Route Planning for Mobile Care Teams using Digital Twin Technology

For the course
TRA310 Improving healthcare

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Abstract

The ageing global population that we are facing is significantly increasing the strain on healthcare systems worldwide. Mobile care teams, a key component of the Hospitals at Home initiative in Sweden, Västra Götalandsregionen, offer a promising solution by delivering hospital-level care directly in patients' homes. This report explores the potential of integrating Digital Twin (DT) technology to optimize the routing and coordination of these teams. By creating a real-time virtual replica of the mobile care workflow, DT technology can dynamically adjust routes based on patient status, team locations, and potential emergency calls, improving resource efficiency and healthcare in general. The proposed solution utilizes existing healthcare data systems, algorithms like TOA*, and real-time data integration to enhance care delivery. The solution also addresses challenges like scalability and workflow efficiency of today's operations of the mobile care team unit.

Contents

1 Why Digital Twins for route planning of Mobile Teams?

By 2050, the population of humans aged over 65 years is expected to rise to 16%, compared to 10% which was the case in 2022 [1]. This rapid increase in life expectancy poses great challenges to the health care system as elderly people are more prone to diseases, especially communicable diseases such as Alzheimer's or diabetes that require continuous monitoring and management. The pressure on the healthcare system is further increased by the decrease in caregiver workforce which limits the resources that are available to care for the growing elderly population. A primary societal goal is to maintain autonomy and safety at home for this population while supporting healthy ageing.

Because of this, various initiatives to use technology to treat more patients and more efficiently with less resources have emerged. One of these initiatives is Hospitals at Home which aims to move treatment from hospitals to patients' homes [2]. By delivering advanced medical care directly in patients' homes, individuals who face challenges visiting the hospital due to age or illness can receive the same quality of treatment in a more convenient setting. This approach facilitates earlier discharges or eliminates the need for hospital admission altogether, easing the strain on limited hospital resources.

Mobile care teams is one of the actors in Hospitals at Home which provide in-home care by routing between patients during the day. The initiative, launched in 2017 at Sahlgrenska University Hospital in Gothenburg, Sweden, is now fully operational. Currently, coordinators rely on a pre-planned daily route based on scheduled visits [3]. However, urgent calls from the Sjukvårdens Larmcentral (SvLc) can disrupt this plan, requiring immediate route modifications. The system currently operates with twelve vehicles, but this number is projected to increase to meet the growing demand for the service. As the system scales, managing route optimization may become increasingly challenging for the two coordinators responsible for overseeing operations, potentially leading to inefficiencies and unoptimized routing of the mobile teams. Given the existing constraints on resources, expanding staff to handle these complexities may not be a feasible solution. Therefore, this report aims to propose a technical solution, based on a digital twin, to optimize the route planning for mobile teams by requiring less resources. A digital twin is a digital replica that maps a physical system to a virtual system by exchanging data in real time [4]. This enables analyzing of the behaviour of the real-world system it mirrors and by that providing useful insights to make better decisions. The technical solution to be developed should be designed to integrate multiple dynamic factors, by using the concept of a digital twin, such as the real-time locations of the vehicles, the positions of the patients, the schedule with planned visits, and incoming emergency calls from SvLc. By analyzing this information, the system should aim to recommend optimal route adjustments for all vehicles whenever new data becomes available during the day.

2 What is a Digital Twin?

Digital twins have become a powerful tool across various industries, and healthcare [5]. This section will define digital twins and explore their applications across different sectors.

2.1 Definition of Digital Twins

A digital twin (DT) consists of three components: physical, virtual, and a connection [4]. The virtual system is mapped to the physical system by exchanging data in real-time. However, a

DT is not just a digital or virtual replica of a physical system. Besides mirroring the physical system in real-time, it should be designed to analyze the behaviour of the real-world system it mirrors and provide useful insights to make better decisions. It does so by making use of advanced tools and technologies such as machine learning (ML) and artificial intelligence (AI) which enable modelling and simulations to create these virtual representations.

DTs have not always been this advanced though. They have evolved from basic static models to sophisticated AI-driven systems [4]. The simplest type is the static twin model, which creates only a static virtual representation of a physical system, lacking the capability to dynamically update based on real-world changes. The next development was the mirror twin, which is a static twin enhanced with basic dynamic behaviour, though it still lacks real-time updates. Following this is the self-adaptive twin, also known as the shadow twin, which incorporates real-time data to continually update the model, requiring a digital thread to track its evolution. The most advanced form, the intelligent digital twin, builds on the self-adaptive model with AI-driven learning, reasoning, and prediction abilities, allowing it to optimize performance dynamically through simulations and machine learning. The intelligent twin is what is referred to today when defining what a DT is.

2.2 Applications of Digital Twins Across Sectors

Digital twin technology is increasingly popular in sectors like smart cities, logistics, engineering, and automotive [6]. Some applications of DT technology are presented below.

2.2.1 Digital twins in smart cities

By creating virtual replicas of urban spaces, DTs can be used to enhance sustainability, citizen welfare, and economic growth in cities [6]. The DTs represent everything from buildings to entire city neighbourhoods to improve quality of life and citizen services. The DTs enable urban planning, infrastructure monitoring and real-time data-driven decision-making. However, this requires the ability to manage large datasets. For instance, Bentley's OpenCities Planner in Helsinki uses cloud-computing and web-based 3D visualization to manage large datasets.

Machine learning and deep learning can be used for scenario simulation and deep urban analysis [6]. The DTs of the urban spaces can use information from citizens, Internet of Things (IoT) from smart devices and sensors, 3D data, and Urban Mobility data. These data sources are connected through the internet, allowing the city's council to access and use the information. This enables 3D simulations of various scenarios, such as urban planning for buildings and infrastructure, natural disasters, and green space simulations of the city. DT implementations in smart cities can use real-time IoT sensor data to enhance urban efficiency, sustainability, and security, while also reducing costs and resource consumption. Simulations in a DT smart city can be used for citizen surveillance to prevent crime, manage traffic, and reduce waste, among other things.

2.2.2 Digital twins in freight and logistics sector

One of the key sectors where DTs are making significant improvements is freight and logistics [6]. In this sector, DTs optimize operations by creating virtual replicas of different processes to enable data-driven decision-making to avoid bottlenecks. For instance, DTs can use real-time data to optimize shipping routes to prevent delays. In last-mile delivery, DTs use GPS and customer data to find the routes where the usage of resources is optimized and the urban delivery challenges are addressed. For online trading, DTs support fast deliveries by predicting demand and planning for many small shipments. DTs also improve port operations by organizing data from cranes, ships, and other equipment to make the flow of goods more efficient.

Kongsberg Digital (KDI), a leader in digital twins for the energy sector, has expanded into the maritime industry with a new DT platform [7]. This DT provides a holistic view of the vessel and its surroundings by combining real-time data from the Vessel Insight data infrastructure and its ecosystem of applications. The purpose of the DT is to perform advanced simulations to troubleshoot operations, make predictions of future performance and enable condition-based maintenance to reduce cost and operational downtime. The data-driven decision-making and risk-assessment will improve efficiency and reduce fuel consumption.

Another DT, Qualco Maritime Digital Twin, is an intelligent decision support for efficient vessel and fleet operations by the leading technology company Qualco [8]. The DT consists of digital replicas of vessels to enable real-time monitoring, voyage planning and scenario simulation. It also enables optimization of vessel setup, CO2 emissions, and routing. Additionally, it tracks multiple vessels to optimize fleet performance, monitor operations, and predict maintenance needs, reducing downtime and increasing efficiency. Natural Language Processing (NLP) of signals from the Platform-as-a-Service (PaaS) is used to enable professionals to monitor critical systems while their vessel is at sea. PaaS is described as “A cloud computing model where a third-party provider delivers hardware and software tools to users over the internet.” [9].

2.2.3 Digital twins in manufacturing

In manufacturing, various methods for gathering data throughout different stages of a product’s lifecycle are increasingly used to optimize product performance and improve production efficiency [5]. This approach requires close interaction between physical and virtual spaces, driving a growing demand for DTs in the industry. DTs connect physical and virtual data across a product’s lifecycle, enabling the analysis of large datasets to improve product or process performance in the physical space.

In product design, DTs support designers in making better and faster decisions [5]. DTs enable seamless collaboration between design and production, allowing for quality assessments early in the design process. DTs also enhance the production process by monitoring it in real time, visualizing the current status, and enabling adjustments through simulations. By linking computer simulations to the physical system, DTs help reduce material waste and extend machine lifespan, contributing to a more efficient and sustainable production cycle.

2.3 Applications of Digital Twins in Healthcare

The field of DTs is also emerging in healthcare settings, where a DT could be characterized by different levels in regards to a person [4]. It could be a body system, an organ or a body function, but it could also be of finer body components on a cellular level. It is also common to create DTs of a disease or disorder. These DTs of an individual person can be used to personalize patient care and aid physicians in decision-making in regards to the patient’s needs. Other applications for DTs in healthcare are hospital management, facility design, care coordination, treatment design, surgical planning, medical device design and workflow development. No matter what the digital representation is built from, the main aim of applying digital twins in healthcare settings encompass the efficiency of resource utilization to minimize resource shortages, enhance patient care, manage hospital workflow and revolutionize clinical care processes.

Different DTs can be combined to unitedly improve patient care. For instance, a DT of an organ such as the heart is mainly developed using detailed image data and is a virtual representation of a patient's heart [4]. This can be combined with another DT in the form of a disease model, including molecular profiling data and clinical information to support precision medicine. The organ-specific DT is crucial to predict how medical devices such as a pacemaker will perform whereas the disease model provides insights in the effectiveness of a certain drug and how it will interact with the biological tissue. Therefore, specialized analytics and modelling are needed for each DT to take advantage of the full potential of DTs in healthcare and thereby improve patient outcomes. For example, in 2014, a virtual twin of the heart was created in the Living Heart project [4], to enable testing of in silico organ drug interactions. The project later teamed up with Philips and Siemens Healthineers to use the DT of the heart to develop and improve the design of cardiac devices more efficiently.

In relation to the concept of Hospitals at Home (patients staying at home), DTs have been embedded in wearable devices that gather personal information to enable real-time health supervision of patients, well enough to be located in their homes [4]. Liu et al. have suggested a cloud-based DT framework that enables real-time monitoring and crisis alerts to support elderly self-care. Babylon is another company that makes use of the health data captured from wearables and fitness devices. Their main aim is to support the engagement between doctors and patients and use DT technology in wearables to improve wellness by delivering more personalized healthcare services.

Moreover, real-time monitoring has been implemented in settings other than of patients, for example in Oregon, during the COVID-19 pandemic. The development of Care Command, a DT of the hospital to optimize workflow and care coordination, by GE HealthCare, enabled monitoring of the hospitals' resources. The DT included predictive models to anticipate shortages in critical care resources such as beds and ventilators. By tracking bed and ventilator availability in real time for hospitals across the state, resources could be optimized and the risk of making uninformed decisions without examining statewide resources was mitigated.

3 What are Hospitals at Home and Mobile Teams?

Hospitals at Home is a new way of providing healthcare by moving treatment from hospitals to patients' homes. This section looks at what Hospitals at Home means, why it has become important, and how mobile care teams help make it work.

3.1 Meaning of Hospitals at Home

The Hospital at Home (HaH) model is a modern healthcare model that challenges the traditional view of where and how acute care should be delivered. The core idea behind the HaH model is to replace traditional hospital care with care for patients, who would normally need to be hospitalized, in their own homes [2]. The difference between the HaH model and other healthcare models, such as palliative home care, is its focus on providing more advanced, hospital-level care at home.

The two main strategies for admitting patients into HaH programs are early supported discharge (ESD), and admission avoidance (AA). ESD allows stable patients who are still in need of some medical care to leave the hospital earlier than usual. The patient continues their recovery at home with medical support, thus reducing their hospital stay. AA aims to prevent hospital admission altogether, instead providing care at home for patients who would otherwise need hospitalization.

3.1.1 Driving forces behind Hospitals at Home

An important reason for why the HaH model has recently emerged is the steadily increasing strain on hospital capacity [2]. Sweden has, among many other countries, an ageing population, and therefore also a rise in chronic disease which strains hospital resources. In this era of continuously rising healthcare demand, the traditional hospital, which has been the primary center for complex and acute healthcare, may no longer be optimal. HaH offers an alternative to this by providing advanced medical care in the comforts of the patients' own homes.

Another reason for why the HaH is popularized is the technological advancement. New technology, such as remote monitoring and advanced medical devices allows healthcare personnel to monitor and treat patients remotely with the same precision as in the traditional hospital setting. The Covid-19 pandemic has been another key driver, accelerating the acceptance of alternative healthcare solutions. Hospital care at home minimized the number of patients in hospital, therefore limiting further virus transmission. The patients' willingness to receive care at home increased, simultaneously.

A further driving force behind the HaH is the ambition to achieve patient-centered care. In the HaH model, the patient's needs and well-being are put at the center by taking into consideration the individual's needs and preferences. Their quality of life may also increase by allowing the patient to remain in a familiar environment, allowing more independence, especially true for the elderly.

Another aspect for why HaH is emerging are economic considerations. By reducing traditional hospital admissions, the HaH model can offer significant cost savings. However, the scalability of HaH models comes with challenges, as financing the necessary elements for ensuring provision of care would come at a great cost. Costs would include development and implementation of remote monitoring technology and training of staff.

3.2 Mobile Teams

As HaH programs expand, the demand for mobile care teams is rising. Mobile care teams are multidisciplinary groups of healthcare professionals, including physicians, nurses, medical technologists, pharmacists, medical technicians and mental health professionals who bring medical care directly to patients' homes. These teams offer comprehensive expertise to address a wide range of healthcare needs, allowing patients to receive high-quality treatment in a familiar and comfortable environment.

Mobile care teams have been implemented worldwide, addressing various needs such as mental health care, humanitarian crises, remote populations, and palliative care. In 2023, the Republic of Croatia launched a project to enhance community-based mental health care [10]. Multidisciplinary teams comprising psychiatrists, nurses, social workers, peer workers, and psychologists provided biopsychosocial interventions to individuals recently discharged from psychiatric hospitals. This approach promoted faster recovery, community reintegration, and reduced the likelihood of re-hospitalization. Following its success, Croatia established a network of 30 mobile psychiatric teams in 2024.

France, on the other hand, embraced a patient-centered approach by implementing mobile palliative care teams tailored to meet patients' needs and preferences [11]. General practitioners in these teams view the provision of at-home palliative care as both a moral obligation and a testament to the value of human presence, ensuring compassionate support during critical moments.

Mobile care teams are a relatively new concept in Sweden, but some regions, such as Västra Götaland and Skåne, have already embraced the approach. In 2017, Sahlgrenska University Hospital launched an initiative to deliver in-home care for elderly patients, aiming to provide safer treatment by avoiding risks associated with hospital infections and confusion [12].

Initially, two mobile teams comprising physicians and nurses were established, one based at Mölndal Hospital and the other at Östra Hospital. By 2023, Sahlgrenska University Hospital expanded the program to ten mobile teams. Their role has evolved from primarily conducting follow-up visits after emergency department visits to performing urgent assessments and interventions directly in patients' homes. These teams now perform a wide range of services, including evaluating patients' conditions, conducting diagnostic tests, administering intravenous medications, dressing wounds, inserting access lines for fluids or nutrition, and replacing catheters or nasogastric tubes [13]. While their largest patient group is elderly patients, the scope of care has broadened to include chronically ill individuals, ensuring comprehensive support for a wider group of patients.

3.2.1 Mobile Teams at Sahlgrenska University Hospital

Study visits were conducted at Östra Hospital to observe the daily operations of the mobile teams. These observations were followed by an interview with one of the coordinators to gather detailed information about the current route planning process. The findings from the study visits and the interview are presented in this section.

The mobile teams act like an extended arm of other health care units. To become a patient of the mobile teams, a referral must come from another caregiver, such as the ambulance, the emergency department or a healthcare center. For example, the hospital could suggest early discharge of a patient who then receives follow-up visits at home by the mobile teams instead. After the first visit from the mobile teams, patients are provided with a phone number they can call if their condition worsens or if similar symptoms recur.

Currently, two coordinators are responsible for managing the mobile teams at Östra Hospital, Sahlgrenska Hospital, and Mölndals Hospital. Each morning, the teams are assigned a number of patients based on planned visits, which is visible via the booking system ELVIS. It is then up to each team to determine the most optimal route for them based on the addresses of their patients. However, as the day progresses, the coordinators must adjust these routes to address new, urgent incoming calls from SvLc which is the regional emergency call center in the Västra Götaland Region (VGR). By the end of the day, the initial planned route rarely matches the route actually followed. This is due to urgent calls being prioritized over less critical visits. High-priority cases, such as patients experiencing chest pain or difficulty breathing, are always addressed first, while less urgent issues like wound dressing, foot pain or sampling are rescheduled as needed. The teams can also contact each other by phone, in case they don't have time to visit their planned patients, to rearrange visits between the teams. It is rare that a patient that is booked does not receive a visit during the day, but the time and team assigned to the task may change during the day. The patients are told that they will receive visits from the mobile teams some time during 9 am to 3 pm, which introduces some latencies as the patients may not be alert when the mobile teams arrive.

The coordinators use a real-time map, updated via the Rakel communication system, to track the locations of the mobile teams from Östra and Sahlgrenska Hospital. However, Mölndal's mobile teams only have one Rakel unit, meaning that only one of their teams is visible on the real-time map. This system allows them to assign new cases to the teams, based on the proximity to the patients. When an urgent case arises, the coordinators analyze the map to locate the nearest available team and contact them by phone. If the team accepts, the coordinator alerts SvLc which sends the patient information via Rakel to the mobile team in question. If the team does not have time for the visit, the coordinator must continue to call other teams until they find one that is available, which is time-consuming. All assignments received in Rakel include functionality that allows mobile units to mark their arrival at the destination and indicate when their visit is complete. However, planned visits are not available in Rakel but are instead found in ELVIS. Each morning, the mobile teams check ELVIS to identify which patients to visit and then access their electronic health record (EHR) notes. These notes are printed and taken along in the mobile units to ensure the teams have the necessary information during patient visits. The mobile units also carry a computer, which is used to document the patient's visit in the EHR, either in the car or upon returning to the hospital. Information that could be valuable for other healthcare organizations such as the primary care or the home care, is documented in the system SAMSA to enable communication between organizations.

3.2.2 Rakel

Rakel, Swedish acronym for Radio Communication for Effective Leadership (RadioKommunikation för Effektiv Ledning in Swedish) is a communications system in Sweden, designed to enhance communication and improve coordination during emergencies [14]. Over 650 organizations use Rakel, including police, healthcare, emergency services and the military, but also other authorities such as the public transport authority and establishments dealing with hazardous substances.

Rakel is a digital radio network using TETRA (Terrestrial Trunked Radio), a standard for mobile radiosystems. The infrastructure behind Rakel is designed to be safe and robust, built to withstand extreme weather conditions and power outages and uses encryption to prevent unauthorized access. Communication within the Rakel network is routed through a network of fixed base stations and radio towers. This is similar to standard mobile phone network, but unlike these, Rakel allows for group communication enabling multiple users to speak and listen to each other simultaneously. Rakel is mainly used for voice communication, but is also able to control gates, send geographical positions, send text messages, among other functions and services.

4 What could a Digital Twin solution for mobile team routing look like?

Based on the workflow of the mobile teams at Sahlgrenska University Hospital and the capabilities of digital twins, a solution was developed. In short, the idea is to make use of existing communication systems and workflows while incorporating clinical suggestions into the route planning, using the real-time data currently available. By combining input from the mobile units with patient information, the DT system can provide recommendations for optimized routes. If accepted by the coordinator, these recommendations are communicated to the mobile teams via Rakel. This section presents the technical aspects of the solution, a data flow chart, a user journey illustrating the user interface of the system together with the benefits and limitations of the proposed solution.

4.1 Data flow chart & Algorithm for the DT

Figure 1 illustrates the technical components of the DT solution and the data flow between these components. The DT will receive input from five main sources, three belonging to the patient category and two belonging to the mobile units category. All planned visits and visits due to incoming calls from the patient to the coordinator during the day are booked in the booking system Elvis. The DT receives this information together with the notes from the EHR for the patient in question. The notes in the EHR are needed to include what the aim of the visit is and for the DT to be able to prioritize the visits based on the medical states of the patients. This information may also source from SvLc, sent via Rakel. The input data from this source to the DT includes personal identification number, time stamp, address of the patient, case ID and SBAR. SBAR is a clinical model for communicating in acute scenarios between healthcare instances [15]. In this case, the operators at SvLc report the situation, the background of the patient's medical history, current state of the patient and recommended actions. Moreover, the inputs originating from the mobile units are the geographical position of each unit and their status of availability. When mobile units are unavailable due to an urgent alarm, meaning that they are not available for new assignments, or when they are on break they can change their status in Rakel to unavailable. This information will be fed into the DT to not allow the DT to assign new cases to unavailable teams. By inputting all the mentioned real-time data to the DT, a virtual replica of the physical route planning system can be created, incorporating real-time changes.

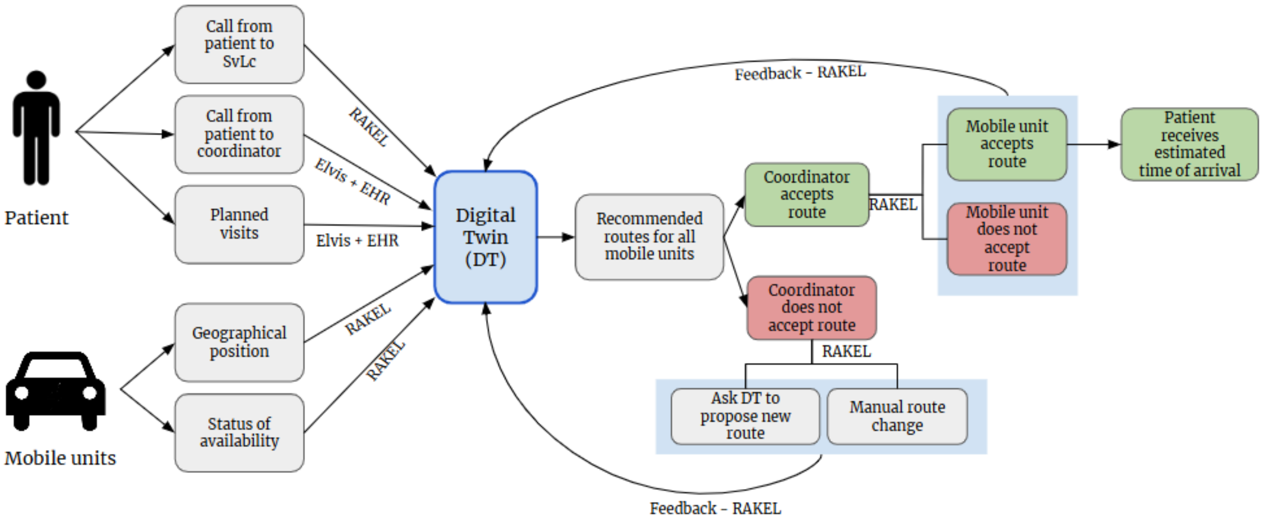


Figure 1: A flowchart illustrating the required inputs for the digital twin to generate outputs, enabling optimized digital route planning.

But it is not that easy to combine data from different sources. First of all, the problem with accessing and sharing health data is that it creates a paradox due to the nature of it [16]. On one hand, patient data is sensitive and requires high security which restrains the possibilities of data sharing. On the other hand, the inability to access patient data when needed could cause great harm to the patient, due to an incomplete understanding of the patient's needs and health, which could threaten the patient safety. This emphasizes the need for interoperability, particularly in solutions like ours where data from multiple sources should be combined. Interoperability refers to the ability of various systems to communicate, interpret, and effectively use data in a standardized manner, ensuring seamless compatibility and cooperation [16]. This is normally achieved by following technical standards which regulates the data format, the structure and content of the data and the security and privacy standards. Moreover, the solution includes the sharing of patient data securely by only using VGR's internal systems for data sharing. These systems are already configured and validated to be safe for patient data sharing via implementation of necessary authentication and authorization procedures.

FHIR (Fast Healthcare Interoperability Resources) is a relatively new standard framework for health data, and is an open-source, easy to implement standard that is being widely adopted in healthcare IT settings in the United States [16]. The adoption is also growing all over the world. Over 60% of the developed nations in the world are already using or plan to use FHIR-based systems by the end of 2024 [17]. There are currently recommendations in VGR to adapt to the FHIR system as part of digitalization [18]. It builds upon RESTful APIs which enables communication over the protocol HTTP/HTTPS [19]. RESTful APIs is an architectural style that makes use of HTTP requests to access and use data using the four methods GET, PUT, POST and DELETE. This enables reading, updating, creating and deleting of operations related to the data, for example in the EHR. This means that fetching patient data is as easy as using the HTTP GET-method, similar to interacting with a web page. Therefore, the solution in this project builds upon the principles of FHIR. FHIR supports the use of JSON and XML as data formats which means that all information that is not formatted accordingly, needs to be exported or transformed to these formats. This is possible both for Excel files and for fetching data from Rakel using API.

The input data to the DT will be structured into DataFrames, allowing efficient storage and processing. Since real-time processing is essential for dynamically adapting route planning to new patient visits, ”Structured Streaming” by Apache Spark is utilized. The Spark SQL engine processes data incrementally and continuously, updating the final results as streaming data arrives [20]. The computation is executed on the same Spark SQL engine and ”Structured Streaming” utilizes a micro-batch engine to process data streams in small batches. This results in latencies as low as 100 milliseconds with exactly-once fault-tolerance, enabling real-time processing. The input data to the DT will be text-based, therefore NLP will be used to interpret this data, similar to the Qualco Maritime Digital Twin. For instance, the model will learn to prioritize patients based on the SBAR information from Rakel.

The algorithm used for optimizing the route planning is TOA*. The TOA* algorithm is a time-efficient version of the conventional A* algorithm [21]. TOA* is mathematically expressed by the cost function, as stated in equation 1. In this context, ”cost” refers to the effort or resources required to follow a route, such as travel distance to patient or patient urgency; it does not describe the monetary expense.

$$F(n) = g(n) + h(n) \tag{1}$$

In equation 1, n is the node of the path that is considered, $F(n)$ is the total cost, $g(n)$ is the cost of the path from the starting node to n, and $h(n)$ is the heuristic function involving estimates of the cost of the cheapest path from n to the goal [21]. The algorithm calculates costs $F(n)$ by incorporating proximity to the next patient, patient priority, workload of the mobile unit, and availability of the mobile units. By analyzing the geographical position of each mobile unit and the patient's address, the algorithm determines the shortest distance between them by utilizing a map that is integrated into the system. This allows the system to identify the most efficient routes for all units, ensuring that urgent patients receive timely care from the nearest units. At the same time, it optimizes resource use by reducing travel time and fuel consumption. The algorithm will also consider the workload of each mobile unit and spread all patient visits equally across the units unless it does not endanger patient safety. TOA* supports real-time adjustments, integrating live updates including accepted new patient visits, rejected new patient visits, mobile unit availability, and manual route changes. All inputs to the DT will be weighted differently, for instance, urgent patient visits will be weighted less to reduce the function's cost. This enables TOA* to dynamically prioritize routes from less costly to most costly, ensuring efficient resource utilization and patient safety.

The DT's output will consist of a list outlining the most optimal order for patient visits. This list adapts in real-time to enable changes, such as new patient visits. The output will be presented to the coordinator, who must approve or reject the proposed route. Each route requires review by the coordinator, a Registered Nurse, to ensure patient safety. Although the system requires the supervision of one nurse, it is designed to reduce the overall burden on healthcare. By streamlining route planning, it minimizes the coordinator's workload and scale-up is possible without significantly increasing resource demands. If the coordinator rejects the DT's proposed route, they can either manually adjust the route or request a new proposal from the DT. This feedback is processed by the DT like any other input. If the coordinator approves the route, a text message is sent to the assigned mobile unit via the Rakel system. Integration with the Rakel system requires a properly configured API to send data. If the mobile unit does not approve the route on their Rakel device, this feedback is sent back to the DT via Rakel communication, prompting the DT to generate a new proposal, potentially assigning a different mobile unit. If the mobile unit accepts the route, the DT sends an SMS to the affected patients with the mobile unit's estimated time of arrival. This feature helps streamline mobile unit operations, as patients can prepare for visits in advance, reducing delays caused by factors such as waiting to be admitted into homes.

4.2 User journey

This section will present the user interface of the proposed system. The main page of the system is shown in Figure 2, where the red dots are representing the positions of the cars. The background is a movable and zoomable map of the target area for the hospital.

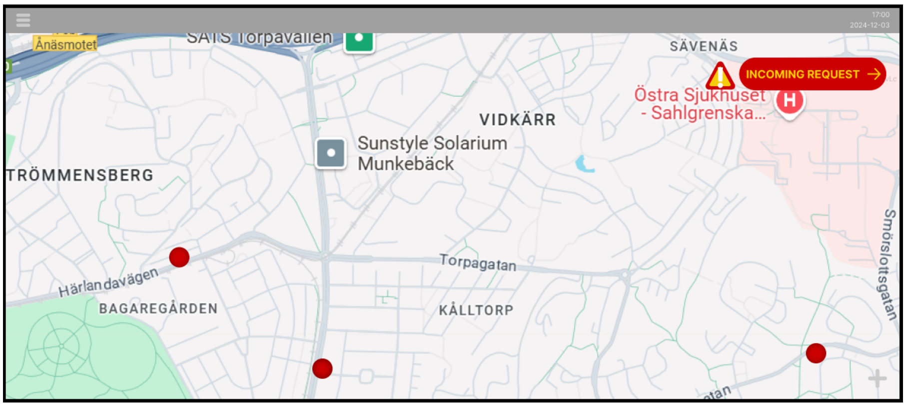


Figure 2: The main page for the proposed system.

In the top left corner of the main page, there is a hamburger menu that will enable the coordinator to directly target a specific car or a specific patient and see the details. Additionally, the teams' schedules can be found in the hamburger menu. This menu is shown in Figure 3.

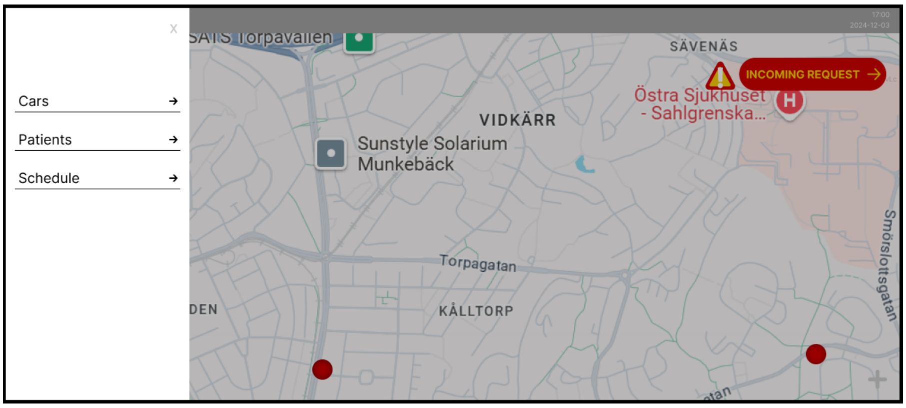
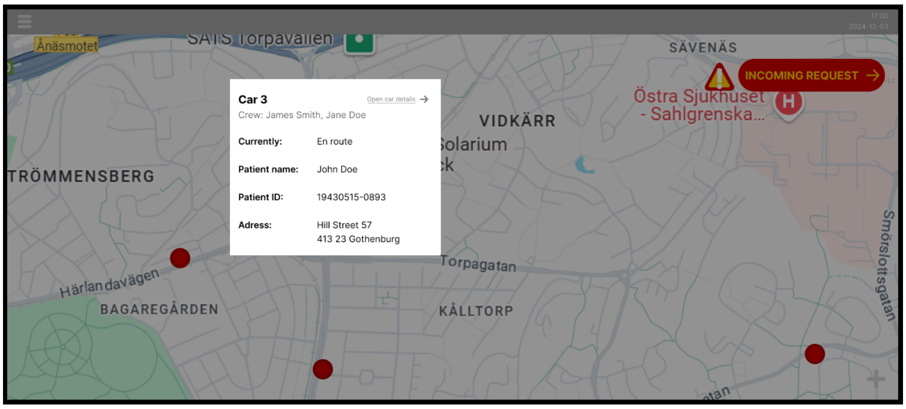


Figure 3: Hamburger menu.

While hovering one of the red dots representing a car, an overlay will appear, offering a quick look at the status of the car, shown in Figure 4.

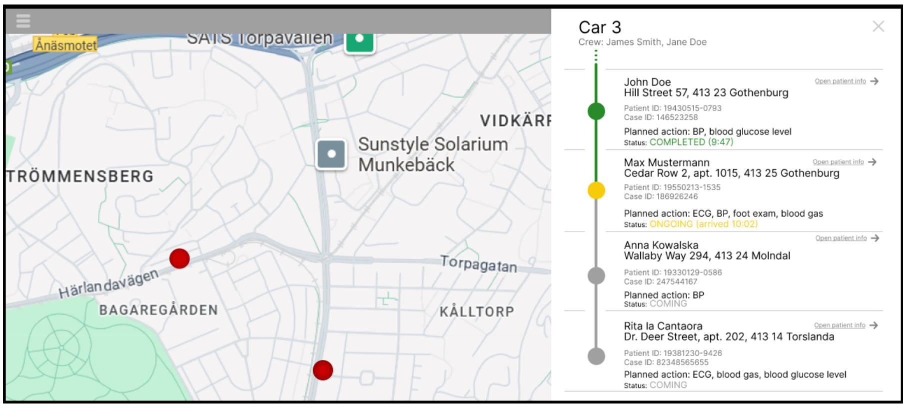


Car 3
Crew: James Smith, Jane Doe

Currently: En route
Patient name: John Doe
Patient ID: 19430515-0893
Adress: Hill Street 57
413 23 Gothenburg

Figure 4: Overlay for hovering over a car.

If further clicking on the red dot, a more detailed view of the car information will appear, shown in Figure 5. This overlay includes where the car has been as well as coming patients. A brief overview of the patient details can also be seen from this overlay.



Car 3
Crew: James Smith, Jane Doe

John Doe
Hill Street 57, 413 23 Gothenburg
Patient ID: 19430515-0793
Case ID: 146523258
Planned action: BP, blood glucose level
Status: COMPLETED (9:47)

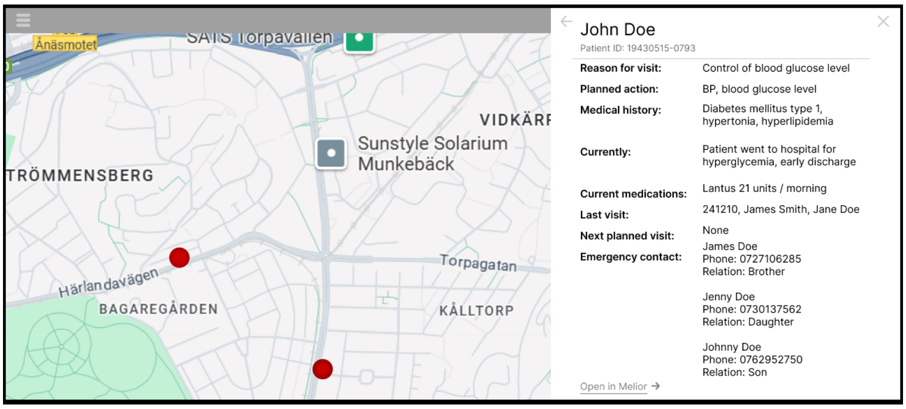
Max Mustermann
Cedar Row 2, apt. 1015, 413 25 Gothenburg
Patient ID: 19550213-1535
Case ID: 186926246
Planned action: ECG, BP, foot exam, blood gas
Status: ONGOING (arrived 10:02)

Anna Kowalska
Wallaby Way 294, 413 24 Molndal
Patient ID: 19330129-0586
Case ID: 247544167
Planned action: BP
Status: COMING

Rita la Cantaora
Dr. Deer Street, apt. 202, 413 14 Torslanda
Patient ID: 19381230-9426
Case ID: 82348565655
Planned action: ECG, blood gas, blood glucose level
Status: COMING

Figure 5: Detailed overlay for clicking on a car.

This menu also offers quick navigation to the patient details by clicking on the "Open patient info" button. This leads to more detailed information about the specific patient, shown in Figure 6. From this menu, an option will also be to open the complete patient journal in the hospital's journal system, in this case, Melior.



John Doe
Patient ID: 19430515-0793

Reason for visit:	Control of blood glucose level
Planned action:	BP, blood glucose level
Medical history:	Diabetes mellitus type 1, hypertonia, hyperlipidemia
Currently:	Patient went to hospital for hyperglycemia, early discharge
Current medications:	Lantus 21 units / morning
Last visit:	241210, James Smith, Jane Doe
Next planned visit:	None
Emergency contact:	James Doe Phone: 0727106285 Relation: Brother Jenny Doe Phone: 0730137562 Relation: Daughter Johnny Doe Phone: 0762952750 Relation: Son

Figure 6: Detailed overlay over patient information.

In the bottom right of the main page, there is an icon for entering a manual booking. This opens a menu where the coordinator enters the patient ID and planned action manually. This is shown in Figure 7.

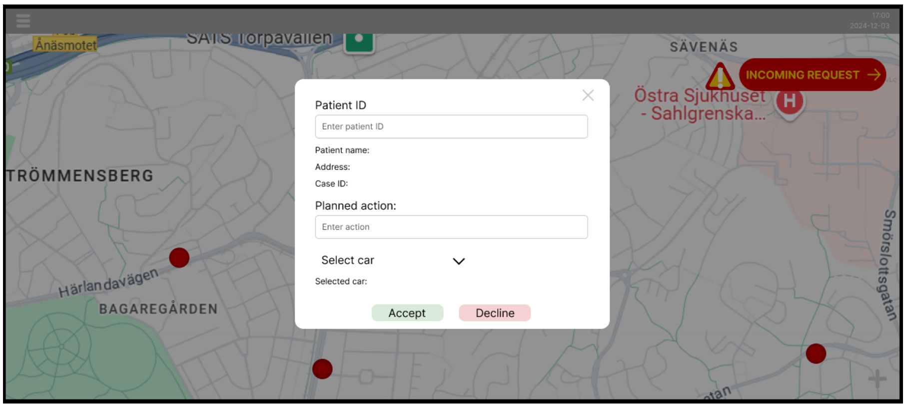
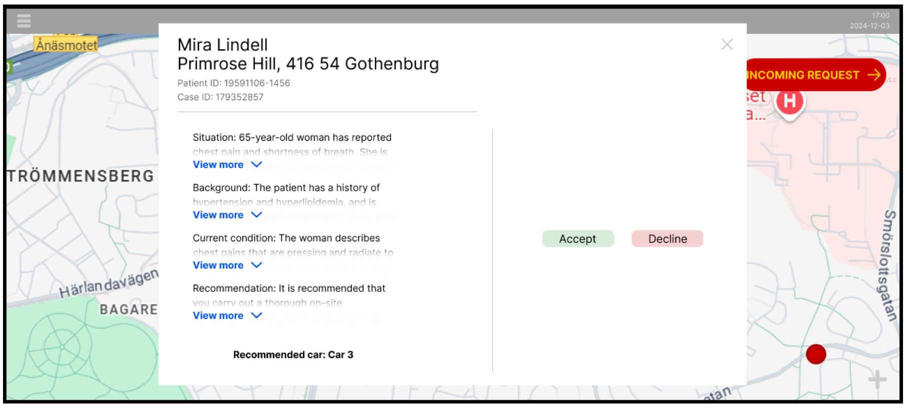


Figure 7: Menu for manual booking of patient by the coordinator.

New requests from the SvLC will first pop up as a warning on the main page in the top right corner. When clicking this, information will first appear about the patient, the condition and situation of the patient. This overlay is shown in Figure 8. From this overlay, the coordinator can choose accept the recommended car or to decline.


Mira Lindell
Primrose Hill, 416 54 Gothenburg
Patient ID: 19591106-1456
Case ID: 179352857

Situation: 65-year-old woman has reported chest pain and shortness of breath. She is

Background: The patient has a history of hypertension and hyperlipidemia, and is

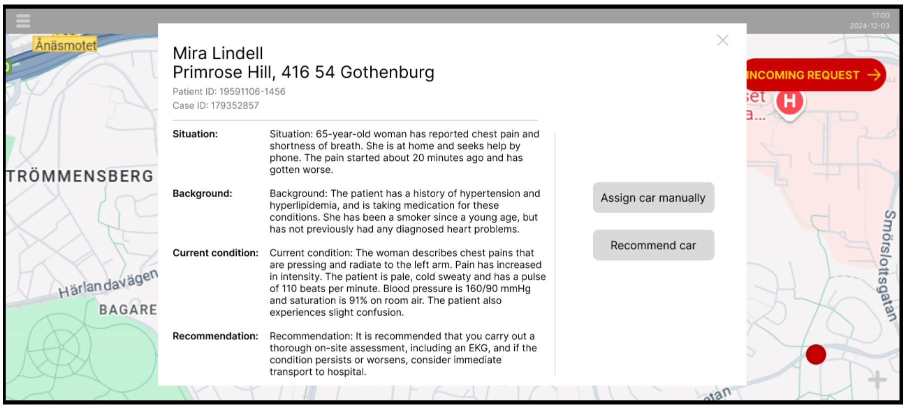
Current condition: The woman describes chest pains that are pressing and radiate to

Recommendation: It is recommended that you carry out a thorough on-site

Recommended car: Car 3

Figure 8: Overlay appearing when SvLc requests a new booking.

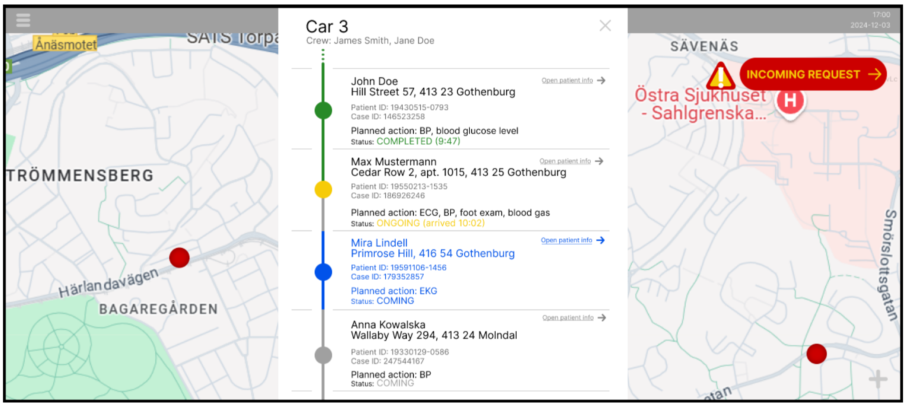
If the coordinator declines, they will get the option to manually assign a car or to ask for a new recommended car, seen in Figure 9. If choosing a car manually, the user is guided back to the same overlay as for a manual booking, shown in Figure 7.


Mira Lindell
Primrose Hill, 416 54 Gothenburg
Patient ID: 19591106-1456
Case ID: 179352857

Situation:	Situation: 65-year-old woman has reported chest pain and shortness of breath. She is at home and seeks help by phone. The pain started about 20 minutes ago and has gotten worse.
Background:	Background: The patient has a history of hypertension and hyperlipidemia, and is taking medication for these conditions. She has been a smoker since a young age, but has not previously had any diagnosed heart problems.
Current condition:	Current condition: The woman describes chest pains that are pressing and radiate to the left arm. Pain has increased in intensity. The patient is pale, cold sweaty and has a pulse of 110 beats per minute. Blood pressure is 160/90 mmHg and saturation is 91% on room air. The patient also experiences slight confusion.
Recommendation:	Recommendation: It is recommended that you carry out a thorough on-site assessment, including an EKG, and if the condition persists or worsens, consider immediate transport to hospital.

Figure 9: Overlay of alternatives after declining a recommended car.

If accepting this, a new detailed car information will appear, shown in Figure 10, with the new booking clearly visible to indicate changes in the schedule for the recommended car.



Car 3
Crew: James Smith, Jane Doe

John Doe
Hill Street 57, 413 23 Gothenburg
Patient ID: 19430515-0793
Case ID: 146523258
Planned action: BP, blood glucose level
Status: COMPLETED (9:47)

Max Mustermann
Cedar Row 2, apt. 1015, 413 25 Gothenburg
Patient ID: 19550213-1535
Case ID: 186926246
Planned action: ECG, BP, foot exam, blood gas
Status: ONGOING (arrived 10:02)

Mira Lindell
Primrose Hill, 416 54 Gothenburg
Patient ID: 19591106-1456
Case ID: 179352857
Planned action: EKG
Status: COMING

Anna Kowalska
Wallaby Way 294, 413 24 Molndal
Patient ID: 19330129-0586
Case ID: 247544167
Planned action: BP
Status: COMING

Figure 10: Overlay with the detailed car information with the changes in the schedule for the recommended car.

4.3 Benefits of the solution

The proposed solution offers several key benefits. The primary advantage is the reduction in the burden on healthcare. Rather than requiring the coordinator to manually interpret patient data, calculate distances between patients and mobile teams, and make numerous calls to the teams and SvLc, the proposed solution will streamline this process. The coordinator's role will shift to overseeing the system rather than handling these tasks directly. As previously mentioned, this will reduce the coordinator's workload and avoid a significant increase in resource demand during scale-up. Additional benefits of the system include its ability to consider multiple factors and make decisions more quickly and accurately than a human coordinator. This solution offers immense potential for maximizing the use of available patient data, thanks to the enhanced interoperability within the system. The combination of incorporating multiple factors and accessing patient data more smoothly, not only enhances patient safety but also optimizes resource use by minimizing travel time and energy consumption. By reducing waste and saving resources, more resources can be allocated to helping additional patients, improving care quality, and improving overall healthcare.

4.4 Limitations of the solution

The system has some limitations and potential for future improvement. Technically, its limitations are mainly due to safety considerations and interoperability. There is always a risk when handling patient data, and the system must comply with Swedish laws regarding patient data. This solution does not address cybersecurity, which is crucial to ensure that patient data is handled by the appropriate systems and personnel. When integrating Rakel into a system, there are also high safety demands that are not considered in this solution. Additionally, the system may risk overburdening SvLc if they receive a message in Rakel every time the system is updated. However, it is assumed that SvLc can regulate how much information they wish to receive. In terms of interoperability, the input data format for the DT requires further investigation to ensure seamless integration with other systems.

The system also has to integrate efficiently into already existing systems used today. For Västra Götalandsregionen, this means systems like Elvis that is currently used for booking, and

Melior which is used for patient journals, but also the soon implemented new journal system Millennium. As different regions across Sweden use different journal systems, the proposed system must also be able to adopt to additional infrastructure if national scaling of the hospital-at-home concept is to be successful.

The user interface for the coordinator and route planning algorithm is designed to minimize the time between the incoming message from Rakel and the personnel arriving at site at the new patient. As mentioned in subsubsection 3.2.1, it is as of now up to the coordinator to find a car that is available, sometimes needing to make several calls before being able to accept the incoming message. The proposed solution reduces this need, but the coordinator must still accept the request manually. This requires the coordinator to always be relatively vigilant and stationed at the computer in order to be able to accept. The proposed system also requires the crew manning the cars to also be conformable and accept the new request without a prior notice from the coordinator.

5 Conclusion

The proposed solution consists of a Digital Twin that uses real-time data to recommend an optimal route for the mobile teams, reducing the burden on the coordinator and implying new opportunities for healthcare. This maximizes resource utilization and enables better scalability and patient care quality. Despite challenges such as cybersecurity and data interoperability, the system's potential to improve healthcare efficiency and patient outcomes outweighs the limitations. This initiative aligns with the broader vision of patient-centered care, demonstrating how innovative technology can address the critical needs of an ageing population while mitigating resource constraints regarding mobile teams and healthcare systems as a whole.

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