Development of a Simulation Platform Addressing the Digitalization of the Stockholm Healthcare System

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Utveckling av en Simuleringsplatform som Behandlar
Digitaliseringen av Stockholms Sjukvårdssystem

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Abstract

As e-Health solutions start being integrated into the healthcare system in Stockholm County, the possibility of moving monitored patients out of the hospitals and into their homes increases. Such a change in the healthcare system could require a major redistribution of resources in order to meet possible changes in resource demands. Simulations can be used in order to understand how the healthcare system needs to adapt to handle the relocation of monitored patients. In this thesis project, a simulation platform has been designed and developed to address possible questions posed by this redesign of the healthcare system. By conducting a literary study, it was found that a discrete event- and agent based-hybrid simulation architecture could address the complexity required for such a large simulation environment by simulating across different abstraction levels. The agent based simulation component of the architecture models resources such as nurses, doctors, and patients as agents. A patient agent has a statechart which allows the patient to move between situational states and require interventions depending on a developed illness progression logic and routines. Interventions are modeled as event workflows in the discrete event simulation architecture. These cover most of the relevant interventions in a home monitored patient's life, such as nurse home visits and doctor video consultations. A communication protocol has been defined which will allow this model to communicate with a healthcare facility model. The platform implements a user interface for changing relevant input parameters, such as the amount of patients or doctors, in order to simulate different scenarios. Therefore the provided framework reduces the need for any major reprogramming between model runs. Outputs provided by simulation runs give relevant insights on patient resource usage and logistics management. A method for automatic generation of locations for patient homes and healthcare facilities on Geographic Information Systems open street maps has also been identified but not implemented. A validation process was conducted by allowing experts in the field to test the platform and give feedback on its validity and outputs. The simulation architecture provided by this thesis achieves the objective of modeling flows and resources in a further digitalized healthcare system in Stockholm County.

Keywords: Agent-Based, Discrete-Event, Healthcare, Hybrid-Simulations, Object Oriented modeling, Simulation, Home-care, Resource distribution.

Sammanfattning

I takt med att e-Health lösningar integreras i Stockholms läns sjukvård ökar möjligheten att övervaka patienter från deras hem. Ändringar i sjukvården såsom denna kan komma att kräva stora förändringar i resurshanteringen för att möta efterfrågan. Simuleringar kan ge en ökad förståelse för vilka anpassningar som krävs för att sjukvården ska klara av att övervaka fler patienter från deras hem. En plattform för simuleringar har utvecklats för att undersöka frågor som tillkommer vid den nämnda ändringen av sjukvården i Stockholms län. En litteraturstudie har utförts som pekar på att en arkitektur i kombination av "Discrete Event Simulations" och "Agent Based Simulations" kan behandla den komplexitet som kommer vid en simulering av denna storlek. I denna hybrida simuleringsplattform modelleras sjuksköterskor, doktorer och patienter som agenter. En patient har en tillståndskarta som beskriver vilka tillstånd patienten kan befinna sig i och hur dessa är sammankopplade. Utifrån rutiner och patientens sjukdomsförlopp byter patienten tillstånd och behöver ett ingripande. Ingripanden från sjukvården modelleras som diskreta händelser som täcker de flesta ingripanden som kan ske i en hemövervakad patients liv, såsom videosamtal med en doktor och hembesök från en sköterska. Ett kommunikationsprotokoll har definierats för att låta denna plattform kommunicera med en modell av vårdplatser. Ett användargränssnitt tillåter ändring av relevanta parametrar, bland annat antalet patienter och doktorer. Det innebär att olika scenarion kan undersökas utan större programmeringsinsatser. Utdata från plattformen ger relevanta insikter kring patienters resursanvändning och logistiken. En metod för automatisk placering av hem och vårdplatser på kartan i plattformen har identifierats men inte implementerats. Validering av simuleringsplattformen utfördes genom att låta experter testa den och ge sina åsikter kring trovärdigheten och graferna. Den framtagna simuleringsarkitekturen uppnår målen kring att modellera flöden och resurser i Stockholms läns sjukvårdssystem vid en ökad digitalisering i form av att övervaka fler patienter hemifrån.

Acknowledgements

List of Abbreviations

ABS - Agent Based Simulation

AD - Ambulance Dispatch

AI - Artificial Intelligence

DES - Discrete Event Simulation

EMS - Emergency Medical Service

GIS - Geographic Information Systems

JSON - JavaScript Object Notation

LBA - Level Based Architecture

MSU - Mobile Stroke Unit

SDS - System Dynamics Simulation

SLL - Stockholm County Council

Contents

1 Introduction

The healthcare system in Stockholm city is undergoing major changes. As digitalization of healthcare grows and e-Health is being integrated into healthcare workflow, Stockholm County Council (SLL) want to move the health monitoring of patients to their homes in order to improve the quality and efficiency of healthcare. Ultimately, since remote treatment and monitoring of patients will increase, it is expected that a major redistribution of resources (such as nurses and ambulances) will be required in order to meet the new demands of a digitalized healthcare system.

The recent development of smart body sensors enables relocation of monitoring to non-clinical locations (Appelboom 2014), such as the patient's home, but following the change in patient location, monitoring and a great part of the treatment workflow also has to be redistributed with the patient. To meet these new resource demands, it is possible that the form of the current healthcare system in Stockholm County needs to change. It is currently unknown what changes need to be implemented. Theories on the subject have been discussed between policy makers and researchers at the healthcare logistics department of KTH Royal Institute of Technology. A great focus has been directed towards introducing a new monitoring system of hospital infrastructure to meet the changing resource demands. Stockholm County Council also believes that a step towards meeting these demands is by building new local emergency wards in the Stockholm region. Before any major changes in the healthcare system such as infrastructure and resource distribution happen, policy makers need a clearer understanding of how these new implementations of e-Health will change the current healthcare system in Stockholm County with regards to patient-, healthcare personnel-, and ambulance flows. A way for them to acquire a better understanding and put their theories to the test is by using simulation modeling. Bliudzius et al. (2016) have conducted interviews with doctors about what impact an increase in patient home monitoring would have on healthcare and their work. According to their statistics, 75-80 percent of home monitored patients do not need regular visits to their hospital, they can instead, with proper instructions, be able to care for themselves at home using their home monitoring devices. About 10-15 percent need to visit the hospital at special occasions for consultation and only 10-5 percent need frequent hospital visits. If such numbers could be achieved by the use of patient home monitoring, doctors believe that the restructuring of the healthcare system would need to focus more on primary care instead of specialized care due to a decrease in hospital visits.

Simulations are used as a tool for analyzing complex real-world systems without interfering with the system itself. Healthcare is an area where simulations have been used for analysis on anything from an individual level, such as patient's health behaviors (S.C Brailsford 2007), to investigating questions on a larger scale such as logistics planning for emergencies (Lane and Husemann 2008). In recent years combinations of simulation approaches have been used to model patient flows and decision making together, enabling policy makers to draw conclusions in planning (Eldabi and Young 2007). No simulation models

have previously been developed which allows policy makers in Stockholm to investigate the impacts of e-Health on the healthcare system.

The purpose of this master thesis is to understand how to build a simulation platform that can be used to develop a large number of scenarios. These scenarios simulate flows of resources and services in a further digitalized healthcare system. The parameters and simulation components are to be easily adjustable to enable comparison between different scenarios and ideas of interest regarding the digitalization of healthcare. This requires an investigation of the relevant parameters and the requirements for digitalization of healthcare since the demands of patients will differ if they are monitored in their homes. Thus the simulation framework will be adjustable for different amounts of personnel and home monitored patients as well as different distributions of patient parameters. This means that scenario changes can be created without major reprogramming efforts while maintaining high usability. The platform will be created in order to have a working proof of concept for evaluation. This will be done with the purpose of, through additional work, creating a way for Stockholm County Council to ultimately get a better understanding of how digitalization will affect the Stockholm healthcare system. The research question of this thesis is:

- What simulation architecture can address the redesign of the healthcare system in Stockholm?

The objectives are:

- Conduct a literary study to understand the state of the art in this simulation paradigm.

- Design an architecture for the simulation platform.

- Implement a proof of concept in AnyLogic.

The simulation will be limited to Stockholm County, also several assumptions and simplifications will be made regarding patient flows, the structure of the system, competence and failure rates of personnel etc. This is due to limitations both in the amount of data that can be acquired and the amount of parameters that can be addressed in the short timespan of a master thesis. Assumptions and simplifications are based on the literature study.

2   Background

The literary study was conducted by performing iterative database searches using keywords relating to the research project. Literary material was mainly collected from; Google Scholar, IEEE Xplore Digital Library and Pubmed. Keywords such as; Hybrid*, Simulation*, Healthcare, Agent, Discrete, Building blocks and Composable, where used in combinations with database operators.

2.1   Simulations in Healthcare

A large part of what this thesis aims toward is understanding new scenarios in healthcare. This can be done by applying simulations in healthcare which allows for monitoring and testing of interactions and scenarios in a safe environment (Marshall 2015).

Simulations have been applied for a large amount of purposes within healthcare to analyze scenarios in order to suggest improvements and model the suggested adjustments (Raghothama 2017; Devine 2013; Katsaliaki 2011).

A requirement on simulations is that they are realistic enough so that the user can trust the model. However, due to limited resources during design, simulations cannot be made too realistic either (Günal 2010; Alinier 2011).

Simulations have been used in healthcare to monitor patient flows, waiting times, length of stay, planning for the staff, and occupancy of beds (Raghothama 2017; Günal 2010). All with the purpose of maximizing effectiveness in some aspect. Simulation models have also been applied to predict what happens if some parameter or resource is altered, patient flows have been visualized for single departments, whole hospitals, and movement between different units, and in an attempt to improve planning, several separate facilities has been modeled using the same schedule for all of them (Katsaliaki 2011; Mielczarek 2012).

2.2   Building Blocks and Composable Simulations

In simulations, a building block is a subsection of code that has internal logic which can be communicated to other blocks via carefully designed interfaces and provide a service or function to the whole simulation. The building block can be reused or it can be replaced by another block with some differing internal logic. This is done in order to model changes in the system without having to create completely new code. A building block must also be customizable to ensure that it can work as intended in the intended environment. Thus, by using building blocks the system can be divided into subparts that communicate via interfaces while the functions are hidden inside the blocks. This enables the subparts to be altered or switched out without loss of function in the simulation (Verbraeck 2002).

The concept of using interchangeable subparts is implemented when creating composable simulations. Composable simulation are created from a larger set of modules that can be combined to achieve the desired behavior and functionality. The user does not need to know exactly what is inside each module or

how they communicate with each other. However, the modules need to be completely inter-operable for this concept to work. This creates strict requirements on the interface of the modules to ensure that they can communicate properly and it also requires clear rules regarding which parts that can be combined (Kasputis 2000).

The final goal of the research conducted by this project, aims to build a platform where parameters and scenarios can be changed without massive efforts. These principles of coding can be used as a way to provide easy customization. This enables a simulation to be used as a way of analyzing the result of different ideas (Kasputis 2000).

2.3   Modeling Methods

Simulation modeling provides a possibility for stakeholders to improve their understanding of certain issues (Katsaliaki 2011). This can provide new insight on how parameters are related and of the system performance. Discrete event simulations (DES), system dynamics simulations (SDS) and agent based simulations (ABS) are three approaches in simulation modeling that have been used for different areas depending on the complexity of the system or situation to be modeled (Katsaliaki 2011). They each serve a certain range in level of abstraction. ABS and DES have frequently been used to model a variety of healthcare systems. To study problems of high abstraction levels, system dynamics models have proven to be useful, while agent based simulations have proven to be better when analyzing problems at a more detailed individual level (Djanatilev et al. 2012). ABS have most commonly been used for interactions between autonomous agents, where an agent moves through a series of states. It allows for assuming medium to low abstraction where the agents, such as ambulances or patients, can influence each others behavior by interacting and choosing a course of action (Aringhieri 2010). For example, in an ambulance service model, an ABS approach allow ambulance agents to make decisions about which location patients should be treated, or choose the most appropriate route to their destination (Anagnostou et al. 2013).

Discrete event simulation modeling allow states and variables to change after events at discrete time points. Such events are triggered at a rate, either after a time interval has elapsed or if conditions are met. DES give a process oriented world view where system processes traverse by resource usage. Entities using resources do not possess behavioral functions and therefore do not contribute to system decision making (Djanatilev et al. 2013a). Planning of services using DES enables assessment and investigation of the effectiveness and complex relations between variables, allowing identification of bottlenecks in healthcare system workflows. Thus, simulations can be used to compare different approaches or policies that aim to improve some aspect of health care systems (Katsaliaki 2011; Mielczarek 2012).

2.4 Hybrid Simulations

Modeling large scale simulations for healthcare applications can be complex and a single modeling technique might not be sufficient to adress certain problems. Therefore, multi-paradigm simulation techniques, combining modeling methods as the ones mentioned before, have been developed to address large scale problems (Viana 2014). Such simulation techniques, also called hybrid-simulations, enable multiple approaches to be combined in the same simulation environment, allowing simulations to run across different abstraction levels (Djanatilev et al. 2013b). AnyLogic (AnyLogic 2017) is a software package allowing multi-paradigm modeling in one common tool.

Aringeri (2010) presents a hybrid DES-ABS model for emergency medical service (EMS) management where a DES was used for modeling the workflows in the EMS management, allowing the identification of bottlenecks and system resource demands. To model ambulance movement within a specific area, ABS was used, which allowed for knowing where an ambulance is at any given time. It was composed of two agents, the operation center and the ambulance. The simulation was built in AnyLogic which allows for integration between ABS and DES models. Instead of using simple delay blocks representing ambulance movement in the DES model, the DES model receives a signal from the ABS model when an ambulance has reached its destination, before moving to the next block. OpenMap Geographic Information Systems (GIS) was used for computing distances and visualising movement. In this model Aringeri (2010) introduced a concept of smart ambulances which allows the Operation Centre to assign new missions to ambulances while they are already on the move. Such a concept allows policy makers of ambulance management to better understand the impact of a GPS tracking system on ambulance efficiency.

Djanatilev et al. (2012) showed with their ProHTA model that hybrid simulations can be used to solve two types of questions in healthcare. What-if questions can be investigated for new technologies and system changes and how-to questions can be answered to understand the process of reaching a desired result. Djanatilev et al. (2013a) demonstrate how what-if questions can be analyzed by modeling a Mobile Stroke Unit (MSU) dispatch system. MSU dispatches were modeled, and positioning tools were used to answer how MSU distribution could optimize efficiency. What-if questions are asked for these types of innovations, thus, model output metrics must be analyzed to understand and optimize function.

Djanatilev et al. (2013b) argue that to create large scale simulations of complex healthcare systems, it is important to use a Level Based Architecture (LBA) to reduce complexity by hiding information using black box modeling. This means that the user only gets to see an interface and not the underlying logic behind the model architecture. In their large-scale hybrid models, architectural aspects are considered using virtual connections between modules. With LBA they introduce a centralized inter-module architecture using a main controller as a central component. Modules implementing, for example, population dynamics or disease dynamics, are directly connected to the main

controller which defines a set of input data objects. Modules implement an interface which allows them to send a reference of themselves to the main controller when they have received all input values. They further stress that hiding complexity and achieving sustainability are requirements for large scale simulations, thus modularization and information hiding should be incorporated. By dividing a simulation into many interconnected modules, the domain-focused modeling enables experts to analyze the ones that they have expertise in.

3   Simulation platform

This section explains what types of locations and agents (for example patients and doctors) are modeled, what the platform can do, how it works, and how the agent based and discrete event parts of the model interact, as well as how the user interface allows the user to change parameters before a simulation run. Some methods to increase automation of the platform that were investigated but not fully implemented are also presented in this section. Lastly, the communication protocol that is intended to allow this platform to communicate with a healthcare facility model is explained.

Articles gathered in the literature study were studied in order to get a better understanding of the healthcare systems resource demands and usage in regards to home care and e-Health. The gathered information was then used to map out a series of sequence diagrams of the communication between the different actors and resources that are involved in the healthcare workflows. Mainly those occurring outside healthcare facility grounds, connecting home care patients to the facilities, were mapped. Some of the conceptually modeled actors involved were; home care patients, personalized doctors, home care nurses, and ambulances. Most of the scenarios were based on patient illness progressions and routine home care situations. As digitalization of healthcare increasingly enables efficient patient data transfer to patient doctors, a concept of "smart patient monitoring" is assumed to be implemented in the simulation. This means that the monitoring technology allows direct resource allocation and patient data transfer for real time health-journal updating. In the platform, this enables patients to automatically get clear information about their condition and, if needed, instructions on which actions to take. Different scenarios could inform the patient that a video meeting has been booked with a doctor or that they need to visit a specific hospital that can meet their needs. In cases of acute illness progression, the monitoring technology can directly communicate with ambulance dispatch systems. This function was introduced as a concept to allow investigation of e-Health:s impact on the healthcare system.

AnyLogic 7.3.6 was used to build a simulation platform in order to model the different actors and workflows defined in the collection of sequence diagrams. An agent based method was used to model home care patients and a discrete event method was used to model workflows involving the specified agents and resource pools. The two parts were connected creating a hybrid simulation framework where the two parts of the architecture communicate by interchanging messages and functions.

3.1   Platform Agents, Resources, and Facilities

This subsection introduces the different components modeled by the framework.

The components are: patients, nurses, doctors, ambulances, nurse dispatch locations, patient homes, and healthcare facilities.

Patients are modeled as agents with a statechart, see section 3.3 and figure 1. They are initially placed in the location of a patient home. The nurses, doctors and ambulances are modeled as agents without statecharts that are added to resource pools. Doctors do not have a designated location since a video conference could be held from anywhere. Nurses are placed in nurse dispatch locations and ambulances in hospitals. Hospitals are one type of healthcare facility. Other types are not shown during a simulation run. When patients travel by themselves to a healthcare facility, travel time is not measured and therefore their movement is not modeled, these visits are represented as a state that a patient can be in. Homes, hospitals, and nurse dispatch locations are modeled as empty agents that are added to collections of each type. These are placed at predetermined locations. The simulation platform provides a map showing all locations of homes and healthcare facilities, it also shows nurse and ambulance movements between homes and healthcare facilities.

3.1.1 User Interface

Before running the model the user is allowed to change the number of patients, doctors, nurses, and medical healthcare facilities, this includes both amount of hospitals and nurse dispatch locations. The user is also allowed to change the number of patients during simulation run-time.

The amount of patients for each municipality can be changed before a run. However, during a run, only the total amount of patients can be altered. A reduction in the amount is done by removing one patient from a randomly chosen home location out of all the ones that exist. If patients are added, one patient is added to the same location as a random one that already exists. Either of these are repeated until the new chosen amount of patients is reached.

A function to alter the amount of doctors during a simulation run has been created, however it is not used currently. The intention is to let the healthcare facility model control the amount of doctors by using this function.

3.2 Platform Function and Logic

As time passes during a simulation, the patient's illness progresses. This can be for better or for worse, with the average across all patients being a worsening. To avoid and deal with this progression, the patients receive healthcare interventions, both routine interventions and extra ones when the illness progresses in some manner. The progression is further explained in the subsection below, 3.2.1. The interventions are initiated by the patient changing state in their state chart, see figure 1 below. A state change is triggered due to either routines at a certain rate, or by illness progression. The new state sends the patient to the DES part of the model where it passes through a defined workflow, see figure 2-6, while allocating resources from the healthcare system. The patient is then sent back to the ABS part and changes state again, either to its original state or to a a different one.

3.2.1 Illness Dynamics

The illness progression of a patient and choice of intervention is handled by two parameters correlating to the severity of the patients illness (*illnessSeverity*) and an intervention parameter (*illnessIntervention*). Severity determines the progression of the illness and correlates to how sick a patient is. The intervention parameter determines which intervention is needed. Both parameters change over time with a certain degree of randomness. A patient's severity gets worse over time, a higher severity causes the intervention parameter to rise faster. When the intervention parameter reaches certain intervals, an intervention is instigated. When an intervention is performed, both values (severity and intervention) are altered with a certain distribution. The average alteration the values are negative, resulting in a lower, improved, value. The amount of change differs depending on the intervention. For example, it is assumed that a hospital visit would benefit a patient more than a video consultation. This means that a hospital visit, on average, lowers the values of intervention and severity for a patient more than a video consultation does. However, higher intervention values are required to get a hospital visit than a video consultation.

3.2.2 Cost Calculations

The interventions with tracked costs are video consultations, nurse home visits and ambulance dispatches. The consultations and home visits are given an hourly cost while ambulance dispatches are given a cost per instance, due to lack of validated data. All of these are tracked by time or number of instances for each patient. Equipment costs are tracked by adding a cost to each patient based on their condition, if the severity increases, the cost is increased. Three levels of these equipment costs are assumed, a base cost and two possible additions. This is intended to correlate to additional equipment added to the patient's home. However, the equipment cost is not lowered or removed if the patient's severity is lowered, it is only removed upon permanent hospitalization or death. This can only occur when a patient has a very high value of both severity and intervention. These costs are shown as outputs. Other provided outputs are certain waiting times and the distribution of the parameters for illness severity and intervention, see section 4.
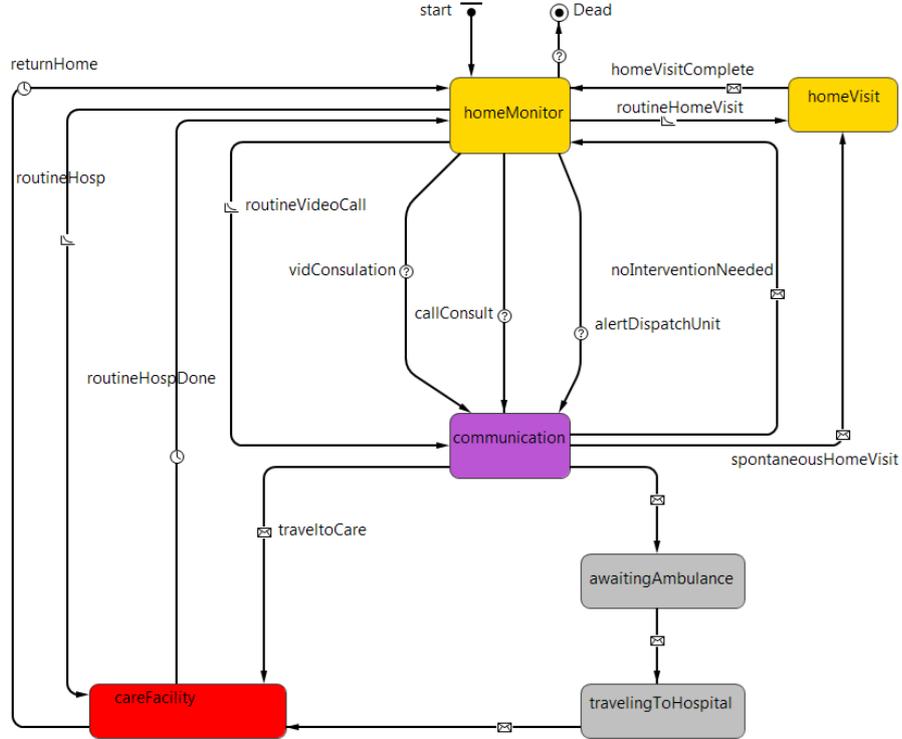
3.3 ABS architecture

Figure 1: State chart of a home monitored patient including all states and transitions.

The default state of a patient is the *homeMonitor* state, this is the state of the patient when no intervention is currently on-going. A patient has routine checks that include home visits by a nurse, video consultations with a doctor and healthcare facility visits. The transition from the *homeMonitor* state to either of these are triggered by a rate that depends on the illness severity parameter mentioned earlier.

All other interventions that occur, those that are not routines, occur due to an update in illness intervention that changes the value into an interval corresponding to a certain intervention. These possible spontaneous interventions are: call consultation with a nurse, extra video consultation with doctor, home visit, healthcare facility visit, and hospital visit via ambulance (for detailed descriptions, see chapter 3.4).

When a non-routine visit to a healthcare facility is needed, the patient will first go through either a call consultation with a nurse or a video consultation with a doctor, the patient is then sent to the healthcare facility from there, see the different exit routes in the DES part of the platform, section 3.4. The same applies for a home visit by a nurse, the patient will first have a video

consultation with a doctor and then get the home visit.

When the patient agent enters the home visit state, it is sent to the DES part of the hybrid platform and enters a workflow, see figure 3. When the home visit is done, the person is sent back to the *homeMonitor* state from the *homeVisit* state via a message from the workflow. This works in the same way regardless of whether it was a routine or not.

When a home visit is not due to routine, it means that the illness intervention parameter has changed and is now within the interval corresponding to a home visit. When that happens, the patient transitions from the *homeMonitor* state into the *communication* state via the transition *vidConsultation*. In communication, the patient is sent to the workflow representing a video consultation with a doctor, see figure 2. The result from the workflow is a message sending the patient to the transition called *spontaneousHomeVisit* and the patient is transferred to the *homeVisit* state where the same thing as in the routine home visit happens.

The illness intervention parameter can also change to an interval corresponding to solely an extra video consultation with a doctor. Then the same transition, *vidConsultation*, is used to get to the *communication* state. From there, the same thing happens as for the extra home visit except that the resulting message from the workflow sends the patient to the transition *noInterventionNeeded* instead. The patient then returns to the *homeMonitor* state. The routine video consultations play out in the same manner as the extra ones except that it is, as mentioned earlier, triggered at a certain rate and the transition from *homeMonitor* to *communication* goes via the transition called *routineVideoCall*.

When a call to a nurse is needed the patient is sent to the *communication* state via the transition *callConsult* and is then sent to the corresponding workflow, see figure 6. The result is determined before the intervention start. This is done by a function either setting a variable to true or false depending on the illness intervention parameter. This variable then decides the outcome of the workflow. Either the workflow sends the patient to the transition *noInterventionNeeded* and back to the *homeMonitor* state or to *travelToCare* and to the state *careFacility*, then after a timeout in the *careFacility* state, the patient is transitioned back to *homeMonitor* via *returnHome*. The same transition from *communication* to the healthcare facility and home can be taken via a video consultation with a doctor. The difference being in the value of illness intervention, the transition to *communication* is *vidConsultation*, and the workflow that the patient is sent to.

When an ambulance is needed, the transition *alertDispatchUnit* is taken to the *communication* state. There the patient is sent to the workflow for contacting the ambulance dispatch unit, see figure 5. The result is either that an ambulance is not needed and the patient is sent back to *homeMonitor* via *noInterventionNeeded* or that an ambulance is dispatched. The patient then goes through a transition to the *awaitingAmbulance* state and is sent to a new workflow, see figure 4. This decision is intended to be handled by the healthcare facility model later on, now it is set to certain percentage chance for each of the two outcomes. When an ambulance picks up the patient it is transferred to

the *travelingToHospital* state and when the ambulance arrives at the hospital the patient is transferred to the *careFacility* state. It experiences the same timeout as the other healthcare facility visits before being transferred back to *homeMonitor*. The healthcare facilities are not intended to be handled by this model, in the future, when entering this state, the patient should be sent into the other model and after the appropriate amount of time according to that model, sent back. That is why the same timeout for a healthcare facility visit is used for every patient, regardless of situation.

3.4   DES architecture

The workflows and resource usage connected to home monitored patients has been modeled in the discrete event part of the architecture. Separate flows model a certain workflow in the home monitored patients day to day lives. Each workflow is described below.

Doctor video consultation is illustrated in figure 2 and is modeled using chained discrete events. As described in the previous section, depending on a patients illness severity and illness intervention values, the patient will be sent to the DES side of the platform to enter a process of intervention. In this case a patient either needs a spontaneous or routine video consultation with a doctor. The patient enters the workflow in the *needVideoConsultation* starting event and immediately moves on to seize an available doctor (*siezeDoctor* event) from the doctor resource pool. If there are no available doctors at the time of entry, the patient will stay in this event until the doctor resource pool has an available doctor. When a doctor is seized, a video meeting is held in form of a time delay. The length of the delay correlates to a distribution based on the patient's illness severity. The doctor is then released and the patient moves on to *DoctorDecision*. Depending on the patients illness severity and intervention value, the patient will either be returned to the *homeMonitor* state in the agent based model through the *toHomeCare* event or move on to the next decision (*DoctorDecision2*). Again, depending on patient status, the patient will either be sent to the *careFacility* state or get a nurse home visit.
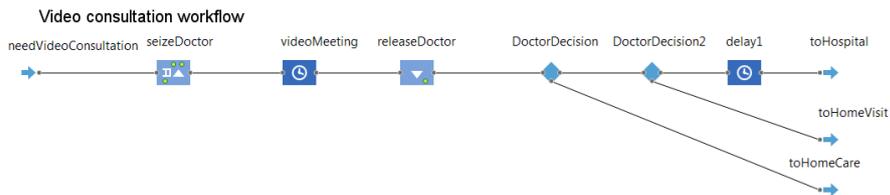

Figure 2: Video consultation workflow.

In the nurse home visit workflow illustrated in figure 3, a patient is first sent to the *homeVisit* event from the agent based model and immediately moves to the *sendNurse* event to seize a nurse resource from the closest nurse dispatch

location. If no nurses are currently available in that location, the patient will wait until there is an available nurse correlated to that dispatch location and then seize the nurse directly from the location of the patient the nurse completed a home visit at. At the same time as a nurse is seized, a nurse enters *homeNurseStart* and then travels from the current location to the patient's home location. The home visit is simulated as a time delay depending on the patient's illness severity. Next, the patient is sent back to the *homeMonitor* state in the agent based model and the nurse either travels back to its dispatch location or to a new patient location. This depends on whether there is a queue or not.

Figure 3: Nurse home visit workflow.

Figure 4 illustrates the ambulance dispatch (AD) workflow. The AD workflow is modeled in the same manner as the nurse home visit workflow. The difference being that ambulances always return to their starting position, which is a hospital, simulating a patient requesting an ambulance from the closest hospital and transportation to it. After the ambulance resource is released, the ambulance task ends and the patient is sent to the *careFacility* state in the agent based part of the model.
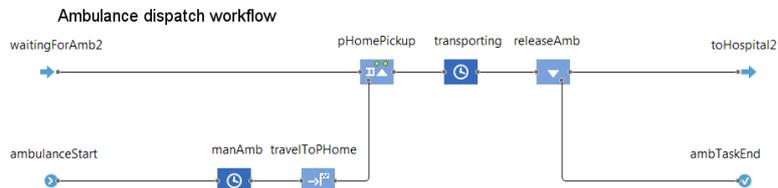

Figure 4: Ambulance dispatch workflow.

Emergency consultations are modeled in the discrete event part of the model as illustrated below in figure 5. The workflow represents both emergency calls executed by patients and emergency alerts sent to ambulance dispatches through artificial intelligence (AI)-monitoring systems in the home patient's home. Patients are sent from the *communication* state in the agent based model to the *emergencyConsulation* event in the discrete event model. The patient immediately enters a time short time delay representing communication with the emergency dispatch center. Depending on a random distribution, the patient will either be sent to the *homeMonitor* state in the agent based model, representing a false alarm, or be sent to the ambulance dispatch workflow.
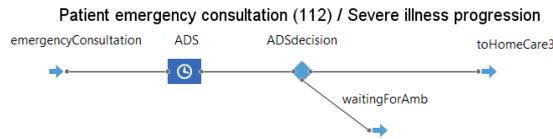
Figure 5: Emergency consultation/alert workflow.

Patient consultation services are simulated in a similar way, as illustrated in figure 6, entering a short time delay and then a decision if the patient will be sent back to the *homeMonitor* state or to the *careFacility* state.
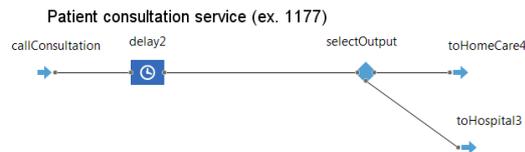

Figure 6: Health consultation service workflow.

3.5   Investigating Automatic Distribution of GIS Locations

This section explains identified (non-implemented) methods to provide additional automation of the model.

It was sought to make the model more flexible by sending a query to openstreetmaps to receive the location of all healthcare centers of interest. A way to automatically query and add the location of all locations with the tag "hospital" within a chosen boundingbox was found. This was done by sending a query to nominatim openstreetmaps and extract address information from the JavaScript Object Notation (JSON) format response. However, the intent of only using the five largest hospitals in Stockholm County did not succeed via nominatim openstreetmaps. Additional tags on the hospitals was found in the regular openstreetmap website, all of the five larger hospitals had, among other tags, the tag of "surgery". Differentiating care locations with the help of these tags could enable the intended automation. All of the municipalities specified, such as "Huddinge" and "Danderyd" can also be found in openstreetmaps and could possibly be queried in the same manner. However, sending a query to anywhere other than nominatim openstreetmaps was not performed since the code handling the query from nominatim openstreetmaps was found on Anylogic's website and only slightly altered, it was not created by us. Thus, due to lack of time, this was not further investigated. To make the patient locations more realistic, a point can be set at a random location within a chosen region. This causes the risk of placing patients in water or other undesired areas. It was found that reverse geocoding can be performed using Mapquest, this can take a point with coordinates and send back, for example, the closest address. In this manner, placing patients in undesired location could possibly be avoided. This was not implemented due to the limited time frame of the thesis.

3.6   Platform-Healthcare Facility Communication Protocol

The developed framework does not handle what happens between the time when a patient arrives at a hospital and the time of release. The framework is made to communicate with another model, which is a model of a healthcare facility. When a patient arrives at a healthcare facility it is sent to that model through a communication protocol written in Java. The protocol was defined as part of this thesis, but the implementation of the communication and complete design of the healthcare facility model is done by a research engineer at the healthcare logistics department at KTH Royal Institute of Technology.

The functions used for communication between the model for healthcare facility platform and the platform created during this thesis, allows for the following: sending a request from a patient in this framework to the healthcare facility model, getting the available resource capacity from the facility model, the facility model can order a patient to return home from a healthcare facility, and the facility model can contact a patient.

The function that sends a request has an attribute connected to it that decides what type of request is sent by a patient to the healthcare facility model. The different types of requests are: nurse home visit, video consultation, ambulance dispatch, healthcare facility visit, and a cancel request.

As mentioned earlier, it is intended that the amount of resources, for example doctors, should be handled by the healthcare facility model. The function that gets the available capacity can then allow the size of the resource pools to be altered.

When a visit to a healthcare facility is finished, the facility model will order a patient to return home from the healthcare facility, this will be done with the mentioned function.

Finally, the healthcare facility model will be able to call a patient for the video consultations with a doctor or call consultations with a nurse. This meaning that the initiation of a video consultation or call consultation can be done by the healthcare facility model instead of directly when the required resource is unallocated.

4   Outputs

It is possible to extract a lot of outputs from the simulation platform. This section presents the output graphs currently provided. It needs to be pointed out that the intended result is the platforms ability to provide these outputs, not the actual values shown, the data used has not been validated and is sensitive to input settings.

Figure 7 shows the distribution of the illness severity parameter for the patients where 8 is the highest possible value. Letting the model run for a few weeks of more, in model time, causes a large amount of patients to get the highest possible value, see figure 8.
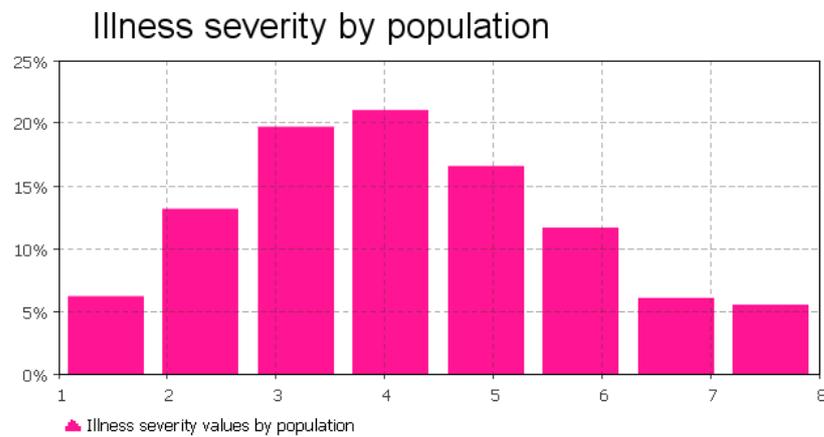

Figure 7: Patient population distribution of illnessSeverity values after 1 week model run time. The y-axis indicates population percentage and the x-axis indicates value.
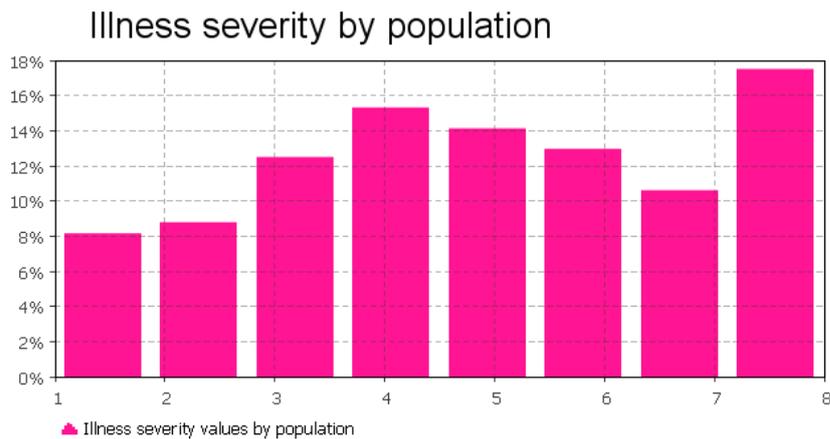

Figure 8: Patient population distribution of illnessSeverity values after 4 weeks

of model run time. The y-axis indicates population percentage and the x-axis indicates value.

Below is an illustration of the distribution of the intervention parameter that decides the needed intervention. This distribution has the same appearance over at least 2 months in model time, longer time periods than that has not been tested.
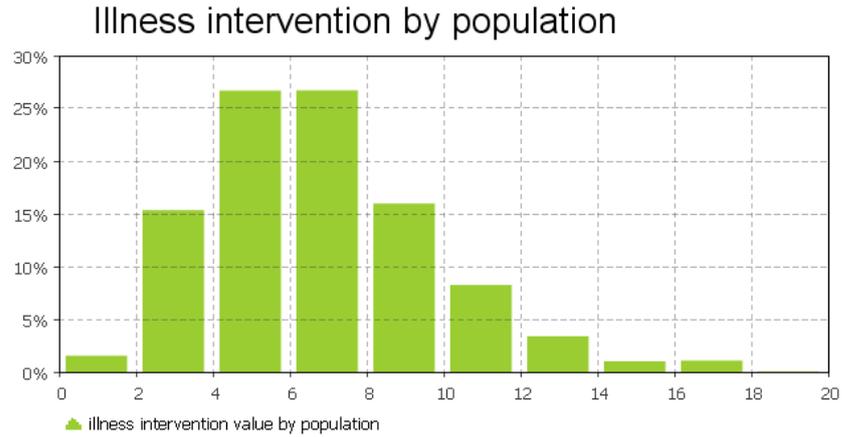
Figure 9: Patient population distribution of illnesIntervention values. The y-axis indicates population percentage and the x-axis indicates value.

Figure 10 displays time spent with the patients in a home visit by a nurse, this would represent the time that actual tasks are performed concerning the patient during the visit.

Figure 10: Nurse home visit times. The y-axis indicates population percentage and the x-axis is time in minutes. The thin line indicates the average value.

The figure below shows the distribution of waiting times for a nurse home visit in minutes. This correlates to the time between the rise of the for a home visit and the time a nurse arrives at the patient and begins the home visit.

Waiting times for nurse home visits
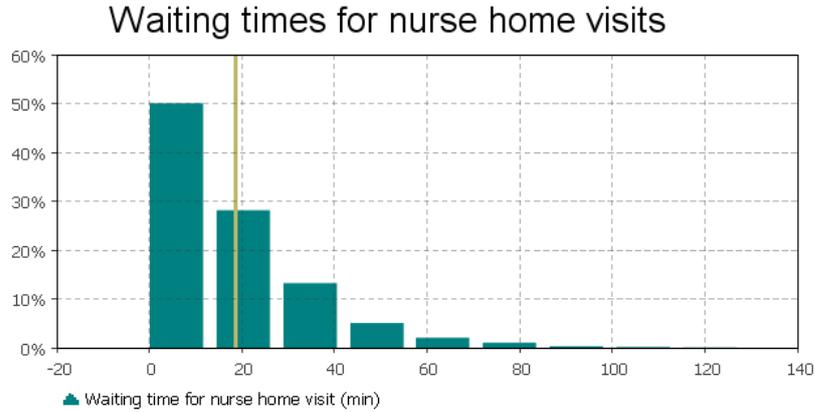
Figure 11: Nurse home visit waiting times. The y-axis indicates percentage of all home visits performed at the time during a simulation run and the x-axis is time in minutes. The thin yellow line indicates the average waiting time.

Figure 12 shows the time doctors spend in each video consultation meeting, this time is the actual video meeting plus 5 min extra per occasion for additional tasks connected to the meeting, paperwork could be one example.
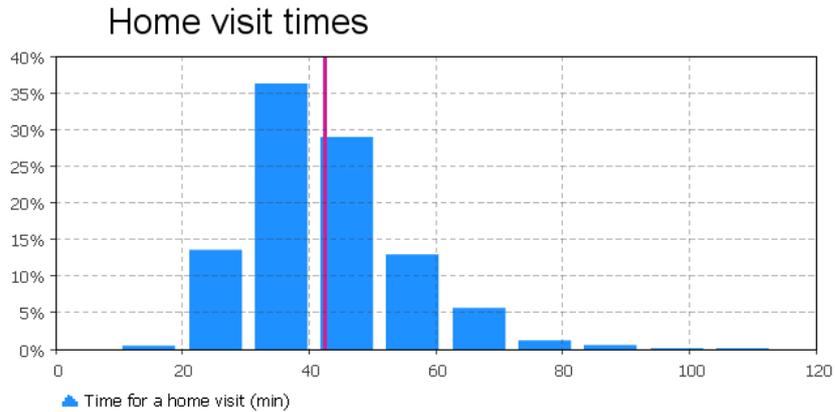
Video consultation times
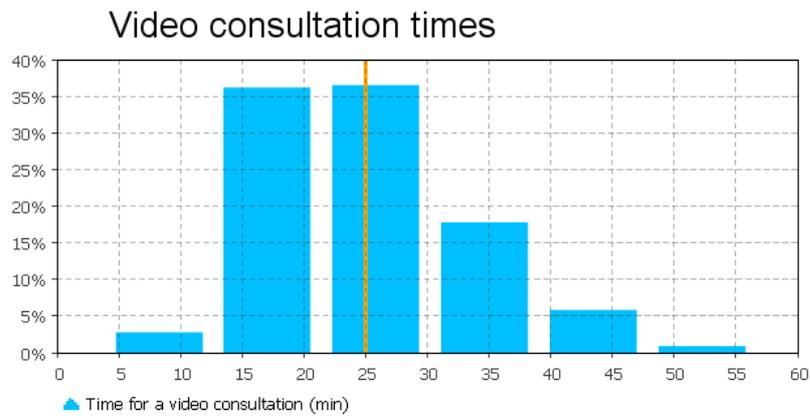
Figure 12: Doctor video consultation times. The y-axis indicates population percentage and the x-axis is time in minutes. The thin line indicates the average value.

The following graph shows how long patients waits from the time when

they need a video consultation with a doctor and the time before it starts. This illustrates both routine- and spontaneous video consultations.
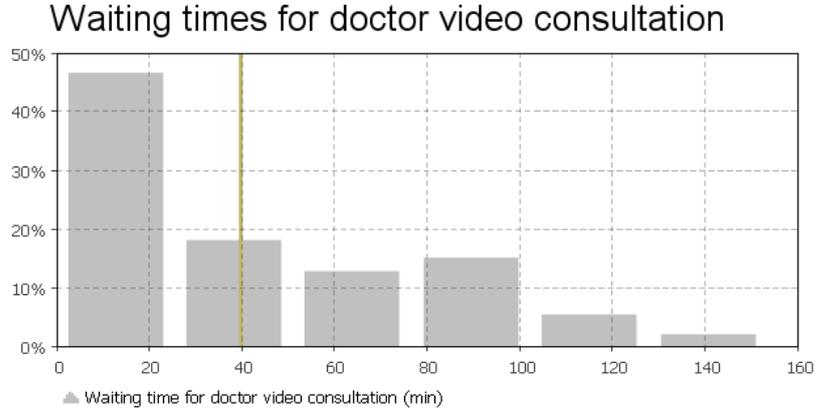
Figure 13: Distribution of time between the request for a video consultation and the start of it. The thin line indicates the average value.

Figure 14 shows the time from when the need of an ambulance arises until it arrives and picks up the patient. This includes time to man the ambulance and the travel time from a hospital to the patient. Queue time would be included if very few ambulances were available.
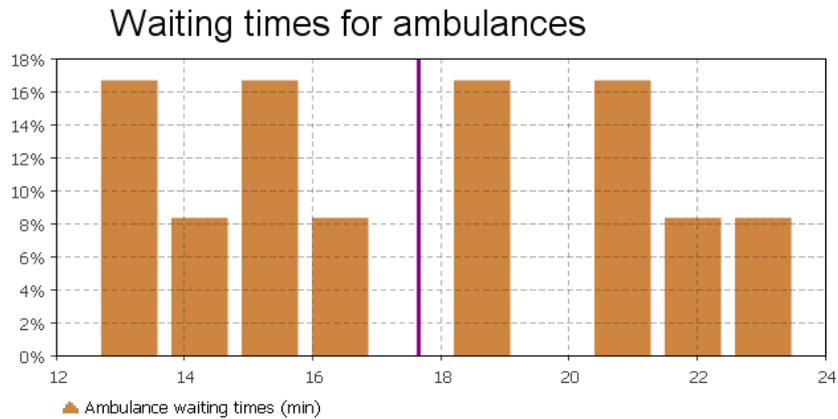
Figure 14: Distribution of time between a request for an ambulance and the arrival. The thin line indicates the average value.

Another available output is the cost of the interventions, in Figure 15 it is illustrated as a weekly cost per patient per type of intervention in SEK. With the current inputs the cost of video consultation is always the highest one regardless of the settings chosen that is allowed to be changed in the interface. The same

can be said about ambulances being the least expensive intervention over time.
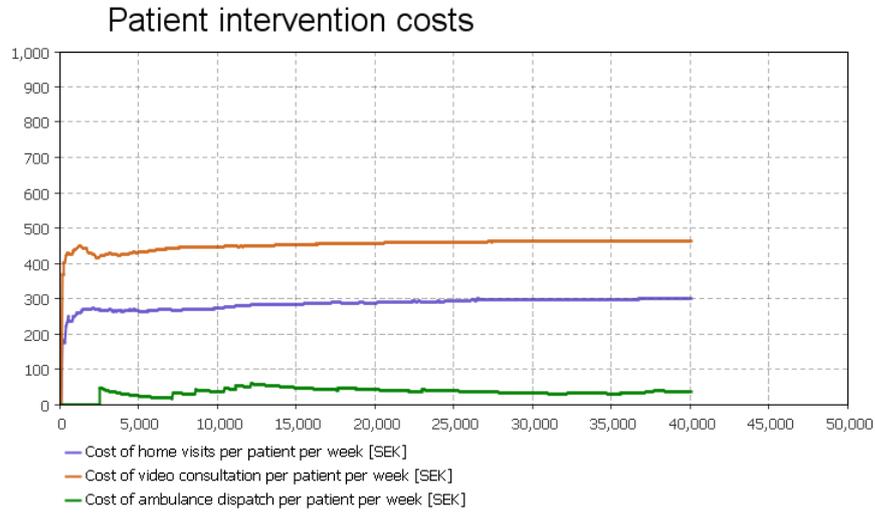
Figure 15: Cost in SEK per patient per week of home visits, video consultations and ambulance dispatches. The x-axis displays time past in the model in minutes, y-axis displays cost.

The following figure shows the distribution of patients with equipment from the three different levels mentioned in section 3. A very small amount has the cost of 0 SEK. This represents the patients that have either died or been permanently hospitalized, thus having their equipment withdrawn since the equipment can be used elsewhere.
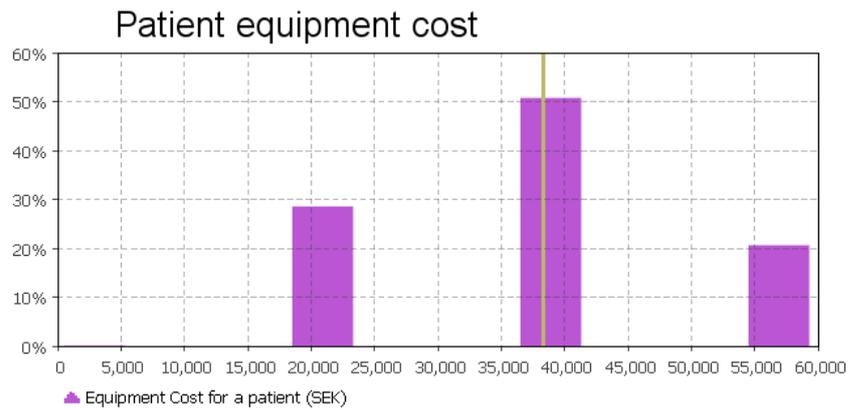
Figure 16: Distribution of equipment cost in SEK for home monitored patients. The thin line indicates the average value.

Parameters can be changed between runs and these outputs can be compared. All the outputs can be affected by changing the input except for the following: equipment cost, and the time in video consultation and home visits. These are not affected by locations or patient to resource (ambulances and personnel) ratio. Changes in waiting times can be observed during a run as well by changing the amount of patients. If resource usage is close to 100 percent and the user choose to reduce the amount of patients, a reduction in waiting times for the intervention correlating to the resource with high usage is observed.

5   Validation

This section explains how the validation was performed. Resulting feedback and expert opinions received concerning the simulation platform and its validity are presented in the subsections below. Each subsection represents the question categories from the validation questionnaire (A.1).

5.1   Validation Process

Validation was performed by gaining experts' opinions of the model since there are no real results to compare with. A pilot session was held to obtain feedback on the validation itself. In total seven sessions, including the pilot session, were held with one expert each time. Since no significant changes were made after the pilot session, the results from that session are included. The platform features and functions were explained and presented, then the expert could ask questions and was allowed to change the input parameters and run simulations. The validation was concluded by asking each expert to fill out a questionnaire (see A.1). Due to the limited time frame of this thesis and limited resources, only seven experts were able to participate in the validation process.

Table 1: Summary of likert scale results from validation questionnaire.

DES workflows	1	2	3	4	5	6	7	
I strongly disagree that the element complexity is sufficient for modeling home monitored patient's requirements and resource usage.					1	4	2	I strongly agree that the element complexity is sufficient for modeling home monitored patient's requirements and resource usage.
I strongly disagree that the model simulates patient resource usage and covers all relevant events in home monitored patients' lives well.			1		4	2		I strongly agree that the model simulates patient resource usage and covers all relevant events in home monitored patients' lives well.
I strongly disagree that the distribution of patients entering and exiting elements is realistic.				5		1	1	I strongly agree that the distribution of patients entering and exiting elements is realistic.
Patient actions								
I strongly disagree that the patient statechart represents a home monitored patient´s states and transitions between situations well.					1	2	4	I strongly agree that the patient statechart represents a home monitored patient´s states and transitions between situations well.
I strongly disagree that the transitions between states are realistic.				1	1	4	1	I strongly agree that the transitions between states are realistic.
Outputs								
I strongly disagree that the simulation outputs where understandable		1			1	3	2	I strongly agree that the simulation outputs where understandable
I strongly disagree that the simulation outputs where relevant					1	4	2	I strongly agree that the simulation outputs where relevant
I strongly disagree that the input values relate to the output values.				1	1	3	2	I strongly agree that the input values relate to the output values.

5.2   DES workflows

All participants in the validation process agree that the workflow complexity in the DES part of the model simulates home monitored patient requirements and resource usage well (see Table 1). An expert in e-Health working for Stockholm County Council stated that even in its early current state the platform already provides better insights of an increase in home monitored patients and the resulting requirements and resource usage, than any analytical tools used today.

Although the workflow complexity in the DES model represents a home monitored patient's actions and resource usage well, the logic behind intervention queuing system should be further developed. Currently the queuing logic implemented in the DES model uses a first in first out method. This should be improved by implementing a priority function where patients with higher severity are prioritized in the queue for certain interventions. In combination with such a priority function, experts believe that waiting times for interventions should have an impact on a patient's illness severity. Longer waiting times should in severe cases have a worse impact on the patient's severity than short waiting times. Although a small improvement, such logic could improve the model validity.

The majority also believe that the model simulates most relevant events and resources in a home monitored patient's life (see Table 1). Since not all booked meetings with a healthcare professional can happen over video, events should be included allowing patients to have booked phone consultations as well. It was also noted by an expert in the development of healthcare and e-Health that resources from municipalities in the form of home care dispatches for elderly care should be included in the model since they cover a large part of an elderly patients every day needs. Doctor home visits should also be included using the exact same logic as nurse home visits, only with a lower occurrence rate. Relatives should also be included as a resource with only the cost of education, since they reduce the need for home care and nurse resources. It was also noted that a basic assumption for the model workflow logic should be that all resources have access to the patient's medical history and environment. Such technology is believed to be available in the future and therefore needs to be taken into consideration since workflows should be more efficient in comparison to todays systems. Although this is already implemented in current workflows, such a concept should also be implemented in any additional model logic where patients are in contact with healthcare resources for consultation or treatment.

All participants agreed that no events should be added or removed from the current workflows.

A few experts leaned towards agreeing, but most were undecided about if the distribution of patients entering and exiting each workflow was realistic (see Table 1 for distribution). The explanation given by the majority was that the reason is a data issue, that due to the lack of real data, it is difficult to understand if the distribution could match real world events. Some participants explained that they did not have enough time with the model to understand.

5.3   Patient Actions

All participants in the validation process agreed that the patient statechart in the ABS model represents a home monitored patient's states and transitions between situations well (see Table 1 for distribution). None of the experts believed that the patients ABS model lacked any states or transitions, or that any should be removed. One was undecided about if the transitions between states are realistic while the rest agreed (see Table 1). The one that was undecided explained that they did not have enough time with the simulation platform to develop an opinion.

5.4   Output

All but one expert agreed that the outputs were understandable (see Table 1) but added comments describing potential improvements on the outputs provided during the validation process. It is currently difficult to calculate times in anything but minutes in the output graphs. Allowing the user to choose which time resolution (minutes, hours, days or weeks) to plot would be an improvement. One expert wanted this change in time frame to be available during simulation run time. Although real time resource usage is currently visible, several users would like to see it plotted over time.

All users agreed that the information currently provided when running a simulation with the platform is relevant (see Table 1). All intervention times such as video consultation times and nurse waiting times where relevant for all experts in their respective field of work. All outputs provided, aid in short and long-term prognosis and prediction for different scenarios concerning patient home monitoring and patient resource usage.

Six out of seven users believe that there is more relevant information that should be provided by the model. Ideas for additional output information are listed below:

- Statistics of resource usage, patient information, waiting times and similar information of relevance should be available for each municipality in the Stockholm region.

- Information on resulting consequences of interventions for each patient should be available to study. The user should be able to study statechart changes and severity change case by case, to better understand a patient's illness progression. This could also be beneficial for the development of the platform logic since it gives us developers a better understanding of patient behavior.

- Aggregated data on costs calculated in the model should be displayed. The user should also be able to see the total cost for the county as well as costs for each municipality. Investment costs should be included.

- Patient severity distributions and any future patient states that could be added to the model, should be plotted and available to the user.

Six out of seven users agreed that the input values relate to the output values and one was undecided (see Table 1). Although the majority agreed, several users (including the one that was undecided) wanted more time with the model to properly answer. It was commented that the improvement previously mentioned of studying patients case by case could also enable users to understand the relation between input parameters and output values.

Due to the lack of real world data used during the validation process, the users could not give their opinion on if the output values provided to them during simulation runtime seemed unrealistic.

5.5   General

All experts believe that the platform could be used for understanding resource distributions in a future healthcare system with an increased amount of home monitored patients. An expert in e-Health from SLL stated that it is a good tool for modeling and planning for patient populations who need monitoring and could be used for investments and agreements during the development of the healthcare system. It can be used as a collaborative learning environment and an interesting feature for most is the ability to study changes in logistics and resource distribution when placing healthcare facilities on the map.

6   Discussion

The architecture for the simulation platform presented by this thesis has the ability of quickly providing information, mainly in the form of outputs, about the possible effects following an increased implementation of patient home monitoring in Stockholm. It has also proven to be useful for quickly altering inputs for comparison of outputs between different model simulation runs. If needed, the platform allows users to easily implement new workflows and agents. Such an architecture shows great promise for answering questions regarding digitalization and logistics in healthcare.

Introducing new technology and solutions in healthcare is usually a slow process that requires great amounts of work and caution. This is due to the highly complex nature of the healthcare system. In order to predict the effects of introducing new technology and system solutions in healthcare, various methods have been used for analysis of data and data acquisition, with the purpose of understanding the future effects of their introduction to the healthcare system. An expert at SLL stated that there currently are no tools available which have the ability of providing a systems-oriented view of patient interactions with healthcare elements of interest, while at the same time providing insights in how changes affect the healthcare system. Such a tool as the one presented by this thesis, using simulation modeling, can provide answers to such questions with greater efficiency and flexibility compared to other currently used methods.

A potential future result of aiding decisions is that this work could cause stakeholders to turn toward simulations to back up their decisions in other complex and large parts of the healthcare system. The part of the healthcare system addressed by this work represents part of the digitalization process and possible developments of healthcare. Other complex aspects could also be addressed with simulations as well. Simulation platforms, such as the one presented, can provide system boundaries or requirements without the need of presenting every possible workflow. This would require help from experts but could be possible (Matlow et al. 2006). Simulations allow for answering questions such as; what increase in the number of doctors and nurses is needed in the home monitoring sector if 2000 additional home monitored patients appear?

All possible workflows that exist in healthcare cannot be simulated but the most important ones might be. This is part of the reason why composability is needed. The provided architecture has mainly considered the technical and logistical aspect of the modeled system. It can likely be assumed that outputs would change if the pathological aspects were implemented. For example, control theory could be applied to achieve and maintain the desired distribution of the parameters *illnessSeverity* and *illnessIntervention* but this would not ensure that rate of each patients fluctuations within the distribution is accurate. Implementation of the pathology and epidemiology could be able to address this issue.

Details of the interventions were not modeled either. The exact tasks during for example a home visit by nurse is not modeled. However, the modeled workflows already have standards and procedures to be followed which could

allow them to be modeled. Logistics wise the medical interventions can be simulated as events that require a defined set of resources and time and occurs according to patient needs. Stakeholders might seek different information, through composability the abstraction of the interventions could be fitted to their needs. Allowing this should be part of the aim for future improvements.

Part of the mentioned composability has been implemented in the sense that most of the rates and agent parameters are either provided as changeable inputs in the interface or can be altered directly in the code without major reprogramming efforts. This allows for easy handling of the platform so that unexperienced users in simulations can use it.

By performing several simulation runs with different input values, the outputs can be compared and the platform can be used as a tool to help optimization of for example, the amount of nurses or doctors per patient or what can be gained by investing in a new nurse dispatch location. If this model would be used for such investigations in decision making, higher demands on the accuracy and validity of the framework architecture would arise, which it most likely does not live up to yet. However, according the validation, the work shows potential to be of use in that kind of scenario if improved upon.

As seen in figures 7 and 8, the severity distribution slowly rises towards higher values as time passes. Most likely, the severity distribution should not behave like that. Patients should probably get worse, get hospitalized, and die in approximately the same rate new patients enter, causing the overall distribution to be more or less stationary.

This architecture is not limited to the outputs provided right now, there are a lot more things that can be tracked, some of them are mentioned in comments from the experts in the validation, subsection 4.2.3. One example that can be added is the total cost, which would grow over time and should be interesting for SLL. For all costs currently provided could be summed. However, that would not include the cost of hospital visits since that is not currently implemented. Another cost not tracked is for the call consultations with nurses. That should probably be tracked in the same manner as cost is tracked for video consultations with doctors. Most consultations happen via doctors in the model, resulting in that this cost would not be as significant but it is most likely of interest.

The actual values of the outputs were not validated, thus the output information provided cannot be used to any large extent yet. They are most likely not correct, probably due to a combination of errors in some rates of intervention and wrong numbers applied to the cost of nurses, doctors, equipment, and ambulance dispatches. Some of the rates could prove to be a challenge to change properly but most of them can be changed by altering one value in the code. If this is done, the accuracy of the simulation platform can be further tested.

In the current framework, the model does not differentiate between day and night nor does it simulate traffic. Since the platform is used to model the healthcare system over large time frames (weeks, months, years) such logic would not have a significant impact on the validity. One example regarding the fact that there is no differentiation depending on time and days could be the following. If it is found that X amount of doctors can provide video consultation

for Y amount of patients, it should be possible to calculate what X amount of doctors working 24 hours per day, 7 days per week equals in amount of doctors in real situations and thus calculate the expected requirements on the amount of doctors for certain times or days.

Due to the limitations of this master thesis, only seven people participated in the validation study. The participants were experts in different fields, such as programming, e-Health, gaming, participatory simulations and healthcare logistics, all of which are relevant to the field of this study. The low number of participants could mean that some things have been overlooked and therefore the validation cannot be considered as definitive. However, since the model was studied by experts with a variety of expertise, feedback and opinions have been given on every aspect of the model, ranging from agent logic to relevant outputs for system decision making. Therefore the validation results give a good overview of how well the simulation platform models real world healthcare situations and how it can be further developed for improvement.

6.1   Future Work

Due to the limitations of this project, mainly shortage of time, there are several features and functions that have not yet been implemented into the platform. Additional thoughts on future work not covered during the validation process are presented below.

As previously mentioned, a healthcare facility simulation platform needs to be developed which will communicate with the platform developed in this thesis using the described communication protocol. Since the user should be able to study the resource usage of patients with different ages and illness severity values, the healthcare facility model needs to have the ability to change departments and specialties. In other words, the user should be able to use the healthcare facility platform to model different types of healthcare facilities. The same platform should have the ability to model a variety of healthcare facilities on different locations on the GIS map modeled in the home monitoring platform. Such a platform will allow a more dynamic and realistic resource usage and availability since it will allow for simulation of the resource agents relevant day to day work activities. The platform could also allow for hospital bed capacities to act as a resource, as well as other relevant medical equipment, which would also make patient visits to healthcare facilities more realistic.

In order to improve usability of the model, automatic generation of homes and resource locations such as healthcare facilities of different categories and nurse dispatch locations should also be implemented as described in subchapter 3.4. Usability could also be improved by allowing the user to place new healthcare facilities, nurse dispatches and patient homes anywhere desired on the map using the user interface, without them having to be hard-coded and only allowing the user to select the amount of each. As mentioned previously, the framework is currently limited to Stockholm County, however by applying the functions described in subchapter 3.4, it could be possible to also choose which region to model without large reprogramming efforts for the user. The platform

does allow the user to model other regions other than Stockholm County, but to do this, all new locations and municipalities need to be hard-coded in the same manner as they are now for Stockholm County.

An experiment that could be conducted to test the validity of the output values is to gather data on the cost of the type of patients that are most likely to get this type of home monitoring for a time period, run the model for that time and compare the costs. The same can be done for the upcoming year, thus being a blind test since the real cost is not known until after the year, or chosen time period, has ended.

6.2 Conclusion

As far as confidence in the literature study and the validation process goes, the type of simulation architecture developed during this thesis project, can address the redesign of the healthcare system in Stockholm County. The platform can not fully simulate all relevant investigatory scenarios yet, but is a working proof of concept that this type of hybrid DES-ABS architecture can give outputs estimating valuable information given the chosen input. This type of architecture can also be of assistance in instigating discussions and allowing stakeholders to back up their decision making with simulations regarding resource distribution where patient home monitoring has been further implemented.

A great variety of outputs are available and can further easily be extracted from the developed framework. The platform also has the ability of modeling healthcare logistics systems on any other geographic location that would be of interest for understanding patient resource distribution and usage. It also allows the user to alter relevant input without major reprogramming efforts.

Implemented workflows in the DES architecture cover most of the relevant events in a home monitored patient's life with the exception of doctor home visits. It also covers all relevant logistics logic and resource distribution functions except for priority queuing logic. All relevant patient states have been included in the ABS architecture in order to properly simulate patient transitions between relevant situations in a home monitored patient's life.

The communication protocol allows for integration between this platform and a healthcare facility simulation platform which is currently under development.

The simulation architecture provided by this thesis has achieved the objective of being able to model flows of resources and services in a further digitalized healthcare system in Stockholm County. Such a platform addressing this change has never been developed before on such a large scale and can provide better insights of an increase in the amount of home monitored patients and their resulting requirements and resource usage, than any analytical tools used today.

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A   Appendix

A.1   Questionnaire

Royal Institute of Technology (KTH)   Date

Questionnaire

This questionnaire is made for assessing whether the presented model can help you better understand the effects of increased patient home monitoring on the healthcare system.

Personal information

Name   _____

Work position   _____

Please answer the questions below. Check one box in each Likert scale according to your degree of opinion.

Workflows

- I believe that the element complexity is sufficient for modeling home monitored patient's requirements and resource usage.

Strongly disagree	- -	-	Undecided	+	++	Strongly agree

  - Comments:

- The model simulates patient resource usage and covers all relevant events in home monitored patients' lives well.

Strongly disagree	- -	-	Undecided	+	++	Strongly agree

- Are there any additional elements that you believe could improve the validity of the model?

- If not, are there any events that could be added to the current elements to improve the validity of the model?

- Are there any events that you think should be removed from the existing elements?

- I believe that the distribution of patients entering and exiting elements is realistic.

Strongly disagree	- -	-	Undecided	+	++	Strongly agree

  - If you are undecided or lean towards disagreeing, which element patient distributions seem incorrect?

Please answer the questions below. Check one box in each Likert scale according to your degree of opinion.

Workflows

- I believe that the element complexity is sufficient for modeling home monitored patient's requirements and resource usage.

Strongly disagree	- -	-	Undecided	+	++	Strongly agree

      o   Comments:

- The model simulates patient resource usage and covers all relevant events in home monitored patients' lives well.

Strongly disagree	- -	-	Undecided	+	++	Strongly agree

- Are there any additional elements that you believe could improve the validity of the model?

- If not, are there any events that could be added to the current elements to improve the validity of the model?

- Are there any events that you think should be removed from the existing elements?

- I believe that the distribution of patients entering and exiting elements is realistic.

Strongly disagree	- -	-	Undecided	+	++	Strongly agree

      o   If you are undecided or lean towards disagreeing, which element patient distributions seem incorrect?

- o Is there any information you think is lacking?

- I believe that the input values relate to the output values.

Strongly disagree	- -	-	Undecided	+	++	Strongly agree

- o Comments:

- Were there any output values that seemed unrealistic?

- o If yes, which ones and why?

General

- How do you believe that this model can be used?

- Do you have any further comments?

- Any additional questions you think we should have included in this questionnaire?

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