Bodnár István[1]

THE EFFECT OF EMBEDDED SYSTEMS ON THE LOGISTIC SUPPORT OF THE MILITARY FORCES

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Abstract

Nowadays, almost all military technology contains some kind of cyber-physical component, with the exception of small arms. Large-scale industrial and military equipment now incorporate embedded systems without exception. The military forces must equip their logistic systems to store, manage, maintain, and repair these devices, asset systems, and components. The increasing complexity of military technologies requires a higher level of expertise, which is why armies alone cannot manage the entire logistics supply chain and therefore need to bring in external companies and specialists with the expertise to keep these technologies in a combat-ready state.

Keywords: military embedded system, procurement, commissioning, in-service-support

Absztrakt

Napjainkban minden katonai felhasználású eszközben található már valamilyen kiber-fizikai összetevő, ez alól talán már csak a kézifegyverek jelentenek kivételt. A nagyméretű polgári ipari és a katonai eszközökben is üzemelnek beágyazott rendszerek. A haderő logisztikai rendszereit fel kell készíteni ezen eszközök, eszközrendszerek és alkatrészeik tárolásra, kezelésére, karbantartására, valamint javítására. A haditechnikai eszközök egyre komplexebb felépítettségük miatt ma-

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gasabb szintű szakértelmet igényelnek, ezért a hadseregek korlátozottan képesek kezelni a haditechnikai támogatás egyes feladatait a logisztikai támogatási láncban, így külső cégeket és szakembereket is alkalmazni kell, akik speciális szaktudásukkal hadra fogható állapotban tudják tartani a haditechnikai eszközöket.

Kulcsszavak: katonai beágyazott rendszer, beszerzés, üzembe helyezés, üzemben tartás

Introduction

In our present days, embedded systems getting to be more and more familiar in our environment as the devices became more complex and the parts of these are highly developed. These systems are made up of specialized computer hardware and software designed to perform specific functions, ranging from simple devices to complex systems.[2]

They are widely used next to ordinary use, we can find them across various industries, including the military. Embedded systems have become an integral part of modern military hardware. These systems offer advanced processing power in Small-Form-Factor (SFF) systems[3]. Military Embedded System (MES) covers various aspects of defense engineering, including radar, avionics, Artificial Intelligence (AI), electronic warfare, unmanned technology, and other defense segments.

In the sorted fields we had to integrate them into the logistics systems from the procurement through the commissioning until the in-service support and at the end of their life cycle we have to remove them from the system. Integrating embedded systems into logistics systems involves incorporating hardware and software components into a supply chain management system.

This integration requires expertise in both logistics and embedded systems, as well as a thorough understanding of the specific requirements of the forces.

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2 Bundalo, Z., & Bundalo, D. (2019). Embedded Systems Based on Open Source Platforms. IntechOpen. https://doi.org/10.5772/intechopen.85806

3 Group, S. M. (2017). Small Form Factor Embedded Systems. Small Form Factor Embedded Systems - Mobility Engineering Technology. https://www.mobilityengineeringtech.com/component/content/article/adt/pub/features/articles/26993

The necessity of the integration

The Hungarian Defense Forces (HDF) in the last decade has launched the Zrínyi Defense and Force Development Program which covers modernization programs and procurement of advanced military equipment. This program is the largest defense and military procurement in the close past in Hungary.[4] The strategic objective of the country is to develop the HDF by 2030 to become a key military force in the region with the help of EU and NATO partners.

The biggest investor in this project is the German government and in particular, next to other huge military-industrial companies is the Rheinmetall incorporation. The company delivered the first Lynx infantry fighting vehicles to the HDF in 2023, including an initial supply of spare parts, and maintenance support as well[5]. This solution is a good example of the cooperation between the forces and the military industry. Outsourcing to external companies with expertise and experience can free up some resources for the military to focus on their core competencies but still, the force needs to upgrade itself to meet the new challenges of the new tools.

Of course, these fighting vehicles are made up of several embedded solutions that work together as part of a big system.

Based on current developments and procurements, the HDF must establish storage and management procedures for newly acquired equipment and parts. In preparation for the future, HDF logistics units must be equipped to handle all components related to embedded systems, including from the motherboard components, through the microchips, FPGAs (Field Programmable Gate Arrays), to the spare parts for the new systems. Proper warehouse management involving key processes such as receiving, storage, picking, and shipping is essential for maximizing space and ensuring accurate order fulfillment for the force.

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4 Pike, J. (2019). Hungarian Defense Force - Modernization. Hungarian Defense Force - Modernization. https://www.globalsecurity.org/military/world/europe/hu-hdf-land-mods.html

5 miniszterelnok.hu. (2021). Hungary to extend cooperation with German defence industry giant Rheinmetall https://2015-2022.miniszterelnok.hu/hungary-to-extend-cooperation-with-german-defence-industry-giant-rheinmetall/

Engineering

Developing an MES-based device requires careful construction design and execution which means from selecting the right hardware components to developing secure software, the systems demand meticulous attention to detail. It must be designed to operate in harsh environments, withstand physical stress, and maintain robustness at all times. Moreover, it must be optimized for power and energy efficiency, ensuring that it can operate for extended periods on limited power sources. The planning and developing process of these devices are intricate that require expertise in various fields, including hardware design, software development, and system integration.

In the developing process before the commissioning, we can count on the following steps[6]:

1. Define the system requirements - Determine the specific functionality and features required for the system.
2. Select the hardware components - Select the components that meet the system requirements and are rugged enough for military use.
3. Design the system architecture - Determine how the hardware components will work together to meet the system requirements.
4. Develop the software - Write the software programs that will run on the embedded.
5. Test the system - Test the system to ensure that it meets the requirements and is reliable.
6. Certify the system - Obtain the necessary certifications to ensure that the system meets military standards.

The MES requires additional considerations beyond those of general-purpose embedded systems. These systems must meet strict requirements for reliability, security, ruggedness, and efficiency[7]. MES must adhere to industry-specific standards and regulations and may require specialized certifications. It is important to carefully plan and

[6] Reay, J.H. (2000). DoD Supply Chain Management Implementation Guide.

[7] Vai, Vhelihan, & R Nahill. (2018, May). Secure Embedded Systems. In Lincoln Laboratory. Retrieved Apr 2, 2023, from https://www.ll.mit.edu/sites/default/files/page/doc/2018-05/22_1_9_Vai.pdf

execute the development process, including defining system requirements, selecting appropriate hardware components, designing system architecture, developing software, testing the system, and obtaining necessary certifications. It is highly recommended to work with experienced engineers and follow best practices for developing industrial- or military-grade embedded systems.

It is unlikely that forces would handle the assembly of embedded systems without external companies, as the development and assembly of electrical systems require expertise and specialized knowledge. Companies in the electronic industry have the necessary resources, equipment, and expertise to handle the development, assembly, and testing of the devices. Additionally, these companies have experience working with various types of microcontrollers and have a better understanding of the latest technological advancements. Therefore, it is more efficient and cost-effective for armies to outsource the development and assembly of embedded systems to external companies rather than trying to handle it themselves.

Procurement

When purchasing electronic or embedded based military hardware, it is also important to understand the expected lifespan of the product. Some solutions are designed for short-term use and may only be produced for a limited time. Others are designed for long-term use and may have a longer lead time.

The availability of replacement parts should also be considered when making a purchase. If replacement parts are difficult to find or no longer available, it may be difficult or impossible to maintain or repair the whole MES-based equipment in the future.

According to my approach, it is necessary to know the manufacturing lead time of the parts to count with this duration. In the case of products that are not commercial or not ready to use. The HDF logistics have to create a mechanism to handle them in their logistics system.

In the industry – which means also the defense -, mostly the hardware but in some cases also the software development approaches are classified into four categories: Commercial Off-The-Shelf (COTS), Modified Off-

The-Shelf (MOTS), Government Off-The-Shelf (GOTS), and Non-Developmental Item (NDI) or NOTS (Niche or NATO off-the-shelf software).[8]

These categories are necessary, especially in the industry, because it helps to identify the most appropriate approach to use for a particular project. Each concept has its advantages and disadvantages, and choosing the wrong approach can lead to project failure or cost overruns. By understanding the differences between these approaches, organizations can make informed decisions about which approach to use based on the project's specific requirements, budget, and timeline. This can help to ensure that software projects are completed on time, within budget, and meet the required specifications:

- COTS are readily available in the commercial market. These products are generally designed to meet the needs of a broad range of customers and do not require any significant modifications to meet the needs of a specific user.
- MOTS products that have been modified to meet the specific requirements of a particular user. This may involve adding new features, customizing the user interface, or integrating the software with other systems.
- GOTS is created specifically for use by the government or military. This type of software may be developed by government agencies themselves or by contractors working on behalf of the government.
- NOTS is available for use without modification. This may include items such as commercial off-the-shelf hardware, or software products that have been certified for use by the government without requiring any modifications.

It is crucial to distinguish between the different sources for obtaining subsystems when looking at military firms involved in projects. The government is responsible for procuring and supplying specific subsystems for military use, while some items can be obtained through specific regulations, emergency requirements, and those unique to nuclear ordnance material. Additionally, contractors must provide comprehensive data requirements for major weapon system subsystems, components, and spare parts. The HDF will be required to purchase certain subsystems, including both government-furnished equipment (GFE)

[8] TechTarget. (2010, April 1). Data Center. https://www.techtarget.com/searchdatacenter/definition/COTS-MOTS-GOTS-and-NOTS

and government-mandated equipment (GME), and provide them for the entire system.

Commissioning and Quality Assurance

Embedded systems have revolutionized the way military hardware operates, enabling sophisticated equipment to function with greater precision and efficiency. Commissioning military equipment with embedded systems requires careful planning, design, and testing to ensure reliable performance in the field.

The Quality Assurance (Q&A) process plays a critical role in the commissioning procedure by helping stakeholders make informed decisions. In the field of logistics, the Q&A process is especially important as it helps identify potential issues that may arise during the assembly and transportation of MES-based electronic systems. By collecting and analyzing data, the Q&A team can closely monitor the logistics process and take corrective action to prevent or mitigate these issues. An effective sampling plan is an integral part of the Q&A process, as it ensures that the data collected is representative of the entire logistics process. By optimizing logistics through an effective sampling plan and Q&A process, stakeholders can ensure that quality standards are met and that the final product is of the highest quality possible.[9]

In the development of embedded systems for military applications, both developmental and operational evaluation perspectives are considered during the planning and evaluation phases. The Test and Evaluation strategy involves on-site inspection acceptance tests, specifically the Systems Integration Test (SIT) the Factory Acceptance Test (FAT), and the Site Acceptance Test (SAT). The SIT involves the testing of complete equipment packages, including both hardware and software control systems. The goal of SIT is to ensure that all components are functioning correctly and that they are properly integrated with one another. By conducting SIT, engineers can identify and resolve any issues before the system is deployed in the field. FAT verifies that the system meets the performance and functional requirements specified by the customer, while the SAT confirms that the system operates correctly in its intended environment. These tests ensure that the MES-based war hardware is reliable and meets the needs of the

[9] Borja, C. (2022, April 26). What is Quality Assurance? How QA Can Improve Your Business - SweetProcess. https://www.sweetprocess.com/quality-assurance/

military and helps to minimize downtime and reduce the risk of costly repairs or replacements.[10]

Military organizations should adopt secure coding practices, including static and dynamic analysis, unit and integration testing, and requirements traceability. When dealing with MES, it is crucial to ensure that they are safe, reliable, and secure, and coding guidelines must follow industrial or government-mandated standards. Testing MES solutions presents unique challenges, and it is crucial to develop and execute test cases that focus on the specific requirements of the system. For life-critical and mission-critical systems, extensive testing is required. A disciplined methodology within an organization can help teams cooperate effectively, and bidirectional traceability is essential to ensure that every requirement is covered and linked back to higher-level objectives. By using a combination of test and analysis tools and methods, military organizations can create secure devices that meet their specific needs.

In-Service Support (ISS)

The ISS is a logistical service management definition that refers to a set of activities that are designed to ensure the reliability, availability, maintainability, and durability of MES equipment during operational missions and training. ISS includes various processes, such as training, ground support systems, technical publications, repair and overhaul, spare procurement, and modifications. The ultimate goal of ISS is to ensure maximum system availability for the forces, and it is critical for maintaining the long-term reliability and availability of the equipment.[11]

To guarantee that MES operates optimally, it is essential to have a robust supply chain for spare parts and logistics management. One way to achieve this is to outsource these tasks in the frame of ISS to external companies with experienced experts instead of relying solely on the military. This approach allows the military to concentrate on its core tasks while freeing up resources that would have been spent on managing and maintaining the supply chain. Moreover, the primary objective of Army

[10] RINA.org. (n.d.). FAT, SIT, String and SAT Services - RINA.org. https://www.rina.org/en/fat-sit-string-and-sat-services

[11] Berkok, U., Penney, C., & Skogstad, K. (2013). In-service support: best practices of selected countries. Contract, 7, 7B4. https://cradpdf.drdc-rddc.gc.ca/PDFS/unc131/p538246_A1b.pdf

maintenance is to guarantee unit readiness by maintaining weapon systems and equipment in a fully mission-capable state. It is critical to have a dependable and efficient supply chain for spares and maintenance to ensure that MES function optimally and are always mission-ready.

The HDF and the ISS company experts can cooperate by working together to ensure that military hardware is properly maintained and repaired. The ISS company can provide technical expertise and knowledge support for the force, while the HDF can provide logistical and operational support. This can be achieved through regular communication, joint training exercises, and the establishment of clear lines of responsibility and accountability. That is a good way to keep the military equipment in good working order, which is essential for the success of military operations.

In the military equipment industry, it's common for manufacturers to bid for or establish a subsidiary dedicated to supplying a specific equipment system for the ISS. This is partly because military equipment production typically lasts for 5-10 years before moving on to newer models and development. However, support for a single piece of equipment may be required for up to 20-30 years after production completion, and the parent company often prefers not to bear this responsibility. As a result, a separate subsidiary is usually set up to handle long-term support.

Logistical challenges in the MES integration

Logistics management plays a critical role in ensuring the success of any military operation. In general, we can obtain the proper management of operations support chains, transportation, and distribution of resources can determine the effectiveness of military operations. This is especially true when it comes to MES, which are critical in modern warfare.[12]

MES refers to the use of advanced technology in military equipment, including communications systems, weapons, and surveillance equipment. These systems require a unique approach to logistics management, as they are often highly specialized and require specialized support and maintenance.

[12] Zijm, H., Klumpp, M., Regattieri, A., & Heragu, S. (Szerk.). (2019). Operations, Logistics and Supply Chain Management. Springer International Publishing. https://doi.org/10.1007/978-3-319-92447-2

One of the key challenges in managing the logistics of MES is the need for rapid deployment. Military operations often require the rapid movement of personnel and equipment to remote locations, with short notice. This requires careful planning and coordination to ensure that all necessary equipment and resources are available when and where they are needed. Another challenge in managing the logistics of MES is the need for specialized training and support. These systems often require highly trained personnel to operate and maintain them effectively. They also may require specialized parts and equipment that are not readily available in all locations. This condition requires careful planning to ensure that the necessary resources are available when needed.

In order to overcome these obstacles, it's crucial for the military to possess a highly advanced logistics management system that can ensure the swift deployment, accessibility, and maintenance of military equipment and systems. Such a system should comprise cutting-edge tools for operations support chain management, transportation management, and distribution networks, which would facilitate the smooth movement of resources and equipment.

In properly acquiring and maintaining MES, the military needs to allocate significant resources towards training programs that empower their personnel to operate and maintain these systems effectively. These training programs should encompass both theoretical and practical aspects and should be complemented by ongoing support and maintenance initiatives that guarantee the long-term viability of these essential technologies.

One of the key benefits of effective logistics management for MES-based equipment is the ability to improve operational efficiency. By ensuring that all necessary MES-related solutions and resources are available when and where they are needed, military operations can be conducted more efficiently and effectively. This can help to reduce costs, improve mission success rates, and minimize the risk of equipment failure or downtime.

Storage

The storage of embedded-based systems is very common in electrical equipment. In logistical warehouses is crucial to ensure their

safety and longevity. The basis of storing electronic equipment in warehouses lies in the proper handling of the equipment, protection from environmental factors such as moisture, dust, and temperature changes, and ensuring adequate security measures to prevent theft or damage. Proper packaging, labeling, and documentation are also essential for efficient storage and retrieval of the equipment when needed. In addition, regular maintenance and periodic checks are necessary to ensure that the equipment remains in good condition during storage. Some devices need to be stored in a way that allows them to be charged with an electric current. [13]

Spare parts for key components of embedded systems could become more and more scarce, mainly in the case of digital technologies. As manufacturers have gone out of business, engineers have retired, and machine tools have rusted. All of us remember that the military has resorted to cannibalization – taking parts from older, not yet supported, mainly Soviet equipment – which increases wear and tear on those devices and contributes to higher maintenance costs. Spare parts shortages and other on-the-job frustrations are the top reasons troops leave the military. Incorporating the use of certified used replacement parts, similar to commercial companies, could lead to cost savings on maintenance and improve the force's mission readiness. Additionally, investing in new spare parts will likely provide better service at the same or lower total cost to the HDF.

System operation

Operating embedded system-based military hardware poses several challenges. MES are designed to perform specific tasks in military applications, from communication through navigation to weapons systems. These systems collect and process information to aid military commanders in making informed decisions. The use of wireless technologies, cloud computing, and AI is driving the demands for MES. They require more reliability, security, and structure than general-purpose embedded systems. The major challenges include managing obsolescence, incorporating new technology, and ensuring not just compatibility but interoperability with other regularized military systems.

[13] Army Regulation 740–1 - Storage and Supply Activity Operations. (2008). DoD. https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/r740_1.pdf

However, emerging trends related to standards AI for military, airspace, and aerospace applications, and more robust safety and cybersecurity measures are helping to meet these challenges. AI is becoming increasingly important in military applications. It can be used to analyze large amounts of data quickly, identify patterns, and make predictions. AI can also be used to control autonomous systems, such as Unmanned Aerial Vehicles (UAVs). The use of AI in MES is expected to grow in the future.[14]

MES are also used in various applications, including airspace and aerospace. Military aircraft and spacecraft require highly reliable and secure systems. MES are designed to operate under extreme conditions. I can mention the main line of my research topic what about the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems.[15] I am looking at how MES-based solutions can be integrated into these systems, from the technicians and soldiers fighting in the field, through the data transmission systems, to the central processing systems.[16]

Safety and cybersecurity are critical concerns in MES as the military hardware must operate reliably and securely, and any compromise of the system can have severe consequences. More robust safety and cybersecurity measures are being developed to ensure that military electrical equipment remains secure and operational.

Remove from the system

MES or a spare part of it at the end of its life cycle can operate no longer as intended. In addition, they may contain hazardous materials such as lead, mercury, and cadmium, which can be harmful to the environment and human health if it is not properly disposed. Removing these records of embedded parts from the logistics system ensures that they are not accidentally used or mistakenly built in again, and that

[14] Zeimpekis, V., Kaimakamis, G., & Daras, N. J. (Szerk.). (2015). Military Logistics: Research Advances and Future Trends (Köt. 56). Springer International Publishing. https://doi.org/10.1007/978-3-319-12075-1

[15] DoD. (1992). *Compatibility, Interoperability, and Integration of Command, Control, Communications, and Intelligence (C3I) Systems*. https://fas.org/irp/doddir/dod/d4630_05.htm

[16] Courtney. (2017). SFF embedded computing for C4ISR. Military Aerospace Electronics. Retrieved May 8, 2023, from https://www.militaryaerospace.com/computers/article/16709883/sff-embedded-computing-for-c4isr

they are properly handled in accordance with actual regulations. Proper disposal or recycling of electronic systems also helps to conserve natural resources and reduce waste.[17]

Removing electronic systems from the logistics system at the end of their life cycle requires proper disposal methods that are safe for both the environment and humans. Here are some steps to follow:

- Identify the electronic systems that need to be removed from the logistics system.
- Ensure that the data in the electronic systems are wiped clean to prevent any sensitive information from getting into the wrong hands.
- Determine if the electronic systems can be reused or refurbished.
- If the electronic systems cannot be reused or refurbished, dispose of them using proper methods such as recycling or sending them to an electronic waste disposal facility.
- Follow all local, state, and federal regulations related to the disposal of electronic systems.
- Document the disposal process to ensure compliance and transparency.

Summarize

This article explores the fusion of MES-based equipment and parts in military logistics, encompassing a range of defense engineering aspects. MES has emerged as an indispensable constituent of contemporary military hardware, as they provide high-performance computing capabilities in compact systems. The integration of such systems into logistics necessitates expertise in both logistics and engineering, along with a comprehensive understanding of the unique demands of the military. This integration involves assimilating hardware and software components into an operational supply chain management system, starting from procurement to the end of their life cycle.

[17] Richard G. Sharpe (2017, September 14). Cyber-Physical Systems in the Re-use, Refurbishment and Recycling of Used Electrical and Electronic Equipment - ScienceDirect. https://doi.org/10.1016/j.jclepro.2017.09.087

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