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Feasibility of evacuation from the front line using unmanned ground vehicles during platoon-level defensive combat

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ABSTRACT

Introduction Advancements in technology and intelligence, as well as deliberate targeting of medical personnel and vehicles, have made casualty extraction increasingly hazardous. The Russo-Ukrainian War has further demonstrated that the rapid development of unmanned technologies may also enable novel approaches. Although some of these systems have been deployed, reporting on their performance is scarce and understandably incomplete, which limits their evidence-based and effective integration with fighting forces. This paper addresses this gap by presenting preliminary findings on potential ranges of evacuation unmanned ground vehicles (UGVs) utilisation.

Methods A virtual simulation experiment was conducted, where a platoon defended against a mechanised infantry company. The experiment was a repeated military exercise with different groups of participants. The defending force had evacuation UGVs, which were placed close behind the defensive line. The aim was to determine whether UGVs could survive long enough to support evacuation and whether evacuation could be carried out before the conflict ended. Furthermore, the availability of UGVs and the likelihood that an evacuation attempt could avoid enemy interference were assessed. The experiment involved 470 participants divided into 11 groups. Each participant completed four combat scenarios. Players of each group switched sides and environments. In total, 44 instances of skirmishes were fought in a virtual simulation environment.

Results The simulation results indicated UGV loss rate of 53%. Evacuations were attempted in 45% of skirmishes. Furthermore, 81% of initiated evacuation attempts were successful.

Conclusions The experiment provided estimates of evacuation UGV loss rates near the defence line amid active conflict. It also offered evidence on the feasibility of initiating evacuation before the active conflict had fully ceased, and the likelihood of the moving evacuation vehicle encountering enemy fire. These findings can guide decisions on whether the risk of losing small evacuation vehicles and their equipment is acceptable when deployed near front lines.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Deliberate targeting of medical personnel and vehicles, along with advancements in military technology, has created an urgent need for novel solutions for the evacuation of casualties from the point of injury.

WHAT THIS STUDY ADDS

⇒ While many technologies perform consistently in controlled settings, human factors and combat environments can alter their usability and performance. This paper provides preliminary estimates of loss rates for evacuation unmanned ground vehicles (UGVs) and of evacuation success rates.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Since front-line evacuation UGVs are expected to experience a high risk of loss, they should be designed to be low-cost, reusable and equipped with only essential capabilities.

INTRODUCTION

The ongoing Russo-Ukrainian War has brought attention in Europe to the possibility of large-scale conflict and the need to reconsider how military health services are organised. As wars become more intense and widespread, the number of casualties can overwhelm existing military medical systems,[1] which may force prolonged field care. This delay could range from hours to even weeks in the worst case.[1 2] Evacuation is further complicated by reported instances of Russian actions aimed at disrupting evacuation efforts.[3] These include the use of drones, indirect fire,[4] as well as attacks on medical vehicles,[5] to increase the risk to Ukrainian forces.[6] These challenges highlight the need for additional information to support the adaptation of military medical healthcare to the dynamic and rapidly evolving operational landscape of modern warfare.[3 7] Specifically, whether evacuation of unmanned ground vehicles (UGVs) would be able to protect casualties from enemy kinetic actions has been identified as an area of interest.[8]

Emerging technologies, such as UGVs and unmanned aerial vehicles (UAVs), have been proposed to provide potential benefits for casualty extraction.[9 10] However, the use of UAVs for safe evacuation[10 11] would be hindered by factors such as lack of air superiority[3 10 12] and disruption of control signals due to electronic warfare. Therefore, exploring alternative land transportation methods might be necessary,[3 8] even with known complexities.[1 13 14] Factors such as enemy fire, terrain and communication disruptions raise doubts about how effectively emerging land-based evacuation technologies[15] can be integrated into early evacuation phases.

The pitch for evacuation UGVs often emphasises benefits such as increased survivability through rapid evacuation,[16] improved adherence to the golden hour principle or enhanced decision-making capabilities.[10] However, these claims are challenging to verify or compare across platforms.[11] The strengths and weaknesses of UGVs in evacuation use cases may partly result from factors such as risk diffusion, compact size and close proximity to the front line. The diffusion of risk involves deploying multiple expendable or attritable unmanned units (low-cost, limited-life assets designed to be recoverable but easily replaceable) instead of a large, expensive, armoured vehicle carrying multiple personnel into a dangerous area. Their compact size and off-road mobility may enable them to take advantage of natural cover provided by obstructed terrain. However, in practice, smaller size often limits their speed and traversability due to mechanical constraints. Classifications of expendable, attritable and survivable systems have been defined for aerial systems,[17] but have not yet been established for medical systems. In our understanding, commonly used medical vehicles would be classified as survivable systems, since they are expensive, carry high-value technology and personnel, and therefore require protection.

Since moving casualties by a single person is highly strenuous,[18] and the primary objective is to prevent new casualties by having all capable soldiers engage in active defence, the transportation of casualties is likely feasible only after the active assault has ended. Moving the evacuation vehicle could also attract enemy fire, possibly making it safer to remain stationary and under cover whenever possible.

Quantifying uncertainties related to the employment of UGVs is challenging, leading to a recognised lack of comparable reporting.[16] In addition to simulation-based analyses, another approach could be to examine combat casualty statistics. However, casualties who die before reaching medical facilities are often recorded simply as 'killed in action'.[19] This practice makes it difficult to determine the proportion of evacuations that encounter enemy interference and fail, at least from registry data alone. One study has reported that 87.3% of battlefield fatalities occurred before reaching a medical treatment facility, 75.7% of which were classified as nonsurvivable.[19] Therefore, fast enough evacuation to guarantee immediate care could increase survivability only up to a limit.

The aim of this paper is to address the knowledge gap regarding the practical applicability of evacuation UGVs near the front line. The experiment was designed to answer the following three questions: First, what is the likelihood of evacuation UGVs becoming damaged or destroyed near the defence line (loss rate)? Second, would evacuation operations be initiated during an ongoing conflict if UGVs were available (evacuation attempts)? Lastly, what is the likelihood of a successful evacuation using UGVs during ongoing combat (success rate)?

METHODS

To quantify these uncertainties, a virtual simulation experiment was conducted in which a platoon defended against a mechanised infantry company. The casualties in this experiment are generated by combat, and evacuations are subjected to enemy intervention. The simulation experiment was designed to replicate a defensive conflict, where the opposing force (OPFOR) attacked with a mechanised infantry company supported by artillery. OPFOR had numerical and firepower superiority over the defending force (DEFFOR), which relied on a single infantry platoon supplemented by defensive and evacuation UGVs. In this paper, the evacuation aspect of this experiment is addressed. DEFFOR had three evacuation UGVs placed close behind the defensive line in every combat scenario. The aim of the experiment was to describe the loss rate, evacuation attempts and evacuation success rate of these UGVs during the skirmishes observed. Overall, four scenarios were prepared, featuring two environments (A and B) and two levels of UGV capability (remotely controlled and autonomous). The environments differed in terrain, OPFOR's attack directions and DEFFOR's corresponding defensive positions. Figure 1 presents an overview of the general mission structure and force deployment.

The simulation experiment was conducted in May and June 2024, involving 470 participants: 432 conscripts, including 37 armoured reserve officer students, 26 commissioned officers as participants, 7 observers and 5 commissioned officers as UGV operators. The conscripts, armoured reserve officer students and commissioned officers were divided into 11 groups of

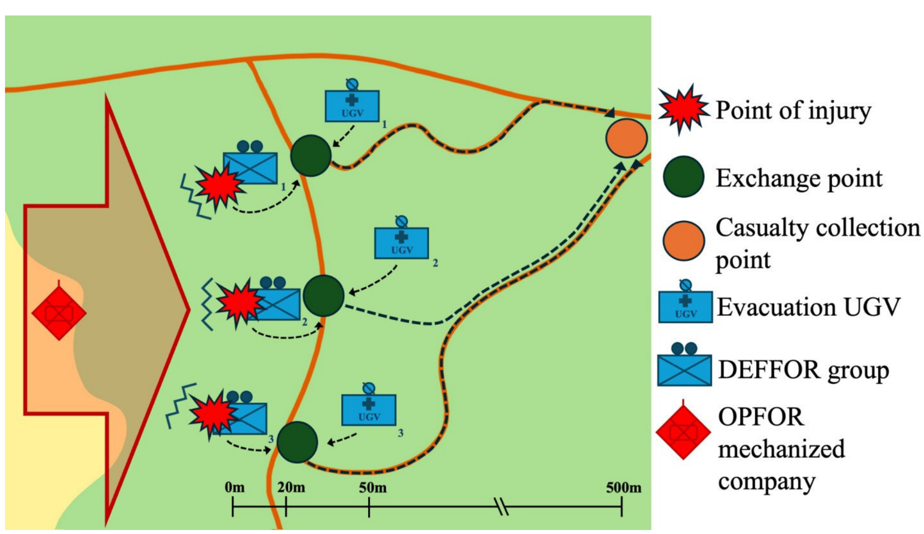

Figure 1 Overview of troop disposition and evacuation points across all scenarios. Each of the three evacuation UGVs was subjected to three defender groups with corresponding exchange points, and a common casualty collection point approximately 500 m away from the front line. DEFFOR, defending force; OPFOR, opposing force; UGV, unmanned ground vehicle.

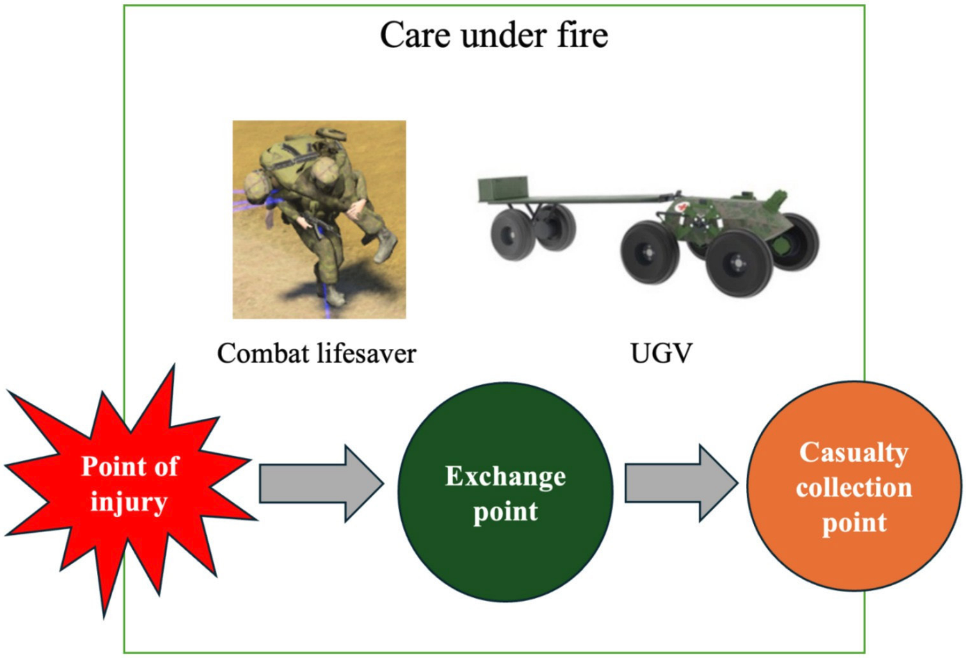

Figure 2 Casualty extraction from the point of injury to the casualty collection point. The extraction process involves the combat lifesaver's actions, the exchange point and the UGV used for evacuation. UGV, unmanned ground vehicle.

approximately 40, each with 20 people on either side. Each participant assumed the role of a simulated soldier. Each group had one person playing as a combat lifesaver (CLS) while on DEFFOR side. Two dedicated commissioned officers served as the OPFOR and DEFFOR company leaders throughout the experiment, and two additional officers served as simulation administrators for either side. Seven observers and five UGV operators facilitated the experiment. Among the observers were one medical professional, two commissioned officers, with one serving as the experiment lead, and four civilian specialists. The UGV operators were responsible for controlling the UGVs. One operator managed all three evacuation UGVs. All observers, simulation administrators and designated officers remained in their assigned roles throughout the experiment to maintain consistency.

In the Finnish Defence Forces (FDF), each platoon typically comprises three to four squads, each with a designated CLS, who is a regular soldier with additional medical training and limited medical supplies.[20] A military medic can be posted further from the defence line. If the wounded individual can care for themselves, they should independently apply necessary first aid and tourniquets. For other squad members, including CLS, the priority is to return fire or deter the enemy to prevent the person providing aid to the wounded from becoming injured themselves. Once the enemy is suppressed or the engagement ends, the casualty can be extracted from the point of injury to a more secure location. In the experiment, the CLS's task was to locate the casualty and transport them to the designated exchange point, where the CLS was primarily expected to meet the UGV to load the casualty onto the litter (see figure 2). The CLS could command their group's UGV to move to a different location, approach their position, or follow them. The exchange point was located closer to the front line than a similar meeting point would often be. The UGV would then transport the casualty to the platoon's casualty collection point. Care at the casualty collection point was not considered in the experiment.

Laykka X.4 (see figure 2), the UGV employed in the experiment, is a modular and expendable platform capable of supporting a variety of tasks.[21] For this experiment, the evacuation module for the Laykka UGV was conceptualised as an attachable stretcher designed to emulate a 'smart stretcher'. The stretcher includes an attached storage container, evoking the idea of transporting medical supplies such as tourniquets, dried plasma and pain medication.

The Wizard of Oz method[22] was used to allow CLSs to interact with what they believed to be an autonomous UGV, while a commissioned officer operated the system. For this purpose, a mock graphical user interface (mGUI) was created on separate tablets. The mGUI had a set of simple preprogrammed commands, such as 'follow me' or 'wait', as well as a text box for more detailed commands.[23] In practice, each UGV operator assumed the role of a simulated infantry soldier who could control the simulated UGVs. UGVs could be represented as either remotely operated or fully autonomous. When the remotely operated system was employed, participants could interact with the operators over the radio or with the mGUI. The operator's simulated infantry soldier could participate in combat if necessary and could also be killed. When the system was autonomous, participants issued all commands solely through the mGUI, which the operator then interpreted to the best of their ability. As the simulated soldier's sole purpose was to operate UGVs, they were located outside of the expected conflict area and could be resurrected when necessary, provided they had operable UGVs.

The virtual simulation environment used was Virtual Battlespace 4 (VBS4).[24] VBS-related verification and validation is a continuous process within the Armoured Brigade (AB), conducted by the FDF's Chief of Simulation and Chief of Virtual Training (CVT). This process ensures that the terrain, unit models, vehicles, weapons, other objects and the mechanics of the virtual world behave as intended and represent real-world systems. For the experiment described in this paper, built-in models of soldiers, tanks and CLSs were used. However, custom

UGV models of Laykka and combat environments were created by virtual training conscripts of AB under the guidance of the FDF CVT. The construction process for the VBS4 models followed the methodology of an earlier experiment described in.[21] All groups operated under identical, scenario-specific conditions, objectives and command structure. Environment A featured semiopen hilly terrain, and environment B featured typical dense Finnish forest with roads. Both had neutral weather and good visibility. While VBS4 does promise improved wounding mechanics, it does not reach the fidelity of purpose-built casualty simulators. Therefore, the research questions of this paper do not rely on injury severity or survivability, focusing instead on group to company level behavioural outcomes such as the occurrence of casualties and evacuation attempts. Similarly, mean time to reach the casualty collection point or mean transportation times are not evaluated, as detailed evaluation of the evacuation vehicle's performance would be better conducted with a more suitable simulator. While more accurate physics engines exist, VBS4 does provide a practical and adequate approximation of battlefield environments and events, allowing evaluation of system integration and its influence on troop dynamics and overall system effectiveness.[21 25–27]

The experiment consisted of 11 simulation sessions, each comprising four scenarios. Each session began with participants receiving a brief orientation on the capabilities of the Laykka UGV and transferring a casualty onto the litter. Participants assigned to the CLS role were additionally trained to use Laykka's evacuation module and the mGUI. Scenarios began with a mission briefing and proceeded through a skirmish that unfolded according to the participants' actions and decisions. After completing two scenarios, the teams switched roles; DEFFOR became OPFOR and vice versa. Evacuations were conducted whenever possible during ongoing combat, as shown in figure 2. The simulation of the scenarios was terminated when either a time limit was reached or the groups' commanding officers deemed the conflict concluded. Across all 11 sessions, this resulted in a total of 44 instances of skirmishes by the end of the experiment. Two additional control scenarios were simulated without UGVs to support the larger study, which included the UGV evacuation analysis, but these scenarios are omitted from this paper.

In the experiment, three metrics were used to evaluate the feasibility and performance of UGV-assisted evacuations during active combat: UGV loss rate, evacuation attempts and evacuation success rate. Binomial point estimates and CIs are reported for each.[28]

RESULTS

UGV loss rate

In total, 70 of 132 evacuation UGVs were destroyed or damaged. The combined proportions of destroyed and damaged UGVs across all scenarios represent an estimated loss rate of 53% in a conflict (95% CI 44% to 62%). Operational failures were primarily attributed to direct or indirect enemy fire.

Evacuation attempts

A total of 46 evacuations were initiated in 20 out of 44 skirmishes. This corresponds to at least one evacuation attempt in 45% of instances (95% CI 30% to 61%). More than one evacuation attempt was made in seven scenarios. In total, 34 evacuation attempts were conducted and completed within scenario time limits.

Evacuation success rate

Of the 34 attempts, 22 resulted in successful extractions, defined as retrieving the casualty without the evacuation being aborted due to hostile interference or technical failure. Five evacuation attempts were interrupted due to direct or indirect enemy fire or equipment failure. This yields a success rate of 81% (95% CI 62% to 94%). An additional seven evacuations were not completed due to the scenario time limit being reached. If these initiated evacuations are included, the success rate is 85% (95% CI 69% to 95%). Their inclusion as successful can be justified, as enemy units were not in their immediate vicinity at the time of termination.

DISCUSSION

Earlier literature has often assumed improved casualty survivability and faster casualty extraction as inherent benefits of UGV-assisted evacuations.[9] However, these assumptions have not, to our knowledge, been validated with empirical or simulation-based data. This simulation experiment is the first to explain the premises underlying such assumptions. Nevertheless, causality regarding improved survivability should not be inferred, as any effects on survivability can only be established through a controlled experiment that measures actual recovery outcomes following treatment.

The loss rate of UGVs under combat conditions was 53% (95% CI 44% to 62%). The primary causes of vehicle losses were direct and indirect enemy fire. This loss rate and CI provide a preliminary estimate of expected vehicle losses associated with the deployment of evacuation UGVs near defence lines, offering guidance for both practical implementation and technical development of such systems. Therefore, the system architecture should reflect acceptable operational risk, incorporating elements suited to potential loss. While the expected loss rates would naturally depend on vehicle characteristics, level of cover, distance to the defence line, terrain and enemy weapon capabilities, the observed CIs did not exhibit sensitivity to the environments A and B.

A total of 46 evacuation attempts were initiated during the simulated conflicts. These attempts occurred in 20 out of 44 skirmishes. This number suggests that a small evacuation vehicle could sometimes be used before the conflict has fully resolved. As the likelihood of an evacuation attempt depends on the number of wounded soldiers in need of evacuation, the number of intact soldiers to perform evacuation, and whether a safe window for evacuation exists, this metric is likely not comparable outside of the context of this study. Environments with higher medical fidelity should be used to evaluate the overall effects on evacuation workflow and patient outcomes.

The evacuation success rate was 81% (95% CI 62% to 94%), which may suggest that transporting casualties could be feasible even before the conflict has concluded. The risk that UGV movement might draw enemy attention was recognised before the experiment. The wide CI likely reflects the small observed count of evacuation attempts as well as factors not included in the simulation or unmodelled associations, such as increased risk from proximity to enemy combatants, which may alter the success rate. However, the success rate indicates that under certain conditions, it may be possible to transport casualties without attracting enemy attention. The success rate is likely influenced by factors such as the presence of drones and electronic warfare, neither of which was addressed in this experiment. This metric did not take into account whether the evacuee survived their wounds.

Overall, the findings of this experiment imply that deploying evacuation UGVs near the defence line does expose them to considerable risk. It could then be argued that an appropriate system would be a low-cost vehicle with just enough technical capability to function effectively for its intended purpose. Low unit cost is necessary to procure sufficient quantities of vehicles to offset the risk of losses. However, as the risk could be mitigated with improved concealment, evacuation UGVs may not need to be considered strictly expendable, but rather attritable. Furthermore, since the vehicle may return to the front line from the casualty collection point, the opportunity to replenish basic medical supplies should not be missed.

Overall, the mode of UGV operation (remotely operated vs autonomous) was not meaningfully different for a CLS. However, a CLS would likely not be able to operate the vehicle during conflict if it was remotely operated. Therefore, a separate operator should be allocated to ensure CLS is able to fulfil their care role.

Future research could explore the coordination of small autonomous UGVs with conventional evacuation systems, with a focus on communication protocols and integrated human-machine training at the unit level. Additionally, studies on human-machine interaction addressing trust in the machine, the workload of UGV operators and medical personnel, and their situational awareness would be valuable. Such efforts could help refine both the technology and tactics for unmanned casualty extraction.

CONCLUSIONS

This study, representing a virtual simulation experiment of UGV-assisted casualty extraction from the defence line, suggests that evacuation UGVs could offer a viable alternative. Attritable or expendable UGVs may complement more capable evacuation vehicles by enabling casualty extraction from high-risk zones. Future research should explore the effectiveness of such layered evacuation practices. UGVs should be low-cost, reusable, limited in capability but functionally sufficient, and potentially equipped to carry basic medical supplies.

Contributors CA, ML and JO conceived the design of the study in collaboration with KH, based on research questions suggested by KH. Methods for the study were designed by all the authors. CA executed and oversaw the experiment with ML and JO. ML provided the analysis of the data with CA. The original draft was written by KH and revised by all authors. The initial literature search was conducted by KH and revised by ML. JO managed the funding for the study. KH is the guarantor and accepts full responsibility for the work, had access to the data and controlled the decision to publish.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by Tampere University, Ethics Committee of the Tampere Region (Statement reference number 17/2024). This approval outlined a detailed protocol in order to ensure distress was minimised. Participants gave informed consent to participate in the study before taking part.

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