Hamburg University of Applied Sciences

Faculty Life Sciences

Analysis of Time-Critical Processes in Hospital Care during a Mass Casualty Incident

Master's Thesis in the Master of Science program Biomedical Engineering

Submitted by:

Talitha Rohwoldt [redacted]

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1. Supervisor: Prof. Boris Tolg
2. Supervisor: Dr. Stefan Behrens

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Abstract

This study investigates in-hospital process times during a simulated mass casualty incident (MCI) with a focus on clinical and logistical workflows. The objective was to analyze time-critical intervals along the patient pathway and to identify potential bottlenecks in hospital response processes.

Data were collected during a full-scale simulation exercise involving two participating hospitals. Using standardized observation sheets, predefined time points were recorded for each patient, including triage, internal transport, diagnostic imaging, and clinical decision-making. The collected data were subsequently processed and analyzed to evaluate the duration and variability of key process steps.

The results demonstrate that early stages of patient management, particularly triage and in-hospital transport, were performed consistently and within short time frames. In contrast, later stages of the clinical workflow, especially the transition from shock room management to diagnostic imaging and subsequent clinical decision-making, showed greater variability and, in some cases, incomplete data. These phases were identified as potential bottlenecks within the patient pathway.

The findings suggest that while structured procedures enable efficient initial patient assessment, the coordination of downstream clinical processes remains a critical factor influencing overall system performance. In addition, the study highlights the importance of communication, resource allocation, and workflow organization in managing patient flow during MCI scenarios.

Despite limitations related to sample size and the use of a simulation-based setting, this study provides valuable insights into hospital processes under surge conditions. The results underline the need for further research, particularly involving larger datasets and real-world scenarios, to support the optimization of hospital emergency preparedness and response strategies.

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List of Abbreviations

Abbreviation	Meaning	German
MCI	Mass Casualty Incident	
KAEP	Internal Emergency Plan	Krankenhausalarm- und -Einsatzplanung
OR	Operating Room	
KPI	Key Performance Indicators	
ICU	Intensive Care Unit	
SR	Shock Room	
SEK	Special Task Force	Spezialeinsatzkommando

1 Introduction

1.1 Background

Hospitals are highly organized and efficient systems designed to provide optimal care for a large number of patients under routine conditions. In everyday operations, processes are structured, resources are coordinated, and patient care is delivered according to established medical standards.

However, there are situations that exceed the operational capacity of hospitals. Such events challenge even well-prepared healthcare systems and require a shift from routine care to emergency management strategies. These exceptional situations are referred to as mass casualty incidents (MCIs).

A mass casualty incident occurs when the number of injured exceeds the immediately available emergency resources and hospital treatment capacities. Under such conditions, it becomes impossible to provide individualized medical care to all patients at once. An MCI therefore represents the transitional state between an overstressed routine rescue system and the declaration of a full-scale disaster. [1]

The causes of MCI situations are diverse and can include traffic accidents, fires, terrorist attacks, mass illnesses, and large public events such as concerts or sporting events. These incidents require a coordinated response involving paramedics, fire and police departments. Depending on regional conditions, such as population density, the number of available ambulances, and the capacities of nearby hospitals, the same event can strain resources to different degrees. [1]

Hospitals play a critical role in responding to such events, but even well-functioning systems can quickly become overwhelmed by a sudden surge in patient numbers. Limited resources, disrupted communication, and increased demand for medical services can significantly impact the ability to provide adequate care. [1]

This study is conducted within the context of the German healthcare system, which is characterized by structured hospital emergency planning frameworks such as the internal emergency plans/ disaster preparedness plans (Ger: Krankenhausalarm- und -einsatzplanung (KAEP)). These frameworks define standardized procedures for hospital response to MCI scenarios and provide guidance for coordination, resource allocation, and patient management within German hospitals.

1.2 Motivation

The complexity and variability of emergency scenarios highlight the importance of structured planning, training, and simulation exercises. These disaster drills allow hospitals to test internal alarm procedures, optimize communication pathways, and evaluate process efficiency. By analyzing time intervals such as the duration of triage, in-hospital transport, and diagnostic procedures, hospitals can identify process inefficiencies and improve preparedness for real mass casualty scenarios.

Due to the collaboration with the Reinbek Hospital St. Adolf-Stift, this thesis focuses specifically on internal hospital processes. These include the time spent in triage, patient transport within the hospital, and diagnostic procedures. The hospital identified these aspects as particularly relevant in order to evaluate potential areas for improvement and to enhance overall response capability for future real-life incidents. By analyzing temporal parameters and process efficiency, this study aims to contribute to a better understanding of hospital performance under mass casualty conditions.

1.3 Problem Statement

Although hospitals in Germany are required to maintain disaster preparedness plans and, in some regions, regularly conduct MCI drills, there is still limited empirical evidence on the detailed internal workflows that occur within hospitals during such events.

In a mass casualty incident, patient care within the hospital follows a structured sequence of processes. After arrival, patients are registered and undergo triage to determine treatment priority. This is followed by initial medical assessment, diagnostic procedures, and, if necessary, further treatment or transfer within the hospital. These processes require coordinated interaction between different departments, clear communication, and efficient patient flow management. [2, 3]

While previous research has primarily focused on pre-hospital management, triage systems, and coordination between emergency services [4, 5], less attention has been given to the performance of these internal hospital processes. In particular, there is a lack of quantitative data on time intervals within the hospital setting, which are critical for evaluating operational efficiency under MCI conditions.

This study therefore focuses on selected key process steps within the in-hospital workflow, specifically triage duration, in-hospital patient transport, and the time to diagnostic procedures. These intervals were chosen because they represent central transition points in patient flow and are particularly sensitive to delays under high patient load. It should be noted

that certain time intervals, especially those related to patient transport, are influenced by the structural layout and spatial organization of the respective hospital.

In cooperation with the Reinbek Hospital St. Adolf-Stift, this study addresses this gap by systematically recording and analyzing time intervals during a simulated MCI scenario. In addition, a second hospital, the Agaplesion Bethesda Hospital Bergedorf, participated in the exercise, providing supplementary data for comparative analysis. The primary analytical focus, however, remains on the Reinbeker hospital.

The aim is to identify process inefficiencies and derive data-driven recommendations to improve hospital performance in future mass casualty incidents.

1.4 Objectives of the Study

The overall aim of this study is to analyze and evaluate the time efficiency of in-hospital processes during a simulated MCI. The study was conducted in collaboration with the Reinbek Hospital St. Adolf-Stift and focuses on evaluating process performance during an exercise scenario simulating a shooting event with multiple perpetrators.

The specific objectives of the study are:

- record and analyze the time intervals between key treatment steps, including triage, patient transfer, and diagnostic procedures.
- identify potential critical process points and delays within the hospital workflow during the MCI.
- compare the temporal process data between two participating hospitals in order to identify structural or organizational differences.
- propose recommendations for improving internal hospital coordination and resource management during future large-scale emergencies.

The findings of this study aim to support hospitals in optimizing their emergency response structures and ensuring more efficient patient care in real MCIs.

2 Theoretical Background

2.1 Mass Casualty Incident Management in Healthcare

Major incidents can overwhelm routine healthcare capacities and therefore require structured management and preparedness. The following sections first outline the definition of a major incident and then describe the exercise scenario used for this study.

2.1.1 MCI by Definition

An MCI refers to a situation in which the number of injured or ill individuals exceeds the immediately available medical and logistical resources, resulting in a mismatch between demand and treatment capacity and making individualized medical care no longer fully possible [1]. In such cases, patients must be prioritized according to triage principles in order to maximize the overall number of survivors [6].

2.1.2 Exercise-Based MCI Training

An MCI exercise simulated a realistic large-scale emergency scenario to evaluate coordination, communication, and time management among emergency services and hospital.

The exercise began with a simulated emergency call to the control center, reporting an incident involving multiple casualties in a public building. The fire department, rescue services, and police were dispatched according to the regional alert protocol. To reflect real-world challenges, limited resources were intentionally simulated. For example, only a small number of ambulances were available, creating conditions of operational stress and prioritization.

Upon arrival, police units secured the area, as the scenario involved a potential threat. Only after the site was declared safe could emergency medical services enter the building and begin the evacuation of casualties. Outside the danger zone, a triage and treatment area was established. Patients were categorized according to injury severity and received initial medical treatment before being transported to designated hospitals. Meanwhile, the emergency control center informed hospitals of the mass casualty situation, allowing them to activate their internal emergency plans and prepare for patient intake.
Overall, the exercise illustrated the importance of structured communication, resource coordination, and clear role distribution between police, fire department, emergency medical

services and hospitals during a mass casualty event. A more detailed description of the simulation setting is provided in Chapter 3.6.

2.2 Hospital Emergency Response Systems

Effective management of an MCI not only depends on the coordination of prehospital emergency services but also on the hospital's ability to rapidly adapt to an increased patient load. Hospitals play an important role in easing the medical consequences of such incidents by activating predefined emergency response systems designed to ensure continuity of care, efficient use of resources, and clear role distribution among medical and administrative staff. [2, 3]

Most hospitals maintain an internal emergency plan, which defines procedures for communication, triage, patient distribution, and clinical management during an MCI [2, 6]. Once the emergency control center notifies the hospital of an ongoing MCI, the hospital incident command structure is activated. This typically includes the hospital emergency coordination team, consisting of representatives from management, emergency medicine, nursing, logistics, and technical services. Their primary tasks include assessing available resources, prioritizing critical departments, and maintaining communication with the control center and other healthcare facilities. [3, 6]

A key aspect of hospital emergency response is the adaptation of patient flow. Depending on the number and severity of incoming patients, non-urgent treatments or elective procedures are postponed to free up staff and treatment areas. Triage zones are set up near the emergency department to allow rapid categorization and initial stabilization before definitive care. In addition, the diagnostic and surgical departments must coordinate closely to prevent bottlenecks and ensure that critical patients receive timely interventions. [6]

Another important role plays the communication in terms of the success of hospital emergency operations. Clear and structured information exchange between prehospital services, hospital command staff and treatment teams is essential. It minimizes confusion and supports timely decision-making. Many hospitals implement additional communication systems as well (e.g., internal paging, or digital alerting platforms) to ensure reliability even under network overload. [2, 3]

Furthermore, staff readiness and training significantly influence response quality. Regular MCI drills and simulations allow personnel to become familiar with alarm procedures, spatial organization, and their specific responsibilities within the emergency chain. Such exercises also serve to identify potential weaknesses, such as delays in patient registration, limited diagnostic capacity, or insufficient information flow between departments. [6]

In the end, the hospital emergency response system aims to maintain medical efficiency under extraordinary pressure. For this reason, continuous evaluation and process optimization are essential. Factors such as treatment times, triage accuracy, and communication efficiency provide measurable indicators that can be analyzed after exercises or real incidents to improve future preparedness. [6]

In the context of this study, the analysis of time-based process data collected during the MCI exercise provides valuable insights into how hospital workflows perform under stress and where potential improvements can enhance overall emergency response effectiveness.
In addition to organizational and managerial structures, the clinical workflow within the hospital represents a crucial component of MCI response. After notification and activation of the hospital emergency plan, incoming patients are typically received at a designated triage area located near the emergency department. Initial triage is performed by a team consisting of medical and nursing staff, allowing rapid prioritization based on injury severity.

Following triage, patients are directed to predefined treatment areas. Critically injured patients are transferred to the shock room (SR), where immediate life-saving interventions are performed by specialized teams. Patients with lower acuity are managed in standard emergency department areas or alternative treatment zones.

Internal patient transport constitutes an additional time-critical process step. Especially in severely injured patients, transport may be delayed due to necessary stabilization measures required to ensure transportability, such as airway management, circulatory stabilization, or immobilization. As a result, internal transport times can vary significantly depending on patient condition and clinical requirements. These process-related factors must be considered when evaluating time-based performance indicators in hospital emergency response.

2.3 Definition and Purpose of Triage

DIN 13050 defines triage as follows:
The medical assessment and decision regarding the priority of patient care in terms of the type and extent of treatment, as well as the timing, method, and destination of transport [7].

According to Neitzel and Ladehof (2012), triage is a structured medical decision-making process used to determine the treatment priority of patients in situations where available resources are limited. It involves the rapid assessment of injury severity and the allocation of clinical attention based on medical urgency rather than the order of arrival. The primary goal of triage is to maximize overall survival by ensuring that patients with life-threatening conditions receive timely care, while those with minor injuries are treated later. This principle

is essential during an MCI, as the number of patients exceeds the available treatment capacity of emergency and hospital services. [6]

In mass casualty incidents, triage decisions are typically communicated using standardized classification systems. In Germany, the PRIOR algorithm (Primary Ranking for Initial Orientation in Rescue Services) is commonly applied for initial patient prioritization. This algorithm is based on a structured assessment of vital functions, including airway, breathing, circulation, neurological status, and the presence of severe bleeding. [8]

Based on this assessment, patients are assigned to predefined triage categories, which are usually communicated using a color-coded system.

PRIOR algorithm:

- Red (SK I): Patients with life-threatening conditions who require immediate medical treatment.
- Yellow (SK II): Severely injured patients whose treatment is urgent but can be delayed for a short period of time.
- Green (SK III): Patients with minor injuries who can tolerate longer waiting times.

Within the simulation scenario analyzed in this study, patients were triaged according to this standardized prioritization scheme using the PRIOR algorithm. This ensured a consistent and structured allocation of patients to treatment categories and formed the basis for subsequent clinical processes and time measurements.

2.4 Key Performance Indicators in Emergency Management

Key Performance Indicators (KPIs) in emergency management are measurable variables used to evaluate the efficiency and effectiveness of clinical and organizational processes during emergency situations. In MCIs, time-critical indicators are particularly relevant, as they directly influence patient outcomes and resource allocation. [3]

Common KPIs include:

- time to triage completion
- time to first medical contact
- time to diagnostic procedures
- overall patient throughput in the emergency department

International frameworks such as the WHO Hospital Emergency Response Checklist [3] and national guidelines such as the IEP identify these time-based indicators as essential reference values for assessing hospital readiness and detecting operational constraints. By evaluating delays and process variability, KPIs provide an objective basis for performance evaluation and process improvement in emergency management. In this study, KPIs serve as a foundational reference for the analysis of internal time structures observed during the MCI exercise. [2]

3 Methods

The following chapter describes the study design and methodological approach used to analyze in-hospital processes during the simulated MCI.

3.1 Literature Research

The literature research for this thesis was conducted using traditional academic search strategies and institutional resources. The primary sources were obtained through the online library system of the HAW Hamburg, which provides access to a wide range of textbooks, e-books, and scientific publications relevant to this study. As well as PubMed and Google Scholar.

Key words included terms such as:

- Mass casualty incident
- Hospital emergency management
- Triage
- Process times

Additionally, technical standards and guidelines for hospital emergency planning were accessed via the Norm-Server, Nautos, to ensure the inclusion of authoritative regulatory documents, such as applicable DIN standards.

ChatGPT was used to explore potential keywords, research directions, and focus areas related to hospital emergency management, mass-casualty incidents, and clinical process times. Suggestions generated by ChatGPT were not used uncritically, due to the potential for inaccurate or non-verifiable content. All references were independently verified before being included.

3.2 Usage of DeepLWrite and ChatGPT

To support the writing process, DeepLWrite and ChatGPT were used as linguistic assistance tools. The content of the thesis, including all arguments, analysis, and descriptions, was written independently. These tools were used only to refine language, improve readability, and enhance the academic tone of the text.

DeepLWrite was used to improve grammar and clarity of expression, while ChatGPT was used in a similar way to rephrase or refine sections of text that had already been drafted.

At no point were external ideas, concepts, or scientific content generated by these tools. They were also not used for data analysis, interpretation of results, or generation of scientific conclusions. All text that was edited with the help of AI-based tools was subsequently reviewed and revised to ensure accuracy, validity, and academic integrity. The use of these systems is documented here to ensure transparency and methodical clarity.

3.3 Study Design

This thesis is based on an observational process analysis conducted during an MCI simulation. Each simulated patient was accompanied by one observer, who followed the patient continuously throughout the entire clinical pathway. The observers documented all relevant steps and time points, without interfering with the operational workflow. This resulted in three complete individual patient datasets for detailed process analysis, and four additional datasets with incomplete time recordings, primarily originating from the Agaplesion Bethesda Hospital Bergedorf, where inconsistencies in documentation and missing time points limited the reconstruction of complete patient pathways. As a result, the primary analysis focuses on the complete datasets, while incomplete datasets were used selectively where appropriate.

The study design was chosen to enable a realistic, minimally intrusive assessment of clinical processes under emergency conditions. By assigning one observer per patient and continuously documenting time stamps along the treatment pathway, this approach enables a detailed reconstruction of patient flow and the temporal structure of clinical processes.

The analysis is conducted on a process level, focusing on the duration of specific operational steps within the patient pathway. In this context, individual time intervals between predefined process points are examined. These are further described in Chapter 3.5.

By analyzing these intervals, the study aims to identify potential delays, inefficiencies, or process constraints within the clinical workflow. These findings can then be interpreted in the broader context of hospital response during a mass-casualty incident. The observational design allows for a realistic representation of process performance under simulated emergency conditions, while maintaining a high level of data accuracy.

3.4 Data Collection and Measurement Methods

The data collection was carried out by three observers, each assigned to a single patient. This one-to-one allocation ensured continuous monitoring and complete documentation of all events relevant to the study. Time recording started when the ambulance transporting the simulated patient arrived at the hospital. From this moment onward, observers documented all relevant time points along the patient's clinical pathway until the predefined endpoint of the scenario was reached.

All time measurements were recorded using the observers' personal smartphones, allowing for precise real time documentation of each time point, although minor deviations due to human reaction time cannot be excluded. The use of smartphones provided a practical, standardized, and universally accessible measurement tool. Since all observers were already familiar with the device, the risk of handling errors was reduced and no additional equipment or training was required. This approach ensured immediate documentation, minimized delays, and increased overall data quality.

Additionally, each observer was provided with a standardized documentation sheet, consisting of one column for recording time stamps and another column for observation notes. This ensured structured, consistent and comparable data collection across all patient cases. An overview of how these raw data were processed and transformed into an analyzable dataset is provided in Chapter 3.5.

To ensure a consistent interpretation of the recorded time data, specific process-related timestamps were defined along the in-hospital patient pathway. Following the arrival of the ambulance, the initial triage at the emergency entrance was considered as a key reference point. Additional timestamps included the completion of triage, the initiation and completion of internal patient transport, and the arrival at the designated treatment area.

Due to the structural layout of the hospital, patients were initially received and triaged at the ambulance entrance located on the basement level. Subsequently, they were transported via elevator to the ground floor emergency department, where further treatment took place. This vertical transport step was explicitly considered in the time measurements, as it represents a distinct logistical component and a potential source of delay within the internal workflow.

Furthermore, the handover from prehospital emergency medical services to the in-hospital treatment team was included as a relevant process step, marking the transition between prehospital and in-hospital care. By incorporating these defined timestamps, the data collection captures both clinical and logistical aspects of patient management and allows for a more differentiated analysis of process durations. Despite the structured data collection

approach, several methodological limitations must be considered when interpreting the results.

First, data collection was performed manually in a dynamic simulation environment. Although the use of smartphones enabled precise real-time documentation, minor inaccuracies due to human reaction time and the simultaneous observation of multiple events cannot be completely excluded.

Second, observer-based data collection introduces a potential source of variability, particularly when identifying the exact start and end points of specific process steps. To reduce this effect, predefined timestamps and standardized observation sheets were used, ensuring a consistent documentation framework across all observers.

Third, the simulation setting itself represents a controlled environment that cannot fully replicate the complexity and unpredictability of a real mass casualty incident. Factors such as stress levels, resource limitations, and patient variability may differ in real-world scenarios. Therefore, the recorded time intervals should be interpreted as approximations rather than exact representations of clinical reality.

Despite these limitations, the applied methodology provides a structured and reproducible approach for analyzing key process intervals. The use of clearly defined time points and standardized documentation enhances data consistency and supports the validity of the findings.

3.5 Data Processing and Analysis Methods

As described in Chapter 3.4, the observation sheets (Appendix A) included relevant time stamps and a wider range of free-text observations. The selection of analyzed time intervals was based on established key performance indicators (KPIs) in emergency management, including time to triage completion, patient transfer times, and time to diagnostic procedures. As this study focuses on the analysis of predefined process-related time intervals, the raw data required systematic preprocessing.

In the first step, all documentation sheets were transferred into Microsoft Excel files. The use of a digital format ensured a consistent data structure, enabled the calculation of time intervals, and provided a structured overview. Once digitized, the entries were reviewed, and only time entries corresponding to the predefined process steps were extracted. The defined time intervals were selected based on their relevance as key performance indicators in emergency management and their measurability within the collected dataset. These intervals

are highlighted in different colors in the observation sheets to indicate which recorded events were used to determine the analyzed time intervals.

The following time-critical process steps were selected for analysis:

1. *RTW arrival → Triage completed (blue)*
   Description from the arrival of the patient at the emergency department (handover from the ambulance team) to the completion of the initial triage assessment. It reflects how quickly patients are prioritized and categorized according to the severity of their condition during the MCI.

2. *Shock Room → Start of Diagnostic Imaging (green)*
   The time from arrival in the shock room to the start of diagnostic imaging. It reflects the efficiency of diagnostic preparation and access to radiological resources.

3. *Completion Imaging → Clinical Decision (yellow)*
   The time from the completion of diagnostic imaging to the clinical decision regarding further treatment, such as transfer to the operating room, intensive care unit, or continued emergency department management. It reflects the efficiency of diagnostic interpretation and clinical decision-making.

4. *Total Time to Definitive Care (pink)*
   Total time from patient arrival at the hospital to the initiation of definitive care, such as surgical intervention, admission to the intensive care unit, or transfer to the appropriate treatment ward. It represents the overall efficiency of in-hospital patient management during the mass casualty scenario.

It should be noted that the duration of the diagnostic imaging procedure itself was not included in the defined intervals, as the analysis focused on process-related time intervals surrounding the diagnostic workflow.

Figure 1 shows an excerpt of the digitized observation sheet in which the recorded observations were color-coded to allow the identification of the process steps associated with each analyzed time interval.

	A	B
1	**Übung Sicherheitsstörung '25 HAW**	
2	**Zeit (hh:mm)**	**Beobachtung**
3	11:15:00	Ankunft RTW
4	11:17:00	Triage: als gelb eingestuft
5	11:19:00	Übergabe in "altem Schockraum"
6	11:21:00	Ende Übergabe Beginn Diagnostik, 1. Medikationsgabe
7	11:23:00	Info/Übergabe an Oberärztin
8	11:26:00	Wechsel Monitoring
9	11:27:00	RD verlässt Schockraum
10	11:29:00	weitere Diagnostik, Anforderung Chirurg
11	11:30:00	Übergabe an Chirurg (cABCDE Schema)
12	11:33:00	Beginn Behandlung, Verbandsanlage, Anforderung T Schiene aus ZNA, Beschluss CT Becken abwärts
13	11:36:00	cABCDE Schema, Info keine T Schiene in ZNA vorhamden
14	11:37:00	Ersatz wird gesucht
15	11:39:00	Frage an Pat nach Unfallhergang -> Beschluss Angio
16	11:39:00	Ankunft Vakuumschiene
17	11:40:00	Ankunft Internist
18	11:41:00	Sonographie
19	11:44:00	Vakuumschiene angelegt, Öffnung Tourniquet
20	11:46:00	cABCDE Schema, Chirurg verlässt Raum
21	11:51:00	Anmeldung CT
22	11:54:00	Pat. wird zu CT gefahren
23	11:56:00	Ankunft CT
24	11:58:00	anderer Pat. Hat Vorrang (gelb, ebenfalls aus Übung)
25	12:05:00	Beginn CT
26	12:15:00	Ende CT
27	12:19:00	Ankunft Intensivstation
28		
29	zus. Notizen:	als gelb von KHS Personal triagiert, den behandelnden Ärzten allerdings permanent als rot bekannt
30		

Figure 1 Excerpt of the digitized observation sheet transferred into Excel, showing color-coded timestamps used to calculate the analyzed time intervals (original German entries).

In addition to clinical decision intervals, several in-hospital transport intervals were analyzed to assess the efficiency of internal patient movement between critical treatment areas:

1. *Arrival → Triage*
2. *Triage → Shock Room*
3. *Shock Room → Imaging*
4. *Imaging → Shock Room/OR/ICU*
5. *Total transport time*

These steps were selected as they represent key transitions within the emergency workflow and were defined in collaboration with the hospital.

After identifying the relevant timestamps, the corresponding time intervals were calculated by subtracting the defined start and end times for each patient. To allow direct comparison between patients and process stages, all intervals were converted into minutes using the following Excel formula. The time difference between the two timestamps was multiplied by 1440 (the number of minutes per day in Excel time format) and rounded to the nearest whole minute.

An example calculation for the interval Shock Room → Start of Diagnostic Imaging (green) is shown below:

$$Interval\ (minutes) = ROUND((End\ Time - Start\ Time) \times 1440)$$

Equation 1

In Excel this was implemented using the following formula:

$$= ROUND((A23 - A5) * 1440{,}0)$$

Equation 2

Non-relevant clinical descriptions and narrative observations were excluded to maintain analytical clarity. Data from both hospitals were reviewed separately, and only those datasets that met the predefined quality criteria were included in the analysis, as some records contained incomplete or inconsistent time entries.

The data processing workflow used to extract and analyze the defined time intervals is illustrated in Figure 2.

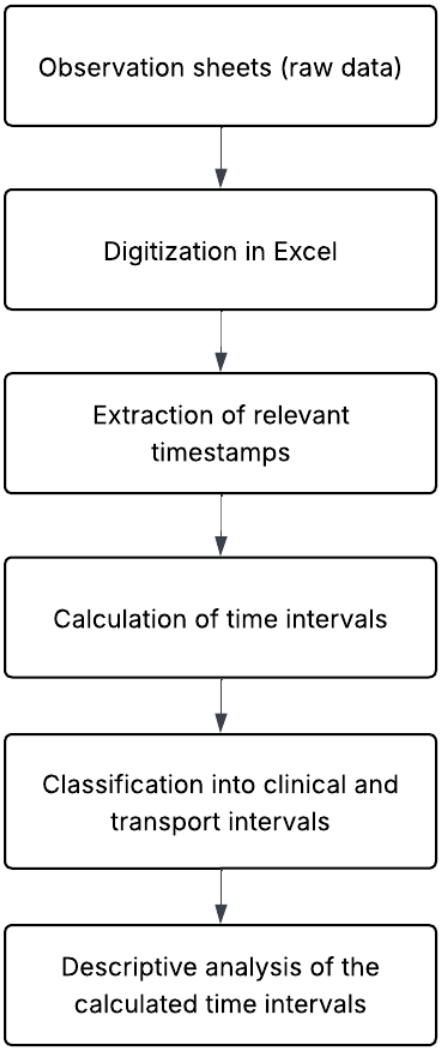


Figure 2 Workflow of data processing

The processed dataset was then prepared for descriptive analysis. The calculated time intervals were analyzed using descriptive comparison to evaluate the duration and variability of each process step. Descriptive statistical measures such as range were used to compare process durations between patients. Differences between patients were assessed based on the observed ranges and were visualized using comparative diagrams. This methodology allows the identification of delays, inefficiencies, or process constraints within the overall emergency workflow. The corresponding results are presented in Chapter 4.

3.6 Study Setting

This section describes the setting in which the exercise and data collection were conducted. It provides an overview of the Reinbek St. Adolf-Stift Hospital as the primary study location, the cooperation with the Hamburg University of Applied Sciences (HAW Hamburg), and the involvement of Agaplesion Bethesda Hospital Bergedorf in the exercise, which served as an additional source of data.

3.6.1 Description of the Reinbek Hospital St. Adolf-Stift

The Reinbek Hospital St. Adolf-Stift served as the primary clinical setting for the observational process analysis. Although the overall exercise scenario involved more than one hospital, only the data collected at this hospital were suitable for analysis and were therefore included in this study.

The exercise was conducted on a Saturday morning. This timing was intentionally chosen to minimize disruption to routine hospital operations and to allow controlled conditions during the simulation. In addition, external factors such as reduced traffic volume and the absence of regular academic activities at the Hamburg University of Applied Sciences (HAW) contributed to a more controlled and manageable environment for the exercise. As a result, overall hospital activity was reduced compared to regular weekday operations. Consequently, certain logistical factors, such as elevator availability, were less affected by competing usage from staff, patients, and visitors than would typically be expected during normal hospital operations.

Prior to the arrival of the patients, observers were positioned at predefined locations within the hospital. Each observer was assigned to a specific simulated patient and followed that patient throughout the in-hospital treatment process in order to document the clinical workflow. The hospital staff were notified by the emergency dispatch center about a mass casualty incident. As part of the hospital's emergency response procedure, internal staff mobilization would normally be initiated via a predefined telephone-based notification system. For the purposes of the simulation, however, this process was only simulated rather than executed in real time.

This system involved the sequential activation of personnel using a structured call list to ensure the availability of medical teams during the exercise. However, the medical teams were not informed in advance that the incoming patients were part of a simulation exercise. The scenario was therefore designed to replicate real-world operational conditions and to observe authentic clinical decision-making and workflow processes. The simulated nature of the scenario only became apparent to the hospital staff upon the arrival of the first ambulance.

For each incoming patient, a dedicated treatment team consisting of medical and nursing personnel was assigned. These teams were responsible exclusively for the assessment, diagnosis, and management of their respective patient. The treatment process followed the standard clinical workflow until the patient reached a predefined endpoint within the scenario, such as transfer to the operating room (OR), admission to the intensive care unit (ICU), or transfer to another hospital.

The observers documented all relevant timestamps starting from the arrival of the ambulance at the hospital, which marked the beginning of the recorded in-hospital patient pathway. This approach ensured a realistic representation of in-hospital processes under MCI conditions.

The structural layout of the hospital had a direct impact on the patient pathway and internal transport processes. The ambulance entrance of the emergency department was located on the basement level, where incoming patients were initially received and triaged. Based on this initial assessment, patients were categorized according to their injury severity (e.g., red or yellow category). Patients classified as green (minor injuries) were, according to the planned MCI concept, intended to be directed to the main hospital entrance and managed outside the emergency department. This measure aims to prevent overcrowding of critical treatment areas and to ensure that resources within the emergency department remain available for severely injured patients.

Following triage, patients were transported from the basement level to the ground floor (EG) using an elevator in order to reach the emergency department. This vertical transport step represented an additional component of the internal patient pathway and a potential source of delay. Upon arrival in the emergency department, patients were transferred to designated treatment areas, such as the shock rooms. There, a structured patient handover from the prehospital emergency medical services to the in-hospital medical team took place, providing all relevant clinical information required for further treatment.

This multi-stage process, including triage in the basement, elevator transport, and subsequent handover in the emergency department, directly influenced the overall duration of in-hospital patient management and therefore represents an important factor in the interpretation of recorded time intervals.

3.6.2 Simulation Scenario at Hamburg University of Applied Sciences (HAW Hamburg)

The MCI simulation was organized in cooperation with the Hamburg University of Applied Sciences (HAW Hamburg), where the initial simulation scenario took place. The exercise began at 10:00 a.m. and simulated a violent attack scenario involving an active shooter situation within the university building. Two perpetrators opened fire inside the building, resulting in multiple injured people. The situation was resolved by a Special Task Force (Ger: Spezialeinsatzkommando, SEK), which entered the building and neutralized the perpetrators. After the scene had been secured, the emergency medical services entered the building to evacuate the injured individuals from the area.

In total, 17 simulated patients were involved in the exercise. After being evacuated from the building, the patients were triaged by emergency medical personnel according to the severity of their injuries. Based on this triage process, five patients were selected for transport to the participating hospital and were subsequently transported by ambulance. The first ambulance departed from the scene at approximately 10:58 a.m., representing the start of patient transport and forming a relevant temporal reference point for subsequent hospital admission. The scenario involved multiple responding agencies, including SEK, emergency medical services, fire department, and hospital staff. The exercise was designed to simulate realistic operational conditions and to evaluate coordination and workflow processes during an MCI incident.

Figure 3 illustrates the overall sequence of the exercise scenario and highlights the main operational steps from the simulated incident to hospital admission.

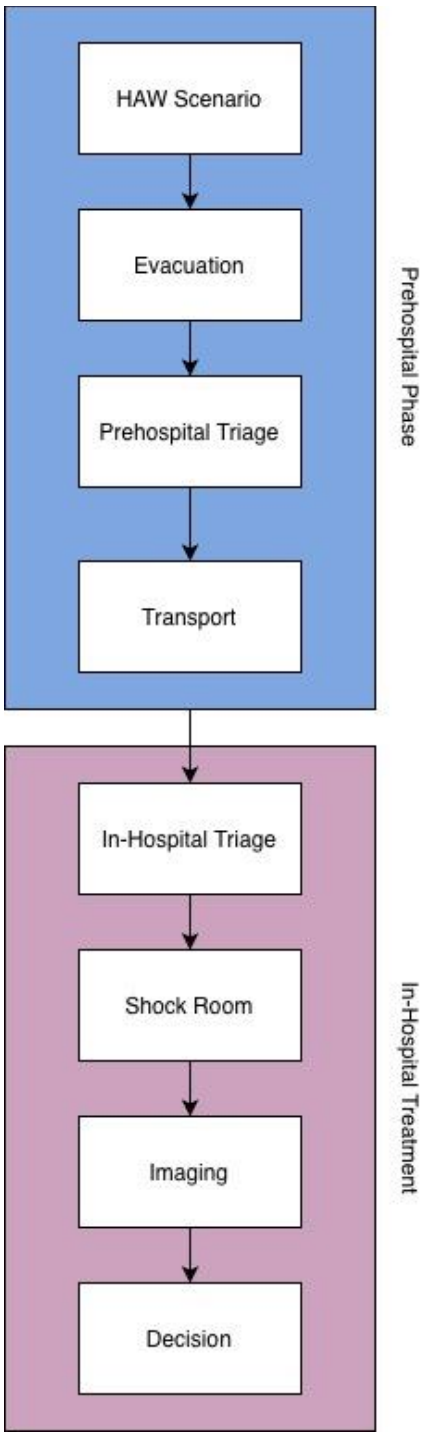


Figure 3 MCI Simulation Workflow

3.6.3 Cooperation with the Agaplesion Bethesda Hospital Bergedorf

In addition to the Reinbek Hospital St. Adolf-Stift, the Agaplesion Bethesda Hospital Bergedorf also participated in the exercise scenario. This hospital fulfilled a comparable operational role and received simulated patients transported by ambulance following the initial triage process. The inclusion of a second hospital aimed to increase the number of observed patient pathways and to enable a comparative perspective on in-hospital workflows under MCI conditions. Observers were therefore also deployed at this site and followed the same data collection approach as described for the Reinbeker hospital, ensuring methodological consistency.

However, the data collected at the Bergedorf hospital were only partially suitable for analysis due to inconsistencies and incomplete documentation. As a result, only selected data points were included in the evaluation, and a systematic comparison between both hospitals was limited. Despite these limitations, the available data provide additional contextual insights and support the interpretation of observed process characteristics.

4 Results

4.1 Overview of Analyzed Data

The results are based on data collected during the MCI exercise. In total, eight patient observations were recorded, each corresponding to one simulated patient pathway. Of these, three complete datasets were obtained from the Reinbeker hospital, allowing for a comprehensive analysis of in-hospital process times. In contrast, five additional datasets were collected at the second participating hospital in Bergedorf. However, these datasets were only partially complete due to inconsistencies and missing time entries. The available datasets differed not only in completeness but also in the level of detail of the recorded time points. While the Reinbek datasets allowed for the reconstruction of complete patient pathways across all predefined process steps, the Bergedorf datasets often contained only isolated time stamps, limiting the ability to analyze full process sequences.

As a result, the primary analysis focuses on the complete datasets from the Reinbeker hospital, while selected data from the Bergedorf hospital are included to provide supplementary insights into specific process steps where sufficient data were available. Due to the limited completeness of the Bergedorf datasets, a full comparative analysis between both hospitals was not feasible. Instead, the comparison is restricted to selected intervals where comparable data were available.

4.2 Results – Reinbek Hospital St. Adolf-Stift

Building on the interpretation of the results, the findings can be further contextualized within existing literature and established emergency management principles. The results are presented in two main categories: clinical time-critical intervals and internal patient transport times. As described in Section 3.5, the collected raw data were filtered and reduced to the predefined process-related time intervals relevant to this study. Intermediate clinical activities that were not part of the analyzed process steps were excluded from the final dataset.

The clinical time-critical intervals for the three observed patients are presented below. The analyzed intervals include Arrival → Triage completion, Shock Room (SR) → Start of Diagnostic Imaging, Imaging → Clinical Decision, and Arrival → Definitive Care. All time intervals are reported in minutes (min).

Table 1 summarizes the recorded time intervals for the three patients included in the analysis. The interval from arrival to triage completion showed consistently short durations, ranging between 2 and 3 minutes across all patients. This indicates minimal variability in the initial assessment phase.

Table 1 Clinical time-critical intervals of observed patients Reinbek

Clinical Time-Critical Intervals [min]				
Patient	Arrival --> Triage completion	SR --> Start of Diagnostic Imaging	Imaging → Clinical Decision	Arrival → Definitive Care
PR 11 (yellow)	2	17	6	37
PR 04 (red)	2	37	13	64
PR 06 (yellow)	3	25	9	42

In contrast, the subsequent interval from shock room admission to the start of diagnostic imaging represented the longest phase within the clinical workflow for all observed cases. This interval also showed the greatest variability between patients, ranging from 17 to 37 minutes. A more detailed examination reveals that the red-coded patient (PR04) experienced the longest duration within this phase (37 minutes), while the yellow-coded patients (PR11 and PR06) demonstrated shorter process times of 17 and 25 minutes, respectively.

The interval from imaging to clinical decision showed moderate variability, with recorded times ranging from 6 to 13 minutes. Compared to the previous process step, this phase showed a narrower distribution of values, although differences between patients remained visible.

The overall time from arrival to definitive care ranged from 37 minutes to 64 minutes among the observed patients. A closer comparison of the individual patient pathways shows that differences in total treatment time were mainly driven by the duration of the intermediate process steps rather than the initial triage phase, which remained consistently short across all patients. In particular, variations in the time required to initiate diagnostic imaging contributed substantially to the overall differences between cases.

Figure 4 visualizes these time intervals in a graphical format, facilitating comparison between the individual patients.

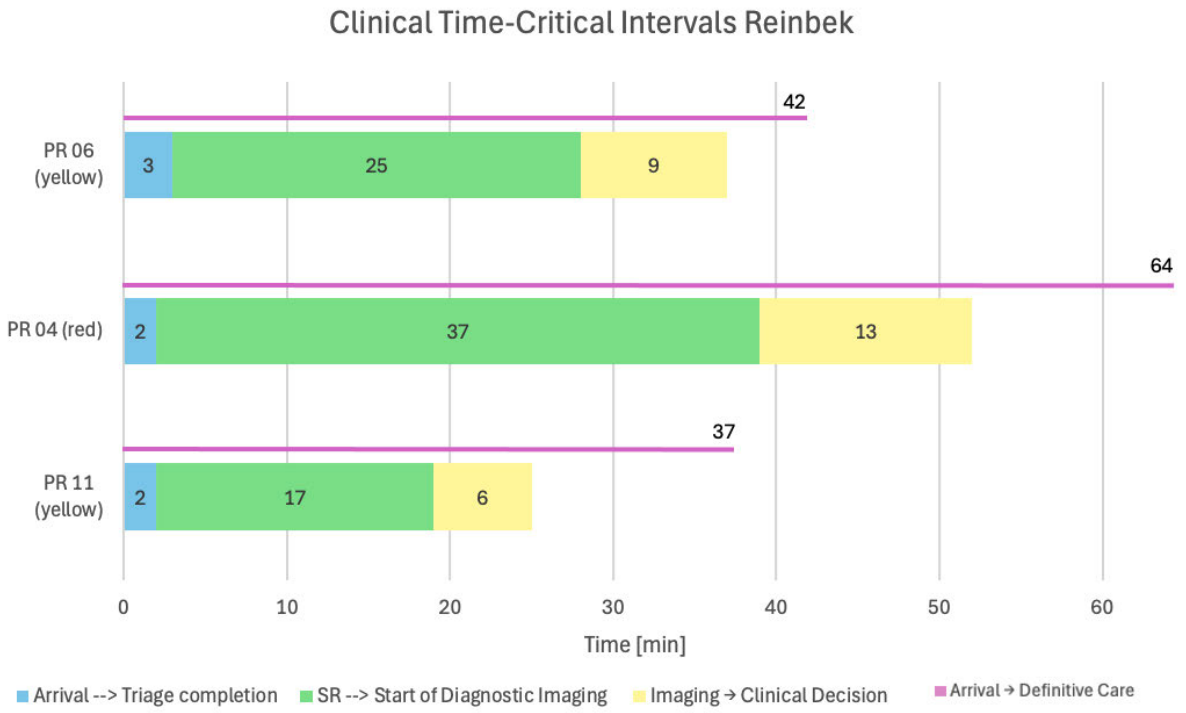


Figure 4 Visualization of clinical time-critical intervals Reinbek

The graphical representation further emphasizes that early process steps are relatively uniform, whereas later stages show a wider spread of values, indicating increased variability in downstream clinical processes.

It should be noted that the apparent gaps between the individual time intervals in the graphical representation do not represent missing data but result from the methodological definition of the analyzed intervals. Specifically, the duration of diagnostic procedures such as CT or X-ray imaging was not included in the analysis. In addition, certain process steps, including internal patient transport (e.g., from triage to the shock room), were analyzed separately and are therefore not reflected within the clinical time-critical intervals shown.

Table 2 presents the recorded transport times for the observed patients. The data indicate that transport-related intervals were consistently short across all patient pathways. No outliers or extreme deviations were observed in any of the recorded transport intervals, further supporting the consistency of internal patient movement within the hospital setting.

Table 2 Recorded Internal Patient Transport Times Reinbek

In-Hospital Transport Intervals					
Patient	Arrival --> Triage	Triage --> SR	SR --> imaging	Imaging --> SR/OR	Total transport time
PR 11 (yellow)	1	1	4	2	8
PR 04 (red)	1	2	2	4	9
PR 06 (yellow)	1	2	2	4	9

The recorded transport times ranged from 1 to 4 minutes depending on the transport route, with only minor variability between patients. Overall transport times per patient ranged between 8 and 9 minutes, indicating a high level of consistency in internal patient movement. Notably, the transport intervals from the shock room to imaging and from imaging back to the shock room or operating room showed similar durations across the observed cases. This suggests a symmetrical pattern in transport durations between these locations. This pattern was observed across all patients, regardless of triage category, suggesting that transport processes were largely independent of patient condition.

Figure 5 provides a graphical representation of the recorded transport times and further illustrates the limited variability between patients.

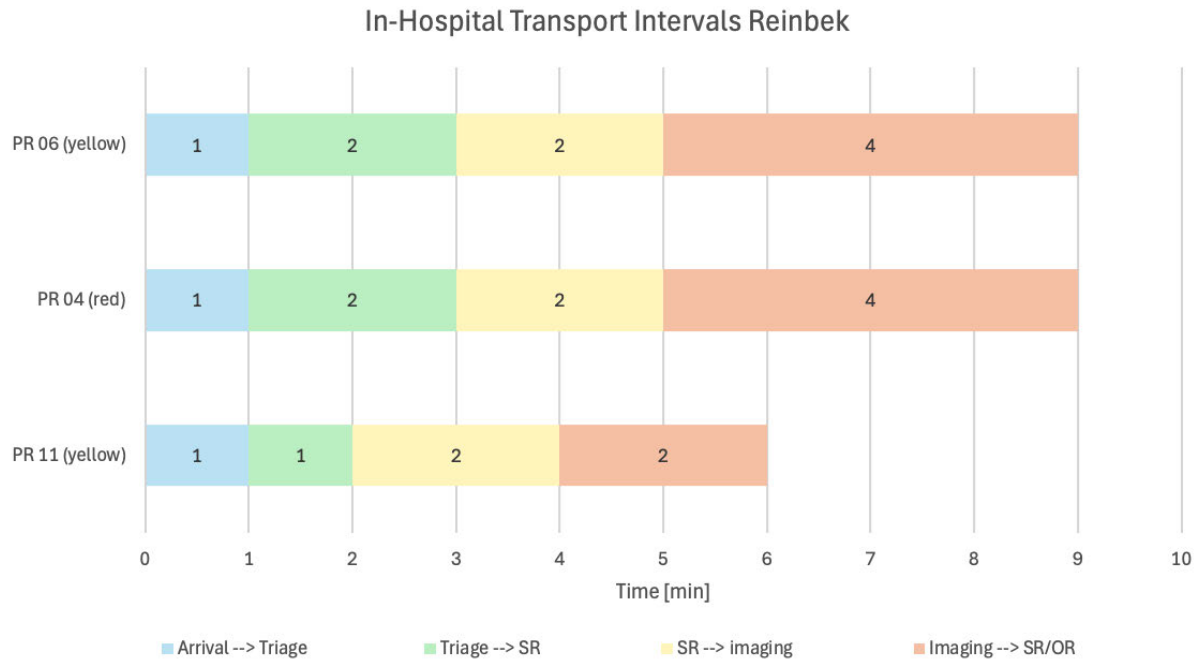


Figure 5 Visualization of Internal Patient Transport Times Reinbek

4.3 Results – Agaplesion Bethesda Hospital Bergedorf

In addition to the results obtained from the Reinbek Hospital St. Adolf-Stift, partial data from the second participating hospital in Bergedorf were analyzed where sufficient data quality was available. Due to incomplete and inconsistent documentation, not all predefined time intervals could be evaluated for every patient. Therefore, the following findings represent a partial analysis of the available datasets.

The clinical time-critical intervals recorded for the Bergedorf hospital are summarized in Table 3. The available data include Arrival → Triage completion, Shock Room (SR) → Start of Diagnostic Imaging, Imaging → Clinical Decision, and Arrival → Definitive Care. However, several intervals could not be determined for all patients.

Table 3 Clinical time-critical intervals of observed patients Bergedorf

Clinical Time-Critical Intervals [min]				
Patient	Arrival --> Triage completion	SR --> Start of Diagnostic Imaging	Imaging → Clinical Decision	Arrival → Definitive Care
PB 1 (red)	7	13	-	20
PB 2 (red)	1	-	-	-
PB 3 (yellow)	2	11	5	19
PB 4 (yellow)	2	16	-	18
PB 5 (yellow)	1	8	-	-

The recorded time from arrival to triage completion ranged from 1 to 7 minutes. Most observations were clustered between 1 and 2 minutes, with one outlier contributing to the wider overall range. Despite this variability, the majority of cases indicate that triage was generally performed within a short time frame.

In contrast, the interval from shock room admission to the start of diagnostic imaging showed greater variability, with recorded values ranging from 8 to 16 minutes in cases where data were available. However, missing data points limit the interpretability of this process step. As a result, the observed values should be interpreted as indicative rather than representative of the overall process performance.

For several patients, the interval from imaging to clinical decision could not be evaluated due to missing or incomplete time entries. Similarly, the total time from arrival to definitive care was only available for selected cases, ranging from 18 to 20 minutes. A detailed reconstruction of complete patient pathways was therefore not possible for all cases. In several instances, only isolated time points were recorded, preventing a continuous analysis of the clinical workflow. This lack of continuity in the data limits the ability to identify patterns or dependencies between consecutive process steps.

Figure 6 visualizes the available time intervals and highlights both the variability of recorded values and the presence of missing data.

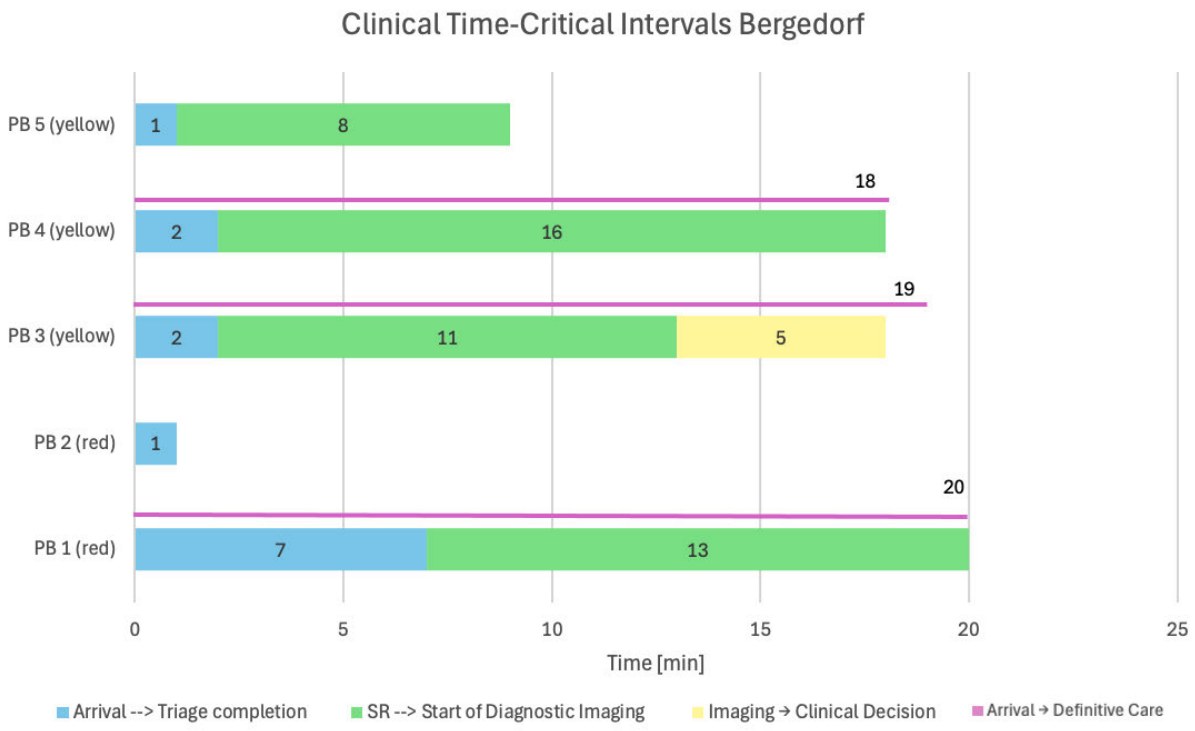


Figure 6 Visualization of clinical time-critical intervals Bergedorf

In total, the results highlight key differences in the duration and variability of in-hospital processes during the simulated MCI and provide the basis for further interpretation in the following discussion Chapter 5.

4.4 Comparison Between the Two Hospitals

Table 4 presents a direct comparison of clinical time-critical intervals between the two participating hospitals.

Table 4 Comparison of Clinical Time-Critical Intervals Between Both Hospitals

Comparison of Clinical Time-Critical Intervals Between Both Hospitals [min]								
Clinical Time-Critical Intervals	Reinbek			Bergedorf				
	PR 04 (red)	PR 11 (yellow)	PR 06 (yellow)	PB 1 (red)	PB 2 (red)	PB 3 (yellow)	PB 4 (yellow)	PB 5 (yellow)
Arrival --> Triage completion	2	2	3	7	1	2	2	1
SR --> Start of Diagnostic Imaging	37	17	25	13	-	11	16	8
Imaging → Clinical Decision	13	4	9	-	-	5	-	-
Arrival → Definitive Care	64	37	42	20	-	19	18	-

- indicates that no data was recorded or the process step was not completed for this patient

The time interval from arrival to triage completion showed relatively similar values across both hospitals, with most observations ranging between 1 and 3 minutes. This indicates comparable performance in the initial triage process across both hospitals. This consistency suggests that the initial assessment process was performed in a similar manner across both institutions.

In contrast, greater differences were observed in the subsequent process step from triage to the start of diagnostic imaging. While Reinbek Hospital showed consistently longer durations, Bergedorf hospital demonstrated shorter but more variable time intervals, accompanied by missing data points.

For the interval from imaging to clinical decision, only limited data were available, particularly for Bergedorf hospital. Due to the small number of recorded values, no meaningful comparison between the hospitals can be made for this process step.

Similarly, the interval from arrival to definitive care showed incomplete data, especially for Bergedorf hospital. As a result, this parameter does not allow for a reliable comparison between the two hospitals.

Overall, the comparison highlights differences not only in process duration but also in data completeness between the two hospitals. While similarities can be observed in early process steps, the later stages of the clinical workflow show greater variability and limited comparability, particularly due to incomplete datasets from the Bergedorf hospital.

4.5 Summary of Key findings

The results of this study highlight several key observations regarding in-hospital processes during the simulated MCI scenario.

First, the interval from arrival to triage completion was consistently short across both hospitals, indicating a stable and reliable initial assessment process.

Second, the transition from shock room admission to diagnostic imaging represented the longest and most variable phase within the clinical workflow, particularly in the Reinbek hospital.

Third, internal patient transport times were consistently short and showed minimal variability, suggesting that transport processes did not represent a limiting factor in patient flow.

Finally, the comparison between the two hospitals revealed differences in data completeness and variability, limiting the extent to which direct comparisons could be made across all process steps. These findings provide the basis for the interpretation and discussion presented in the following chapter.

5 Discussion

5.1 Interpretation of Results

The analysis of clinical time-critical intervals revealed distinct patterns across the different stages of the in-hospital treatment process. While early process steps were performed consistently and within a narrow time range, later stages showed increased variability and, in some cases, incomplete data.

The time interval from arrival to triage completion was consistently short across all observed patients, with values predominantly ranging between 1 and 3 minutes. This uniformity suggests that the initial patient assessment was carried out in a structured and reliable manner in both hospitals. In the context of MCI management, this finding is particularly relevant, as rapid and consistent triage represents a fundamental prerequisite for effective patient prioritization and resource allocation. The low variability further indicates that triage procedures were well understood and consistently applied by the involved staff.

In contrast, the subsequent phase from shock room admission to the start of diagnostic imaging represented the longest segment within the clinical workflow. Particularly in the Reinbek hospital, this interval showed considerable variation, ranging from 17 to 37 minutes. This finding suggests that this phase may represent a critical point within the patient pathway, where both clinical decision-making and organizational processes interact.

When interpreting these differences, the triage classification of the patients must be considered. The red-coded patient showed a substantially longer time interval compared to the yellow-coded patients, which may reflect differences in clinical prioritization and treatment requirements. In severely injured patients, extended durations in the shock room may be necessary to perform life-saving stabilization measures and to ensure that the patient is sufficiently stabilized and transportable before further diagnostic procedures can be initiated. Therefore, prolonged time intervals in this phase should not necessarily be interpreted as inefficiencies but may instead reflect appropriate clinical decision-making under time-critical conditions.

For the Bergedorf hospital, a direct comparison of this process step is limited. The available data do not allow for a consistent assessment, as key time points, particularly the interval from shock room admission to diagnostic imaging, were not documented. In addition, the reliability of the recorded data must be interpreted with caution, which further restricts the overall interpretability of the results for this hospital. This limitation highlights the importance of standardized and complete data collection in order to enable meaningful process evaluation.

The interval from imaging to clinical decision also demonstrated variability, with recorded values ranging from 4 to 13 minutes. Notably, the longest duration was observed in a red-coded patient. According to the observational data, this extended time can be attributed to waiting time, as a yellow-coded patient underwent diagnostic imaging beforehand. This observation suggests that, despite the presence of triage-based prioritization, resource limitations and process coordination may still influence patient flow and lead to temporary deviations from the intended prioritization strategy.

In contrast to the clinical time-critical intervals, in-hospital transport times were consistently short, ranging between 1 and 4 minutes, with minimal variability between patients. Additionally, transport durations between the shock room and imaging, as well as the return pathway, showed comparable values across cases. This indicates that internal logistics functioned efficiently under the simulated conditions and did not represent a limiting factor within the overall workflow.

This is particularly noteworthy given that these transport routes included the use of elevators, which are often considered potential sources of delay in hospital logistics. However, no relevant time delays were observed in this context, suggesting that the physical layout and internal organization of transport processes were well adapted to the simulated scenario. It should be noted, however, that the exercise was conducted on a Saturday morning, resulting in a relatively low level of hospital activity. Under these conditions, the elevators were readily available and not subject to competing usage by staff, patients, or visitors. In routine hospital operations, where elevators are shared and no prioritization mechanism is in place for emergency transports, delays may be more likely to occur. This indicates that the observed efficiency of transport processes may be partly influenced by the specific conditions of the simulation.

Overall, the findings suggest that while early stages of patient management and transport processes were performed efficiently and consistently, later stages of the clinical workflow, particularly those involving diagnostic imaging and clinical decision-making, exhibited increased variability. This highlights these phases as potential bottlenecks within the patient pathway and emphasizes the importance of optimizing coordination, resource allocation, and workflow organization in order to improve overall system performance during MCI scenarios.

5.2 Comparison with Literature and Benchmarks

The analysis of clinical time-critical intervals can be contextualized using established principles of hospital emergency management and key performance indicators (KPIs) commonly applied in mass casualty incident (MCI) scenarios. These KPIs typically include time to triage, time to diagnostic procedures, and time to clinical decision-making, as they reflect the efficiency of patient prioritization and treatment processes.

In the present study, the time from arrival to triage completion was consistently short, with values predominantly ranging between 1 and 3 minutes. This finding aligns with established emergency management principles, which emphasize rapid patient assessment as a fundamental requirement in MCI situations. Triage is essential to ensure that limited resources are allocated effectively and that critically injured patients are identified and treated without delay. [5]

In addition, previous studies underline that standardized triage algorithms contribute to a more efficient distribution of patients and help maintain treatment capacity under conditions of increased demand. The consistency of triage times observed in this study therefore suggests that the applied triage procedures were well structured and effectively implemented during the exercise. [5]

In contrast, the interval from shock room admission to the start of diagnostic imaging represented the longest phase within the observed clinical workflow. According to existing guidelines, efficient coordination of hospital processes and optimal use of available resources are critical to maintaining treatment capacity during MCI scenarios. [2, 3]

However, prolonged durations in this phase should not automatically be interpreted as indicators of inefficient workflow. In the observed cases, part of this interval may reflect necessary clinical treatment and stabilization measures performed in the shock room before patients were sufficiently stable for transport to diagnostic imaging. Thus, the recorded times likely represent a combination of medically required pre-imaging interventions and organizational factors within the hospital workflow.

This interpretation is further supported by the general definition of MCI, which is characterized by a mismatch between the number of patients and the available resources, limiting the ability to provide optimal care for all individuals. In this context, delays in diagnostic imaging and subsequent treatment steps may also be understood as a consequence of resource allocation and process coordination within the hospital rather than purely operational inefficiencies. [1]

The findings related to the interval from imaging to clinical decision further underline the importance of structured workflows. The observed variability, including prolonged waiting times in individual cases, suggests that clinical prioritization may be influenced by operational factors such as resource availability and patient flow. This is consistent with previous research demonstrating that, although triage systems are designed to guide prioritization, their practical implementation may be affected by situational dynamics and organizational constraints. [5]

In contrast to the clinical workflow, in-hospital transport times were consistently short and showed minimal variability. According to hospital emergency management guidelines, internal logistics are an important component of patient flow and play a key role in preventing bottlenecks within the treatment process. However, the findings of this study indicate that transport processes did not represent a limiting factor in the observed scenario. [2, 3]

It must be considered, however, that these favorable transport times may be influenced by the controlled conditions of the simulation. As highlighted in the literature, hospital performance during MCI scenarios is strongly dependent on contextual factors such as resource availability, workload, and external conditions. The exercise in this study was conducted during a period of reduced hospital activity, which likely minimized competition for logistical resources such as elevators. In routine clinical operations, where these resources are shared and no prioritization mechanisms are typically in place, delays may be more pronounced. [1]

Furthermore, previous studies emphasize that communication and coordination within the hospital command structure represent critical success factors in MCI management. [9] Although these aspects were not directly measured in this study, the relatively smooth progression of patient flow and the consistency of several time intervals suggest that coordination mechanisms were generally functional during the exercise.

Overall, the comparison with existing literature suggests that while fundamental principles such as rapid triage and efficient patient movement were successfully implemented, challenges remain in the coordination of diagnostic and decision-making processes. These findings emphasize that, in MCI management, organizational structures, communication, and workflow efficiency represent critical determinants of overall system performance.

5.3 Limitations of the Study

Several limitations must be considered when interpreting the results of this study.
First, the analysis is based on a relatively small sample size, as only a limited number of patients with complete datasets were available for evaluation. This restricts the generalizability of the findings and limits the ability to draw statistically robust conclusions.
In addition, the study was conducted within the framework of a simulation exercise rather than under real clinical conditions. Although the scenario was designed to be as realistic as possible, simulation-based settings cannot fully replicate the complexity, unpredictability, and time pressure of actual mass casualty incidents. Therefore, the observed process times should be interpreted as approximations under controlled conditions rather than exact representations of real-world performance.

Furthermore, the exercise took place on a Saturday morning, resulting in reduced hospital activity compared to routine weekday operations. Under these conditions, logistical resources such as elevators were readily available and not subject to competing demands from staff, patients, or visitors. Consequently, transport times observed in this study may underestimate delays that could occur under normal operating conditions.

Another important limitation concerns data completeness and quality. In particular, the dataset from the Bergedorf hospital contained missing time points and inconsistencies, which restricted comparability between the two hospitals. These limitations can be attributed to organizational and communication-related challenges during the exercise. In some cases, insufficient preparation and unclear communication regarding the execution of the scenario led to incomplete documentation of patient pathways. As a result, key process steps, such as the interval between shock room admission and diagnostic imaging, were not consistently recorded.

Additionally, the data collection process relied on manual observation. In some instances, observers did not fully capture all relevant process steps, partly due to uncertainties regarding the intended scope of patient tracking within the simulation. Consequently, documentation was occasionally discontinued before patients reached later stages of treatment, such as diagnostic imaging.

It should also be noted that the observed triage times did not indicate any delays related to staff mobilization, as the personnel available within the hospital at the time of the exercise were sufficient to manage the incoming patients. However, under routine conditions, staff mobilization would be initiated via a predefined telephone-based notification system. As this process was only simulated during the exercise, its actual impact on response times could not be assessed. It can be assumed that, in a real-world scenario, the sequential activation of

personnel via a manual telephone system may lead to delays in the availability of treatment teams.

Moreover, one observed outlier in the triage interval can be attributed to an interruption of the exercise scenario. According to the observational records, the hospital requested a temporary pause due to a lack of preparedness. This external factor influenced the recorded time and does not reflect routine clinical performance.

It should also be considered that the recorded time intervals were influenced not only by organizational factors but also by clinical decision-making and patient-specific conditions. For example, longer time intervals prior to diagnostic imaging may reflect necessary stabilization and treatment measures rather than process inefficiencies.

Finally, the manual documentation of time points using observational protocols may be subject to minor inaccuracies, as time recording depended on human observation and reaction. Although efforts were made to ensure accuracy, small deviations in recorded times cannot be completely excluded.

Despite these limitations, the study provides valuable insights into in-hospital processes during MCI scenarios and highlights relevant factors influencing clinical workflow and patient management. The findings therefore contribute to a better understanding of process dynamics and offer a basis for further research and optimization of hospital emergency response systems.

5.4 Implications for Practice

The results of this study provide several important implications for clinical practice and highlight opportunities for improving hospital preparedness in MCI scenarios.
First, the results demonstrate that early process steps, particularly triage, can be performed reliably and within short time frames when structured procedures are in place. This underlines the importance of regular training and the consistent application of standardized triage protocols to ensure rapid and effective patient prioritization.

In contrast, the observed variability in later stages of the clinical workflow, especially in the transition from shock room management to diagnostic imaging and clinical decision-making, indicates potential areas for process optimization. Hospitals may benefit from reviewing internal workflows, particularly regarding the coordination of diagnostic resources and the sequencing of patient management steps.

A key practical implication relates to the early response phase of the hospital. The time interval between the occurrence of the incident, the confirmation of hospital readiness, and the arrival of the first patient can be interpreted as a critical performance indicator reflecting the responsiveness of the hospital system. Reducing this response time is essential to ensure timely initiation of patient care.

Feedback from the participating hospital highlighted limitations in current internal alerting and mobilization processes. In particular, the reliance on manual telephone-based notification systems was identified as a potential source of delay, as it may slow down the rapid assembly of treatment teams. As a consequence, the implementation of web- or cloud-based communication systems should be considered to improve the speed, reliability, and coordination of staff mobilization during MCI events.

In addition, the exercise led to the consideration of adapting patient management strategies, such as deploying treatment teams directly to the triage area rather than relying exclusively on patient transport to predefined treatment locations. This approach may facilitate earlier initiation of medical care and improve overall patient flow, particularly in high-demand situations.

The findings also emphasize the importance of clearly defined roles, structured communication, and adequate preparation of all personnel involved in simulation exercises. Improved training of observers and clearer instructions regarding documentation processes may enhance data quality and provide more reliable insights for future evaluations.

Finally, future research should aim to include larger sample sizes, meaning more patients to be observed, and, where possible, real-world data to validate the findings of this study. Additional investigations focusing on the interaction between clinical decision-making, resource availability, and workflow organization may further contribute to optimizing hospital response in MCI scenarios.

Overall, this study demonstrates that while fundamental processes such as triage and patient transport can function effectively under simulated conditions, the coordination of internal clinical workflows and communication structures remains a critical determinant of hospital performance and represents a key area for further improvement in MCI preparedness.

6 Outlook

The findings of this study highlight several areas for future development in hospital emergency preparedness and provide a basis for further research in the context of MCI.
A key aspect concerns the early response phase of the hospital. The time interval between the occurrence of the incident, the confirmation of hospital readiness, and the arrival of the first patient can be considered a relevant performance indicator reflecting the responsiveness of the hospital system. Future analyses should therefore aim to capture and evaluate this response time more systematically, for example by integrating prehospital and in-hospital data sources into a unified timeline.

In this context, the exercise revealed potential for improvement in internal communication and staff mobilization processes. Although no delays in triage were observed during the simulation, this was primarily due to the availability of sufficient personnel already present in the hospital. Under routine conditions, staff mobilization would be initiated via a predefined telephone-based notification system. As this process was only simulated, its actual impact on response times could not be assessed. However, it is likely that the sequential activation of personnel via a manual telephone system may lead to delays in the availability of treatment teams.

Consequently, the implementation of digital communication solutions, such as web- or cloud-based notification systems, should be considered to improve the speed, reliability, and coordination of staff mobilization during MCI scenarios. Future studies should specifically evaluate the effectiveness of such systems compared to conventional notification methods, for example by analyzing response times, staff availability, and overall system performance.
In addition, the deployment of treatment teams directly at the triage area may further optimize patient flow and enable earlier initiation of care. In combination with improved digital alerting systems, such as app-based notification tools, this approach could allow designated teams, consisting of a physician and a nurse, to be pre-positioned at the triage area prior to patient arrival. This would facilitate immediate patient handover from prehospital services and enable the initiation of medical care without delay. Future studies should investigate the impact of such concepts on both clinical and logistical process intervals within MCI scenarios.

Furthermore, future research should place greater emphasis on the identification and consideration of relevant covariates and potential confounding factors that may influence the interpretation of time-critical processes. Variables such as patient injury severity, triage category, availability of medical personnel, and overall hospital workload can significantly affect process durations and should therefore be systematically recorded and analyzed.

In this context, larger sample sizes are essential to allow for more robust statistical analyses and to improve the generalizability of the findings. Multi-center studies involving several hospitals could provide valuable insights into structural differences, organizational strategies, and their impact on process efficiency.

In addition, external factors specific to simulation settings, such as reduced hospital activity, controlled conditions, and observer-related variability, may act as confounders and limit the transferability of results to real-world situations. A more structured approach to data collection, including standardized documentation procedures and clearly defined observation protocols, may improve the validity and comparability of future studies. The use of digital time-tracking systems or automated data capture technologies could further reduce observer-related bias and increase measurement accuracy.

Overall, further investigations based on larger datasets and, where possible, real-world scenarios are required to validate the findings and to support the development of optimized clinical workflows and response strategies in hospital-based MCI management.

In summary, this study demonstrates that while key processes such as triage and patient transport can be performed efficiently under simulated conditions, future improvements should focus on early response coordination, communication systems, and the optimization of downstream clinical workflows in order to enhance overall hospital performance during MCI scenarios.

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Appendices

A. Data Collection Sheets

Table 5 Hospital Reinbek, Observer 1, Patient Nr. 11 (yellow)

Übung Sicherheitsstörung '25 HAW	
Zeit (hh:mm)	**Beobachtung**
11:27:00	Ankunft RTW
11:29:00	Vorstellung Triage
11:30:00	Ankunft Schockraum
11:30 - 11:33	Übergabe vom Rettungsdienst an Krankenhauspersonal im Schockraum
11:33 - 11:41	Diagnostik im Schockraum
11:47:00	Wartezeit auf CT
11:58:00	Weg zum CT und Durchführungszeit
12:00:00	Rückweg vom CT in den Schockraum
12:02:00	Schmerzmittelgabe
12:04:00	Entscheidung zur Verlegung nach Boberg

Table 6 Hospital Reinbek, Observer 2, Patient 4 (red)

Übung Sicherheitsstörung '25 HAW	
Zeit (hh:mm)	**Beobachtung**
11:15:00	Ankunft RTW
11:17:00	Triage: als gelb eingestuft
11:19:00	Übergabe in "altem Schockraum"
11:21:00	Ende Übergabe Beginn Diagnostik, 1. Medikationsgabe
11:23:00	Info/Übergabe an Oberärztin
11:26:00	Wechsel Monitoring
11:27:00	RD verlässt Schockraum
11:29:00	weitere Diagnostik, Anforderung Chirurg
11:30:00	Übergabe an Chirurg (cABCDE Schema)
11:33:00	Beginn Behandlung, Verbandsanlage, Anforderung T Schiene aus ZNA, Beschluss CT Becken abwärts
11:36:00	cABCDE Schema, Info keine T Schiene in ZNA vorhamden
11:37:00	Ersatz wird gesucht
11:39:00	Frage an Pat nach Unfallhergang -> Beschluss Angio
11:39:00	Ankunft Vakuumschiene
11:40:00	Ankunft Internist
11:41:00	Sonographie
11:44:00	Vakuumschiene angelegt, Öffnung Tourniquet
11:46:00	cABCDE Schema, Chirurg verlässt Raum
11:51:00	Anmeldung CT
11:54:00	Pat. wird zu CT gefahren
11:56:00	Ankunft CT
11:58:00	anderer Pat. Hat Vorrang (gelb, ebenfalls aus Übung)
12:05:00	Beginn CT
12:15:00	Ende CT
12:19:00	Ankunft Intensivstation
zus. Notizen:	als gelb von KHS Personal triagiert, den behandelnden Ärzten allerdings permanent als rot bekannt

Table 7 Hospital Reinbek, Observer 3, Patient 6 (yellow)

Übung Sicherheitsstörung '25 HAW	
Zeit (hh:mm)	**Beobachtung**
10:05:00	Übungsstart
11:27:00	Ankunft RTW 34-NTW-A mit Gelben Patienten (Einschuss linker Unterschenkel, Unterschenkelfraktur) - Ungünstige Parksituation aufgrund Parkplatzknapph
11:29:00	RTW erfolgreich geparkt und Beginn mit Entladen des Patienten (2 min vergangen)
11:30:00	Patient bei Registierung (Fachkräfte zur Dokumentation vorm Fahrstuhl)
11:31:00	Patient im Fahrstuhl
11:32:00	Beginn Patientenübergabe Rettungsdienst an Krankenhauspersonal (Patient wird triagiert)
11:34:00	Ende Patientenübergabe (sehr ruhig und qualitativ hochwertig)
11:35:00	Beginn Diagnostik (Primär Survey)
11:39:00	Neupositionierung Tourniquet (durch Arzt)
11:39:00	Sauerstoffgabe
11:40:00	Ende Diagnostik (Primär Survey)
11:41:00	erste Diagnose: Fraktur am linken Unterschenkel durch Schusswunde, kein Durchschuss
11:41:00	Anmeldung Röngten
11:44:00	Neuanlage Druckverband
11:48:00	Schienung linken Unterschenkel
11:49:00	Beginn Secondary Survey
11:54:00	Ende Secondary Survey mit anschließender Übergabe an Oberarzt
11:55:00	Abfahrt zum CT
11:57:00	Ankunft beim CT
11:58:00	Übergabe und Vorbereitung CT
12:01:00	Start CT
12:04:00	vollständige Diagnose via CT
12:05:00	Abfahrt von CT zurück zum Behandlungszimmer
12:07:00	nahloser Weiterleitung zur OP Schleuse
12:08:00	Ankunft OP-Schleuse
12:09:00	Beginn Übergabe OP-Schleuse
12:09:00	Übungsende für Patient -gelb, Einschuss linker Unterschenkel, Unterschenkelfraktur
12:14:00	zwei grüne Patienten sitzen bei Anmeldung
12:16:00	Beginn Traige vom ersten grünen Patienten
12:18:00	Ende Traige
12:19:00	Übungsende für beide grünen Patienten

Table 8 Hospital Bergedorf, Observer 1

Übung Sicherheitsstörung '25 HAW	
Zeit (hh:mm)	**Beobachtung**
10:05 Uhr	Übungsstart
11:05:00	Ankunft erster RTW (23-RTW-K)
11:05 Uhr	Vorbereitung auf MANV seitens des Krankenhauses, laut Personal wurde kein Übungsalarm durch Übungsleitstelle ausgelöst
11:11 Uhr	Start Triage Patient 1
11:12:00	Triage Patient 1 abgeschlossen (rot), parallel Ankuft des 2. RTW (26-RTW-K)
11:13:00	Start Triage Patient 2
11:14:00	Triage Patient 2 abgeschlossen (rot), Start der Behandlung in Raum 6
11:25:00	Ankunft 3. RTW (31-RTW-C)
11:27:00	Start Triage Patient 3
11:50:00	Ankunft 4. Fahrzeug/ITW (ITW 24B) mit 2 Patienten
11:51:00	Start Triage Patient 4
11:53:00	Triage Patient 4 (gelb) abgeschlossen, Start der Behandlung in Raum 3, Beginn Triage Patient 5
11:54:00	Triage Patient 5 (grün, Schussverletzung linker Arm) abgeschlossen, Start der Behandlung in Raum 2 (als gelb angekommen, grün eingestuft)
11:58:00	Bodyscan Patient 5: Schussverletzung mit Tourniquet abgebunden, starkes Bluten beim Öffnen feststellbar -> Einstufung auf gelb erhöht
12:02:00	Weiterleitung an Röntgen/CT, anschließend OP
	Anmerkungen
	Laut Notaufnahme sei keine Alarmierung durch die Feuerwehr/Übungsleitstelle erfolgt -> Vorbereitung auf MANV startete erst mit Ankunft des ersten Patienten.
	Patient 5 wurde während Triage auf von gelb auf grün zurückgestuft. Während des Bodychecks wurde er aufgrund des Verletzungsbildes wieder auf gelb erhöht

Table 9 Hospital Bergedorf, Observer 2

Übung Sicherheitsstörung '25 HAW	
Zeit (hh:mm)	**Beobachtung**
11:04:00	ZNA im Regelbetrieb. Keine Vorbereitungen für MANV-Lage
11:06:00	1. RTW trifft ein
11:06:00	Patient nicht angemeldet. Diskussion zw. RD- und Klinik-Personal
11:07:00	ZNA fährt Notfallbetrieb vor (Bereitstellung Sichtungsmaterial, Personaleinteilung)
11:10:00	Beginn Übergabe 1. Patient (SK Rot)
11:11:00	2. RTW (26-RTW-K) trifft ein
11:11:00	Schreibkraft an der Triage fehlt/muss gesucht werden
11:13:00	Übergabe und KH-Sichtung des Patienten (SK Rot) (Pat-Nr. 1)
11:14:00	Transport in normalen Behandlungsraum (kein Schockraum)
11:16:00	Versorgung Pat-Nr. 1 durch 1 Arzt, 1 Pflegekraft, 1 Schreibkraft
11:19:00	Sichtungskarten Polizei und Feuerwehr noch am Patient
11:19:00	First-Survey abgeschlossen
11:19:00	10-for-10/Team-Timeout
11:19:00	Sonographie-Gerät muss geholt werden
11:20:00	FAST-Sonographie
11:22:00	Feststellung Pneumothorax links -> Anlage Drainage
11:23:00	Anmeldung Thorax-CT
11:25:00	weiteres 10-for-10
11:24:00	Thoraxentlastung durchgeführt
11:29:00	Umsichtung zu SK Gelb
11:29:00	Entschluss: Verlegung auf Intensiv, wenn möglich Transport nach extern (KH mit Thoraxchirurgie)
11:57:00	23-RTW-K trifft ein
12:00:00	Sichtung des Patienten durch KH-Personal nach PRIOR-Algorithmus -> Ergebnis: SK Gelb
12:01:00	Übergabe durch RD an Facharzt (Anästhesie) in einem Behandlungsraum
12:04:00	Überlagerung
12:07:00	Vollständiger Bodycheck + Monitoring
12:10:00	Entschluss: Röntgen Fuß + Umsichtung zu SK Grün
12:10:00	Transport in Konferenzraum 1 (Sammelstelle SK Grün)

Table 10 Hospital Bergedorf, Observer 3

Übung Sicherheitsstörung '25 HAW	
Zeit (hh:mm)	**Beobachtung**
11:03:00	Ankunft 23-RTW-K
11:09:00	Ankunft 26-RTW-K
11:24:00	Ankunft 31-RTW-L (gelber Patient)
11:25:00	Beginn Übergabe (Triage) von RD an KH
11:26:00	Ende Übergabe, Transport zu Raum 2
11:27:00	Übergabe in Raum 2 von RD an KH-Personal (Arzt und Pflegerin)
11:28:00	Umlagerung von Trage auf KH-Bett
11:29:00	RD verlässt Raum, Arzt beginnt mit Diagnostik und stellt Fragen an Patient
11:30:00	Patient wird entkleidet, Lunge wird abgehört (-> A und B unauffällig)
11:32:00	Bodycheck
11:34:00	Blutabnahme
11:38:00	Beginn Ultraschalluntersuchung der Brust und des Bauchraumes
11:42:00	Ultraschall beendet, weiteres Vorgehen (geplant): CT und Röntgen
11:43:00	Ende der Behandlung (Patient darf KH verlassen)

Table 11 Hospital Bergedorf, Observer 4

Übung Sicherheitsstörung 25	
Zeit (hh:mm)	**Beobachtung**
11:04:00	Ankunft 23-RTW-K, roter Patient
11:05:00	Betreten der ZNA
11:05:00	Ankündigen das sie da sind - keiner aus dem Krankenhaus weiß bescheid
11:06:00	KH will übungsstop, da sie keine Info erhalten haben. Schockraum wird alamiert, RTW wartet in der Triage
11:07:00	Team der MANV Triage ist vorort, Doku muss noch organisiert werden
11:08:00	Westen werden Verteilt
11:09:00	erneute frage RD wann die übergabe starten darf
11:10:00	Start übergabe RD
11:11:00	Richtung Schockraum 3
11:12:00	Start der Übergabe im Schockraum
11:13:00	Arzt aus Schockraum wiederholt die Übergabe
11:14:00	beginn des Umlagerns von RD Trage auf KH Trage
11:15:00	Auf KH Trage
11:15:00	umkabeln und weiter ausziehen
11:16:00	Arzt beginnt untersuchung
11:17:00	Hose zerschneiden und Bodycheck und Arzt
11:18:00	legen eines Zuganges angesprochen
11:18:00	Auf die Seite drehen zum Wirbelsäulen check
11:19:00	Zugedeckt und Sonogerät wird geholt
11:19:00	Sonogerät ist da
11:19:00	Zugang wird gelegt und Blut abgenommen
11:20:00	Temperatur wird gemessen und der Arzt beginnt das schallen des Pat am Bauch
11:22:00	Schallkopfwechsel
11:22:00	Schallen vorbei
11:22:00	Arzt fässt die untersuchungsbefunde zusammen
11:23:00	Ein CT soll gemacht werden
11:24:00	Pat. Soll Intubiert werden und nach dem CT auf die Intensivstation
11:24:00	Bespricht Intubation und Sedierung mit Pflege, die bereitet währenddessen vor
11:24:00	Ende, da pat. Nun fiktiv intubiert und zum CT verlegt wird
11:50:00	Ankunft 24-R der Malteser ein gelber Pat und ein weiterer Fußläufig dabei
11:51:00	Übergabe in der Triage beginnt
11:51:00	Vorsichtung KH der liegenden Pat. - gelb
11:52:00	Richtung Schockraum 3
11:53:00	Start der Übergabe im Schockraum
11:54:00	Arzt aus Schockraum wiederholt die Übergabe
11:54:00	beginn des Umlagerns von RD Trage auf KH Trage
11:55:00	Auf KH Trage
11:56:00	beginn der Untersuchung durch Arzt, klamotten aufschneiden
11:57:00	Lunge Auskultieren
11:57:00	SpO2 und Blutdruck anbauen
11:58:00	Zudecken
11:58:00	Temperatur messen, Idee der Pflege ein Schmerzmittel zu geben
11:59:00	Anlage Zugang
11:59:00	Bodycheck, durch Arzt
11:59:00	Labor abgenommen
12:00:00	schmerzmittel läuft
12:00:00	TQ seit 10:30
12:01:00	kleines EGK anbauen
12:02:00	lösen des TQ
11:02:00	Klamotten komplett aufschneiden
12:03:00	Pflege will Verbandwagen, Arzt setzt sich zum Dokumentieren zur Seite
11:04:00	Verbandwagen da
12:04:00	Klebt Pflaser auf Wunde am Oberarm
12:05:00	Arzt schaut sich die wunde an und geht dann zurück zur Doku
12:02:00	Pflege gibt O2
12:06:00	Röntgen angeordnet
12:06:00	DMS Kontrolle der 4 Extremitäten
12:08:00	Ende, Pat geht fiktiv zum Röntgen