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Operational Verification of Mechanized Battalion Capabilities in Defensive Operations through Constructive Simulation

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Abstract

This paper verifies mechanized battalion defensive capabilities using constructive simulation. The methodology employs the MASA SWORD environment with Monte Carlo replications, randomized A/B testing of Courses of Action, and standardized metrics (MoE, MoP, MoFP, MoS). The results show that ISR quality and C2 latency are decisive for defensive effectiveness, while obstacle system design and logistical throughput significantly influence enemy tempo and operational endurance. The findings support capability assessment, operational planning, and training design. The paper's value lies in a reproducible, metrics-based framework for battalion-level capability verification.

KEY WORDS: *analytic indicators; capabilities; constructive simulation; defensive operation; MASA SWORD; mechanized battalion; scenario.*

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1. Introduction

The verification of mechanized battalion capabilities in defensive operations represents a core requirement of contemporary military art and operational analysis, directly supporting combat readiness, doctrinal refinement, and informed decision-making. Defensive operations require the tightly coordinated employment of fires, maneuver, obstacle systems, intelligence, command and control (C2), sustainment, and force protection. The effectiveness of defense does not emerge from individual functions in isolation but from their synchronized interaction across time and space. Consequently, these interactions must be examined using methods that enable systematic assessment, controlled variation, and reproducible analysis.

Field Training Exercises (FTXs) remain indispensable for validating tactical realism and human performance. However, their inherent limitations restricted repeatability, high financial and organizational costs, limited scalability, and intrinsic safety risks significantly constrain their suitability for systematic experimentation and comparative evaluation of alternative tactical concepts. These constraints are particularly pronounced when assessing the quantitative effects of variations in intelligence quality, C2 latency, fire support procedures, obstacle design, or logistical performance.

Constructive simulation offers a complementary analytical approach capable of overcoming these limitations. It enables fully controlled, transparent, and repeatable experimentation, allowing the isolation and precise analysis of the effects of military decision-making, operational procedures, and environmental conditions on combat performance. Within this environment, complex spatio-temporal interactions among warfighting functions: Command and Control, Intelligence, Surveillance and Reconnaissance (ISR), Fires, Maneuver and Movement, Sustainment, and Force Protection can be modeled with a level of consistency and granularity not achievable through live training alone. Moreover, related domains such as Information Operations (INFOOPS) and Civil-Military Cooperation (CIMIC) can be incorporated to capture the influence of the broader operational environment.

The integration of multiple replications, Monte Carlo variability, randomized A/B testing of alternative Courses of Action (COAs), and advanced analytical tools such as After Action Review (AAR) and Smart Layers establish a robust framework for the quantitative assessment of defensive capabilities. This framework enables the application of standardized metrics, including MoE, MoP, MoFP, and MoS, thereby ensuring analytical traceability and comparability across scenarios and experimental conditions.

Accordingly, this study focuses on a systematic examination of how ISR quality, C2 latency, fire support modes, obstacle system structure, logistical throughput, and enemy operational tempo interact to shape the defensive performance of a mechanized battalion. The objective is not only to assess outcomes but also to identify causal mechanisms and sensitivity relationships that are directly relevant to capability development, operational planning, and training design.

2. Method of Investigation

The research was conducted using the constructive simulation environment MASA SWORD [1], which provides precise control of input parameters, transparent scenario replication, and detailed analytical processing of defensive operations conducted by a mechanized battalion [2]. The suitability of constructive simulation tools for tactical-level analysis and planning has been extensively demonstrated in recent national and international studies, particularly in relation to capability assessment, engineer support optimization, and fire support effectiveness [10–12].

The primary objective of the study was to determine whether mechanized battalion Capability Codes and Capability Statements [3] can be assessed in a consistent, quantifiable, and replicable manner using MoE, MoP, MoFP, and MoS metrics. The analytical framework simultaneously examines how these metrics reflect and integrate the warfighting functions of Command and Control, Intelligence, Surveillance and Reconnaissance (ISR), Fires, Maneuver and Movement, Sustainment, and Force Protection [4].

Measures of Effectiveness were defined to capture the overall quality of the defense [6] as an emergent outcome of coordinated warfighting functions across time and space. These measures focused primarily on the duration of holding key terrain, the ability to disrupt or defeat enemy intent, and the achievement of the desired end state within the allocated timeframe. Measures of Performance assessed procedural and functional components enabling effective coordination, including C2 latency and continuity, the accuracy and timeliness of fire support, and ISR quality in terms of coverage, precision, and information dissemination speed. Measures of Force Protection monitored relative personnel and equipment losses, the incidence of fratricide, and the effectiveness of casualty evacuation procedures. Measures of Sustainment focused on resource consumption, replenishment rates, and the throughput of logistical nodes defining the operational endurance of defensive operations.

The experimental design was based on variables identified in doctrinal literature [2, 4–6] as key determinants of defensive outcomes:

- enemy operational tempo and combat power,
- depth and structure of obstacle systems,
- ISR quality and information-sharing latency,
- fire support modes,
- logistical throughput.

For the Monte Carlo analysis, input variables were represented by appropriate statistical distributions (beta, lognormal, triangular, and truncated normal) and parameterized using doctrinal norms and expert judgment. The scenario (see Fig. 1) was executed in 50 replications with stabilized pseudorandom number generator seed values to ensure comparability.

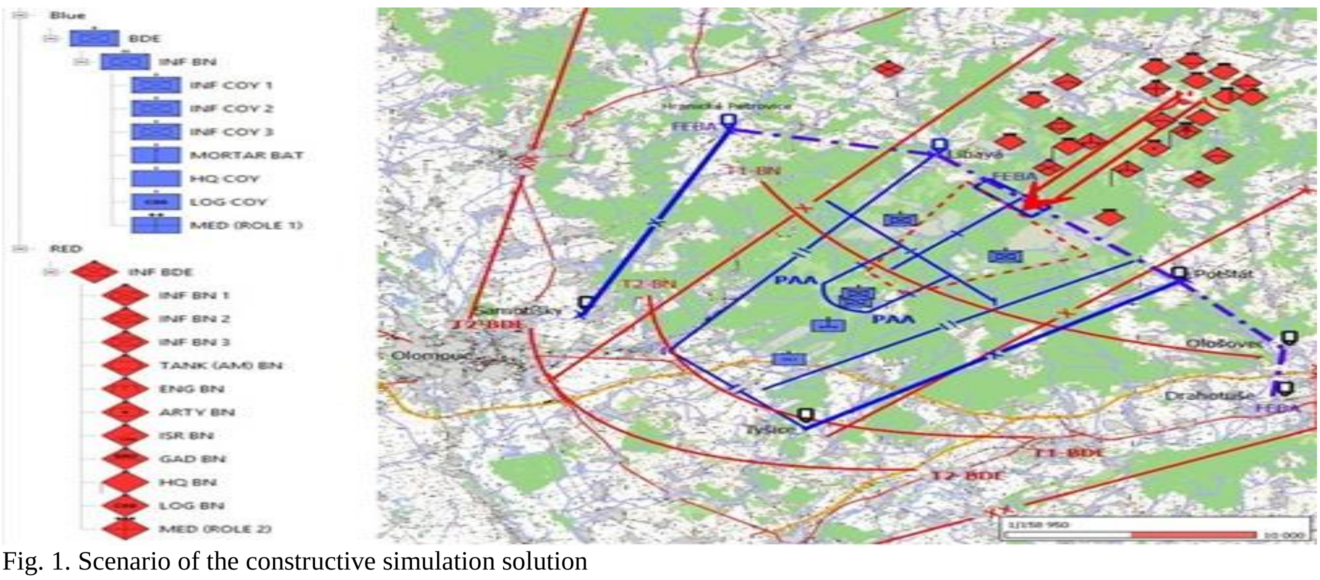

Fig. 1. Scenario of the constructive simulation solution

Statistical evaluation included the calculation of medians (or means where appropriate), 95% confidence intervals (bootstrap BCa where assumptions of normality were violated), randomized A/B comparisons of COAs with blocking by enemy tempo and terrain, correction for multiple hypothesis testing using the Holm–Bonferroni method, and the calculation of effect sizes (Cohen's d, Hedges' g, or odds ratios).

AAR outputs and Smart Layers enabled reconstruction of operational progression, identification of critical spatio-temporal points, localization of ISR blind spots, detection of logistical bottlenecks, identification of fire support desynchronization, and analysis of delayed C2 responses. Verification and validation procedures included: (1) verification of internal model consistency, (2) comparison of parameters with doctrinal tactics, techniques, and procedures (TTPs) [2–6] and available reference data, and (3) expert assessment by subject matter experts (SMEs). This approach ensured full traceability between metric selection, model configuration, experimental design, and result interpretation.

3. Investigation Result

The results synthesize findings derived from Monte Carlo replications, randomized A/B comparisons, and detailed operational reconstructions using AAR and Smart Layers. The structure reflects logical progression from observed outcomes (MoE) through performance determinants (MoP), force protection (MoFP), and sustainment (MoS), to sensitivity analysis and causal interpretation.

3.1 Measures of Effectiveness

The results confirm that timely enemy detection and a well-designed obstacle system constitute key prerequisites for successful defensive operations. This finding is consistent with previous analytical and simulation-based studies identifying information superiority and deliberate battlefield shaping as decisive factors influencing defensive outcomes [9, 13]. High-quality ISR enabled C2 to accelerate decision cycles and synchronize Fires and Maneuver within decisive time windows. Deep, layered obstacle systems effectively slowed enemy advancement and created favorable conditions for fire engagement. Monte Carlo analysis demonstrated that even minor increases in initial detection latency significantly reduced the probability of achieving operational objectives, with observed effect sizes ranging from medium to large (see Fig. 2).

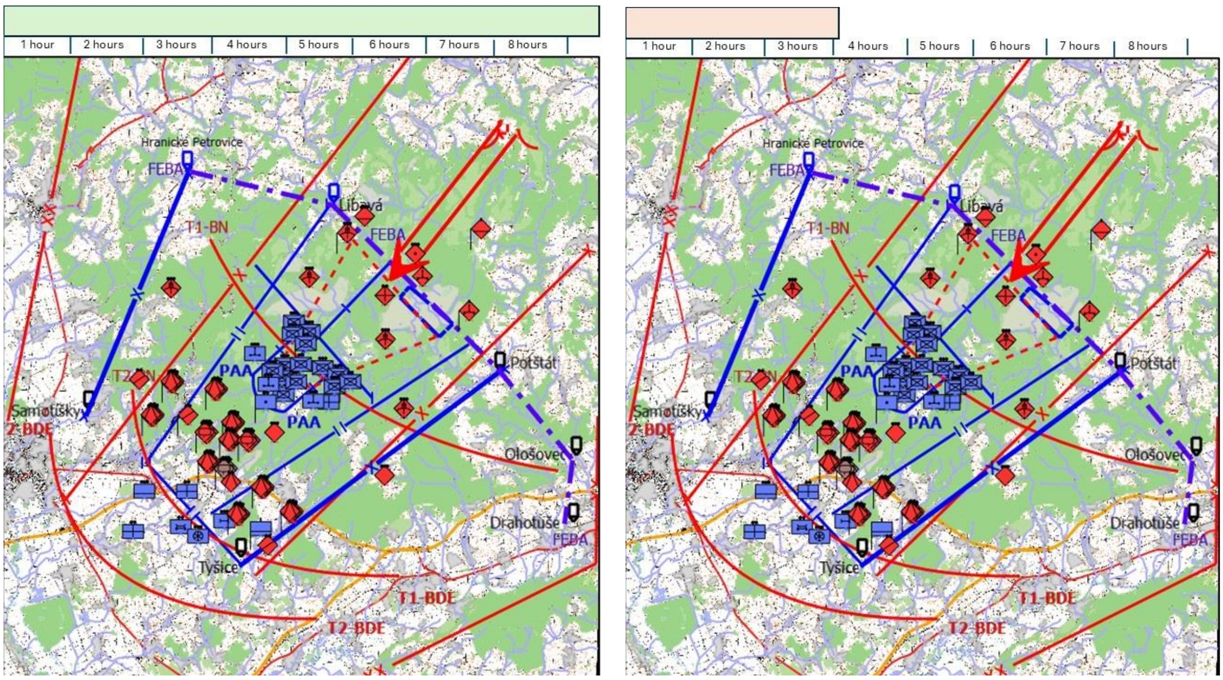

Fig. 2. ISR in optimal state (left) and after simulation (right).

These findings clearly demonstrate that timely detection represents a necessary condition for successful defensive operations.

3.2 Measures of Performance

Performance metrics revealed the dominant influence of C2 latency and continuity in conjunction with ISR quality. Accelerated fire support modes proved effective only when supported by a complete and rapidly disseminated ISR picture. Information flows were visualized through reports generated for both Red and Blue forces (see Figs. 3 and 4).

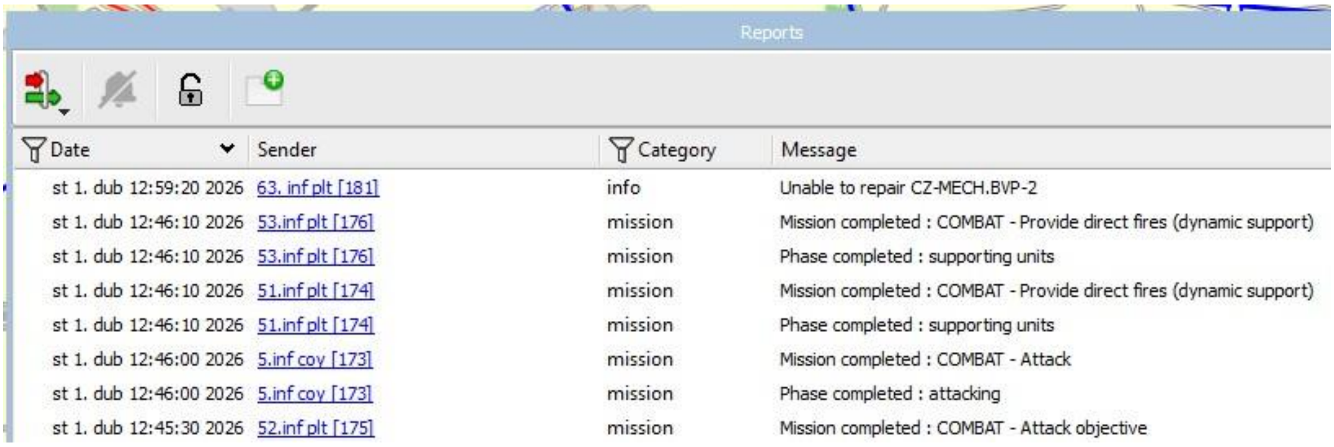

Fig 3 Fragment reports for Red forces

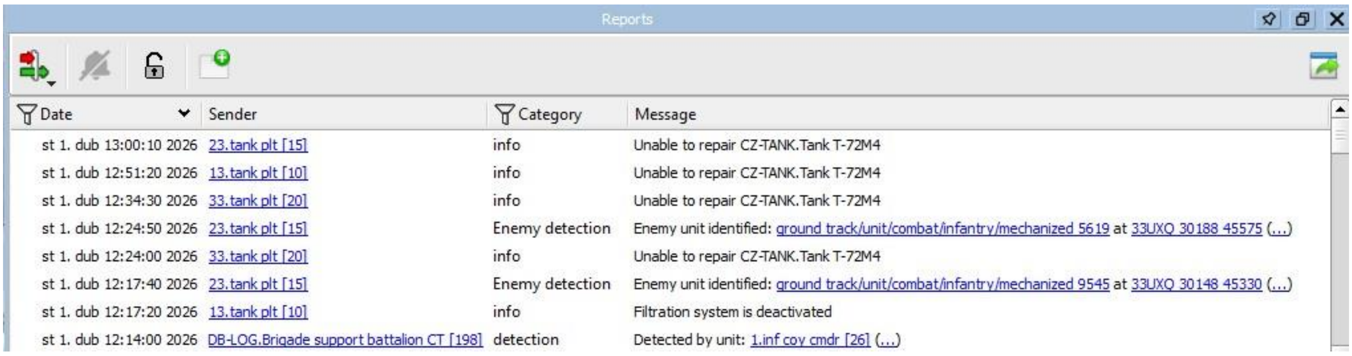

Fig. 4. Fragment reports for Blue forces

Figure 4 illustrates a report entry indicating "Enemy units identified," which was transmitted only after the initiation of combat operations (10:20 hours). This delay significantly reduced its operational utility and contributed to fire support desynchronization.

3.3 Measures of Force Protection

High levels of force protection were achieved when ISR provided reliable situational awareness, obstacle systems were layered, and fire assets were precisely coordinated. Delayed ISR inputs or improperly accelerated fire modes increased the risk of fratricide. Rapid CASEVAC/MEDEVAC procedures and robust maintenance capabilities significantly contributed to sustaining combat power throughout the engagement.

Simulation outputs (see Table 1) further demonstrate that the modeled operational scenario enables a systematic assessment of whether available medical evacuation capacities within the Tactical Combat Casualty Care (TCCC) continuum, as well as recovery, evacuation, and maintenance capabilities organic to the mechanized battalion, are sufficient to sustain combat effectiveness throughout the operation. The relationship between observed KIA, WIA, and MIA rates and the throughput of CASEVAC/MEDEVAC processes indicates that appropriately scaled and well-integrated medical support elements play a decisive role in limiting irreversible personnel losses and preserving force readiness.

Table 1.

Simulation result summary presents personnel losses for both Blue and Red forces

Units	**Personal**							
	Operable before battle	***KIA***	***WIA***				***MIA***	***EPOW***
			P1	***P2***	***P3***	***P1H***		
Blue (-/%)	802/100	32/4,0	14/1,8	11/1,4	21/2,6	13/1,6	16/2,0	0/0
Red (-/%)	4512/100	146/3,0	97/2,1	137/3,0	207/4,6	81/1,8	57/1,3	19/2,4

Legend: KIA= Killed in Action; WIA= Wounded in Action (Priority 1, Priority 2, Priority 3, Priority 1 Hold); MIA=Missing in Action; EPOW= Enemy Prisoner of War.

In parallel, the capability to recover, evacuate, and repair damaged combat equipment (see Table 2) particularly through a high proportion of forward and on-site repairs proved essential for maintaining operational tempo and preventing the cumulative degradation of combat power. The simulation results thus confirm that force protection effectiveness is not determined solely by ISR-enabled situational awareness and kinetic effects but is critically underpinned by the sufficiency and resilience of medical and logistic support structures at the battalion level.

Table 2.

Simulation result summary presents equipment losses for both Blue and Red forces

Units	**Combat equipment**		
	Operable before battle	***DBR***	***F***
Blue (-/%)	174/100	14/8,0	29/17,0
Red (-/%)	827/100	47/5,6	56/6,8

Legend: DBR = Destroyed Beyond Repair; F= Unserviceable (Reparable)

3.4 Measures of Sustainment

Logistical performance defined the battalion's maximum operational horizon. The throughput capacity of logistical nodes, rates of ammunition and fuel resupply, and available maintenance and repair resources directly constrained the intensity and duration of both Fires and Maneuver. Sustainment therefore acted as a critical enabler and limiter of combat power.

Even limited disruptions in logistical flows produced cumulative and compounding effects. Delays in resupply or shortages of critical classes of supply progressively reduced the battalion's ability to maintain a coherent defensive posture. Over time, these constraints degraded combat effectiveness and narrowed tactical flexibility, forcing commanders to prioritize survival and conservation over proactive defensive action.

Table 3.

Supplies consumption Blue forces

Category	***Total/DOS***	***Percentage (%)***
Class I	802	46
Class II	72	17
Class III	43308	7
Class IV	102	15
Class Va (Ammo under 120 mm)	112500	41
Class Vb (Ammo over 120 mm)	90	60

Consumption data (see Table 3) further illustrate disparities in sustainment demand across supply classes. Class V supplies (ammunition) dominated both volume and operational significance, while medical and personnel-related supplies, although consumed in smaller quantities, represented disproportionately critical sustainment requirements due to their direct impact on force survivability and morale.

3.5 War Fighting Functions Analysis

Sensitivity analysis confirmed a hierarchical structure of influences consistent with doctrinal warfighting functions. ISR and C2 exerted the strongest influence on defensive effectiveness, followed by Protection (obstacle systems), Fires (conditioned by ISR and C2), Sustainment, and enemy operational tempo. Comparable hierarchies have been reported in prior modeling and simulation research [7–9], underscoring the decisive role of information superiority and deliberate battlefield shaping.

3.6 A/B testing Course of Actions

The effectiveness of individual COAs was unequivocally conditioned by C2 and ISR quality. Reserve employment proved advantageous only under conditions of low C2 latency. Accelerated fire modes were beneficial exclusively under high-quality ISR conditions. Obstacle-centric COAs achieved the best outcomes under standard fire support modes and medium enemy operational tempo.

3.7 After Action Review and Smart Layers

Advanced analytical tools revealed critical moments determining defensive success or failure, including overloaded logistical routes, ISR blind spots, fire support desynchronization, delayed C2 reactions, and the loss of defensive coherence. Modeled INFOOPS and CIMIC effects demonstrated that the civil and information environment can significantly influence ISR availability, route accessibility, and the commander's decision space.

3.8. Limitations

The use of constructive simulation is subject to several inherent limitations that must be considered when interpreting results:

- abstraction and model bias, as fidelity depends on data library quality, model calibration, and doctrinal behaviors embedded in the system;
- reliance on a predefined physical database;
- non-real ORBAT structures for Blue forces and modeled adversary ORBATs due to classification constraints;
- limited representation of human factors, including stress, intuition, creativity, and improvisation;
- high sensitivity to scenario configuration, including ORBAT, environmental, ROE, and logistic settings;
- validation challenges arising from limited availability of high-quality field training exercise reference data, necessitating expert judgment and comparative testing.

Despite these limitations, constructive simulation remains a suitable and practical tool for verifying mechanized battalion defensive capabilities when applied with appropriate doctrinal grounding and expert oversight.

4. Conclusions

This study demonstrates that constructive simulation using the MASA SWORD environment provides an analytically robust means of verifying mechanized battalion defensive capabilities. The proposed framework enables systematic definition and measurement of MoE, MoP, MoFP, and MoS, supports repeatable execution of complex scenarios, and facilitates rigorous comparison of alternative COAs under controlled conditions. Advanced analytical tools particularly AAR and Smart Layers—significantly enhance result interpretability by enabling precise reconstruction of when, where, and why critical operational outcomes occur.

The analysis identifies ISR quality and C2 timing as decisive factors shaping the battalion's ability to detect enemy actions, accelerate decision-making, and coordinate Fires and Maneuver. The depth and structure of obstacle systems directly influence enemy tempo and engagement opportunities, while logistical throughput determines the sustainability and operational endurance of defensive operations.

Beyond unit-level capability verification, the results indicate that MASA SWORD constitutes a scalable tool for broader applications, including operational planning, capability development, and multi-domain training. These findings reinforce earlier conclusions that constructive simulation and computer-supported wargaming are essential components of contemporary defense experimentation frameworks when integrated with doctrinal analysis and expert judgment [7, 8, 11–13].

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