BACHELOR ASSIGNMENT

THE EFFECT OF TRANSPORT SCHEDULING STRATEGIES ON THE PLANNING OF PATIENT TRANSPORT

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MANAGEMENT SUMMARY

The fire department in Lübeck is an integrated coordination centre, therefore they are responsible for the emergency medical services (EMS) and the fire department within their operational area. Emergency medical services include emergencies as well as non-life-threatening medical patient transport. The latter takes place, if patients need to be brought to fixed appointments such as dialysis or radiotherapy, moved between two medical institutions, transported after being discharged from the hospital, hospitalized or transported with an infectious disease.

Problem definition

The core problem of the fire department is dealing with short notice for a large number of transport requests. This does not allow for efficient route planning and therefore results in long waiting times for patients. Besides that, dispatchers experience a high level of stress due to the number of short-notice requests. To improve the situation of the non-emergency patient transport system the research aims at answering the following research question: *'What is the effect of different transport scheduling strategies for non-emergency patient transport on the coordination of the patient transport ambulances in Lübeck?'*

Methods

To answer the research question, interviews and literature research were conducted to get a thorough understanding of the problem context, laws, guidelines and the theory that needs to be applied.

Laws and guidelines, that influence the scheduling practices of dispatchers, have been identified. The laws are posed by the German government and the state of Schleswig-Holstein. These are general laws regarding, e.g. break times of employees, and non-urgent patient transport specific ones such as the prerequisites a patient needs to fulfil to be transported and the types of vehicle allowed to be used.

In addition to the laws, the fire department has its guidelines. These discuss aspects such as vehicle requirements, prioritization of certain types of transports in case of high demand and the type and frequency of disinfection of the vehicles.

Based on the context analysis and the literature review on relevant scheduling theories and models, a deterministic solution approach was chosen based on Discrete-Event Simulation. Additionally, it was found that the insertion heuristic by Campbell & Savelsbergh (2004) is most suitable to apply for testing the effect of different scheduling strategies on the patient transportation system.

The testing of the solution algorithm included multiple experiments on three scheduling strategies with different parameters. The strategies are: scheduling each transport directly when receiving the transport, waiting until X number of transports have been received and scheduling every X hours. Every strategy was tested on three different data sets. These data sets were based on non-emergency patient transport data from January, February and March 2024.

Results

The strategies were tested using seven key performance indicators (KPIs): Number of transports after 17:00 per day, total operating time per day, number of delayed transports per day, average delay of transports per day, total driving time to patients per day, number of scheduling moments per day and average number of transports scheduled at once. Scheduling every X hours was shown to be the most effective strategy. Other than the other strategies, it can balance the trade-off between long waiting times with fewer scheduling moments and shorter waiting times in combination with longer distances driven between transports. The strategy was applied to the parameters 30 minutes, one hour and two hours. "30 minutes" was chosen as the most suitable parameter out of the tested ones. This interval

resulted in the lowest number of transports after 17:00 per day, the lowest total operating time per day, the lowest number of delayed transports per day and the lowest average delay per delayed transport for all three months.

Compared to the historical schedule, scheduling every 30 minutes scores better on all KPIs. However, since the solution algorithm is likely to be more efficient than the planning by the dispatchers, it should be compared to the direct strategy, which is the closest to the current practices. Figure 1 shows that, except for the number of delayed transports, the 30-minute interval improves all KPIs. While the number of delayed transports increased, the average delay decreased.

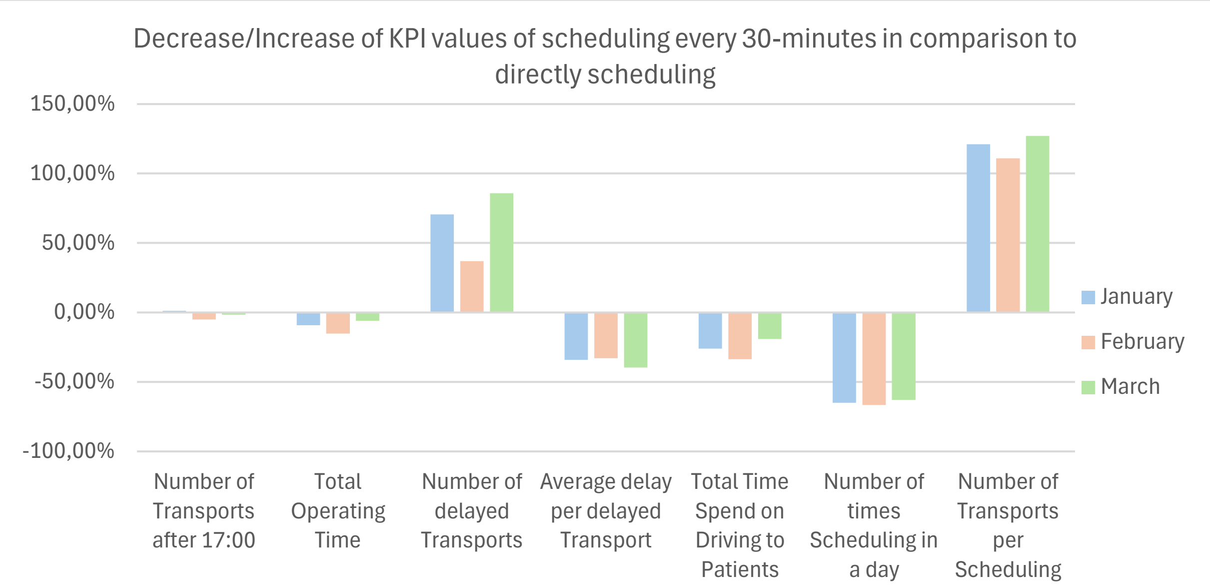

Figure 1 Performance of scheduling every 30 minutes in comparison with direct scheduling

Conclusion & Limitations

Using a solution algorithm, we analysed the impact of scheduling strategies on Lübeck's non-emergency patient transport system. Direct planning of transports results in fewer delays but increases travel time to patients. The other strategies reduce travel time by having more transports available at once, which allows us to find better combinations of transports. However, the X-request strategy has a high average delay and underperforms in most KPIs. Scheduling every X hours, results in shorter intervals between scheduling moments than for the X-strategy and therefore performs better overall.

The research has shown, that the different strategies have different impacts on the KPIs. The X-hour strategy performs best with 30 minutes as a parameter. It improved on 6 out of 7 KPIs in comparison to directly scheduling each transport. It needs to be taken into account that a dispatcher has more tasks at hand than scheduling. Therefore, such a time interval can be difficult to realize in practice. The next step should be to explore the possibilities of these results for the fire department.

The results allow the fire department to understand the consequences of each scheduling strategy better and at the same time use it as a base for the consideration of discussions with the larger medical institution to adapt their request strategies. For the latter, a similar effect is expected.

The patient transport system's complexity required several simplifications, such as all vehicles having the same equipment or not allowing the cancellation of transports. While these simplifications decrease the accuracy of the results of testing the solution algorithm, they are expected to influence the different experiments similarly. Therefore, a valid conclusion can still be drawn. Due to time constraints, a deterministic approach was used. Future research should identify whether introducing variabilities through probability distributions yields similar results.

ACKNOWLEDGEMENT

Dear reader,

The document you are currently reading is my bachelor thesis which I conducted in the coordination centre with the fire department of Lübeck.

In the last six months, I had the privilege to learn more about the fire department in Lübeck and non-emergency patient transport with the help of multiple people. All the employees at the fire department I encountered warmly welcomed me and helped me where needed. Thank you, for helping me realise this bachelor assignment. A special thank you to Luka Schmied and Saskia Rostowiski who always took the time to answer my questions and took on additional workload to help me with this thesis. Additionally, I would like to thank the dispatchers for taking the time to explain their tasks to me and giving me feedback on how realistic I demonstrated their work.

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Before rounding off this section, I also would like to thank my family and friends who supported me during the whole duration of this thesis and gave me additional feedback on my thesis.

Chantal Ermling
August 27th, 2024

TABLE OF CONTENTS

1. INTRODUCTION

This chapter gives background information to understand the research conducted for the coordination centre of the fire department in Lübeck, Germany. Section 1.1 gives a general introduction to the coordination centre and its operation. The problem description is given in Section 1.2. Lastly, Section 1.3 explains the research methods used.

1.1 FIRE DEPARTMENT LÜBECK, GERMANY

The fire department in Lübeck has an integrated coordination centre which means that they are responsible for the emergency medical services (EMS) and the fire department within their operational area. The operational area is Lübeck with 214,19km^2 (Schleswig-Holstein, 2024) which corresponds to 218.095 inhabitants in 2022 (Statistisches Bundesamt, 2023b) and a few surrounding towns and villages. They coordinate four fire stations, 22 volunteer fire departments and five executing emergency services out of which three are aid organizations: the Deutsche Rotes Kreuz, Johanniter and the Arbeiter Samariter Bund (ASB). In total, they coordinate around 20 emergency ambulances, 23 patient transport ambulances and two emergency physician rapid response cars daily (Feuerwehr Lübeck, 2023b)[1]. For special circumstances also specialized vehicles are available. The coordination centre is reachable by phone 24/7 and receives around 640 calls daily. In 2023 the fire department and ambulances were sent out to 73.355 operations. This included 34.385 non-live threatening medical patient transport (L. Schmied, personal communication, 5. March 2024).

This thesis focuses on non-life-threatening medical patient transports. As the name suggests, it is the transportation of patients who are stable to transport and do not need urgent care. However, due to their medical state, they are reliant on making use of the transport service instead of other modes of transport such as their car or public transport (Fogue et al., 2016). There are five situations when non-emergency patient transport is used: patients that need to be brought to fixed appointments such as dialysis or radiotherapy, moving between two medical institutions, transport after being discharged from the hospital, hospitalization and specialized transportation such as infectious transports. Some of these such as the dialysis transports are usually requested ahead of time and repeated multiple times a week. However, for many transport requests, such as transports after discharge, the requests are received spontaneously. Currently, most of the planning is done manually. Depending on the dispatcher, travel distance is not necessarily considered in the allocation of operations for the specific ambulances. It is also important to note that no transports which fulfil the requirements are denied (Section 2.2). This means that in case of high demand, it results in waiting times that are too long. Moreover, it is also not rare that patients have already left the hospital when the ambulance arrives without the coordination centre being notified.

1.2 PROBLEM DESCRIPTION

The problem identification was conducted, as can be seen in Appendix A, based on the Managerial Problem Solving Method by Heerkens & Van Winden (2017). This is a systematical framework for problem-solving. The problems were identified by talking with the management, the dispatchers responsible for the general operations of the coordination centre, the planners for non-emergency patient transport and the quality manager of the coordination centre. In the end, the core problem *'The coordination centre of the fire department in Lübeck, Germany, deals with a short notice of transport requests for many transports which do not allow for efficient route planning and therefore results in long waiting times for patients.'* was chosen.

[1] This source is an internal document (no open access)

Currently, medical institutions often request transports on very short notice and multiple at the same time. Therefore, it is often the case that the capacity limit is reached and patients experience long waiting times. The goal of tackling this problem is to reach a more efficient utilization of the available capacity of patient transport ambulances so that patients experience shorter waiting times and dispatchers experience less stress.

Solving this problem would avoid potential health risks for the employees. Stress over a long timeframe can lead to lower productivity, worsening of mental health and increased risk of experiencing physical health issues, e.g. heart disease and digestive problems (acas, 2023). This could result in more dispatchers being absent due to illness, which likely increases stress for their other colleagues. Resolving the problem would also increase the patient and medical institution's satisfaction with the transport services by building more trust in the system.

1.3 RESEARCH METHODOLOGY

Section 1.3 discusses the research methodology, which includes the research approach, research questions, research design and scope of the entire research.

As described in Section 1.2 the MPSM methodology by Heerkens & Van Winden (2017) is used for problem identification. As a deliverable, a solution algorithm has been chosen to give the fire department a better understanding of the effect of different scheduling strategies. To evaluate the algorithm multiple experiments will be run. Due to similarities to a simulation model, the DEGREE methodology by Rossetti (2021) (i.e. a simulation methodology) was chosen for the further steps. Unlike the MPSM framework, the DEGREE methodology includes explicit steps for preparing and running experiments. The methodology is based on the idea of problem-solving through system analysis, includes iteration and has precise steps to follow, which are the following:

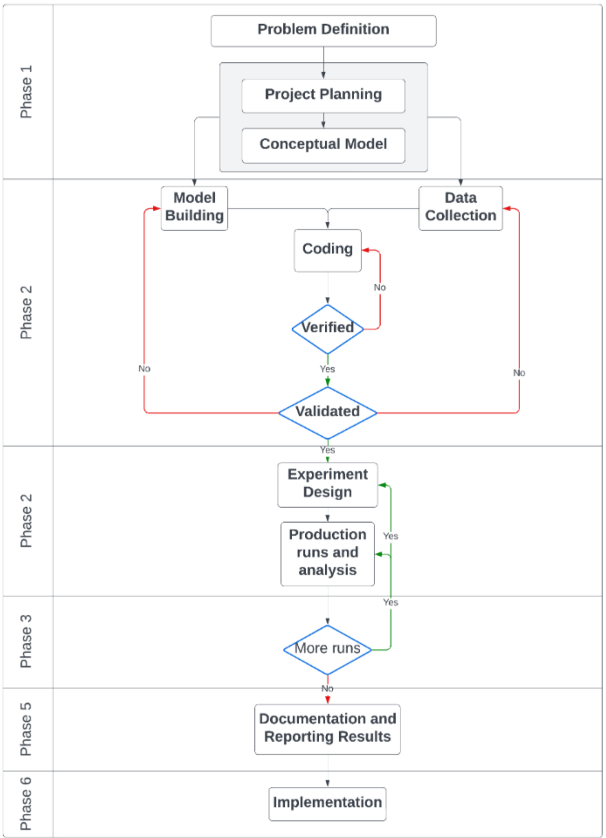

Figure 2 Flow chart of DEGREE methodology by Rossetti (2021)

Phase 1: Define Problem
Phase 2: Establish measures of performance for evaluation
Phase 3: Generate alternative solutions
Phase 4: Rank alternative solutions
Phase 5: Evaluate and iterate during the process
Phase 6: Execute and evaluate solution

Each of these phases includes multiple steps, which can be seen in Figure 2. Chapter 1 explains the problem definition, setting objectives and project planning and corresponds to the first two parts of phase 1. The problem identification is supported by aspects of the MPSM methodology by Heerkens & Van Winden (2017). The conceptual model and phases 2 to 4, along with the related knowledge questions, are discussed in the following subsection. During phase 5 the evaluation results will be demonstrated. Additionally, a manual will be created for the fire department but will not be included in this report. Phase 6 will be included in the form of recommendations regarding the implementation of the results of the experiments. For more information see Section 1.3.1.

1.3.1 Research Questions

The main research question posed for this thesis is: *'What is the effect of different transport scheduling strategies for non-emergency patient transport on the coordination of the patient transport ambulances in Lübeck?'* To be able to answer this research question multiple sub-research questions will be posed for the different phases of the research. An overview of the research methods can be seen in Appendix B. The main deliverable is a solution algorithm, which with the help of running experiments can determine the performance of various transport scheduling strategies.

Chapter 2: Context Analysis

The next step is the conceptual model. To be able to create a suitable model, a thorough understanding of the current situation is necessary. Therefore, a context analysis is performed. This step is about understanding the context of the planning of patient transport better and producing the knowledge needed for recreating the planning process. To do so the planning process will be mapped out and laws and guidelines summarized based on the research questions:

- *What does the current planning process for patient transports look like at the coordination centre in Lübeck?*
- *What activities need to be taken into account when creating the schedule?*
- *Which capacity does the coordination centre have for patient transport?*
- *Which laws and guidelines need to be taken into account in the planning process?*

Chapter 3: Theoretical Framework

In addition to the knowledge gained in Chapter 2, the relevant and existing theory is needed to be understood to choose the most suitable theory to base the conceptual model on. Therefore, Chapter 3 concentrates on identifying the relevant theories.

With the help of a literature review, relevant existing theories were determined and their applicability to the research problem was assessed. Three research questions were chosen to give guidance in this step:

- *What type of transport scheduling strategies for patient transport exist?*
- *What transport planning theories and models are used for non-emergency patient transport?*
- *Which transport planning theories and models can most efficiently represent the patient transport system of the coordination centre of the fire department in Lübeck?*

Chapter 4: Modelling

Chapter 4, includes all relevant modelling steps that correspond to the last step of phase 1, the conceptual model, and phase 2, the solution algorithm structure of the DEGREE methodology. Additionally, the characteristics of the input data will be discussed.

1. <u>Conceptual Model:</u>
   The conceptual model shows a detailed overview of the planning activities of non-emergency patient transport with the help of flow charts and pseudocode. The information gathered in Chapter 2 and Chapter 3 will be used as input. To later be able to evaluate the model and experiments, Key Performance Indicators (KPIs) will be chosen based on the following research questions:

   - *Which assumptions and simplifications need to be included in the model?*

- *Which KPIs capture the success of a transport scheduling strategy for the coordination of the transports best?*

2. Input Data:
   The solution algorithm needs input data to be tested. Various data types can be used for this. The data type and its characteristics are discussed in this section.

3. Model to test solution algorithm:
   This section is about phase 2 of the DEGREE methodology. The conceptual model will be translated into a programmable solution algorithm. This includes preparing the input data, verification and validation of the model. For the input data it will be determined whether additional data is necessary, the data will be analyzed and translated in a suitable matter to fit the model. After the model is built it needs to be verified that the model runs as intended and otherwise the model gets debugged. Further, it needs to be validated that the model is representing the reality. Therefore, the model will be compared to the historical data.

- *How can the conceptual model be translated model to test the solution algorithm?*

Chapter 5: Experiments & Analysis
In this chapter, phase 3 of the DEGREE methodology will be performed. Different experiments will be defined and conducted. For this, the model created in phase 2 will be used and altered to fit the scenarios of the experiment. The experiments were executed to answer the research question.

- *How do the transport scheduling strategies perform that were identified in Chapter 3?*

Each strategy decides in which time intervals transports are scheduled and with that the timing of the input of data being used in the experiments. Each strategy is expected to influence the transportation system differently. These effects are analyzed and the best-performing strategy is selected.

- *Which transport scheduling strategy performs best based on the chosen KPIs?*

Chapter 5: Conclusion & Recommendation
After phases 1 to 4 of the DEGREE methodology have been conducted a conclusion about the outcomes of the research can be formulated. Based on the evaluation of solutions, also a recommendation regarding the ideal scheduling strategies will be given to the fire department in Lübeck, based on the analysis of different scheduling strategies with the help of a solution algorithm.

- *Which recommendations and conclusions can be given to the coordination centre regarding patient transport planning?*

1.4 CONCLUSION

The coordination centre of the fire department in Lübeck receives many of its transports on short notice. Therefore, the goal of this research is to answer the following research question *'What is the effect of different transport scheduling strategies for non-emergency patient transport on the coordination of the patient transport ambulances in Lübeck?'.* The idea behind it is to find a strategy that can best support the transportation system with the short notice of transport.

To answer the research question multiple steps were taken. First, a context analysis is performed. Then the theoretical framework is explained. After a theoretical construct is found, the theoretical context is used to create a conceptual model for a solution algorithm. The relevant Key Performance Indicators identified in the conceptual model, are then included in the solution algorithm as an output. These outputs are explained and demonstrated and then used to answer the research question. Additionally, the limitations of the research are discussed.

2. CONTEXT ANALYSIS

The purpose of this chapter is, to give deeper insights into the related concepts. To have a good basis for creating a conceptual model, the planning process and activities that have to be planned need to be well understood. Therefore, this is demonstrated in Section 2.1. Moreover, many practices are based on laws and guidelines. To ensure these are taken into account, the relevant laws, guidelines and the planning process need to be investigated. Those are explained in Section 2.2

2.1 CURRENT PLANNING PROCESS

As mentioned above the planning process needs to be understood. To do so the following section will answer research questions one to three. We will start with the question "*What does the current planning process for patient transports look like at the coordination centre in Lübeck?*"

Between 7:00 and 17:00, dispatchers, specialising in non-emergency patient transport, schedule the transports. After 17:00 they hand over the coordination of non-urgent patient transports to the regular dispatchers on shift. From then on, the dispatchers are responsible for emergency and non-emergency patient transport simultaneously. Especially because the team of dispatchers has two dispatchers less after 17:00 the goal is to keep the workload as low as possible. This is done by executing as many non-emergency patient transports as possible before 17:00.

The coordination centre receives some requests for non-emergency patient transports in advance. These are usually transports to appointments such as for dialysis. However, most transports are requested during the day on which they need to be fulfilled. The specialised dispatchers start their day by creating a preplanning for the day with the known transport requests. This usually happens every morning. Figure 3 describes the planning process for the preplanning or in case a vehicle becomes unavailable. This planning is supposed to help the dispatcher allocate resources during the day but is likely to be adapted during the day. The procedure when a new request arrives is displayed in Figure 4. A new request is always based on a phone call. The key difference between Figure 3 and 4 is that Figure 3 checks which vehicles are unavailable for the entire day before scheduling. Further, when creating the preplanning all received transport requests are scheduled based on their requested execution time. In contrast, Figure 4 looks at individual transports after the request has been received and additionally to the criteria used for Figure 3, also assesses the likelihood of a direct return transport for the same patient.

To coordinate the ambulances, the coordination centre uses multiple types of software. All necessary information for the coordination of the transport gets documented. This includes information about the patient, start and end locations of the transport, all the vehicles and the equipment they have on board. Due to this information, it can mostly be ensured that the right medical equipment is available based on the patient's needs. To plan the transport itself, a tool with a Gantt chart is used. Every vehicle has its bar in the chart. The information gathered for each transport will be automatically displayed in the Gantt chart. The tool calculates for the dispatcher the expected length of the transport but does not take live routing into account. The transports can easily be pre- and replanned for a vehicle by a drag-and-drop principle. The decision on the sequence of transports and the vehicle selection is decided by the dispatcher and follows the logic presented in Figures 3 and 4.

Different types of vehicles can be used to fulfil the requests as explained in Section 2.2. The following abbreviations are used for the different ambulance types In Figures 3 and 4: KTW - non-emergency ambulances, MZF – multipurpose vehicle and I-KTW – non-emergency ambulance for patients with infectious disease. The latter is used only for specific diseases based on the hygiene plan of the fire department (Section 2.2).

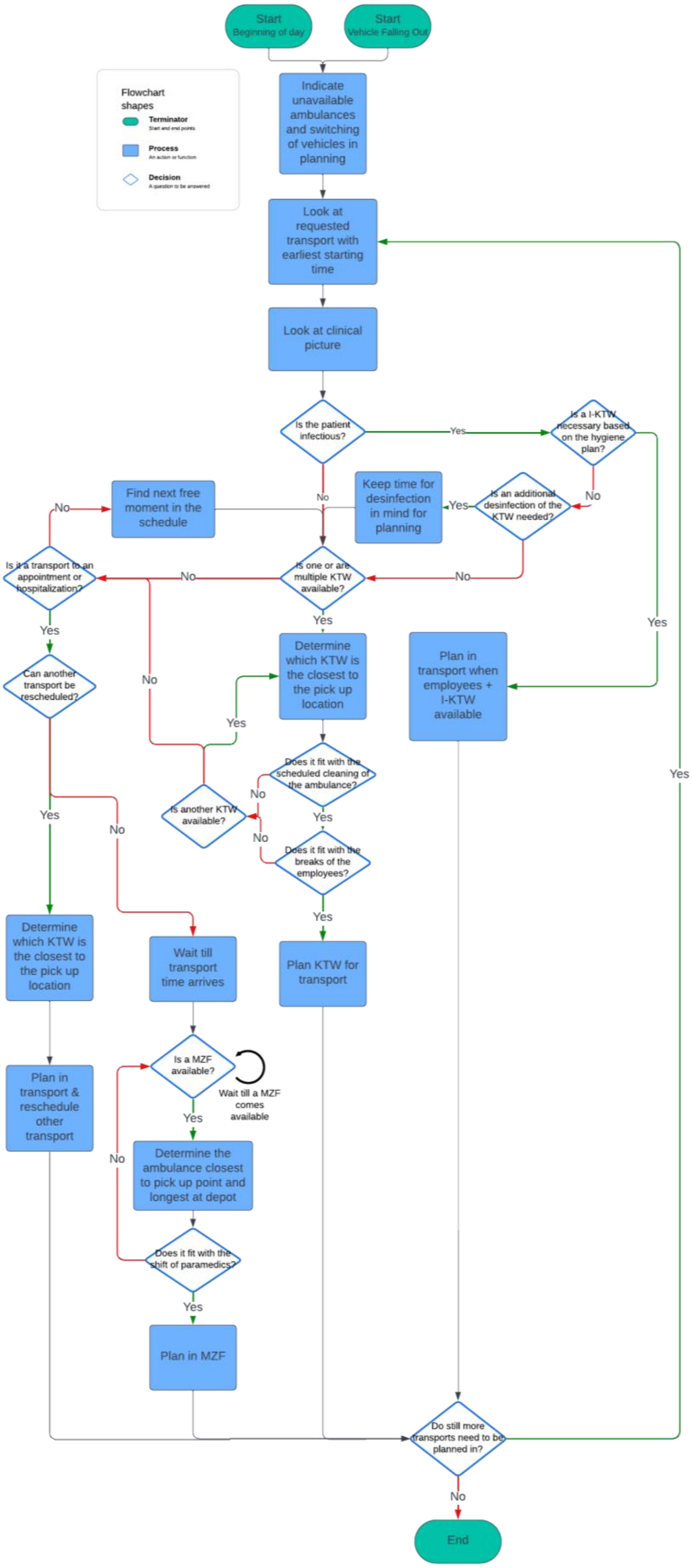

Figure 3 Flow Chart: Preplanning Process

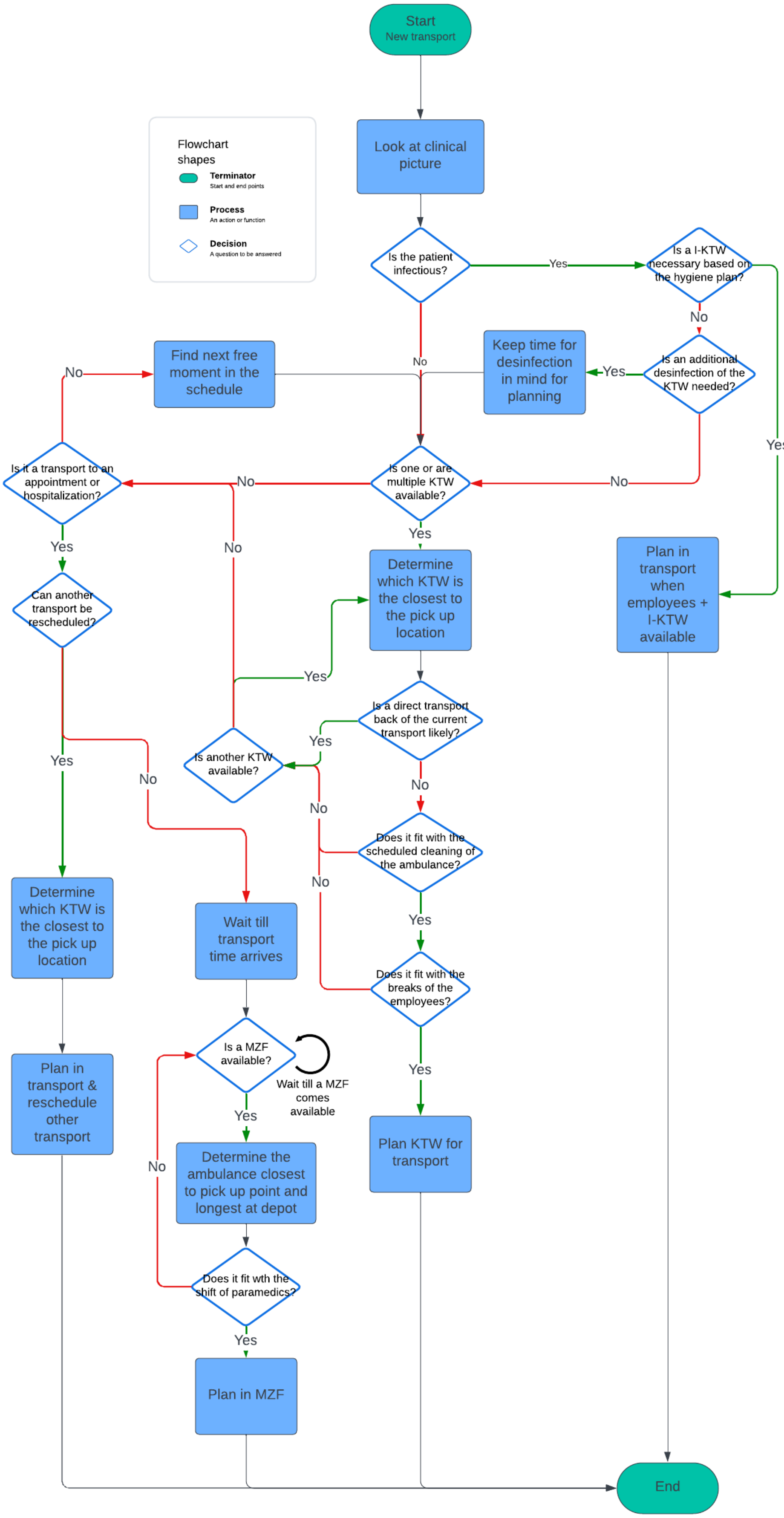

Figure 4 Flow Chart: Planning Adjustment Process

After identifying what the current planning process looks like it is crucial to understand what activities need to be taken into account in the planning process. Therefore, the following paragraphs will answer the research question "*What activities need to be taken into account when creating the schedule?".*

In the planning the following activities/aspects are included:

- **Transports:** start and end location & personal information of patient
- **Time of service of the ambulance:** This is based on a plan, which gets negotiated every year with the health insurance.
- **Switch of shifts:** A few ambulances are in operation two shifts per day. The switch of shifts indicates when the paramedics are switching. 15 minutes is planned for this.
- **Unavailability of vehicles:** Multiple reasons can lead to the unavailability of an ambulance. This can be for example, due to malfunctioning of the vehicle or a paramedic calling in sick for work. If a different vehicle can not be used/ a replacement for the paramedic cannot be found, it leads to the unavailability of the vehicle.
- **Cleaning/disinfection time** (see Section 2.2)
- **Break window** (see Section 2.2)

To be able to create a schedule for non-emergency patient transports, also the available capacity should be known. These paragraphs therefore answer the following research question:

Which capacity does the coordination centre have for patient transport?

The fire department has a plan called "Vorhalteplanung" (Feuerwehr Lübeck, 2023b)[2] which indicates when each vehicle is expected to be in service. In the rest of this report, this plan will be referred to as the "vehicle service plan". It is revised yearly, based on negotiations with the health insurance and the number of transports in the year before. In the plan, the length of each shift per vehicle and the cleaning/disinfection times can be seen. It differentiates between the first half of the week, Friday, Saturday and Sunday. Most non-emergency ambulances are in service during the day. Planning of transports during the night is being avoided if possible. Usually, transports occur during the night only in two scenarios:

1. If not all transports were able to be executed during the day.
2. It has an urgent reason and it cannot wait until the next day.

Furthermore, during the week more ambulances are available. This is also due to higher demand caused by the dialysis appointments, which mostly take place on Monday, Wednesday and Friday. On the weekend, especially on Sunday, the number of non-emergency ambulances is considerably reduced. Similarly, the cleaning times of the ambulances are limited to weekdays. Most of them are cleaned during the week with three exceptions which get cleaned on Fridays or Saturdays. Table 1 demonstrates the available capacity in terms of the number of scheduled vehicles and total service hours for transports available based on the shifts scheduled each day. It can be seen from the table that the coverage by the non-emergency patient ambulances is greatly dependent on the day of the week.

[2] This source is an internal document (no open access)

Day of the week	Number of non-emergency ambulances planned	Timeframe of coverage	Number of shifts + length of shifts	Total available service time per day (in hours)	Number of vehicles with a double shift in a day
Monday - Thursday	23	5:00-22:00	2 x 6 Hours 23 x 8 Hours 1 x 9 Hours	205 Hours	3
Friday	24	5:00-00:00	1 x 6 Hours 1 x 7 Hours 17 x 8 Hours 5 x 9 Hours 2 x 10 Hours	214 Hours	3
Saturday	5	00:00-23:59	4 x 6 Stunden 3 x 8 Stunden 1 x 10 Stunden	58 hours	3
Sunday	3	00:00-23:59	2 x 7 Stunden 3 x 8 Stunden	38 hours	2

Table 1 Overview of ambulance service times (Feuerwehr Lübeck, 2023b)[3]

The vehicle service plan shows the expected service time of each vehicle. The specific times can differ in reality. In case of the malfunctioning of a vehicle or sickness of a paramedic, a vehicle can be unavailable for a day. The shifts can also take slightly longer if a delay in transport occurs. There are multiple reasons, which can cause a delay, such as traffic jams, long waiting times when handing over patients to hospital staff, etc.

2.1.1 Available Data

As described above, to schedule transports dispatchers need various information to schedule a transport. The time of service of the ambulance is necessary to determine when ambulances are available. This information, the break time windows and the weekly disinfection times of the ambulances are gathered in the vehicle service plan (Feuerwehr Lübeck, 2023b)[3]. See Section 2.2 for an elaborate explanation of this.

Information regarding the transport itself such as start and end location, is available for this research from the fire department's management information system for January until March 2024. An overview of the available data from the management information system can be found in Table 2. The data is demonstrated based on fictive transports to show the quality of the available data. In the case of an en dash, this data is not given. This can have multiple reasons. For example, when picking a patient up at home, no institution name is needed. But it can also simply be that the data point is unknown.

Furthermore, data privacy is a very political aspect of healthcare topics. Therefore, the data was anonymized. This means that data about each transport is available without the name of the patient, the house number of the departure/arrival address or other personal information.

[3] This source is an internal document (no open access)

Transport Number	1240101001	1232912056
Request Number	1240000001	1240000002
Transport Reason	KBF.ENT	KBF.AMBU
Transport Type	85	85
Vehicle	HL 01-85-01	HL 01-85-02
Pick-Up: Institution Type	Hospital	-
Pick-up: Institution Name	Hospital Lübeck	-
Pick-Up: street	Example Street	Second Street
Pick-up: Postal Code	23560	23558
Pick-up: Town	Lübeck	Lübeck
Destination: Postal Code	23617	23562
Destination: District	-	St. Jürgen
Destination: Town	Stockelsdorf	Lübeck
Destination: Institution Name	-	Example Hospital
Transport Request Date	01/01/2024	29/12/2023
Request Time	10:30	17:45
Reaction Time	0:05	0:02
Driving time to pick-up location	00:18:29	00:17:28
Scheduling Time	10:32	13:45
Alarm Date	01/01/2024	01/01/2024
Alarm Time	10:36	13:47
Time: Paramedics confirm Transport	10:37	13:50
Time: reaching patient	10:50	14:20
Time: Transport start	11:01	14:26
Time: partially available	11:19	14:43
Time: partially available via radio	11:30	14:52
Time: available	11:32	14:59
Total Operating Time	01:00:00	01:14:00

Table 2 Available data demonstrated on two fictive examples.

2.1.2 Descriptive data

Based on the data a few operating figures can be determined. Table 3 shows, that while the number of transports declined after January, the percentage of transports requested in advance and on short notice are similar each month. “Short notice” refers here to transport requests on the day of expected execution. Furthermore, in all months around 75% of transports take place within Lübeck. The other 25% are transports from Lübeck to a hospital in a different region.

	January 2024	February 2024	March 2024
Number of executed transports	2 473	2 270	2 158
Average number of transports per day	80	78	70
Number of transports requested in advance	881 (35.6%)	797 (35.1%)	789 (36.6%)
Number of transports requested on short notice	1 592 (64.4%)	1 473 (64.9%)	1 369 (63.4%)
The average time between request and execution	34min	41min	32 min
The average length of an operation	1h 35min	1h 33min	1h 32min
Number of transports in Lübeck	1 848 (74.7%)	1 702 (75.0%)	1 611 (74.7%)
Number of transports without a given reason	0	5	2
Number of transports of a person with obesity	9	8	8
Number of small emergency transports	15	18	16
Number of long-distance transports	15	5	3
Number of transports due to compulsory treatment	22	19	16
Number of transports of an infectious person	96	118	62
Number of transports due to hospitalization	211	174	165
Number of transfer transports	381	341	343
Number of transports after patient is discharged	728	644	634
Number of transports to appointments	996	938	909

Table 3 Descriptive data of non-emergency patient transport in Lübeck

For the different types of transports, the absolute numbers differ, but the percentage of transport types is similar for all months. Furthermore, Figure 5 shows that most non-emergency patient transports are transports to appointments with 40.3% to 42.1% of the transports depending on the month. After that, transports after discharging and transfer transports are the most common. Less often transports of patients with obesity and long-distance transports take place. These reach 0.0% to 0.2% and 0.1% to 0.6% of transports per month respectively. The percentages of types of transports can slightly differ in reality because some transports can fall under multiple categories.

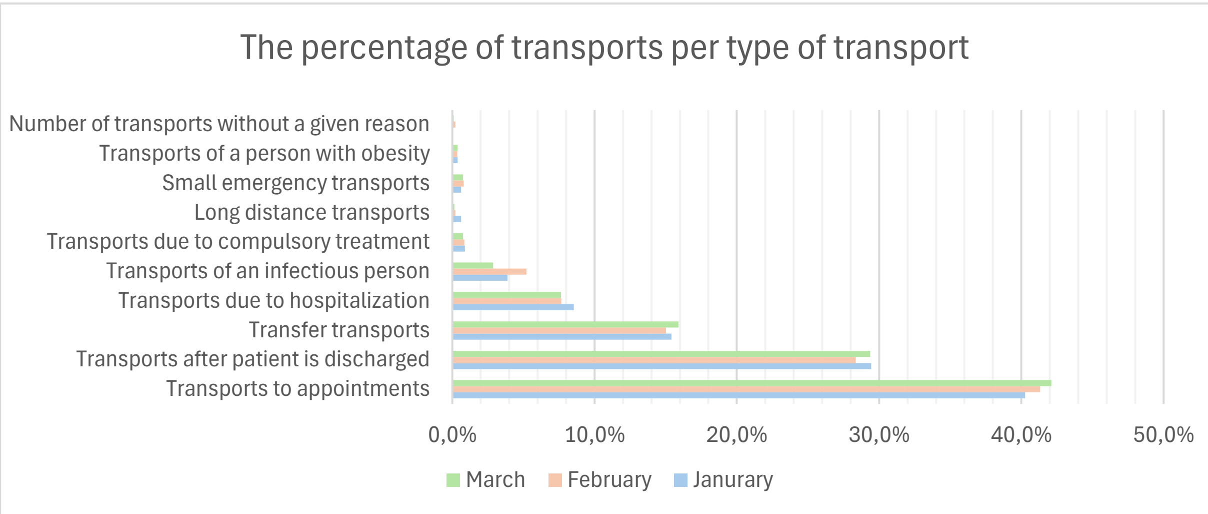

Figure 5 Overview over the different type of transports and the share of the total number of transports

2.2 LAWS AND REGULATIONS

This research is about the transport planning of humans in a vulnerable stage due to sickness or injury. This implies that norms play a large role when designing the research approach and the patient's welfare comes first. Due to the large interest of the society and policymakers, many laws and internal regulations by the fire department exist, that need to be taken into account in the research. These laws have different categories such as hygiene, purview, requirements for a transport and aspects regarding the execution. Therefore, this section covers all aspects related to the sub-research question:

Which laws and guidelines need to be taken into account in the planning process?

Non-emergency patient transports are defined in the Schleswig-Holsteinische Rettungsdienstsgesetz (2020, §2, Abs. 2) as “ the professional medical care and transport of injured, ill or otherwise physically impaired persons who require medical care or the special facilities of an ambulance during the journey or for whom this is to be expected due to their condition and who are not emergency patients, in a suitable rescue vehicle“ [Translation from German]. Each vehicle needs to have at least two paramedics on board of which one needs to be an experienced paramedic (SHRDG, 2020, §15, Abs. 3). Every coordination centre has an assigned operational area and is responsible for transports within and out of their operational area. Only under special circumstances, they are allowed to pick up a patient from outside the operational area (Feuerwehr Lübeck, 2023a)[4].

Prerequisite for patient transport

For non-urgent patient transport a medical prescription is needed which needs to be issued before the transport takes place (Gemeinsamer Bundesausschuss, §2, Abs. 2, 2024). This prescription can be issued by a doctor or a hospital in case of needed medical assistance, due to the medical situation or infectious disease (Gemeinsamer Bundesausschuss, §6, 2024). This also includes ambulant treatment such as dialysis or cancer treatments (Gemeinsamer Bundesausschuss, Anlage 2, 2024).

Vehicle Requirements

In general, all non-emergency patient transports are supposed to be fulfilled with non-emergency patient ambulances (Feuerwehr Lübeck, 2023a)[4]. In Schleswig-Holstein next to non-emergency ambulances also multipurpose vehicles can be used under certain circumstances (SHRDG, §12, Abs. 3, 2020). Those ambulances can be used for emergency and non-emergency patient transports in times of high demands for non-urgent transports. Nevertheless, it needs to be ensured that at any given moment enough ambulances are available for emergencies in every region, which means that every fire station needs to have at all times one emergency ambulance available or it needs to be ensured that an ambulance from another station can take over. Another constraint is that non-emergency ambulances should be used for transport out of the operational area. If none is available also a multipurpose vehicle can be used between 06:00 and 23:00 but only one multipurpose vehicle at a time (Feuerwehr Lübeck, 2023a)[4].

Prioritization

In particular in timeframes with a high demand the capacity can reach its limits. In this case, prioritization is needed to decide who will be transported first. In the regulations of the fire department (2023) the following prioritization is given:

1. Appointments and time-critical transports
2. Hospitalization
3. Discharging from institutions with opening times

[4] This source is an internal document (no open access)

4. Discharging or transferring

Next to the prioritization it needs to be taken into account that the waiting time is not allowed to be longer than 8 hours (Feuerwehr Lübeck, 2023a)[5].

Cleaning/Disinfection and Break Regulations

Every non-emergency ambulance needs to be cleaned and disinfected at least once per week. For this type of vehicle, that takes around 60 minutes (Feuerwehr Lübeck, 2023a)[5]. Besides routine disinfection, ambulances also need to be properly disinfected after the transport of a patient with an infectious disease. It depends on the sickness which type of disinfection will be performed. Besides a full disinfection also only contact surfaces disinfection can be conducted. This one only takes 15 minutes. What type needs to be performed is determined in the hygiene plan of the fire department (Feuerwehr Lübeck, 2024)[5]. When the disinfectant is exerting, the paramedics can already drive to the next patient. It needs to be waited until it has fully exerted, until a patient can be transported. If the cleaning is planned during the break window the break is expected to be taken during this time (Feuerwehr Lübeck, 2023a)[5].

A break window is a timeframe in which the paramedics are allowed to take a break. This is between four to six hours after the shift has started. The paramedics are responsible themselves, for ensuring to take a break before the break window ends, if not differently agreed on with the coordination centre. If a trip is planned outside of the operational area of the fire department in Lübeck the break either needs to be taken beforehand in Lübeck or on their way back but before they have reached Lübeck (Feuerwehr Lübeck, 2023a)[5].

The length of the break depends on the length of the shift. For an overview in this regard see Table 4.

The planned length of the shift	Length of break
≤ six hours	No break
Six hours < shift < nine hour	30 minutes
≥ nine hours	45 minutes

Table 4 Overview of the break regulation based on the length of the shift (ArbZG, *2020; Feuerwehr Lübeck, 2023a)*

Additionally, during the break time, the paramedics get ten minutes to find a suitable location to take a break. After the break has been completed the ambulance is expected to be driven back to the fire station if no transport has been scheduled for the ambulance (Feuerwehr Lübeck, 2023)[5].

2.3 CONCLUSION

Chapter 2 gives a more extensive picture of the problem context and answers 4 of the sub-research questions. Below the answers to each question will be shortly summarized.

What does the current planning process for patient transports look like at the coordination centre in Lübeck?

In the morning a preplanning with transport requests received in advance is made. This preplanning is made based on multiple criteria: time of transport, length of transport, break times of paramedics, the cleaning schedule of the ambulances, type of vehicle needed and unavailable ambulances due to for example repairs. After the preplanning is created every new received transport is planned.

[5] This source is an internal document (no open access)

What activities need to be taken into account when creating the schedule?

Multiple activities are taken into account when creating the schedule. First of all, general information regarding the transports, such as starting and end location and personal information of the patient, are considered. Besides that, the number of shifts, times of each shift and the timeframe of switching crews in case of two shifts on the same day in the same vehicle and ambulance is in service. It can also of course occur that vehicles are unavailable. Additionally, time gets planned for the disinfection of each vehicle and a break window for the paramedics. During this time the vehicles can also not be used.

Which capacity does the coordination centre have for patient transport?

The highest number of ambulances are available from Monday to Friday. Where Monday to Thursday 205 service hours are available in total and on Fridays 221. On the weekend on both days are less than 60 service hours available. This is mostly due to the case that appointments take place during the week and therefore, then a higher capacity is needed.

Which laws and guidelines need to be taken into account in the planning process?

There are various laws which need to be taken into account. On one hand standard laws such as the ones regarding the working times of employees and on the other also specific laws for this sector such as what type of vehicles can be used for non-emergency patient transports and who is allowed to be transported.

Besides laws, internal guidelines need to be taken into account. These focus on the disinfection regulations such as how often ambulances need to be disinfected, after which type of sickness of a transported person and what type of disinfection, but also which type of vehicles can be used when and which patient get prioritized.

3. THEORETICAL FRAMEWORK

To be able to develop a good conceptual model, relevant theories need to be researched and understood. Therefore, this chapter aims to answer the research questions:

1. *"What transport planning theories and models are used for non-emergency patient transport?"*
2. *"Which of them can most efficiently represent the patient transport system of the coordination centre of the fire department in Lübeck?"*

To identify relevant theories a systematic literature review has been performed. The steps of it can be seen in Appendix C. In Section 3.1, first, the Dial-A-Ride Problem is introduced and how this routing method fits in the context of patient transport. Afterwards, the different characteristics the models can have, are described. Section 0 describes the characteristics of the transportation system of the fire department in Lübeck. Section 3.3 discusses the potential scheduling strategies that can be experimented on. Further, Section 3.4 assesses different types of simulation models. The section will be rounded off with a conclusion on the type of model and simulation type to use. Section 3.1, 3.3 and partially 3.4 answer question number one and Section 3.2 and partially 3.4 answers question two.

"Over the years, there has been an increasing demand for transports by disabled and invalid people requiring health care but cannot hospitals by themselves" (Cappart et al., 2018). One of the reasons for this is the ageing population in large parts of the world. This is also not different in Germany where the number of over 65-year-olds increased by 12% between 1950 and 2021 to 22% of the population (Reuter-Oppermann et al., 2015; Statistisches Bundesamt, 2023a). Due to this, an increase in patient transport has been recorded in the last few years. To manage the increase in demand the planning needs to be optimised to keep operational costs low and "maintaining a sufficient quality of services" (Cappart et al., 2018). To optimise patient transport different models can be identified in literature. For modelling it is important to differentiate between emergency and non-emergency patient transport due to their differing characteristics and objectives (Fogue et al., 2016). The most common type of model for non-emergency patient transport is the Dial-a-Ride Problem (DARP).

3.1 DIAL-A-RIDE PROBLEM

A DARP is a specific form of a vehicle routing model and is a generalisation of the pickup and delivery problem with time windows with the difference that patients instead of goods are transported (Detti et al., 2017). The goal is, to find the optimal routes for the ambulances which offer door-to-door transportation for several requests in a demand-responsive manner (Ritzinger et al., 2016). Each transport has a starting and end point. Traditionally the DARP includes so-called time windows which means that the patient needs to be picked up and dropped off within specific timeframes (Molenbruch, Braekers, & Caris, 2017). The difference from other vehicle routing problems is that next to the common economic objective also the comfort and convenience of the patients are taken into account (Souza et al., 2022). Discomfort, for example in the form of long waiting times, can potentially lead to a negative influence on the health of the patients (Hains et al., 2010). Many variants of the DARP exist based on the different characteristics of the patient transport system researched (Cappart et al., 2018).

Objectives

Based on the characteristics of a transportation system and the research goal, different objective functions can be chosen. The conceptual matrix (Appendix C) shows minimizing the total transport costs, travel time, and travel distance or maximizing the number of served requests are the most common objective functions. Other possible objective functions are: minimising the overall maximum travel time (Cappart et al., 2018), total tardiness (Schilde et al., 2011), minimizing the average waiting time (Fogue et al., 2016) or operation time (Oberscheider & Hirsch, 2016). The reasoning behind choosing an objective can greatly differ, based on the perspective chosen. An example case is the aim to minimize waiting times. “While for the patient this is often due to convenience, for hospitals and EMS providers waiting times can mean additional unnecessary costs” (Reuter-Oppermann et al., 2015).

Characteristics

A DARP model can have different characteristics for the fleet types, number of depots, capacity of vehicles and the request nature of the problem. Below, these characteristics will be briefly explained.

In most cases, the patient transport system operates heterogonous vehicles which means that the vehicles can differ between types of vehicles, capacity and type of equipment. In the case of a homogenous fleet, all vehicles have the same characteristics and are therefore treated the same way.

The fleet can be divided over one or multiple depots. Usually, vehicles start at a pre-determined depot and also return at the end of their shift back to this depot. In some models, the vehicles also return to their depot for the breaks of employees or after every transport.

Depending on the transportation system and the capacity of the vehicles, shared rides or exclusive rides are offered. In the case of shared rides, patients get picked up from home or a collection point, depending on their medical state. Often also vehicle requirements regarding the combination of patients exist in case of transport on the stretcher or in a wheelchair.

Transportation systems commonly have a finite capacity. The systems differ in handling this. Either it leads during periods of high demand to rejection of patients or patients experience long waiting times.

The biggest difference in approach depends on the nature of the requests. It is differentiated between static and dynamic systems. Static, also called offline solving, describes a system in which all transportation requests are known beforehand (Cappart et al., 2018). In the case of a dynamic system, the problem is solved online, due to the requests being received throughout the day (Cappart et al., 2018). This means that every time a new request is received the schedule needs to be reevaluated (van den Berg & van Essen, 2019). In some cases, some requests are known beforehand while additionally receiving transport requests during the day. The initial planning is made, which will be reevaluated when new requests are received (van den Berg & van Essen, 2019). It needs to be taken into account that only the static version can be solved optimally through a mathematical model because only in this case all relevant information is known in advance (Reuter-Oppermann et al., 2015).

Solution approaches

To solve the models a few approaches have been proposed in the literature: **Mixed Integer Linear Programming (MILP), Local Search, Dynamic Programming** and **Constraint Programming** (Cappart et al., 2018). We will have a look at the different approaches.

MILP is one of the most common approaches. For a MILP quantities, such as the objective function or constraints, have linear (in-) equalities which can have real and integer values (Stadtler & Kilger, 2008). With a MILP model, an exact solution can be determined for smaller instances with software such as CPLEX or Gurobi (Tóth et al., 2024) or in combination with heuristics.

Dynamic programming can be used to solve a DARP exactly for smaller systems or with an approximation. For this, a large problem is split up into multiple better-manageable smaller problems (Ritzinger et al., 2016). The advantage of solving the problem exactly with dynamic programming is that it is solvable in a relatively short computation time.

Cappart et al. (2018) propose to use **Constraint Programming** due to its flexibility. In the first instance, this approach works with variables. A domain then regulates which values each variable is allowed to take and constraints set the relationship between the variables (Stadtler & Kilger, 2008). In combination with their efficient approach, Cappart et al. (2018) suggest that Constraint Programming can help in modelling and solving practical and static DARP due to constraints easily being added.

The DARP problem is an NP-hard problem (Tóth et al., 2024). Therefore, the computation of the exact solution for large systems is very time-intensive. Next to being time intensive, calculating an exact solution of a model with all real-life constraints is a limitation aspect, due to its difficulty (Detti et al., 2017). Often heuristics and metaheuristics are used instead. Heuristics approximate the exact solution. (Meta-) heuristics such as variable neighbourhood search, large neighbourhood search, TABU search or insertion heuristics are commonly applied.

3.2 TRANSPORT SYSTEM IN LÜBECK

To find a suitable model it needs to be clear what the transportation system looks like. When building a realistic model, it is important to consider that dispatchers are unlikely to find the exact optimal solution. As described in Section 3.1, various characteristic options exist. In Table 5 these are shortly summarized and the characteristics used for this system are marked:

Character-istics	Type	Repre-sented in system	Kergosien et al. (2014)	van den Berg & van Essen (2019)	Schilde et al. (2011)	Ritzinger et al. (2016)	Madsen et al. (1995)	Souza et al. (2022)
Simulation /Experi-ments approach	Stochastic		X		X			
	Deterministic	X						
Nature of requests	Dynamic							
	Static							
	Mix	X	X	X	X	X	X	X
Fleet type	Hetero-geneous			X			X	X
	Homo-geneous	X	X		X	X		
Number of depots	One				X	X	unknown	X
	Multiple	X	X	X			unknown	
Capacity in vehicles	One patient	X	unknown	X				X
	Multiple patients		unknown		X	X	X	
Rejection of patients	Yes							
	No	X	X	X	X	X	X	X

Table 5 Overview of characteristics of the patient transportation system for non-urgent medical transport in Lübeck

Below these characteristics are explained in more detail:

- **Approach:** The system is deterministic as no distribution is used as input data.
- **Nature of request:** The transportation system is dynamic. As Cordeau & Laporte (2007) describe, in reality a dynamic system often does not appear in a pure form. This is also the case here. Several transport requests are known before the planning of the day is made around 7:20 in the morning. The rest of the transport requests are received during the day.

- **Multiple depots:** The fire department has four stations throughout Lübeck where ambulances are stationed. The aid organisations have their stations for their ambulances. Each ambulance starts its shift at a depot and returns at the end of its shift again to the same depot.
- **Fleet type:** In reality, the fleet is heterogeneous due to varying equitment in the vehicles. During high demand, emergency ambulances can be used next to non-emergency ambulances. Due to missing data on the patient's needs and the equipment in the vehicles, this research assumes a homogeneous fleet, with a capacity of one per vehicle. No shared rides are possible.
- **Fleet size:** The size of the fleet is generally seen as fixed depending on the day of the week but due to repairs or personnel shortages it can differ (see Section 2.1).
- **Rejection of requests:** No transports are denied as long as they fulfil the requirements explained in Section 2.2. In this case, no rejection means that even during high demands no transports get rejected. This can result in long waiting times for patients.

The transportation in this research is considered partially dynamic. Therefore, below different types of dynamic systems are introduced. A summary of each of the models introduced can be seen in Table 5. Here, each model can be compared to the characteristics of the system in Lübeck.

For dynamic models, it is possible to investigate the problem as a collective of emergency and non-emergency patient transport. This problem has been addressed by Kergosien et al. (2014) and van den Berg & van Essen (2019). The former showed, that integrated fleet management, especially a proactive version, results in higher service quality. The latter's main focus is on emergency coverage. Further, they showed, that through the combination of the two types of transports, the utilization of non-emergency and emergency ambulances can be increased. In reality, the coordination centre in Lübeck also has an overlapping fleet for both types of transport. However, due to the time limitations of this thesis, only pure non-emergency patient transports will be considered.

When looking at the non-emergency patient transports in a dynamic setting, various models exist. Schilde et al. (2011) introduced a stochastic approach. Based on historical data they stochastically estimated the likelihood of a return transport of a patient. They were able to show, that under certain constraints, such as a short horizon for a stochastic outlook, the stochastic approach has a significant positive effect on the solution quality. Ritzinger et al. (2016) on the other hand, developed a hybrid dynamic programming algorithm. It can be solved exactly and with the help of metaheuristics. Furthermore, it can be used both for dynamic and static DARPs. Both approaches are in our case not suitable. The model should represented the scheduling techniques of the dispatchers as realistic as possible. Both approaches are more complicated than the considerations of the dispatcher. It is unlikely that the dispatchers include probabilities such as in Schilde's approach. The approach of Madsen et al. (1995) and Souza et al. (2022) are closer to the characteristics of the patient transport system and the method of the dispatcher.

The approach of Madsen et al. (1995) makes use of their own created insertion algorithm REBUS. The insertion algorithm calculates the changed values in the objective function for every possible vehicle for a request and chooses the vehicle with the least change in the objective function. At this point, the request gets inserted into the tour. The order in which the requests are considered depends on the costs and the expected difficulty to plan the job.

Souza et al. (2022) also work with an insertion heuristic. They first create an initial static planning with the help of a general variable neighbourhood search while minimizing transportation costs and user inconvenience. Later on, when new requests come in they get added to the planning with an insertion heuristic. They used computational experiments to test their approach. Their analysis of the experiments showed, that with a high percentage of dynamic approaches, the number of vehicles needed and time window violation increase.

The dispatcher's approach is most similar to that of Souza et al. (2022). Additionally, they investigate a similar effect. Therefore, their model can be best used to help model the planning system of non-emergency patient transport in Lübeck. However, a few changes, such as having a homogenous fleet instead of a heterogenous fleet, need to be made to the insertion heuristic for a dynamic DARP, so that it fits our problem. The applied heuristic is explained in Section 4.2.

3.3 SCHEDULING STRATEGIES

This thesis aims to identify the impact of different transport scheduling strategies on non-emergency patient transports for the fire department in Lübeck. To be able to test the effect of various transport scheduling strategies, different strategies need to be chosen. Ton et al. (2024) investigate different strategies for handling transport requests within hospitals. They apply the following policies:

Rescheduling…

1. …every time a new request arrives
2. …X number of requests are waiting or an urgent request comes in
3. …every X number of hours
4. …every time a transport is completed

Other papers such as Fiegl & Pontow (2009) and Segev et al. (2012) make use of strategy one and/or strategy four. The papers introduce strategies for intra-hospital transportation. Nevertheless, due to the great similarity to non-emergency patient transport, these strategies can be applied in this case. This thesis focuses on the first three strategies. A slight difference to the simulation done by Ton et al. (2024) is that for the second strategy urgent requests are not used as a trigger because this thesis does not consider emergency transports. The fourth strategy has been excluded from this research due to time constraints and the other strategies appeared more promising.

3.4 TYPE OF SIMULATION

The product of this research is the insights from testing a solution algorithm, which is a similar process to a simulation. As inspiration for the set-up of the test, different simulation types are discussed below.

Testing different strategies of scheduling in real life, would have included challenges regarding the reliability and validity of the research. Due to the time limitations of the bachelor thesis, each strategy's testing period would be short. Additionally, testing the strategies could not have been done parallelly. This results makes comparing the strategies difficult due to fluctuations in the type of transports and the number of transports per day. Further, it is difficult to measure the KPIs in real life, because the data is not directly available. The dispatcher would experience additional stress. An adjustment time for each strategy could potentially lead to the data being inaccurate during this induction time. To avoid all of these aspects, testing a solution algorithm was chosen to be used. Additionally, the solution algorithm to support dispatchers would have been difficult to implement in the current IT system. The insights from testing different scheduling strategies with the help of a solution algorithm similar to the practices of dispatchers is in this case more valuable.

In the literature, several simulation types exits, including Discrete-Event-Simulation, Monte-Carlo-Simulation, System Dynamics and Agent-Based Simulation. Each has distinct characteristics and needs to be chosen based on the research purpose and resources available (Borshchev & Grigoryev, 2021a).

Monte Carlo Simulation

Monte Carlo Simulation generates different outcomes, that are influenced by chance and can be described by statistical distributions (Robinson Stewart, 2014). For a simulation, a high number of repetitions is used, to determine the probabilities of the different outcomes. Commonly this type of model gets applied in the context of risk assessment, such as portfolio assessment.

System Dynamics
For a system dynamic approach, the system is seen as a "causally closed structure" (Borshchev & Grigoryev, 2021b) with stocks which are affected by flows. Especially feedback loops are of interest here. It is a continuous simulation approach focusing on strategic modelling (Borshchev & Grigoryev, 2021b). Therefore, it has a high abstraction level which does not allow for looking at individuals (Borshchev & Grigoryev, 2021a).

Agent-Based Simulation
For this type of model, not all relationships and variables need to be known in advance. It will be started with the known and then built based on the bottom-up principle (Borshchev & Grigoryev, 2021b; Robinson Stewart, 2014). The idea is to study the overall behaviour, which results from the interaction of individuals. The abstraction model depends strongly on researched phenomena due to its wide range of abstraction: can be very detailed to highly abstract (Borshchev & Grigoryev, 2021a).

Discrete-Event-Simulation
Discrete Event Simulation is defined by Borshchev & Grigoryev (2021b) as "the system being modelled as a process, i.e. a sequence of operations being performed across entities". Commonly the activities have queues attached to them (Robinson Stewart, 2014). It has a medium to medium-low abstraction, therefore individual objects are simulated to go through a system Borshchev & Grigoryev (2021a).

As can be seen, various types of simulation models with different characteristics can be chosen. In this case, the model should be discrete, because the given data has events (transports) at concrete times, and dynamic, to be able to evaluate dynamic transportation requests. Further, it should be possible to base the model on historical data.

The goal of a Monte Carlo Simulation is to understand the uncertainties of potential outcomes. However, we want to evaluate the various strategies based on historical data. For System Dynamics, the main idea behind it is to analyse stock flows which is not the focus of this research. Agent-based simulation can be applied to various abstraction levels. It focuses on examining the relationship between. The focus of this research is not to understand the relationship different institutions have.

Discrete-Event-Simulation fulfils the requirements in a simulation model. It also gives us a chance to evaluate the intended outcome and allows to model the system in a medium to medium-low level of abstraction. This is needed because each patient needs to be separately scheduled.

3.5 CONCLUSION

Answering the two research questions "*What transport planning theories and models are used for non-emergency patient transport?"* and *"Which of them can most efficiently represent the patient transport system of the coordination centre of the fire department in Lübeck?"* showed that the non-emergency patient transportation system in Lübeck can be represented by the Dial-A-Ride Problem. The characteristics of the DARP are deterministic, a mix of dynamic and static approaches, multiple depots, a homogeneous fleet, a fixed size of the fleet and no rejections are allowed.

The DARP construct is used as a basis for the solution algorithm. On top of that the scheduling strategies identified are regulating within the DARP when requests are scheduled. To test the solution algorithm, the transportation system the discrete-event-simulation approach is chosen.

4. MODELLING

This chapter describes all modelling steps and decisions made regarding the testing of the solution algorithm. In Section 4.1 the problem description for the solution algorithm is given. The conceptual model is described in Section 4.2. Section 4.3 discusses then the input data used to test the solution algorithm and Section 4.4 the structure of the solution algorithm.

4.1 PROBLEM DESCRIPTION

Several transports are received in advance, planned statically and will be executed during the day. The rest of the transports are received dynamically throughout the day. Each transport needs to get a vehicle and a spot assigned $(i-1, i)$ and is denoted with j. The set of transports is represented by N. Each transport starts at a pick-up location p_i and ends at a delivery location d_i. Both locations can be private addresses or medical institutions. A patient needs to first be picked up, and then brought to its destination. To execute the transports a homogenous fleet V with vehicles v with a capacity for one patient is available. Each vehicle starts at a fixed depot d_v and also needs to return to the same one at the end of a shift. The number of vehicles in service differs based on the time of the day and the day of the week.

The problem can be split up into two parts. The first one is the static part. This planning is made once at the beginning of the day. For the second part, transports are assigned dynamically. The scheduling of transports is triggered at different points in time, based on different strategies and then inserted with an insertion heuristic. The goal is, to see the influence of the strategies on the quality of the schedule for non-emergency patient transport in Lübeck.

4.2 CONCEPTUAL MODEL

The conceptual model is a simplified version of the real system it represents. It helps to find the right level of simplification and abstraction. A "conceptual model is a non-software specific description of the computer simulation model describing the objectives, inputs, outputs, content, assumptions and simplifications of the model"(Robinson, 2008). It further needs to be "valid, credible, feasible and have utility"(Robinson Stewart, 2014).

The objective of the research is, to find the effect of the different scheduling strategies with the idea of determining a scheduling, which should result in shorter waiting times for patients, more efficient planning and reduced workload for the dispatcher. Therefore, in the different experiments, the scheduling strategies will be adapted. To test the solution algorithm, three instances will be applied. The months of January, February and March of 2024 are looked at separately, so there are different instances which can be compared. To evaluate the strategies KPIs will be used. These KPIs are calculated for every month. Therefore, the research question "*Which KPIs capture the success of a transport scheduling strategy for the coordination of the transports best?" n*eeds to be answered.

Below all chosen KPIs and the reasoning for the choice is given:

Number of transports taking place after 17:00:
As explained in Section 2.1, dispatchers, specialized in non-emergency patient transport, are working until 17:00. Afterwards, other dispatchers, who are then responsible for non-emergency and emergency transport requests, take over. To ensure a low workload, as many as possible transports need to be executed before 17:00.

Total operating time:
In Section 3.1 different DARP models get introduced. One of them is by Schilde et al. (2011) which introduces a DARP model using stochastic information. For this, they use a three-fold objective

function with the third one being the total route duration. In our case, we are interested in the performance of the whole system instead of one particular vehicle and its route. Therefore, not the total route length but the total operating time of all vehicles together is chosen.

Number of delayed transports:
Another model introduced in Section 3.1 is by Kergosien et al. (2014). They investigated the emergency coverage of different combinations of a united fleet for emergency and non-emergency patient transports. Next to the coverage they also looked at KPIs for transfer transports. For this, they use the number of demands, the sum of transport delays in seconds and the number of delayed demands. Latter is also in our case a good indicator of the quality and convenience the patients experience.

Average delay of delayed transports:
This KPI is based on research by Kergosien et al. (2014). The second KPI named above "sum of delays in seconds" was used as inspiration. Due to calculating the KPIs per month, we decided to use the average instead of the sum of the delay. This gives a more conceivable magnitude.

Total time spent on driving to patients:
This KPI was chosen to test the hypothesis that strategies, with more transports known in advance, can reduce the time needed to drive to patients due to a better combination of transports.

Number of scheduling moments in a day:
The non-emergency transport dispatchers have indicated that the current workload is resulting in additional stress. Therefore, the number of scheduling moments in a day should be taken into account. If these can be reduced it would potentially reduce the stress levels of the dispatcher.

Number of transports planned per time of scheduling:
Souza et al. (2022) showed that a higher dynamism leads to more time window violations. So differently said to longer waiting times for the patient. A higher dynamism also means, that at the beginning of the day, fewer transports are known in advance. To relate it to the chosen KPI, it can be expected if more transports are known at once, waiting time can be reduced due to a more efficient combination of routing.

Next, the research question "*Which assumptions need to be included in the model?"* will be answered.

Assumptions are made in case information is missing which is needed to fill the gaps in our model (Robinson Stewart, 2014). For some postal code destinations, the distance needed to be estimated, as explained in Section 4.3besides that, no further assumptions have been made.

Simulation models are a simplified representation of the real system with a focus on the examined phenomena (Borshchev & Grigoryev, 2021a). Also for testing the solution algorithm, the following simplifications are chosen:

- Only non-emergency transports of patients are considered.
- Every transport can directly be planned in
- All vehicles have the same equipment (homogenous fleet)
- Paramedics have the right qualification
- No transport will be cancelled. The historical data only includes realized transports.
- Vehicles can always perform a transport when a transport gets assigned to a specific time and there passes no time between them being notified and starting to drive to the patient. In reality, there can be a difference of a few minutes between these two aspects.
- Transports cannot be cancelled

Model

The process flow of testing the solution algorithm is as follows (see Figure 6): Every morning the dispatchers make a preplanning of the day with the requests received in advance. For this thesis, it is made based on historical data. The transports, which come in dynamically, will be scheduled based on an insertion heuristic which is explained below. After the best-suiting vehicle for the transports is found, the transport gets inserted in the route of the vehicle. At the end, the KPIs are calculated.

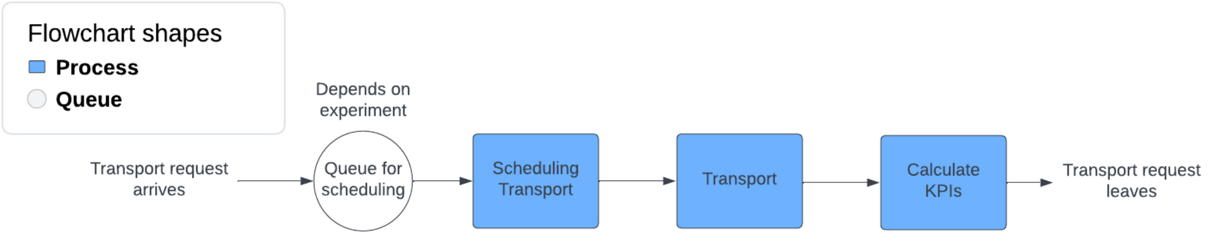

Figure 6 Process flow: Testing of solution algorithm

Heuristic

As Section 0 explains the DARP model by Souza et al. (2022) comes the closest to the real-life situation of the coordination centre in Lübeck. They use for dynamic transport requests an insertion heuristic based on Campbell & Savelsbergh (2004). Their paper introduces also variations of the insertion heuristic which are also relevant in our case. Figure 7 shows the general insertion heuristic introduced by them. A loop is used which continues until all customers get assigned. For every customer every route is considered and tested for feasibility and whether they improve the profit. After the best route is found, the transport is inserted in this route, the number of unassigned customers is corrected and all relevant values are updated.

```
N= set of unassigned customers

R= set of routes (initially empty)

p= profit

While N ≠ Ø do
      p* = -∞
      for j ∈ N do
            for r ∈ R do
                  for (i − 1, i) ∈ r do
                        If Feasibility (i,j) and Profit (i,j)> p* then
                              r* = r
                              i* = i
                              j* = j
                              p* = Profit (i,j)

                        End if

                  End for
            End for

      End for

      Insert (i*, j*)
      N = N\j*
      Update (r*)

End while
```

Figure 7 Insertion Heuristic by Campbell & Savelsbergh (2004)

The insertion heuristic checks for the feasibility of adding the transport and the objective function. The paper introduces multiple feasibility requirements and objective functions to choose from depending on the goal of the research. In the basic insertion heuristic, the feasibility is determined by the capacity constraint. Due to the capacity always being the same in our case, we choose other criteria based on our constraints. These criteria are the service schedule of the vehicle, the cleaning schedule of the vehicle, the availability of the vehicle and the break times of the paramedics. Also, our objective function differs. This is the case because the idea is to realistically as possible simulate the scheduling processes done by the dispatcher. They try to minimize the distance between transports as much as possible. Therefore, our objective function is instead of minimizing the total travel time to find the closest vehicle to the pickup location of the patient.

Software

To program and execute the testing of the solution algorithm, Excel was chosen to use. The reason for this is that Excel is a software the fire department already uses, it is easier to understand and therefore adds more value for the fire department after the completion of this thesis.

4.3 INPUT DATA

Section 2.1.1 introduces the available data. As input for the solution algorithm the information provided in the Vorhalteplanung (Feuerwehr Lübeck, 2023b)[6] and the outputs of the fire department information management system are used. From the latter, not all data points, which are available, are used. The data points used as input for the solution algorithm are:

- Transport Number
- Transport Reason
- Vehicle
- Pick-up: Postal code
- Pick-up: Town
- Destination: Postal code
- Destination: Town
- Transport request date
- Request time
- Alarm date
- Time: Paramedics confirm transport
- Time: Reaching patient
- Time: Transport start
- Time: Partially available via radio
- Time: Available

A few transports were taken out of the data set due to being duplicates, due to the vehicle getting newly assigned after a maximum of a couple of minutes or transports got planned but not executed.

The postal codes are used to estimate the distance between the locations. The existing data is used, to calculate the average distance between the postal codes. Due to new postal combinations through using the heuristic, also more combinations are necessary. The distances of these combinations were found via Google Maps (Google, 2024). For some transports the transport end postal code or starting postal code is unknown. Here the average of all the other transports length with the same starting or end postal code is used.

4.4 MODEL TO TEST SOLUTION ALGORITHM

The research question "*How can the conceptual model be translated model to test the solution algorithm?*" will be answered in the course of this chapter.

All the experiments follow the same basic principle, which can be seen in Figure 8. The dispatcher makes every morning a preplanning of the day with the requests received in advance. In the model,

[6] This source is an internal document (no open access)

this planning is made once from historical data and then used for all the experiments. For the initial planning, the code goes through all transports and adds all the transports to a sheet with the initial planning for each day when the transport request date is not the same as the transport execution date.

For the experiments, three different strategies will be tested. First of all, planning each transport directly after receiving it. Secondly, waiting until X number of requests have been received. Parameters five and ten will be used for X. The last experiment will be on scheduling every X hour. For this, the parameters one hour, two hours and half hour will be used. Additionally, the KPIs are calculated based on the historical data.

The experiments can be run independently from each other. The transports, which come in during the day, will be scheduled based on an insertion heuristic which is explained below. After the best-suiting vehicle for executing the transports is found, the transport gets inserted in the route of the vehicle. This is done by the first-in-first-out principle. In the end, the KPIs are calculated for an individual month and strategy. This procedure is demonstrated in Figure 8.

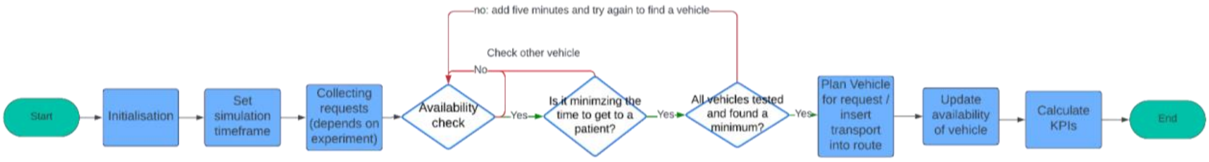

Figure 8 Process flow of solution algorithm

For the experiments when waiting until X requests have been received or scheduling every X hours, there is an additional step before inserting the transports. The transports, that are collected together, are checked for overlapping on the same vehicle. In case of overlapping one of the transports gets rescheduled. Therefore, this is not done based on the first in first out principle. The exact process of it is explained in Section 4.4.1.

4.4.1 Solution algorithm process based on scheduling strategy

The exact scheduling process of the transport depends on the chosen scheduling strategy. Below the process of each strategy is shortly explained.

For the version based on the **historical** schedule, the process is slightly different (see Figure 9). Similar then for the initial planning the code also goes through all transports based on the historical data. Here though only transports are considered who's request day and transport execution day are the same. Differently than for the other simulations it does not get evaluated which vehicle and combination of transports would be best suiting but instead, the vehicle used which got applied in reality. Figure 9 describes the planning process based on the historical schedule.

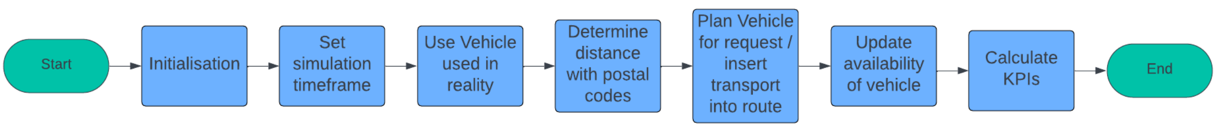

Figure 9 Flow chart: Solution algorithm process for historical version

For **scheduling directly** every transport after it has been requested, each transport gets considered. Only transports whose request date is the same as the execution date are selected. Afterwards, the insertion heuristic is called. After a suitable insertion spot is found the KPIs are calculated. For the process flow of this strategy see Figure 10. Figure 10 has a small difference from Figure 8 which is that for Figure 10 the transports get directly planned and not first gathered and then scheduled.

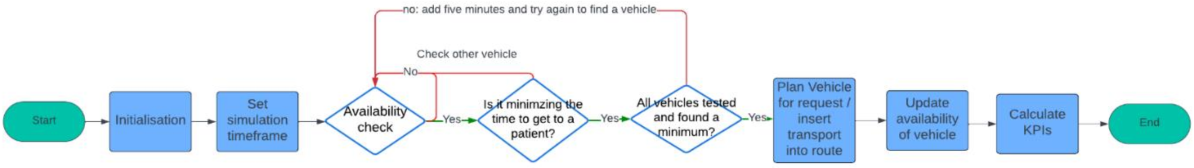

Figure 10 Flow chart: Solution algorithm process for direct scheduling

For the **X request,** the start looks similar (see Figure 11). Also here every transport and day is looked at and it is verified that only transports requested on the same day are considered. There are three significant differences to scheduling every transport directly. First of all, it gets waited until X transports have been collected before scheduling them and secondly, the timesteps of the corresponding transport will be adapted to the time the last transport came in until X requests have been collected. Lastly, for every transport, the best vehicle and insertion spot are found but because transports can overlap all transports in the same collection moment get compared. If transports have the same best vehicle, the same insertion spot and overlap, one of the transports gets replanned. Here we prioritize based on the reason for the transport. For the rules on prioritization see Section 2.2. If the transports have the same reason, the transport with the longer distance between the previous transport scheduled for that vehicle and the transport itself is newly evaluated. To avoid the insertion heuristic to suggest the same vehicle and insertion spot, the initial suggested vehicle will be memorized. In the availability check this vehicle will then directly return as being unsuitable. Because multiple transports can be changed to the same vehicle this gets double-checked. Afterwards, the transports are inserted and the vehicle data is updated. After all transports have been scheduled the KPIs are computed.

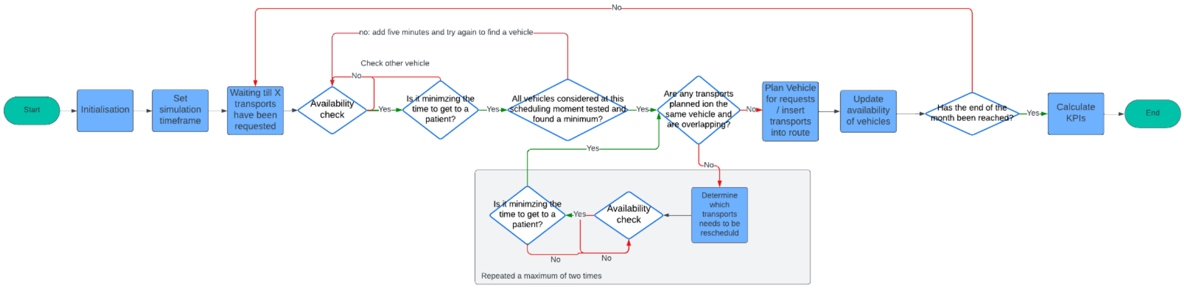

Figure 11 Flow chart: Solution algorithm process for waiting until X transport requests have been received

The **X-hour** strategy works very similarly to the X-request strategy as can be seen in Figure 12. A difference is that the transports are not collected until X amount of transports have been requested but transports get scheduled every X hours.

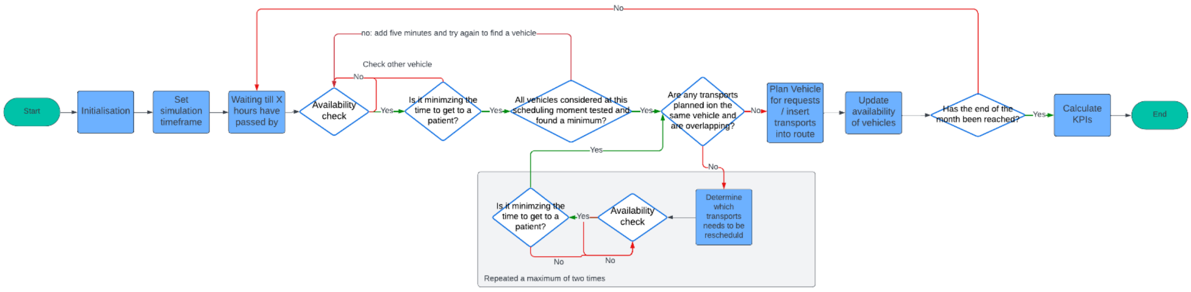

Figure 12 Flow chart: Solution algorithm process waiting X hours to schedule

4.4.2 Insertion Heuristic

For the insertion heuristic two slightly different versions are used. Both versions are in the core the same and are based on the insertion heuristic introduced by Campbell & Savelsbergh (2004). The pseudocode of their insertion heuristic can be seen in Section 4.2. The pseudo-code of the adapted heuristic is as follows:

```
d= Sum of distance between patient(i-1) and j and the distance between j and i
Do
      d* = high value
      v*= 0
      For v = 1 to V
            d = 0
            If feasibility = true then
                  If d < the d* then
                        v* = v
                        d* = d
                  End if
            End if
      End for
      If v* = 0 then
            If j is an appointment then
                  Let also multi-purpose vehicles be considered
            Else
                  t= t+5minutes
                  count=count+1
            End if
      End if
      If count = 50 then
            Allow also multipurpose vehicles to be used
      End if
Loop while v* = 0 found
Call Insertion Sub
```

Figure 13 Pseudocode of Insertion Heuristic

The insertion heuristic introduced in Figure 13 differs from the heuristic by Campbell & Savelsbergh (2004) in terms of the order of the feasibility and objective function check. One of them is that the availability and the objective function are not tested simultaneously. This has been chosen because for the availability multiple criteria are checked and finding an insertion spot to calculate the distance is not possible when the availability in our case is not true because no insertion spot can be found. Additionally, this approach reduces the computation time. As soon as a vehicle does not satisfy one of the feasibility criteria, the next vehicle is considered, instead of first calculating also the distance for a vehicle, which can in either way not be used.

Another difference is that Campbell & Savelsbergh (2004) loop over all potential insertion spots. In this research, this is done in a separate function which is used to calculate the distance between the transport and the previous transport.

There are multiple reasons why not directly a suitable vehicle can be found. Such as all vehicles being in use at that time or the time interval not being during the service time of the vehicles. Additionally, in this model, the breaks of the paramedics are fixed. Therefore, if the transport overlaps with a break of the paramedics the transport cannot be executed at this point. Next to it, some transports have a long duration and it might not be directly possible to find a big enough gap in the schedule. The next step is then, to consider all vehicles for the transport again but five minutes later and for transports to appointments also multi-purpose vehicles get considered. This process will be repeated until a suitable vehicle is found. After 50 iterations of the process also the multipurpose vehicles are considered.

For the strategies of waiting until X number of requests are received and scheduling every X hours, the transport does not get directly inserted after the rest of the insertion heuristic has been executed. Instead, the best vehicle option for the vehicle is saved in an array. This is the case because for these strategies transports get first collected, and then individually their best vehicle and insertion spot are determined. Only after it has been checked, if any of the transports are planned on the same vehicle and overlap, the transports get inserted.

4.4.3 Feasibility Check

A feasibility check is necessary to assess whether a vehicle is suitable for transport. Multiple criteria are considered for it: the operation times of the vehicles, the cleaning schedule of the vehicles, the schedule of the vehicle and the break time for the paramedics. For the X hours and X request strategies additionally, it is checked whether certain vehicles cannot be used due to otherwise overlapping with other transports. The order of checking can be seen in Figure 14.

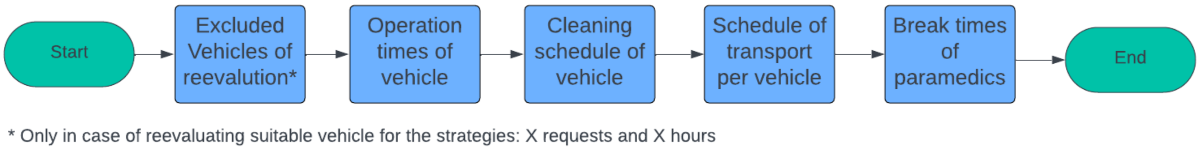

Figure 14 Process of Feasibility Check

The order of checking is chosen this way to minimize unnecessary computation time. Vehicles where it is known through the overlapping check for the X hour and X request strategy, that transports overlap with each other do not need to be considered any further. Additionally, many vehicles can already not be considered anymore due to their service times. Therefore, this check is at the beginning.

For checking if the transport is requested during the working times of the vehicle, the shift length and timeframe of the vehicle on the day when the transport is supposed to take place. The next step is then, to see if the transport would fit in the duration of one of the shifts the vehicle has that day.

Additionally, the transport would need to take place outside of the cleaning times of the vehicle. Therefore, the first step is to determine if on the day of the transport, the vehicle needs to be cleaned and if yes the transport times overlap with the cleaning times.

For determining if the transport would overlap with the break of the paramedics, it gets first determined with the help of the length of each shift if the paramedics need to take a break and if yes how long it needs to be. The next step is then to see if the transport overlaps with the transport.

Lastly, it is crucial to determine whether the vehicle already has a transport taking place at the time the new transport should take place. If none of the transports overlap and all other criteria are met, positive feedback is returned. If a criteria is not met, the vehicle is not considered further and the next vehicle gets checked for feasibility.

4.4.4 Distance

The distance between transports is determined based on the insertion spot. The postal code of the transports before and after the transport is used to look up the postal code combination and the resulting distance between the transports. In case, it is the first transport of the day, the distance between the depot and the pick-up location is determined.

4.4.5 Inserting

After finding the insertion spot on the most suitable vehicle, the transport gets inserted there and all necessary values get updated. Because the distance calculated between transports for the transport after the new transport is not accurate anymore, this gets recalculated.

4.4.6 KPIs

All KPIs are computed at the end of every experiment. The computation of each KPI is explained below.

Number of Transports after 17:00 per day

The sum of transports after 17:00 per day is determined. Only transports starting after 17:00 are considered and not transports starting before 17:00 but ending afterwards. This is because the reason for having as few as possible transports after 17:00 is so that the dispatchers specialized in non-emergency patient transports can schedule as many as possible transports before their shift ends.

Total Operating Time per day
For this KPI the time difference between the start and end of each transport is added to the total sum of operating time for each day.

Number of delayed Transports per day
To determine the number of delayed transports the expected starting time of each transport is compared to its original starting time. If the difference between the two values is greater than five minutes, one is added to the sum of the delayed transports that day. The delay of a transports refers in this case to the difference between when the paramedics should leave towards a patient and the actual time. It is not the duration by which the vehicle arrived late at the pickup location.

Average delay of Transports per day
For the average delay of transports, the difference between the intended and actual starting time of each transport gets added to the sum of delay per day. To calculate the average delay the sum of delay per day is divided by the previously calculated number of delayed transports per day.

Total Driving Time to Patients per day
Here the time between each transport is summed up for each day.

Number of Scheduling Moments per Day
The number of scheduling moments is expected to differ based on the strategy. In the case of scheduling directly when a transport request is received the number of transport requests equals the number of scheduling moments. For the other strategies, the number of scheduling moments will be lower because more transports can be scheduled at once. Therefore, this KPI returns the sum of times it gets scheduled in a day.

Average number of Transports Scheduled at once
The number of transports in a day is divided by the number of times transports get scheduled in a day.

4.5 CONCLUSION

To conclude the experiments were performed based on selected data points of the output of the management information system of the fire department for January, February and March 2024. This data is used to run experiments on three different strategies: planning transports directly when receiving them, waiting until X number of requests have been received and scheduling every X hours. The strategies are used to determine when the transports will be scheduled and how many at once. Then the insertion heuristic gets triggered, which includes a thorough feasibility and objective function check. The objective is to have as little as possible distance between transports. The insertion heuristic selects the most suitable vehicle and an insertion spot where the transport is then inserted. After this process has been done for all transports, the strategies will be assessed based on seven KPIs.

5. EXPERIMENTS & ANALYSIS

This section first gives a general introduction to the experiments and aims to answer the research question "*How do the transport scheduling strategies perform that were identified in Chapter 3?*" Section 0 shows the results of the scheduling strategy per KPI. The best strategy based on the performance of the KPIs is then determined in Section 5.2.

To be able to answer the question, 21 experiments were conducted in Excel with Visual Basic. Table 6 shows the experiments and their differences which are based on the combination of months and the scheduling strategies. The strategies where it gets waited until X number of transports have been received and it gets scheduled every X hours, get applied with different values for X.

Every month, a different number of transports is requested (see Section 2.1.2). Therefore, three different months will be used as cases, to see how the strategies perform regarding the fluctuation in the number of transports.

Number of Experiment	Strategy	Data used of month…
1	Historical view	January
2		February
3		March
4	Directly planning transports in	January
5		February
6		March
7	Waiting until 5 requests have been received	January
8		February
9		March
10	Waiting until 10 requests have been received	January
11		February
12		March
13	Scheduling every hour	January
14		February
15		March
16	Scheduling every two hours	January
17		February
18		March
19	Scheduling every half-hour	January
20		February
21		March

Table 6 Overview of experiments conducted

During validation and verification, debugging was used to find potential irregularities in the code. Additionally, the schedule for each day was printed on the screen and spot-checked for irregularities. Initially, a handful of transports did not get planned. This error was able to be eliminated. Next to it, some overlapping transports and at times a wrong order of transports were found. These irregularities were reduced to a minimum. Additionally, the KPIs were calculated by hand for a few example transports and compared to the outputs of the model, to ensure they were computed correctly.

5.1 KPIS

As mentioned above the different strategies get assessed based on KPIs. In Section 0 each of them is briefly explained and then the results of the strategies per KPI are discussed.

5.1.1 Transports after 17:00

Considering the number of transports that still need to be executed after 17:00 is important for the fire department because the dispatchers who are specialised and solely responsible for non-emergency patient transports work until 17:00. Afterwards the dispatchers on shift are responsible for emergency and non-emergency patient transport together. Especially because the team of dispatchers has two fewer dispatchers after 17:00 the goal is to keep the workload as low as possible by executing as many non-emergency patient transports as possible before 17:00. The results for the number of transports after 17:00 per day for all strategies and tested months can be seen in Figure 15.

For January, it can be observed that the historical schedule has a greater range of values than the other strategies. Most of the other ones have a similar range of values except for the 5 requests strategy. This strategy has a higher range. For the waiting X hours on transports, it can be seen that if the intervals between scheduling moments get longer, slightly more transports take place after 17:00 based on the average and median.

For February and March, the results look similar. In all three instances, the scheduling after every transport and scheduling once per hour perform best.

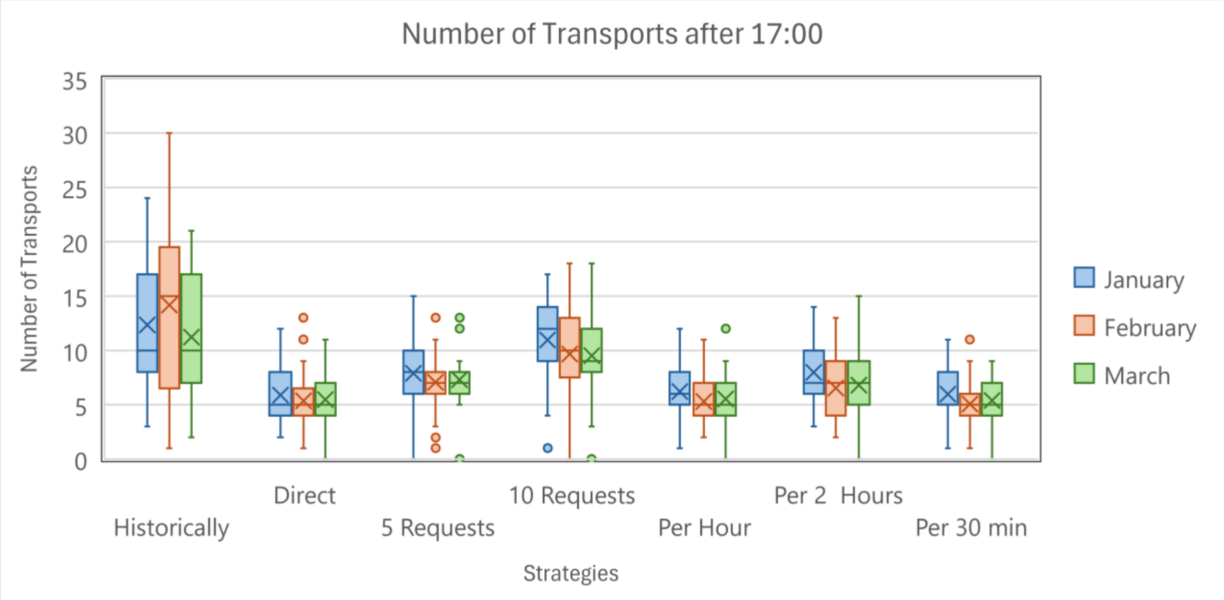

Figure 15 Box-Plot Diagram: Number of Transports after 17:00

5.1.2 Total Operating Time per Day

The goal is to keep the total operating as low as possible. This decreases the operating costs such as gas and potentially more transports can take place during the day. Knowing more transports at the same time, can influence the distances between transports and with that decrease or increase the total operating time. The results for the total operating time per day for all strategies and tested months can be seen in Figure 16.

In January and March, the range of values is very similar for all the strategies. The only difference is a slightly higher range for waiting until 10 requests are received before scheduling. The strategies which result in scheduling every X hours have a noticeably lower average and median.

For February the range is very similar for all strategies. Also here the median and average for the X hours strategies are lower than for the others. Additionally, the difference between the 25- and 75 percentile is smaller than for the other strategies. For all three variables for X, the X-hours strategy could keep the total operating time per day on average the lowest. With only slight differences between the different hour parameters.

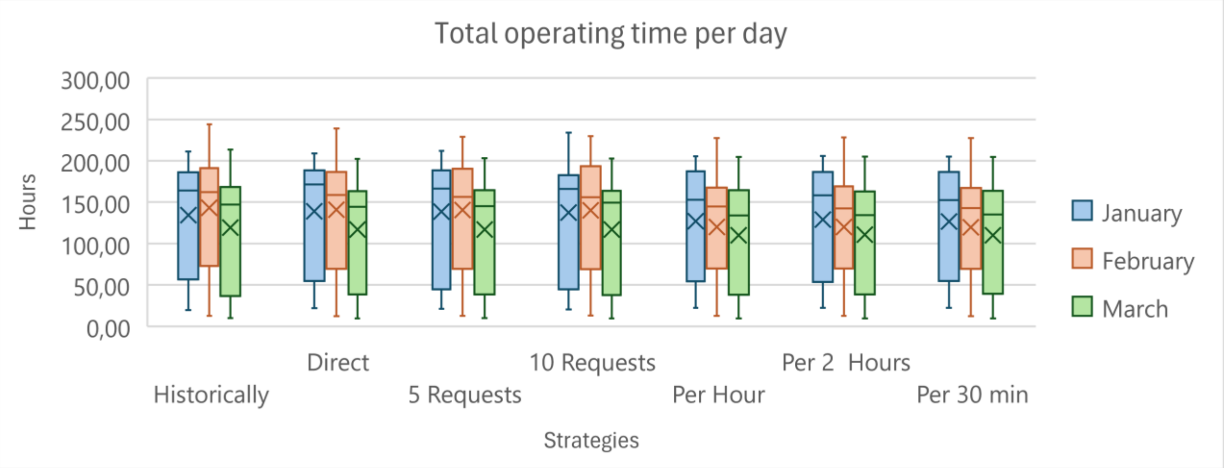

Figure 16 Box Plot: Total Operating Time per day

5.1.3 Number of Delayed Transports per Day

As mentioned in Section 1.2 the delay of non-emergency patient transport can mean additional stress for patients and with that can influence their wellbeing. Therefore, the number of delayed transports should be kept to a minimum. Of course, this needs to be seen in relation to the length of the delay which is the focus of Section 5.1.4. The results for the number of delayed transports per day for all strategies and tested months can be seen in Figure 17.

The 5-request and 30-minute strategies have similar ranges of values compared to the historical data. However, with the 5-request strategy, both the median and average are higher, while the 30-minute strategy shows significantly lower values. For the 10-request, 1-hour, and 2-hour strategies, the range is broader, but the average values are lower. For February and March, it is similar.

For all three months, the strategy of scheduling transports directly performs significantly better than the others including the historical values. A reason for this could be, that the heuristic is more efficient than the schedule of the dispatcher. In all three months, for X hours as well as X requests, the closer the scheduling moments are to each other the fewer delayed transports are recorded based on the median and average.

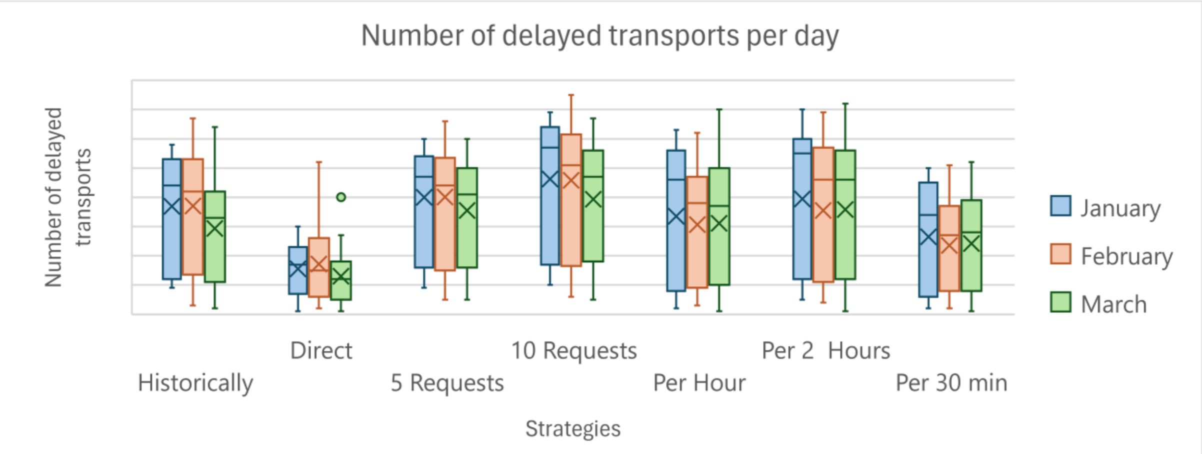

Figure 17 Box Plot: Number of delayed Transports per day

5.1.4 Average Delay of Transports

As mentioned in Section 5.1.3 also, the average delay needs to be taken into account. Many delays with a short duration can be better than a few delays of a very long length. The results for the average delay per delayed transport per day for all strategies and tested months can be seen in Figure 18.

It can be seen that especially the 5-request and 10-request strategies have an enormous range and a high average in all months. This can be based on the fact that waiting until X number of transports have been collected can take multiple hours. Therefore, this effect is not surprising. For the X hours - strategies the longer the time interval is to wait for scheduling the transports the higher the average is for January and March. In February it is the other way around.

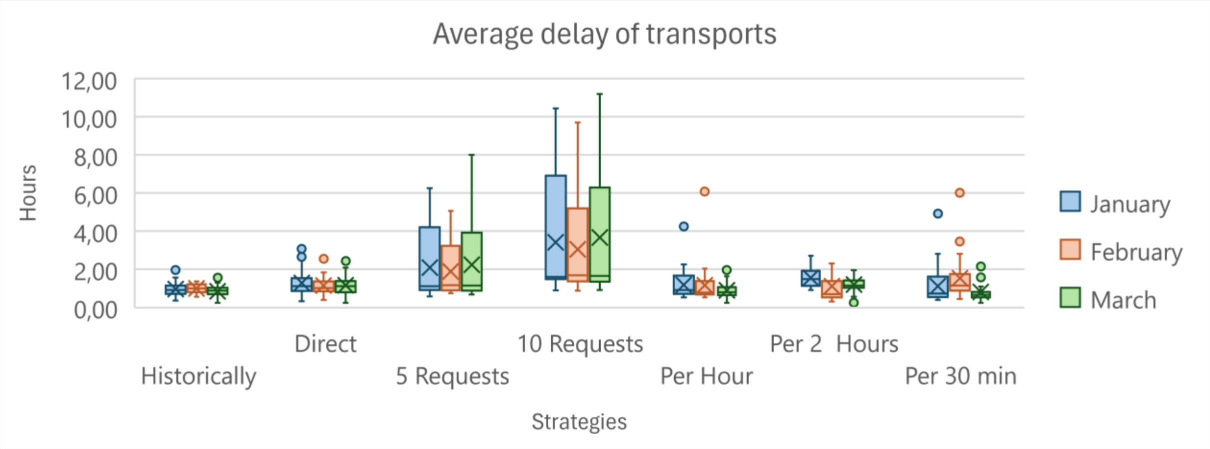

Figure 18 Box plot: Average delay of transports per day

5.1.5 Total Time Spend on Driving to Patients

The results for the total time spent on driving to patients per day for all strategies and tested months can be seen in Figure 19. Through a more efficient sequence of transports, the total time spent on driving to patients can be reduced. It can be seen that the more transports can be planned at the same time the smaller the average, median and spread are. This also seems logical because when more transports can be planned simultaneously, they can be planned with shorter distances between transports. This trend can be seen in all three instances.

Additionally, it is noticeable that the X-hour strategies overall perform better than the standard strategy and X requests. An explanation for this could be that at times more transports are available at the same time to consider.

The difference between the historical values and the direct planning of transports can be explained by the fact that for the historical values, the vehicles have been used for each transport as in reality. For the direct planning on the other hand the vehicle and insertion spot are determined by the insertion heuristic. The insertion heuristic focuses on finding an available vehicle with the least distance between transports. The dispatchers try to do this in reality too, but it can be expected that the heuristic is more likely to find a better solution through more evaluations.

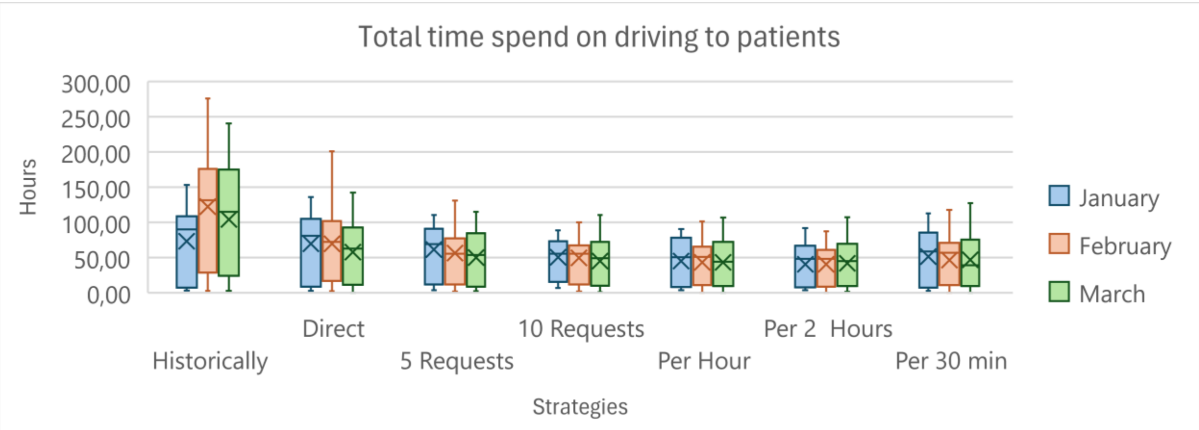

Figure 19 Box Plot: Total Time Spend on Driving to Patients

5.1.6 Number of Scheduling Moments per Day

This KPI is especially relevant, to take into account for the dispatcher. They currently experience a very high workload. If it could be potentially reduced through fewer times of scheduling in a day while keeping the quality, it would be appreciated. Here only the scheduling besides the preplanned transports are taken into account. The results for the number of times scheduling per day for all strategies and tested months can be seen in Figure 20.

The number of scheduling moments is as high as the number of transports executed per day in case of directly scheduling a transport after receiving a request for it and the historical version. The exact number of scheduling moments varies due to it being dependent on the number of transports that day. This is logical because every transport is planned separately. Further, the X requests per day result in the lowest amount of times of scheduling in a day. Whereas X hours is slightly higher. This is explainable by looking at Section 5.1.7. For the X hours strategies, fewer transports are planned per the time of scheduling compared to the X request strategy.

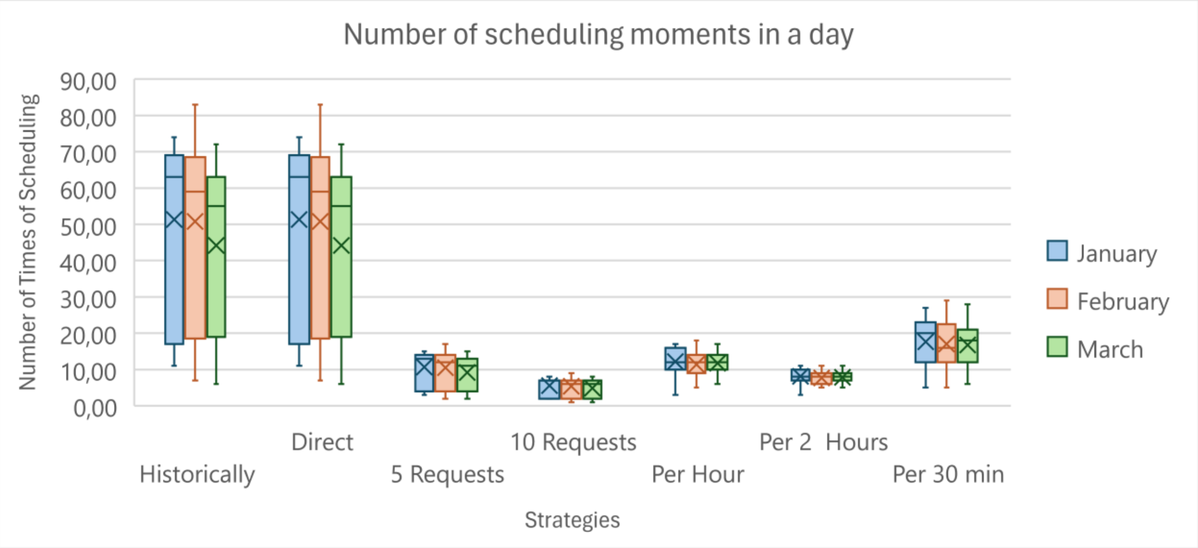

Figure 20 Box Plot: Number of Moments of Scheduling per day

5.1.7 Number of Transports per Scheduling

This KPI is especially interesting to look at together with the number of moments in a day it gets scheduled. A side note for this KPI is that only the numbers of schedules are taken into account for the X-hour strategies where scheduling took place. The results for the number of transports per moment of scheduling per day for all strategies and tested months can be seen in Figure 21.

The three months give a similar picture. For the historical data and the standard procedure, it is clear that if only one transport is planned at once this KPI is constant. For the 5 and 10 requests at the same time, some spread and outliers can be seen. This is because if at the end of the day, not exactly five or ten transports are left over, only the leftover amount gets planned in before moving on to the next day.

The X-hour strategies have a greater range of values than the other strategies. This is due to in some hours only very few transports being planned but in others, a large number of transports can be scheduled.

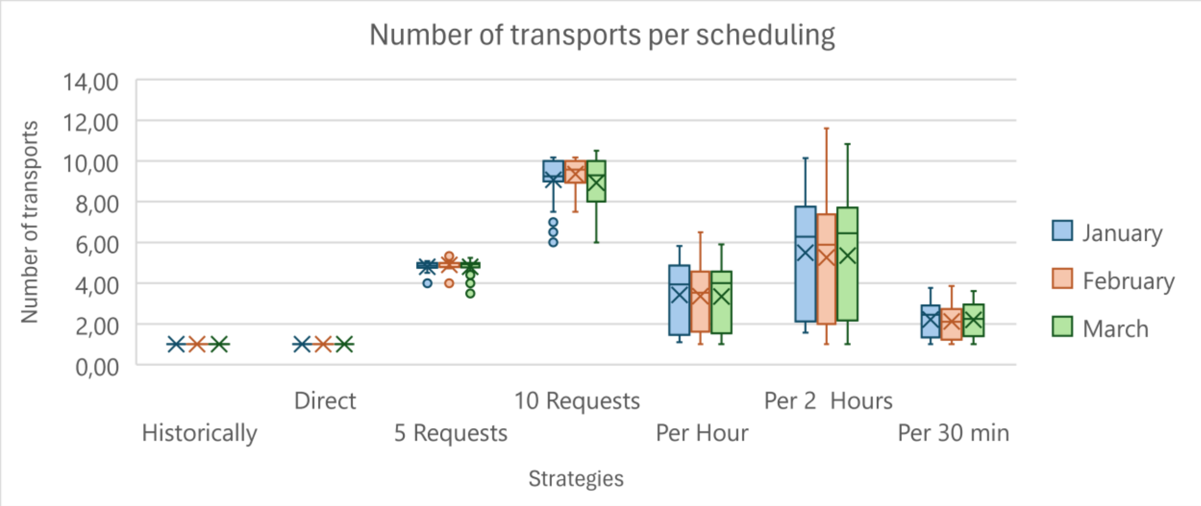

Figure 21 Box Plot: Number of Transports per Scheduling Moment per day

5.2 BEST STRATEGY

The goal of this research is to answer the research question: *'What is the effect of different transport scheduling strategies from hospitals for non-emergency patient transport on the coordination of the patient transport ambulances in Lübeck?'* For this, we conducted interviews, a literature review, experiments on solution algorithms and analyzed the experiments. With these steps taken this section will answer the research question "*Which transport scheduling strategy performs best based on the chosen KPIs?*"

When looking at all criteria at once it can be directly seen that the different strategies and parameters have different strengths and weaknesses. An overview of the average values for each KPI for each strategy in January can be found in Table 7. Green indicates the best value per KPI and red one the worst value. For the other month, the overview can be found in Appendix D.

Direct Scheduling

Scheduling the transports directly when receiving them results in a low number of delayed transports and with that also in a small number of transports after 17:00. On the other hand, the time spent on driving to patients is on average significantly higher than for other strategies. Additionally, it negatively affects the number of times dispatchers need to schedule in a day due to it being very high.

X Requests

The X-Request strategy is usually always in the midfield of the KPIs. It does not score significantly well on any of the KPIs. The average delay of each delayed transport is very high. On the other hand, fewer times it needs to be scheduled during the day and more transports can be scheduled at once. The exact effect depends on the parameter chosen for X.

X Hours

This strategy has the second lowest values for the number of transports scheduled after 17:00, has a lower total operating time and scores rather low on the average delay per day in comparison to the other strategies. Additionally, the strategy has a lower median and average when looking at the total operating time per day which will decrease costs for the fire department. This can be seen in connection with less time spent on driving to patients because a certain amount of transports is always available to create a more efficient schedule.

KPIs	Historically	Direct	5 Requests	10 Requests	1 hour	2 hours	0.5 hours
Number of Transports after 17:00	12.35	5.9	7.9	10.97	6.23	7.7	5.97
Total Operating Time	134.16	139.13	138.44	137.36	126.87	128.77	126.42
Number of delayed Transports	36.97	15.52	40.03	46.19	33.52	39.48	26.45
Average delay per delayed Transport	0.94	1.13	1.34	2.1	0.89	1.39	0.74
Total Time Spend on Driving to Patients	72.97	69.38	60.99	50.12	44.63	40.43	51.4
Number of scheduling moments in a day	51.35	51.35	10.68	5.58	12.23	8.1	17.68
Number of Transports per Scheduling	1	1	4.8	9.08	3.43	5.5	2.21

Table 7 Average values for KPIs in January

Even though each strategy has its strengths and weaknesses, there is one, which overall performs best. This strategy is X-hours. The strategy scores well on all KPIs. It does not always have the best values but performs best, on the three most important KPIs. These KPIs are the number of transports after 17:00, the average delay per delayed transport and the number of times to schedule in a day. As can be seen in Table 7, the number of Transports after 17:00 is only slightly higher, than when scheduling transports directly. The average delay in January is for scheduling every one hour or every 0.5 hours lower than any other strategy based on the average. For the number of times, it gets scheduled in a day, with an average between eight and 18 times a day, depending on the value for X, it is a reasonable number of times without increasing the risk of unnecessary delay due to waiting too long to schedule.

When looking at the different parameters for the X-hour strategies the 30-minute interval performs best for most KPIs such as number of transports after 17:00 per day, total operating time per day, number of delays per day, average delay per transport and number of transports per scheduling moment. It performs worse than the other two parameters for the total time spent on driving to patients and the number of times scheduled. For the latter, the difference is depending on the month. For the former, scheduling every half hour requires more frequent scheduling throughout the day, but each scheduling instance involves less transports. For these two KPIs, a trade-off needs to be found. As it can be seen in Figure 22 the values on the right side schedule too many times in a day and the ones on the left wait very long until they get scheduled. The 30-minute interval values on the KPIs are in neither of the two extremes and are therefore fitting.

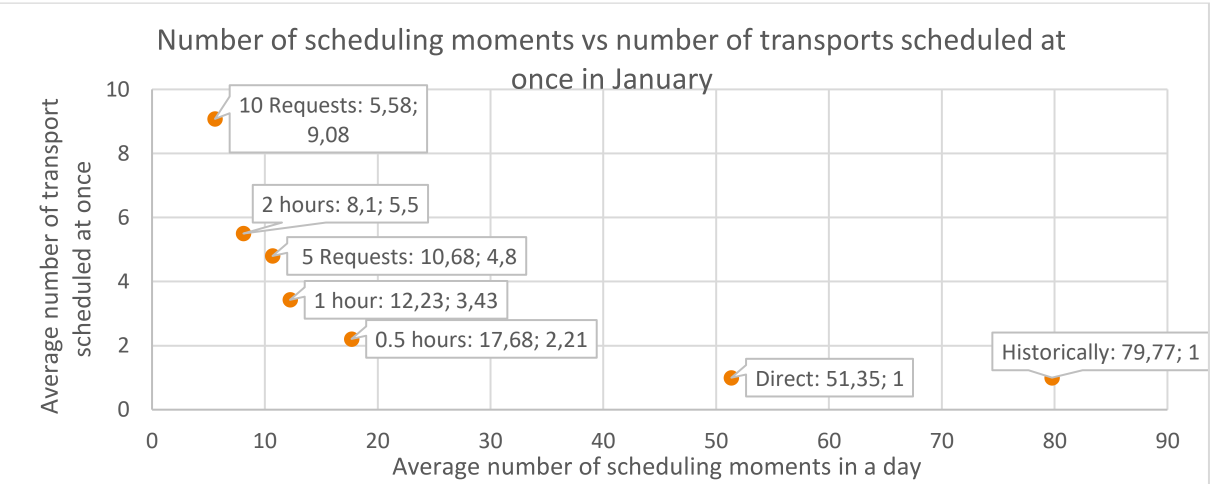

Figure 22 Scatter plot: Number of scheduling moments vs number of transports scheduled at once

An important aspect of any research is to see if the proposed changes also would improve the current situation of the stakeholders. As can be seen in Figure 23 scheduling every 30 minutes improves the KPIs in five out of seven criteria in comparison to directly scheduling transports. Only the number of delays increased which is not a positive influence of the strategy. At the same time though the average delay decreased significantly.

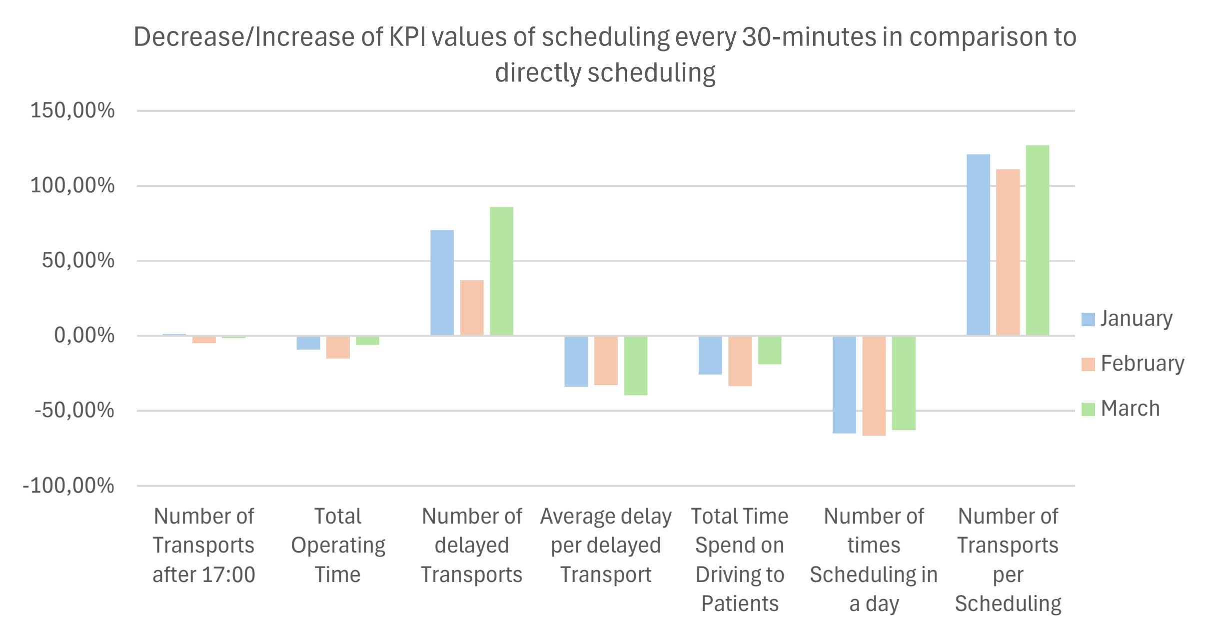

Figure 23 Graph: Performance of scheduling every 30 minutes in comparison with direct scheduling

To conclude the best strategy, out of the ones tested in this research, is to schedule transports every half hour. It needs to be taken into account that the optimal time could also still lie between the different parameters and are not tested with these experiments.

5.3 CONCLUSION

In the process of this thesis, we ran 21 different experiments to see the influence of scheduling strategies on the patient transport system. With the three different sets of input data based on the first three months of this year, also the influence of fluctuating numbers of transports can be seen.

The research question "*How do the transport scheduling strategies perform that were identified in Chapter 3*?" can be answered as follows: Directly scheduling results in a low number of delayed transports which also affects other KPIs positively. However, at the same time, it takes a significantly longer time to drive to patients. Waiting until X number of requests have been received on the other hand leads to long waiting times because the intervals in which it gets scheduled can be rather long. Scheduling every X hours is a solution between directly scheduling and waiting until X requests have been received. Here the time intervals between scheduling moments are fixed and can be individually adapted. Therefore, as long as not a very high interval length is chosen, the waiting time until it gets scheduled the next time is lower. This results in shorter waiting times.

This also leads to the answer to the question: "*Which transport scheduling strategy performs best based on the chosen KPIs?*" All strategies have different KPIs they perform well in. In the end, the X-hour strategy performed overall best. The parameter 30 minutes is based on this research the most suitable for the fire department.

6. CONCLUSION & RECOMMENDATION

Based on the sub-research question "*Which recommendations and conclusions can be given to the coordination centre regarding patient transport planning?*" this chapter aims to form a conclusion and give the fire department a recommendation based on the results of the research. Therefore, in Section 6.1, a conclusion is formulated. The chapter concludes with a discussion of the limitations encountered in the research.

6.1 CONCLUSION

This research was conducted to answer the research question:

'What is the effect of different transport scheduling strategies for non-emergency patient transport on the coordination of the patient transport ambulances in Lübeck?'

To answer the question, we performed a deterministic experiment approach based on an insertion heuristic. The experiments were based on three different strategies which are: scheduling a transport directly after its request has been received, waiting until X number of requests have been collected and scheduling every X hours. As input, data from the fire department's information management system for January, February and March 2024 were used. The results can help the fire department to deal with the short notice of requests. From a research perspective, the research uses existing routing models and scheduling strategies and slightly adapts them to the case of the fire department in Lübeck. This research adds to the current research on the combination of heuristics used within DARP and different scheduling strategies within the context of non-emergency patient transports. Additionally, the strategies get evaluated based on their level of inconvenience for patients and the workload for dispatchers.

The strategies tested have different strengths and weaknesses. Directly planning the transports results in a low number of delayed transports which also affects other KPIs positively. However, at the same time, it takes a significantly longer time to drive to patients. On this KPI the other two strategies perform better due to having more transports available at once, which allows us to find better combinations of transports. However, for the X-request strategy having to wait until X number of transports are reached, can take a long time, which results in a higher average delay. In general, this strategy does not perform well in any of the KPIs. Scheduling every X hours allows also for a better combination of transports. But the duration until the next time of scheduling is shorter, and therefore it performs overall better with less delay and a lower total travelling time.

The best strategy from the ones considered in this research is scheduling transports every half hour, which improved on almost all KPIs compared to direct scheduling. For example, it reduced the total operating time by 6% to 21.9% depending on the month. This allows for four to fourteen additional transports based on the average length of a transport.

Due to only testing specific instances scheduling every half hour is most likely not the best parameter. This research can give a guideline. Therefore, we recommend choosing a suitable parameter. A wider interval increases the likelihood of delayed transports. Additionally, it needs to be taken into account, that for the solution algorithm solely the scheduling part of the dispatcher's job is considered. A dispatcher also has additional tasks to fulfil such as taking calls with transport requests which also takes time. Therefore, a too-small interval might be difficult to realise and the effect of being able to plan multiple transports simultaneously shrinks.

In the beginning, the idea was to solely look at the transports of the main medical institutions in the operational area of the hospital and to find a strategy for requesting transports by the medical institutions, that are best for the non-emergency patient transport system. For that, a smaller amount of transport would be considered. However, the general effects of the strategies could be expected to be similar and decrease the workload for paramedics due to fewer phone calls in a day. Due to having fewer transports to consider, a larger time interval would most likely create a better effect in this case. Because otherwise, the likelihood of every time having only one or two transports increases and the effect of being able to schedule multiple transports at the same time is diminishing.

Even though the experiments include several simplifications, the results give the fire department a good idea of the effect of different strategies on the non-emergency patient transport system. It needs to be taken into account that these simplifications limit the accuracy. It is acceptable in this case because it is to be expected that most simplifications affect the different strategies evenly.

The focus of further research should be on the potential effect of seasonality on the different strategies and testing if a stochastic model offers the same conclusions.

6.2 LIMITATIONS

This research includes multiple simplifications and limitations. The reasoning behind them and their expected influence on the results as well as further research areas will be discussed in the following sections. This reflection is split up into three parts: data-related aspects, the differences between reality and the experiments and experiments choices.

6.2.1 Data

The data used for this research included on one hand missing data such as missing postal codes which were estimated with the help of Google Maps (Google, 2024). These are only estimations and in reality, the duration of driving from one to another patient can differ due to traffic jams, constructions, choice of route or other reasons. Additionally, only the postal codes were used and not the exact address of the pick-up and delivery point, due to data privacy.

The timestamps introduced in Section 2.1.1 are triggered by the paramedics pressing a status on a device during their shift. It is likely that in some cases the timestamps used are not accurate. It can be expected that at times paramedics forgot to press the button or did it later than they were supposed to due to forgetting it. This cannot be easily recognized in the data except if the time between the stamps only differs by a few seconds.

Further, the data includes some transports, that have been planned but never been executed, executed at a later point in time or executed with a different vehicle. As explained before these were neglected for the testing of the algorithm (see Section 4.3**Error! Reference source not found.**).

Each of the aspects above decreases the accuracy of the outputs but as long as the same values are used for all experiments, the results of the experiments can be compared.

6.2.2 Experiments vs Reality

As mentioned in Section 4.1, the solution algorithm includes a few simplifications. In this section, the effects of these are discussed.

First of all, besides non-emergency ambulances multi-purpose ambulances can be used for non-urgent patient transport. This is also the case for the solution algorithm but with a few differences. First of all, the demand for multi-purpose ambulances for emergencies is not taken into account. In reality, emergencies are always priorities. For the experiments, transports which have been received in advance, have been scheduled on multipurpose vehicles, if it was done so in reality. For the transport that gets scheduled dynamically every transport gets first tried to be scheduled on a non-emergency vehicle. If this is not possible and it is a transport to an appointment, also multi-purpose ambulances are considered. For the other transports, it is first tried to reschedule it up to fifty times by five minutes before the emergency ambulances get considered.

Another aspect is that as explained in Section 2.2, multipurpose vehicles are only allowed to be used in specific circumstances and within the city. These rules are not taken into account here. Therefore, it is likely that a multipurpose vehicle will be used more often. This is the same for all strategies but needs to be taken into account when comparing the KPIs of the strategies to the historical values.

The different equipment the different vehicles have on board is not taken into account in this research. This is due to not having data on the patient's requirements for equipment. In reality, this could result in longer waiting times for patients due to only being able to be transported in a specific vehicle depending on their condition. Similarly, this is the case for switching vehicles. Depending on the condition of the patient, also special vehicles can be made use of. The paramedics then switch vehicles at the station where the special vehicle is stationed and then perform the transport with the special vehicle. The number of these transports is small and therefore does not influence the results largely.

The number of vehicles is fixed. The vehicles used for dynamic planning and the preplanning can slightly differ. The vehicles used in the preplanning are based on historical data and the dynamic planning is based on the Vorhalteplanung (Feuerwehr Lübeck, 2023b)[7]. In reality, the vehicles used can differ from the year planning. As for the other aspects, this is the same case for all the strategies.

Similarly, paramedics can take dynamic breaks in reality but in the solution algorithm not. This can complicate finding an available vehicle. Especially for transports which take over four hours and can lead to longer waiting times for patients. The waiting time for patients is difficult to assess due to not having data on which transports have a set time for pick up and what that time would be.

6.2.3 Experiments

In a few cases, the model shows overlapping transports for the X hour and X request strategies. This is most likely caused by too few iterations when checking for overlapping transports during a specific scheduling moment. This should be solved for future versions of this research. These are not excluded due to the overlap taking place at different points, for the different experiments and the number of overlaps also differ per experiment. Therefore, when excluding these transports some strategies automatically would score better on the KPIs.

Also, the number of selected instances should be taken into account. Currently, the data for January, February and March are included in this research. It is questionable though if seasonality can be noticed when looking at the different months of the year. A reason to research is, that during school holidays, also more doctors might be on holiday and therefore fewer appointments take place. Therefore, seasonality should be researched and the impact it might have on scheduling strategies.

Seasonality is a type of variability. In reality, the non-life threatening medical patient transport services are influenced by diverse types of variability such as the unavailability of vehicles, the needed equipment for a patient or the type of transport a patient needs. Due to time limitations, a deterministic approach was chosen. A stochastic approach could demonstrate and include these variabilities better. Therefore, future research should make attempts towards a stochastic approach. Instead of the exact transport information, a probability distribution based on the historical values would be needed to be used. For this research, the results say the same when run multiple times due to the deterministic approach. In the case of a stochastic approach, the same experiments need to be run multiple times because the results can differ.

[7] This source is an internal document (no open access)

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APPENDICES

APPENDIX A: PROBLEM IDENTIFICATION

In this section, an overview of the problems occurring at the coordination centre of the fire department will be given and a specific core problem will be chosen based on the Managerial Problem Solving Method by Heerkens & Van Winden (2017) which is a systematical framework for problem-solving. The problems were identified by talking with the management, dispatchers responsible for the general operations of the coordination centre, the planners for non-emergency patient transport and the quality manager of the coordination centre. In general two main issues were identified. On one hand, the dispatchers experience a high workload which results in high stress levels and on the other hand the waiting times for patients are higher than necessary. For both problems, multiple reasons can be found. All action problems and their relationships can be seen in the problem cluster below.

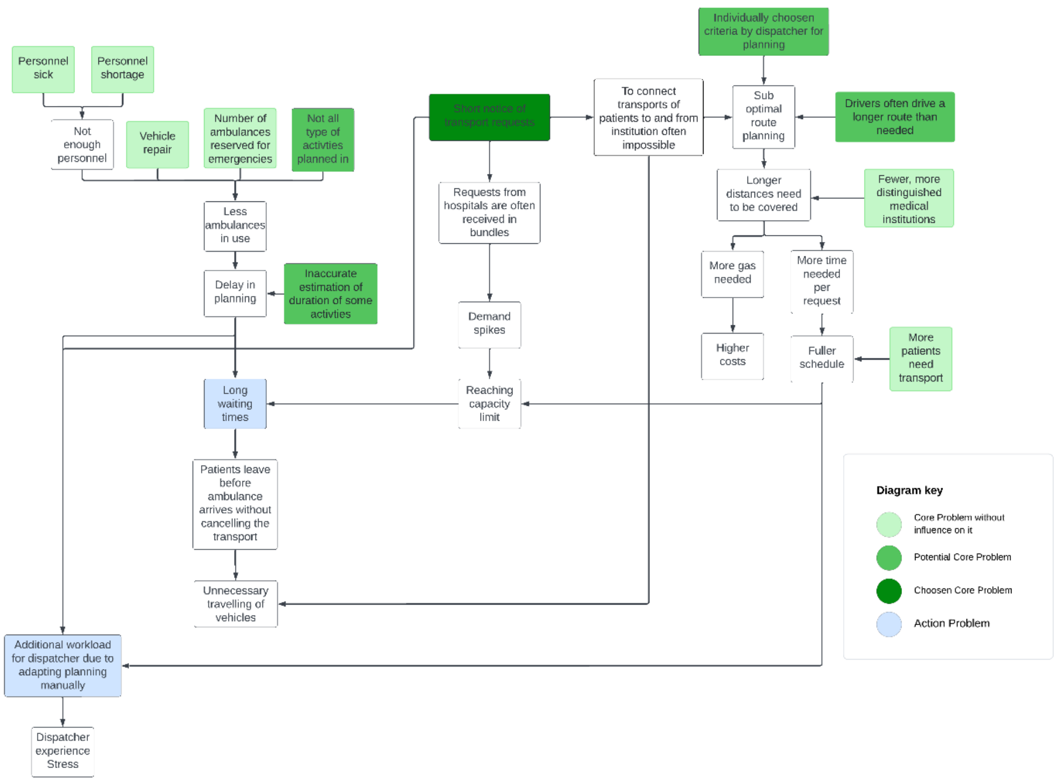

Figure 24 Problem Cluster: Planning of non-emergency patient transports of the coordination centre of the fire department in Lübeck.

A.1 Stakeholder

Most involved in the planning processes are the dispatchers for non-emergency patient transport. They are experiencing a high workload which results in high stress levels. They are interested in having less stress through for example better estimation of activities or automatic planning suggestions in case of delays in the planning by the planning tool.

The coordination centre itself sees the welfare of the patients as most important. Next to it, they are interested in the welfare of their employees while ensuring the health of their employees. They are interested in a reduction of uncertainty due to late requests for transports by medical institutions to reach a more efficient utilization of their capacity. Concerning the dispatcher, they often experience a high load of stress. Stress over a long timeframe can lead to lower productivity, worsening of mental health and increased risk of for example heart disease and digestive problems (acas, 2023). This could result in more dispatchers being absence due to illness which again is likely to increase the stress for the other colleagues. Therefore, they would like to decrease the stress levels for dispatchers and the waiting times for patients.

The external stakeholders are the medical institutions such as hospitals and dialyze centres and the patients. In general medical institutions are expecting a reliable transport service and a short response time.

Currently, due to spontaneous transport requests and sub-optimal route planning, it comes to long waiting times for patients which results in high uncertainties for the patients especially if they are supposed to be transported to an appointment and rely on being on time. Depending on the sickness or injury delay in the transport can hinder the care and with that increase the time of recovery. Further, low efficiency can lead to patient anxiety (Hains et al., 2010; NHS, 2021).

Medical institutions are usually interested in receiving their patients on time. Especially the emergency rooms are struggling with their capacity and therefore would like for patients to be quicker released and then picked up by a means of transport to release pressure on their capacity. Requesting transports is commonly done in bundles and with short notice. This is practical for the staff of the institution but can result in sub-optimal route planning and overloading the patient transport system which results in high waiting times for patients.

A.2 Core Problem and the Gap between Norm and Reality

Based on Heerkens & Van Winden (2017) a core problem is a problem which is not directly caused by a different problem. Therefore, to identify the core problem the chain of causes needs to be followed until its end. In this case, eleven potential core problems can be identified which are indicated in green in Figure 24. The next step is to eliminate all potential core problems which one is not certain about and/ or cannot influence. Then five potential core problems are left which are indicated in dark green in Figure 24: *'Not all type of activities planned in'*, *'Inaccurate estimation of duration of some activities'*, *'Drivers often drive a longer route than needed'*, *'Manual planning based on individually chosen criteria by dispatcher'* and *'Short notice of transport requests'.*

After identifying the potential core problem a cost-benefit analysis needs to be conducted to find the most important problem to tackle (Heerkens & Van Winden, 2017). For the core problems *'Not all type of activities planned in'* and *'Inaccurate estimation of duration of some activities'* the fire department is currently already working on a solution. Of course, this problem could be investigated to support the planners until the new solution is implemented. But especially in combination with the fact that the margin for implementing aspects in the current system is relatively narrow, it seems more effective to focus on a problem which has not been addressed yet.

That *'drivers often drive longer routes than needed'* affects at the end the availability of the given capacity of ambulances of the fire department. If this core problem is chosen additional focus should lie on change management because it is to be expected that drivers of the ambulances will not be directly willing to change their way of working and factor human has still a great influence. The size of the effect of decreasing the distances driven is unknown at this point in time. When the routes would be shortened the ambulances would be earlier available again for other transports. It is further also questionable if, with the available data, it is possible to properly assess this problem. The data collect is for example the driving time. If this time is longer than expected based on the data, it is not known whether this was due to a traffic jam or a longer route. Also from an ethical point of view, research in this area is controversial because a comparison with the current behaviour of drivers would conflict with the data privacy rights of the drivers because each vehicle can get associated with particular drivers.

The next core problem is the *'individually chosen criteria by the dispatcher for planning'.* This aspect if addressed would most likely result in a decrease of stress levels experienced by dispatchers and would make it easier for new dispatchers to start up. Stress levels would be though difficult to measure. Depending on the approach chosen also a decrease in waiting time for patients can be expected. On the other hand, depending on the solution limits regarding the implementation of the current software are likely to be experienced.

Lastly, the problem of *'short notice of transport requests'* needs to be considered. Currently, medical institutions often request transport on very short notice and multiple at the same time therefore it is often the case that the capacity limit is reached and patients experience long waiting times. The goal of tackling this problem would be to reach a more efficient utilization of the available capacity of patient transport ambulances so that patients experience less waiting times and dispatchers less stress. It needs to be taken into account that for this problem also external stakeholders are strongly involved. Therefore, a strong and convincing argumentation for a new strategy would need to be presented.

As far as it can be estimated most feasible and direct impact can be achieved by addressing the problem of *'short notice of transport requests'.* Therefore, this problem was chosen to investigate further.

With that said the core problem can be formulated as follows:

'The coordination centre of the fire department in Lübeck, Germany, deals with a short notice of transport requests for many transports which do not allow for efficient route planning and therefore results in long waiting times for patients'

As described in the core problem efficient route planning is not possible due to short notice of transport requests. This is the case because too few transports are known beforehand to connect them in the most efficient way possible. Therefore, not the ideal utilization of the capacity of ambulances is reached and patients experience longer waiting times than necessary. The average waiting time is at the start of the research unknown. In an ideal situation, enough transports are known in advance that the total movement time of the ambulances and the waiting time for patients can be minimized.

A.3 Scope and Limitations

As explained in Section 1.1 the coordination centre of the fire department is responsible for the coordination of operations of the fire department, emergency vehicles and non-emergency patient transport. For this thesis, the focus will be on the planning of non-emergency patient transport due to the existence of a time constraint. For conducting the thesis only ten weeks were available. Therefore, the efforts needed to be concentrated on the steps determined in Section 1.3 and solely on the non-emergency patient transport.

APPENDIX B: RESEARCH DESIGN

What is the effect of different transport request strategies from hospitals for non-emergency patient transport on the coordination of the patient transport ambulances in Lübeck?							
Knowledge Problem	**Type of Research**	**Research population**	**Sampling**	**Research Approach**	**Data gathering technique**	**Data processing/ representation**	**Time horizon**
1. *What does the current planning process for patient transports look like at the coordination centre in Lübeck*	Exploratory	Employees	Dispatcher	Qualitative	Participant observation as a collaborative observer	Flow charts	Cross-sectional
2. *What activities need to be taken into account when creating the schedule?*	Descriptive	Employees	Databases, Planners, Quality Assurance Responsible	Qualitative	Semi-structured interviews	List of activities	Cross-sectional
3. *Which capacity does the coordination centre have for patient transport?*	Descriptive	Employees	Management	Qualitative	Semi-structured interview	Overview over capacity	Cross-sectional
4. *What type of transport scheduling strategies for patient transport exist?*	Descriptive	Employees, Literature	Planners, Databases	Qualitative	Semi-structured interview, Systematic literature study	Text explaining different strategies	Cross-sectional
5. *Which laws and guidelines need to be taken into account in the planning process?*	Descriptive	Literature	Governmental web portals for laws	Qualitative	Narrative literature study	Describe in a text which laws apply	Cross-sectional
6. *What transport planning theories and models are used for non-emergency patient transport?*	Descriptive	Literature	Databases	Qualitative	Systematic literature study	Text explaining theories	Cross-sectional
7. *Which of them can most efficiently represent the patient transport system of the coordination centre of the fire department in Lübeck?*					Make use of previous questions		Cross-sectional
8. *Which assumptions need to be included in the model?*	Descriptive	Literature, Employees	Databases, Planners, Quality	Qualitative	Systematic Literature study, Semi-structured interview	Text with explanation	Cross-sectional

			Assurance Responsible				
9. *Which KPIs capture the success of a transport scheduling strategy for the coordination of the transports best?*	Evaluative	Literature, Employees	Databases, Planners, Quality Assurance Responsible	Qualitative	Semi-structured interview, Systematic literature study	List with KPIs	Cross-sectional
10. *How can the conceptual model be translated model to test the solution algorithm?*	Explanatory				Modelling	Code	
11. *How do the transport scheduling strategies perform that were identified in Chapter 3?*	Evaluative	Dataset		Quantitative	Data generated through testing of solution algorithm	Data analysis, Statistical Analysis, Graphs/ Tables	Cross-sectional
12. *Which transport scheduling strategy performs best based on the chosen KPIs?*	Evaluative	Dataset		Quantitative	Generated through testing of solution algorithm	Comparison of outcomes of question eleven	Cross-sectional
13. *Which recommendations and conclusions can be given to the coordination centre regarding patient transport planning?*	Descriptive	Employees	Planner	Qualitative	Based on the outcomes of questions eleven and thirteen	Text	Cross-sectional

Table 8 Research Design for each sub-research question

Research Design

This research follows a mixed-method approach. With this, the strength of quantitative and qualitative research can be used together to give a more comprehensive answer and picture of the question (Creswell & Plano Clark, 2017). Qualitative data is used from observations, interviews and meetings with employees of the fire department in Lübeck. For the quantitative analysis data from the management information system of the coordination centre and the outputs of the experiments are used.

The main research question has an explanatory nature. This is the case because the relation between transport scheduling strategies and the performance of the planning of non-emergency patient planning will be researched. Different KPIs will be chosen to assess this. The sub-questions are descriptive, exploratory, explanatory and evaluative. Descriptive and exploratory questions are mainly used at the beginning to get insight into the topic and current processes and regulations involved in non-emergency patient transport. Later on, evaluative and explanatory questions are chosen to assess the research and understand certain relationships.

A detailed overview of the applied research methods per research question can be found in Appendix B. Per research question the type of research, the population, sampling strategies, research approach, data gathering techniques, data representation and time horizon are listed.

Validity and Reliability

In this section, the validity and reliability of the general setup of the thesis and the applied techniques are discussed. To ensure that other researchers can replicate this research and the fire department can retrace it the conducted research, each step is carefully documented. Further, regular meetings with the company and university supervisors have been conducted to ensure appropriate methods are chosen, the state-of-the-art is considered and the research is aligned with the standards in the research area such as the European Code of Conduct for Research Integrity demands (ALLEA, 2023). The latter aspect is also supported by literature reviews. For the different data-gathering techniques also measures are taking to ensure validity and reliability of the research.

The interviews conducted for this research are semi-structured. Some guiding questions and routines were prepared in the form of an interview guide to ensure comparability of interviews and that to a certain degree, replication is possible. It needs to be though taken into account that other researchers might not have the same access to employees or other employees are present. In general to give a full picture and avoid a one-sided view multiple employees will be interviewed. Further, leading questions should be avoided and a natural tone used to get an answer from the participants that is independent of the interviewer's opinion and depicts the reality (Saunders et al., 2019).

For the literature review, only peer-reviewed sources were chosen to base this research on accurate and reliable information. Furthermore, two databases were used to minimize database bias. This also includes that search terms have been adjusted through the literature review based on experts' terminology to avoid filter bubbles.

Also in the case of observation, validity and reliability needs to be considered. In case of observation observer bias and/or errors can occur. Often observers interpret situations in their subjective way. In the case of a participant observation as a collaborative observer such as used in this research, it can be avoided through informant verification. Due to which follow-up questions were asked and notes were taken. Additionally, to get a complete picture of the situation and limit the observer effect the observation has been carried out multiple times and with multiple dispatchers. Which are all methods based on Saunders et al. (2019) which limit the risk errors and biases.

APPENDIX C: SYSTEMATIC LITERATURE REVIEW

In this appendix, all relevant information regarding the performed systematic literature review to find relevant models for non-emergency patient transport planning can be found.

Knowledge Question

With the help of this systematic literature review the research question "*What transport planning theories and models are used for non-emergency patient transport and which of them can most efficiently represent the patient transport system of the coordination centre of the fire department in Lübeck?"* will be answered.

Search Matrix

From the research question three key concepts can be identified: "*planning*" and *"non-emergency patient transport".* A search matrix helps to find additional terms for the key concepts and to later combine these into search terms. The search matrix of this systematic literature review can be found in Table 9.

Key Concepts	Related terms/ synonyms	Broader terms	Narrower terms
Planning	Schedule	Operation Research	Route Planning
		Resource planning	Routing
			Ambulance planning
			Vehicle Routing Problem
			Dial-a-ride-problem
Non-emergency patient transport	Patient relocation	Transport	
	Medical transport	Movement	
	Patient transport	Health care services	
		Health care logistics	

Table 9 Systematic Literature Review: Search Matrix

Inclusion & Exclusion Criteria

Inclusion and exclusion criteria are defined when a source can answer the research question. Further, defining them makes the process of a systematic literature review more transparent and replicable to the reader (Tod, 2019). Inclusion criteria are criteria which need to be fulfilled for a source to be included in the research. Exclusion criteria on the other hand are criteria which make a source ineligible to be considered. In Tables 10 and 11 the criteria for this systematic literature review together with a short reasoning for selection can be seen.

Inclusion criteria	Explanation
English OR German	The main academic language is English. Therefore, it is to be expected that most sources will be available relevant sources will be available in English. German sources will also be considered because they might be able to describe the system in Germany better as the research location is in Germany.
Full-text access	Only sources with access through a UT account will be considered.
Non-emergency patient transport	Emergency patient transport has different characteristics of the planning system. Therefore, solely papers focused on non-emergency patient transport will be considered.

Table 10 Inclusion criteria of the systematic literature review

Exclusion criteria	Explanation
Not peer-reviewed	For validation purposes, the sources must be peer-reviewed. Peer-reviewed sources have already been thoroughly evaluated on the quality and reliability of the information.

Table 11 Exclusion criteria of systematic literature review

Databases

For this research, multiple databases will be considered. On one hand, the multidisciplinary databases Scopus and Web of Science will be used. Both include a large number of academic sources. On the other hand, also one specialized database will be included. PubMed focuses on medical aspects. A large number of sources are already included in Scopus but the databases might still give more results.

Search log

To construct the search terms the search matrix was used. In Table 12 the order of the used search terms can be seen together with the used database, the number of hits and comments regarding the relevance of the found sources.

Date	Source	Search Term	Number of hits	Comments
16/04/2024	Scopus (database)	TITLE-ABS-KEY (Planning AND “non-emergency patient transport”)	3	- 1 relevant paper
		TITLE-ABS-KEY ((Plan* OR “Operation Research” OR rout*) AND (“non-emergency patient transport” OR “patient transport*” OR “medical transport”))	5,776	- Mostly irrelevant sources - Focus of sources on emergency transport or transport within the hospital
		TITLE-ABS-KEY ((plan* OR schedul* OR "operation research" OR rout*) AND ("patient transport*" OR relocat* OR "transport* in health care" OR "health care services"))	24, 252	- Mostly irrelevant sources
		TITLE-ABS-KEY ((plan* OR schedul* OR rout* OR “vehicle routing”) AND (“patient transport*” OR relocat* OR “transport* in health care” OR “Medical transport*”))	18, 588	- Mostly irrelevant sources - A lot of papers on air medical transports
		TITLE-ABS-KEY ((plan* OR schedul* OR rout* OR “vehicle routing”) AND (“non-emergency patient transport*“ OR relocat* OR “transport* in health care”))	12,268	- Multiple relevant papers - New term: non-urgent transportation - Many non-relevant papers on vehicle routing

		TITLE-ABS-KEY ((plan* OR “Operation research” OR rout*) AND (“non-emergency patient transport*“ OR “transport* in health care”))	10	- Most papers identified in earlier searches as relevant are included here - Quick searches before also named dial-a-ride. This has not come back so far. Therefore, this will be still extra investigated
		TITLE-ABS-KEY ((plan* OR "operation research" OR rout* OR "dial-a-ride") AND ("non-emergency patient transport*" OR "transport* in health care"))	11	- No new articles
		TITLE-ABS-KEY (("dial-a-ride" OR "operation research") AND ("patient transport*" OR "transport* in health care"))	49	- A few relevant papers
16/04/2024	Web of Science	TITLE-ABS-KEY ((plan* OR “Operation research” OR rout*) AND (“non-emergency patient transport*“ OR “transport* in health care”))	3	- No new sources
		TITLE-ABS-KEY ((plan* OR rout* OR “Operation Research” OR “dial-a-ride”) AND (“patient transport*“ OR “transport* in health care”))	216	- Some new and relevant sources
		TITLE-ABS-KEY ((“Operation Research” OR “dial-a-ride”) AND (“patient transport*“ OR “transport* in health care”))	17	- Mostly doubled ones
16/04/2024	PubMed	TITLE-ABS-KEY ((plan* OR “Operation research” OR rout*) AND (“non-emergency patient transport*“ OR “transport* in health care”))	203	- mostly irrelevant sources
		(plan* OR rout* OR “Operation Research” OR “dial-a-ride”) AND (“patient transport*“ OR “transport* in health care”))	424	- mostly irrelevant sources

Table 12 Search log of the systematic literature review

The sources identified with search terms six, eight, ten and eleven were chosen for closer inspection. Additionally, one source which has been recognized as relevant when looking at the results of other search terms was included. In total 293 sources were found this way. Table 13 explains how the selection of papers was narrowed down to 23 sources.

Total number hits	293
Removal of sources for which no reference could be created	-3
Removal of duplicates	-43
Selection based on title	-190
Selection based on abstract	-30
No full-text access	-2
Based on full-text different focus than attended	-5
Snowballing	+3
Total	23

Table 13 Overview of narrowing the selection of sources found through the systematic literature review

Out of the 23 sources mentioned above 19 are represented in the conceptual matrix below. The other four sources do not include a model and therefore are more appropriate as background knowledge. To give still an idea about the content they are included in the literature matrix (Table 15). Two sources were chosen for additional knowledge but are in neither of the matrices represented.

The conceptual matrix (Table 14) gives an overview of the characteristics of models and approaches presented in the chosen sources. For the conceptual matrix (Table 14) the following abbreviation is used: DARP = Dial-a-Ride-Problem, VRP = Vehicle Routing Problem, TSP = Traveling Salesman Problem, MILP = Mixed-Integer Linear Programming, CP = Constraint Programming, VNS = Variable Neighbourhood Search, LNS = Large Neighbourhood Search, TC = Travelling Cost, TTT = Total Travel Time, TTD = Total Travel Distance, NSR = Number of served requests, TW = Time Window, SR = Shared Rides, HV = Heterogeneous Vehicles, RR = Request Rejection and ? = unknown.

Article/concept		Type of model				Approach			Heuristics				Objective function					Constraints				
		DARP	VRP	TSP	Else	MILP	CP	Else	VNS	LNS	TABU search	Else	TC	TTT	TTD	NSR	Else	TW	SR	HV	no RR	Dynamic / Static?
1	Bernardo et al., 2021	X				X			X				X					X		X (at one depot)	X	S
2	Bowers et al., 2012				X			X (Monte Carlo Simulation)				X		X				X	X	X (mult. depots)	X	S
3	Cappart et al., 2018	X (PTP)					X			X		Branch and bound with depth search + Conflict Order Search				X		X	X	X (non-continuous availability)		S
4	Coppi et al., 2013	X				X						Column generation approach	X					X	X	X (Mult. depots)	?	S
6	Delecluse et al., 2022	X (+PTP)		X			X			X		insertion heuristic			X	X		X	?	X	X	S
7	Detti et al., 2017	X				X			X		X		X					X	X	X	?	?
8	Fogue et al., 2016		X									NURA (Evolutionary algorithm + scheduling algorithm)					X (Average waiting time)	X	X	X	?	S
9	Kergosien et al., 2014	X						X (discrete-event simulation experiment)			X						X (sum of transport delays + total urgent demands covered + sum of empty running ambulances)	X	?		X	S/D
10	Luo et al., 2019	X				X									X	X		X	X			S
11	Madsen et al., 1995	X										X (insertion algorithm)						X	X	X	X	S/D
12	Molenbruch et al., 2017	X										Multi-Directional Local search including Variable neighbourhood decent		X	X			X	X	?	?	S
14	Nasir et al., 2022	X				X						K-means algorithm	X				X (see Table 15)	X	X	?	?	S
15	Nasir et al., 2020	X				X							X				X (See Table 15)	X	X		?	S
16	Oberscheider & Hirsch, 2016	X									X						X (operation time)	X	X	X (mult. depot)	X	S
19	Ritzinger et al., 2016	X						X (Dynamic Programming)		X				X				X	X		X	S/D
20	Schilde et al., 2011	X							X (dynamic + stochastic)			Multiple plan approach + multiple scenario approach					X (total tardiness)	X	X		X	S/D
21	Souza et al., 2022	X				X						General Variable neighbourhood Search + insertion heuristic	X		X			X		X	X	S/D

22	Tóth et al., 2024	X		X		X									X			X	X	1 vehicle	?	S
23	van den Berg & van Essen, 2019	X			X (Discrete formulation)			X (iterative) integer linear programming				X					Coverage of emergencies			X	X	S/D

Table 14 Conceptual matrix of systematic literature review

The literature matrix (Table 15) names the author, the title and a short impression of the content of each of the selected sources.

Nr.	Author	Title	Comment
1	Bernardo et al., 2021	The dial-a-ride problem in the case of a patient transportation system in Brazil	Are looking at transport costs by looking at routing and vehicle costs with the help of DARP. Making use of metaheuristics.
2	Bowers et al., 2012	Developing a resource allocation model for the Scottish patient transport service	Main focus: trade-off resource provision and level of service including geographical differences → Goal: Decision support system. Taking into account differences between rural and remote areas. Preference for providing transparency, flexibility and speed (regarding models). Comparison with DARP and open VRP
3	Cappart et al., 2018	A Constraint Programming Approach for Solving Patient Transportation Problems	Goal: optimize transportation logistics for non-profit organizations while maximizing the number of served requests Constraint Programming flexible approach with the possibility to add more constraints. Cappart et al. showed that their approach provides better results than greedy strategies.
4	Coppi et al., 2013	A planning and routing model for patient transportation in healthcare	The integrated approach combines tactical (planning + routing) and operational (agreements + constraints) dimensions. 1. Heuristic approach with column generation approach 2. The branch & cut algorithm is exactly solved with Cplex. Reduction of total transport cost through an algorithm on average 58%
5	Cordeau & Laporte, 2007	The dial-a-ride problem: models and algorithms	This paper summarizes the most common DARP models and their characteristics.
6	Delecluse et al., 2022	Sequence Variables for Routing Problems	Goal: Show flexibility of Constraint Programming. With the help of sequence variables limitations of CP should be addressed
7	Detti et al., 2017	A multi-depot dial-a-ride problem with heterogeneous vehicles and compatibility constraints in healthcare	Special: which non-profit organisation performs the transport can be chosen by the patient. Goal: solve real-life cases with DARP including variable neighbourhood search and TABU search.
8	Fogue et al., 2016	Non-emergency patient transport services planning through genetic algorithms	Using genetic algorithms to diversify the solution space and getting a complete planning for all ambulances including pick-up times and an overview of where which patient needs to be picked up and brought to. The genetic algorithm is based on evolution theories. Two-Step approach: 1. Assignment of ambulances 2. Create schedule. Reduces waiting time compared to schedules created by experts by 13,33%.
9	Kergosien et al., 2014	Managing a Fleet of Ambulances to Respond to Emergency and Transfer Patient Transportation Demands	Designs and evaluates based on three objectives the three different approaches regarding emergency and non-emergency patient transport. Solved for some approaches exactly with CPLEX and for others with heuristics. Proactive integrated fleet management increases the quality of service and is easy to implement.
10	Luo et al., 2019	A two-phase branch-and-price-and-cut for a dial-a-ride problem in patient transportation	Goal: minimize total costs. If the profit is large enough it will first maximize the number of served requests and then minimize the total travel distance otherwise it is the other way around. Exactly solved with Label algorithm, branch-and-price-cut algorithm.
11	Madsen et al., 1995	A heuristic algorithm for a dial-a-ride problem with time windows, multiple capacities, and multiple objectives	For a dynamic approach for the DARP, the insertion heuristic REBUS gets applied. The order of insertion depends on the cost of the transport and the difficulty of planning the request.
12	Molenbruch et al., 2017	Multi-directional local search for a bi-objective dial-a-ride problem in patient transportation	Looks into a multi-objective approach, combination restrictions (combination of users and medical personnel) and a new efficient scheduling heuristic to assess the feasibility of a solution. Regarding the combination restrictions, the effect on the cost structure was researched. With that, it helps providers in decision-making.
13	Molenbruch, Braekers, & Caris, 2017	Typology and literature review for dial-a-ride problems	Literature review of DARP. Considers different types and constraints
14	Nasir et al., 2022	Clustering-based iterative heuristic framework for a non-emergency patient transportation problem	Based on source 11. Now heuristic approach instead of exact solution. Look at the trade-off between user inconvenience and costs. Therefore, uses four folded objective functions: Total travelling costs, total waiting time at the pick-up location, extra ride time and underutilized capacity. Using priority rules for objective functions
15	Nasir et al., 2020	Optimizing Operator's and Users' Objectives in Non-emergency Patient Transportation	Goal: Insights in impacts of objective weights. The objective function consists of terms regarding total travelling cost, total waiting time at the pick-up location and underutilized capacity. The exact solution determined with CPLEX
16	Oberscheider & Hirsch, 2016	Analysis of the impact of different service levels on the workload of an ambulance service provider	Goal: The impact of minimum service levels for providers Includes transports of people and goods (such as organs or samples) For solving the model a Matheuristic approach including a TABU search gets applied
17	Reuter-Oppermann et al., 2017	Towards designing an assistant for semi-automatic EMS dispatching	Focuses on what type of model is suitable for non-emergency patient transport and emergency transports. Goal: increase the efficiency of planning to decrease costs, waiting time, etc. through an IT-supported system

18	Reuter-Oppermann et al., 2015	Towards an IT-Based Coordination Platform for the German Emergency Medical Service System	Well-suiting information that can be used as background information. Strong focus on emergency transports and general explanation of mathematical models for optimization in the context of ambulances. Goal: create a decision-making tool for dispatchers with a focus on user acceptance
19	Ritzinger et al., 2016	Dynamic programming-based metaheuristics for the dial-a-ride problem	Hybrid approach: Dynamic Programming approached embedded in metaheuristics Exact solution algorithm for a small benchmark instance. For larger instances = restricted Dynamic Programming formulation
20	Schilde et al., 2011	Metaheuristics for the dynamic stochastic dial-a-ride problem with expected return transports	Partially transports are known in advance or are received during the day. Uses stochastic to estimate expected returns. Makes use of the lexicographic objective function. Evaluation of four metaheuristic solution approaches.
21	Souza et al., 2022	Bi-objective optimization model for the heterogeneous dynamic dial-a-ride problem with no rejects	The definition of static and dynamic requests is important to take into account. First a static pre-planning through General Variable Neighbourhood Search then dynamic requests added with an insertion heuristic. Goal: improve transportation service through mathematical model + effect on a number of vehicles regarding static or dynamic approach.
22	Tóth et al., 2024	MILP models of a patient transportation problem	The specific case of one single vehicle and only one hospital. Limitation: most likely cannot be used for large-scale problems due to the exact solution approach. Goal: Impact of multiple capacity transport and the efficiency of MILP formulation.
23	van den Berg & van Essen, 2019	Scheduling Non-Urgent Patient Transportation While Maximizing Emergency Coverage	Goal: maximization of coverage for emergency calls. Online and offline models are considered. Usually make with the offline model first planning and in case of new requests optimize the existing planning. DARP and discrete formulation performance accessed and DARP performance better (online case) For the offline case the discrete formulation performs better.

Table 15 Literature Matrix

APPENDIX D: AVERAGE RESULTS OF KPIS FOR FEBRUARY AND MARCH

Tables 16 and 17 show the results for the KPIs for February and March respectively. The green highlighted numbers are the best-reached value for the specific KPI and the red one is the worst-performing.

KPIs	Historically	Direct	5 Requests	10 Requests	1 hour	2 hours	0.5 hours
Number of Transports after 17:00	14.17	5.34	7.07	9.66	5.31	6.55	5.07
Total Operating Time	143.28	140.81	140.41	140.17	120.14	120.13	119.52
Number of delayed Transports	37.03	17.14	40.07	45.83	30.66	35.52	23.48
Average delay per delayed Transport	1.07	1.14	1.27	2	0.85	1.25	0.77
Total Time Spend on Driving to Patients	122.12	69.49	56.35	49.33	42.89	40.22	46.13
Number of scheduling moments in a day	50.83	50.83	10.48	5.41	11.38	7.72	17
Number of Transports per Scheduling	1	1	4.9	9.35	3.37	5.25	2.11

Table 16 Average values for KPIs in February

KPIs	Historically	Direct	5 Requests	10 Requests	1 hour	2 hours	0.5 hours
Number of Transports after 17:00	11.23	5.48	7.29	9.52	5.55	6.81	5.39
Total Operating Time	119.42	116.89	117.11	116.74	109.78	110.62	109.86
Number of delayed Transports	29.35	13	35.52	39.32	31.06	35.84	24.16
Average delay per delayed Transport	0.94	1.19	1.39	2.15	0.85	1.26	0.72
Total Time Spend on Driving to Patients	103.89	57.79	49.96	44.82	42.91	41.79	46.78
Number of scheduling moments in a day	46.17	46.17	9.59	5.07	11.66	7.72	16.97
Number of Transports per Scheduling	1	1	4.8	9	3.5	5.6	2.27

Table 17 Average values for KPIs in March

APPENDIX E: STATEMENT ON USE OF AI

"During the preparation of this work, the author used ChatGPT for assistance and F explanation of the VBA code development of the experiments. Additionally, Mendeley has been used for the management of citations used in this thesis and Grammarly for spelling checking. After using these tools/services, the author reviewed and edited the content as needed and takes full responsibility for the content of the work.

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