Journal of Field Robotics

WILEY

RESEARCH ARTICLE OPEN ACCESS

Effectiveness of an Expendable Unmanned Ground Vehicle Stalling a Mechanized Infantry Company's Primary Combat Units—A Virtual Simulation Experiment

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Received: 27 March 2024 | **Revised:** 19 August 2024 | **Accepted:** 9 September 2024

Funding: The authors received no specific funding for this work.

Keywords: ground combat | mechanized infantry | military | simulation | stalling action | unmanned ground vehicle | virtual simulation

ABSTRACT

Technological advancements have spurred the development of unmanned ground vehicles (UGVs) and their innovative military applications and strategies. Such applications include expendable UGVs. However, public research concerning expendable military UGVs remains sparse. Particularly, the unclassified literature does not contain studies regarding their capabilities and effectiveness in combat. This study introduces a new low-cost expendable UGV called Laykka. Moreover, the study presents a virtual simulation experiment to evaluate Laykkas' operational capabilities and their impact on advancing mechanized infantry units. The experiment involved armored reserve officer students assuming the roles of infantry troops forming an attacking opposing force while staff officers controlled simulated infantry troops operating the UGVs. A total of 16 battle simulations were fought. The simulated UGVs operated by a single soldier were able to stall the advancement of the mechanized infantry company's primary combat units three times out of four and a smaller force 11 out of 12 times. The best stalling effect was observed using a mix of UGVs with different module types. These modules allowed reconnaissance, loitering mine, and anti-tank operations. The simulation experiment revealed that the UGV was an effective defensive tool due to its self-destructive capability, causing marked battle damage, disruption, and confusion to the opposing forces.

1 | Introduction

The rapid progress in various technologies, such as computing, artificial intelligence, optics, and telecommunications has significantly sped up the development of unmanned ground vehicles (UGVs) within military contexts. For an overview of current military UGVs (see Andersson 2021). UGVs and similar automated vehicles offer numerous advantages, including alleviating the physical strain on individual infantry troops, enhancing their understanding of a situation at hand, and facilitating the successful completion of combat missions (Ben-Tzvi, 2010; Nguyen-Huu et al. 2009; Whitney, Fidock, and Gassdorf 2012). UGVs possess significant potential for military applications due to their adaptability and ability to be killed. Their significance in countering or impeding mechanized infantry companies during conflicts such as the Russia-Ukraine war has also been underscored by recent studies and reports (Bendett 2023; Edmonds and Bendett 2022; Hunder 2023; Kallenborn and Plichta 2023; Militarnyi 2023). Traditional approaches often result in substantial losses of infantry troops and equipment, making flexible and expendable UGVs particularly valuable.

Although UGVs are primarily controlled remotely (Odedra, Prior, and Karamanoglu 2009), advancements in their development have led to a large variety of adaptations in other respects (Andersson 2021; Choi et al. 2019). These modern UGV systems vary in size and purpose, ranging from small reconnaissance UGVs (Andersson 2021; Smolarek 2019) to larger war machines weighing several thousand kilograms. UGVs can also be used for rescue and support missions (Andersson 2021; Blokhin et al. 2015; Choi et al. 2019). Some UGV designs follow a modular approach. This allows for customization based on mission requirements. For instance, "RoBattle" (Israel Aerospace Industries 2023) is a platform capable of carrying out different types of missions using interchangeable modules. These modules include manipulator arms and sensor platforms (Eshel 2016). Alternatively, the UGV system known as THeMIS (Milrem Robotics 2023) also employs a similar approach where the central compartment can accommodate multiple module types, thus altering its operational capabilities.

2 | Overview of Laykka UGV

The Laykka system is an experimental UGV developed by the first author of this study. It is designed as a platform that can accommodate various modules to adapt its functionality for different tasks. The main objective of Laykka is to serve as an affordable and disposable UGV system. The version of Laykka used in this study is Laykka X.3 (Figure 1) and referred to from here on as Laykka. The study also includes attachable modules for anti-tank, reconnaissance, and loitering mine functions.

Laykka is compact and repairable. It has been developed to be small and lightweight enough to be transportable with a regular car and other common means of transportation. Its construction incorporates passive sensors for localization and navigation, making it relatively lightweight at approximately 100–150 kg. Laykka is mainly built using commercially off the shelf (COTS)

FIGURE 1 | Laykka X.3 with a loitering mine module and an armored infantry fighting vehicle in the background. [Color figure can be viewed at wileyonlinelibrary.com]

components. COTS components reduce expenses and alleviate availability concerns about main components, unlike parts required to be custom-made or made with specialized production lines. An additional benefit of using general and COTS components is having the possibility to cannibalize components from other devices and machines, if there would be a severe availability shortage.

Laykka can be operated remotely through radio, Wi-Fi, or 4G/5G connections as an Internet of Things (IoT) device. Because it is an IoT device, a generic gamepad controller can be used to control Laykka from long distances via telecommunication networks. Laykka incorporates three types of cameras: a primary 720p USB day camera, an ultraviolet camera for nighttime activities, and a thermal imaging camera modified from a thermal monocular. Laykkas's current maximum speed is mechanically limited to 10 km/h, but it can reach 20 km/h. Additionally, the UGV features a ground clearance of approximately 20 cm and four-wheel drive. Each wheel is equipped with an electric motor of 350 W, providing a total torque of 118 Nm through gears. Laykka utilizes differential steering for turning, making it capable of full 360-degree pivot turns in both directions. Laykka has a built-in self-destruct sequence that simulates a detonation radius equivalent to that of a 120 mm mortar grenade and possesses explosive force similar to approximately 20 kg of trinitrotoluene, i.e., TNT. The inclusion of this mechanism enables further tactical capabilities.

Laykka's modules are separate components that can be easily attached or detached from the UGV. They add functionality to the platform and can be nonweaponized or weaponized. For instance, with a reconnaissance module, Laykka can provide up-to-date enemy information before the advance of friendly troops. In addition, it can provide cover fire with its integrated rifle. The module can be swapped out for a more heavily weaponized one, that is, equipped with light antiarmor weapons and high explosives. In that case, it can defend against opposing troops, nonarmored vehicles, and armored infantry fighting vehicles (IFVs) with lethal force. Laykka has undergone extensive live testing to evaluate its maneuverability in various terrains and weather conditions. Additional tests were conducted alongside IFV for data collection. These tests took place across all four seasons, ensuring the functionality of Laykka in diverse environments. However, it has not undergone testing in a combat environment against or as a part of any troops. In this study, Laykka's operational capacity is analyzed in a virtual simulation experiment.

2.1 | Literature on Operational Capabilities and Effectiveness of UGVs

In the existing unclassified literature, limited research explores the operational capabilities and effectiveness of military UGVs in ground war scenarios. The lack of such studies is unexpected, considering the variety of known military UGVs actively being developed and used (Andersson 2021). Still, some papers examine the performance of military equipment through field experiments and simulations (Bielawski, Chmieliński, and Szagała 2018; Buttcher et al. 2016; Mansikka et al. 2021a, 2021b; Whitney, Fidock, and Gassdorf 2012). However, these papers concentrate on individual components or subsystems, such as cameras or control signals, rather than assessing the overall combat effectiveness of UGVs in real-world scenarios with human actors. Thus, the potential of military UGVs has not been thoroughly examined from a human perspective, such as the reactions and behavior of opposing forces' (OPFOR) troops to UGVs when fighting against them (Oskarsson et al. 2023; Visnevski and Castillo-Effen 2010). To the authors' knowledge, this study is the first unclassified and peer-reviewed study trying to measure combat performance and effectiveness of an expendable military UGV against enemy troops in either live or virtual simulation with human actors.

Evaluating the effectiveness of emerging defensive technologies, like self-destructing UGVs, presents challenges due to resource, safety and time constraints associated with real-world testing (Toptester 2023). Conversely, simulated-based testing methods may introduce discrepancies compared to real-world testing. Real-world testing should be started in the early stages of development to identify and address discrepancies in physical properties, environment, or other details that may lead to a lack of operational properties or anomalous behavior (Moses et al. 2015). Nevertheless, simulation experiments offer advantages despite potential differences from real-life tests (Moses et al. 2015). To evaluate the effectiveness of UGVs and their impact on troops, conducting repeated trials against armored vehicles in the real-world would be impractical and ethically questionable. Such risks can be eliminated using simulation environments for preliminary assessments. This study uses a virtual simulation environment, Virtual Battlespace 3 (VBS), to provide realistic virtual worlds for battlefield testing scenarios.

2.2 | Literature on Virtual Battlespace Simulation Environments in Military Setting

VBS, that is developed by Bohemia Interactive Simulations (Bohemia Interactive 2023), is employed for military training in over 50 countries, such as the United States, Germany, Norway, Poland, Romania, and Finland (Chmielewski 2020; Göllner et al. 2019; Kainuu Brigade 2017; Riotto 2021; Vesa and Gligorea 2020; Vold et al. 2018). For instance, a study by Bundeswehr investigated using VBS as an analytical tool to compare commissioned military equipment and equipment in the early stages of development (Buttcher et al. 2016). Moreover, Buttcher et al. evaluated realism and limitations of soldiers', vehicles' and weapons' models in VBS. The Australian Defense Science and Technology Organization has conducted a VBS test to assess the impact of a new vehicle on existing training and tactical practices (Whitney, Fidock, and Gassdorf 2012). The Polish army has used VBS to simulate mortar observation systems in analyzing a new grenade launching platform (Bielawski, Chmieliński, and Szagała 2018). The Swedish Defense Research Agency tested a simulated UGV in VBS using the Wizard of Oz method. The goal was to define which voice commands are necessary to operate the UGV autonomously in combat situations (Rantakokko et al. 2022). Recently, VBS has also been used in a combination with constructive simulation to analyze tactical responses to drones (Mittal and Fenn 2024).

The current open literature reveals a notable gap in understanding the use of UGVs as a part of defensive forces and their effect on OPFORs' movements. The defensive capabilities of UGVs and successful tactics of defending against UGVs are crucial areas that have not received sufficient exploration. Emerging technological capabilities have the potential to disrupt tactics as well as shift the balance of power on the battlefield (Mazal et al. 2019), which this study assumes the UGVs to be capable of. A practical method of verifying the disruption caused by UGVs is to include several UGVs in a virtual or live simulation. In this setting, the mission target of the OPFORs can be predetermined, and the movement of those troops can be assumed to continue toward the target unless a sufficient intervention is launched. This kind of assumption is feasible within a controlled simulation environment, whereas in real world scenarios, enemy behavior is neither fully predictable nor controllable. Such interventions could aim to stall the OPFORs, delaying their progress toward their target, or temporarily prevent them from reaching their target for a limited time.

2.3 | Overview of Virtual Simulation Experiment

This study presents a virtual simulation experiment regarding the operational capabilities of Laykka. The study involved modeling Laykka and its modules in VBS. The performance of Laykka was evaluated in four simulation scenarios where participants played the roles of simulated infantry troops, UGV operators, and observers. Armored reserve officer students (AROS) formed an OPFOR, ranging from small groups up to a company. In contrast, staff officers formed a defensive force (DEFFOR) with UGVs. Additional staff officers acted as higher-up officers to AROS and observed the experiment. The experiment aimed to determine if different numbers of UGVs with various modules could impede or stop the advancement of mechanized infantry units up to a company's primary combat unit. Such a unit contains IFVs and mechanized infantry. A full company would also include supporting units, for example, repair and supplement groups. Additionally, the effectiveness of the alternative UGV modules and their combinations was compared. Moreover, the user experience of UGVs' operators was evaluated, and areas of inadequate performance were identified. The experimental design enabled the assessment of the efficacy of different compositions of modular UGVs in stalling a range of OPFOR forces, along with UGVs' impact on battle outcomes.

2.4 | Structure of the Study

The study is structured as follows. In Section 2, methods, participants and their roles as well as means to evaluate the performance of UGVs used in the simulation experiment are presented. Section 3 introduces the results and analysis of the experiment. Section 4 discusses the results and delves into future research themes. Finally, concluding remarks are given in Section 5.

3 | Methods

In this section, the virtual simulation experiment is described. First, missions are outlined in four simulation scenarios. Second, the virtual simulation environment, participants and their roles as well as the course of the experiment are discussed. Finally, performance measures and scores are introduced to assess the outcomes of combat scenarios analyzed in the experiment.

The scenarios include a small part of a whole conflict between attacking mechanized infantry forces and a defending infantry grouping. For example, aerial defense, electronic warfare (EW) and other possible new technologies are not included beside the UGVs afforded to DEFFOR. A single operator controlled all of the UGVs in each scenario. It was assumed that there would likely be limitations to the operators' capability to utilize multiple UGVs during a conflict, as the operators commonly have only one device that they are controlling at a time. Additionally, it was assumed that attacking forces would react differently if they had prior knowledge about a new UGV in the area of attack. Thus, three test groups did not have prior knowledge about UGVs and a control group did. Specifically, it was thought that the UGVs' effectiveness to stall OPFOR would be diminished in the control group. The limitations ensure consistent test conditions and make data collection more manageable, which is particularly important for early-stage testing before committing to larger-scale trials.

3.1 | Missions of Scenarios

The experimental study encompassed a series of intricately crafted scenarios labeled as "Antitank," "Recon," "Loitering mine," and "Mixed modules" scenarios. The missions of each scenario for both OPFOR and DEFFOR are presented in Table 1 including numbers of UGVs and OPFOR troops. Furthermore, Figure 2 visually depicts the missions given to OPFOR and DEFFOR for each scenario on the overview map. These scenarios included elements of convoy march, attack, and defense. The mission of DEFFOR was to engage with reactive, defensive tactics in all scenarios, but OPFOR had distinct missions in each scenario. In the "Anti-tank" scenario, OPFOR was tasked with launching an aggressive assault on designated territory and eliminating any encountered OPFORs. They were instructed to get through the opening rapidly to reach cover in the forest, from where they would continue the advance. In the "Recon" scenario, OPFOR was required to execute an attack along a predetermined route while successfully clearing the target area. They were to stay between the lake and middle of the clearing where there was a risk of overlapping with neighboring platoons' attack lines and lines of fire. Additionally, OPFOR was instructed to capture a strategically important hill marked on the map and remain prepared for any potential enemy counterattacks. In the "Loitering mine" scenario, the OPFOR's mission was to march along a planned route, following the main road. OPFOR was also expected to be ready to launch subsequent attacks and effectively clear its target area until reinforcements arrived. The "Mixed modules" scenario is similar to the "Recon" scenario, emphasizing diverse aspects of combat proficiency among participants. The route was similarly restricted by the lake and middle of the clearing in the east. The main difference between the contesting forces is that OPFOR is bigger and matches the strength and size of the primary combat units of the mechanized infantry company. Without the UGVs, DEFFOR would have minor ability to affect OPFOR's advance in any of the scenarios.

3.2 | DEFFOR

DEFFOR utilized simulated UGVs, that is, simulated Laykkas, in all four scenarios, each equipped with specialized modules for different tasks. In each scenario, there were six simulated soldiers to protect the UGV operator, who was also described as a simulated individual soldier controlled by the human operator. The soldiers formed a defensive perimeter around the operator and remained passive. Thus, they would not engage if they were not

TABLE 1 | The description of the scenarios used in the experiment including numbers of UGVs and OPFOR troops.

Scenario	Mission	DEFFOR	OPFOR
"Anti-tank"	**OPFOR**: Attack and clear opposing forces from the target area. **DEFFOR**: Defend reactively.	3 * UGVs with Anti-tank—module. 7 * Infantry troops.	Mechanized infantry group. 2 * IFVs11 * Infantry troops.
"Recon"	**OPFOR**: Attack along a planned route and clear the target area. Be ready to fend off enemy forces. **DEFFOR**: Defend reactively.	2 * UGVs with a reconnaissance module. 7 * Infantry troops.	Mechanized infantry platoon, including artillery and mortar fire. 4 * IFVs 16 * Infantry troops.
"Loitering mine"	**OPFOR**: March along the planned route and be ready to attack and clear the target area. When captured, hold the area until reinforcements arrive. **DEFFOR**: Defend reactively.	6 * UGVs with a loitering mine- module. 7 * Infantry troops.	Mechanized infantry platoon, including artillery and mortar fire. 6 * IFVs 31 * Infantry troops.
"Mixed modules"	**OPFOR**: Attack along a planned route (same as the "Recon" scenario) and capture the target area. Be ready to fend off enemy forces. **DEFFOR**: Defend reactively.	2 * UGVs with Anti-tank—module. 2 * UGVs with a reconnaissance module. 6 * UGVs with a loitering mine- module. 7 * Infantry troops.	Mechanized infantry company's primary combat units, including artillery and mortar fire. 8 * IFVs 56 * Infantry troops.

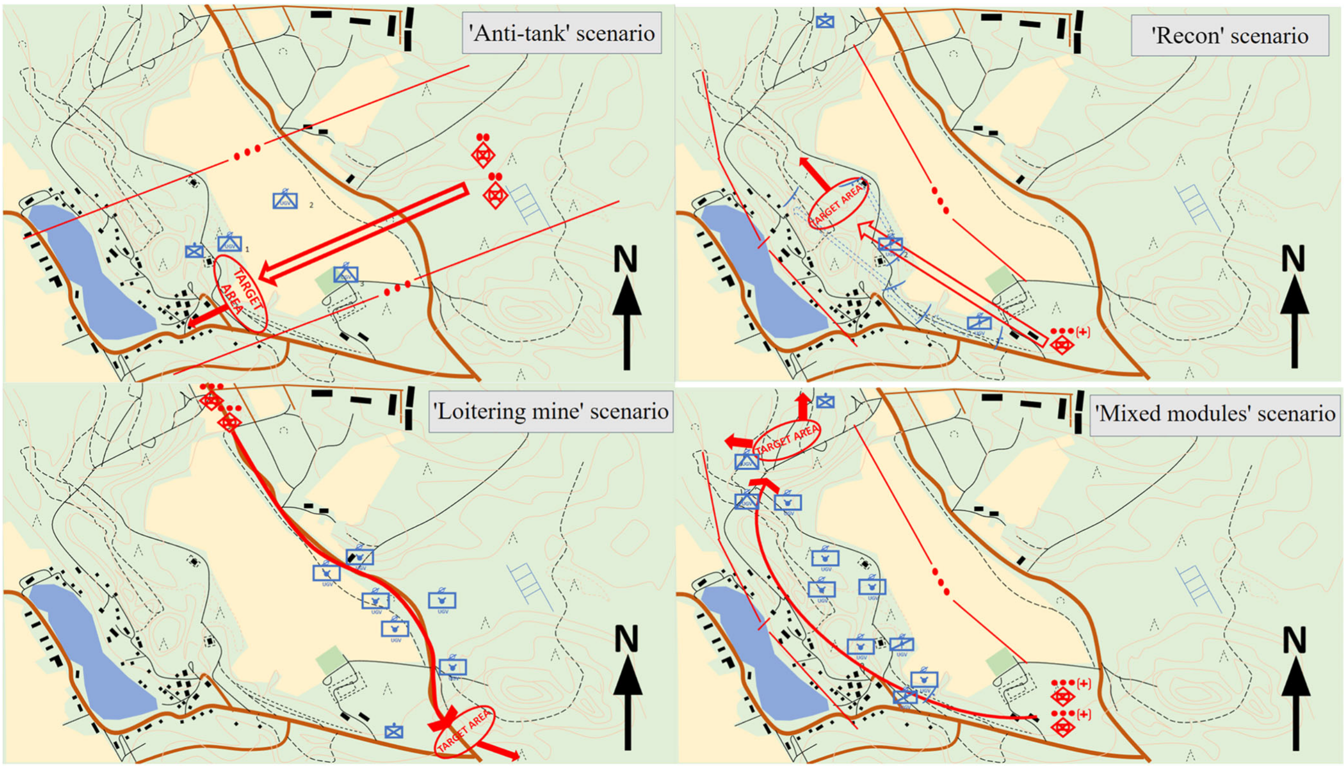

FIGURE 2 | The missions given to OPFOR and DEFFOR in each scenario on the overview map. The positions of DEFFOR's operator and UGVs are marked with blue and the OPFOR troops initial position, attack route, and target area are marked with red. The size of OPFOR increased from two IFVs and 11 infantry troops to eight IFVs to 56 infantry troops. [Color figure can be viewed at wileyonlinelibrary.com]

attacked directly. The six simulated soldiers were controlled by VBS's automation only.

In the "Anti-tank" scenario, the UGVs were equipped with an anti-tank module featuring a turret with four rocket-propelled grenade launchers to eliminate armored vehicles from a vantage point. In the "Recon" scenario, the UGVs used a reconnaissance module to support and divert attention toward deceptive targets using an assault rifle. In the "Loitering mine" scenario, modules contained anti-tank mines. The UGVs with loitering mine modules were designed to incapacitate or eliminate armored vehicles by detonating the attached mine and self-destructing. Finally, in the "Mixed modules" scenario, DEFFOR's UGVs utilized all three modules to repel OPFOR. These scenarios as well as the compositions of OPFORs' troops and DEFFORs' UGVs are presented in Table 1.

The numbers of UGVs in each scenario were chosen to be equivalent to the weaponry force that a commonly occurring defensive grouping would be equipped with. For example, one anti-tank module which carries four light anti-tank weapons (LAW) would equate to two soldiers carrying two LAWs each. The DEFFOR group of three UGVs in the anti-tank scenario would then be roughly equivalent to a group of six soldiers. Equivalent human groups could be expected to cause some damage and slow down the advance of OPFOR to some extent, but they would be unlikely to incapacitate the OPFOR in the scenarios. They could have a better chance if they had fortifications, such as trenches or minefields. Positioning UGVs in places and formations where an attacker would not expect any defending forces, stalling forces, or any other obstacles might create enough disruptions. This could discompose the plan of attack, giving DEFFOR the required advantage in force and fire power to stall a mechanized infantry attack.

3.3 | OPFOR

OPFOR utilized mechanized infantry units. They are infantry troops equipped with IFVs or other armored vehicles for transport and combat. Military branches use different kinds of units, each with its own composition. In the experiment, there were three different sizes of OPFOR: group, platoon, and company's primary combat units, see Table 1.

In the "Anti-tank" scenario, OPFOR had a mechanized infantry group consisting of two IFVs accompanied by 11 infantry troops. This small yet agile unit can easily maneuver through various terrains. In the "Recon" and "Loitering mine" scenarios, OPFOR had a mechanized infantry platoon that consisted of four IFVs working together alongside 16 infantry troops. With increased numbers and firepower, this unit possesses more outstanding offensive capabilities as it engages enemy forces on the battlefield. In the "Mixed modules" scenario, OPFOR had the most significant formation among mechanized infantry units which are the company's primary combat units. It comprises eight IFVs teamed with a force consisting of 56 infantry troops. This unit possesses superior mobility due to its numerous vehicles and has access to artillery and mortar capabilities, significantly enhancing its effectiveness during combat scenarios. In addition to their robust vehicle resources, all mechanized infantry units boast diverse equipment and indirect fire capabilities, ensuring they are well-equipped for any mission.

3.4 | Virtual Simulation Environment

As discussed in the introduction, the experiment employed a virtual simulation environment VBS3 developed by Bohemia Interactive Simulations. VBS3, referred to simply as VBS, includes various ready-made equipment and an advanced, realistic physics engine. The experiment used some IFVs' and weapons' models provided by the developers of VBS. The physics engine manages, for example, movement dynamics of all entities in simulation in varying terrains and weather providing close to realistic battlefield experience with explosions, injuries, and even simulated soldiers' deaths. VBS also allows recording scenario events in an interactive rendering of after-action review (AAR), where a viewer can move freely to see events from all points of view. Some key statistics, such as numbers of rounds fired and casualties, can be exported without additional scripting.

Regarding the experiment of this study, Virtual Training Conscripts of Armored Brigade in the guidance of Finnish Defense Forces (FDF) Chief of Virtual Training rendered combat environments, Laykka and its command terminal into VBS. The scenario area had been previously reconstructed by them to replicate the training grounds utilized by AROS and operators in live exercises, ensuring readiness for all participants. A familiar scenario area offers an immersive setting for the experiment based on real-life buildings, roads, vegetation and environmental features such as typical weather encountered during summertime operations in a Nordic country.

3.5 | The Integration of Laykka UGV into VBS3

The VBS model of Laykka (Figures 3 and 4) was created with guidance by the authors of this study to match accurate technical details and properties (dimensions, weight, speed, steering radius, controls, explosives, and armaments) of Laykka. The creation and validation process of a model into VBS used by the FDF is described in Figure 3. Unlike OPFOR IFVs, Laykka was destroyed if it was hit once with any ammunition fired by infantries' or IFVs' weapons. The lethality of Laykkas' modules were in accordance with the VBS's generic weapon models with corresponding accuracy and ammo penetrability. This means that the reconnaissance module could not do any significant damage to an IFV by shooting it, whereas the anti-tank module could. Laykkas' explosive power was simulated to be equivalent to 20 kg of TNT and its shrapnel radius was constrained to match that of a 120 mm mortar grenade. These adjustments to the explosion directed the explosion similarly to the explosives in the real Laykka. Such an explosion can destroy an IFV at point blank range and damage nearby IFVs.

Laykkas' command terminal was simulated as a laptop, as seen in the top left bottom corner in Figure 4. The command terminal needed to be activated in the game to choose and control the UGVs. After activation, the operator's computer screen displayed the view from the default camera (Figure 4). The operator could switch between front, rear, thermal and weapon cameras (Figure 4), all of which had similar fields of view as their real counterparts. Additionally, a compass and a mini map

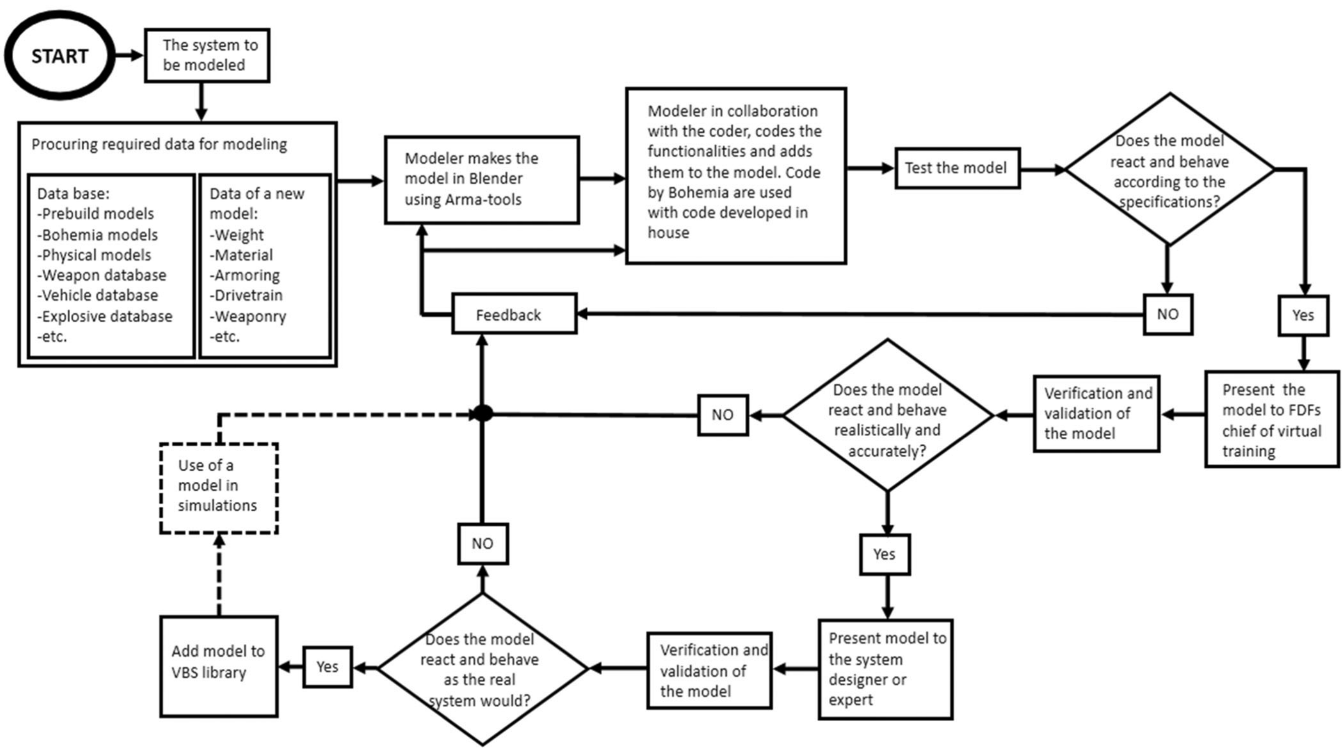

FIGURE 3 | The framework of the Finnish Defense Forces for the creation and validation of new simulation models into VBS.

displaying only the GPS location of the UGV in question could be opened as an adjustable pop-up frame. An operator could not switch to a third person view of the UGV. The view options were restricted to those included in the actual user interface. The model of Laykka was steered with an identical gamepad controller and had the same controls as the real Laykka. The physical game controller was held by the operator.

An operator was able to manage and switch between Laykka units assigned to the control terminal but was limited to having one unit active at a time. Those Laykka units not in active use were passive and did not transmit any signals, stimuli, or relay information about approaching OPFOR. Consequently, the operator was expected to have to maintain situational awareness by switching the Laykka in active use. The passivity of the inactive UGVs and having access to only one unit at a time are expected to reduce the operators' effectiveness, compared to a situation where the number of operators matched the number of UGVs. Initially, more UGVs per operator might increase the effectiveness of an operator to a point, after which diminishing returns are probable. This was expected to happen because the operator could be distracted by multiple options and has to keep track of several UGVs during a developing battle situation. A larger number of UGVs also increases the probability of choosing a different UGV than intended.

FIGURE 4 | Top picture represents the VBS visualization of the Laykka models including anti-tank, reconnaissance and loitering mine modules positioned from left to right. In the leftmost side picture, a command terminal is situated on the ground in front of an UGV operator. Three views from Laykka's cameras are in the bottom picture. The leftmost picture displays the view from the front camera, middle one from the reconnaissance module's rifle scope camera and right one from the thermal camera. [Color figure can be viewed at wileyonlinelibrary.com]

The functionalities, controls and the view on the operator's screen were very close to the actual user interface, including the most relevant functionalities of the real command terminal. The simulation team and observers also had an opportunity to confirm the accuracy and functionality of the Laykka model before conducting the experiment. These observers were the same that observed the simulation experiment. They were familiar with Laykka, and therefore they were able to assess the integrity of the Laykka model in terms of lethality, survivability, and usability.

3.6 | Participants and Their Roles

The simulation experiment involved the participation of AROS, operators, and observers. Ranks, roles, and combat sides of the participants are shown in Table 2. AROS ($n = 26$) were divided into four homogenous OPFOR study groups (Group 1, Group 2, Group 3, and Control group) of equal conscript time and similar military branch backgrounds. These groups had similar tactical, operational, and specialized knowledge regarding scenario-wise mission requirements. All AROS had prior experience using VBS, and they were proficient enough to operate it to complete their missions. The groups comprised six to eight AROS forming mechanized infantry units in VBS, with extra virtual troops to fill in all missing OPFOR roles. The overall OPFOR size was the same between groups but did vary between scenarios.

Two staff officers participated as DEFFOR operators (Operator 1 and Operator 2) controlling UGVs. A single operator operated multiple UGVs consecutively in each scenario. Their expertise as tank officers allowed them to determine how best to employ defensive tactics to hinder enemy progress. Both had prior experience using VBS.

Seven observers consisted of military personnel. They participated in the experiment to assess whether VBS could be a viable tool in testing systems being developed or new military systems, and to ensure that the simulation model of Laykka is realistic and not over performing. Their objective was to observe the reactions, activity and tactics of OPFOR and to determine other potential uses beyond existing applications with the existing modules of Laykka. The observers also played a crucial role by acting as higher-up leaders for AROS. The observers regularly checked in with the OPFOR's unit leaders to gather updates on the OPFOR's status and any significant events OPFOR encountered. This practice ensured that AROS self-assessed capability to continue with the mission was regularly evaluated objectively by a higher staff officer.

TABLE 2 | The rank, role and combat side of each participant.

Description	AROS	Operators	Observers
Rank	Army reserve officer students	Staff officers	Higher staff officers
Role in the experiment	Controlled simulated troops of opposing forces	Controlled simulated UGVs' operators of defending forces	Acted as higher up officers for opposing forces and were the observers of the experiment
Side of combat	OPFOR	DEFFOR	OPFOR/Neutral

3.7 | Procedure

The agenda and schedule of the experiment day are presented in Figure 5. Operators 1 and 2 of DEFFOR were assigned two OPFOR groups each, one for the morning session and one for the afternoon session. Before the experiment began, the operators had 4 h of training in maneuvering the simulated UGV in VBS. They received practical instructions on preferred and effective UGV tactics for each module. The operators completed all four scenarios with their first group and continued with their second group after a break according to Figure 5. In total, information about 16 instances of scenarios were gathered.

AROS groups received a mission briefing before each scenario. In these briefings, a unit leader was appointed, who then received the mission objective including the target area for the scenario at hand. Each scenario continued until an AROS group reached its target area or the group were incapacitated due to casualties, damaged equipment, or depleted ammunition. After each scenario, the AROS groups and the operators filled out respective questionnaires, while the observers watched recordings of simulation events from the VBS-generated AAR-recording. After completing all scenarios, each group was interviewed and asked to elaborate on events and their responses to questionnaires as well as observers' questions.

The three study groups (Group 1, Group 2, and Group 3) had no precise information on the enemy's size or structure. The lack of information meant that they had no cause to suspect encountering anything out of the ordinary but still had the uncertainty of the battle ahead. The control group was provided with an additional briefing about simulated UGVs and their capabilities. However, they were not given any advice in case they encountered UGVs. All OPFOR groups were separated, and no communication between the groups was allowed during the experiment. In case some communication between the

Session	Agenda	
MORNING	**Operator 1 vs. Group 1** Before each scenario • Mission briefing for AROS After each scenario • AROS questionnaire • Operator questionnaire • AAR review by observers Order of scenarios: 1. 'Anti-tank' 2. 'Recon' 3. 'Mixed modules' 4. 'Loitering mine'	**Operator 2 vs. Group 2** Before each scenario • Mission briefing for AROS After each scenario • AROS questionnaire • Operator questionnaire • AAR review by observers Order of scenarios: 1. 'Recon' 2. 'Loitering mine' 3. 'Mixed modules' 4. 'Anti-tank'
	Group interview	Group interview
MIDDAY	Break	
AFTERNOON	**Operator 1 vs. Group 3** Before each scenario • Mission briefing for AROS After each scenario • AROS questionnaire • Operator questionnaire • AAR review by observers Order of scenarios: 1. 'Loitering mine' 2. 'Anti-tank' 3. 'Mixed modules' 4. 'Recon'	**Operator 2 vs. Control Group** UGV briefing for AROS Before each scenario • Mission briefing for AROS After each scenario • AROS questionnaire • Operator questionnaire • AAR review by observers Order of scenarios: 1. 'Anti-tank' 2. 'Recon' 3. 'Loitering mine' 4. 'Mixed modules'
	Group interview	Group interview

FIGURE 5 | The agenda and schedule of the experiment day.

OPFOR groups would happen despite separation, the simulations of the scenarios were conducted in varying orders (see Figure 5) to preserve some elements of surprise. The operator and the group were in the same room for the duration of the experiment. They wore headsets to communicate with their team members and to facilitate immersion. The experiment room is shown in Figure 6.

3.8 | Performance Evaluation of UGVs

The DEFFOR's effectiveness to stall OPFOR with UGVs was evaluated in several ways. The primary performance measure was the DEFFOR's ability to stall OPFOR. It was rated according to two binary questions: (1) was OPFOR incapacitated and requiring significant replenishment to continue their mission, and (2) was OPFOR able to reach the target area. OPFOR's incapacitation was determined by unit leaders and their higher-up leader, that is, an observer. The OPFOR's unit leader and the observer periodically contacted each other for routine reporting on the situation, the status of OPFOR and possibly requesting replenishment. DEFFOR was successful in stalling OPFOR if they were deemed incapacitated—whether or not OPFOR reached their target area. However, DEFFOR failed to stall the advance of OPFOR if OPFOR reached its target area and maintained its operational capacity.

Secondary measures were numbers of casualties and losses of both sides at the end of each scenario, that is, the end-states of DEFFORs' UGVs as well as of OPFORs' IFVs and troops. The end-states of DEFFORs were classified as destroyed, killed, operational and used in the following way: If OPFOR destroyed a UGV, it was classified as "destroyed," whereas an intentionally self-destroyed UGV was classified as "killed." If a UGV was used by an operator but not destroyed, it was classified as "operational," and "unused" if it was not destroyed or used. The classification was used to evaluate the proportion of UGVs lost through enemy fire and killed to damage or destroy enemy forces.

These end-states were determined manually from the AAR-recordings. The end-states of OPFOR were classified for IFVs and infantry troops. The end-states of the IFVs had three categories: those that were unaffected by DEFFOR and could continue the mission were "intact," those that were damaged and had their combat abilities reduced were "damaged," and those that were destroyed by DEFFOR were "destroyed." Similarly, the end-states of infantry troops were "intact," "wounded," or "killed." OPFORs' end-states were obtained from VBS-generated statistics.

FIGURE 6 | The simulation room used for experimenting with an operator (front left) and a participating group in the background. [Color figure can be viewed at wileyonlinelibrary.com]

AROS scored their own performance and battle situation with a questionnaire. It included five-point Likert scale statements and open questions. AROS were asked to assess whether they achieved the goal of their mission and to estimate the size of enemy troops. These questions were chosen to measure the self-assessed performance of AROS and to verify if the use of UGVs would obscure DEFFOR's location and size.

Operators also scored their own performance with a questionnaire. Just like the AROS questionnaire, it included five-point Likert statements and open questions. The operators were asked to assess the fulfillment of mission goals measured with a mission score as well as to rate the general satisfaction with alternative combinations of UGVs and modules measured with a UGV score. In addition, they evaluated UGVs' technical aspects, that is, usability, controllability, and terrain traversability. The questions to the operators were selected to measure their self-assessed performance and to quantify the user experience with the UGVs and alternative modules.

Lastly, the battle situations were observed by observers. They were especially asked to evaluate how battles unfolded and the causes-and-effects of combat events. Additionally, the observers assessed UGVs', AROS', and operators' performance. The observers also considered what other technical capabilities they deemed necessary and what kind of other uses for UGVs they thought would be useful after seeing UGVs in use. The observation was carried out during the experiment as well as from the AAR-recordings.

4 | Results

The results of the experiment are described in this section. All 16 simulated scenarios were completed according to predetermined plans and schedules. On average, each scenario lasted approximately 13 min, with the shortest lasting 2 min and the longest almost reaching 24 min. R (The R foundation 2023) and RStudio (RStudio 2020) were used in data analysis and generating graphics. The packages readxl (Wickham and Bryan 2023) and tidyverse (Wickham et al. 2019) were used in importing and cleaning data, and graphics were generated with ggplot2 (Wickham et al. 2016).

4.1 | DEFFOR's Ability to Stall the Advancements of OPFOR

The DEFFOR's capability to stall OPFOR's progress using UGVs is considered next. Simulation instances where DEFFOR was able to incapacitate or prevent OPFOR from reaching its target position are presented in Table 3. In the "Anti-tank" scenario, Group 3 was the only one to reach the target area without being incapacitated, which means that DEFFOR was unsuccessful in stalling OPFOR. The remaining groups were incapacitated before reaching their target area, and thus they were stalled by DEFFOR. All OPFOR groups were incapacitated in the “Recon” and “Loitering mine” scenarios. Group 1 was able to reach its target area without major losses in the “Recon” scenario, but it had depleted their ammunition to the point of becoming easy targets without ammunition resupply, rendering them susceptible to adversary exploitation. In the “Loitering mine” scenario, Group 2 experienced heavy losses and would have been unable to defend their position. Conversely, Group 3 would have been able to defend the target area, but they would have not been able to proceed further without personnel, ammunition, and equipment replenishment. However, all OPFOR groups were incapacitated in the “Loitering mine” scenario, even though Groups 2 and 3 reached the target area before incapacitation. For the “Mixed modules” scenario, only Group 2 accomplished the mission while sustaining full force by eliminating the DEFFOR operator with artillery fire. The other groups failed on both counts. The control group was not more effective against the UGVs than other groups.

4.2 | End-States of DEFFOR and OPFOR

Next, the DEFFOR's use of UGVs is discussed by examining the end-states of UGVs. The numbers and proportions of unused, operational, intentionally killed UGVs, and UGVs destroyed by the enemy are displayed in Figure 7. Notably, only in two instances, that is, against Group 4 in the “Loitering mine” scenario and Group 2 in the “Mixed module” scenario, not a single UGV was intentionally killed. Out of those instances where OPFOR was incapacitated, 71.8% of the UGVs were utilized, meaning that not all available UGVs were needed to stall OPFOR. Out of the UGVs used, 56.9% were intentionally killed, fulfilling their designed purpose. This result would indicate that approximately four UGV units are needed for three to be intentionally killed.

The outcome of the “Mixed module” scenario is interesting, since OPFOR had the full force of the primary combat unit for their attack. They had 56 infantry troops and 8 IFVs against 10 UGVs, which was the largest scenario of power imbalance in favor of OPFOR. In three instances out of four, DEFFOR was able to incapacitate the OPFOR's company's primary combat unit. Incapacitation required a median of six UGVs with various modules. In the fourth instance (Group 2 in the “Mixed module” scenario), no UGVs were used because the operator was eliminated by artillery fire, and thus there was no hindrance to the advancement of OPFOR.

The extent to which DEFFOR incapacitated OPFOR is analyzed by examining the battle damage inflicted on OPFOR's IFVs and infantry. Battle damage inflicted on vehicles and crews needs to be considered together because damage to either can incapacitate both of them (Wainstein 1986). Figure 8 presents proportions and numbers of IFV's end-states, while Figure 9 describes the same for infantry. Overall, 38.0% of IFVs were destroyed by UGVs, 13.6% were damaged, and the remaining 48.4% remained

TABLE 3 | DEFFOR's ability to stall OPFOR by rendering it incapacitated and requiring significant replenishment or preventing it from reaching the target area.

	“Antitank” scenario		“Recon” scenario		“Loitering mine” scenario		“Mixed modules“ scenario	
OPFOR	**Incapacitated**	**Prevented from reaching target area**	**Incapacitated**	**Prevented from reaching target area**	**Incapacitated**	**Prevented from reaching target area**	**Incapacitated**	**Prevented from reaching target area**
Group 1	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Group 2	Yes	Yes	Yes	Yes	Yes	No	No	No
Group 3	No	No	Yes	Yes	Yes	No	Yes	Yes
Control group	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

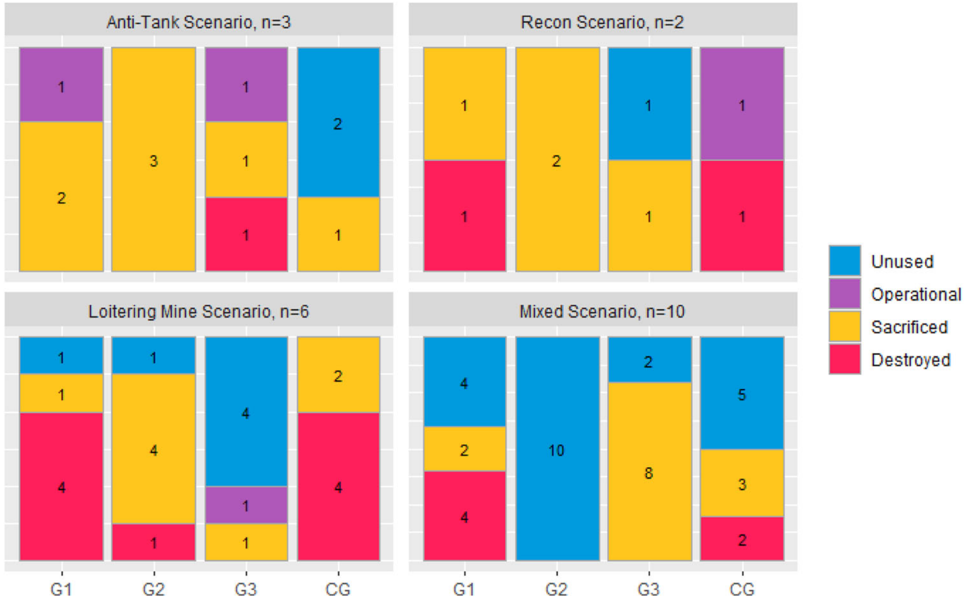

FIGURE 7 | The proportions and numbers of the unused, operational, killed and destroyed UGVs at the end-states of the scenarios for OPFOR groups 1 (G1), 2 (G2), and 3 (G3) as well as for the control group (CG). The total number of UGVs in the scenario is denoted by *n*. [Color figure can be viewed at wileyonlinelibrary.com]

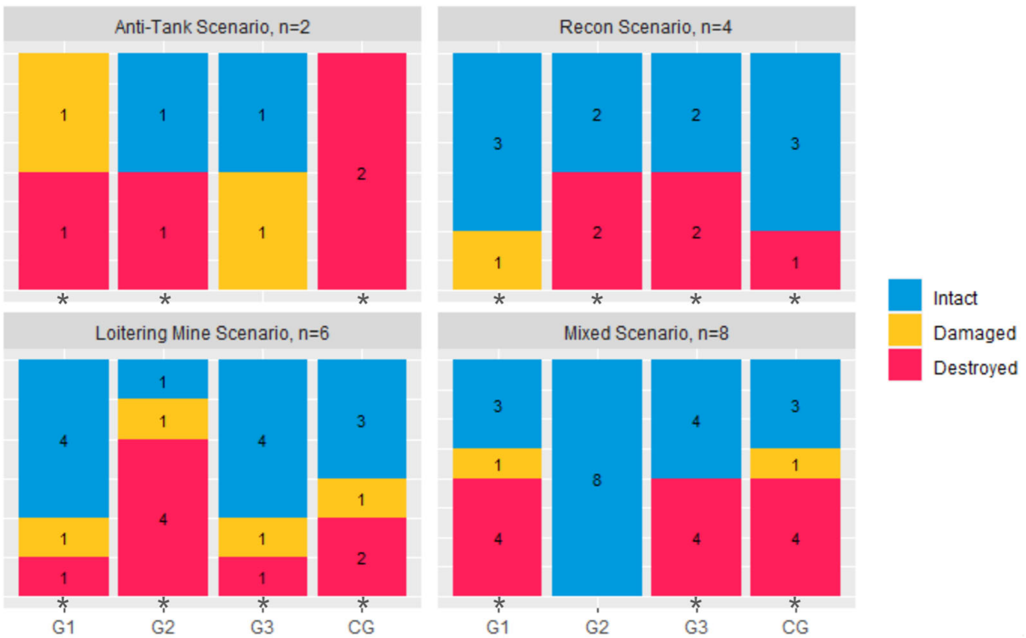

FIGURE 8 | The proportions and numbers of intact, damaged, and destroyed OPFOR's IFVs at the end of each scenario. The total number of IFVs in the scenario is denoted by n and incapacitation of OPFOR by *. [Color figure can be viewed at wileyonlinelibrary.com]

intact. Approximately 53.3% of infantry were killed, 5.3% were wounded, and 41.4% remained intact. The overall inflicted battle damage, 51.6% of IFVs and 58.6% of infantry, was enough to cause difficulties to OPFOR in reaching its target area in 11 instances out of a total of 16 instances as pointed out in Table 3 as well as denoted with * in Figures 8 and 9.

4.3 | AROS's Experience Fighting against UGVs

The self-evaluated performance of AROS groups was somewhat unsatisfactory which was indicated by its mean of 2.4 (SD = 1.2). No apparent differences were perceived in the OPFOR control group's performance compared to the other OPFOR groups. AROS were also asked to estimate the size of enemy troops they had contact with. The estimated troop sizes are depicted in Table 4. Individuals exhibited considerable disagreement within groups indicated by large standard deviations and over-estimated the enemy size rather consistently. The control group had lower estimates and seemed to assume that they encountered a smaller enemy group or only UGVs without an accompanying unit. Group 2 had especially low estimates of the enemy troop size in Scenario 4 which might again be explained by OPFOR eliminating the DEFFOR's operator by chance with artillery fire.

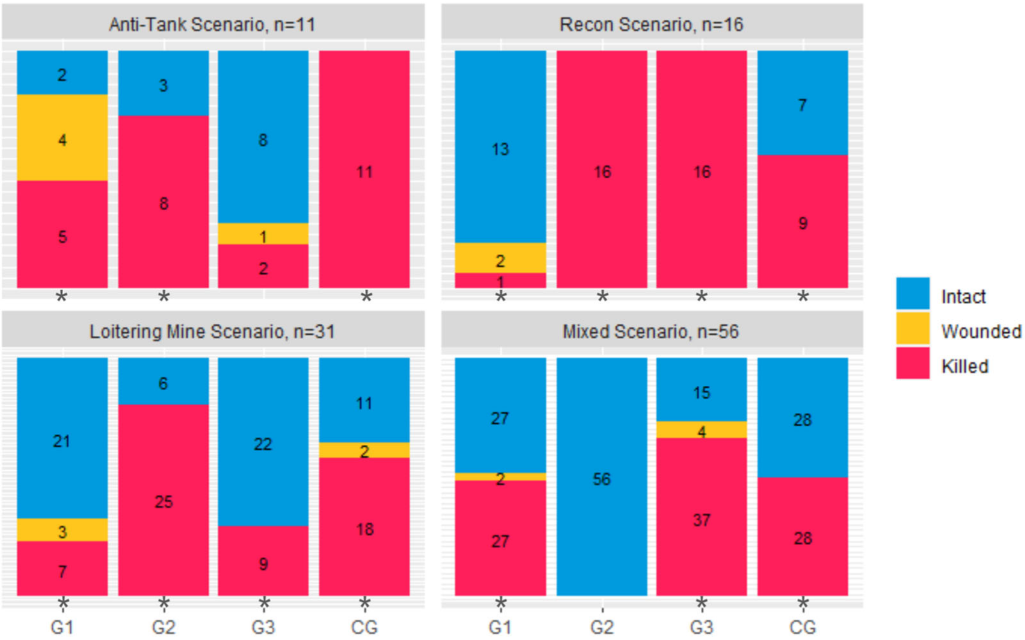

FIGURE 9 | The proportions of intact, wounded, and killed OPFOR infantry troops at the end of each scenario. The total number of infantry troops (11–56) in the scenario is denoted by *n* and incapacitation of OPFOR by *. [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 4 | The means and standard deviations of enemy troop sizes estimated by the AROS groups in all scenarios.

	Antitank		Recon		Loitering mine		Mixed module	
Scenario	Mean of enemy size	Standard deviation	Mean of enemy size	Standard deviation	Mean of enemy size	Standard deviation	Mean of enemy size	Standard deviation
Group 1	2.6	2.4	10.1	8.6	2	1.3	12.4	12.9
Group 2	20.4	12.5	12.2	13.2	8.7	9.7	1.6	2.3
Group 3	10.8	10.6	15.5	20.5	20.0	14.1	12.3	11.0
Control group	2.8	2.4	2.7	2.0	5.3	2.6	3.7	0.8
Aggregated mean	9.1		9.1		6.7		7.7	
Number of UGVs	3		2		6		10	

4.4 | DEFFOR Operators' Experience of Using UGVs

DEFFOR operators felt they were more successful in their defense missions than OPFOR. Their self-evaluated performance was somewhat satisfactory (aggregated mean = 3.6, aggregated SD = 1.1). The operators perceived themselves as most successful in the "Recon" and "Mixed modules" scenarios. They were also rather consistently satisfied with the UGV's performance as the mean of the UGV score was 3.73 with aggregated SD = 1.1. The mission and UGV scores are presented in Table 5. In particular, the operators recognized that the loitering mine module employed in the "Loitering mine" scenario was an efficient tool for countering mechanized infantry units which was pointed out by the highest UGV score (4.0). The "Loitering mine" module had effective explosive capabilities, rendering an IFV damaged or destroyed. In the "Recon" scenario, the reconnaissance module successfully hindered the advancement of OPFOR and altered offensive strategies of OPFOR by diverting its attention. This phenomenon likely explains the highest self-assessed mission score (4.1). The performance of the anti-tank module in the "Anti-tank" scenario (3.5) was nearly that of the reconnaissance module (3.9). Similarly, the anti-tank module disables or destroys the OPFOR's IFVs. Although the UGV score in the "Mixed modules" scenario was lower, open questions revealed that applying together all three modules was perceived to render superior effectiveness compared to using just one type of module, especially when used with a self-destruct capability. In the "Mixed modules" scenario, a group of six simulated UGVs could compel OPFOR to change the direction of their attack or completely halt their advance.

The UGVs' usability, controllability, and ability to traverse terrain were mostly rated positively (Figure 10). As an exception, the anti-tank module in the "Anti-tank" scenario proved more complicated to operate than the other two modules, because Laykka's turret could not be turned independently from the chassis. This limitation meant that the whole UGV had to be turned when

TABLE 5 | The means and standard deviations of the mission and UGV scores evaluated by the operators.

	Mission score		UGV score	
Scenario	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**
"Anti-tank"	3.5	1.0	3.5	0.5
"Recon"	4.1	1.0	3.9	1.4
"Loitering Mine"	3.1	0.3	4.0	0.0
"Mixed Modules"	3.8	1.9	3.5	1.7

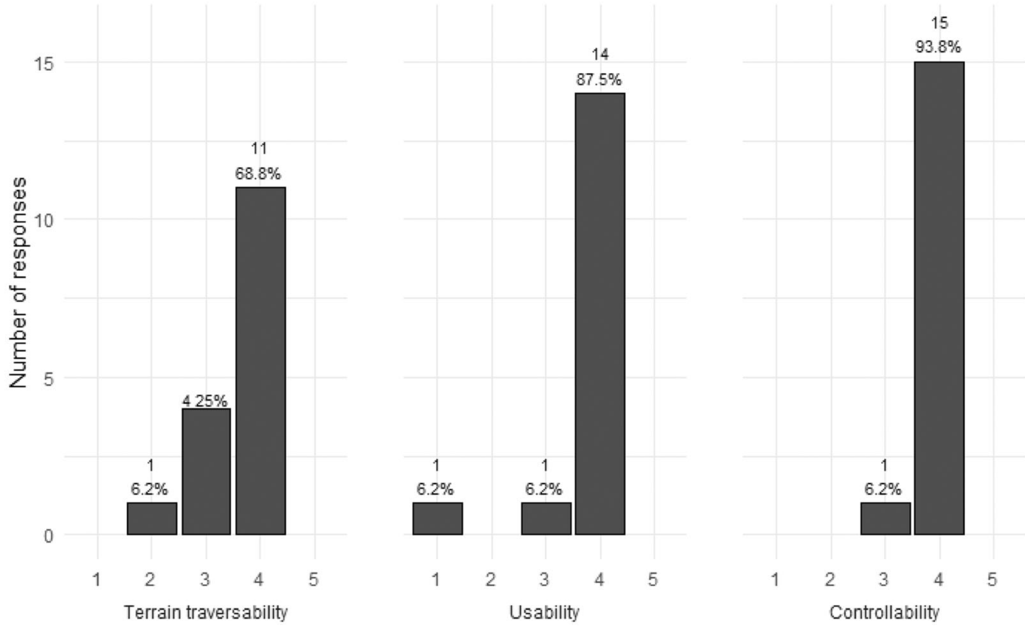

FIGURE 10 | The operators' evaluation of UGVs' terrain traversability, usability, and controllability. The responses (1–5) are ratings on a scale from poor to excellent. The pooled number of responses of the operators is 16.

aiming at a target. Responses to open questions revealed that the UGV's top speed and slow camera switching speed were perceived to limit its usability. Likely, the usability and terrain traversability scores were affected by these shortcomings. Additionally, it was mentioned that the compact dimensions of the UGV allowed the operators to exploit the OPFOR IFVs' limited aiming capabilities and narrow field of view.

4.5 | Observer Assessments

The observer assessments were in line with the results above and supports the findings discussed previously. The small dimensions of Laykka made it easy for them to stay unnoticed in forested areas and roadsides. Consequently, if a UGV was spotted, there was often insufficient time for counteraction. This effect of delayed counteraction was compounded by the IFV's turret weaponry having limited ability to turn into low-angles and fire at small and nearby targets. At times, a targeted IFV would separate from the formation by driving backward quickly to avoid destruction by an approaching UGV. The unit leader of OPFOR found this erratic behavior perplexing as it disrupted battle formations. To be able to proceed, OPFOR needed to regroup. Effective communication facilitated maintaining order and combat effectiveness within some OPFOR groups. However, most of the time AROS could not accurately estimate the size and location of enemy troops (Table 4). In some cases, AROS could not even determine what had caused their forces' destruction which led them to speculate that it may have been mortar fire or a mine.

The observers also noted that growing awareness of UGVs instigated some stages of fear and extra caution in OPFORs. The caution was exhibited by slowing down the advance of OPFORs and showing over-vigilant supervision of their surroundings. The unit leaders grew anxious of taking hasty actions. This alertness surfaced in the communications between IFV crews as they would report seeing UGVs in places without any. Some members of OPFOR even opened fire at empty locations, wasting ammunition. When engaging a UGV, sometimes the IFV crews would shoot long, unpurposeful, and inaccurate spurs of fire in its general direction in the hope of destroying it and inadvertently depleting ammunition storages of IFVs. By doing so, the IFV crews could not continue the attack without ammunition refill, leaving the OPFOR group practically defenseless.

5 | Discussion

5.1 | On Hypothetical Scenarios Without Laykkas

The effectiveness of Laykka was not compared to DEFFOR without UGVs in this study. Performing such a comparison would not be entirely unambiguous, as in the scenarios DEFFOR consisted of just one active soldier: the UGV operator. This active soldier was protected by six passive soldiers controlled by VBS's automation, but they were programmed to engage only if they were under attack. Both the soldiers and UGVs were all unprotected by fortifications, having cover only from the surroundings. The active soldier controlled a varying number of UGVs, and had to spread their attention to surveilling events of the whole battle. As seen during the experiment, some UGVs could remain unused if the operator did not have enough time to use them, or if they overcommitted to just a few. None of the UGVs had any automated functionalities. Therefore they remained passive if the operator did not use them at the time. If the UGVs of DEFFOR were replaced by humans, the number of humans would have to be adjusted to account for the larger amount of weaponry a UGV could carry to keep the number of weaponry constant. Each of those soldiers would be active and the group would be able to spread out, exchange information and act simultaneously, which might give them the required advantages over a single active soldier using multiple UGVs. A human group would also have to make more preparations to minimize casualties and to gain some advantages over an overpowered attacker. These preparations are discussed further in a later paragraph.

An attacker could reasonably be assumed to have some advantage over a defender before committing to an attack. Therefore, OPFOR would at least have some kind of advantage in manpower or equipment over the defender, because otherwise the attack would be doomed to fail. The attacker would be expecting to confront enemy defenses and to encounter some kind of initial attacks from a defender. Thus, OPFOR would be inclined to be equipped with fast moving vehicles and high fire power to outmaneuver and overwhelm the defender with superior firepower. This combination can be extremely detrimental for the defender.

The defender needs to find some kinds of possible advantages to stop the attacker. They would have to find a way to slow down the fast advancing attacking forces to be able to use its LAWs and other weapons, such as artillery or mortar fire. In this case, digging trenches and making obstacles, such as minefields, would be beneficial to slow down the OPFOR's advancement. However, building fortifications is very time consuming and it requires a lot of manpower. Built fortifications can also expose defenders' positions to satellite and aerial recognizance. Therefore, the element of surprise would most likely be lost, and a clear target for an attack would be provided instead. Without trenches, a defender is highly vulnerable to a mechanized attacker and would likely be overrun. Stalling the attacker is required to gain as much time as possible to prepare for the incoming assault. If possible, any effort to weaken the attacker before they engage the main defending forces would increase the defender's chances of success.

Stalling an attacking mechanized infantry force with a small group of defenders, rifle fire and light anti-tank weapons is a difficult task. As fire often draws fire, drawing the fire of armored vehicles with smaller caliber weapons spells disaster for the disengaging group, because mechanized troops will give chase to a retreating opponent. This tactic is very tiring for the disengaging group over a long distance, which means that the rest of the platoon should be nearby in their defensive positions ready to break the chase. The disengagement maneuver can easily fail and cause more harm to the defender. It is possible to accomplish this task, but it requires a high skill level and good leadership in the stalling group.

5.2 | On Results of Laykka

Even though OPFOR had the attacker's advantage in the scenarios of the simulation experiment due to larger forces, more effective equipment, capability of indirect fire and familiar terrain, OPFOR was prevented from reaching its target area in 11 instances and incapacitated in 14 instances out of 16 (Table 3). Six Laykkas was estimated to be enough to stall even the primary combat unit of an OPFOR company which is a small number of UGVs. However, a surplus of Laykkas should be reserved to ensure effectiveness by accounting for possible losses in combat (Figure 7). This finding highlights the importance of an expendable UGV to be low-cost.

Whenever Laykkas were able to reach enemy IFVs, the UGV inflicted meaningful battle damage. Laykka was small enough to approach IFVs without being noticed while still being able to deliver armament to the weak bottom of an IFV. This tactic damaged or destroyed the IFV and thus further wounding or killing a significant portion of its crew in the process which was implied by the results presented in Figures 8 and 9. OPFOR troops were killed or wounded when seated inside the IFV well as if they were too close to the explosion.

The casualties experienced by OPFOR, that is, 58.6% of the OPFORS' company's primary combat unit (Figure 9), exceeded an estimated threshold of 20%–30% for an infantry battalion and smaller units to lose combat effectiveness. However, the extent of battle damage does not explain loss of combat effectiveness alone, as high morale might keep a unit in action despite heavy casualties (Wainstein 1986). Other causes, such as low morale, issues of maintenance, or disruptions in a command chain might lead to a unit losing combat effectiveness even with minimal battle damage (Wainstein 1986). This phenomenon is seen in a couple of instances in the "Loitering mine" and "Recon" scenarios (Figures 8 and 9 and as well as Table 3). In these cases, OPFOR was incapable of continuing fighting despite reaching their target area.

Table 3 and Figure 7 also revealed Laykka's weakness which is its operator. If the operator was killed, Laykkas under his/her control became immediately inoperative. Positioning and protecting the operator is therefore paramount for the effectiveness of the UGV system which was highlighted by indirect fire killing the operator and allowing Group 2 to advance without resistance in Scenario 4 (Figures 7–9 and Table 3). This weakness could also be mitigated by incorporating automated or autonomous control procedures in the UGVs.

The experiment also implied that Laykka seamlessly blended into the surrounding terrain during movement, making it difficult for OPFOR consisting of AROS to spot or target it. Therefore, AROS were unable to estimate the size of DEFFOR accurately (Table 4). AROS were likely led astray by having difficulty seeing Laykkas and their effective fire power. Reasonably AROS seemed to believe that a group normally associated with the weapon types they had encountered was attacking them, instead of a handful of UGVs. Some AROS attributed their experienced confusion about enemy location and difficulties in countering enemy attack to their personal shortcomings. AROS would particularly blame defeat on their supposed lack of proficiency in using VBS's controls. Observations of all AROS groups operating in VBS revealed no significant obstacles associated with its usage. They demonstrated sufficient competence in interacting with the VBS's interface and utilizing VBS's features to perform all required actions. It should be noted that even with prior information about the existence of Laykkas, the control group did not succeed in any scenario. This highlights the importance of providing conscripts—and staff officers—specific and detailed guidance on countering UGVs effectively.

The UGV operators' experience was more positive than AROS. Generally, the operators were satisfied by their performance, as was seen in their self-assessed mission scores (Table 5). They also perceived Laykka's general performance (Table 5) as well as its traversability, usability, and controllability (Figure 10) rather positively. Moreover, the operators were able to reach sufficient skills to maneuver Laykkas with a short training and to utilize the tactics developed for each module. Some learning might have happened during the experiment day since the operator's self-evaluated mission scores seemed slightly higher during the afternoon sessions than in the morning sessions.

Laykka's expendability enabled a compelling aspect to its tactical employment. Expensive ammunitions are often underutilized because they are being saved for a better opportunity. This burden on the decision-making process for the operators of UGVs is removed by having expendable UGVs and their modules be as low-cost as possible. Laykka's operators do not have to worry about the equipment's monetary value. Instead, the operators could concentrate on fulfilling their mission by being bolder in their actions.

The observers noted that the reason for the OPFOR's drastic maneuvers could be attributed to the integrated weaponry of the UGVs, mainly their explosives used for self-destruction. The power of this explosion proved highly effective against the IFVs, instilling even more distress and caution in OPFOR. Additionally, it was noticed that in several simulation instances, the OPFOR group became aware that the UGVs were operating against it and being capable of eliminating it using explosives. This revelation led OPFOR to recognize the importance of keeping a distance from the UGVs and neutralizing them from afar. No substantial differences could be observed by comparing the actions, confusion, and excessive caution exhibited in AROS groups 1–3. The control group was able to remain slightly calmer, but they made similar mistakes as other groups. Regardless of having prior knowledge about possibly encountering UGVs, the control group was incapacitated and prevented from reaching their target area in all four scenarios.

5.3 | Limitations of the Experiment

Due to the small sample size of the experiment, statistical testing was not used in the analysis of this study. All group-wise differences discussed might be caused by random variability. The responses of AROS could not be assumed to be independent because the individual group members affect the formation of the group's questionnaire responses. Moreover, the number of operators was too low to compare neither operator-wise nor group-wise differences. To overcome the issues stemming from the small sample size, the effectiveness of the UGV was assessed holistically in several ways. The results obtained did consistently support the conclusion that Laykka was an effective defensive tool in stalling the advance of attacking forces. They also showed a need to develop tactics and procedures to fight with and against UGVs, especially in forested environments.

Even though the results of the experiment seemed promising, replication and further experiments are necessary to further understand and verify current findings. The number of participants limited the number of groups, leading to limitations to groups-wise comparisons of the battle damages and overall outcomes. Having only two operators is also not enough to draw generalizable conclusions about the usability of the UGV: a larger sample would be needed to overcome bias from individual differences and possible personal preferences of the operators. The selection of scenarios and having just one UGV system limits the generalizability of the results to the different types of conflicts, forces, and terrains in the scenarios.

The experiment conducted in this study did not consider the length or content of training for using or countering the UGV. Further, this experiment was not designed to quantify the difference in a given defensive forces' ability to stall an offending force with and without UGVs. Quantifying such a difference would require including a selection of scenarios where the defending side would have a larger number of players without UGVs. Additionally, the exclusion of some aspects of war, such as aerial combat, medical evacuations, and EW could alter the effectiveness of the UGV significantly. Finally, the conducted simulation scenarios should be replicated in a military training exercise to verify the fidelity of the simulations and real-world effectiveness of the UGV. While simulation environments strive to replicate the real world, remaining differences are significant and can alter experiment results. Conducting studies addressing these limitations would provide robustness and generalizability to the estimates of Laykkas' effectiveness and reliability. Future studies have been planned to build on the study introduced in this study and to overcome the small sample size and other mentioned limitations.

5.4 | Future Development

Some limitations and points of improvement of Laykka were identified in the experiment. These findings are not limited to Laykka and could be taken into consideration when developing any UGV. To effectively keep pace with mechanized troops, the top speed of the UGV should reach 25–30 km/h. Currently Laykka can reach the top speed of 20 km/h. The speed of 30 km/h is also the maximum realistic speed that IFVs can travel through a Nordic forest environment in the middle of a skirmish. Enhanced top speed will not only facilitate improved maneuverability but also enable expedited arrival at potential ambush locations.

To guarantee better performance of Laykka, rapid transitions between the thermal and day view cameras are essential which was stated by the operators. This aspect affected the usability of Laykka. Therefore, an upgraded viewing system that integrates sensor-fused cameras capable of accurately identifying targets through thermal imaging and regular visual perspectives should be implemented.

A range of potential solutions can be explored to enhance the precision of UGVs' aiming at moving targets. One possibility involves implementing a turret system that operates independently from the platform, enabling precise rotation and tracking without compromising other aspects such as the weight and cost of a UGV. Another avenue for improvement lies in providing operators with specialized training on effectively targeting moving objects. On the other hand, one could incorporate advanced features like automatic target locking and tracing into modules with a turret.

In the simulation experiment discussed in this study, Laykka was remote-controlled. However, increasing autonomous capabilities would significantly expand its usability. Laykka could also possess the ability to independently identify and evaluate the position of a target to intercept and eliminate it. Unhindered advance of enemy troops could be prevented by pre-planning autonomous reactions for Laykka in case its operator became incapacitated. For instance, if the operator were to die, a "dead man's switch"—sequence could be activated, allowing Laykka to detect potential threats and safeguard the combat area. This kind of autonomous controlling system could be implemented with, for example, evolutionary computing (Visnevski and Castillo-Effen 2010).

Additionally, Laykka, equipped with autonomous capabilities, could operate in a given area and collaborate with other operators and Laykkas. Autonomous Laykkas could share information, such as locations of enemy positions, and assign separate targets to conduct multiple simultaneous coordinated attacks. Such high-level autonomy and synchronized actions would require the capability to predetermine and choose between multiple paths toward a target, to change a path to avoid obstacles and to take into account other UGVs' positions and lines of movements (e.g., Nohel et al. 2023). While traversing a chosen route, Laykka should also be able to make minor adjustments to its course of movement to hit its target precisely, if the target changes its direction or speed. To avoid exposure by laser and various signal-detecting sensors commonly used in military combat vehicles (Graswald et al. 2020; Heikkila et al. 2004), autonomous navigation toward the target should rely exclusively on visual or audio-based sensor fusion techniques, without emitting any signals. Being able to navigate without relying on the global positioning system (GPS), lasers and other signals, Laykka would require advanced capabilities for the determination of distance. These capabilities could be based on passive sensor data, stereo vision or a 360° camera for accurate locking and recognition of targets.

Another potential area for the development of UGVs is to utilize additive manufacturing methods and materials for most of Laykka's parts. To the authors' knowledge, additive manufacturing is not commonly utilized in the production of military or civilian vehicles including UGVs beyond a prototype phase. Such an additive manufacturing method could provide maintenance reliability in battlefield and emergency situations, without the need to rely on an extensive storage of spare parts or procuring production lines for various parts (Rautio and Valtonen 2022). Swift repairs using the digital library of 3D-printable models of components could become possible, resulting in increased cost-effectiveness of the maintenance and repairs of UGVs.

Creating a medical support module for Laykka could be beneficial, building on previous approaches for supporting medical activities on the battlefield (e.g., Lejeune and Margot 2018; Rettke, Robbins, and Lunday 2016). Control models used in these approaches could be applied to developing the medical support module. This concept would bring medical assistance and capabilities of an operating room to the front lines and could offer assistance and advice to combat medics. The significance of this extension of Laykka lies in its potential to enhance the care provided during the critical first hours following an injury. By facilitating immediate and advanced medical interventions, the medical support module could substantially improve the survivability percentage of wounded infantry troops. With such a module, Laykka could change medical care on a battlefield and serve as a support means for emergency response in various challenging combat environments.

Conducting a military exercise in near future where the UGV system is actively tested in realistic combat scenarios would offer valuable insights into its performance under actual battlefield conditions. As the battlefield incorporates many other aspects of combat elements, such as EW and joint elements, it would be necessary to conduct individual separate virtual simulation experiments. These single experiments need to be carried out, with all of these aspects in mind to assess the effectiveness of the UGV. By doing this, it will ensure that Laykka and its modules remain functional and effective even when faced with the complex challenges of modern warfare. This applies also to other UGV platforms.

6 | Conclusion

This study introduced a new military UGV system called Laykka and evaluated its combat effectiveness in a set of four simulated scenarios. This UGV has been designed to be a low-cost, expendable, and modular platform that can perform various tasks when a task-specific module is attached. A virtual simulation experiment was conducted for evaluating Laykka's operational capabilities. In the experiment, armored reserve officer students controlled simulated attacking forces, while staff officers controlled the UGVs. Virtual Battlespace 3 was chosen as the simulation environment because it has been previously used widely in training of armored forces. Events in simulation scenarios were close to those in real battlefields. Comprehensive virtual simulation or field-testing studies, where the effectiveness of UGVs are analyzed in environments resembling real battlefield situations, have not been earlier presented in the unclassified literature.

The main objective of this study was to verify whether expendable UGVs could stall the advance of attacking mechanized infantry units up to a company's primary combat units.

Furthermore, the battle damage inflicted by the UGVs was measured to evaluate the UGVs' performance. The number of the UGVs that were used, intentionally killed and destroyed were also determined. Additionally, the user experience of UGVs' operators was measured, and areas of inadequate performance were identified for the future development of Laykka.

The experiment was carried out successfully in a planned schedule. The virtual simulation environment was practical for testing a new UGV and its tactical usage in a chaotic battlefield. By utilizing the simulation environment, the analysis of near-realistic engagement scenarios with UGVs was enabled without risk of human casualties or unnecessary consumption of fuel and ammunition.

UGVs' potential to shift the balance of power on the battlefield was demonstrated by the experiment. In most simulation instances, the defensive forces were able to stall OPFORs using only UGVs. Approximately six UGVs were enough to stall a mechanized infantry company's primary combat unit. The UGVs were particularly effective when all three modules—anti-tank, reconnaissance, and loitering mine—were used together in combating mechanized infantry units. The UGVs' ability to self-destruct caused significant confusion, inflicted damage, and instilled fear among enemy combatants. The officer students frequently diverged from standard tactics of mechanized infantry when engaging UGVs. The control group of the students had prior knowledge about UGVs' existence in combat, but it was no more successful in fulfilling missions than the other groups that were not aware of UGVs. Therefore, it can be concluded that clear guidelines for effectively combating UGVs need to be established to maintain combat effectiveness.

The potential of Laykka and UGVs in general is promising based on the results of the virtual simulation experiment conducted in this study. UGVs could serve as a meaningful force multiplier for defending infantries, and they offer effective means for suitable diversion to minimize casualties. Nevertheless, further comprehensive tests and experiments involving larger samples of conscripts, UGV operators, and a wider range of scenarios are required to make conclusive and statistically significant statements. The results obtained in this study should also be considered when developing military UGVs and their tactics including countermeasures. In summary, Laykka has demonstrated mechanical readiness and tactical effectiveness which justifies further development as well as thorough testing in field experiments and military exercises.

Acknowledgments

The authors received no specific funding for this work.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

Andersson, C. A. 2021. "The Unmanned Ground Vehicles to Be Used in Future Military Operations." *Tiede ja Ase* 2021, no. 79: 90–106.

Bendett, S. 2023. Bureaucrat's Gambit: Why is Dmitry Rogozin Sending Russian Uncrewed Ground Vehicles to Ukraine—And Does it Matter?. https://mwi.westpoint.edu/bureaucrats-gambit-why-is-dmitry-rogozin-sending-russian-uncrewed-ground-vehicles-to-ukraine-and-does-it-matter/.

Ben-Tzvi, P. 2010. "Experimental Validation and Field Performance Metrics of a Hybrid Mobile Robot Mechanism." *Journal of Field Robotics* 27, no. 3: 250–267. https://doi.org/10.1002/rob.20337.

Bielawski, K., M. Chmieliński, and D. Szagała. 2018. "Mobile Training Station for Training Form 120 mm Self-Propelled Mortar." *AUTOBUSY–Technika, Eksploatacja, Systemy Transportowe* 19, no. 6: 1002–1006. https://doi.org/10.24136/atest.2018.217.

Blokhin, A., A. Koshurina, M. Krasheninnikov, and R. Dorofeev. 2015. "The Analytical Review of the Condition of Heavy Class Military and Dual-Purpose Unmanned Ground Vehicle." *MATEC Web of Conferences 2015* 26: 1–4. https://doi.org/10.1051/matecconf/20152604002.

Brigade, K. 2017. Simulator-Assisted Systems Enhance Combat Training. https://maavoimat.fi/en/-/simulaattoriavusteiset-jarjestelmat-tehostavat-taistelukoulutusta.

Bohemia Interactive. 2023. Home Page. https://www.bohemia.net/.

Buttcher, D., C. Dreilich, S. Fleischmann, T. Löffler, S. Luther, and F. Spanier. 2016. "Virtual Battlespace 3: Scenario Analyzing Capability and Decision Support Based on Data Farming." In *10th NATO Operations Research and Analysis (OR&A) Conference. How does analysis help the Alliance think differently?, STO-MP-SAS-OCS-ORA-2016 NATO Public Release*, 1–10.

Chmielewski, M. 2020. "Virtual Simulation Environments Supporting Scenario-Based Tactical Border Protection Training—A Case Study Based on SymSG Border Tactics." In *Language Policy and Security in the 21st Century, Warsaw, Dom Wydawniczy Elipsa, Bogusław Jagusiak, Agata Jagiełło-Tondera*, 191–212. https://www.researchgate.net/profile/Mariusz-Chmielewski-2/publication/342702374_Virtual_simulation_environments_supporting_scenario-based_tactical_border_protection_training_-_a_case_study_based_on_SymSG_Border_Tactics/links/5f0209daa6fdcc4ca44e7f1c/Virtual-simulation-environments-supporting-scenario-based-tactical-border-protection-training-a-case-study-based-on-SymSG-Border-Tactics.pdf.

Choi, B., W. Lee, G. Park, Y. Lee, J. Min, and S. Hong. 2019. "Development and Control of a Military Rescue Robot for Casualty Extraction Task." *Journal of Field Robotics* 36, no. 4: 656–676. https://doi.org/10.1002/rob.21843.

Edmonds, J., and S. Bendett. 2022 *Russian Military Autonomy in a Ukraine Conflict*. Center for Naval Analyses, 1–20. https://apps.dtic.mil/sti/citations/trecms/AD1181580.

Eshel, T. 2016. RoBattle–A New Robot to Spearhead Combat Formations in Battle. https://defense-update.com/20160608_robattle.html.

Göllner, J., A. Peer, C. Meurers, et al. 2019. "Virtual Reality CBRN Defence." *NATO Public Release*: 1–25.

Graswald, M., R. Gutser, J. Breiner, F. Grabner, T. Lehmann, and A. Oelerich. 2020. "Defeating Modern Armor and Protection Systems." In *2019 15th Hypervelocity Impact Symposium*. Destin: American Society of Mechanical Engineers Digital Collection, 74–81. https://doi.org/10.1115/HVIS2019-050.

Heikkila, H., A. Brigade, P. Eskelinen, P. Hautala, and J. Rmiskimen. 2004. "Upgrading Armored Vehicle Sensor Systems." *IEEE Aerospace and Electronic Systems Magazine* 19, no. 1: 26–32. https://doi.org/10.1109/MAES.2004.1263989.

Hunder, M. 2023. Ground Vehicles Are the New Frontier in Ukraine's Drone War. https://www.reuters.com/world/europe/ground-vehicles-are-new-frontier-ukraines-drone-war-2023-07-13/.

Israel Aerospace Industries. 2023. Autonomous Combat System—IAI and ELTA's RoBattle Robotic Solutions. https://www.iai.co.il/p/robattle.

Kallenborn, Z., and M. Plichta 2023. Release the Robot Hounds: Providing Unmanned Ground Vehicles to Ukraine. https://www.csis.org/analysis/release-robot-hounds-providing-unmanned-ground-vehicles-ukraine.

Lejeune, M. A., and F. Margot. 2018. "Aeromedical Battlefield Evacuation Under Endogenous Uncertainty in Casualty Delivery Times." *Management Science* 64, no. 12: 5481–5496. https://doi.org/10.1287/mnsc.2017.2894.

Mansikka, H., K. Virtanen, D. Harris, and J. Salomäki. 2021a. "Live–Virtual–Constructive Simulation for Testing and Evaluation of Air Combat Tactics, Techniques, and Procedures, Part 1: Assessment Framework." *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology* 18, no. 4: 285–293. https://doi.org/10.1177/1548512919886375.

Mansikka, H., K. Virtanen, D. Harris, and J. Salomäki. 2021b. "Live–Virtual–Constructive Simulation for Testing and Evaluation of Air Combat Tactics, Techniques, and Procedures, Part 2: Demonstration of the Framework." *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology* 18, no. 4: 295–308. https://doi.org/10.1177/1548512919886378.

Mazal, J., A. Bruzzone, M. Turi, M. Biagini, F. Corona, and J. Jones. 2019. "NATO Use of Modelling and Simulation to Evolve Autonomous Systems." In *Complexity Challenges in Cyber Physical Systems: Using Modeling and Simulation (M&S) to Support Intelligence, Adaptation and Autonomy*, edited by S. Mittal, and A. Tolk, 53–80. Hoboken, NJ: Wiley. https://doi.org/10.1002/9781119552482.ch3.

Militarnyi. 2023. Ukraine and Russia Prepare Ground "Kamikaze Drones" for War. https://mil.in.ua/en/news/ukraine-and-russia-prepare-ground-kamikaze-drones-for-war/.

Milrem Robotics. 2023. The THeMIS UGV. https://milremrobotics.com/defence/.

Mittal, V., and J. E. Fenn, IV. 2024. "Using Combat Simulations to Determine Tactical Responses to New Technologies on the Battlefield." *The Journal of Defense Modeling and Simulation* 2024. https://doi.org/10.1177/15485129241239364.

Moses, A., K. Obenschain, J. Boris, and G. Patnaik. 2015. "Using Real-Time Chemical Plume Models in Virtual Training Systems." In *2015 IEEE International Symposium on Technologies for Homeland Security (HST)*, 1–6. Waltham, MA, USA: IEEE. https://doi.org/10.1109/THS.2015.7225277.

Nguyen-Huu, P.-N., J. Titus, D. Tilbury, and G. Ulsoy. 2009. *Reliability and Failure in Unmanned Ground Vehicle (UGV)*, 1–33. University of Michigan. https://dl.icdst.org/pdfs/files/eed2cb9cd60d2627c1664946bcbb305c.pdf.

Nohel, J., P. Stodola, J. Zezula, P. Zahradníček, and Z. Flasar. 2023. "Area Reconnaissance Modeling of Modular Reconnaissance Robotic Systems." *The Journal of Defense Modeling and Simulation* 2023. https://doi.org/10.1177/15485129231210302.

Odedra, S., S. D. Prior, and M. Karamanoglu 2009. *Investigating the Mobility of Unmanned Ground Vehicles*.

Oskarsson, P.-A., P. Svenmarck, K. Bengtsson, A. Melbi, and A. Pestrea. 2023. "Semi-Autonomous Units for Mechanized Combat Controlled by Voice Commands." In *International Conference on Human-Computer Interaction*, edited by M. Kurosu, and A. Hashizume, 380–395. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-35602-5_27.

Rantakokko, J., V. Rask, C. Brännlund, et al. 2022. Autonomous CASEVAC – Annual Report 2022 (No. FOI-R--5390--SE; pp. 1–39). Totalförsvarets forskningsinstitut - FOI. https://www.foi.se/rapporter/rapportsammanfattning.html?reportNo=FOI-R–5390--SE.

Rautio, S., and I. Valtonen. 2022. "Supporting Military Maintenance and Repair With Additive Manufacturing." *Journal of Military Studies* 11, no. 1: 23–36. https://doi.org/10.2478/jms-2022-0003.

Rettke, A. J., M. J. Robbins, and B. J. Lunday. 2016. "Approximate Dynamic Programming for the Dispatch of Military Medical Evacuation Assets." *European Journal of Operational Research* 254, no. 3: 824–839. https://doi.org/10.1016/j.ejor.2016.04.017.

Riotto, A. M. 2021. Teaching the Army: Virtual Learning Tools to Train and Educate Twenty-First-Century Soldiers. https://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/January-February-2021/Riotto-Teaching-the-Army/.

RStudio. 2020. RStudio: Integrated Development Environment for R. http://www.rstudio.com/.

Smolarek, M. 2019. "Unmanned Ground Vehicles in Development and Practice: Country Studies—Germany". In *Digital Infantry Battlefield Solution* (pp. 61–68). Milrem Robotics. https://depot.ceon.pl/handle/123456789/17122.

The R Foundation. 2023. R: The R Project for Statistical Computing. https://www.r-project.org/.

Toptester. 2023. What Tests Are Included in MIL-STD-810H Testing?. https://toptester.com/news/what-tests-are-included-in-mil-std-810h-testing/.

Vesa, D. C., and I. Gligorea. 2020. "Creating Modeling and Simulation Scenarios Using Dedicated Tools." *International Conference Knowledge-Based Organization* 26, no. 1: 172–175. https://doi.org/10.2478/kbo-2020-0027.

Visnevski, N. A., and M. Castillo-Effen. 2010. "Evolutionary Computing for Mission-Based Test and Evaluation of Unmanned Autonomous Systems." *2010 IEEE Aerospace Conference*: 1–10. https://doi.org/10.1109/AERO.2010.5446782.

Vold, T., H. Have, O. J. S. Ranglund, et al., 2018. "Flipped Gaming - testing three simulation games," In *2018 17th International Conference on Information Technology Based Higher Education and Training (ITHET), Olhao, Portugal*, 1–6. https://doi.org/10.1109/ITHET.2018.8424622.

Wainstein, L. 1986. *The Relationship of Battle Damage to Unit Combat Performance*, 1–101. Institute for Defence Analyses. https://apps.dtic.mil/sti/tr/pdf/ADA170631.pdf.

Whitney, S. J., J. J. Fidock, and J. Gassdorf 2012. Simulation-Based Development of Safe Operating Procedures for the Australian Army's Future Land Vehicles. *Occupational Safety in Transport Conference 2012*. Presented at the Occupational Safety in Transport Conference 2012. https://trid.trb.org/view/1238278.

Wickham, H., M. Averick, J. Bryan, et al. 2019. "Welcome to the Tidyverse." *Journal of Open Source Software* 4, no. 43: 1686. https://doi.org/10.21105/joss.01686.

Wickham, H., and J. Bryan 2023. readxl: Read Excel Files. https://readxl.tidyverse.org.

Wickham, H., W. Chang, L. Henry, T. L. Pedersen, K. Takahashi, and C. Wilke 2016. ggplot2: Elegant Graphics for Data Analysis. https://ggplot2.tidyverse.org/.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.