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Achieving Resilience in Military Logistics with Cluster-Forming Technologies

Gerald Schneikart*, Josef Frysak, Karoline Langner, Walter Mayrhofer

Abstract: The combat power of military troops is highly dependent on resilient supply chain management. Recent trends in the application of offensive drone technologies elevate the risks of supply chain failures along the last mile and demand pre-emptive resilience strategies. This paper presents a concept for increased resilience in military logistics that considers requirements elicited with methods from process engineering in collaboration with experts from the Austrian military logistics school. On a basic level, the concept is defined by a) decentralization of repositories at the battalion and company level achieved by cluster-forming technologies, and b) cross-docking for short-time supply points. The presented concept depends on the successful integration of cluster-forming technologies, but if done properly, it has the potential to improve the resilience of modern military logistics.

Keywords: clustering; cross-docking; decentralization; last mile; military logistics; resilience; supply chain management

1 INTRODUCTION

1.1 Increasing Resilience of Logistics Systems

Even though logistics originated in the military during the second half of the 20th century, research in civilian logistics outpaced military logistics [1]. Both sectors aim at improving efficiency and effectiveness when integrating novel technologies or strategies, but the overarching objectives may be different. In contrast to civilian industries, which strive for high efficiency with respect to financial terms [1], military operations need to remain effective in supporting combat powers of their troops at all costs [2, 3]. The stability against unexpected disruptions threatening either the efficiency or the effectiveness of a supply network and the ability to "restore normal supply network operations" can be dubbed "resilience" [4], while there might not be a commonly accepted definition of supply chain resilience [5].

Novel strategies and technologies can be implemented to improve resilience. One civilian example that illustrates this issue, is the introduction of counterfeit drugs into circulation somewhere along the pharmaceutical logistics chain. Recent developments in blockchain and robotics technology could therefore establish more transparent, automatized and resilient pharma supply chain processes that are much harder to corrupt [6]. On a more global scale, other threats to logistics and supply chain security are associated with a rising probability of natural disasters resulting in supply outages [7, 8]. As a possible countermeasure, artificial intelligence may attenuate the negative effects by providing backup plans and fast solutions for alternative routings [9].

Although certain novel technologies like blockchain, Internet-of-Things (IoT) or Artificial Intelligence may be appropriate to improving resilience in civilian logistics, their application in the military context often needs to consider a different set of requirements to show comparable positive effects. Effective military supply chain management requires a high level of flexibility in the establishment of supply routes, especially on the last mile [10]. If enemy attacks targeting single entities, such as transport vehicles or supply points, are successful, reactive mitigation measures can be implemented to reduce the risk of supply disruptions [11], e.g., using alternative means of transportation or by establishing other supply points at different locations.

1.2 Optimization of Resilience by Decentralization

Continuous improvements to modern reconnaissance and weapons systems for precision strikes against long-distance targets, such as the application of drone technologies, increase supply chain vulnerability [12, 13]. As countermeasure, pre-emptive strategies for resilience optimization are needed at any supply level [11], even at locations far behind the frontline. In this respect, decentralization of repositories seems promising [10].

Civilian logistics are often highly centralized, and efficiency is achieved by minimizing resource utilization, e.g., a single supplier, process automation, or relying on a single authority for decision-making. However, such highly efficient supply chains have low resilience against any kind of disturbance due to sole dependency on single resources and little redundancy. For example, the COVID-19 crisis and subsequent supply chain disruptions were associated with highly dependent and vulnerable supply chains. This suggests that companies with decentralized logistics structures and processes are more capable to adapt to unforeseen changes or impacts [14, 15].

While it may seem obvious, what decentralization in logistics means in a civilian context, decentralization of military logistics remains, to our knowledge, an open research gap and raises the following questions:

- Q1: How can decentralization of the military supply chain, from the battalion level to the frontline, be achieved?
- Q2: What are the requirements for a transformation towards logistical decentralization of the last mile?
- Q3: Which risks and opportunities may arise from such a supply chain decentralization?
- Q4: How can the resilience of decentralized military logistics be evaluated?

1.3 The Research Project RESISTANT

The demand for decentralizing technology solutions and pre-emptive transformation strategies is the basis of the research project RESISTANT. The importance of keeping armed forces ready for potential future threats due to modern weapon systems, e.g., autonomous or unmanned aerial and ground vehicles, is increasingly showcased in foreign military conflicts. Therefore, the Austrian government partly funded RESISTANT in order to develop a concept for supply chain decentralization, that also meets the demands of western military logistics (NATO). RESISTANT is a consortium project composed of collaborating research institutions of universities, universities of applied sciences, start-up companies in the industry 4.0 sector, and the Austrian Federal Ministry of Defence [16-19].

The project addresses aforementioned research questions by applying a combination of qualitative research and design science approaches to develop a concept for decentralization and first versions of the enabling communication and transportation technology solutions. The project scope primarily comprises small expendable supply items, including commodities needed by squads to maintain combat power, e.g., ammunition for rifles and guns, rations, or medical supplies. Goods needed by specific branches, e.g., fuel, spare parts, or electronics, are out of project scope.

This paper presents the concept of the envisioned logistical decentralization, and its enabling technology currently developed in collaboration with logistics experts from the Austrian armed forces as part of RESISTANT.

1.4 Organization of the Rest of the Article

This article is organized as follows: Section 2 describes the methods applied for elicitation of the requirements of the solution and the development of the decentralization concept. Section 3 describes the envisioned concept, the underlying technology paradigm and is complemented with a short risk-benefit analysis. Section 4 discusses the advantages and limitations of the decentralization concept.

2 METHODS

2.1 The Overall Design-Science Research Approach

The RESISTANT project essentially follows a design-science research approach. Design-science research is a framework in Information Systems research, which aims at acquiring new knowledge by combining behavioural and system design and development approaches. More specifically, the Information System research paradigm proposes to derive new knowledge by developing artifacts (products or services) that serve specific business needs. These artifacts originate from the practical environment but are developed based on theoretical foundations and methodologies. A key aspect of the design-science approach is the constant, iterative assessment and refinement of the artifact based on field applications. Thereby, theoretical as well as practical rigor drive the developmental process while simultaneously generating novel knowledge [20].

2.2 Semi-Structured Interviews and Process Analyses

In order to gain a basic understanding of the practical socio-technical environment, e.g., logistics processes of the Austrian military, methods from the process management discipline were applied. Process survey techniques in the form of semi-structured interviews were used to collect qualitative data about respective environments. Based on that data, process analyses were conducted using the Business Process Model and Notation (BPMN) standard, version 2.0.2 [21].

The BPMN models enabled basic requirements elicitation and process optimization under consideration of various technology implementations and were discussed with the experts of Austrian military logistics. This paper presents the schematics of a future state process model and summarizes the basic knowledge gains.

3 RESULTS

3.1 Decentralization Achieved by Dynamic Clustering

The idea envisioned by RESISTANT is to increase the resilience of military logistics by the fragmentation of repositories at different organizational levels and keeping each fragment mobile in order to reduce reconnaissance from the enemies. The inherent challenges with such an approach are apparently associated with dynamically managing goods distributed to each repository fragment and controlling the entire repository's inventory that is spread across a pre-defined geographic terrain. Therefore, cluster-formation enabled by communication technology is needed for the synchronization of inventory information between individual repository fragments. The resulting "network" of mobile repository fragments represents a dynamic cluster of data points.

The applied principle of dynamic clustering is illustrated by the example shown in Fig. 1, which shows a two-dimensional terrain with three clusters spread at distinct locations at time (t) = 0. The third dimension that would represent differences in altitudes was avoided for simplicity. Each cluster is defined by seven cluster-forming units (CFUs), which refer to single repository fragments represented by, e.g., a single container or a mobile storage rack distributed in the field within a kilometre.

Cluster formation depends on visual or radio contact as well as pre-defined thresholds for distances between individual CFUs. A CFU belongs to a cluster, as long as connection to at least one other CFU is established. Considering that the CFUs are mobile (dynamic clustering), a CFU could thus leave its cluster by exceeding the distance threshold to proximal CFUs ($t = 1$ and $t = 2$) or losing contact.

The single condition for cluster formation is visual or radio contact and the threshold for distances between CFUs. Accordingly, two CFUs are sufficient to form a cluster, as long as they are separated by a distance smaller than the threshold ($t = 3$).

Since individual CFUs are mobile, even entire clusters could theoretically move within the terrain. If clusters or CFUs of distinct clusters approach each other, both clusters integrate, once at least one CFU in each cluster moves within the threshold and connects to at least one CFU of the other cluster (t = 4 and t = 5, respectively).

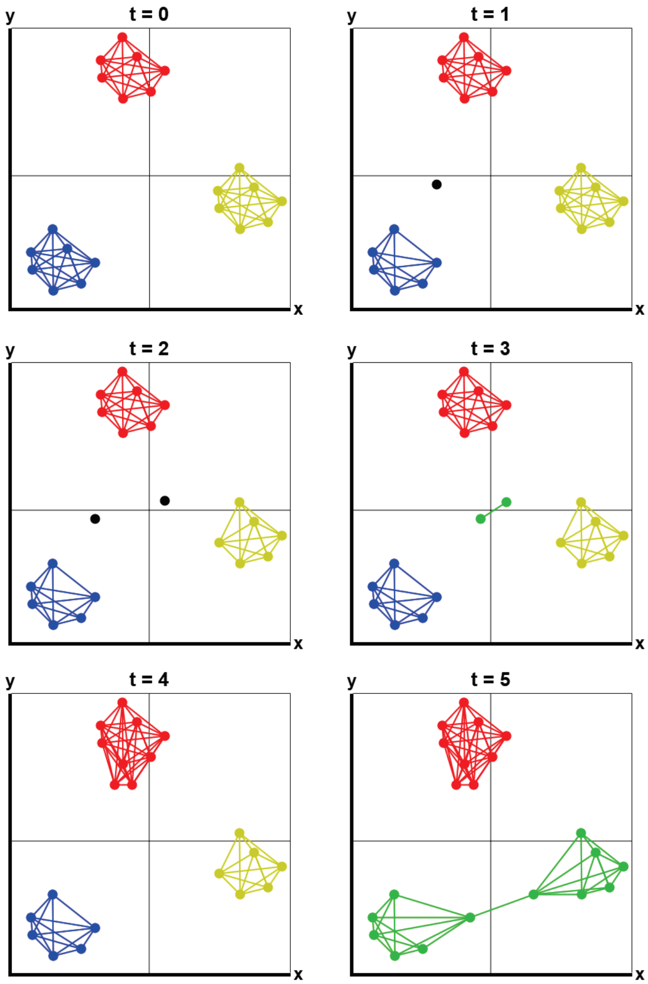

Figure 1 The principle of dynamic clustering

3.2 Cross-Docking for Commodity Transactions between Clusters

Since military supply chains have repositories of goods at each hierarchical level, dynamic clustering could theoretically be applied at each level. The presented concept for decentralization focuses on all downstream hierarchies, starting from the battalion level and ending at the foxhole, because military supply is increasingly vulnerable towards the frontline [10]. According to the analysis of the current supply processes (unpublished), two levels for cluster formation were considered reasonable, e.g., at the battalion and the company or platoon level (Fig. 2).

In the resulting concept, the transfer of commodities between those cluster levels requires solutions for cross-docking of transported goods between CFUs of different cluster levels. In the current supply process, different technologies for storage and transportation are used at each military hierarchical level. For example, a warehouse is established at the battalion level and trucks are generally used for transportation to distribution points near the frontline. Final delivery to the foxhole happens by manual carriage.

Considering the current logistical situation, the envisioned concept works with trucks capable of picking up roller containers (also called a hooklift container) intended for transport of multiple days of supply (DOS) of commodities (see Section 1.3 for specifications). The containers are equipped with communication technologies for cluster-formation. When loaded onto a truck, each container represents a mobile CFU capble to form clusters with nearby containers at the battalion level.

For cluster formation at downstream levels, i.e., clusters affiliated to companies or platoons, trucks and heavy containers are considered less suitable for dynamic clustering due to their insufficient degree of possible decentralization. Reasons for this rationale are, first and foremost, the vicinity of the frontline, which signifies high risk of detection by the enemy and loss of several DOS in a single strike. Hence, larger numbers of smaller vehicles are needed, ideally autonomous unmanned ground vehicles (UGVs) capable of carrying supplies close to the frontline [10].

When DOS are ordered for delivery, a truck from the battalion cluster and a CFU from the company or platoon cluster need to meet at a temporary supply point for the downstream transfer of DOS. Whatever the means of transport at the company or platoon level are, the technologies of the meeting CFUs require a technical solution for semi- or fully automated cross-docking. The major requirement is to keep the duration of the meeting to a minimum, because the increased resilience of the decentralized dynamic clustering should not be compromised by elongated times needed for setting up the temporary supply point and the exchange of goods.

Once the truck from the battalion delivered the ordered DOS to a downstream cluster, it either can move to a new temporary supply point to meet another downstream CFU for further DOS delivery, return to the battalion cluster to wait for a new order, or go further upstream to a repository at the brigade level to pick up a new container with fresh DOS.

After the CFU from the company or platoon acquires the ordered DOS from the battalion truck, it returns to its cluster waiting for instructions to finally deliver the goods to the combat troops. If squads from the frontline are ready for resupply (e.g., during a combat break) and order a pick-up of DOS, the CFU meets a squad from the ordering troops at a temporary supply point near the frontline, where the soldiers acquire the DOS and eventually distribute it to their comrades in the foxholes. The empty CFU then returns to its cluster at the company or platoon level until it receives new instructions for resupply with DOS delivered by a battalion truck.

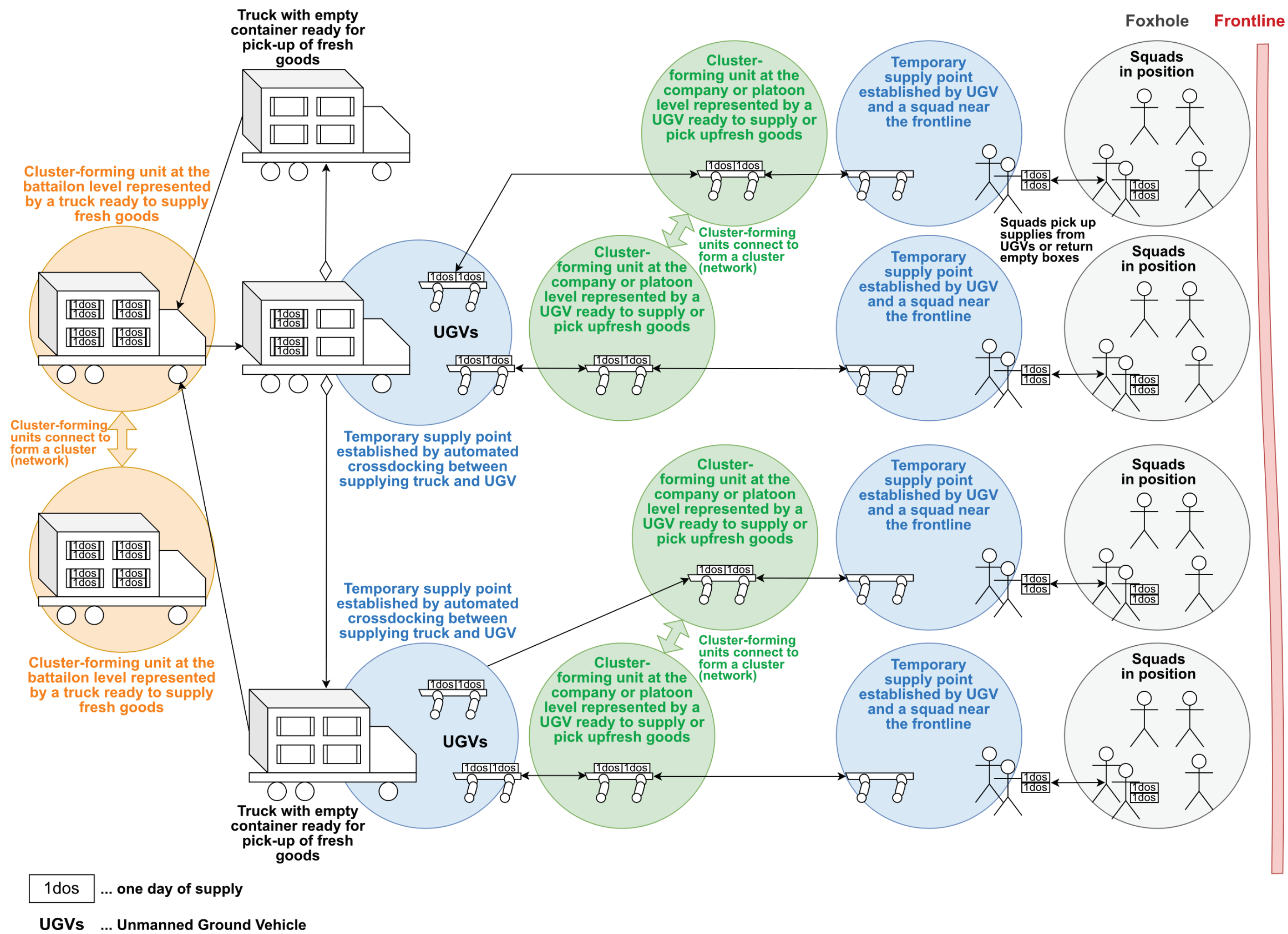

Figure 2 Decentralization of military repositories at different supply levels enabled by mobile cluster-forming solutions. The infographic illustrates the path of goods (amounts measured in one Day-Of-Supply; *dos*) distributed from cluster-forming container systems at the battalion level (orange circles) via cluster-forming unmanned ground vehicles (UGVs) at the company or platoon level (green circles) to the consuming troops (gray circles) at the frontline (red line). Cross-docking between clusters happens at temporarily established meeting points (blue circles). The black double-arrows illustrate possible paths of cluster-forming units or squads transporting one or multiple *dos*. Orange or green bold double-arrows between circles represent cluster formation of at least two connected cluster-forming container units or UGVs.

3.3 A Paradigm Technology Solution for DOS Transportation and Dynamic Clustering

The decentralization concept presented above was used for technical requirement elicitation and refinement in the RESISTANT project. While the technical development activities are still ongoing at the time of writing this paper, in the following the status of the transport item technology that enables dynamic clustering is presented. The core technology is a smart box/rack-system developed by the Austrian start-up company BOOXit. In the context of previous applied research projects, their returnable transport item solution has been improved [22] and evaluated for specific use cases in the pharmaceutical industry [6, 23].

The proprietary BOOXit technology is a promising transport solution providing a range of innovative features. The top of the box is covered with nobs reminiscent of Lego® bricks (Fig. 3A). The knobs allow for simple load securing without additional means of fixation (e.g., straps, shrink wraps, nets, tie downs, or fasteners), when multiple boxes are stacked, or storage of boxes in proprietary racks, which enable the usage of the boxes as drawers (Fig. 3B). The racks themselves also contain the knob feature for pooled transportation and fixation on compatible pallets (Fig. 3C, 3D).

The underlying vision of the BOOXit technology is to provide a smart transportation and logistics ecosystem relying on a single transport item solution, which consists of fully automated processes along entire supply chains. Moreover, the BOOXit technology allows for the integration with various logistics 4.0 technologies, e.g., communication systems for real-time monitoring of current positions or temperatures, as well as robotic systems for full automation of warehousing and a pick-by-light/put-by-light system for semi-automated assistance of delivery personnel (Fig. 3B) [22]. BOOXit also is the enabling transport item solution for the decentralization concept described above, and the box/rack-system is compatible with previously mentioned roller containers (Fig. 3E).

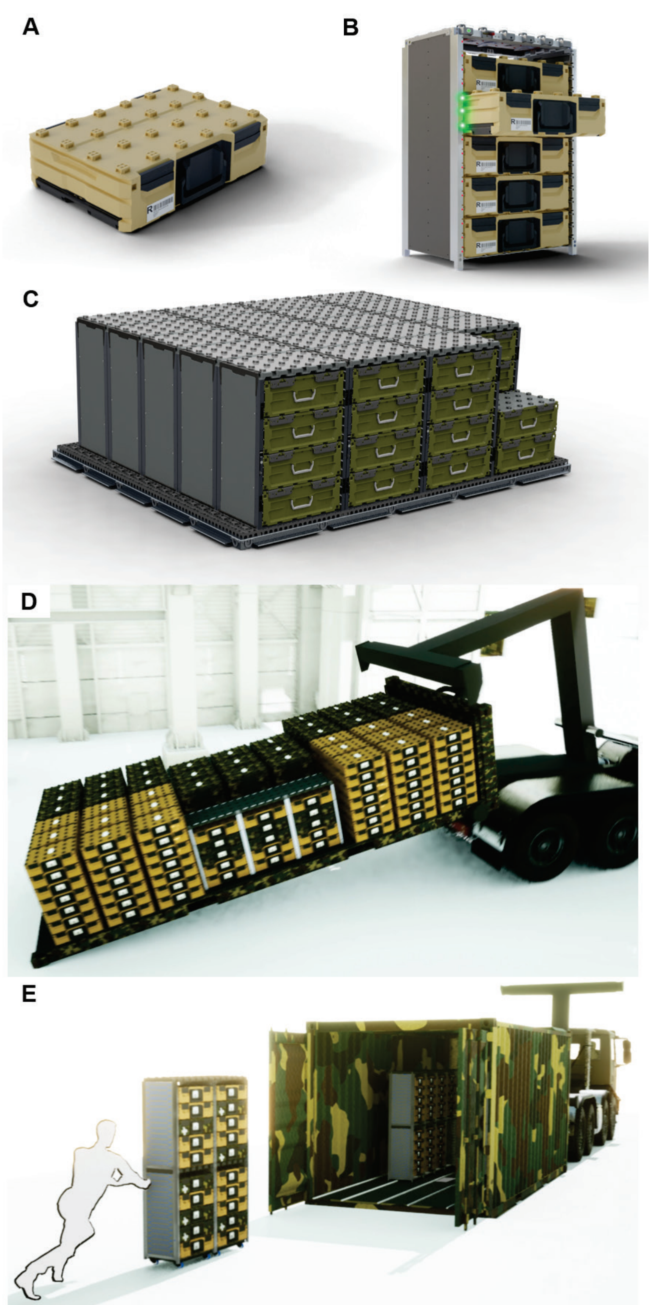

Figure 3 A 3D rendering of the BOOXit box/rack-system. (A) A BOOXit box with the proprietary knob structure visible. (B) The boxes can be used as a drawer in BOOXit racks. An integrated pick-by-light system assists warehouse personnel with box handling. (C, D) The knob structure on BOOXit racks allows pooling of multiple rack units to be loaded onto various transport systems without additional tie downs, fasteners or load securing. (E) One-shot-load storage of BOOXit box-rack-units into a roller container (also called a hooklift container)

Furthermore, the communication technology required for dynamic cluster formation is also developed in the RESISTANT project (Fig. 4A). The envisioned roller containers are equiped with automatic inventory control system in its interior (Fig. 4B), which provides the required cross-docking features for semi- or fully automated delivery of goods to company or platoon clusters (out of scope of the RESISTANT project).

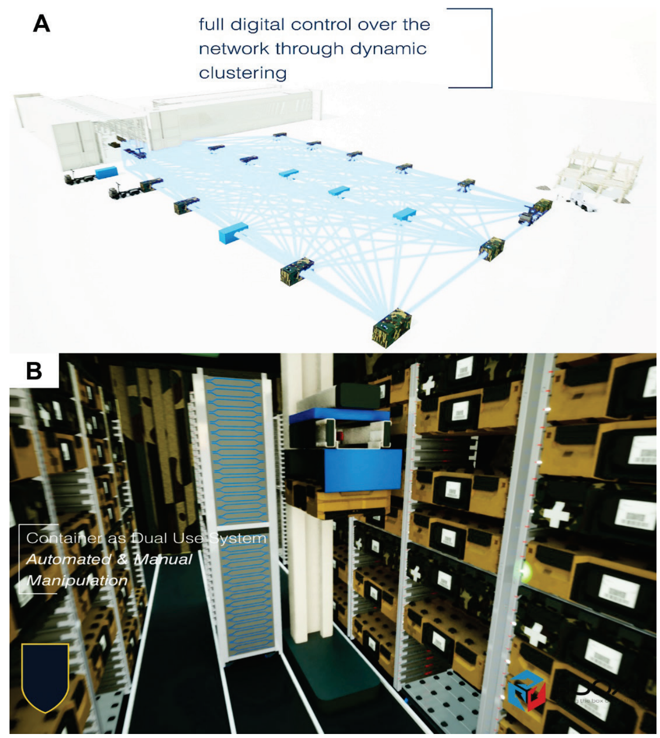

Figure 4 A 3D rendering of the BOOXit container system. (A) The principle of roller containers forming clusters. Each container directly connects with all nearby containers to form a cluster of equivalent network points. Connection between units happens automatically and depends on visibility in the field. (B) The envisioned roller containers are equipped with a fully automated inventory control system for cross-docking purposes.

3.4 Requirements in View of Further Development

The major challenge in implementing the presented or a comparable concept for the decentralization of logistics is the integration of technical solutions that enable dynamic clustering. The reason for this is that the repository fragments (CFUs) are dislocated and spread across a smaller or larger geographical terrain, but there still is the need to keep a "virtual common inventory", just as there would be in an integrated, central warehouse system. Therefore, the CFUs of a cluster permanently need to synchronize information about their individual inventory. The major requirement is a stable connection of each CFU with at least another CFU of the same cluster. In case a single CFU loses its connection, it saves the information about its current inventory status until automatic reconnection with a cluster for synchronization with the entire cluster's inventory takes place.

Another essential technical requirement enabling dynamic clustering is an independent power supply of each CFU. Different from warehouse entities, which can directly be connected to a supply network, mobile CFUs distributed in the field need to carry their own batteries for prolonged energy supply. This requires the integration of recharging technologies, such as energy-self-sufficient means (photovoltaics or other forms of energy harvesting) or power generators, e.g., when carried by a truck. Alternatively, recharging stations need to be established within clusters or at nearby locations.

3.5 Risks Associated with the Presented Decentralization Concept

Dynamic clustering as illustrated in this paper certainly contains considerable risks that could turn into threats substantially compromising the resilience level of the supply chain. The most obvious risks are summarized in the following.

For example, the dependency on independent energy sources, e.g., integrated batteries, represent risks associated with the unavailability of CFUs during the process of recharging, i.e., the working number of CFUs is temporarily reduced. In addition, charging stations could become a target of enemy sabotage. In order to minimize the risk of no charging opportunities within the cluster, multiple charging stations would be required, which increases the necessary effort to implement the decentralization concept by dynamic clustering (e.g., due to geographical constraints of the charging infrastructure).

The problem with energy supply is even aggravated by the fact that the cluster concept needs to be "dynamic", which results in high-energy demands, compared to a static network, which would demand energy only for communication. Constantly moving CFUs consume electric energy (transportation by electric UGVs) or gasoline (e.g., transportation of the container system by truck). In further consequence, operating costs are most likely higher compared to the current situation of central warehousing and supply chain management. In order to counteract this problem, energy-self-sufficient solutions, e.g., solar panels or wind power can be considered.

The functionality of the concept is highly dependent on transport units constantly circulating back and forth. If the backhaul of empty boxes from the frontline to the brigade does not occur, the supply chain ultimately breaks down due to the unavailability of transport crates. In order to keep the supply chain running, the circulation of boxes needs to be tightly controlled. The automatic communication system of the clustering system itself could provide the necessary information of individual crates' position, movement and availability.

3.6 Opportunities Presented by the Decentralization Concept

Once implemented, dynamic clustering offers several opportunities, each of which contributes to improved resilience. Apart from keeping a stable supply chain, despite outage or destruction of a single CFU, the communication infrastructure that keeps the cluster functional theoretically enables real-time demand monitoring. Since each CFU synchronizes its inventory information with the residual cluster, the entire cluster is capable to communicate specific demands from the frontline back to the brigade. The prerequisite is permanently running a continuous and stable communication line from the frontline via each cluster level back to the brigade warehouse system. However, real-time detection of consumption currently might not be possible for most of the consumables, i.e., rifle ammunition. Consumption of consumables at the frontline can only be indirectly measured by the number of DOS delivered or by the number of empty crates returned. Eventually, the near real-time monitoring also would improve accuracy in demand forecasting.

3.7 Evaluation of Resilience

The available literature about evaluating resilience of supply chains, which is reviewed in detail in other publications [24], indicates industrial and research interest in having benchmarking solutions available. However, comparability of resilience performance is difficult, because of differences in supply chains' dependencies on reference factors, which determine resilience. As implied in the introduction, resilience can basically be defined by reactive or pre-emptive (also proactive) factors and metrics defining the resilience strategy [11, 25], although more dimensions were also suggested [24].

The probably most suitable evaluation method that could currently be adapted for the evaluation of the presented decentralization concept was published by Mari et al. [26]. They defined four metrics to determine supply chain resilience: 'accessibility', 'robustness', 'responsiveness' and 'flexibility' based on the holistic view of supply chains as complex networks of interconnected units. This approach intends to capture all players and factors involved in a supply chain network. As for the evaluation of the presented decentralization concept based on dynamic clustering, the evaluation approach (or other published means) would require a confined analysis of supply with commodities delivered from the battalion level to the foxhole. The analyses of any upstream factors of the supply chain process would thus be redundant.

Alternatively, the implementation of the decentralization concept itself could be seen as the introduction of an additional resilience metric (next to the other four) that captures the level of decentralization of the supply chain. Regardless of the approach applied, it must be considered that the development of the metrics by Mari et al. were derived from civilian logistics [26], which might change in the context of military logistics due to different overall objectives, i.e., cost efficiency vs. fail-safety.

4 DISCUSSION

The described concept for the decentralization of military logistics by fragmentation of repositories appears promising for increasing the resilience of supply chains between battalions and troops at the frontline. Probabilities of sabotage of entire repositories or delivery routes is reduced, because enemies would need to uncover the positions of all fragments and delivery points for successful supply chain disruption. Furthermore, the likelihood of enemy detection is even reduced as all repository fragments are mobilized, and delivery points are established only temporarily within short timeframes due to automated cross-docking and constant repositioning.

The inherent advantage of dynamic clustering is an increased degree of automation when managing the flow of goods from the battalion to the frontline. This would also allow for more accurate demand forecasts based on the consumption rates continuously reported back from the frontline. However, the problem of monitoring consumption rates at the frontline still leaves room for discussion, since automatic detection of consumption rates (of rations or ammunition) is currently only possible by indirect means, e.g., by extrapolation from backhaul of empty transport items.

Note that the backhaul of empties can be accomplished by applying the same mechanisms used for forward transportation. Squads could exchange empty boxes at the temporary delivery points once they meet for pickup of fresh supplies (Fig. 2). The UGVs would then carry the empties within their cluster until cross-docking with the truck from the battalion at the upstream delivery point (in return, the UGV picks up a full box). Eventually, the truck returns the empties upstream to the brigade for refilling. The circle of the transport items would thus be closed, which provides the potential to reduce costs and environmental burdens associated with packaging waste, thus contributing to efforts in executing strategies for "Green Defence" [27, 28]. Moreover, this backhaul circle might even be used to remove garbage or dirty clothing from the frontline for recycling or cleaning.

The derived decentralization concept obviously has its limitations. The cluster and transportation technologies in their current developmental stages still need to clear the proof-of-concept readiness level and be piloted in selected processes. Therefore, testing the concept by employing real military resources is currently not possible. Nevertheless, it serves as a platform for iterative requirements elicitation, because it was derived based on expert information from the Austrian military logistics school and involves the latest science-based knowledge in logistics solutions.

5 CONCLUSION

The presented research underscores the importance of integrating modern logistics technologies and innovative strategies to ensure the continuous or even improved combat readiness level of military forces. As the RESISTANT project progresses, it will contribute valuable insights and solutions for resilient supply chain management with implications beyond military applications.

Acknowledgements

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6 REFERENCES

[1] Rutner, S. M., Aviles, M., & Cox, S. (2012). Logistics evolution: A comparison of military and commercial logistics thought. *The International Journal of Logistics Management, 23*(1), 96–118. https://doi.org/10.1108/09574091211226948

[2] Serrano, A., Kalenatic, D., López, C., & Montoya-Torres, J. R. (2023). Evolution of military logistics. *Logistics, 7*(2), 22. https://doi.org/10.3390/logistics7020022

[3] Piggee, A. F. (2002). *Transformation – Revolution in military logistics*.

[4] Rice, J. B., Jr., & Caniato, F. (2003). Building a secure and resilient supply network. *Supply Chain Management Review, 7*(5), 22–30.

[5] Valtonen, I., Rautio, S., & Lehtonen, J.-M. (2023). Designing resilient military logistics with additive manufacturing. *Continuity & Resilience Review, 5*(1), 1–16. https://doi.org/10.1108/CRR-08-2022-0015

[6] Schneikart, G., Mayrhofer, W., Löffler, C., & Frysak, J. (2024). A roadmap towards circular economies in pharma logistics based on returnable transport items enhanced with Industry 4.0 technologies. *Resources, Conservation and Recycling, 206*, 107615. https://doi.org/10.1016/j.resconrec.2024.107615

[7] Lima, M. (2024). Strengthening healthcare supply chains: A comprehensive strategy for resilience in the face of natural disasters. *Health Emergency Management, 5*(2), 47–67. https://doi.org/10.61093/hem.2024.2-04

[8] Kungwalsong, K., & Ravindran, A. R. (2014). Assessment of disruption risks in supply chains. In J. Wang (Ed.), *Encyclopedia of Business Analytics and Optimization* (pp. 209–219). IGI Global.

[9] Zhai, A., Guo, D., Gollapudi, S., Kollias, K., & Delling, D. (2024). Deep learning-based alternative route computation. In S. Dasgupta, S. Mandt, & Y. Li (Eds.), *Proceedings of the 27th International Conference on Artificial Intelligence and Statistics* (pp. 4078–4086). Proceedings of Machine Learning Research: PMLR.

[10] Alexa, A. (2021). *Militärlogistik 4.0 – Trends und deren Auswirkungen auf die Militärlogistik*. Landesverteidigungs-akademie. (in German)

[11] Sani, S., Schaefer, D., & Milisavljevic-Syed, J. (2022). Strategies for achieving pre-emptive resilience in military supply chains. *Procedia CIRP, 107*, 1526–1532. https://doi.org/10.1016/j.procir.2022.05.186

[12] Oleksenko, O., Misiuk, H., Ikaïev, D., Korshok, V., & Palka, V. (2024). Main trends in the use of unmanned aircraft in the Russian-Ukrainian war. *DNDIVSOVT, 20*(3), 99–105. https://doi.org/10.37701/dndivsovt.21.2024.12

[13] Boliubash, O., Ponomarov, A., Shulezhko, V., & Shulezhko, A. (2024). The procedure for the use of unmanned aerial vehicles to conduct reconnaissance on the ground in wartime conditions. *DNDIVSOVT, 19*(1), 7–13. https://doi.org/10.37701/dndivsovt.19.2024.01

[14] Supply chain resilience through decentralization. (2023). *Strategic Direction, 39*(6), 29–31. https://doi.org/10.1108/SD-04-2023-0050
[15] Adana, S., Manuj, I., Herburger, M., Cevikparmak, S., Celik, H., & Uvet, H. (2024). Linking decentralization in decision-making to resilience outcomes: A supply chain orientation perspective. *The International Journal of Logistics Management, 35*(1), 256–280. https://doi.org/10.1108/IJLM-07-2022-0308
[16] FHWien der WKW. (2025, January 10). *RESISTANT – Resilientere Militärlogistik auf Basis einer durchgehend digitalisierten, dislozierten und autonomen Supply Chain*. https://www.fh-wien.ac.at/forschung/forschung-an-der-fhwien/resistant/ (in German)
[17] Langner, K., Frysak, J., Schneikart, G., Riegler, W., & Herburger, M. (2024). Challenges for military supply chain resilience: A digitalized, decentralized, and transparent approach. In *NOFOMA 2024* (pp. 1–18). Stockholm, Sweden.
[18] Krenn, F., Lampl, S., & Stary, C. (2025). Towards resilient digital supply chains. In M. Elstermann & M. Lederer (Eds.), *Subject-Oriented Business Process Management: Models for Designing Digital Transformations* (pp. 230–236). Springer Nature Switzerland.
[19] Johannes Kepler Universität Linz. (2025, January 10). *RESISTANT – Resilientere Militärlogistik auf Basis einer durchgehend digitalisierten, dislozierten und autonomen Supply Chain*. https://www.jku.at/institut-fuer-wirtschaftsinformatik-communications-engineering/forschung/forschungsprojekte/laufende-projekte/resistant/ (in German)
[20] Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly, 28*(1), 75–105. https://doi.org/10.2307/25148625
[21] Object Management Group. (2025, March 31). *Business Process Model and Notation (BPMN), Version 2.0.2 (Specification No. V2.0.2)*. https://www.omg.org/spec/BPMN
[22] Schneikart, G., Mayrhofer, W., Frysak, J., & Löffler, C. (2023). A returnable transport item to integrate Logistics 4.0 and circular economy in pharma supply chains. *Tehnički glasnik, 17*(3), 375–382. https://doi.org/10.31803/tg-20230504144856
[23] Schneikart, G., Löffler, C., Brandner, M., Pfoser, S., & Mayrhofer, W. (2024). Requirements for the transformation towards returnable transport item-enabled circular economies in the Austrian parcel industry. *Tehnički glasnik, 18*(2), 254–261. https://doi.org/10.31803/tg-20240420173731
[24] Pangarkar, G. (2023). *Measuring supply chain resilience*. FH Vorarlberg.
[25] Agarwal, N., Seth, N., & Agarwal, A. (2022). Evaluation of supply chain resilience index: A graph theory based approach. *Benchmarking: An International Journal, 29*(3), 735–766. https://doi.org/10.1108/BIJ-09-2020-0507
[26] Mari, S. I., Lee, Y. H., & Memon, M. S. (2015). Complex network theory-based approach for designing resilient supply chain networks. *International Journal of Logistics Systems and Management, 21*(3), 365–384. https://doi.org/10.1504/IJLSM.2015.069733
[27] Mihailov, M.-E., & Ichim, M. (2024). Enhancing Romanian naval resilience to climate change: Advanced functional materials for green defence strategies. *Journal of Environmental and Sustainability Studies, 7*(2), 17. https://doi.org/10.20849/jess.v7i2.1466
[28] Larsen, K. K. (2025). *The NATO Green Defence Framework*.

Authors' contacts:

Gerald Schneikart, MBA, MSc, PhD
(Corresponding author)
FHWien der WKW, Institute for Digital Transformation and Strategy,
Währinger Gürtel 97, 1180 Vienna, Austria
+43 1 476 77 5761, Gerald.Schneikart@fh-wien.ac.at

Josef Frysak, Dr.
FHWien der WKW, Department of Digital Economy,
Währinger Gürtel 97, 1180 Vienna, Austria

Karoline Langner, MSc
University of Applied Sciences Upper Austria, Logistikum Steyr,
Wehrgrabengasse 1-3, 4400 Steyr, Austria

Walter Mayrhofer, Prof. Dr.
FHWien der WKW, Institute for Digital Transformation and Strategy,
Währinger Gürtel 97, 1180 Vienna, Austria