# Standardisation Of Field Hospital Development Through A DSM

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**Abstract:** In a changing world with increasing conflicts and natural disasters, many countries have begun to refresh their infrastructure and equipment for catastrophe management and civil protection. Regarding the new spending plans of the German government for billions of Euros, the German Armed Forces, as well as the German civil disaster relief organisations, will refresh their field hospitals (Staff members of Deutsche Welle, 2025). Although there are existing standardisation documents from the North Atlantic Treaty Organization (NATO), there are no official civil German, European or international standardisations for general purposes in existence, which could offer a product development thread (NATO, 2018a; Staff members of CEN, 2025; Staff members of DIN Media, 2025; Staff members of ISO, 2025). With this paper, a first standardisation approach for field hospital development is presented by identifying and linking parameters of mobile sanitary solutions via a Design Structure Matrix (DSM) (Maurer et al., 2008a).

*Keywords: Field hospital, mobile sanitary module (MSM), DSM optimisation, standardisation, development*

## 1 Introduction

With the increasing number of natural catastrophes, such as in Germany 2021, the devastating military conflicts in the Ukraine since 2022 and counting, the German Federal Ministry of the Interior (BMI) and the German Federal Ministry of Defence (BMVg) have started to renew their vehicle, ship and aircraft inventories as well as equipment and facilities in the fields of population protection and disaster control (Hoffmann and Staff members of Rheinmetall, 2023; Seidel et al., 2023; Staff members of BBC, 2022; Staff members of bpb, 2021; Staff members of Bundestag, 2022). The four domains of digitalisation, internationalisation, multimodalities and civil-military cooperation in rescue services have become apparent, as threats have occurred to steadily increasing economic losses from disasters worldwide in the twenty-first century (Yuryeva et al., 2023).

This paper offers a complete collection of identified parameters for the development and design, digitalisation, production and testing of mobile sanitary modules (MSM) with medical or laboratory purposes for field hospitals, which is covered by real industrial and university projects between 2022 and 2025. The identified parameters are crosslinked in a Design Structure Matrix (DSM), followed by two optimisation steps, which are carried out for engineering and economical goals. This resulted in a process DSM and a deduced flow chart for standardised developing and designing field hospital modules (Maurer et al., 2008a, 2008c).

## 2 Methodology

There are several analytical and numerical possibilities for deducing an optimised process model from a DSM. For this research, the fast Gaussian elimination method in combination with deeper lower-upper matrix decomposition (LU decomposition) is used (Atkinson, 1989a; Golub and van Loan, 1996). To use a DSM mathematically, converting markings within a DSM between elements into figures is necessary. Markings, also known as cross-linking relations, are set as "1", when a matrix row influences a column unidirectionally, otherwise set "0", if there is no direct relation at all.

The most important case is the system of equations with a quadratic and regular (non-singular) coefficient matrix A, representing the DSM. This means for m equations with n unknowns, the value of the determinant of this matrix must be non-zero. For the filled DSM, more equations are available than necessary, making it an overdetermined linear system. Regarding this linear system of equations for a DSM, with m equations and n unknowns ($m \geq n$), the Gaussian normal equations are found by left multiplication on both sides with the transposed coefficient matrix A (Atkinson, 1989a):

Overdetermined system of equations → Gaussian normal equations

$$\boldsymbol{A} \cdot \boldsymbol{x} \approx \boldsymbol{b} \qquad (1) \qquad \rightarrow \qquad \boldsymbol{A^T} \cdot \boldsymbol{A} \cdot \boldsymbol{x} = \boldsymbol{A^T} \cdot \boldsymbol{b} \qquad (2)$$

Vector x includes the unknown parameters and vector b is a well-known vector. This system of equations has a symmetrical matrix of coefficients. Then, the Gaussian elimination method is applied. Its solution $\widetilde{\mathrm{A}} \cdot \mathrm{x} = \tilde{\mathrm{b}}$ is the approximate solution for the initial system in the sense of the requirement for the minimum of the error sum of squares (Atkinson, 1989b). In a second and deeper optimisation step, the pre-optimised DSM results are further improved using a Lower-Upper-Matrix related decomposition algorithm (LU decomposition). The goal is to shift as many relations over the matrix diagonal as possible into the upper triangle area of the DSM to display the best possible process chain (Golub and van Loan, 1996):

Pre-optimised Matrix | LU decomposition of matrix $\tilde{A}$ (Lower and Upper Matrix)

$$\tilde{\boldsymbol{A}} \cdot \boldsymbol{x} = \tilde{\boldsymbol{b}} \quad (3) \quad \rightarrow \quad (\boldsymbol{L} \cdot \boldsymbol{U}) \cdot \boldsymbol{x} = \tilde{\boldsymbol{b}} \quad (4)$$

For the product of the upper triangular matrix U and the vector of unknowns x, an (unknown) vector y can be assumed

$$\boldsymbol{U} \cdot \boldsymbol{x} = \boldsymbol{y} \quad (5) \quad \rightarrow \quad \boldsymbol{L} \cdot \boldsymbol{y} = \tilde{\boldsymbol{b}} \quad (6)$$

by so-called forward insertion calculation, because L is a triangular matrix, only the unknown $y_1$ appears in the first equation. After calculating $y_1$ only $y_2$ appears as an unknown in the second equation until the algorithm is done with all equations step by step. If vector y is known, an analogous strategy can be used to calculate vector x from equation number 5 via backwards insertion calculation of the classical Gauss algorithm. The resulting equations are then:

$$(\hat{\boldsymbol{L}} \cdot \hat{\boldsymbol{U}}) \cdot \boldsymbol{x} = \hat{\boldsymbol{b}} \quad (7) \quad \rightarrow \quad \boldsymbol{A}_{optimal} \cdot \boldsymbol{x} = \hat{\boldsymbol{b}} \quad (8)$$

The results are presented in the subchapter "Calculation and optimisation of the DSM" in chapter 4.

## 3 State of the art and input data collection

The prior art of field hospitals is quite diverse. One must differentiate between, on the one hand, military or civil knowledge base and, on the other hand, the purpose of field hospitals. Moreover, a field hospital comes in different sizes, which gives the classification of those unique product-service-systems a third dimension. The three dimensions must be explained before showing the state of the art. First, developing and designing field hospitals in the military sphere is partially well documented, often not published, which is not the case for civil field hospitals. Civil solutions are based on books, literature, previous requirement lists but not based on standards at all. Second, an ordered field hospital comes with a specific purpose, so-called capabilities. Every conceived, ordered mobile sanitary system is highly diverse in deployment topics depending on the customer's wishes, mostly relief organisations or states, often in cooperation with their disaster protection ministries or ministries for the interior. For instance, there are specialised field hospitals for pandemic handling, quick casualty evacuation (CasEvac) and medical evacuation (MedEvac), medical intensive operations, laboratory analysis, general sanitary needs, provision of shelter and many more, which can also be combined to larger mobile settlements This leads to point number three, which classifies the sizes of field hospitals as follows (NATO, 2018b):

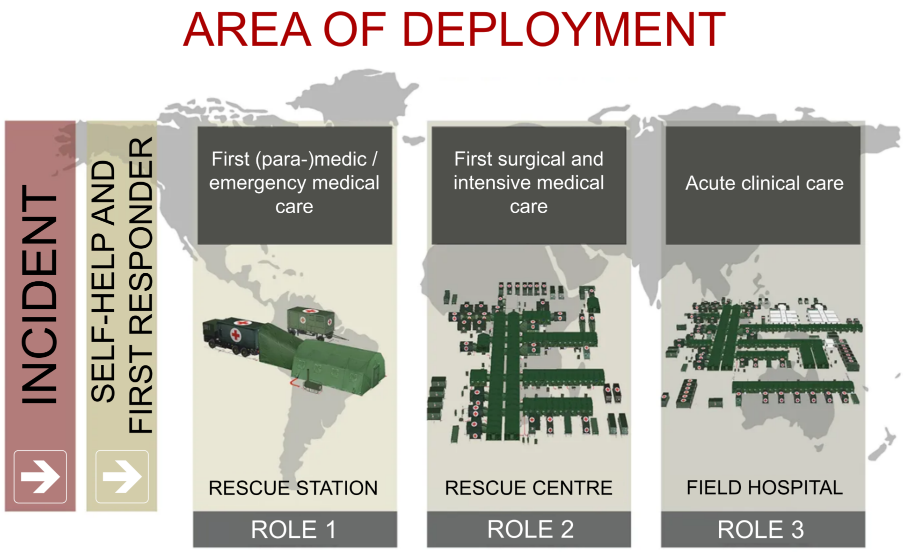


Figure 1. Rescue chain via "Role" respective level 1, 2 and 3 with mobile sanitary modules (MSM), which contain mobile medical entities (MME), mobile laboratory entities (MLE) and/or general sanitary components (Staff members of Bundeswehr, 2022c).

If a larger incident happens, which requires mobile infrastructure support, such as natural disasters or military conflicts, those mobile sanitary modules (MSM) or mobile sanitary entities (MSE) in the shape of a mobile medical entity (MME), a mobile laboratory entity (MLE) or other general sanitary entities are subclassified into

- "Role 1" or "Level 1" for up to 4 patients, usually two containers or tents for the first (para-)medic, respectively emergency medical care (Staff members of Bundeswehr, 2022c),

- "Role 2" or "Level 2" for up to 72 patients, usually 19 containers or tents for first surgical and intense medical care (Staff members of Bundeswehr, 2022d; Staff members of ECHO, 2023; Staff members of RI Group, 2018),
- "Role 3" or "Level 3" for up to 150 patients, usually 52 containers or tents for acute clinical care (Staff members of Hospital Container, 2022)

In military context, the word "Medical Treatment Facility (MTF)" or "Combat Support Hospital (CSH)" is often used and a field hospital is its largest possible mobile size (Department of the U.S. Army and McConville, J.C., 2020; NATO, 2018a, 2019). In civil context, it varies considerably with the civil organisations' terms or producers' product names. For completion, a rescue chain ends with "Role 4", which is a stationary hospital. Role 4 is necessary for further demanded specialisation, such as pediatric heart surgery, special trauma surgery, treatment of allergies, skin and environmental diseases, unique military topics and others. For this paper, an analysis of "Role 4" is unnecessary as immobile facility. Moreover, MSM can be deployed on the ground and at sea. At sea, those are called hospital ships and exist in civil and military variants in sizes from "Role 2" to "Role 3" (Staff members of Bundeswehr, 2022a; Staff members of Mercy Ships, 2018). In addition, "Role 1"-systems can be dropped from aeroplanes as an airborne variety, which is not to be mistaken with ambulance aircrafts or rescue helicopters (Staff members of Bundeswehr, 2022b).

Between 2006 and 2018, NATO published two standards with decisive content (NATO, 2018a, 2019). With the "AMedP-9.1- MODULAR APPROACH FOR MULTINATIONAL MEDICAL TREATMENT FACILITIES (MTF)", modular components were subclassified into (NATO, 2018b):

- Core Modules, such as emergency area or medical supply, 7 domains in total
- Enhancing Modules (NATO medical toolbox), such as imagery or pharmacy, 14 domains in total and
- Complementary Contributions, such as oxygen production or physiotherapy, 13 domains in total.

Furthermore, nine main points are mentioned on how to run a field hospital efficiently and what to consider in sanitary and non-sanitary issues. Since 2018, no further updates have been made (NATO, 2018b).

As a relief organisation, the Red Cross owns customised field hospitals with 26 sanitary and non-sanitary domains. Those modules are, for example, a surgery room, a sterilisation chamber, a mother-child ward, a general laboratory, waste incineration and many more. The Red Cross field hospitals are designed for up to 120 Patients (Staff members of Red Cross, 2010).

In the name of the World Health Organisation (WHO), Norton et al. summarised the global field hospital knowledge in the report "CLASSIFICATION AND MINIMUM STANDARDS FOR FOREIGN MEDICAL TEAMS IN SUDDEN ONSET DISASTERS" in 2013 (Norton et al., 2013a). It focuses on the medical teams deployed in disasters and comes with larger attachments about field hospitals. The attachment "Annex 1 - DIFFERENT CLASSIFICATION SYSTEMS" lists the most essential field hospital domains worldwide with subdomain related size scaling: "FMT - Foreign Medical Team Classification", "IFRC - International Federation of Red Cross and Red Crescent Societies - Emergency Response Units (ERU)", "EU CPM - European Union Civil Protection Modules", "OAH - AECID/SEMHU - Oficina de Acción Humanitaria - Spanish Agency for International Development Cooperation/Agencia Española de Cooperación Internacional para el Desarrollo"", "NATO", "United Nations", "USAR - Urban Search And Rescue" and a further own civil protection classification proposal for field hospital sizes (Norton et al., 2013b). The attachment "Annex 2 - Specific Technical Standards" offers a detailed list of important medical and laboratory modules (Norton et al., 2013c).

The standard work for field hospitals is the book "Field Hospitals" by Bar-On, Peleg and Kreiss. With the chapters of this work of literature, it is possible to divide up a field hospital into the structural-oriented domains "subsystems and modules" and process-oriented or secondary topic domains "general and miscellaneous" (Bar-On et al., 2020a). The content of the chapters 8, 10, 11, 12, 13, 15, 16, 18, 19, 20, 21, 22, 24, 25, 27, 28, 29, 30 and 31 can be assigned to structural oriented subdomains and elements such as auxiliary medical services pediatrics, orthopedics, burn care, ICT and many more while the other chapters are mixed in terms of coordination management, ethical aspects, legal issues and so on (Bar-On et al., 2020b).

In May 2020, Bell et. al. wrote about the role of field hospital planning within 10 days. They describe those mobile facilities for humanitarian logistics as "Alternate care sites (ACS)" to provide either inpatient or outpatient emergency care services with 500 beds, including 21 care beds, regarding the "coronavirus disease 2019 (COVID-19)" pandemic. Regular hospitals in the mixed urban and rural area of the cities Ann Arbor and Detroit in the USA exceeded their available bed capacities. For those circumstances, the deployed "Michigan Medicine Field Hospital (MMFH)" managed positive tested patients. The field hospital planning is organised into six domains of an incident command system (ICS): Personnel and labour, security, clinical operations, logistics and supply, planning and training, and communications. Based on this ICS, a COVID-19 patient bedroom as a core subdomain is shown in detail with a superior implemented clinic operations process, including patient eligibility criteria for transfer from a regular hospital to this specific field hospital. This hospital and patient bedroom design represents a non-generic single-topic use only (Bell et al., 2021).

As the core city for the COVID-19 outbreak, the city of Wuhan needed a rapid way to set up field hospitals for mass incidents regarding this pandemic in 2020. Chen et al. show a detailed description of the modular composite building of the Wuhan Thunder God Mountain/Leishenshan hospital. The development of this field hospital is displayed in three process-oriented domains as building phases for an initial 400 to a final 1392-bedroom facility complex. In total, the field hospital system contains six domains with bedrooms, dispatching centre, incoming call module, medical technique information and communication unit, fire station, oxygen station and sewage treatment plant. For architectural planning, a detailed nursing unit module of the isolated medical area is shown with 12 subdomains and an additional unit plan. Then, for structure design, a medical technology unit module of the isolated therapeutic area with 21 subdomains and the additional unit plan is displayed with the final field hospital design of three zones and two exchange channels to run through. Furthermore, the core COVID-19 patient bedroom elements are presented and listed, including physical civil engineering construction details about the foundation construction below the field hospital. This hospital and patient bedroom design represents a non-generic single-topic use only (Chen et al., 2021).

Pillai et. al. analyse the impact of digitalisation of the healthcare industry in combination with field hospitals in Abu Dhabi and Dubai, United Arab Emirates (UAE) during the COVID-19 pandemic in 2021. Ten innovations as new domain elements are listed: Wearable blood pressure monitors, drones for medical supplies, audio-visual pain therapy, biosensors for monitoring drugs, online mental wellbeing apps, sleep improvement programs, smart toothbrush for enhanced dental hygiene, monitoring of infant vital signs, digital Alzheimer´s disease surveillance and at-home fertility testing. In the UAE, a new digital field hospital for pandemics has following subdomains: Contact tracing and tracking, 3D-printing for spare parts and other goods, telehealth consultations and remote healthcare, artificial intelligence, big data and machine learning. To lower the time of unpacking a pandemic field hospital, instructions are presented in chronological process order: First, provision of personnel, followed by physical inspection after unpacking, activation and adding of database assets, taking equipment to specified space for a COVID-19-bed, setting up equipment on the spot, connecting equipment, executing electrical safety monitoring, doing functional verification and signing off (Pillai et al., 2021). The resulting field hospitals can be set up within 17 days (Malem, 2021; Staff members of Recchie, 2023).

In 2023, Araghizadeh and Gharari published that the ideal field hospital is having all the functional standard domains of a hospital, autarkic, connected to a network including an advanced telemedicine system, task- and mission-oriented, easy to transport, having multiple patient-oriented subdomains for (medical) tasks, having special equipment for intense medical operations and equipped with a command and control domain. This paper tries to be as generic as possible for a field hospital description without a detailed listing of the mentioned domains and subdomains (Araghizadeh and Gharari, 2023).

In the paper "Medical staff planning for field hospital deployments: the START hospital" by Martin-Campo et al. in 2024, a multi-criteria optimisation model is used to consider the preferences of the three main stakeholders involved in the deployment of a field hospital: Cooperation organisation, staff and end users. With this model, not only are the different hospital professions listed, but also the different related domains of a field hospital, including overall cost efficiency estimation. This START field hospital was deployed during the earthquake disaster in Turkiye (Turkey) in 2023 (Martin-Campo et al., 2025).

Besides reference books and military documents about field hospitals, no more recent research has been found about domain models, subdomains, elements or process models of a modern field hospital in a most possible generic modelling approach with a detailed listing at the same time. The most recent hospital paper which addresses the topic complexity is the 2025 "Addressing the Causal Complexity of Institutional Change: A Configurational Analysis in the Field of Hospitals" by Baly et al., which describes the complexity in staff change, which is also suitable for mobile hospital solutions (Baly et al., 2025). Other recent papers refer to a patient-centric information management system with digital subdomains and elements in field hospitals, written by Schreiber et al. in 2025 (Schreiber et al., 2022) or the risky deployment of field hospitals in the Russo-Ukrainian war by Hodgetts et al. in 2023 (Hodgetts et al., 2025). Two further recent papers refer to the optimised positioning of field hospitals, either via the application of a mobile field hospital in emergency public incident response in Ganus, China by He et. al. in 2023 (He et al., 2023) or via GPS-tracked persons as potential casualties in the surrounding area, calculated and described by Xiao et. al in 2024 (Xiao et al., 2024).

## 4 The field hospital module domain list

Based on the results in research, literature and industry in chapter 3, a DSM in the shape of a multiple-domain matrix (MDM) is set up with the following domains, whereas each domain also represents a DSM again on a more profound and detailed level (Kreimeyer, 2010; Maurer et al., 2008b). The modelled MDM is a process-oriented DSM (Yassine, 2004). The superior DSM, respectively, MDM is symmetrically composed of 80 times 80 elements, shown in Table 2, assigned to 19 domains, shown in Table 1, as input data. The MDM with 19 domains represents the most generic form of a mobile sanitary module to cover all kinds of possible modules of a field hospital, independent from purpose, size and civil-military use. For clarity and unambiguity, the model word DSM is used instead of MDM with the 19 domains as follows:

Table 1. Main domains of the DSM "Mobile Sanitary Module (MSM)"

| | | | |
|---|---|---|---|
| RQL-[1.1]-Requirements (including customer wishes, standards, test reports etc.) | EQP-[6.1]-Equipping | SIM-[11.1]-Simulation | COS-[16.1]-Container states |
| CNE-[2.1]-Exterior and armoured surfaces | MEP-[7.1]-Main equipment products (each) | TST-[12.1]-Tests (given by customers, standards etc. - with possible settings levels) | CHM-[17.1]-Change management (from customers, standards, tests, cost management etc.) |
| CNI-[3.1]-Interior | PAS-[8.1]-Product accessories (each) | DOC-[13.1]-Documentation | TRC-[18.1]-Training concept (incl. law-bound, standards and rules) |
| MFP-[4.1]-Manufacturing parts | WPL-[9.1]-Workplaces (For A-B-C room value analysis) | TRR-[14.1]-Transport readiness | NDR-[19.1]-New, donor or regeneration |
| ASP-[5.1]-Assembly parts and respective logistics portfolio (including air conditioning systems and utility room products) | ITW-[10.1]-IT work | PRS-[15.1]-Production stages (mainly assembly related) | |

The detailed list with domains, subdomains and elements for building this DSM can be viewed under the given static DOI-link as follows. This list forms the basis for the symmetrical DSM, which in turn is used for calculation purposes:

Table 2. DSM "Mobile Sanitary Module (MSM)" with domains, subdomains, elements and detailed explanations

| |
|---|
| Please click on the static DOI-link at Technical University of Munich: https://doi.org/10.14459/2025mp1779436 |

Slight colour variations may occur between the different documents, as they have been formatted differently.

**Calculation and optimisation of the DSM**

The applied DSM elements are cross-linked in a unidirectional way, which means a row influences a column. Mathematically, a relation marking equals 1, otherwise 0 (zero). As a knowledge base, two main content packages are considered:

- Documentation from former projects: Shock room, pharmacy and medication testing laboratory, (pre-)operative room, computer tomography (CT), magnetic resonance tomography (MRT), dentist practice, dentist laboratory, microbiology laboratory, veterinary laboratory, sanitary and medical supply, pathology laboratory, cold room, internal medicine, otolaryngology (ear-nose-throat practice), urology, general physician practice, dermatology, neurology, gynaecology and entry container with decontamination
- 3 years of industry work with five different, successfully produced modules, namely ophthalmologist practice, equipment supply container, protected wounded transporter, clinical chemical laboratory for blood and biofluid testing, food chemistry laboratory,

The Gaussian elimination method for pre-optimisation is applied in combination with a subsequent deeper LU decomposition for final and optimal results (Atkinson, 1989a, 1989b; Golub and van Loan, 1996). Both calculation steps are done by the software LOOMEO (Maurer and Braun, 2015). The results are illustrated step by step. For clarity, the matrices of the original, unoptimised DSM and the pre-optimised DSM are shown in a roughly qualitative comparison. On the other hand, the final LU decomposed DSM is presented quantitatively with colour differentiation of the various domains. This visualises the triangularisation in the most suitable way (Maurer et al., 2008c). Since the LOOMEO software only has a limited colour palette for colouring elements, the colours in the optimised DSM differ slightly from the original document in Table 2 above. Moreover, the software overlaps colours according to chronological calculation and processing order, which is why the final, optimised DSM appears visually asymmetrical. To assign explanations of the 19 domains and 80 elements with their enumeration in the final DSM, it is necessary to use the external university DOI-database file of Table 2. The goal, which is also intended to answer the main research question, is to find an optimal guideline, an optimal arrangement in particular, as there are no corresponding process models in either academic or industrial applications. Both low-iteration, engineering-related implementation as well as cost-effectiveness in industrial development, design, digitalisation, testing and production remain unresolved at this stage.

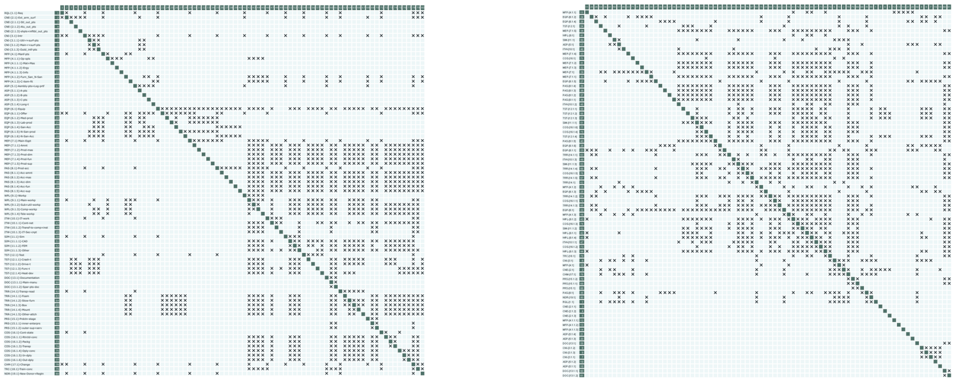

Figure 2. Qualitative illustrations of the original, unoptimised DSM (left) and the Gaussian elimination-optimised DSM (right)

**Deeper optimisation and sequencing**

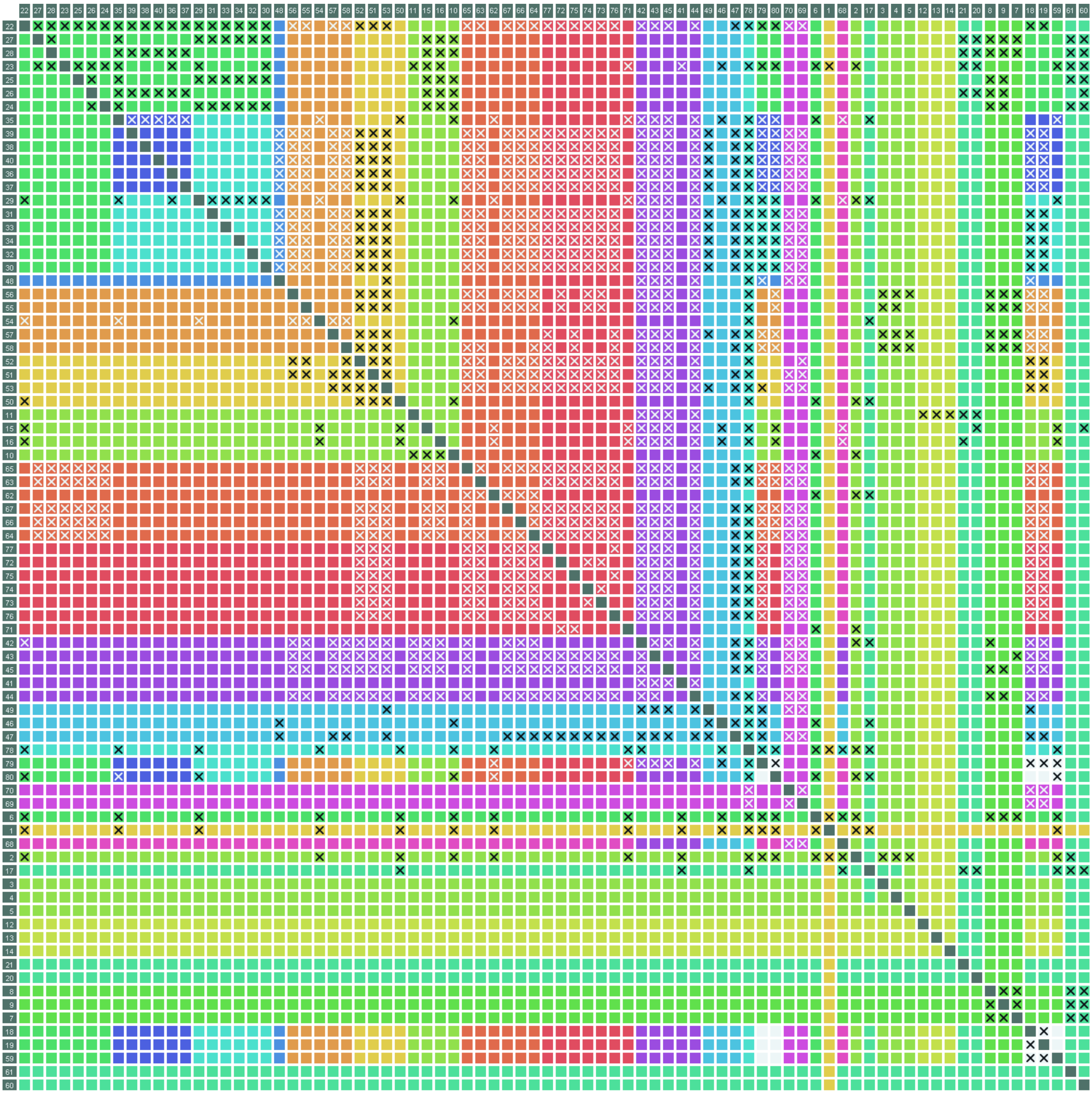


Figure 3. Deeper optimised DSM with final results through LU decomposition.

The optimal DSM shows newly sorted and characteristic block formations of the domains that appeared to be resolved in the pre-optimisation. It is seen that certain domains have a feedback effect on the process elements at the top, respectively, at the beginning. To avoid iterations in product development, this must be considered at the start of the development:

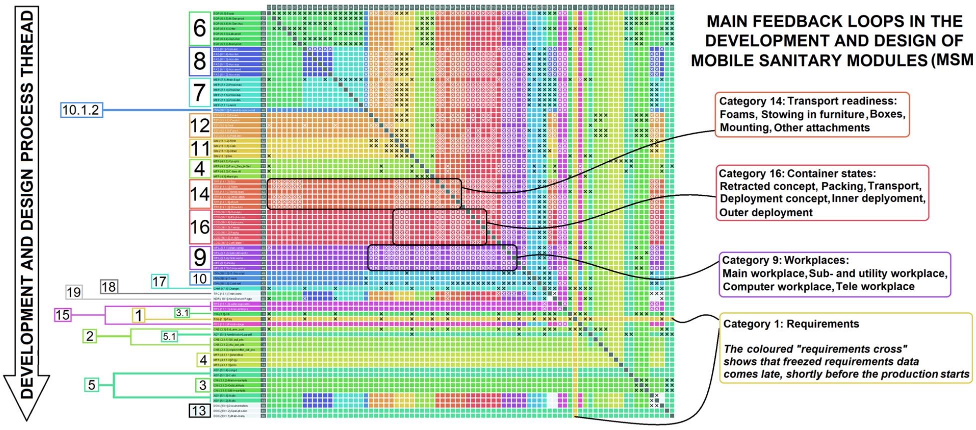


Figure 4. Main feedback loops in the optimal DSM. Domain and partially element numbers are shown on the left side.

## Flow chart as a final process model

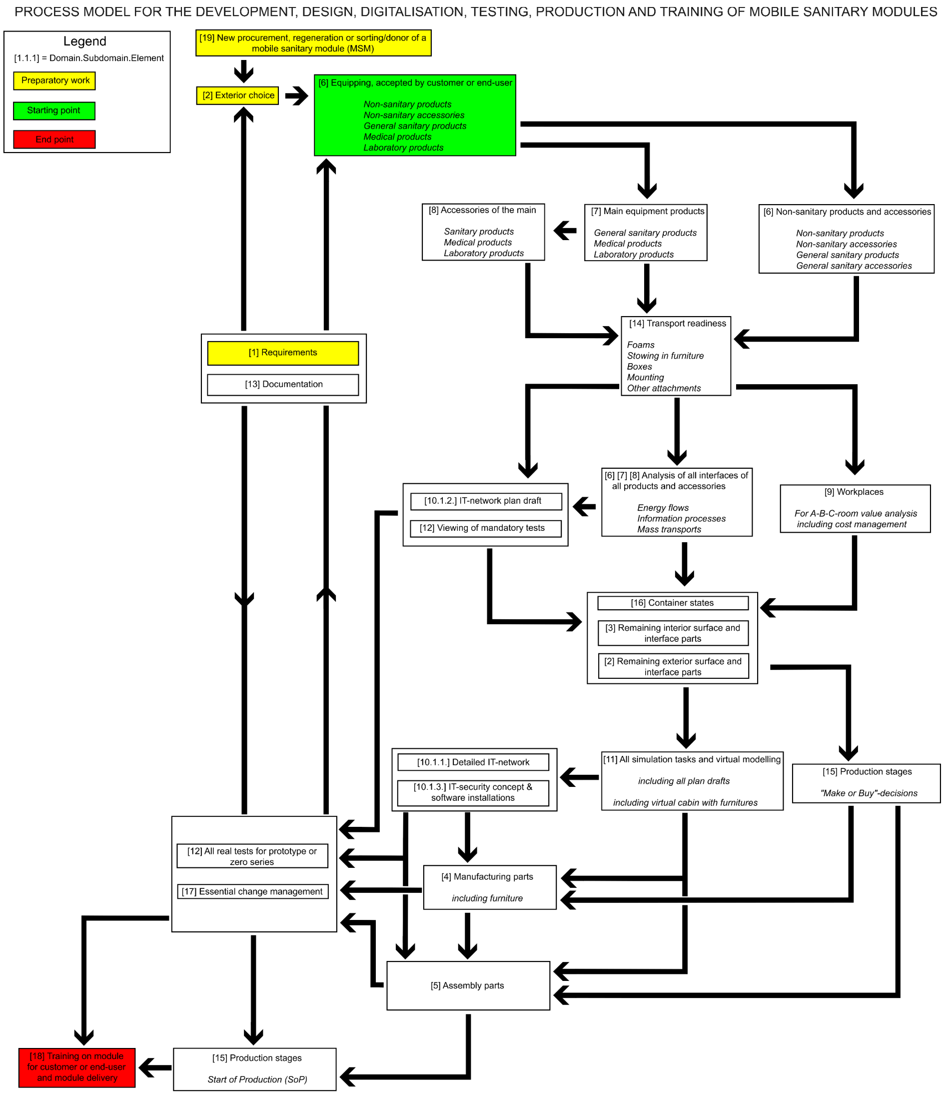


Figure 5. Process model for the development, design, digitalisation, testing and production of MSM for field hospitals.

The flow chart shown above is the deduction for what needs to be considered in which process step during the development of an MSM. The analysis method to deduce an exemplary flow chart from a process-oriented DSM is called sequencing (Eppinger and Browning, 2012). The flow chart takes into account not only the main feedback loops but all feedback loops in the early stages of product development, which can be seen inside the flow chart blocks. Since an MSM is statistically only renewed every 10 to 20 years, development paths for IT-networks and software integration or installations are different and more dispersed than the traditional engineering (sub)domains. A new mobile module or mobile module regeneration often comes with a technological leap of at least a decade, especially in the field of information technology and respectively the increasing amount of novelly digital sanitary, medical and laboratory products which must be connected safely to a network or a computer.

## 5 Summary and Conclusions

The research objective for having a complete and generic DSM for any kind of field hospital module has been achieved. Furthermore, with the sequencing of the shown optimised DSM, a holistic development thread is being deduced, which is valid for every conceivable mobile (non-)sanitary subsystem. Limitations of this approach concern genuine stationary, time-independent solutions such as permanently constructed hospitals and accommodation, which are already defined by established standards and rules for each country, region or organisation. Practical experience in the technical realisation proves that procured sanitary, medical and laboratory products with their accessories must be analysed first. Then, packaging and fastening concepts must be created for those before the cabin is even built around them. Considering the transport state of an MSM is equally important to their deployment states. The core equipment and transport safety define the cabin, not the other way around.

The time-consuming collection, sorting and allocation of domains, subdomains and elements in the subject of field hospitals with their versatile modules show that it is necessary to develop an overarching development guideline. The complexity of the implementation arises from the wide range of hospital topics and the interdependencies between mobile topics such as “transport readiness” and “container states” as well as the classic technical and medical workstations. At the end of each major development cycle, there is always one big iteration step for the preset requirements regarding module crash and drive test results, as well as customer change requests. One iteration loop too many can directly lead to uneconomical development, design and production. The key to engineering and economical success are highly interdisciplinary project teams, which form their groups spontaneously, depending on the current task. For MSM, engineers from the fields of mechanics, electrical engineering, digitalisation, furniture manufacturing, assembly and production, crash and drive testing, medical and laboratory engineering should work together in a more agile way with an ad-hoc approach (Drutchas and Eppinger, 2023).

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