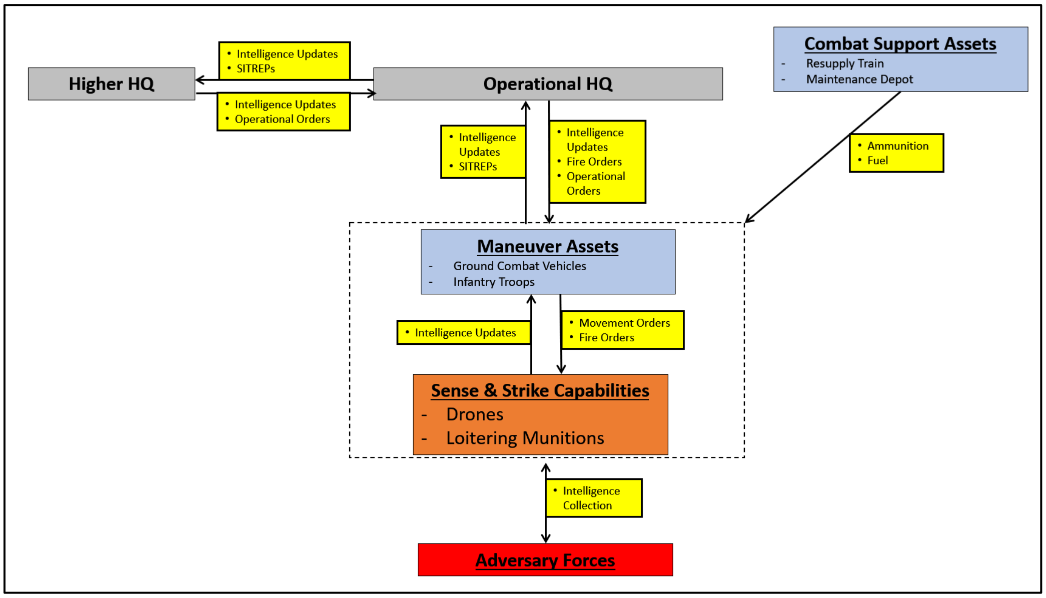

Figure 4. Envisaged OV-2 of Combined Arms Battalion (CAB)

B. STAKEHOLDER ANALYSIS

The CAB and its assets operate as part of the larger service and nation. As such, the stakeholders identified in Table 8 are the following: (1) U.S. Department of Defense (DOD); (2) U.S. Army; (3) CAB; (4) GCV Crew; and (5) Defense Contractors.

By analyzing the needs and goals of each stakeholder, it is then possible to develop measures that determine the success of the system of interest . Table 8 shows the analysis of the key stakeholders.

Table 8. Combined Arms Battalion (CAB) Stakeholders' Analysis

STAKEHOLDERS	TYPE	NEEDS	GOALS
U.S. Department of Defense (DOD)	Sponsor	To have the ability to conduct a full spectrum of operations	To conduct the full spectrum of operations
U.S. Army	Decision Maker	To succeed in any ground military operations	To achieve mission success with the least resources
CAB	High Level User	To achieve desired combat effect dictated by U.S. Army	To perform different types of operational maneuvers
GCV Crew	Operators	To be able to destroy adversary platforms and survive against attacks	To defeat adversary in the battlefield
Defense Contractors	Developers	To generate profits	To develop suitable defense platforms

C. FUNCTIONAL ANALYSIS

The functional analysis serves to develop the top-level system architecture using the various system requirements (Blanchard and Fabrycky 2014). Figure 5 shows the functional decomposition of a military's offensive operation, which forms the top-level system architecture to support offensive operations and facilitates the identification key functions (U.S. Department of the Army 2021b).

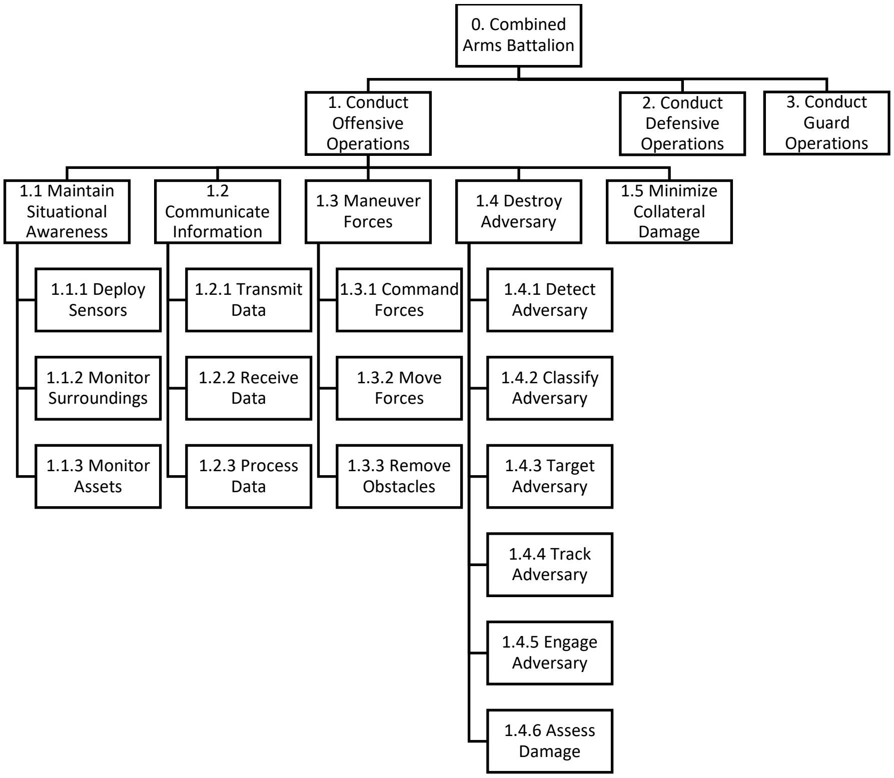

Figure 5. Functional Decomposition of Combined Arms Battalion (CAB).

D. MEASURES OF EFFECTIVENESS

With the design of a new system, it is crucial to determine the MOEs of a system. The MOE serves as a metric to determine the effectiveness of a system through the degree to which the system attains its objectives. The following MOEs were defined to portray the relationship between the resources invested and the outcome achieved.

1. Blue and Red Forces’ Casualties

This MOE serves as the benchmark to study the effects of lethality on the battlefield and is calculated according to the number of casualties. Ideally, military forces aim to inflict damage on an adversary, while experiencing fewer casualties and expending fewer resources than the adversary.

2. Loss Exchange Ratio (LER)

Should lethality be defined with only the simple metric of number of casualties sustained, it may not provide a comprehensive measure as compared to studying the ratio of casualties between two forces (Carpenter and Libertini 2019). As such, the LER in this research incorporates the number of casualties sustained by both the Blue and Red Forces, comparing the relative losses through the following equation:

$$LER = \frac{Red\ Casualties}{Blue\ Casualties + 1}$$

The equation accounts for the possibility of Blue achieving zero casualties in exchange for Red. A higher LER would then indicate that the Blue Force is able to inflict more damage on the Red Force, while suffering a lower number of casualties.

The LER, though suggesting that it is the combat power or attrition ratio of a single entity, represents a multitude of factors and assumptions. Some examples are proficiency, fatigue, morale, and system/asset status.

3. Time Steps Taken for Mission Completion

Given that every military has finite resources, the duration of operations is one of the many aspects that militaries would look to reduce in achieving a decisive victory with minimal losses. As such, the metric of time steps would be utilized to study the system's effectiveness.

4. Probability of Mission Success

As the battlefield is dynamic and relies on multiple factors and interactions between operational environments, no one engagement or operational scenario is truly the same as another (U.S. Department of the Army 2017). Even in simulation models, random seeds are generated to provide some sort of stochastic behavior to each simulation run, to generate insights through probabilities of events occurring (Law 2014). As such, collecting and analyzing the probability of mission successes within a simulation model would assist future military commanders and analysts in determining the risk they would have to undertake during operations, given the probability of mission success.

This was evaluated by calculating the number of times the Blue Force is able to reach two of four egress points, signifying the isolation of Red Forces within the area of operations and is expressed through the following equation:

$$Probability\ of\ Success = \frac{\#\ of\ times\ Blue\ captures\ 2\ of\ egress\ points}{Total\ number\ of\ runs}$$

IV. SCENARIO DEVELOPMENT

A mission-based approach was utilized to develop an operational scenario that represents an armored combat team of a CAB advancing in a defended urban terrain. This allows the envisaged sense and strike capabilities consisting of loitering munitions and tactical drones, along with other available and relevant assets, to be modeled to identify key insights into the CAB's operational effectiveness. As compared to a homogeneous and segregated study, the effects of the operating force are better studied with the possible and most stressing scenarios (Treml 2013).

A. OPERATIONAL SCENARIO

The following operational scenario, concept of operations, and conditions for mission success form the basis of the simulation model for analysis.

1. Operational Overview

As part of the ABCT and CAB, the armored combat team (Blue Force) was deployed to City X as a supporting effort for the CAB to secure the city as a critical terrain. The Blue Force is to secure two of the four land links to the west of the city.

A mechanized company (Reduced) (Red Force) was tasked to deny any penetration into City X. The Red Force was equipped with anti-tank weapons, MBTs, armored fighting vehicles (AFV), and improvised explosive devices (IED).

2. Urban Terrain

The identified terrain focuses on an isolated urban terrain with major connecting roads running from east to west. The city controls all movements to the west, through a major highway and two bridges spanning a water body. Within the city, a large network of small roads stemming from the major roads offers alternative routes into the depth of the city.

3. Force Composition

The Blue Force's composition was assumed to be a company-level armored combat team from one of the CAB, under the ABCT. The CAB, as shown in Figure 6, consists of two mechanized companies and a tank company.

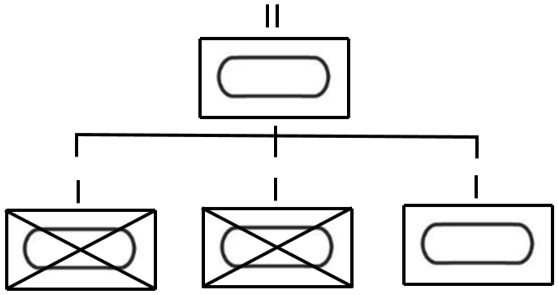

Figure 6. Maneuver Units within the CAB

Shown in Figure 7, the armored combat team consists of three mechanized platoons equipped with the M2 Bradley IFV as its main maneuver platform, reinforced with a platoon of M1A2 Abrams MBTs. In addition, support elements like the reconnaissance and artillery from the CAB was deployed to support the armored combat team.

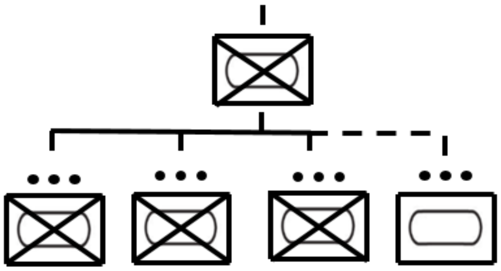

Figure 7. Armored Combat Team Task Organization

B. CONCEPT OF OPERATIONS

The concept of operations forms a summary of intended actions to be taken by a military force during operations.

a. Red Force Concept of Operations

The Red Force, composed of a reinforced mechanized platoon, was tasked to prevent Blue Force's advance beyond the four egress routes, west of City X, through the employment of mechanized forces and anti-vehicular weapons. The Red Force was deployed in two layers. Along the eastern perimeter of the city, IEDs are deployed at critical junctions which are deemed to provide direct access into the depth of the city. These IEDs are sufficient to destroy MBTs upon direct contact. Dominating these IEDs by direct fires were ATGM teams and mechanized vehicles like BMP-3 and T-90 MBTs. In the depth of the city, additional mechanized forces and ATGMs are deployed as the second layer to deny Blue Force's advance to the egress routes.

b. Blue Force Concept of Operations

The Blue Force's armored combat team, consisting of three mechanized infantry platoons and reinforced with a tank platoon, was tasked to capture City X. This is achieved by deploying four mechanized infantry teams of two AFVs, each reinforced with an MBT, holding a mechanized platoon in reserve to advance and secure the egresses to the west of the city. The mechanized infantry teams would perform a concurrent penetration into City X and advance westwards to secure egress points for the passage of follow-on forces. The mechanized infantry platoon in reserve would provide security during the passasge of follow-on forces through the city. This was supported by battalion-level reconnaissance and strike capabilities to collect intelligence and destroy high-value targets.

C. CONDITIONS FOR MISSION SUCCESS

Before the start of operations, conditions for mission success must be determined, allowing forces to utilize and focus their capabilities and resources to achieve these objectives.

1. Defender Attrition

In military operations, Relative Combat Power (RCP) is a force-ratio that must be considered during operations to ensure military planners have sufficient combat power to perform its operations (Barham 1995). Therefore, should two and a half of its platoons be destroyed, the Blue Force would be deemed as not operational, while the Red Force would be deemed as not operational if all its combat vehicles were destroyed.

2. Capturing Retrograde Points

One of the top considerations of a defender is to be able to sustain operations with its Combat Service Support, which requires egress routes to be available. There are four egress routes identified west of the battle area, and they are deemed critical for the defense force for retrograding and for the attack force as an avenue of passage. Should the attack force be able to capture 50% of the egress points by having its GCVs secure the egress points, the simulation would be terminated. If the simulation is terminated, a snapshot of the battle area would be produced to understand the force structure of Red and Blue Forces' remnants.

V. MODEL DEVELOPMENT

This chapter discusses the simulation model's design and development in terms of how it interfaces with the conceptual operational scenario from the previous chapter.

A. MANA-V SOFTWARE

MANA-V was developed by the New Zealand Defense Technology Agency. It is a form of agent-based simulation which does not require a controller for the model and provides autonomy for each acting agent to move, organize, and react to various scenarios (Williams 2014). These actions are driven by input parameters defined by the user, which provides insight into complex interactions like military operations and engagements.

Conveniently, MANA-V has a simple user interface and is capable of fast run times, allowing multiple iterations of simulation runs for a robust analysis (Williams 2014). In addition, it allows users to incorporate geospatial data and maps by creating terrain files that capture key characteristics of the chosen simulation location. For example, the terrain map allows for defining how individual terrain elements impede movement and line-of-sight. As seen in Figure 8, the different types of terrain are depicted by different colors, each of which represents different values of concealment, protection, and mobility.

Step Delay[ms] 0
Max. Steps 15000
Seed -903477309
Lock ☐

```
Terrain Type BilliardTable added
Terrain Type Wall added
Terrain Type Hilltop added
Terrain Type Road added
Terrain Type LightBush added
Terrain Type DenseBush added
Terrain Type Open added
Terrain Type Water added
Terrain Type Bush added
Terrain Type Building added
```

☑ Calculate LOS
☑ Intra Squad Net
☑ Inter Squad Net

Run: 1
Model Step: 0
Blue Cas: 0
Red Cas: 0
Neutral Cas: 0
Elevation= 0 m
x = 14795.4 meters, y = 2029.9 meters
Real time = 0.0 seconds
Real time = 0 hour 0 min 0 sec
Total SA Contacts: 0

Figure 8. Example of MANA-V Interface with Terrain Data

B. MODEL ASSUMPTIONS

As the model was designed to capture simulated agent behavior at the company level, the model would have certain limitations in capturing certain levels of detail. It is also important to note that should simulation models try to incorporate every form of variable and interaction to mimic a live scenario, the matrix of variables would be infinite and become too complex to simulate (Williams 2014). As such, it is crucial to identify certain model assumptions that are made to focus the simulation on aspects related to the operational effectiveness of UAVs.

1. Tactics

In the battlefield, tactics were defined to be a combination of art and science and were highly subjective due to the ability to apply concepts and methods given the operational context (Department of the Navy 2018). To reduce the number of variables available for this analysis, the consideration of tactics was limited to the variation of individual agents' movements and behavioral preferences, rather than the employment of a group of agents to induce a specific battlefield effect.

2. Reserves

As one of the principles of war, Economy of Force is deemed the effective and purposeful use of the forces available to sustain operations (Litton 1999). The principle of Economy of Force would entail the deployment of reserve forces to perform certain tactical actions and could be considered as a form of tactics. Therefore, a mechanized platoon from the tactical unit was not modeled in the scenario, as it was assumed to be a secondary force that would secure safe passage for follow-on forces from the ABCT, upon securing of the different egress routes.

3. Environmental Factors

Environmental factors such as weather would result in different model parameters, as well as potentially resulting in a need for different types of capabilities. As such, the model environment was assumed to consist of clear weather with high visibility and was held constant throughout the simulation.

4. Human Factors

Tactical actions of the additional assets like the loitering munitions and small class drones would require a controller (software or human) to provide inputs. As the vehicular crews were assumed to be the controller of the additional assets and heavily involved in controlling the vehicles during combat, the notion of being able to effectively control these systems would not be considered.

5. Assets and Weapons Specifications

Due to security measures, actual specifications of assets and weapons are highly classified information. Therefore, the agents developed in this model were not developed according to actual specifications and were edited from past work done by Treml (2013) according to the author's experience.

C. AGENTS

The following assets modeled as agents, less the loitering munitions and small class drones, were adapted from Treml's (2013) model and included adjustments to the parameters to suit the fictitious scenario and context, based on the knowledge and experiences of the author.

1. M2 Bradley

As one of the key GCVs in a CAB, the M2 Bradley serves as an IFV. It provides the ability to protect and transport troops into the battlefield swiftly (U.S. Department of the Army 2016a). Each mechanized platoon was equipped with four M2 Bradley IFVs, with the capacity to carry three separate rifle squads of nine soldiers (U.S. Department of the Army 2016b). The main armaments on the M2 Bradley are (1) 25 mm cannon; (2) Tube-Launched, Optically Tracked, Wireless-Guided (TOW) Missile; and (3) 7.62 mm machine gun (U.S. Department of the Army n.d.). The main armaments of the M2 Bradley provides the tactical combat unit with the ability to target and destroy targets like troops, lightly armored vehicles and potentially MBTs (General Accounting Office and National Security and International Affairs Division 1992; U.S. Department of the Army n.d.) Despite the M2 Bradley's protection from small and medium arms, it is usually susceptible to anti-tank weapons or an MBT's cannons. As such, it is useful to deploy the M2 Bradley together with an MBT for protection.

2. Mechanized Infantry Platoon

Supported by the M2 Bradley vehicle, the mechanized infantry provides a highly versatile force that can operate mounted and dismounted during its operation (U.S. Department of the Army 2016a). Within each squad, there are two riflemen who are designated either as an "Anti-Armor Specialist" or a "Marksman." The designated Marksman fields a weapon equipped with an enhancement in optics for precision engagements against adversarial infantry (U.S. Department of the Army 2016b). The Anti-Armor Specialist is equipped with a Javelin AT missile system that allows anti-tank engagement of up to 2,000 m (U.S. Department of the Army 2016b). Within a single platoon, there are two dedicated Javelin teams to perform anti-tank operations. Despite the importance of small arms infantry within urban operations, this scenario focuses on the sense and strike capabilities from and against armored vehicles. Therefore, only the infantry anti-tank teams are included.

3. M1A2 Abrams

The M1A2 Abrams MBT is one of the maneuver assets that provides direct firepower within the ABCT and CAB (U.S. Department of the Army 2021b). The M1A2 Abrams is equipped with a 120 mm with High Explosive Antitank (HEAT) and sabot rounds to target adversarial armored vehicles and MBTs, along with a 7.62 mm and 0.50 caliber heavy machine gun (U.S. Department of the Army n.d.). In the simulation model, the M1A2 Abrams was deployed alongside the M2 Bradley to enhance protection and survivability of the tactical unit.

4. RAVEN RQ-11

As part of the ABCT's battalion, the RAVEN RQ-11 UAS (Unmanned Air System) is a small UAS that can be easily launched to scout for information within the battlefield before the commencement of the battle (U.S. Department of the Army 2021a). Despite aerial advantage, unmanned systems like the RAVEN RQ-11 are vulnerable to dectection by radar or visual means (Haider 2021). As such, detection and classification of adversary units were not guaranteed during the simulation. The UAS agent's sensor was assigned appropropriate probabilities of detection. Given that it is under the command of the battalion, the UAS was deployed in support of the armored combat teams deployed forward and would therefore have a higher latency in transmission of information to the Company Commander and, subsequently, to the armored platoon.

5. M109A6 155 mm Howitzer

As the main targeting force of the ABCT, the M109A6 155 mm Howitzer provides the ABCT with the capability to strike adversaries from a distance to aid maneuver forces (U.S. Department of the Army 2016c). The M109A6 battery was modeled to have a command relationship of "General Support" to the CAB and is under the command of the CAB commander (U.S. Department of the Army 2020). As the armored combat team within this scenario was a supporting effort within the entire scheme of maneuver of the CAB, fires might be directed towards other armored combat teams as the main effort.

6. Tactical Drones

Smaller group 1 drones provide instantaneous battlefield information to forward deployed troops (UAS Center of Excellence 2010). With its light and Vertical Take Off and Landing (VTOL) capabilities, it can be retrofitted onto combat vehicles and launched during operations. The drones can be controlled remotely, or software could be designed to allow autonomous patrolling.

In the simulation model, the tactical drones were assumed to be controlled by software which enables the tactical drones to follow a pre-defined path based on the level of threat during operation. The tactical drones were fitted onto the spearheading force of M1A2 Abrams and launched prior to the M1A2 Abrams' penetration of the first line of buildings. During operations, the tactical drones were programmed to return to their respective tactical squad for recharging before being launched once again.

7. Loitering Munitions

Similar to a group 3 drone, loitering munitions like the Switchblade 600 tactical missile system are equipped with warheads and can engage Non-Line of Sight (NLOS) targets such as armored vehicles and IEDs from a stand-off distance (UAS Center of Excellence 2010). This system is highly portable and can be easily fitted on vehicular platforms, as well as be man-portable for operations (AeroVironment, Inc n.d.). The loitering munitions in the model was designed to engage armored assets and provide an alternative to having assets provide indirect fires. The loitering munitions were assumed to be launched successfully in all scenarios and would achieve a P_{Hit} of 1 upon correct classification of adversaries.

8. Tactical Headquarters

Tactical Headquarters were deployed for the Red and Blue Forces, respectively, as a means to communicate information between the maneuvering forces, as well as between additional forces like UAVs or artillery. The Tactical Headquarters could not be detected by any forces and was not equipped with any form of weapon. Communication parameters were constant as they were not the focus of the study.

9. Red Force's Explosive Devices

Mobility, Counter-mobility, and Survivability (M/CM/S) is a type of operation that aims to deter maneuvers and reinforcements or to ambush and destroy adversaries, using man-made or natural obstacles (U.S. Department of the Army 2019a). Such obstacles include explosive devices like mines, which can be deployed by adversary's forces. Explosive devices with the ability to destroy MBTs and AFVs were incorporated into the scenario to factor in M/CM/S operations against the Blue Force. Blue Force's maneuver forces had a low probability of detecting the explosive device, while tactical drones had a higher probability of detecting them.

10. Red Force's Infantry Fighting Vehicle (IFV)

IFVs like the BMP-3 were deployed within the scenario as part of the Red Force's armored unit. The IFVs were equipped with cannons that could demolish buildings with

High Explosive (HE) rounds, as well as ATGMs meant for armored vehicles (U.S. Department of the Army n.d.). The ATGMs were configured to be able to destroy the M1A2 Abrams and the M2 Bradley, but with limited ammunition and low reloading rate.

11. Red Force's MBT

MBTs like the T-90MS MBT were deployed within the scenario as part of the Red Force's armored unit. The MBTs provide the armored unit with the highest level of protection and firepower with their 125 mm cannon (U.S. Department of the Army n.d.). The MBT was modeled with sufficient firepower to destroy the M1A2 Abrams or M2 Bradley.

12. Red Force's ATGM

The Red Force's dismounted infantry elements were represented by anti-tank teams of two soldiers equipped with MILAN anti-tank missiles and anti-infantry small arms. These missiles are wire-guided semi-automatic command to line-of-sight (SACLOS), which require a continuous line-of-sight to guide the missiles toward the target (U.S. Department of the Army n.d.). The ATGM team were configured to be able to destroy the M1A2 Abrams or M2 Bradley with the MILAN system, as well as the Javelin teams with the small arms.

13. Dummy Agent

A special dummy agent was developed within the model as a method to execute the stopping condition of Blue Forces capturing the egress points. Each dummy agent generated at the egress points as an immobile agent that could only be destroyed by a special short-range weapon equipped on the GCVs. The stopping condition would be triggered when two such agents were destroyed.

D. BASELINE SIMULATION EXPERIMENT

As shown in Figure 9, the baseline simulation experiment was designed in an urban terrain of 5 km by 15 km size, containing buildings, roads, and water bodies. It consisted of multiple ingresses into the city from the east and four egresses to the west.

Figure 9. Baseline Model in MANA

The baseline simulation experiment consisted of a Combined Arms Unit's assets in three different configurations, by varying the availability of the Raven RQ-11 and M109A6 155 mm Howitzer. With the stochasity of MANA, each configuration was simulated 1,000 times to produce the relevant statistics on the MOEs identified. Table 9 shows the different configurations of the baseline experiment.

Table 9. Configurations of Baseline Experiment

	Configuration 1	**Configuration 2**	**Configuration 3**
Constant Assets	**Blue Forces** 4 x M1A2 Abrams 8 x M2 Bradleys 8 x Javelin Teams 1 x HQ **Red Forces** 2 x T-90 4 x BMP 3 4 x MILAN ATGM Team		
Varied Assets	1 x Raven RQ-11 1 x M109A6	1 x Raven RQ-11 0 x M109A6	0 x Raven RQ-11 0 x M109A6

E. ENHANCED SIMULATION EXPERIMENT

In the enhanced simulation experiment, the Raven RQ-11 and M109A6 from the baseline simulation experiment were replaced with the loitering munitions and tactical drone, respectively. Instead of varying assets, the performance parameters of the loitering munitions and tactical drones were varied to analyze the effects of such assets in the battlefield. The number of replications was determined using the standard deviation of Blue Force's casualties in the baseline simulation experiment. Based on assessment of the variation in the baseline simulation experiment, the required number of replications per design point was estimated as 327, which was rounded to 350 replications per design point.

Figure 10. Enhanced Model in MANA

F. MODEL FACTOR SELECTION

The factor selection was anchored on the assumption that the loitering munitions and tactical drones are the key differences from a conventional task organization, and thus, the performance parameters of these assets were selected for analysis. Table 10 shows the summary of the loitering munitions' and tactical drone's respective performance parameters and their maximum and minimum values within the simulation experiment.

Table 10. Summary of Seven Experiment Factors.

Agent	Performance Parameters	Effects	Minimum Value	Maximum Value
Loitering Munitions	**Classification Range (m)**	Minimum range before beginning process of target classification	2000	3000
	Probability of Classification	Increases probability of classifying a target	0.7	0.9
	Endurance (s)	Increases assets' operational time upon deployment	3000	4800
	Force Structure	Number of agents within task organization	4	8
Tactical Drone	**Classification Range (m)**	Minimum range before beginning process of target classification	800	1200
	Probability of Classification	Increases probability of classifying a target	0.7	0.9
	Endurance (s)	Increases assets' operational time upon deployment	900	2700

1. Classification Range

The classification range is defined as a continuous variable and was applied to the sensors of both the loitering munitions and the tactical drone. The range of classification is an important factor because it limits the sensing capability of the assets. The ability to classify targets from a longer range would provide forces more time to decide and adjust the appropriate courses of action.

Given that loitering munitions were designed to detect and classify targets from a stand-off range of more than 1 km, the range modeled was varied more broadly as compared to the tactical drone, which was designed as a close-in tactical drone.

2. Probability of Classification

The classification probability was defined as a continuous variable and was applied to both the loitering munitions and the tactical drone. Complementing the classification range, the probability of classification defines how often a sensor can classify the target correctly in a given time interval, which affects the engagement time and decision.

3. Endurance

The endurance of the assets was defined as a discrete variable and was applied on both the loitering munitions and tactical drone. With smaller sized assets deployed and expected to cover a larger area of operations, endurance is essential to ensure that the asset can perform its operations.

4. Force Structure

Tactical units are usually provided a certain contact rate and task organization for their operations. With the deployment of sense and strike assets, the ideal force structure of such assets would allow military planners to consider the right level of deployment. The force structure of the loitering munitions was varied as a binary factor with values of either four or eight, representing a total of one or two loitering munitions within each tactical team.

G. DESIGN OF EXPERIMENT

Given the multiple factors and possible levels, a full factorial design was deemed infeasible given the limited resources and time for this study. Therefore, flexible space-filling designs such as Nearly Orthogonal Latin Hypercube (NOLH) and Nearly Orthogonal and Balanced (NOB) were considered.

The NOLH as a space filling design was initially considered due to its ability to efficiently utilize the design space while reducing overall resources needed to complete a design, compared to a full factorial design (Sanchez 2011). Nevertheless, the NOLH design was determined to not be ideal due to the fact that binary and discrete factors were included. The rounding of decimal places was required to handle these factors, which could lead to increased pairwise correlation or undesirable balance. Comparatively, the NOB was designed to accommodate a mix of discrete, continuous, and categorical factors with minimal correlation and imbalance (Vieira, Jr. et al. 2011). Therefore, a NOB 256-design point spreadsheet was utilized to create the space filling design (Vieira Jr. 2012). The correlation matrix and values of each design point are contained in Appendix B.

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VI. RESULTS ANALYSIS

The results from the baseline and enhanced experiments were analyzed with JMP Pro 16. The four MOEs were: (1) Blue and Red Forces' casualties; (2) LER; (3) Time Steps; and (4) Probability of Mission Success. Histograms and summary statistics were developed to provide a descriptive analysis of the configurations and a nonparametric test was used to compare means of the configurations, to determine where statistically significant differences occurred. Regression and partition tree models were used to help identify the influence of the experiment factors and also capture where particularly good, bad, or extreme outcomes occurred.

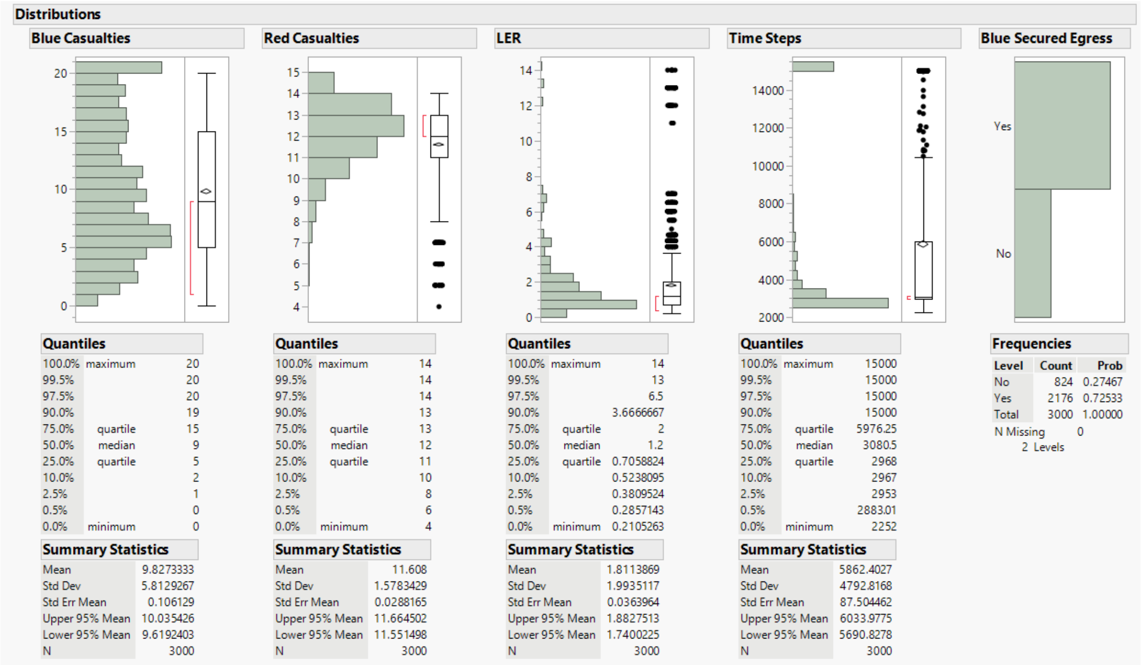
The results from the baseline experiment was compared to the enhanced experiment to identify potential improvements. The numerical results indicated within this thesis are neither indicative of any actual operational scenarios or tests, nor modelled to a level of precision to be utilized for actual operational scenarios.

A. BASELINE SIMULATION EXPERIMENT

Histograms and summary statistics were developed to provide a descriptive analysis of the various MOEs. In addition, nonparametric evaluation using the Wilcoxon Method was performed on the means of the MOEs by configuration. The full statistical results from the statistical software are included in Appendix C.

1. Summary Statistics

Histograms and summary statistics of the baseline model's MOEs in Figure 11 were developed to observe the variance across all three configurations. Configuration 1 corresponds to a scenario where both the Raven RQ-11 and M109A6 Howitzer are present. Configuration 2 removes the M109A6 Howitzer, and Configuration 3 removed both the Raven RQ-11 and the M109A6 Howitzer. The MOEs were further segregated by configurations to understand the impact on the MOEs when employing the Raven RQ-11 and M109A6 Howitzers.



Blue Casualties

Quantiles

100.0%	maximum	20
99.5%		20
97.5%		20
90.0%		19
75.0%	quartile	15
50.0%	median	9
25.0%	quartile	5
10.0%		2
2.5%		1
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	9.8273333
Std Dev	5.8129267
Std Err Mean	0.106129
Upper 95% Mean	10.035426
Lower 95% Mean	9.6192403
N	3000

Red Casualties

Quantiles

100.0%	maximum	14
99.5%		14
97.5%		14
90.0%		13
75.0%	quartile	13
50.0%	median	12
25.0%	quartile	11
10.0%		10
2.5%		8
0.5%		6
0.0%	minimum	4

Summary Statistics

Mean	11.608
Std Dev	1.5783429
Std Err Mean	0.0288165
Upper 95% Mean	11.664502
Lower 95% Mean	11.551498
N	3000

LER

Quantiles

100.0%	maximum	14
99.5%		13
97.5%		6.5
90.0%		3.6666667
75.0%	quartile	2
50.0%	median	1.2
25.0%	quartile	0.7058824
10.0%		0.5238095
2.5%		0.3809524
0.5%		0.2857143
0.0%	minimum	0.2105263

Summary Statistics

Mean	1.8113869
Std Dev	1.9935117
Std Err Mean	0.0363964
Upper 95% Mean	1.8827513
Lower 95% Mean	1.7400225
N	3000

Time Steps

Quantiles

100.0%	maximum	15000
99.5%		15000
97.5%		15000
90.0%		15000
75.0%	quartile	5976.25
50.0%	median	3080.5
25.0%	quartile	2968
10.0%		2967
2.5%		2953
0.5%		2883.01
0.0%	minimum	2252

Summary Statistics

Mean	5862.4027
Std Dev	4792.8168
Std Err Mean	87.504462
Upper 95% Mean	6033.9775
Lower 95% Mean	5690.8278
N	3000

Blue Secured Egress

Frequencies

Level	Count	Prob
No	824	0.27467
Yes	2176	0.72533
Total	3000	1.00000

N Missing 0

2 Levels

Figure 11. Statistical Summary of Baseline Simulation Experiment (Three Configurations of 1,000 Replications Each)

Table 11 shows the summary statistics of the baseline experiment, broken down by configuration. Data shows that Blue Force casualties, LER, probability of success, and time steps worsened when Raven RQ-11 and M109A6 Howitzer agents were removed. This trend could be attributed to lower sense and strike capabilities due to the lack of artillery support as well as forward deployed sensing systems. Blue Forces were deployed to engage Red Forces directly without any form of superior operational intelligence or attrition of Red Forces. Configuration 1 was observed to produce the highest MOE values as compared to the other configurations and suggested that both the Raven RQ-11 and M109A6 Howitzer should be deployed in unison for maximum effectiveness.

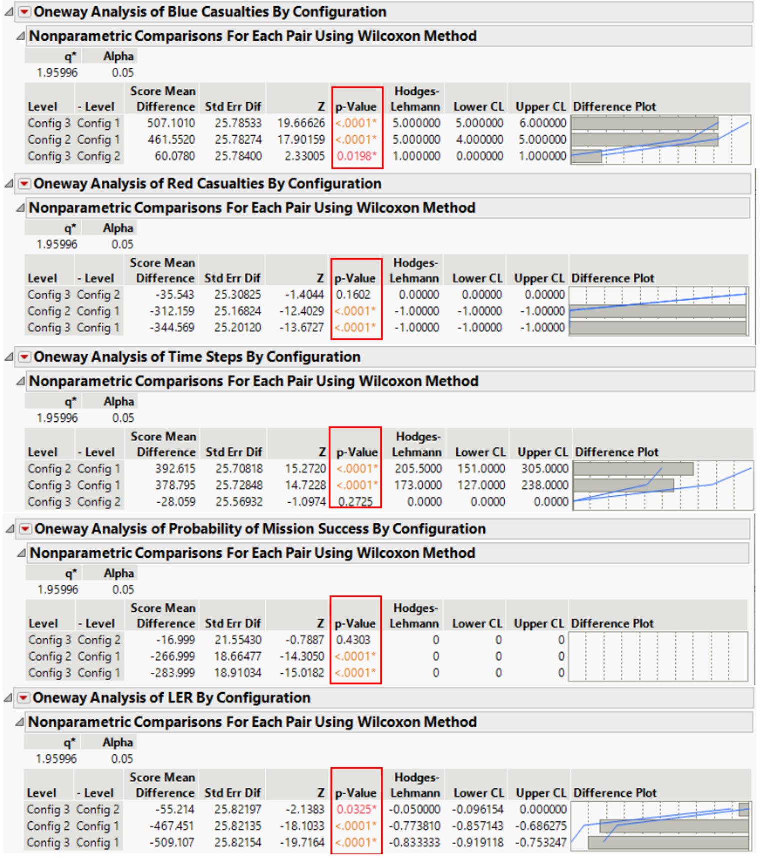
Table 11. Summary Statistics of Baseline Simulation Experiment by Configurations.

Configuration	1		2		3	
	Blue	**Red**	**Blue**	**Red**	**Blue**	**Red**
Average Allegiances' Casualties	6.595	9.778	11.158	9.131	11.729	8.954
Average LER	2.65		1.43		1.34	
Average Probability of Success (%)	90.9%		64.2%		62.5%	
Average Time Steps (s)	4074.65		6939.70		6572.85	

2. Comparison of Configurations

Figure 12 presents a series of pairwise comparisons for the different configurations in terms of each MOE. The null hypothesis was that there was no difference between the MOE of two configurations. The p-values determined whether the difference was significant relative to the chosen significance level of 0.05. If the p-value was less than 0.05, then the null hypothesis was rejected in favor of the alternative hypothesis that there was significant difference between the two configurations in terms of the MOE. Results showed that Configuration 1 was statistically significant from Configurations 2 and 3. Further, Configurations 2 and 3 were statistically similar for all MOEs except (1) Blue Force's casualties and (2) LER. As LER is calculated by Blue Force's casualties, the difference in casualties likely affected the means comparison of LER.

The analysis from the comparison further supported the theory of deploying both the Raven RQ-11 and M109A6 Howitzer in unison for maximum effectiveness. Additionally, the lack of significance between Configuration 2 and substatiated Foo's (2014) insight that there was no increase in operational effectiveness when a reconnaisance asset like the Raven RQ-11 was deployed without long-range strike due to the obstruction of ground units' line-of-sight by buildings.



Oneway Analysis of Blue Casualties By Configuration

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
Config 3	Config 1	507.1010	25.78533	19.66626	<.0001*	5.000000	5.000000	6.000000	
Config 2	Config 1	461.5520	25.78274	17.90159	<.0001*	5.000000	4.000000	5.000000	
Config 3	Config 2	60.0780	25.78400	2.33005	0.0198*	1.000000	0.000000	1.000000	

Oneway Analysis of Red Casualties By Configuration

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
Config 3	Config 2	-35.543	25.30825	-1.4044	0.1602	0.00000	0.00000	0.00000	
Config 2	Config 1	-312.159	25.16824	-12.4029	<.0001*	-1.00000	-1.00000	-1.00000	
Config 3	Config 1	-344.569	25.20120	-13.6727	<.0001*	-1.00000	-1.00000	-1.00000	

Oneway Analysis of Time Steps By Configuration

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
Config 2	Config 1	392.615	25.70818	15.2720	<.0001*	205.5000	151.0000	305.0000	
Config 3	Config 1	378.795	25.72848	14.7228	<.0001*	173.0000	127.0000	238.0000	
Config 3	Config 2	-28.059	25.56932	-1.0974	0.2725	0.0000	0.0000	0.0000	

Oneway Analysis of Probability of Mission Success By Configuration

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
Config 3	Config 2	-16.999	21.55430	-0.7887	0.4303	0	0	0	
Config 2	Config 1	-266.999	18.66477	-14.3050	<.0001*	0	0	0	
Config 3	Config 1	-283.999	18.91034	-15.0182	<.0001*	0	0	0	

Oneway Analysis of LER By Configuration

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

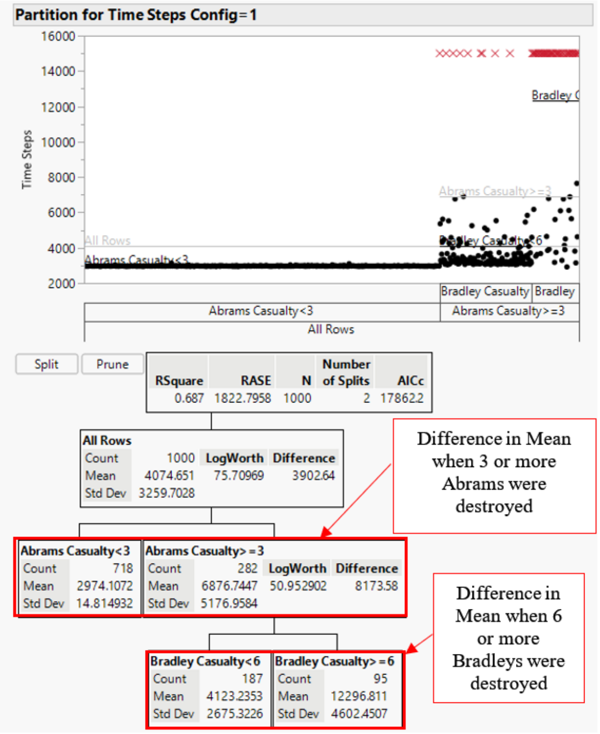
Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
Config 3	Config 2	-55.214	25.82197	-2.1383	0.0325*	-0.050000	-0.096154	0.000000	
Config 2	Config 1	-467.451	25.82135	-18.1033	<.0001*	-0.773810	-0.857143	-0.686275	
Config 3	Config 1	-509.107	25.82154	-19.7164	<.0001*	-0.833333	-0.919118	-0.753247	

Figure 12. Nonparametric Comparisons on MOEs by Configuration

a. Analysis of Time Steps

The simulation model was designed to stop at 15,000 timesteps if none of the stopping conditions were met. Recall that the average across all configurations shown in Figure 11 was 5,800 time steps, so any model run that did not conclude by 15,000 time steps represented a substantial increase in model run time. A partition tree was applied to determine the conditions where the simulation concluded indecisively. The partition tree for Configuration 1, depicted by Figure 13, showed that scenarios where three or more M1A2 Abrams were destroyed yielded extreme results. While the average number of time steps for Configuration 1 was approximately 4,000, it increased to 6,800 when three or more M1A2 Abrams were destroyed. This suggested the correlation of M1A2 Abrams' survivabilility to the mission duration and probability of mission success.

For the next factor, M2 Bradley casualties was chosen instead of Javelin casualties due to the possible effect of M2 Bradley agents being destroyed with Javelin agents mounted within them but not vice versa. Notice the bottom right-hand branch of the partition tree, which corresponds to scenarios that had three or more M1A2 Abrams destroyed and six or more M2 Bradleys destroyed. In these cases, the average time steps was approximately 12,300. Configurations that had more than three M1A2 Abrams destroyed were associated with particularly long model run times, thereby suggesting that fewer capabilities or lesser firepower required a longer time to accomplish the mission. As a result, longer mission durations present the possibility for more Blue Force casualties.



RSquare	RASE	N	Number of Splits	AICc
0.687	1822.7958	1000	2	17862.2

All Rows

		LogWorth	Difference
Count	1000		
Mean	4074.651	75.70969	3902.64
Std Dev	3259.7028		

Abrams Casualty<3

Count	718
Mean	2974.1072
Std Dev	14.814932

Abrams Casualty>=3

		LogWorth	Difference
Count	282		
Mean	6876.7447	50.952902	8173.58
Std Dev	5176.9584		

Bradley Casualty<6

Count	187
Mean	4123.2353
Std Dev	2675.3226

Bradley Casualty>=6

Count	95
Mean	12296.811
Std Dev	4602.4507

Difference in Mean when 3 or more Abrams were destroyed

Difference in Mean when 6 or more Bradleys were destroyed

Figure 13. Partition Tree of Configuration 1 (Red Crosses Marking Extreme Time Steps)

Partition trees for the other two configurations appear in Appendix C. To further explore the conditions that led to extreme time step observations, Table 12 summarizes the number of scenarios exhibiting extreme results of 15,000 time steps. It was observed that Configurations 2 and 3 had more scenarios producing extreme time steps, suggesting that the absence of a destructive long-range asset like the M109A6 Howitzer could induce higher casualties and potentially a lower probability of achieving mission success for the Blue Force.

Table 12. Summary of Scenarios with ≥ 3 M1A2 Abrams and ≥ 6 M2 Bradleys Destroyed

Configuration	1	2	3
Total Scenarios with Extreme Time Steps	80	285	250
Scenarios with < 6 M2 Bradleys Destroyed	10 (12.5%)	20 (7.1%)	24 (9.6%)
Scenarios with ≥ 6 M2 Bradleys Destroyed	70 (87.5%)	265 (92.9%)	226 (90.4%)

3. Conclusion of Baseline Simulation Experiment Analysis

Through the analysis of the MOEs, the results showed that the employment of both the M109A6 Howitzers and Raven RQ-11 enabled Blue Forces to achieve a higher LER. By contrast, the employment of only the Raven RQ-11 without the M109A6 Howitzers achieved a lower LER and was statistically similar to the configuration where there were no Raven RQ-11 and M109A6 Howitzers employed. This highlighted the impact of a system of systems, which produced a higher impact than just the sum of the systems deployed individually. Nonetheless, there could be different operational scenarios where the employment of the Raven RQ-11 in silo could introduce significant impacts.

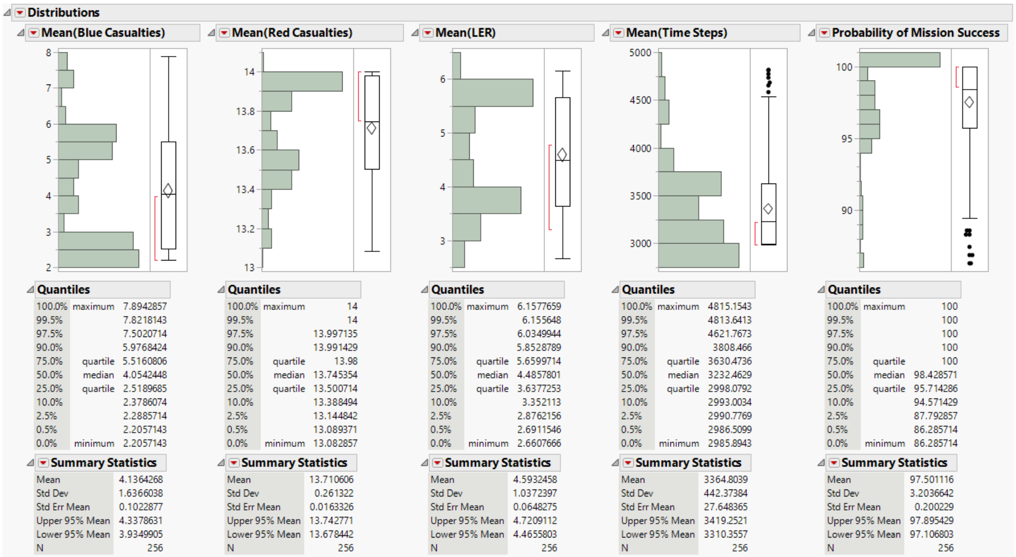
In addition, the results showed that the preservation of the GCVs, especially the MBTs, was crucial to the Blue Force achieving mission success. The employment and preservation of MBTs in an offensive operation within an urban terrain provided a higher rate of mission success due to its higher firepower and protection systems, as compared to IFVs.

B. ENHANCED SIMULATION EXPERIMENT

The baseline analysis suggested that the presence of the Raven RQ-11 along with the M109A6 Howitzer substantially improved performance across multiple MOEs. Based on that insight, an enhanced simulation experiement was developed to assess the impact the new assets, which complement or enhance the performance of those systems, may have on operational effectiveness. The enhanced simulation experiment focused on identifying significant performance parameters of the loitering munitions and tactical drones. Statistical summary, regression analysis, and partition trees were applied to identify significant factors that affected the MOEs and produced noteworthy results in the simulation. The full statistical results from the statistical software were included in Appendix D.

1. Statistical Summary

The statistical summary of the enhanced simulation experiment in Figure 14 shows an overall increase in the MOEs, indicating higher operational effectiveness upon the deployment of the loitering munitions and tactical drones, in place of the Raven RQ-11 and M109A6 Howitzers. The comparison of MOEs between models and configurations was summarized in Table 13. Note that there was an improvement in all four MOEs when comparing the enhanced model to each of the configurations modeled in the baseline model.



Mean(Blue Casualties)

Quantiles

100.0%	maximum	7.8942857
99.5%		7.8218143
97.5%		7.5020714
90.0%		5.9768424
75.0%	quartile	5.5160806
50.0%	median	4.0542448
25.0%	quartile	2.5189685
10.0%		2.3786074
2.5%		2.2885714
0.5%		2.2057143
0.0%	minimum	2.2057143

Summary Statistics

Mean	4.1364268
Std Dev	1.6366038
Std Err Mean	0.1022877
Upper 95% Mean	4.3378631
Lower 95% Mean	3.9349905
N	256

Mean(Red Casualties)

Quantiles

100.0%	maximum	14
99.5%		14
97.5%		13.997135
90.0%		13.991429
75.0%	quartile	13.98
50.0%	median	13.745354
25.0%	quartile	13.500714
10.0%		13.388494
2.5%		13.144842
0.5%		13.089371
0.0%	minimum	13.082857

Summary Statistics

Mean	13.710606
Std Dev	0.261322
Std Err Mean	0.0163326
Upper 95% Mean	13.742771
Lower 95% Mean	13.678442
N	256

Mean(LER)

Quantiles

100.0%	maximum	6.1577659
99.5%		6.155648
97.5%		6.0349944
90.0%		5.8528789
75.0%	quartile	5.6599714
50.0%	median	4.4857801
25.0%	quartile	3.6377253
10.0%		3.352113
2.5%		2.8762156
0.5%		2.6911546
0.0%	minimum	2.6607666

Summary Statistics

Mean	4.5932458
Std Dev	1.0372397
Std Err Mean	0.0648275
Upper 95% Mean	4.7209112
Lower 95% Mean	4.4655803
N	256

Mean(Time Steps)

Quantiles

100.0%	maximum	4815.1543
99.5%		4813.6413
97.5%		4621.7673
90.0%		3808.466
75.0%	quartile	3630.4736
50.0%	median	3232.4629
25.0%	quartile	2998.0792
10.0%		2993.0034
2.5%		2990.7769
0.5%		2986.5099
0.0%	minimum	2985.8943

Summary Statistics

Mean	3364.8039
Std Dev	442.37384
Std Err Mean	27.648365
Upper 95% Mean	3419.2521
Lower 95% Mean	3310.3557
N	256

Probability of Mission Success

Quantiles

100.0%	maximum	100
99.5%		100
97.5%		100
90.0%		100
75.0%	quartile	100
50.0%	median	98.428571
25.0%	quartile	95.714286
10.0%		94.571429
2.5%		87.792857
0.5%		86.285714
0.0%	minimum	86.285714

Summary Statistics

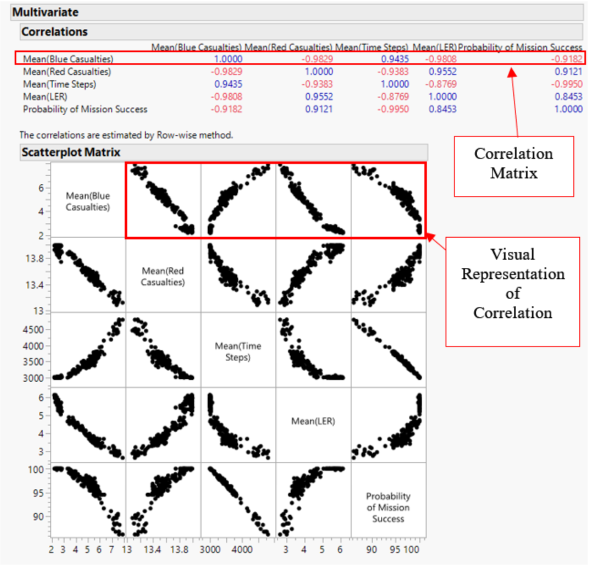
Mean	97.501116
Std Dev	3.2036642
Std Err Mean	0.200229
Upper 95% Mean	97.895429
Lower 95% Mean	97.106803
N	256

Figure 14. Statistical Summary of Enhanced Eimulation Experiment (256 Design Points)

Table 13. Comparison of Summary Statistics by Experiments

Configuration	**Baseline Experiment**						**Enhanced Experiment**	
	1		**2**		**3**			
Average Allegiances' Casualties	**Blue**	**Red**	**Blue**	**Red**	**Blue**	**Red**	**Blue**	**Red**
	6.595	9.778	11.158	9.131	11.729	8.954	4.14	13.71
Average LER	2.65		1.43		1.34		4.59	
Average Probability of Success (%)	90.9%		64.2%		62.5%		97.5%	
Average Time Steps (s)	4074.65		6939.70		6572.85		3364.80	

A correlation matrix of the MOEs was developed to determine the presence of correlation between the MOEs and to succinctly scope the analysis. Figure 15 summarizes the high correlation between the MOEs, where Blue Force's casualties appeared to have the highest correlation with other MOEs. Blue Casualties was observed to be positively correlated with Time Steps and negatively with LER, Probability of Mission Success, and Red Force's Casualties. Therefore, Blue Force's Casualties was identified as the main MOE for further analysis.



Multivariate

Correlations

	Mean(Blue Casualties)	Mean(Red Casualties)	Mean(Time Steps)	Mean(LER)	Probability of Mission Success
Mean(Blue Casualties)	1.0000	-0.9829	0.9435	-0.9808	-0.9182
Mean(Red Casualties)	-0.9829	1.0000	-0.9383	0.9552	0.9121
Mean(Time Steps)	0.9435	-0.9383	1.0000	-0.8769	-0.9950
Mean(LER)	-0.9808	0.9552	-0.8769	1.0000	0.8453
Probability of Mission Success	-0.9182	0.9121	-0.9950	0.8453	1.0000

The correlations are estimated by Row-wise method.

Scatterplot Matrix

Correlation Matrix

Visual Representation of Correlation

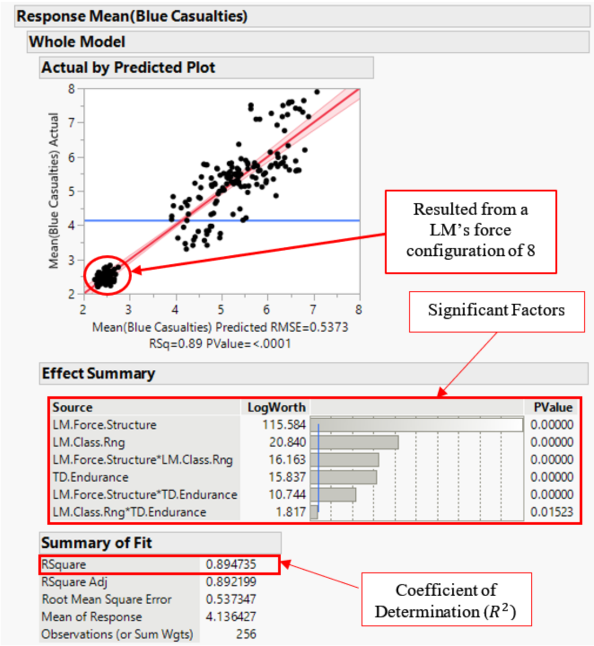
Figure 15. Correlation Matrix of MOEs

2. Analysis of Effects of Factors on MOEs

Two meta-modeling approaches: (1) stepwise regression and (2) partition trees, were utilized to analyze the effects of factors on MOEs. These two methods are complementary in analysis due to the strengths and limitations of each method. Regression analysis is a low complexity parametric approach which can provide robust and easily implementable models, but it is sensitive to outlier or irregular data points (Iqbal 2021). The classification tree algorithm (also known as a partition tree) is a non-parametric method that could better fit discontinuities in the data, and its output could be better interpreted into a form of decision tree to guide decision making (Song and Lu 2015).

Stepwise regression was applied to Blue Force's Casualties to determine whether the model's variance could be explained by the identified factors. A high R^2 indicates that the model's variance could be accounted for by the identified factors and vice versa. This was interpreted through the Coefficient of Determination (R^2) of 89.5%, as shown in Figure 16, indicating that the model's variance could be accounted for by the underlying regression model.

The stepwise regression analysis allowed all first and second order terms to enter the model to capture main effects, two-way interactions, and quadratic terms. As such, the analysis was able to show the effects of factors on the MOE in their order of significance, where "Loitering Munitions' Force Structure" was the most significant factor. This was also observed in the "Actual by Predicted Plot" that the data points of Blue Force's Casualties due to different "Loitering Munitions' Force Structure" were well segregated. Stepwise regression was applied to other MOEs, and the data were included in Appendix D for reference.



Response Mean(Blue Casualties)

Whole Model

Actual by Predicted Plot

Resulted from a LM's force configuration of 8

Significant Factors

Effect Summary

Source	LogWorth	PValue
LM.Force.Structure	115.584	0.00000
LM.Class.Rng	20.840	0.00000
LM.Force.Structure*LM.Class.Rng	16.163	0.00000
TD.Endurance	15.837	0.00000
LM.Force.Structure*TD.Endurance	10.744	0.00000
LM.Class.Rng*TD.Endurance	1.817	0.01523

Summary of Fit

RSquare	0.894735
RSquare Adj	0.892199
Root Mean Square Error	0.537347
Mean of Response	4.136427
Observations (or Sum Wgts)	256

Coefficient of Determination (R^2)

Figure 16. Stepwise Regression of Blue Force's Casualties

Using the results from the stepwise regression analysis of each MOE, the significant factors, and their interactions in order of their significance were summarized in Table 14. It was observed that the main factors identified across the MOEs were similar. Notably, the "Loitering Munitions' Force Structure" was the most important variable for all MOEs. Additionally, the "Loitering Munitions' Classification Range" and "Tactical Drone's Endurance" were statistically significant for all MOEs. With the exception of the presence of the "Tactical Drone's Classification Range" appearing for Red Force's Casualties, these three factors ("Loitering Munitions' Force Structure," "Loitering Munitions' Classification Range," and "Tactical Drone's Endurance") as well as the interactions between those factors, dominated the analysis.

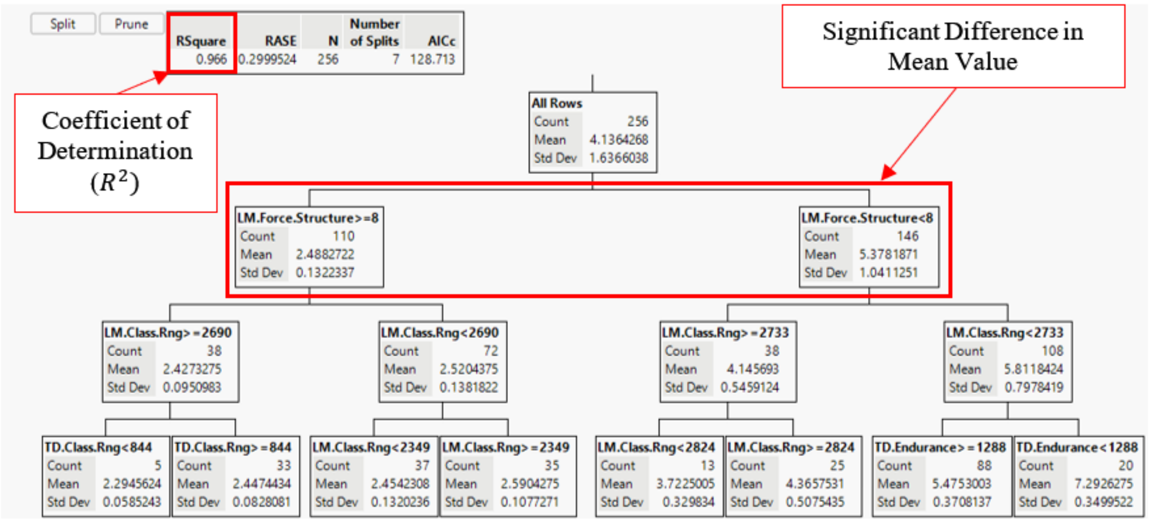
Table 14. Summary of Significant Factors and Interactions of MOEs

MOEs	Identified Significant Factors and Interactions
Blue Force's Casualties	• LM's Force Structure • LM's Classification Range • LM's Force Structure × LM's Classification Range • TD's Endurance • LM's Force Structure × TD's Endurance • LM's Classification Range × TD's Endurance
Red Force's Casualties	• LM's Force Structure • TD's Endurance • LM's Classification Range • LM's Force Structure × LM's Classification Range • **TD's Classification Range** • LM's Force Structure× TD's Endurance • LM's Force Structure× TD's Classification Range
Time Steps (s)	• LM's Force Structure • TD's Endurance • LM's Force Structure× TD's Endurance • LM's Classification Range • LM's Force Structure× LM's Classification Range • LM's Classification Range× TD's Endurance
LER	• LM's Force Structure • LM's Classification Range • LM's Force Structure × LM's Classification Range • TD's Endurance • LM's Force Structure × TD's Endurance
Probability of Mission Success (%)	• LM's Force Structure • TD Endurance • LM's Force Structure× TD's Endurance • LM's Classification Range • LM's Force Structure × LM's Classification Range • LM's Classification Range × TD's Endurance

TD – Tactical Drone

LM – Loitering Munitions

Partition trees were applied to visualize the significant factors for each MOE's response. As shown in Figure 17, the partition tree of Blue Force's Casualties yielded "Loitering Munitions' Force Structure" as the most significant factor in accounting for large differences in average Blue Force's Casualties. Other analyses also identified "Loitering Munitions' Force Structure" as the most significant factor for other MOEs. See Appendix D for the results.



RSquare	RASE	N	Number of Splits	AICc
0.966	0.2999524	256	7	128.713

Coefficient of Determination (R^2)

Significant Difference in Mean Value

Figure 17. Partition Tree of MOE (Blue Force's Casualties)

Given that "Loitering Munitions' Force Structure" was the most significant factor, histogram plots and summarized data in Figure 18 and Table 15 were developed to analyze its effects on the different MOEs. Both data indicated that the increase in "Loitering Munitions' Force Structure" yielded significant improvement in all MOEs.

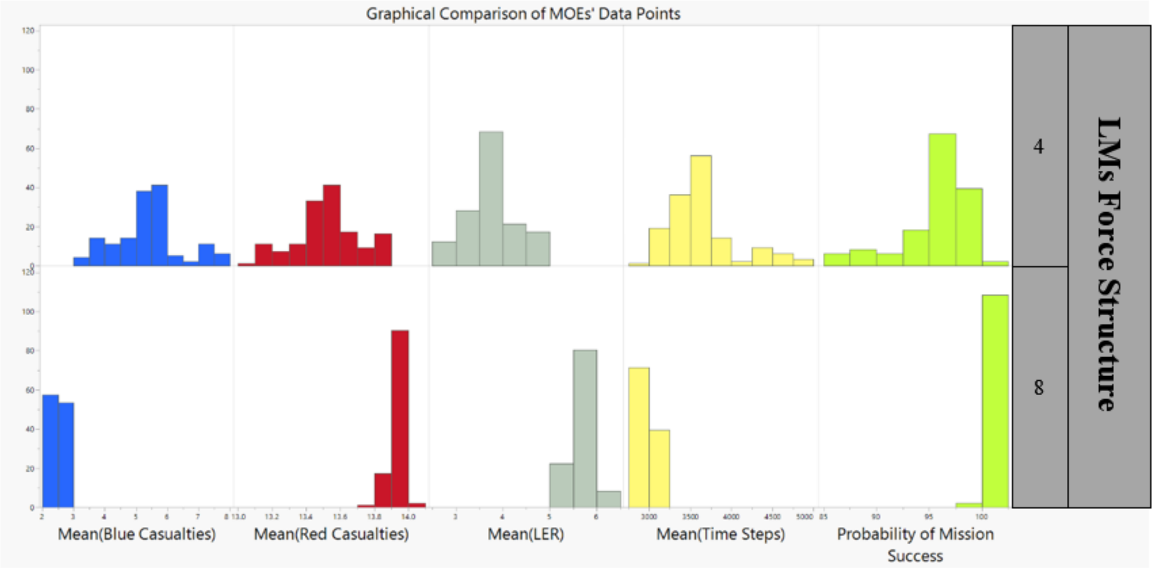


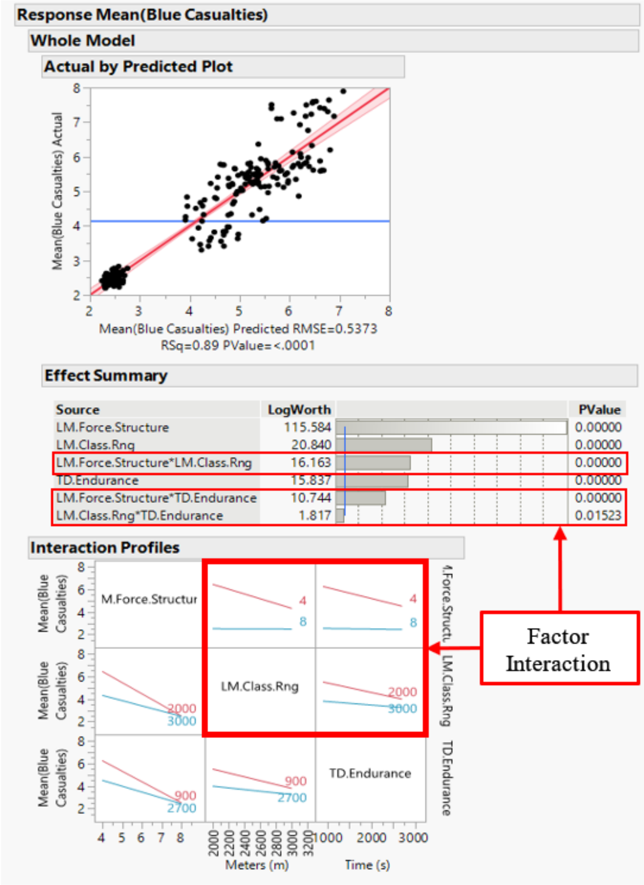
Figure 18. Graphical Comparison of MOEs' Data by Loitering Munitions' Force Structure

Table 15. Comparison of MOEs' Average Value by Loitering Munitions' Force Structure

Configuration	4 x Loitering Munition		8 x Loitering Munition	
Average Allegiances' Casualties	Blue	Red	Blue	Red
	5.38	13.52	2.49	13.96
Average LER	3.77		5.69	
Average Probability of Success (%)	95.62%		99.99%	
Average Time Steps (s)	3638.19		3001.95	

The interaction profile from Blue Force's Casualties' stepwise regression in Figure 19 shows that the two-way factor interactions were significant due to its low p-values (< 0.05). By analyzing the graphical representation of the two-way factor interactions, the slope of Blue Force's Casualties provided insights on how performance factors of the loitering munitions and tactical drones affected the MOEs. The two performance factors, "Tactical Drone's Endurance" and "Loitering Munitions' Classification Range," were compared to "Loitering Munitions' Force Structure."

In the scenario where the “Loitering Munitions’ Force Structure” was eight, the slope of Blue Force’s Casualties remained constant despite the improvement of two factors: (1) “Tactical Drone’s Endurance” and (2) “Loitering Munition’s Classification Range.” However, when “Loitering Munitions’ Force Structure” was reduced to four, improvements to the two performance factors produced a negative slope for Blue Force’s Casualties. The results suggested two ways to improve MOEs: (1) deploy more assets to achieve a higher MOE, and/or (2) consider trade-offs between higher performance assets and number of assets to achieve the same level of MOE.



Source	LogWorth	PValue
LM.Force.Structure	115.584	0.00000
LM.Class.Rng	20.840	0.00000
LM.Force.Structure*LM.Class.Rng	16.163	0.00000
TD.Endurance	15.837	0.00000
LM.Force.Structure*TD.Endurance	10.744	0.00000
LM.Class.Rng*TD.Endurance	1.817	0.01523

Figure 19. Significant Factors and Interactions of Blue Force’s Casualties

C. CONCLUSION OF ANALYSIS

By understanding how the various significant factors and their interactions affected the MOEs, operational insights could be developed to guide future capability development efforts.

1. Summary of Factors

The analysis of factor effects yielded three significant factors: (1) “Loitering Munitions’ Force Structure,” (2) “Loitering Munitions’ Classification Range,” and (3) “Tactical Drone’s Endurance.”

a. Loitering Munitions’ Force Structure

The force structure of loitering munitions (four and eight) provides Blue Forces with the ability to destroy up to four or eight of the Red Force’s assets, respectively. The ability to destroy adversary assets prior to Blue’s maneuvering force entering the area of operations significantly increases Red Force’s attrition while reducing Blue Force’s possible attrition. Fewer numbers of Red Force remaining would lead to higher force preservation of the Blue Force, resulting in a better possibility of the Blue Force achieving its mission.

b. Loitering Munitions’ Classification Range

The classification range defines the effective range in which the assets can detect and begin their classification process of the identified asset. With a higher classification range, the loitering munitions have a higher probability of correct classification, thus enhancing the kill chain of the forces and potentially inducing higher attrition among the adversary forces.

c. Tactical Drone’s Endurance

As tactical drones provide users the capability to perform forward reconnaissance and potentially identify threats, the endurance of the tactical drone throughout the mission is crucial to providing such capability during operations. With a higher drone’s endurance, military forces can better perform their mission due to higher availability of forward reconnaissance and intelligence.

2. Operational Insights

From the analysis, valuable operational insights was derived to guide future capability development and acquisition processes.

a. Effective Deployment of Sense and Strike Capability

Despite the deployment of sensing assets like the Raven RQ-11 with maneuver units, operations were more effective when artillery was deployed. Identified as an issue by Foo (2014), buildings in the urban terrain prevented ground units from effectively engaging adversary assets, and could also be mitigated by integrating assets or systems like air assets or long-range missiles with sensing systems. This was reinforced in the enhanced simulation experiment where the loitering munitions effectively combined both sense and strike capabilities into a single asset as an alternative and enhanced the MOEs.

b. System of Systems Approach to Capability Development

Significant interactions observed consisted of interactions among the performance parameters of an asset, as well as between the assets themselves. This observation highlighted the importance of analyzing the impact during the deployment of multiple systems within a system. In the case when an improvement in the tactical drone's endurance led to a reduction in Blue Force's casualties despite a lower loitering munitions' classification range, showed that the deployment and integration of multiple sensors was complementary and contributed to force preservation.

c. Prioritization of Technological Procurement and Development Efforts

Trade-offs between any procurement or developmental assets' performance parameters must be considered, given the technological, budgetary, and physical limitations of the assets. Based on the results, the number of loitering munitions deployed was the most significant factor of the model and showed essential insights from its interaction with other performance factors. There was an inherent relationship between the number of loitering munitions deployed and the performance factors of both loitering munitions and tactical drones. The reduction in operational effectiveness caused by deploying lower performance loitering munitions could be mitigated by increasing the number of loitering munitions deployed. Similarly, the reduction in operational effectiveness caused by deploying a lower number of loitering munitions could be mitigated by deploying higher performance loitering munitions.

The significant performance parameters of (1) “Loitering Munitions’ Force Structure,” (2) “Loitering Munitions’ Classification Range,” and (3) “Tactical Drone’s Endurance” could be prioritized for analysis to procure or develop suitable loitering munitions or tactical drones for operations.

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VII. CONCLUSION

This thesis has utilized an SE approach and agent-based simulation modeling to assess the integration of emerging technologies like unmanned systems and munitions with existing armored CABs. Specifically, the thesis assessed the operational impact that loitering munitions and tactical drones may have in urban operations when deployed as part of armored CABs. The adoption and employment of loitering munitions and tactical drones allows militaries to achieve the intended mission. Coupled with existing systems, such technologies can be considered as complementary or even as a capability multiplier.

A. SUMMARY

The following questions were determined as research questions to guide this thesis.

1. How does the incorporation of loitering munitions and drones as a sense and strike capability affect the probability of combined arms units with GCVs achieving mission success in an offensive MOUT?
2. What are the key performance parameters of loitering munitions and drones as sense and strike capabilities that should prioritized during development?

This thesis utilized agent-based modeling to simulate an armored combat team supported by UAVs and artillery performing an offensive scenario in an urban terrain. The unit was thereafter equipped with loitering munitions and tactical drones with varying performance parameters to analyze the impact that those assets have on operational effectiveness. Analysis was conducted in two phases, a baseline analysis that investigated the impact that loitering munitions and tactical drones have on the overall force structure and a detailed analysis that investigated the performance characteristics of loitering munitions and tactical drones.

The baseline experiment highlighted the importance of employing both sense and strike assets concurrently to yield higher operational effectiveness of the armored combat team, represented by the Raven RQ-11 and M109A6 Howitzers. An insight from the analysis showed that the sense and strike capabilities could either comprise of different assets but integrated within a kill chain or unit, or an asset which incorporates both sensing and strike capabilities. Based on that insight, a more detailed analysis was conducted to determine the key performance parameters of those assets that had the largest impact on operational effectiveness.

The enhanced experiment was designed to replace the Raven RQ-11 and M109A6 Howitzers with loitering munitions and tactical drones, and showed improvements in the combined arms unit's operational effectiveness and probability of achieving mission success. Overall, the employment of loitering munitions and tactical drones was observed to enhance the operational effectiveness of an armored combat team in offensive urban operations through enabling both long and short range reconnsaisance coupled with the ability to engage targets beyond ground troops' line-of-sight.

The enhanced experiment modified seven performance parameters of loitering munitions and tactical drones as experimental factors within the simulation model to identify significant performance parameters to consider as part of the capability development process. The results were able to scope from seven factors to three important ones, listed in the order of significance:

1. Loitering Munitions' Force Structure
2. Loitering Munitions' Classification Range
3. Tactical Drone's Endurance

The three performance parameters can serve as a guide for trade-off analysis during the capability development process, allowing capability development analysts to focus on enhancing the three performance parameters to achieve the ideal performance level of the individual assets and operational effectiveness of the military unit.

Beyond the specific recommendations regarding the design of the loitering munitions and tactical drone, it is important to review the stakeholders' analysis (Table 8) and link the results of the simulation analysis to the needs and goals identified. Table 16 presents an updated version of the stakeholders' analysis table and adds a Review column to summarize the recommendations developed through modeling and analysis.

Table 16. Review of Combined Arms Battalion (CAB) Stakeholders' Analysis

STAKEHOLDERS	TYPE	NEEDS	GOALS	Review
U.S. Department of Defense (DOD)	Sponsor	To have the ability to conduct the full spectrum of operations	To conduct the full spectrum of operations	CAB can conduct operations within urban terrain
U.S. Army	Decision Maker	To succeed in any ground military operations	To achieve mission success with the fewest resources	CAB can conduct operations with higher LER
Combined Arms Unit	High Level User	To achieve desired combat effect dictated by U.S. Army	To perform different types of operational maneuvers	CAB can conduct different maneuvers with sense and strike assets, as well as maneuver assets
GCV Crew	Operators	To be able to destroy adversary platforms and survive against attacks	To defeat the adversary in the battlefield	GCVs can achieve its mission and defeat its adversary
Defense Contractors	Developers	To generate profits	To develop suitable defense platforms	Defense Contractors can analyze and study the feasibility of developing relevant sense and strike assets.

Returning to the functional decomposition of a CAB, the loitering munitions and tactical drone were able to fulfill some of the CAB's functions, as highlighted in Figure 20. Shown in Table 17, the functional mapping shows that the employment of loitering munitions and tactical drones would be able to fulfill functions Table 17, thus enhancing a CAB's operational effectiveness during offensive operations.

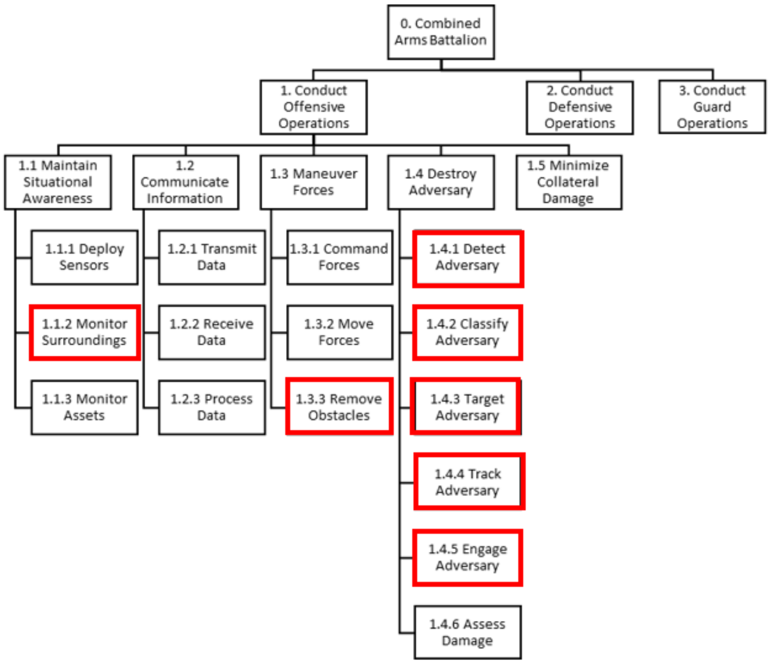

Figure 20. Review of Functional Decomposition of Combined Arms Battalion (CAB).

Table 17. Functional Mapping of Loitering Munition and Tactical Drone to CAB's Functional Decomposition.

Functions	Asset	Remarks
1.1.2 Monitor Surroundings	Loitering Munitions Tactical Drone	Deployment of more loitering munitions with higher classification range, coupled with tactical drones, would increase the situational awareness of the combat armored team.
1.3.3 Remove Obstacles	Tactical Drone	Tactical drones enhance unit's ability to detect obstacles, thus enabling the removal of obstacles.
1.4.1 Detect Adversary 1.4.2 Classify Adversary	Loitering Munitions Tactical Drone	Loitering munitions with higher classification range can detect and classify threats. Tactical drones also provide the ability to detect any new adversaries.
1.4.3 Target Adversary 1.4.4 Track Adversary 1.4.5 Engage Adversary	Loitering Munitions	Loitering munitions with higher classification range can maintain targeting and tracking of adversary forces, enhancing the probability of a successful engagement.

B. FUTURE RESEARCH

This study serves as a guide for decision makers to analyze the significant performance parameters when introducing new sense and strike capabilities into military units. This study made various assumptions about and estimations of parameters which are usually classified as military secrets. Therefore, there is room for future research, and following are the recommended topics to consider to build upon this thesis and gain additional insights.

1. Human Factors in the Operation of Unmanned Systems

As this study focused mainly on the implementation and deployment of unmanned assets within the unit, the human factors aspect and controlling of the system were not considered. Though results indicated that an increased number of assets was beneficial to a combined arms unit's operational effectiveness, it may not be the case when analyzed with the availability of manpower and the ability to control such assets effectively.

2. Systems Development and Its Effect on Chain of Command

As better systems are introduced, it is crucial to determine the echelon at which newer systems or capabilities are deployed. With the battlefield being labeled as Volatile, Uncertain, Complex and Ambiguous (VUCA), it requires military commanders to adapt quickly and effectively to changes on the battlefield (Takano 2021). Should a system be deployed to a higher echelon, lower echelon units become dependent on the higher echelon for such assets. Conversely, the deployment of systems to lower echelons provides them with tactical flexibility but increases their cognitive load.

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APPENDIX A. GROUND COMBAT VEHICLE SURVIVABILITY FACTOR LIST

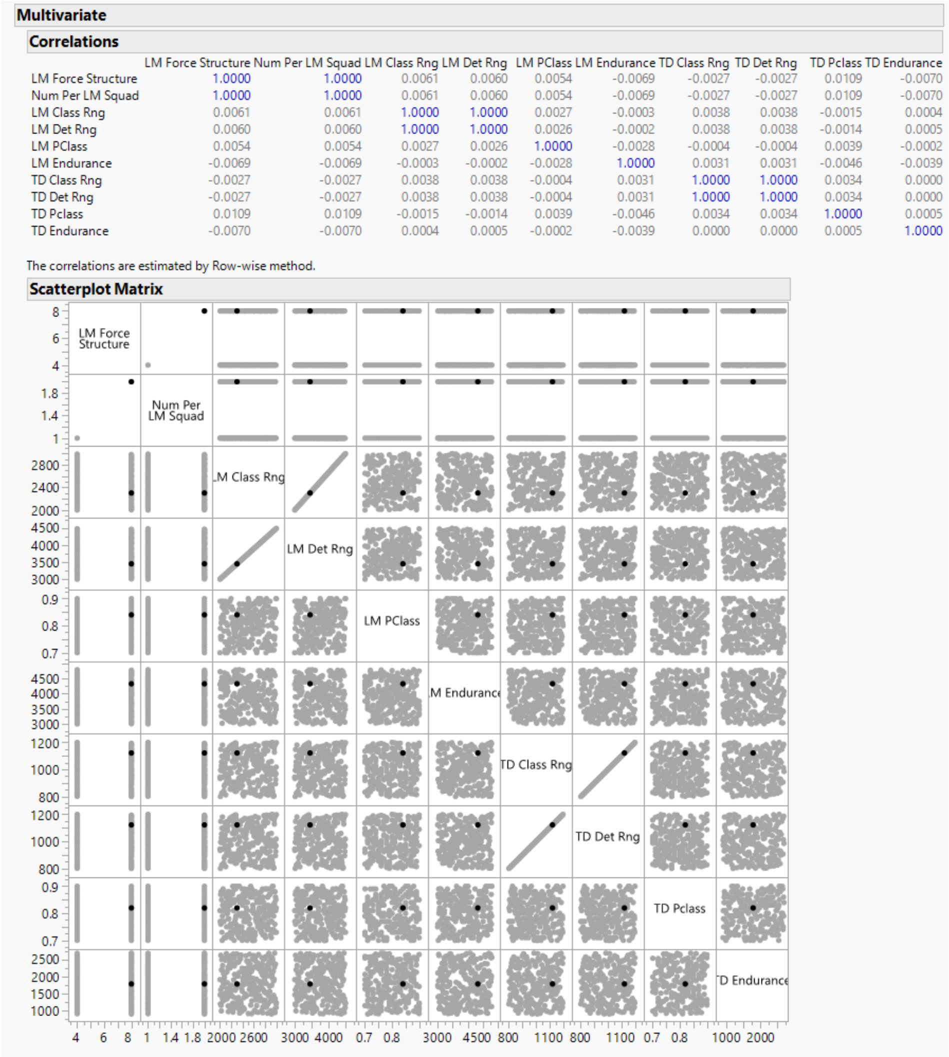
The following vehicle survivability factor list was developed by Capstone Cohort 311–114G (2013) and referenced as a more comprehensive list of factors that is related to a GCV's survivability. Due to the security classification of the capstone research by Capstone Cohort 311–114G (2013), this list was extracted and adapted from Treml (2013).

- Manage System States
    - Transition between States Enable
    - Disable Functions by State
- Survivability
    - Avoid Detection
        - Manage Signatures
    - Avoid Acquisition
        - Avoid Hit / Activation of Threat
    - Avoid Penetration
    - Avoid Kill / Incapacitation
        - Protect Personnel
            - Protect Against Acceleration Effects
            - Protect Against Fragments
            - Protect Against Blast Effects
    - Protect Against CBRN
    - Protect Against Fires
    - Protect Against Electromagnetic Effects
- Mobility
    - Traverse Terrain
        - Traverse Distances
        - Ascend Grades
        - Descend Grades
        - Traverse Lateral Slopes
        - Negotiate Ramps
    - Control Motion
        - Control Speed
            - Maintain Speed
            - Increase Speed
            - Reduce Speed
            - Hold Vehicle Stationary
    - Overcome Obstacles
        - Vertical Step
        - Cross Gaps
        - Breach Barrier

- Transport Loads / Personnel
    - Accommodate Personnel
        - Carry Personnel
            - Personnel Capacity
        - Secure Personnel
    - Transport Loads
- Situational Awareness
    - Enable Common Situational Understanding
    - Enable Vision
        - 360° Situational Awareness
    - Detect Objects
    - Identify Objects
- Lethality
    - Prioritize Threats
    - Select Threats
    - Acquire Threat
    - Track Threat
    - Engage Threat
        - Guide Ammunition to Target
        - Deliver Ammunition to Weapons
            - Track Ammunition Status
        - Control Weapons
    - Host Weapons
        - Manage Weapon Recoil/Impact
        - Manage Weapon Biproducts
- Power Vehicle
    - Generate Electrical Power
    - Generate Mechanical Power
    - Distribute Electrical Power
- Mission Command
    - Communications
        - Communicate Internally
        - Communicate Externally
    - Data Management
- Life Cycle
- Transportability
- Sustainability
    - Reliability
    - Availability
    - Maintainability

APPENDIX B. DESIGN OF EXPERIMENT (DOE)

This appendix serves to provide additional information on the DOE. Together with the design points of the enhanced simulation experiment shown in Table 22, a correlation matrix was developed to study the correlation of the varied model factors in Table 13.



Multivariate

Correlations

	LM Force Structure	Num Per LM Squad	LM Class Rng	LM Det Rng	LM PClass	LM Endurance	TD Class Rng	TD Det Rng	TD Pclass	TD Endurance
LM Force Structure	1.0000	1.0000	0.0061	0.0060	0.0054	-0.0069	-0.0027	-0.0027	0.0109	-0.0070
Num Per LM Squad	1.0000	1.0000	0.0061	0.0060	0.0054	-0.0069	-0.0027	-0.0027	0.0109	-0.0070
LM Class Rng	0.0061	0.0061	1.0000	1.0000	0.0027	-0.0003	0.0038	0.0038	-0.0015	0.0004
LM Det Rng	0.0060	0.0060	1.0000	1.0000	0.0026	-0.0002	0.0038	0.0038	-0.0014	0.0005
LM PClass	0.0054	0.0054	0.0027	0.0026	1.0000	-0.0028	-0.0004	-0.0004	0.0039	-0.0002
LM Endurance	-0.0069	-0.0069	-0.0003	-0.0002	-0.0028	1.0000	0.0031	0.0031	-0.0046	-0.0039
TD Class Rng	-0.0027	-0.0027	0.0038	0.0038	-0.0004	0.0031	1.0000	1.0000	0.0034	0.0000
TD Det Rng	-0.0027	-0.0027	0.0038	0.0038	-0.0004	0.0031	1.0000	1.0000	0.0034	0.0000
TD Pclass	0.0109	0.0109	-0.0015	-0.0014	0.0039	-0.0046	0.0034	0.0034	1.0000	0.0005
TD Endurance	-0.0070	-0.0070	0.0004	0.0005	-0.0002	-0.0039	0.0000	0.0000	0.0005	1.0000

The correlations are estimated by Row-wise method.

Scatterplot Matrix

Figure 21. DOE Factor Correlation Analysis

Table 18. Design Points and Values for Enhanced Eimulation Experiment

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
1	4	2663	0.82	3805	1043	0.78	2354
2	4	2275	0.81	3148	1197	0.78	2396
3	8	2122	0.85	3635	957	0.8	1345
4	4	2271	0.76	3169	838	0.85	1599
5	4	2035	0.76	4546	1098	0.73	2199
6	4	2980	0.79	3988	960	0.88	1352
7	8	2627	0.79	3713	849	0.8	1415
8	8	2969	0.76	4080	985	0.84	2700
9	8	2988	0.79	3056	925	0.81	1253
10	8	2259	0.7	4581	1054	0.73	2072
11	4	2918	0.71	4278	988	0.77	1747
12	8	2090	0.71	4405	1048	0.83	1853
13	8	2349	0.72	3452	869	0.84	928
14	8	2416	0.82	3981	949	0.73	1084
15	4	2345	0.88	4800	915	0.9	2573
16	8	2302	0.84	4334	1122	0.82	1789
17	8	2545	0.79	4602	827	0.9	1161
18	4	2537	0.85	3967	864	0.72	2361
19	8	2906	0.72	4031	1172	0.77	2446
20	8	2710	0.84	4765	803	0.74	1860
21	4	2565	0.73	3120	1162	0.89	1288

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
22	8	2439	0.78	3918	1170	0.89	2079
23	8	2118	0.88	4024	911	0.75	1542
24	4	2110	0.81	4271	1145	0.82	1818
25	8	2008	0.79	3593	800	0.77	1196
26	8	2412	0.77	4151	924	0.71	1888
27	4	2314	0.85	4384	979	0.72	1239
28	4	2812	0.88	3162	1183	0.79	2171
29	4	2459	0.77	3826	1051	0.77	2622
30	8	2408	0.74	3028	1062	0.86	1881
31	8	2502	0.9	3353	968	0.78	914
32	8	2820	0.85	4680	817	0.75	1804
33	4	2635	0.86	3536	1045	0.88	1316
34	4	2106	0.88	3381	946	0.71	2121
35	8	2467	0.87	3064	1109	0.82	1429
36	8	2282	0.76	4793	1192	0.79	1119
37	8	2353	0.71	4002	1001	0.86	1182
38	8	2016	0.75	4172	1148	0.76	2636
39	8	2745	0.89	3212	1064	0.85	2566
40	8	2914	0.71	3642	1010	0.71	900
41	8	2192	0.87	3769	893	0.84	2432
42	8	2631	0.71	3501	1067	0.78	2580
43	8	2671	0.8	4207	990	0.75	2411
44	4	2388	0.81	4355	1082	0.75	978
45	8	2098	0.89	3226	1120	0.81	2488

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
46	8	2396	0.71	3579	1158	0.7	1571
47	4	2463	0.81	4461	1021	0.87	1472
48	8	2424	0.86	4511	1078	0.77	1380
49	8	2200	0.83	3466	974	0.85	1585
50	4	2475	0.79	3776	1106	0.81	2467
51	8	2067	0.83	4518	842	0.81	1705
52	4	2655	0.71	3727	1140	0.84	1133
53	8	2196	0.9	3508	1178	0.71	1027
54	8	2729	0.89	3791	814	0.88	2135
55	8	2020	0.81	4419	993	0.88	1154
56	4	2400	0.73	3600	882	0.83	1069
57	4	2694	0.77	3586	1040	0.8	1444
58	4	2898	0.72	4588	836	0.89	2587
59	4	2957	0.71	3868	806	0.81	1302
60	4	2361	0.74	3332	891	0.75	1034
61	8	2612	0.88	3692	1037	0.7	985
62	4	2404	0.88	4779	820	0.87	1959
63	4	2102	0.81	3995	813	0.84	1408
64	8	2780	0.82	4687	1191	0.79	1246
65	4	2741	0.81	4165	1071	0.73	1006
66	4	2945	0.84	4708	802	0.82	2164
67	4	2357	0.86	3000	1123	0.75	1740
68	4	2310	0.8	3445	1085	0.74	2425
69	8	2247	0.72	4744	866	0.84	1126

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
70	4	2871	0.77	4016	867	0.79	2418
71	4	2659	0.81	4341	809	0.85	1655
72	4	2161	0.77	3678	930	0.88	2594
73	4	2553	0.81	3720	1136	0.89	1479
74	4	2365	0.85	4094	863	0.74	2531
75	8	2420	0.82	4489	805	0.85	2100
76	4	2824	0.9	3748	1195	0.79	1098
77	4	2533	0.81	4553	1125	0.86	1634
78	4	2243	0.79	4496	897	0.81	1909
79	8	2392	0.78	3113	1153	0.89	2255
80	8	2004	0.89	4736	933	0.77	1465
81	4	2212	0.75	3360	883	0.76	1168
82	4	2329	0.76	3480	875	0.8	1387
83	8	2882	0.71	3494	847	0.81	1564
84	4	2322	0.73	3388	858	0.72	1366
85	4	2525	0.78	3035	1169	0.89	2665
86	8	2894	0.76	4454	885	0.72	1260
87	4	2149	0.72	4101	955	0.81	971
88	8	2616	0.79	3374	850	0.87	1013
89	8	2443	0.73	3621	952	0.78	1493
90	8	2043	0.89	4475	1181	0.79	1359
91	4	2039	0.87	3021	1005	0.7	1698
92	4	2643	0.77	3289	1049	0.77	1521
93	8	2529	0.84	3007	1126	0.76	2114

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
94	8	2588	0.88	3974	971	0.82	1952
95	8	2976	0.86	4609	1180	0.88	942
96	8	2961	0.83	3268	1156	0.73	1924
97	4	2596	0.85	3042	904	0.8	2629
98	4	2137	0.78	3134	940	0.87	1394
99	8	2114	0.74	3960	1013	0.86	2686
100	4	2012	0.76	3896	995	0.87	1613
101	4	2573	0.83	4299	1070	0.74	2516
102	4	2804	0.74	3092	1164	0.89	2227
103	4	2478	0.88	3812	1092	0.84	2178
104	4	2169	0.71	4440	1167	0.85	1676
105	4	2490	0.72	4525	1133	0.79	2008
106	4	2753	0.78	3325	845	0.89	2051
107	4	2082	0.87	4694	977	0.82	1507
108	4	2204	0.75	3176	874	0.72	1754
109	4	2239	0.74	3431	907	0.74	2672
110	8	2690	0.79	4186	1076	0.81	1606
111	8	2455	0.85	4073	1057	0.78	2220
112	4	2953	0.76	4722	1004	0.79	1451
113	4	2561	0.75	4249	976	0.81	907
114	8	2973	0.73	3367	1189	0.76	1048
115	8	2384	0.75	3572	918	0.8	1648
116	8	2839	0.76	3798	844	0.86	2298
117	4	2702	0.84	3953	1112	0.78	1436

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
118	4	2678	0.84	4348	877	0.76	2248
119	4	2773	0.89	3741	1144	0.82	2524
120	4	2855	0.71	4539	811	0.83	1458
121	4	2510	0.74	4567	1161	0.89	2389
122	4	2267	0.77	3318	871	0.85	1373
123	8	2827	0.75	4666	856	0.82	1535
124	4	2427	0.7	4179	833	0.72	1768
125	4	2706	0.8	4595	1038	0.86	1295
126	8	2094	0.7	4426	1137	0.83	2552
127	4	2765	0.73	3946	1012	0.81	1627
128	8	2071	0.78	4306	828	0.77	1500
129	4	2498	0.88	4221	1165	0.73	1902
130	4	2929	0.8	4772	1200	0.9	2559
131	8	2875	0.73	4136	1007	0.77	2453
132	4	2325	0.74	4616	1134	0.73	1062
133	8	2757	0.86	3233	929	0.86	935
134	8	2984	0.84	3544	894	0.86	2375
135	4	2051	0.89	4447	996	0.88	2347
136	4	2949	0.84	3155	965	0.74	1874
137	4	2761	0.89	4631	852	0.72	1105
138	4	2647	0.71	3939	1029	0.85	1931
139	4	2522	0.72	4369	896	0.71	1620
140	4	2482	0.87	4362	831	0.7	1994
141	4	2788	0.83	3656	1115	0.83	1549

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
142	4	2294	0.8	3628	1159	0.9	1211
143	4	2451	0.74	3889	1081	0.77	2241
144	4	2620	0.83	4320	816	0.73	2291
145	4	2165	0.74	3459	973	0.75	2481
146	8	2847	0.72	4786	1139	0.76	2029
147	4	2859	0.87	3649	822	0.89	2326
148	4	2133	0.8	4214	1079	0.8	1825
149	4	2639	0.89	3558	999	0.78	964
150	8	2682	0.9	4758	1175	0.8	2658
151	4	2776	0.72	4327	1015	0.84	1811
152	4	2557	0.82	4158	1173	0.73	2156
153	8	2902	0.76	3219	962	0.8	999
154	8	2737	0.72	4624	1073	0.75	1338
155	4	2435	0.75	3522	936	0.8	2185
156	4	2965	0.75	3664	1128	0.83	2284
157	4	2086	0.74	3205	888	0.87	1331
158	8	2318	0.82	4638	1093	0.85	2022
159	4	2341	0.73	3847	1024	0.71	2128
160	8	2722	0.9	3304	1089	0.74	1712
161	4	2063	0.88	4256	1020	0.83	2093
162	4	2290	0.79	3875	839	0.74	2036
163	8	2796	0.87	3671	932	0.72	2538
164	4	2380	0.83	3904	941	0.74	1020
165	4	2047	0.82	3882	830	0.83	2333

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
166	4	2604	0.82	4193	1042	0.71	1578
167	8	2251	0.78	3685	1016	0.7	2545
168	8	2494	0.86	3551	1103	0.72	2460
169	8	2925	0.81	3099	886	0.82	1973
170	8	2024	0.83	4264	1026	0.77	992
171	8	2180	0.75	3247	855	0.83	2262
172	8	2059	0.82	3402	1090	0.83	1832
173	8	2937	0.76	3833	819	0.83	2404
174	4	2224	0.83	3275	889	0.88	1218
175	4	2486	0.81	4532	958	0.84	2001
176	8	2031	0.82	3416	825	0.87	2509
177	8	2188	0.74	3339	902	0.76	2615
178	8	2831	0.85	3184	963	0.76	2044
179	4	2651	0.7	4292	1065	0.79	1147
180	8	2157	0.73	3282	899	0.78	2608
181	4	2608	0.84	3395	824	0.71	1761
182	4	2867	0.77	4701	1186	0.79	2693
183	8	2506	0.88	3911	916	0.87	2065
184	4	2220	0.86	3706	1060	0.87	1422
185	4	2675	0.82	4391	1104	0.87	949
186	8	2580	0.77	3755	1142	0.83	1726
187	4	2518	0.82	4052	954	0.78	2305
188	8	2749	0.78	4645	947	0.75	2382
189	4	2996	0.85	3487	1018	0.82	1091

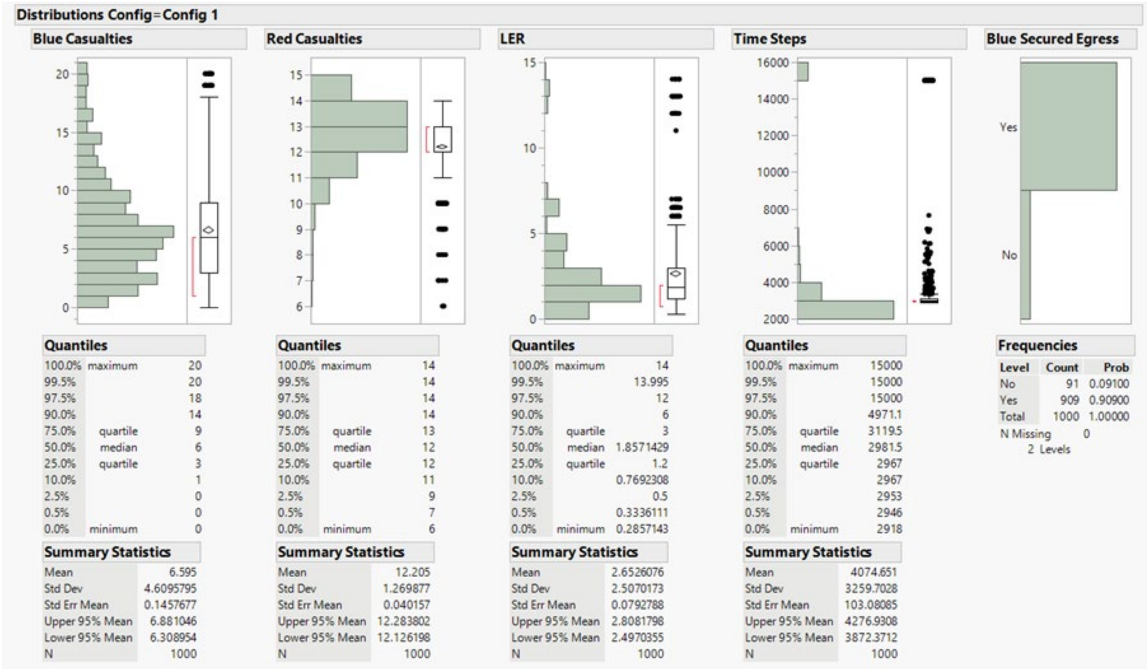
Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
190	4	2000	0.7	4313	944	0.81	1916
191	8	2255	0.77	4009	1087	0.9	2319
192	4	2145	0.73	4087	922	0.78	1140
193	4	2843	0.74	4659	1031	0.75	921
194	4	2216	0.81	3311	1155	0.76	1076
195	4	2173	0.75	3254	905	0.72	2368
196	4	2851	0.8	4129	1023	0.86	1189
197	4	2569	0.8	3854	1111	0.86	2213
198	4	2714	0.85	3840	908	0.84	1684
199	8	2231	0.8	4433	1118	0.84	956
200	8	2878	0.85	3346	982	0.87	1719
201	8	2725	0.89	4715	1032	0.78	1733
202	4	2784	0.85	4504	938	0.83	1987
203	4	2278	0.78	3106	1176	0.89	1691
204	4	2286	0.82	3127	1068	0.76	1669
205	4	2584	0.77	3861	1114	0.7	1556
206	8	2541	0.87	3932	835	0.87	1966
207	4	2208	0.87	4398	853	0.71	1592
208	8	2624	0.86	4122	1184	0.72	2474
209	8	2376	0.79	4468	951	0.79	1175
210	4	2235	0.75	3049	1187	0.84	1055
211	8	2800	0.75	4059	1131	0.8	1309
212	8	2298	0.79	3409	910	0.75	2679
213	4	2992	0.9	3607	969	0.85	1204

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
214	4	2514	0.89	4285	980	0.74	1775
215	4	2125	0.73	4652	1100	0.72	2149
216	8	2941	0.85	4673	966	0.9	1324
217	8	2808	0.73	3191	991	0.71	1528
218	8	2686	0.74	3438	998	0.85	2312
219	4	2863	0.71	3565	1053	0.8	2234
220	4	2184	0.87	3734	1009	0.73	1514
221	4	2141	0.87	4376	1117	0.88	2276
222	4	2910	0.72	3085	1059	0.71	2142
223	4	2592	0.79	3614	1107	0.81	1839
224	8	2176	0.89	3078	1002	0.86	1112
225	4	2835	0.72	3529	913	0.74	2340
226	4	2733	0.84	3819	1084	0.73	2269
227	4	2263	0.76	3071	872	0.77	2086
228	8	2431	0.78	3141	1035	0.86	1041
229	4	2933	0.86	3240	841	0.88	2495
230	8	2306	0.84	4482	1129	0.75	2015
231	4	2667	0.83	4200	921	0.76	1662
232	4	2886	0.89	3014	927	0.87	1401
233	8	2698	0.88	4751	900	0.82	1846
234	8	2055	0.84	4242	943	0.89	1281
235	4	2075	0.86	4115	1046	0.71	2107
236	8	2333	0.8	3424	935	0.75	2439
237	4	2227	0.86	3925	1151	0.9	2651

Design Point	Loitering Munitions Force Structure	Loitering Munitions Classification Range (m)	Loitering Munitions Probability of Classification	Loitering Munitions Endurance (s)	Tactical Drone Classification Range (m)	Tactical Drone Probability of Classification	Tactical Drone Endurance (s)
238	4	2792	0.87	3296	861	0.78	1895
239	8	2718	0.78	4144	808	0.77	2192
240	4	2153	0.73	4560	1147	0.85	1486
241	4	2769	0.8	4235	1027	0.76	2502
242	8	2549	0.78	4108	1101	0.71	1782
243	4	2471	0.83	4066	1075	0.79	1867
244	4	2369	0.8	3515	880	0.73	1267
245	8	2890	0.83	3198	1194	0.74	1274
246	4	2078	0.87	4228	878	0.82	1980
247	8	2576	0.75	3699	987	0.7	1796
248	8	2816	0.7	3762	919	0.89	2601
249	8	2129	0.7	4045	1095	0.82	1641
250	4	2447	0.78	4412	984	0.88	1945
251	4	2922	0.86	4729	860	0.74	2058
252	4	2337	0.86	3784	1034	0.86	1232
253	8	2600	0.77	4038	1096	0.88	1938
254	4	3000	0.9	3473	1198	0.73	1225
255	4	2373	0.77	4574	1150	0.79	2644
256	8	2027	0.83	3261	1056	0.85	2206

APPENDIX C. BASELINE SIMULATION EXPERIMENT RESULTS

This appendix serves to compile the statistical analysis of the baseline simulation experiment as well as its visual statistics. The histograms and partition trees were developed by individual configuration for analysis.



Blue Casualties

Quantiles

100.0%	maximum	20
99.5%		20
97.5%		18
90.0%		14
75.0%	quartile	9
50.0%	median	6
25.0%	quartile	3
10.0%		1
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	6.595
Std Dev	4.6095795
Std Err Mean	0.1457677
Upper 95% Mean	6.881046
Lower 95% Mean	6.308954
N	1000

Red Casualties

Quantiles

100.0%	maximum	14
99.5%		14
97.5%		14
90.0%		14
75.0%	quartile	13
50.0%	median	12
25.0%	quartile	12
10.0%		11
2.5%		9
0.5%		7
0.0%	minimum	6

Summary Statistics

Mean	12.205
Std Dev	1.269877
Std Err Mean	0.040157
Upper 95% Mean	12.283802
Lower 95% Mean	12.126198
N	1000

LER

Quantiles

100.0%	maximum	14
99.5%		13.995
97.5%		12
90.0%		6
75.0%	quartile	3
50.0%	median	1.8571429
25.0%	quartile	1.2
10.0%		0.7692308
2.5%		0.5
0.5%		0.3336111
0.0%	minimum	0.2857143

Summary Statistics

Mean	2.6526076
Std Dev	2.5070173
Std Err Mean	0.0792788
Upper 95% Mean	2.8081798
Lower 95% Mean	2.4970355
N	1000

Time Steps

Quantiles

100.0%	maximum	15000
99.5%		15000
97.5%		15000
90.0%		4971.1
75.0%	quartile	3119.5
50.0%	median	2981.5
25.0%	quartile	2967
10.0%		2967
2.5%		2953
0.5%		2946
0.0%	minimum	2918

Summary Statistics

Mean	4074.651
Std Dev	3259.7028
Std Err Mean	103.08085
Upper 95% Mean	4276.9308
Lower 95% Mean	3872.3712
N	1000

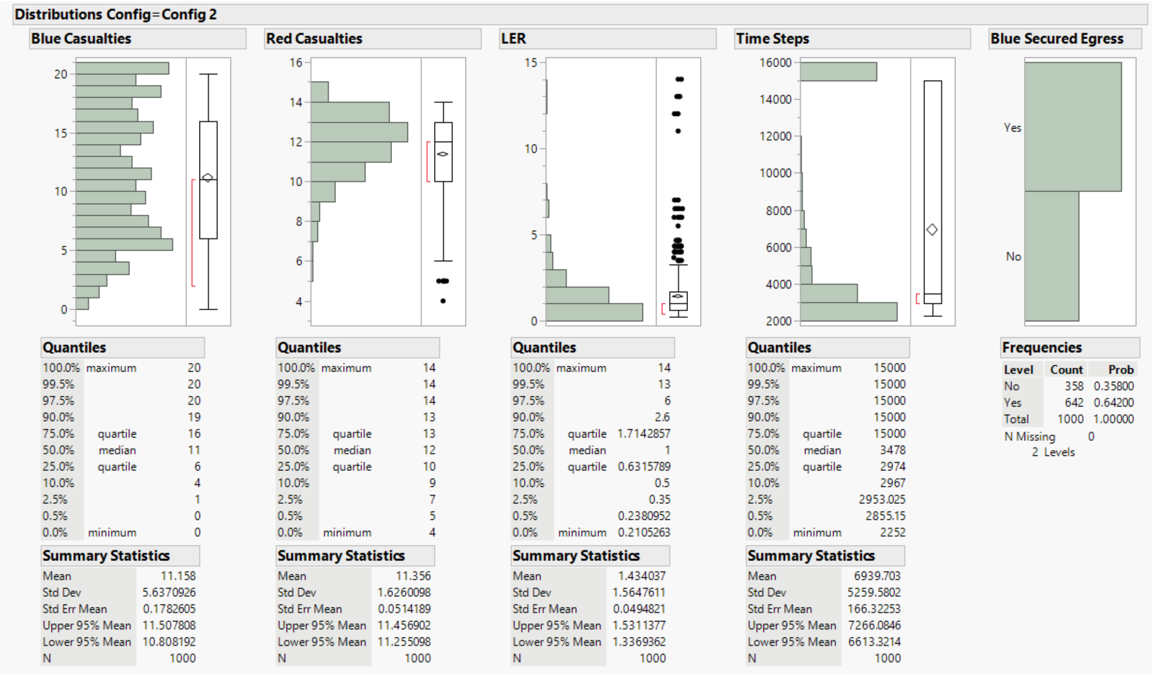
Blue Secured Egress

Frequencies

Level	Count	Prob
No	91	0.09100
Yes	909	0.90900
Total	1000	1.00000

N Missing 0
2 Levels

Figure 22. Statistical Summary of Baseline Simulation Experiment Configuration (Configuration 1)



Distributions Config=Config 2

Blue Casualties

Quantiles

100.0%	maximum	20
99.5%		20
97.5%		20
90.0%		19
75.0%	quartile	16
50.0%	median	11
25.0%	quartile	6
10.0%		4
2.5%		1
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	11.158
Std Dev	5.6370926
Std Err Mean	0.1782605
Upper 95% Mean	11.507808
Lower 95% Mean	10.808192
N	1000

Red Casualties

Quantiles

100.0%	maximum	14
99.5%		14
97.5%		14
90.0%		13
75.0%	quartile	13
50.0%	median	12
25.0%	quartile	10
10.0%		9
2.5%		7
0.5%		5
0.0%	minimum	4

Summary Statistics

Mean	11.356
Std Dev	1.6260098
Std Err Mean	0.0514189
Upper 95% Mean	11.456902
Lower 95% Mean	11.255098
N	1000

LER

Quantiles

100.0%	maximum	14
99.5%		13
97.5%		6
90.0%		2.6
75.0%	quartile	1.7142857
50.0%	median	1
25.0%	quartile	0.6315789
10.0%		0.5
2.5%		0.35
0.5%		0.2380952
0.0%	minimum	0.2105263

Summary Statistics

Mean	1.434037
Std Dev	1.5647611
Std Err Mean	0.0494821
Upper 95% Mean	1.5311377
Lower 95% Mean	1.3369362
N	1000

Time Steps

Quantiles

100.0%	maximum	15000
99.5%		15000
97.5%		15000
90.0%		15000
75.0%	quartile	15000
50.0%	median	3478
25.0%	quartile	2974
10.0%		2967
2.5%		2953.025
0.5%		2855.15
0.0%	minimum	2252

Summary Statistics

Mean	6939.703
Std Dev	5259.5802
Std Err Mean	166.32253
Upper 95% Mean	7266.0846
Lower 95% Mean	6613.3214
N	1000

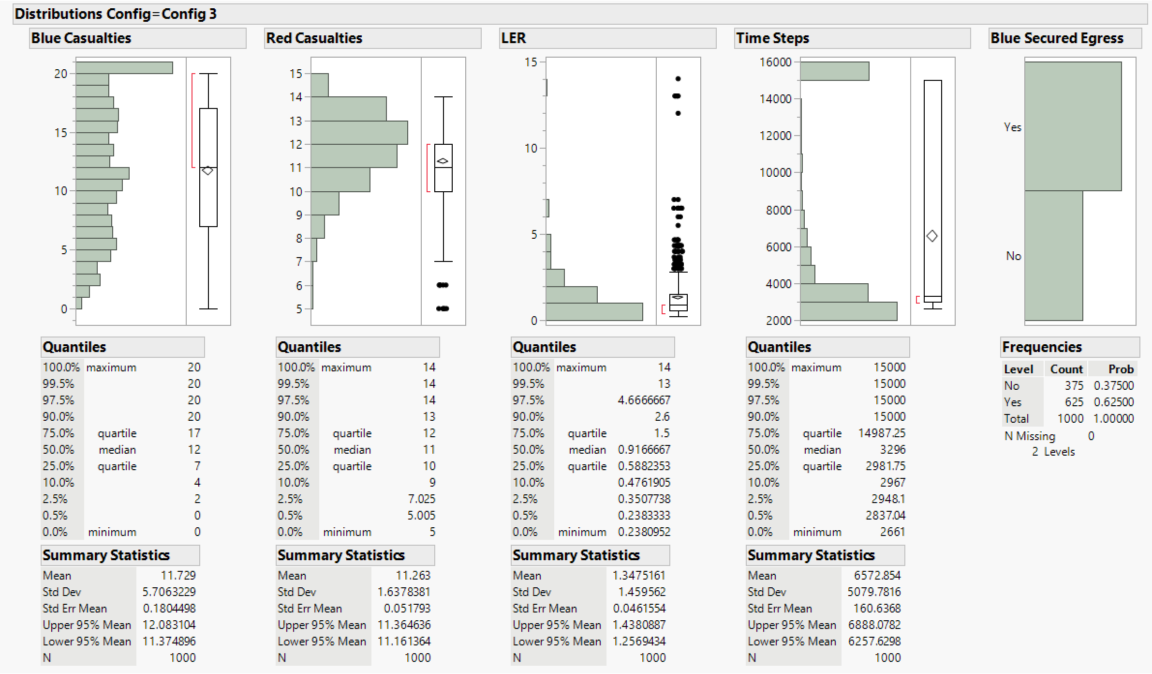
Blue Secured Egress

Frequencies

Level	Count	Prob
No	358	0.35800
Yes	642	0.64200
Total	1000	1.00000

N Missing 0
2 Levels

Figure 23. Statistical Summary of Baseline Simulation Experiment Configuration (Configuration 2)



Distributions Config=Config 3

Blue Casualties

Quantiles

100.0%	maximum	20
99.5%		20
97.5%		20
90.0%		20
75.0%	quartile	17
50.0%	median	12
25.0%	quartile	7
10.0%		4
2.5%		2
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	11.729
Std Dev	5.7063229
Std Err Mean	0.1804498
Upper 95% Mean	12.083104
Lower 95% Mean	11.374896
N	1000

Red Casualties

Quantiles

100.0%	maximum	14
99.5%		14
97.5%		14
90.0%		13
75.0%	quartile	12
50.0%	median	11
25.0%	quartile	10
10.0%		9
2.5%		7.025
0.5%		5.005
0.0%	minimum	5

Summary Statistics

Mean	11.263
Std Dev	1.6378381
Std Err Mean	0.051793
Upper 95% Mean	11.364636
Lower 95% Mean	11.161364
N	1000

LER

Quantiles

100.0%	maximum	14
99.5%		13
97.5%		4.6666667
90.0%		2.6
75.0%	quartile	1.5
50.0%	median	0.9166667
25.0%	quartile	0.5882353
10.0%		0.4761905
2.5%		0.3507738
0.5%		0.2383333
0.0%	minimum	0.2380952

Summary Statistics

Mean	1.3475161
Std Dev	1.459562
Std Err Mean	0.0461554
Upper 95% Mean	1.4380887
Lower 95% Mean	1.2569434
N	1000

Time Steps

Quantiles

100.0%	maximum	15000
99.5%		15000
97.5%		15000
90.0%		15000
75.0%	quartile	14987.25
50.0%	median	3296
25.0%	quartile	2981.75
10.0%		2967
2.5%		2948.1
0.5%		2837.04
0.0%	minimum	2661

Summary Statistics

Mean	6572.854
Std Dev	5079.7816
Std Err Mean	160.6368
Upper 95% Mean	6888.0782
Lower 95% Mean	6257.6298
N	1000

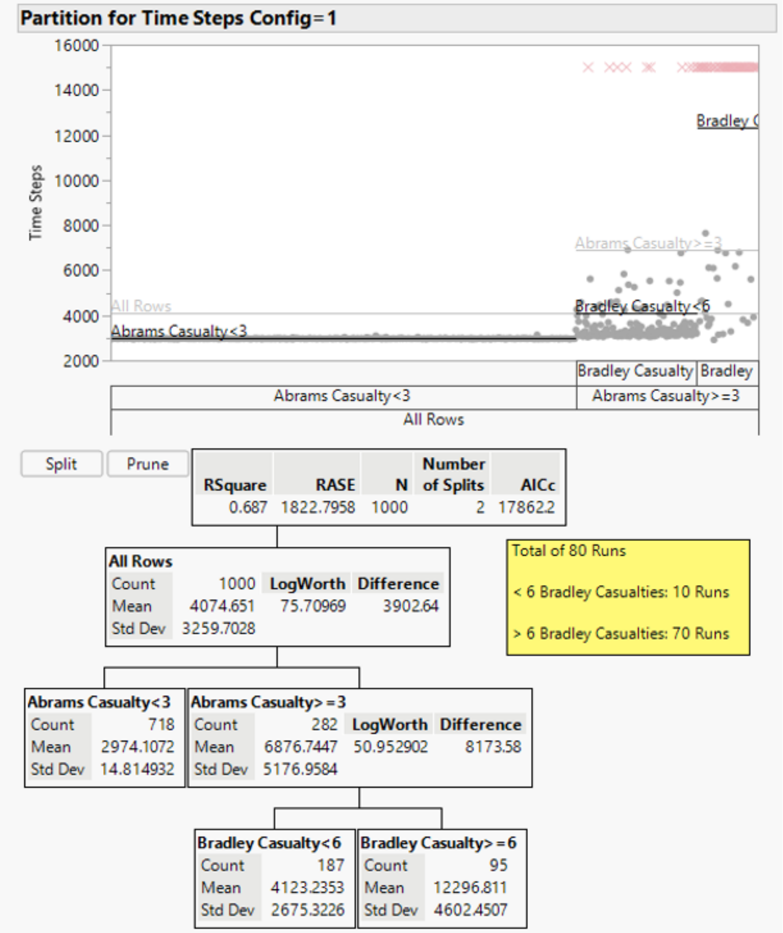
Blue Secured Egress

Frequencies

Level	Count	Prob
No	375	0.37500
Yes	625	0.62500
Total	1000	1.00000

N Missing 0
2 Levels

Figure 24. Statistical Summary of Baseline Simulation Experiment Configuration (Configuration 3)



RSquare	RASE	N	Number of Splits	AICc
0.687	1822.7958	1000	2	17862.2

Total of 80 Runs

< 6 Bradley Casualties: 10 Runs

> 6 Bradley Casualties: 70 Runs

All Rows

		LogWorth	Difference
Count	1000		
Mean	4074.651	75.70969	3902.64
Std Dev	3259.7028		

Abrams Casualty<3

Count	718
Mean	2974.1072
Std Dev	14.814932

Abrams Casualty>=3

		LogWorth	Difference
Count	282		
Mean	6876.7447	50.952902	8173.58
Std Dev	5176.9584		

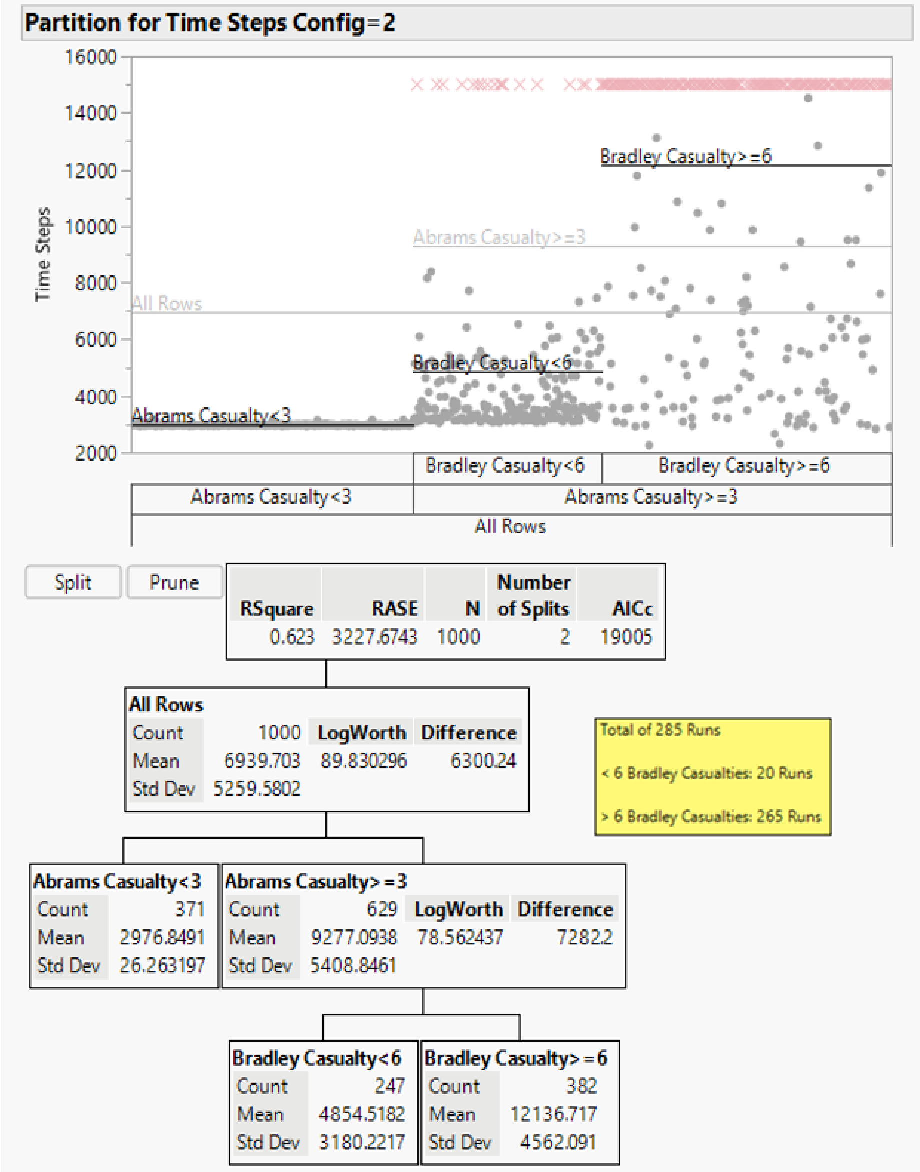
Bradley Casualty<6

Count	187
Mean	4123.2353
Std Dev	2675.3226

Bradley Casualty>=6

Count	95
Mean	12296.811
Std Dev	4602.4507

Figure 25. Partition Tree of Baseline Simulation Experiment’s Time Steps (Configuration 1)



RSquare	RASE	N	Number of Splits	AICc
0.623	3227.6743	1000	2	19005

All Rows

		LogWorth	Difference
Count	1000		
Mean	6939.703	89.830296	6300.24
Std Dev	5259.5802		

Total of 285 Runs

< 6 Bradley Casualties: 20 Runs

> 6 Bradley Casualties: 265 Runs

Abrams Casualty<3

Count	371
Mean	2976.8491
Std Dev	26.263197

Abrams Casualty>=3

		LogWorth	Difference
Count	629		
Mean	9277.0938	78.562437	7282.2
Std Dev	5408.8461		

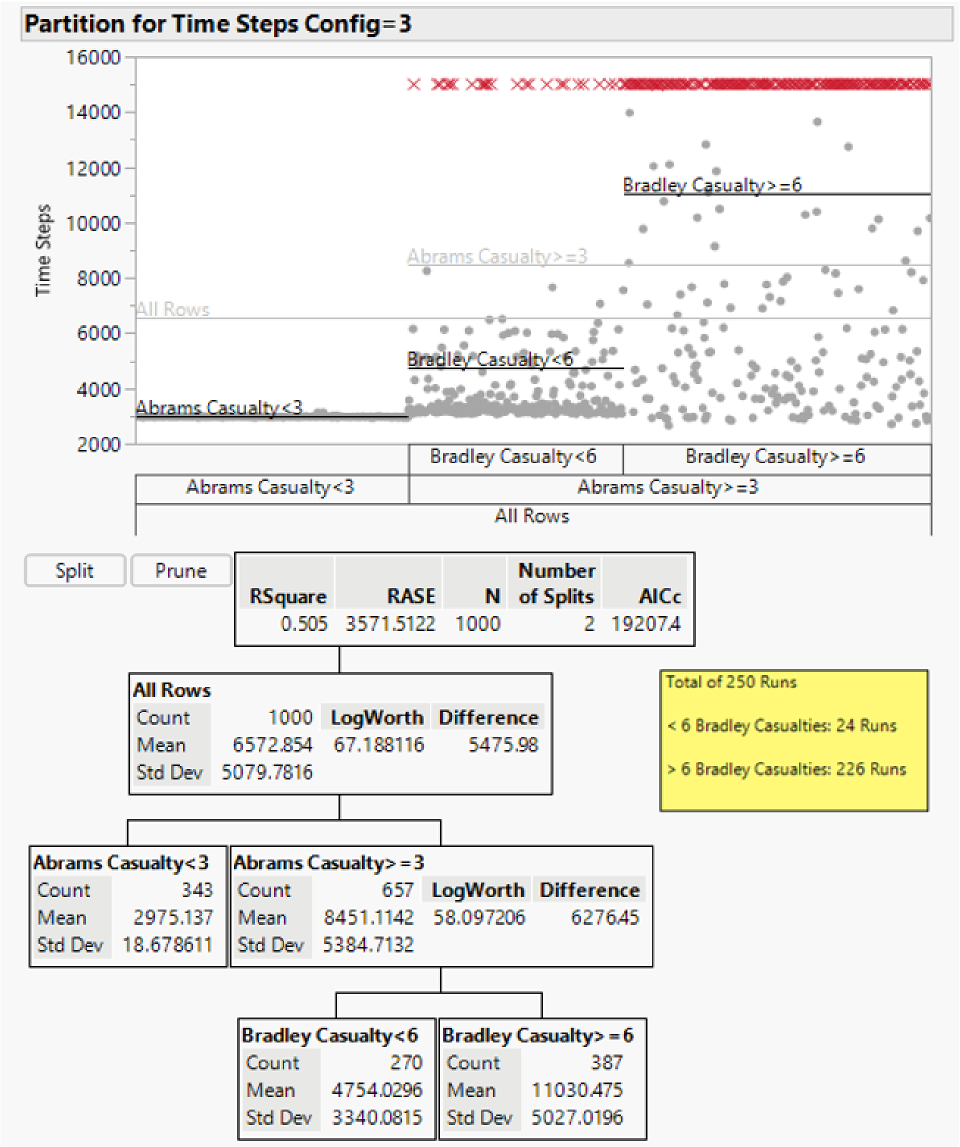
Bradley Casualty<6

Count	247
Mean	4854.5182
Std Dev	3180.2217

Bradley Casualty>=6

Count	382
Mean	12136.717
Std Dev	4562.091

Figure 26. Partition Tree of Baseline Simulation Experiment's Time Steps (Configuration 2)



Partition for Time Steps Config=3

RSquare	RASE	N	Number of Splits	AICc
0.505	3571.5122	1000	2	19207.4

All Rows

		LogWorth	Difference
Count	1000	LogWorth	Difference
Mean	6572.854	67.188116	5475.98
Std Dev	5079.7816		

Total of 250 Runs

< 6 Bradley Casualties: 24 Runs

> 6 Bradley Casualties: 226 Runs

Abrams Casualty<3

Count	343
Mean	2975.137
Std Dev	18.678611

Abrams Casualty>=3

Count	657	LogWorth	Difference
Mean	8451.1142	58.097206	6276.45
Std Dev	5384.7132		

Bradley Casualty<6

Count	270
Mean	4754.0296
Std Dev	3340.0815

Bradley Casualty>=6

Count	387
Mean	11030.475
Std Dev	5027.0196

Figure 27. Partition Tree of Baseline Simulation Experiment’s Time Steps (Configuration 3)

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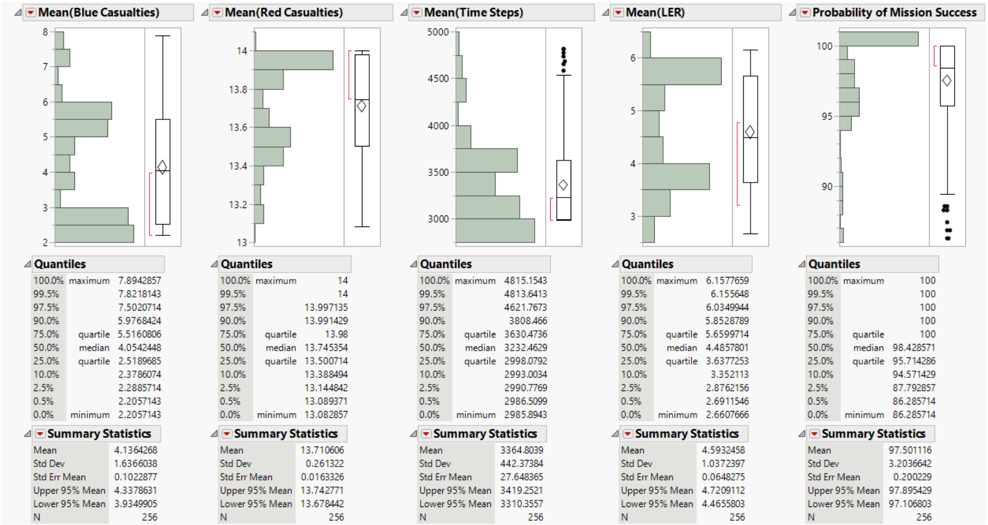
APPENDIX D. ENHANCED SIMULATION EXPERIMENT RESULTS

This appendix serves to compile the statistical analysis of the enhanced simulation experiment as well as its visual statistics. The histograms and partition trees were developed by individual configuration for analysis.



Mean(Blue Casualties)

Quantiles

100.0%	maximum	7.8942857
99.5%		7.8218143
97.5%		7.5020714
90.0%		5.9768424
75.0%	quartile	5.5160806
50.0%	median	4.0542448
25.0%	quartile	2.5189685
10.0%		2.3786074
2.5%		2.2885714
0.5%		2.2057143
0.0%	minimum	2.2057143

Summary Statistics

Mean	4.1364268
Std Dev	1.6366038
Std Err Mean	0.1022877
Upper 95% Mean	4.3378631
Lower 95% Mean	3.9349905
N	256

Mean(Red Casualties)

Quantiles

100.0%	maximum	14
99.5%		14
97.5%		13.997135
90.0%		13.991429
75.0%	quartile	13.98
50.0%	median	13.745354
25.0%	quartile	13.500714
10.0%		13.388494
2.5%		13.144842
0.5%		13.089371
0.0%	minimum	13.082857

Summary Statistics

Mean	13.710606
Std Dev	0.261322
Std Err Mean	0.0163326
Upper 95% Mean	13.742771
Lower 95% Mean	13.678442
N	256

Mean(Time Steps)

Quantiles

100.0%	maximum	4815.1543
99.5%		4813.6413
97.5%		4621.7673
90.0%		3808.466
75.0%	quartile	3630.4736
50.0%	median	3232.4629
25.0%	quartile	2998.0792
10.0%		2993.0034
2.5%		2990.7769
0.5%		2986.5099
0.0%	minimum	2985.8943

Summary Statistics

Mean	3364.8039
Std Dev	442.37384
Std Err Mean	27.648365
Upper 95% Mean	3419.2521
Lower 95% Mean	3310.3557
N	256

Mean(LER)

Quantiles

100.0%	maximum	6.1577659
99.5%		6.155648
97.5%		6.0349944
90.0%		5.8528789
75.0%	quartile	5.6599714
50.0%	median	4.4857801
25.0%	quartile	3.6377253
10.0%		3.352113
2.5%		2.8762156
0.5%		2.6911546
0.0%	minimum	2.6607666

Summary Statistics

Mean	4.5932458
Std Dev	1.0372397
Std Err Mean	0.0648275
Upper 95% Mean	4.7209112
Lower 95% Mean	4.4655803
N	256

Probability of Mission Success

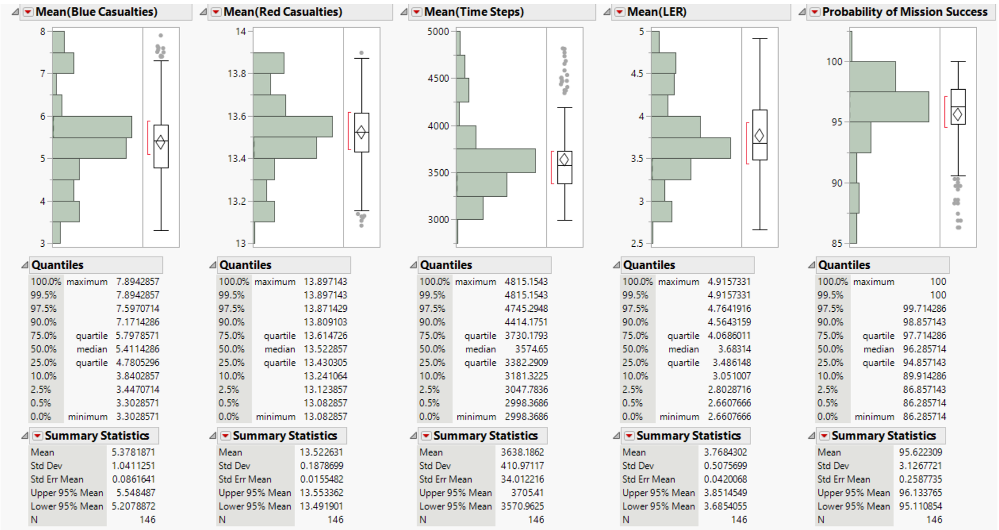
Quantiles

100.0%	maximum	100
99.5%		100
97.5%		100
90.0%		100
75.0%	quartile	100
50.0%	median	98.428571
25.0%	quartile	95.714286
10.0%		94.571429
2.5%		87.792857
0.5%		86.285714
0.0%	minimum	86.285714

Summary Statistics

Mean	97.501116
Std Dev	3.2036642
Std Err Mean	0.200229
Upper 95% Mean	97.895429
Lower 95% Mean	97.106803
N	256

Figure 28. Statistical Summary of Enhanced Eimulation Experiment (256 Design Points)



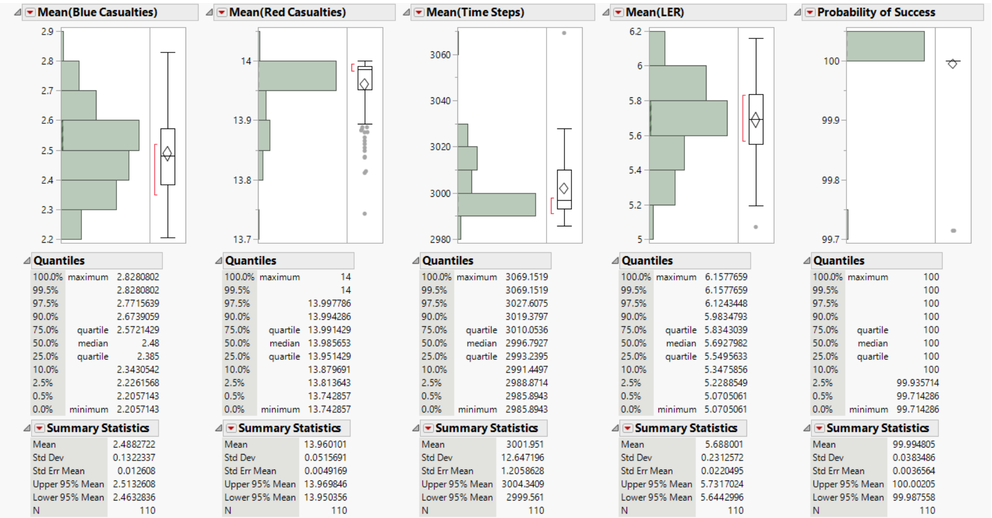
Quantiles

		Mean(Blue Casualties)	Mean(Red Casualties)	Mean(Time Steps)	Mean(LER)	Probability of Mission Success
100.0%	maximum	7.8942857	13.897143	4815.1543	4.9157331	100
99.5%		7.8942857	13.897143	4815.1543	4.9157331	100
97.5%		7.5970714	13.871429	4745.2948	4.7641916	99.714286
90.0%		7.1714286	13.809103	4414.1751	4.5643159	98.857143
75.0%	quartile	5.7978571	13.614726	3730.1793	4.0686011	97.714286
50.0%	median	5.4114286	13.522857	3574.65	3.68314	96.285714
25.0%	quartile	4.7805296	13.430305	3382.2909	3.486148	94.857143
10.0%		3.8402857	13.241064	3181.3225	3.051007	89.914286
2.5%		3.4470714	13.123857	3047.7836	2.8028716	86.857143
0.5%		3.3028571	13.082857	2998.3686	2.6607666	86.285714
0.0%	minimum	3.3028571	13.082857	2998.3686	2.6607666	86.285714

Summary Statistics

	Mean(Blue Casualties)	Mean(Red Casualties)	Mean(Time Steps)	Mean(LER)	Probability of Mission Success
Mean	5.3781871	13.522631	3638.1862	3.7684302	95.622309
Std Dev	1.0411251	0.1878699	410.97117	0.5075699	3.1267721
Std Err Mean	0.0861641	0.0155482	34.012216	0.0420068	0.2587735
Upper 95% Mean	5.548487	13.553362	3705.41	3.8514549	96.133765
Lower 95% Mean	5.2078872	13.491901	3570.9625	3.6854055	95.110854
N	146	146	146	146	146

Figure 29. Statistical Summary of Enhanced Eimulation Experiment (Four Loitering Munitions Deployed)



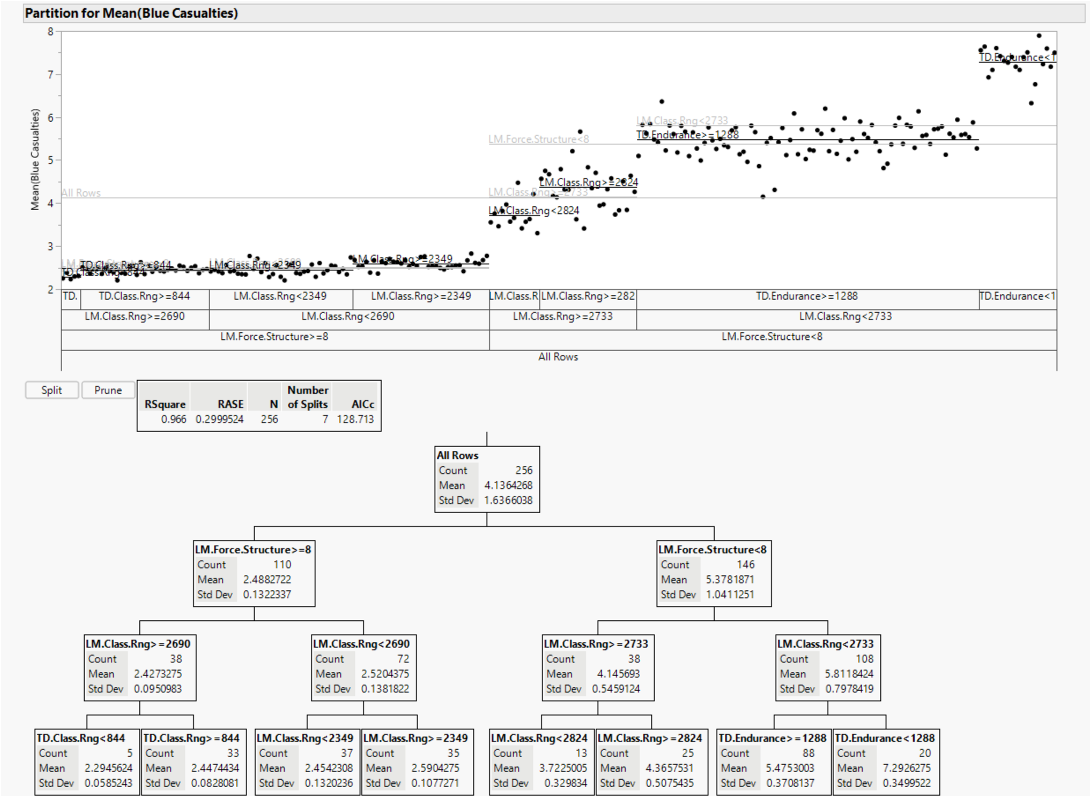
Quantiles

		Mean(Blue Casualties)	Mean(Red Casualties)	Mean(Time Steps)	Mean(LER)	Probability of Success
100.0%	maximum	2.8280802	14	3069.1519	6.1577659	100
99.5%		2.8280802	14	3069.1519	6.1577659	100
97.5%		2.7715639	13.997786	3027.6075	6.1243448	100
90.0%		2.6739059	13.994286	3019.3797	5.9834793	100
75.0%	quartile	2.5721429	13.991429	3010.0536	5.8343039	100
50.0%	median	2.48	13.985653	2996.7927	5.6927982	100
25.0%	quartile	2.385	13.951429	2993.2395	5.5495633	100
10.0%		2.3430542	13.879691	2991.4497	5.3475856	100
2.5%		2.2261568	13.813643	2988.8714	5.2288549	99.935714
0.5%		2.2057143	13.742857	2985.8943	5.0705061	99.714286
0.0%	minimum	2.2057143	13.742857	2985.8943	5.0705061	99.714286

Summary Statistics

	Mean(Blue Casualties)	Mean(Red Casualties)	Mean(Time Steps)	Mean(LER)	Probability of Success
Mean	2.4882722	13.960101	3001.951	5.688001	99.994805
Std Dev	0.1322337	0.0515691	12.647196	0.2312572	0.0383486
Std Err Mean	0.012608	0.0049169	1.2058628	0.0220495	0.0036564
Upper 95% Mean	2.5132608	13.969846	3004.3409	5.7317024	100.00205
Lower 95% Mean	2.4632836	13.950356	2999.561	5.6442996	99.987558
N	110	110	110	110	110

Figure 30. Statistical Summary of Enhanced Eimulation Experiment (Eight Loitering Munitions Deployed)



RSquare	RASE	N	Number of Splits	AICc
0.966	0.2999524	256	7	128.713

All Rows	
Count	256
Mean	4.1364268
Std Dev	1.6366038

LM.Force.Structure>=8	
Count	110
Mean	2.4882722
Std Dev	0.1322337

LM.Force.Structure<8	
Count	146
Mean	5.3781871
Std Dev	1.0411251

LM.Class.Rng>=2690	
Count	38
Mean	2.4273275
Std Dev	0.0950983

LM.Class.Rng<2690	
Count	72
Mean	2.5204375
Std Dev	0.1381822

LM.Class.Rng>=2733	
Count	38
Mean	4.145693
Std Dev	0.5459124

LM.Class.Rng<2733	
Count	108
Mean	5.8118424
Std Dev	0.7978419

TD.Class.Rng<844	
Count	5
Mean	2.2945624
Std Dev	0.0585243

TD.Class.Rng>=844	
Count	33
Mean	2.4474434
Std Dev	0.0828081

LM.Class.Rng<2349	
Count	37
Mean	2.4542308
Std Dev	0.1320236

LM.Class.Rng>=2349	
Count	35
Mean	2.5904275
Std Dev	0.1077271

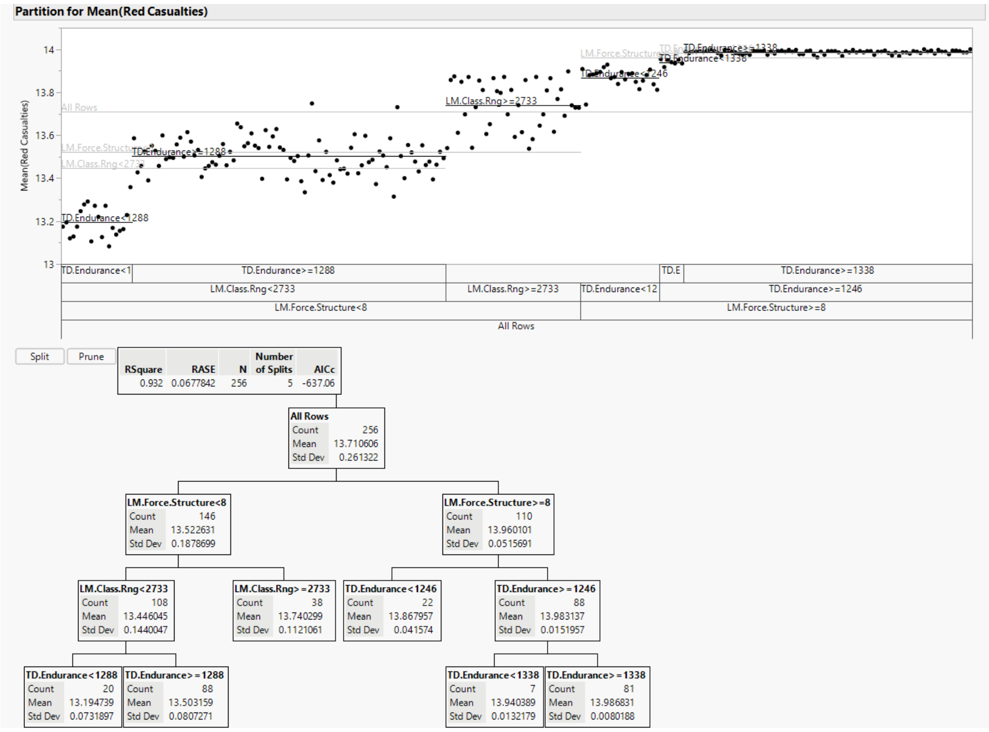
LM.Class.Rng<2824	
Count	13
Mean	3.7225005
Std Dev	0.329834

LM.Class.Rng>=2824	
Count	25
Mean	4.3657531
Std Dev	0.5075435

TD.Endurance>=1288	
Count	88
Mean	5.4753003
Std Dev	0.3708137

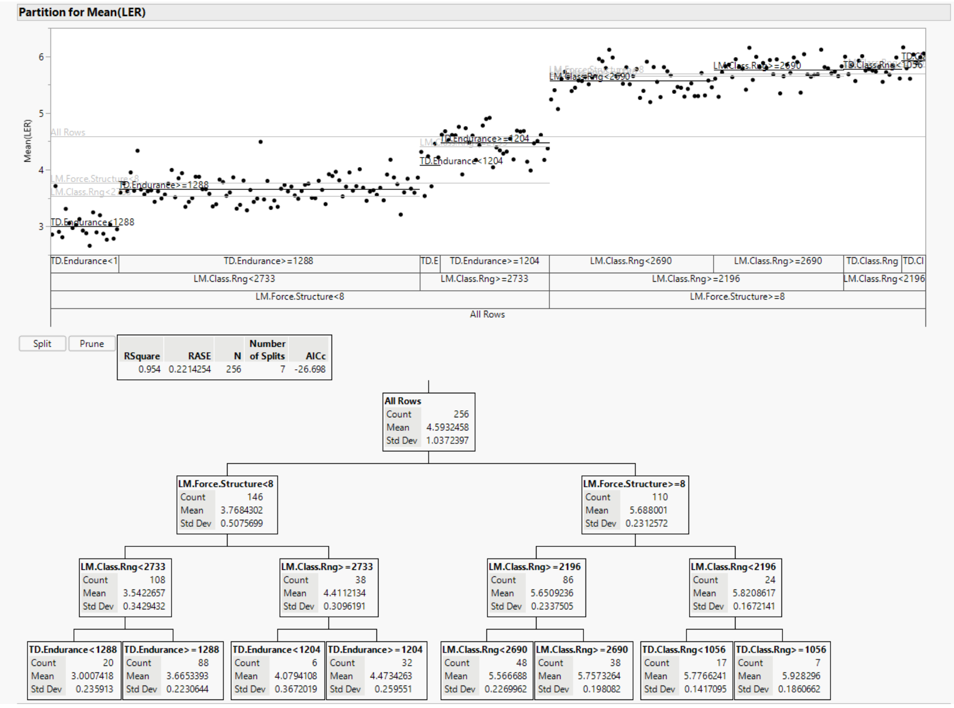
TD.Endurance<1288	
Count	20
Mean	7.2926275
Std Dev	0.3499522

Figure 31. Partition Tree for Blue Force’s Casualties



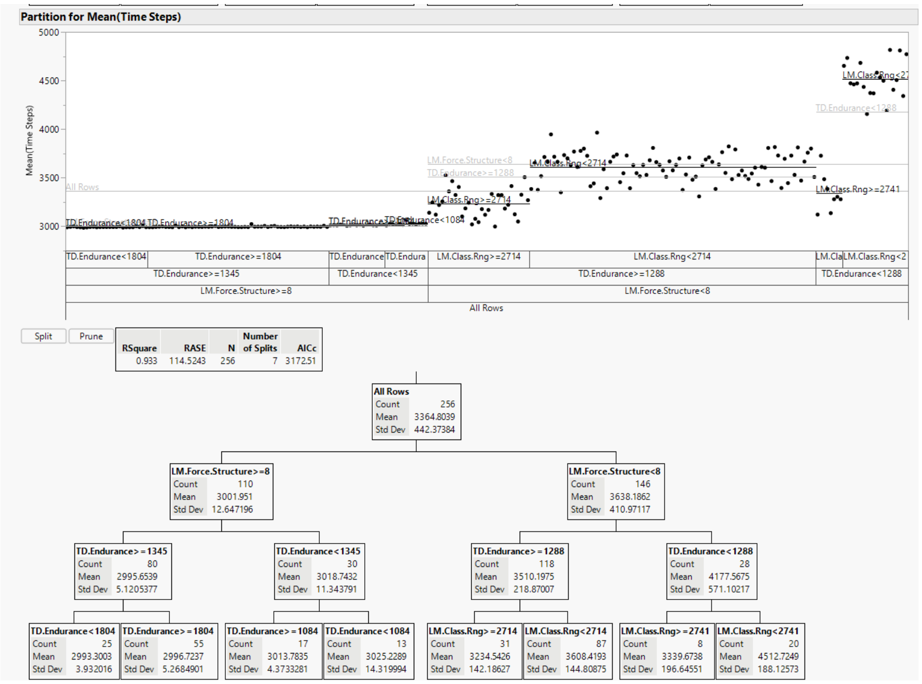
RSquare	RASE	N	Number of Splits	AICc
0.932	0.0677842	256	5	-637.06

Figure 32. Partition Tree for Red Force's Casualties



RSquare	RASE	N	Number of Splits	AICc
0.954	0.2214254	256	7	-26.698

Figure 33. Partition Tree for LER



RSquare	RASE	N	Number of Splits	AICc
0.933	114.5243	256	7	3172.51

All Rows
Count 256
Mean 3364.8039
Std Dev 442.37384

LM.Force.Structure>=8
Count 110
Mean 3001.951
Std Dev 12.647196

LM.Force.Structure<8
Count 146
Mean 3638.1862
Std Dev 410.97117

TD.Endurance>=1345
Count 80
Mean 2995.6539
Std Dev 5.1205377

TD.Endurance<1345
Count 30
Mean 3018.7432
Std Dev 11.343791

TD.Endurance>=1288
Count 118
Mean 3510.1975
Std Dev 218.87007

TD.Endurance<1288
Count 28
Mean 4177.5675
Std Dev 571.10217

TD.Endurance<1804
Count 25
Mean 2993.3003
Std Dev 3.932016

TD.Endurance>=1804
Count 55
Mean 2996.7237
Std Dev 5.2684901

TD.Endurance>=1084
Count 17
Mean 3013.7835
Std Dev 4.3733281

TD.Endurance<1084
Count 13
Mean 3025.2289
Std Dev 14.319994

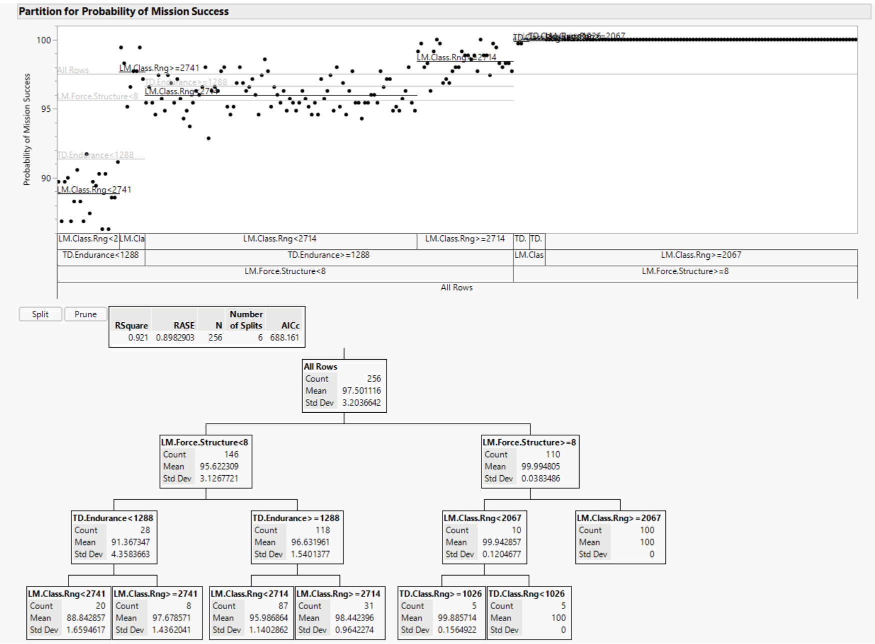
LM.Class.Rng>=2714
Count 31
Mean 3234.5426
Std Dev 142.18627

LM.Class.Rng<2714
Count 87
Mean 3608.4193
Std Dev 144.80875

LM.Class.Rng>=2741
Count 8
Mean 3339.6738
Std Dev 196.64551

LM.Class.Rng<2741
Count 20
Mean 4512.7249
Std Dev 188.12573

Figure 34. Partition Tree for Time Steps



RSquare	RASE	N	Number of Splits	AICc
0.921	0.8982903	256	6	688.161

All Rows
Count 256
Mean 97.501116
Std Dev 3.2036642

LM.Force.Structure<8
Count 146
Mean 95.622309
Std Dev 3.1267721

LM.Force.Structure>=8
Count 110
Mean 99.994805
Std Dev 0.0383486

TD.Endurance<1288
Count 28
Mean 91.367347
Std Dev 4.3583663

TD.Endurance>=1288
Count 118
Mean 96.631961
Std Dev 1.5401377

LM.Class.Rng<2067
Count 10
Mean 99.942857
Std Dev 0.1204677

LM.Class.Rng>=2067
Count 100
Mean 100
Std Dev 0

LM.Class.Rng<2741
Count 20
Mean 88.842857
Std Dev 1.6594617

LM.Class.Rng>=2741
Count 8
Mean 97.678571
Std Dev 1.4362041

LM.Class.Rng<2714
Count 87
Mean 95.986864
Std Dev 1.1402862

LM.Class.Rng>=2714
Count 31
Mean 98.442396
Std Dev 0.9642274

TD.Class.Rng>=1026
Count 5
Mean 99.885714
Std Dev 0.1564922

TD.Class.Rng<1026
Count 5
Mean 100
Std Dev 0

Figure 35. Partition Tree for Probability of Mission Success

Response Mean(Red Casualties)

Whole Model

Actual by Predicted Plot

Effect Summary

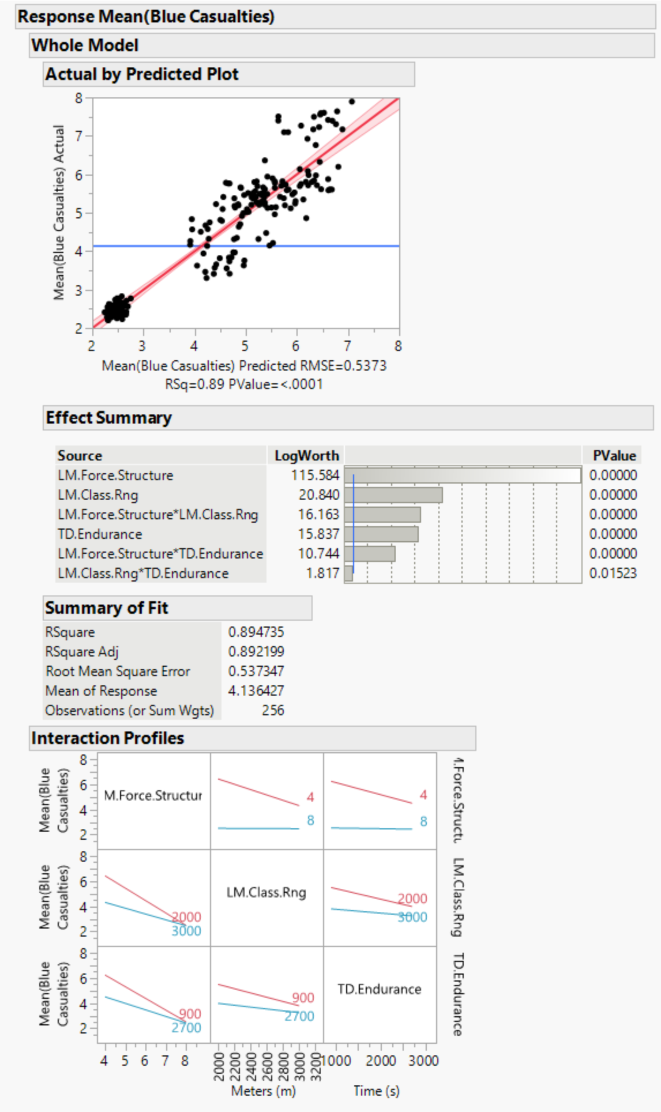
Source	LogWorth	PValue
LM.Force.Structure	95.750	0.00000
TD.Endurance	19.671	0.00000
LM.Class.Rng	17.910	0.00000
LM.Force.Structure*LM.Class.Rng	13.662	0.00000
TD.Class.Rng	4.013	0.00010
LM.Force.Structure*TD.Endurance	3.857	0.00014
LM.Force.Structure*TD.Class.Rng	1.708	0.01960

Summary of Fit

RSquare	0.855592
RSquare Adj	0.851515
Root Mean Square Error	0.100697
Mean of Response	13.71061
Observations (or Sum Wgts)	256

Interaction Profiles

Figure 36. Stepwise Regression Analysis of Red Force’s Casualties


Response Mean(Blue Casualties)

Whole Model

Actual by Predicted Plot

Effect Summary

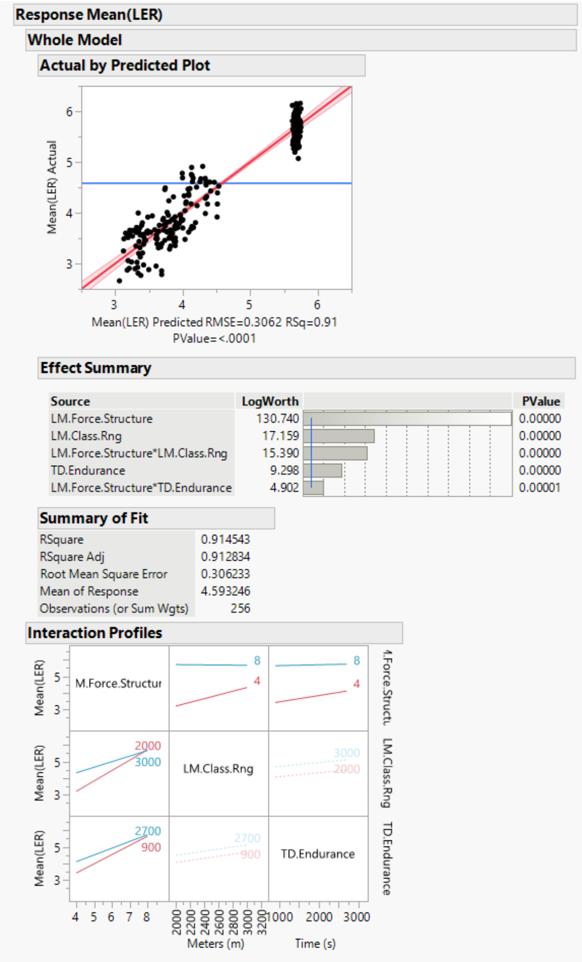
Source	LogWorth	PValue
LM.Force.Structure	115.584	0.00000
LM.Class.Rng	20.840	0.00000
LM.Force.Structure*LM.Class.Rng	16.163	0.00000
TD.Endurance	15.837	0.00000
LM.Force.Structure*TD.Endurance	10.744	0.00000
LM.Class.Rng*TD.Endurance	1.817	0.01523

Summary of Fit

RSquare	0.894735
RSquare Adj	0.892199
Root Mean Square Error	0.537347
Mean of Response	4.136427
Observations (or Sum Wgts)	256

Interaction Profiles

Figure 37. Stepwise Regression Analysis of Blue Force’s Casualties



Response Mean(LER)

Whole Model

Actual by Predicted Plot

Effect Summary

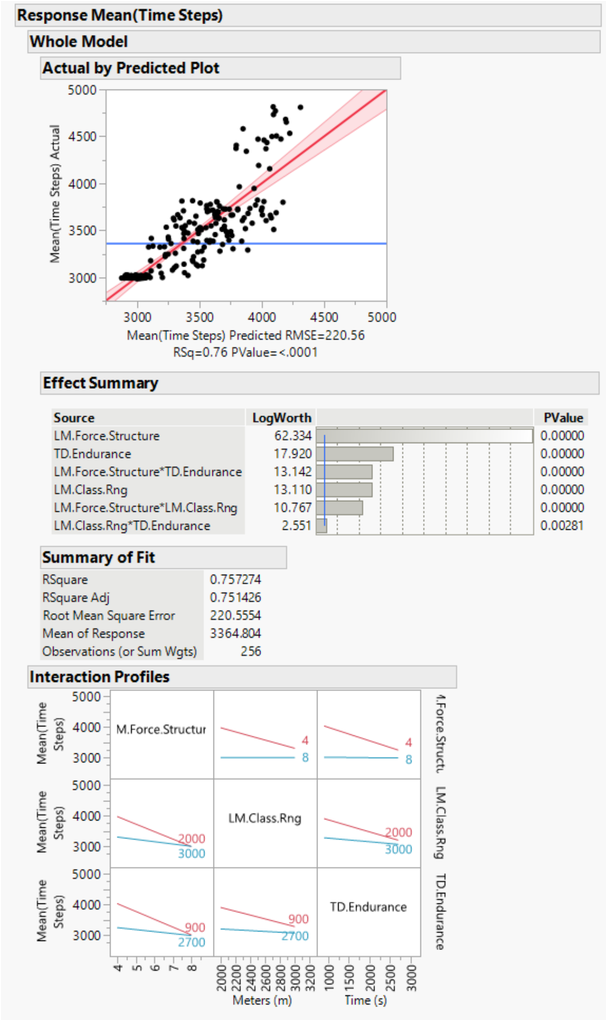
Source	LogWorth	PValue
LM.Force.Structure	130.740	0.00000
LM.Class.Rng	17.159	0.00000
LM.Force.Structure*LM.Class.Rng	15.390	0.00000
TD.Endurance	9.298	0.00000
LM.Force.Structure*TD.Endurance	4.902	0.00001

Summary of Fit

RSquare	0.914543
RSquare Adj	0.912834
Root Mean Square Error	0.306233
Mean of Response	4.593246
Observations (or Sum Wgts)	256

Interaction Profiles

Figure 38. Stepwise Regression Analysis of LER



Response Mean(Time Steps)

Whole Model

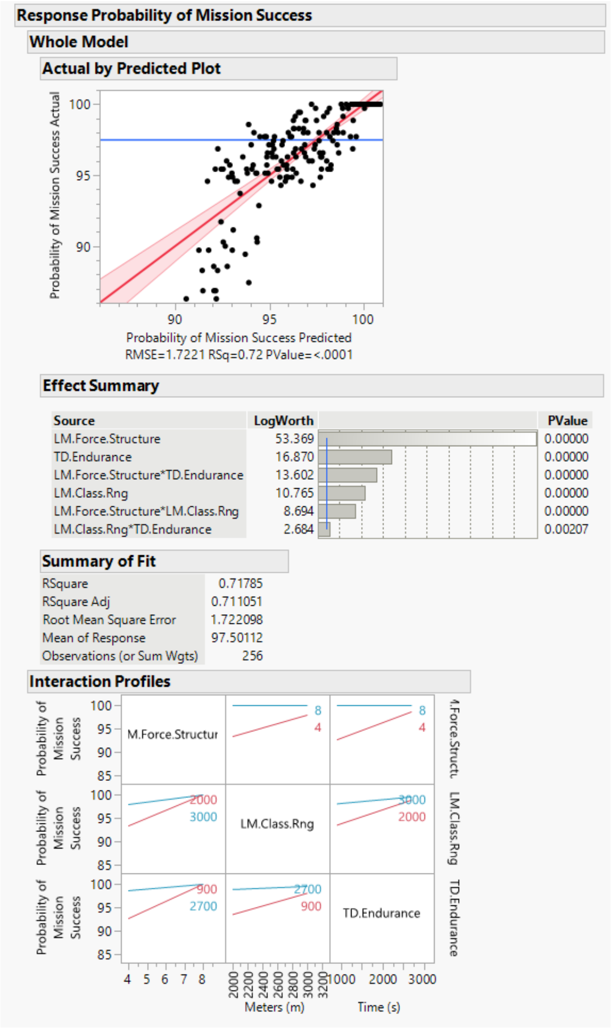
Effect Summary

Source	LogWorth	PValue
LM.Force.Structure	62.334	0.00000
TD.Endurance	17.920	0.00000
LM.Force.Structure*TD.Endurance	13.142	0.00000
LM.Class.Rng	13.110	0.00000
LM.Force.Structure*LM.Class.Rng	10.767	0.00000
LM.Class.Rng*TD.Endurance	2.551	0.00281

Summary of Fit

RSquare	0.757274
RSquare Adj	0.751426
Root Mean Square Error	220.5554
Mean of Response	3364.804
Observations (or Sum Wgts)	256

Figure 39. Stepwise Regression Analysis of Time Steps



Response Probability of Mission Success

Whole Model

Actual by Predicted Plot

RMSE=1.7221 RSq=0.72 PValue=<.0001

Effect Summary

Source	LogWorth	PValue
LM.Force.Structure	53.369	0.00000
TD.Endurance	16.870	0.00000
LM.Force.Structure*TD.Endurance	13.602	0.00000
LM.Class.Rng	10.765	0.00000
LM.Force.Structure*LM.Class.Rng	8.694	0.00000
LM.Class.Rng*TD.Endurance	2.684	0.00207

Summary of Fit

RSquare	0.71785
RSquare Adj	0.711051
Root Mean Square Error	1.722098
Mean of Response	97.50112
Observations (or Sum Wgts)	256

Interaction Profiles

Figure 40. Stepwise Regression Analysis of Probability of Mission Success

Table 19. Summary of Enhanced Simulation Experiment's Data

Design Points	Mean Time Steps (s)	Mean Blue Casualties	Mean Red Casualties	Mean LER	Probability of Mission Success (%)
1	3546.582	5.097421	13.5702	3.710977	96
2	3466.393	5.272206	13.59885	3.747159	97.14286
3	2999.931	2.574286	13.97429	5.564094	100
4	3680.191	5.748571	13.48571	3.453954	95.42857
5	3442	5.117143	13.53143	3.803578	97.42857
6	3220.175	3.73639	13.81089	4.895153	98.28571
7	2999.434	2.702857	13.97429	5.574597	100
8	2998.643	2.36	13.99429	5.824262	100
9	3015.514	2.391429	13.93429	5.731688	100
10	3007.23	2.738506	13.98851	5.070506	100
11	3465.641	4.79023	13.59195	4.141833	97.14286
12	2995.289	2.4	13.99429	5.848335	100
13	3015.043	2.605714	13.81143	5.564283	100
14	3011.186	2.64	13.84857	5.507371	100
15	3708.18	5.662857	13.47429	3.354242	95.42857
16	2985.894	2.288571	13.99143	6.115714	100
17	3017.109	2.762857	13.74286	5.453931	100
18	3308.074	4.309456	13.73066	4.335522	98
19	2994.226	2.477143	13.98571	5.58381	100
20	2992.677	2.308571	13.98857	6.150335	100
21	3718.16	5.82	13.53143	3.638641	95.14286
22	2996.335	2.747851	13.99713	5.281393	100
23	2991.514	2.342857	13.96286	5.979507	100
24	3291.163	4.86	13.62857	3.99632	98.57143
25	3011.301	2.56447	13.86533	5.675573	100
26	2992.157	2.52	13.98857	5.662135	100
27	4368.897	6.762857	13.22857	3.198982	90
28	3102.123	3.657143	13.86571	4.614085	99.42857
29	3611.499	5.765043	13.46132	3.477723	95.71429
30	2992.751	2.52	13.99143	5.54906	100
31	3018.074	2.68	13.86	5.266443	100
32	2997.097	2.252149	13.99713	6.037504	100
33	3726.177	5.897143	13.4	3.458072	95.14286
34	3479.671	5.605714	13.45714	3.461689	97.14286
35	2993.394	2.417143	13.97714	5.775909	100
36	3018.862	2.352436	13.90544	5.978363	100

Design Points	Mean Time Steps (s)	Mean Blue Casualties	Mean Red Casualties	Mean LER	Probability of Mission Success (%)
37	3020.321	2.82808	13.88825	5.239196	100
38	2992.991	2.412607	13.99427	6.049984	100
39	2995.271	2.5	13.98857	5.683156	100
40	3027.367	2.518625	13.88539	5.810615	100
41	2994.997	2.56	13.99143	5.749624	100
42	2997.763	2.362857	13.99714	5.806543	100
43	3000.011	2.528571	13.98571	5.572885	100
44	4732.834	7.554286	13.22	2.927715	86.85714
45	2994.014	2.205714	13.99143	6.157766	100
46	2990.694	2.674286	13.97714	5.29889	100
47	3728.18	5.731429	13.49429	3.494399	95.14286
48	3000.391	2.511429	13.98857	5.653481	100
49	2989.109	2.357143	13.97429	5.913514	100
50	3529.917	5.17765	13.55874	3.850475	96.28571
51	2992.669	2.397143	13.98857	5.8191	100
52	4405.337	7.505714	13.16857	2.858304	90.57143
53	3026.559	2.710602	13.87966	5.375733	100
54	2999.609	2.382857	13.98286	5.816723	100
55	3020.989	2.571429	13.88	5.718005	100
56	4434.797	7.497143	13.12571	2.767391	90.28571
57	3700.2	5.494286	13.5	3.598229	95.42857
58	3414.599	4.833811	13.54155	3.918449	96.85714
59	3269.438	4.312321	13.69054	4.375631	98.28571
60	4815.154	7.594286	13.16286	3.02621	86.28571
61	3025.441	2.670487	13.88825	5.629821	100
62	3637.483	5.488571	13.43143	3.658135	95.71429
63	3687.977	5.605714	13.46	3.559409	95.42857
64	3010.683	2.38	13.93429	5.946381	100
65	3304.057	4.2149	13.73066	4.459511	97.71429
66	3222.131	3.942857	13.72857	4.606444	98.28571
67	3445.129	5.38	13.50571	3.666657	97.71429
68	3574.229	5.402857	13.55714	3.501019	96
69	3015.072	2.596542	13.83862	5.391054	100
70	3322.046	4.505714	13.69714	4.431281	98
71	3776.849	5.8	13.38571	3.506453	94.85714
72	3815.771	5.797143	13.47429	3.394683	94.28571
73	3394.694	4.96	13.60857	3.86204	97.71429
74	3485.451	5.645714	13.39429	3.43459	96.57143

Design Points	Mean Time Steps (s)	Mean Blue Casualties	Mean Red Casualties	Mean LER	Probability of Mission Success (%)
75	3003.573	2.676218	13.98567	5.403029	100
76	3279.186	4.317143	13.76857	4.315129	97.71429
77	3350.12	4.148997	13.74785	4.492939	97.42857
78	3662.549	5.585714	13.48	3.618863	95.71429
79	2999.054	2.587393	14	5.46084	100
80	2991.226	2.60745	13.97421	5.549731	100
81	4472.114	7.394286	13.08286	2.906698	89.71429
82	3769.612	5.804598	13.37931	3.530641	94.57143
83	2993.009	2.43553	13.97708	5.882526	100
84	3822.557	6.085714	13.31429	3.210455	94.57143
85	3428.755	4.815562	13.65418	4.177442	97.14286
86	3017.369	2.534286	13.91714	5.898517	100
87	4809.846	7.894286	13.12	2.660767	86.28571
88	3009.991	2.611429	13.81429	5.445496	100
89	2995.011	2.557143	13.99143	5.446017	100
90	3003.143	2.368571	13.96857	5.881117	100
91	3739.737	5.62	13.47714	3.657917	94.85714
92	3695.337	5.451429	13.52286	3.665615	95.42857
93	2996.914	2.458453	13.9914	5.705875	100
94	2999.957	2.774286	13.98571	5.289562	100
95	3018.129	2.205714	13.92857	6.116799	100
96	2994.971	2.46	13.98857	5.649582	100
97	3533.46	5.225714	13.52286	3.806548	96.57143
98	3509.477	5.585714	13.39143	3.596004	96.85714
99	2995.26	2.422857	13.99429	5.6841	100
100	3661.473	5.60745	13.5043	3.600349	95.42857
101	3629.486	5.411429	13.52	3.68216	95.42857
102	3077.716	3.570201	13.87106	4.671515	99.71429
103	3374.903	5.025714	13.59714	3.921288	98
104	3576.398	5.716332	13.57593	3.435939	96.28571
105	3528.089	5.411429	13.59429	3.499896	96.57143
106	3140.115	3.567335	13.86533	4.613235	98.85714
107	3632.63	5.876791	13.44413	3.514551	95.42857
108	3633.408	5.695402	13.4454	3.381556	95.42857
109	3516.486	5.46	13.48286	3.631552	96.57143
110	2992.637	2.405714	13.98857	5.788143	100
111	2997.917	2.528571	13.99143	5.640812	100
112	3182.909	3.834286	13.79714	4.732392	98.85714

Design Points	Mean Time Steps (s)	Mean Blue Casualties	Mean Red Casualties	Mean LER	Probability of Mission Success (%)
113	4471.072	7.266476	13.13754	2.881427	89.71429
114	3027.874	2.627507	13.91691	5.346293	100
115	2992.868	2.550143	13.97135	5.651586	100
116	2994.797	2.482857	13.98286	5.671787	100
117	3664.54	5.208571	13.52286	3.877663	95.42857
118	3632.771	5.782235	13.4212	3.731649	96.28571
119	3043.406	3.462857	13.89714	4.547881	99.71429
120	3506.052	4.704871	13.61605	4.044191	96.85714
121	3412.803	5.137143	13.54857	3.86456	97.42857
122	3664.22	5.84	13.39429	3.63742	95.71429
123	2995.486	2.451429	13.98	5.85219	100
124	3611.734	5.82235	13.38968	3.328864	96.28571
125	3729.151	6.362857	13.33429	3.285888	94.57143
126	2993.791	2.551429	13.98857	5.604304	100
127	3124.37	3.630372	13.85673	4.689269	99.14286
128	2993.161	2.344828	13.98276	5.922845	100
129	3547.746	5.271429	13.58857	3.82717	96.28571
130	3177.622	4.169054	13.73926	4.524078	98.85714
131	2998.703	2.411429	13.99714	5.605354	100
132	4771.174	7.602857	13.17429	2.897351	86.85714
133	3019.437	2.511429	13.83714	5.411544	100
134	2997.491	2.425714	13.98	5.707508	100
135	3575.071	5.417143	13.48286	3.626123	95.71429
136	3120.431	3.411429	13.87143	4.915733	99.14286
137	3485.56	4.474286	13.61429	4.237398	96.57143
138	3508.117	4.991429	13.58571	3.875674	96.85714
139	3515.406	5.137143	13.50571	3.761059	96.57143
140	3698.363	5.691429	13.46286	3.347145	94.85714
141	3185.072	3.756447	13.80516	4.779674	98.85714
142	4155.871	6.323782	13.35817	3.712676	91.71429
143	3651.009	5.512894	13.52436	3.735763	96.28571
144	3811.88	5.762857	13.45143	3.620133	94.85714
145	3529.46	5.285714	13.54	3.754839	96.57143
146	2997.983	2.541547	13.99427	5.638634	100
147	3325.603	4.671429	13.60571	4.172237	98
148	3518.503	5.345714	13.55143	3.564574	97.14286
149	4341.454	7.097143	13.19429	2.951199	89.42857
150	2996.671	2.628571	13.98857	5.311195	100

Design Points	Mean Time Steps (s)	Mean Blue Casualties	Mean Red Casualties	Mean LER	Probability of Mission Success (%)
151	3168.954	3.968571	13.80857	4.467066	98.85714
152	3385.214	4.917143	13.61429	3.964603	98
153	3024.579	2.418338	13.85387	5.647419	100
154	3009.717	2.468571	13.97429	5.701497	100
155	3791.169	5.467049	13.52722	3.866703	94.57143
156	3119.444	3.624642	13.87393	4.602664	99.14286
157	3799.54	6.197143	13.39714	3.488956	94.57143
158	2991.069	2.375358	13.99713	5.953997	100
159	3392.326	5.208571	13.45714	3.89067	97.71429
160	2991.774	2.351429	13.98286	5.823298	100
161	3663.77	5.528736	13.50287	3.754946	96.28571
162	3757.788	5.782235	13.42693	3.492549	94.85714
163	2995.62	2.522857	13.98857	5.632454	100
164	4498.983	7.231429	13.17429	2.81084	88.28571
165	3800.289	5.702857	13.40571	3.621995	94.57143
166	3630.803	5.4	13.50286	3.645647	95.42857
167	2995.601	2.606936	13.99422	5.507346	100
168	2993.811	2.636103	13.98854	5.298812	100
169	2995.86	2.371429	13.98571	5.809095	100
170	3069.152	2.770774	13.90831	5.730871	99.71429
171	2994.111	2.451429	13.98286	5.829627	100
172	3023.59	2.412607	13.97135	6.031599	99.71429
173	2996.103	2.232092	13.98854	5.979346	100
174	4505.054	7.417143	13.10571	3.032412	88.57143
175	3729.043	5.817143	13.45714	3.548416	95.42857
176	2992.303	2.288571	13.99429	5.749732	100
177	2993.651	2.471429	13.97429	5.775741	100
178	3004.651	2.557143	13.98	5.779499	100
179	4372.272	7.398281	13.15473	2.786322	90.28571
180	2995.537	2.534286	13.99143	5.608849	100
181	3374.501	5.561605	13.44126	3.434275	98
182	3322.668	4.26361	13.72779	4.393074	97.71429
183	3006.591	2.52	13.99143	5.72619	100
184	3807.003	5.717143	13.48857	3.61557	94.85714
185	4581.444	7.097421	13.24642	3.311143	87.42857
186	2993.449	2.637143	13.98286	5.425262	100
187	3471.057	5.194842	13.60458	3.842126	96.85714
188	2991.929	2.362857	13.98857	5.990413	100

Design Points	Mean Time Steps (s)	Mean Blue Casualties	Mean Red Casualties	Mean LER	Probability of Mission Success (%)
189	3279.006	4.348571	13.74	4.21738	98.28571
190	3733.263	5.802857	13.49714	3.54208	95.14286
191	2992.591	2.374286	13.99143	5.810484	100
192	4533.006	7.171429	13.12857	3.24934	89.71429
193	3726.751	5.662857	13.54	3.538421	95.14286
194	4651.571	7.64	13.27143	2.872364	88.28571
195	3763.506	5.94	13.42286	3.392343	95.14286
196	3384.929	5.208571	13.53714	3.708626	97.14286
197	3587.689	5.222857	13.58571	3.702221	96
198	3322.114	5.094286	13.47714	3.952921	98.28571
199	3027.53	2.426934	13.89398	5.602635	100
200	2988.054	2.334286	13.99143	5.933913	100
201	2993.511	2.502857	13.99429	5.286624	100
202	3049.891	3.554286	13.85714	4.68303	99.71429
203	3384.754	5.240688	13.54155	3.601359	98
204	3603.76	5.305714	13.54571	3.643583	95.71429
205	3511.685	5.126074	13.55301	4.00963	96.85714
206	2997.751	2.385714	13.98571	5.792541	100
207	3946.355	5.982808	13.43266	3.703211	93.71429
208	2995.669	2.531429	13.99143	5.666494	100
209	3013.089	2.668571	13.88286	5.193235	100
210	4681.771	7.30659	13.27794	3.058976	86.85714
211	3010.24	2.451429	13.94	5.679282	100
212	2991.086	2.440922	13.98559	5.808501	100
213	3121.536	3.971347	13.81375	4.341803	99.42857
214	3806.477	5.614286	13.46286	3.620859	94.28571
215	3543.871	5.194286	13.55143	3.916466	96.28571
216	3007.517	2.548571	13.95143	5.359217	100
217	2993.266	2.5	13.96857	5.682406	100
218	3004.6	2.54	13.98571	5.387746	100
219	3246.797	4.322857	13.69714	4.285674	98
220	3713.783	5.974286	13.41429	3.34709	95.14286
221	3669.782	5.146552	13.62356	3.940161	95.42857
222	3404.831	4.575931	13.58166	4.320141	97.42857
223	3393.077	5.365714	13.55429	3.68412	97.71429
224	3011.317	2.348571	13.89429	5.993331	100
225	3242.794	4.137143	13.69714	4.618186	98.57143
226	3256.626	3.818966	13.81034	4.507105	98

Design Points	Mean Time Steps (s)	Mean Blue Casualties	Mean Red Casualties	Mean LER	Probability of Mission Success (%)
227	3628.583	5.651429	13.49429	3.566598	96
228	3018.799	2.593123	13.87106	5.639822	100
229	3332.86	4.567335	13.6447	4.173474	97.71429
230	2990.691	2.36	13.99143	5.904719	100
231	3710.743	5.517143	13.46	3.809922	94.85714
232	3525.431	4.637143	13.65143	4.182441	96.28571
233	2992.674	2.357143	13.99429	5.798746	100
234	3006.854	2.411429	13.95143	6.003546	100
235	3487.349	5.48	13.54286	3.576363	97.14286
236	2995.82	2.408571	13.98	5.672423	100
237	3550.006	5.017143	13.63714	3.953529	96.28571
238	3020.614	3.414286	13.85429	4.756737	100
239	2997.614	2.297143	13.98857	5.948493	100
240	3603.891	5.613181	13.52436	3.651447	96
241	2998.369	3.302857	13.87143	4.679177	100
242	2990.889	2.597143	13.99143	5.522603	100
243	3454.88	5.260745	13.49284	3.814153	97.42857
244	4191.129	6.925714	13.27143	2.973708	91.14286
245	3017.181	2.429799	13.95415	5.718865	100
246	3964.585	6.13467	13.37249	3.315045	92.85714
247	2990.549	2.494253	13.98563	5.736766	100
248	2993.783	2.468571	13.99429	5.854485	100
249	2991.443	2.474138	13.99138	5.789381	100
250	3716.229	5.534286	13.50571	3.629914	94.85714
251	3359.98	4.751429	13.61143	3.98737	97.71429
252	4460.717	7.171429	13.29143	3.131011	88.57143
253	2997.323	2.517143	13.99714	5.516214	100
254	3136.366	3.842857	13.84857	4.478621	99.42857
255	3666.494	5.377143	13.56286	3.784182	95.42857
256	2991.626	2.282857	14	5.983921	100

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