Integrated Solutions for NATO Forward Medical Evacuation: Experiences and Insights

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***Abstract* — The term "medical evacuation" means accelerated transport of casualties from the point of injury, through several levels of Medical Treatment Facilities, to the country of residence. "Forward evacuation" denotes the first and most critical step, i.e., delivering the wounded to a field hospital.**

To enable medical evacuation in a coalition environment, its particular areas, including messages, processes, and architecture, are standardized by NATO. Also, several solutions supporting medical evacuation are emerging, including a reference implementation by NATO and various systems developed by individual countries. It seems, however, that the literature on the technical aspects of these solutions is scarce. Our goal is to at least partially fill this gap and discuss the requirements and challenges related to the implementation of integrated systems supporting (forward) medical evacuation. Our observations and requirements are drawn from both development work on the MEDICS[1] project and experience from Poland's missions in Iraq and Afghanistan.

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I. Introduction

The term "medical evacuation" refers to a logistic chain that enables expedited transport of casualties from the point of injury, through several levels of Medical Treatment Facilities (MTFs), to the country of residence, where the final, possibly long-term treatment may be provided (see Fig. 1). The lowest level, referred to as "forward evacuation," concerns delivery of the wounded from the battlefield to a nearby field hospital (level one MTF, or MTF Role1). This level is both the most important, as its performance directly affects the survivability of casualties, and the most challenging, because of the strict time regimes and the dangers of possible enemy activity.

This paper discusses building an integrated software solution that supports medical evacuation, with a focus on support for forward evacuation. Our solution developed in the MEDICS project contains a set of tools that enable initiation and management of the evacuation process and provide situation awareness. We deliver guidelines and remarks that result from both past experience and development efforts.

The observations and remarks contained in the paper are based on (1) the authors' development work on Medical Information Management System (MEDICS), an integrated solution supporting medical evacuation for the Polish Armed Forces, (2) participation in standardization efforts within the Health Information Systems and Technology Working Group (HIST-WG) [1] as well as interoperability tests performed during Coalition Warrior Interoperability eXploration, eXperimentation, eXamination eXercise (CWIX) [2], and (3) experience gained during Polish missions in Iraq and Afghanistan.

The main contribution of the paper is twofold: First, it contains a quite complete overview of forward evacuation operation from the software implementation perspective of a system that supports the process. Second, we present our experiences and conclusions. We believe that similar research publications in the area are rare.

The paper is organized as follows: section II includes a brief comment on standardization efforts in the area of medical evacuation. Section III contains an overview of related work. In section IV, general architecture and operation of forward evacuation are presented. Section V contains a discussion on individual components and includes the authors' observations. The paper ends with conclusions and future work proposed in section VI.

II. Standardization and Interoperability Testing

There are a number of initiatives supporting standardization and interoperability testing within NATO. The NATO Health Information Systems and Technology Working Group (HIST-WG) focuses on experimentation, cyber security, and interoperability between nations in the field of military health information systems, technology, and information exchange. It incorporates Medical Information

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Exchange Requirements Panel (Med-IER), which discusses the required changes to the format of medical messages for publication in APP-11 (NATO Message Catalogue) [3]. HIST-WG members are involved in Think-Tank for Information Decision and Execution Superiority Sprint (TIDE SPRINT) [4], CWIX exercises, and the development of Federated Mission Networking (FMN) [5] Spiral 6 documents.

The NATO Centre of Excellence for Military Medicine (NATO MILMED COE) [6] is a multinational organization that supports Alliance in the medical field transformation. Training Branch is responsible for education, training, exercises, and medical evaluation. It organizes biennially Vigorous Warrior (VW) NATO medical exercises [7].

The Coalition Warrior Interoperability eXploration, eXperimentation, eXamination eXercise (CWIX) is an annual NATO military initiative designed to bring about continuous improvement in interoperability for the Alliance. CWIX focuses on testing and improving interoperability of NATO and national C4I systems, with particular emphasis on those that would be deployed within the NATO Response Force (NRF) or Combined Joint Task Force (CJTF). The LOG-MED Focus Area aims to support, among others, medical communities with respect to information interoperability and to capability, concept, and standards development. It also ensures the integration of existing, new, and emerging technologies and capabilities necessary to the creation of the Recognized Medical Picture. The CWIX Medical Focus Area involves more and more participating countries every year (8 in 2022: Poland, Romania, Spain, Netherlands, Finland, Belgium, United States, and Canada).

In Poland, the Military Medical Training Center (MMTC) [8] cooperates with the U.S. Army to improve interoperability in military health services. The training includes medical care on the battlefield and in urban areas, medical evacuation, and advanced life-saving procedures.

III. Related Work

In this section, we present an overview of related solutions and literature.

A. VitalsIQ

VitalsIQ [9] is a Dutch solution for care in the field and evacuation support. It works on smartphones or tablets and supports multi-patient monitoring of physiological parameters read from wearable biosensors (measuring, e.g., blood pressure, heart rate, respiratory rate, and oxygen content in the blood). In the field, medical staff can monitor vital signs, which leads to faster triage, including automated MIST (M-Mechanism of injury, I-Injury, S-Signs & Symptoms, T-Treatment) reports. It supports both online and offline (using Near Field Communication tags) medical data transfer to Electronic Health Record (EHR) deployed on every MTF. The evacuation process is supported by 9-liner reports, and Patient Tracking Messages (PTMs) reported to the Patient Evacuation Coordination Cell (PECC). It has been successfully tested on the Vigorous Warrior and CWIX exercises.

B. NATO NCIA Medical Management PECC prototype

NCIA Medical Management application [10] supports patient tracking with PTMs, patient identification with NATO Identifier (no personal data needed), and patient regulation with 9-liners, Patient Movement Request - PMRs (including bulk mode), and missions. Management of medical assets like MTFs (Role1 - Role4) and transport assets are also included. Basic charts provide a medical situational awareness. The Data Lake interface is used to feed Recognized Medical Picture or Medical COP in order to provide a higher level of situational awareness. It is probably the most NATO standards-oriented approach (APP-11 [3] medical messages, as well as proposed PTMs and NATO identifier schema (a de facto standard), are supported by this software. NATO NCIA Medical Management has been successfully tested during CWIX. The prototype is ready to use by NATO countries (under a free license restricted by NCIA).

C. NATO First Responder

NATO First Responder (FR) [11] is the US Defense Health Agency Android application for field medics to facilitate documenting injuries and care at the time of treatment on the battlefield. It allows reporting medical data from the front lines to the next level of care, i.e., EHRs on MTFs. In this way, the patient's medical data reaches the MTF before the patient arrives, allowing the medical staff to prepare in advance. Transfer of the patient's medical record to an EHR system is conducted over the cellular network or using an NFC tag (offline) in encrypted form. Smartphone-to-smartphone transfer is also supported. NATO FR is compliant with the following NATO standards: a 9-liner for evacuation, and Field Medical Card (FMC), Tactical Combat Casualty Care Card (TCCC) for clinical data. It has been successfully tested during CWIX. The software is free (available on Google Play).

D. OpenAhlta

OpenAhlta [12] is an open version of the US DoD battlefield electronic health record system AHLTA-Theater for Windows. AHLTA-Theater is a field tested and battle-proven solution. Its functionality includes immunization tracking, meds, rads, labs, full pharmacy, allergy/med interaction checking, bed management, vitals tracking, kiosk scheduling, and check-in. It provides both outpatient and inpatient encounter documentation. Medical standard terminology dictionaries like Snomed CT [13] and the International Classification of Diseases, Tenth Revision (ICD-10) [14] are supported. OpenAhlta uses the HL7 standard (Fast Healthcare Interoperability Resources - FHIR) [15] for clinical data, but it uses proprietary formats for patient tracking, so translation (e.g., with Mirth Connect broker [13]) is needed to meet NATO needs (also refer to section V.E). In terms of mappings, there are some serious limitations, i.e., gaps, incompatible naming conventions, and contradictions. In general, OpenAhlta is old-fashioned (implemented in Visual Basic 6) and complex software, but still, it is the best candidate for testing interoperability among NATO nations. It has been successfully tested during CWIX. MHS GENESIS is the modernized electronic health record managed by the US DoD that will replace AHLTA-Theater in the near future.

E. e-MED

e-MED [17] is a Polish national project (carried out by a consortium of WAT, TELDAT, and WIM). The aim is to support decisions on evacuation based on biosensor monitoring. Colors (red – critical, higher priority, yellow – urgent, green – postponed, black – no chances) are automatically presented/provided to support the triage decision-making process. For situational awareness, integration with the national Common Operating Picture is available.

F. Mewa MED

Mewa MED [18] is another Polish national project supporting medical command and control, particularly in the area of medical resource planning, monitoring the current tactical situation and medical incident management process with the use of a reconnaissance drone, delivering medical supplies directly to the battlefield, medical evacuation of the

injured from the point of injury to MTF Role 1 (forward evacuation).

G. BATDOK

US Air Force Research Laboratory (AFRL) Battlefield Assisted Trauma Distributed Observation Kit (BATDOK) [19] solution is a multi-patient, point of injury, casualty software for mobile devices that assist field medics. BATDOK allows monitoring multiple patients in the field, observing vital information (via attached monitoring devices), documenting the treatment, and transferring data to EHRs. In particular, BATDOK is a collector of real-time health status information for multiple patients, a treatment documentation tool, a medical library, and a portal to integrate patient data into their electronic health records. It is interoperable with the US DoD Ahlta-Theater EHR system and US battlefield digital situation awareness maps, which help identify the exact location of casualties. With BATDOK, field medics can wirelessly monitor multiple patients' vitals simultaneously, even in volatile environments. Medics can quickly capture full patient history, describe treatment from the point of injury through medical evacuation and assist with follow-up guidance that transfers to the patient's next stage of care. BATDOK supports MIST and TCCC for medical documentation. Data can be sent to EHR directly or can be written to an NFC tag (offline communication). Medics can manually assign triage color to the patient. Medicines can be chosen from a set that reflects the typical content of a field medic's bag; they can also be scanned by NFC. Data can be easily synchronized among different medics. BATDOK provides quick reference medical documents, interactive medical cards, and simple tools, e.g., dosing calculators. It supports audio recording. Encrypted storage of patient records is provided, and compression and packaging for low-bandwidth communication are used. The evacuation process is supported with a 9-liner. BATDOK is to be tested during CWIX'2023 exercises.

H. Research publications

In general, scientific papers refer to statistics about medical evacuation missions during conflicts or optimization of the medical evacuation process.

In [21], the authors present the results of research on the causes for medical evacuations of Polish military personnel taking part in the International Security Assistance Force (ISAF) operation in Afghanistan. 75% of soldiers who were medically evacuated from Afghanistan were no longer fit for military service in the area of operations due to the traumas they had suffered. One of the reasons for such a number may be inadequate care in the field and insufficient evacuation support.

Research based on French PECC real data for medical evacuation in Serval and Barkhane is presented in [22]. Medical evacuations in an area of five million square kilometers of the joint operation were analyzed. The authors discovered that Bravo and Charlie patients were evacuated in NATO recommended time frame. However, due to distance, Alpha patients time frame was longer than recommended by NATO.

In [23], the authors propose a Markov Decision Process for dispatching MEDEVAC assets such that prioritized battlefield casualties are transported quickly and efficiently to nearby medical treatment facilities

Analysis of triage classification errors and blood transfusion kits impact on military medical evacuation system performance is presented in [24].

IV. Integrated Solutions for Medical Evacuation

In this section, we present an overview of typical architecture and tasks for systems supporting medical evacuation.

A. Four Evacuation Levels

The complete process of medical evacuation is composed of four levels, from forward evacuation (from point-of-collection to MTF-1) to strategic evacuation (from MTF-3 to MTF-4, located in the country of residence). This is depicted in Fig. 1.

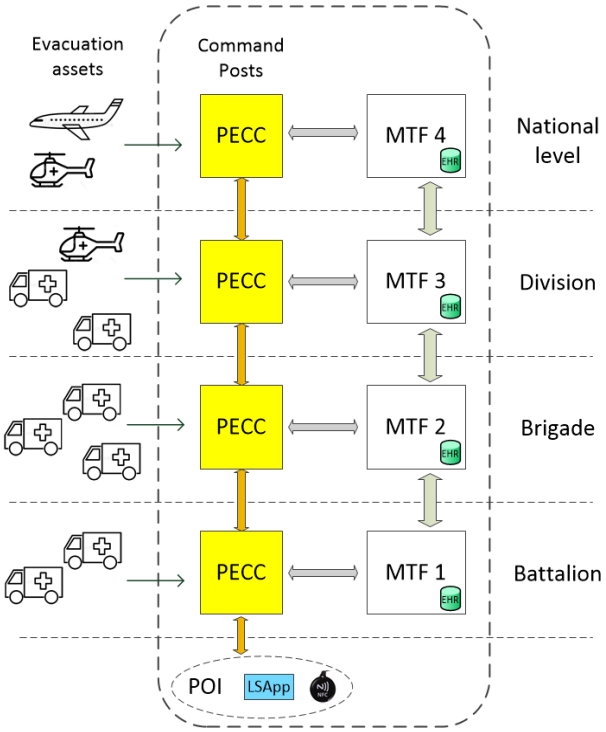

Fig. 1. Evacuation levels

Usually, with a growing level, the urgency of treatment decreases while its duration and the competence level of an MTF increase. Software systems should adhere to this hierarchy.

B. Main Tasks

The main tasks of a software system supporting medical evacuation include:

- medical evacuation planning,
- patient tracking,
- patient regulating,
- medical assets tracking,
- evacuation assets management,
- support for teleconsultations (both synchronous and asynchronous),
- medical documentation management,
- medical situation reporting (including epidemiological situation), also with the use of Medical Common Operating Picture (Medical COP),
- enabling interoperability in a multinational NATO environment.

C. Forward Evacuation

As we have already mentioned, we focus on forward evacuation, the first and most important step that comprises the delivery of casualties from a point-of-collection to a level one MTF (MTF-1). The architecture for forward evacuation is presented in Fig. 2. The main components are as follows:

- Life-Saver Application, often called "First Responder," a mobile application for a medic on the battlefield;
- Application supporting the Patient Evacuation Coordination Center (PECC), responsible for the management of the whole process and operated by PECC's staff. In our MEDICS solution, the PECC application is supported by a multi-criteria optimizer (MCO) that suggests "optimal" evacuation. As far as we know, this feature is unique for MEDICS. MCO takes into consideration the following parameters: available evacuation assets (including the number of seats for litter patients, lift, etc.), unoccupied beds in MTFs, potential evacuation routes, and limitations of evacuation time depending on the patient's state of health.
- Electronic Health Record (EHR) software for an MTF.

D. Message Flow

Medical evacuation is triggered by a MEDEVAC message. MEDEVAC is still the same good old friend, the 9-liner, just dressed in a new XML uniform[2]. The message may be interpreted as "calling a taxi" and is issued immediately. MEDEVAC contains a number of statistics describing casualties (e.g., their number and priorities, required medical equipment) and information describing the point of collection (location, marking, security in the area). MEDEVAC is followed by a series of MIST reports for individual patients. MIST reports are intended for evacuation staff and allow them to prepare physically (equipment) and perhaps also mentally for a situation at the point of collection. On the other hand, Field Medical Cards (FMC) are filled in later, e.g., during transport, are more elaborate than MIST forms, and constitute medical documentation intended for a hospital. While most messages use the APP-11 format, FMCs are transmitted as Health Level 7 (HL7) messages.

V. Discussion

Below, we review the whole process of forward evacuation, including components and messages, and provide insights.

A. Messages

Originally, the MEDEVAC and MIST reports were separate messages. In the new APP-11 XML format, they are combined, i.e., MIST reports for individual patients are embedded in MEDEVAC. Practical experience shows that this solution is unfortunate. In fact, in an emergency, MEDEVAC is issued immediately. MIST reports are completed later and only when time permits. This means they may never be generated. Also, in a dynamic situation, they may be partially incorrect or inconsistent with the original MEDEVAC. Also, the MEDEVAC message may need to be updated (e.g., more wounded arrive[3] or their priorities change dynamically) – the Life-Saver application (see below) should handle such situations.

Considering the above, a proposal has been submitted to the HIST-WG standards committee to "return to the roots" and define a separate APP-11 MIST report.

B. Life-Saver Application

A Life-Saver Application is used by medics at the Point of Injury (PoI), the Point of Collection (POC) and may also be used by evacuation staff during patient transport. The application must support the generation of MEDEVAC, MIST and FMC messages, and should support Patient Tracking Messages (PTMs). Note that the successful reception of MEDEVAC by PECC must always be confirmed. The application runs on a mobile device; practical experience shows that a smartphone is more handy than a tablet. Considering the user interface, it should be based on standard, proven message forms, as medics are able to fill them "with their eyes closed;" the application should just enable additional features to facilitate their quick completion ("single-click" functions). Advanced, useful features should include data entry from photos, such as manually completed MIST or FMC paper forms (handwriting recognition). It is important to support the night vision mode (the screen is dimmed and visible only in special goggles). A voice interface would be an advantage. The application should support teleconsultations (sometimes the situation allows them). Support for medical devices would be an advantage, but it is not critical.

Each soldier is expected to be equipped with a Near Field Communication (NFC) tag that includes the soldier's personal information (NATO or national ID, name, rank) and possibly basic medical information (blood type, allergies, etc.). The application should be able to read the tag and possibly also write medical forms (MIST, FMC) to it. In this way, in the absence of network communication, patient data will be delivered to the hospital along with the patient. Interestingly, it is typical practice to record medical data directly on the patient (e.g., by writing on a cast), and tags may provide a better alternative.

C. PECC Application

According to AJP-4.10 [20], the Joint Operations Centre (JOC) should include a permanent theatre patient evacuation coordination cell (PECC). Depending on the size and complexity of the area of operations, PECC might need to be established at different levels of command in the commander's combined joint operations center. PECC must include the following capabilities:

- patient regulation (MEDEVAC/9-liner, PMRs), including missions management (each MEDEVAC creates a new mission with assigned patients);
- patient tracking (using PTMs);
- MTF and evacuation assets configuration – in the future, the required data may be imported from Medical Capability Directory (which supports mission planning), but so far, there is no standard data format for this purpose;

[2] In fact, the XML schema for MEDEVAC is much complex and generating binding classes creates a lot of code.

[3] There is usually a single MEDEVAC serving a given location. If additional casualties appear, the current MEDEVAC is updated rather than a new one issued.

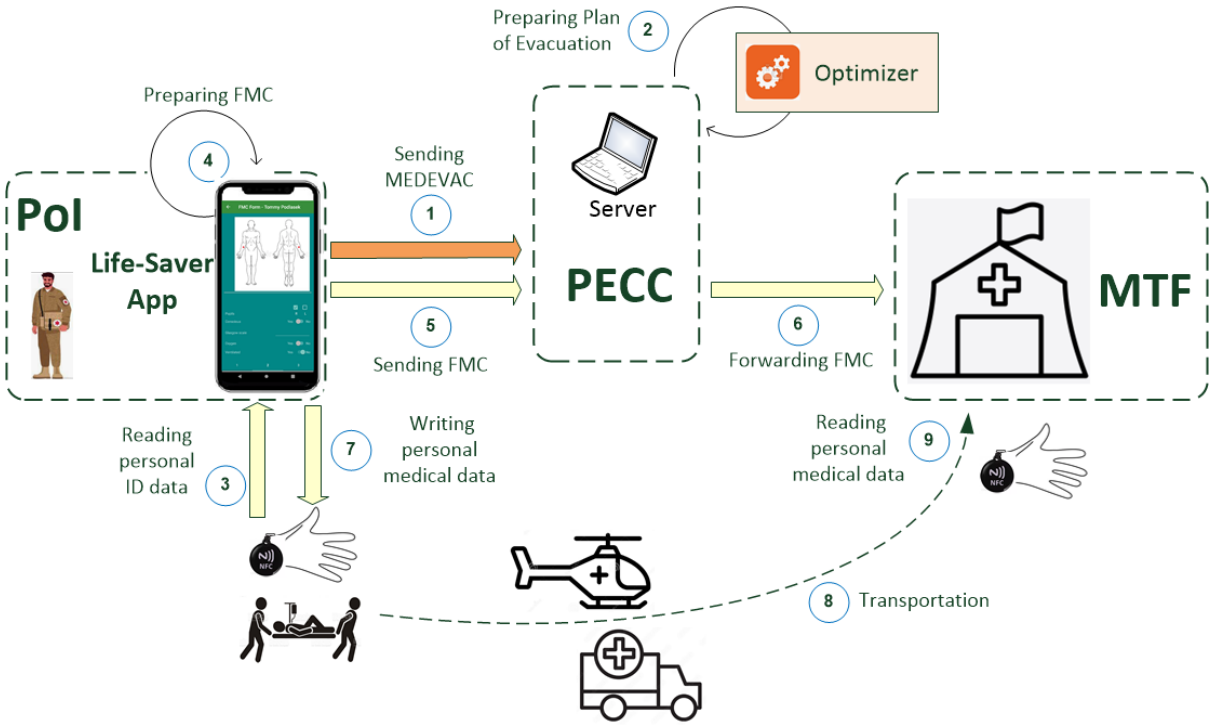

Fig. 2. Forward evacuation: components and message flow

- MTF status and capabilities monitoring on the basis of Medical Situation Reports (MEDSITREPs) (periodically sent by individual MTFs);
- evacuation assets management (for higher evacuation levels);
- interface to an optimizer (see the next subsection);
- providing situation awareness in the form of:
  - presenting individual messages;
  - statistics (e.g., charts showing the number of patients or available beds in MTF);
  - Medical Common Operational Picture (COP) for the supervised area – to ensure interoperability within NATO, the NATO Vector Graphics (NVG) standard should be employed.

Most of the functions listed above are available in MEDICS (COP is under development) as well as in NATO's PECC application (described in section III).

In the context of interoperability with other NATO systems, there is an important conclusion from the CWIX'2022 exercise. Despite preliminary arrangements (agreements on standards versions), it still happened that some systems used outdated schemas or sent messages that violated the schemas. As a result, some messages were rejected by our PECC. In order to enable interoperability in such cases, our PECC maintains a log of rejected messages. Each message is described with a list of errors. The PECC operator may manually[4] correct a given message and retry delivery to PECC (as though a correct message had been sent by the original source). Such a function allowed us to solve all interoperability issues during CWIX, but we think it should be retained for real-world operation. Additionally, to avoid causing such problems with our applications, we always verify messages against XML schemas before sending them.

D. Optimizer

The optimizer's task is to calculate optimal strategies for new evacuations. The strategy may include a selection of an MTF and particular evacuation assets according to the location, number, and priorities of patients. Calculations are triggered by receiving a new or updated MEDEVAC, and their results are delivered to PECC. Note that the optimizer only gives suggestions, but the final decision is always made by a human.

Paradoxically, in the case of forward evacuation, the selection of MTF is imposed in advance by pre-planned responsibility zones (within a zone, a given MTF handles patients using its own evacuation assets). However, the whole situation may be dynamic: MTFs may be overloaded, inaccessible (hit or forced to move), or unable to provide a sufficient number of evacuation assets. This is where the optimizer can provide valuable support.

E. EHR Software for MTF

The software for MTF may be perceived in several ways:

- A traditional EHR system for a hospital enables the handling of patients, management of medical assets (wards, beds, doctors, medical supplies), and keeping medical records. For interoperability with higher-level MTFs, support for HL7 medical standards is a must.
- As a part of a NATO medical evacuation support system, able to generate APP-11 messages that include (as a minimum) Patient Tracking Messages

[4] Doing this automatically is rather impossible as there may be too many possible errors.

(PTMs), Patient Movement Requests (PMRs), EPINATO-2 messages, and Medical Situation Report (MEDSITREP) reports.

In the case of the MEDICS project, we assumed that we would be able to find ready-made (preferably open-source) EHR software that performs medical functions and adapt it to NATO messages. (Implementing an EHR solution from scratch would certainly require a dedicated project.) Unfortunately, a review we conducted a few months ago showed that no such solution exists. Many modern, attractive open-source EHR solutions are available, but their functionality is limited to operating clinics (planning outpatient visits). MTFs need fully-fledged hospital software. Thus, we have decided to follow the route selected by other HIST-WG participants and use OpenAhlta, a proven but quite outdated solution.

Note that OpenAhlta does not support APP-11 messages, nor does it support HL7. OpenAhlta is only able to generate (and consume) files in a specific XML format. Translation from and to HL7 (e.g., to accept an FMC card sent by a Life-Saver Application), as well as generation of APP-11 messages, must be provided by a separate tool. HIST-WG members employ Mirth Connect [16], a messaging broker used for the integration of healthcare systems. As OpenAhlta generates its files as a result of an operator's action (e.g., after a patient has been admitted or discharged), the files may be intercepted, and required APP-11 messages may be generated. Unfortunately, this approach would not work for Medical Situation Report (MEDSITREP), which is a periodic report containing statistics on both patients and the MTF itself. Moreover, despite Mirth is equipped with advanced message handling and processing features, converting a complex message into a completely different format (e.g., OpenAhlta's XML into APP-11 PMR) would be easier to implement in a dedicated application, and this is the approach we have decided to follow in MEDICS.

Support for teleconsultations must be implemented additionally, in MEDICS one of the consortium partners implements a dedicated set of tools for this purpose.

Finally, it is important to mention that level one MFT-s (MTF-1) have assigned evacuation assets (armored ambulances, helicopters). These assets must be managed (traced, reported) by a dedicated tool. We are not aware of any available solution, and projects like ours have to implement one from scratch.

VI. Conclusions and Future Work

Creating an effective system supporting medical evacuation is an uneasy task. Many experts are needed for consultation; some activities in the real world look different than one could assume beforehand. Interoperability in a coalition environment is a requirement and must be thoroughly tested.

Our MEDICS solution follows NATO standards and additionally offers unique features, i.e., a multi-criteria optimization module that supports PECC operators in the decision-making process.

The future work includes further development and testing of our MEDICS solutions, with attempts to address the issues identified so far (and listed in the paper). We will participate in standardization process managed by the HIST group. We also plan to participate in subsequent CWIX exercises (MEDICS has been registered to participate in CWIX'2023) and continue interoperability testing – each subsequent year results in new functions implemented by participating solutions, and the scope of tests is also extended. Effective and interoperable medical evacuation means potentially more lives saved.

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