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OPTIMIZING HOME HOSPITAL HEALTH SERVICE DELIVERY IN NORWAY USING A COMBINED GEOGRAPHICAL INFORMATION SYSTEM, AGENT BASED, DISCRETE EVENT SIMULATION MODEL

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ABSTRACT

Home hospital services; provide some hospital level services at the patient's residence. The services include for example: palliative care, administering chemotherapy drugs, changing dressings and care for newborns. The rationale of the service is that by providing high quality care to patients at their homes their experience of the care is better and hence they respond to the treatment and/or recover quicker and are less likely to need to report to hospital to receive care for more serious/expensive conditions. The aim of this study is to evaluate the effectiveness of the home hospital service, to optimize the current configuration given existing constraints and to evaluate potential future scenarios. Using a combined discrete event simulation, agent based model and geographical information system we assess the system effects of different demand patterns, appointment scheduling algorithms (e.g. travelling salesman problem), varying levels of resource on patient outcomes and impact on hospital visits.

1 INTRODUCTION

A hybrid simulation model consisting of agent based models (Law 2014; Noble et al. 2012) and discrete event simulation (Zeigler et al. 2000) models is being developed to assess the delivery of advanced home hospital services (AHHS) in Norway. These types of service are also known as home hospital services (HHS), and are referred to as "avansert hjemmesykehus" (AHS) advanced home hospitals in Norway. This paper presents the model as it currently stands with some preliminary results and reflections thus far.

This project is part of the Centre for Connected Care (C3), research Centre funded through the Norwegian Research Council to investigate the acceleration and adoption of innovation between industrial, health and academic partners relating to healthcare.

The next section will provide a brief overview of AHS and specifically from a Norwegian perspective. Additionally summary data will be presented before discussing the model development in section 3. Early results shall be presented in section 4. The paper will conclude with a discussion focusing on modelling steps, data collection and validation, scenario elicitation and thoughts on future directions.

2 BACKGROUND

2.1 Home hospital services

Demand for hospital services is increasing rapidly due to ageing populations and advances in the treatment of previously untreatable conditions and disease. AHS have gained traction over the last 20 years due to increases in medical knowledge and improvements in medical technology. AHS is a popular response to the increasing demand for acute hospital beds. Cutting costs by avoiding admission to hospital, and reducing hospital length of stay are central goals of such schemes. However, it is not known if patients admitted to hospital at home have better or equivalent health outcomes compared with patients receiving in-patient hospital care. Nor is it known if the provision of hospital at home results in a reduction, or increase, in costs to the health service. (Shepperd et al. 1998).

There are numerous definitions of home hospital services, due to the type and complexity of service(s) provided. Additionally differences can be attributed to variations in health care delivery by country. Other definitions of home hospital services are provided by (Thome et al. 2003; Jeppseesen et al. 2012; Parab et al. 2013; Varney et al. 2014; Sheperd et al. 2016; Park et al. 2013).

2.2 Oslo University Hospital and Akershus University Hospital

This paper will focus on home hospital services delivered by two large hospitals in the South East of Norway: Akershus University Hospital (Ahus) and Oslo University Hospital (OUS), see figure 1. The population of the OUS catchment area, the orange area, is around 650,000 people and the region is densely populated. The population of the Ahus catchment area is around 420,000 people and the geographical distances and terrain present different challenges, e.g. fjords, mountains, forests, rivers etc.

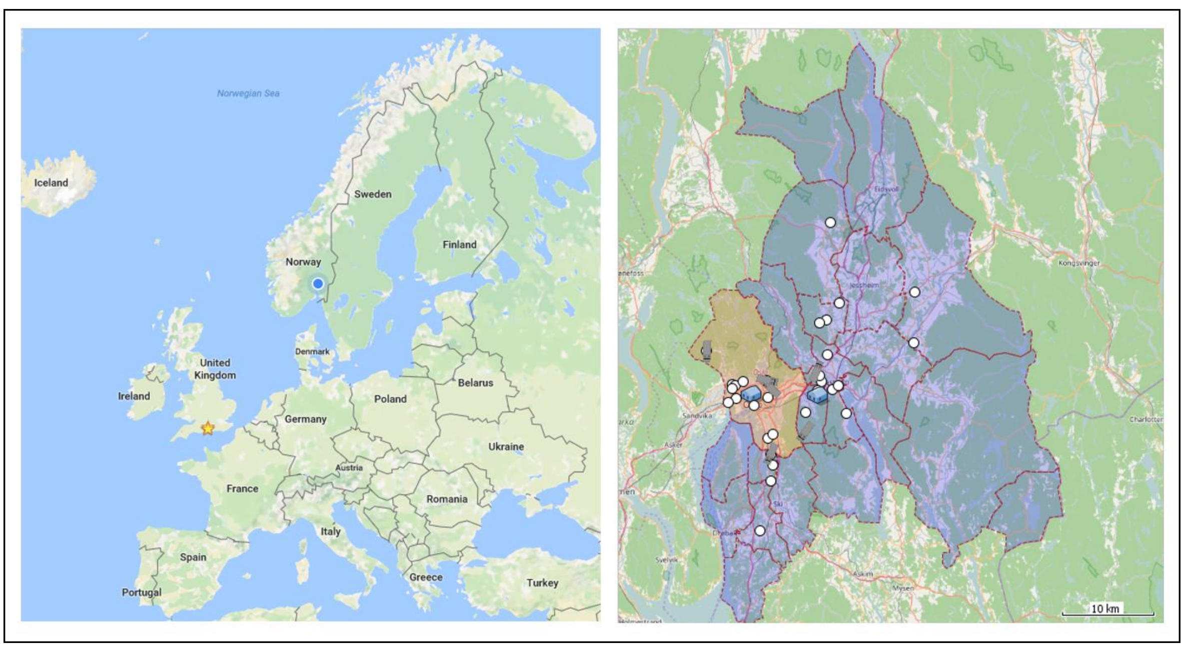


Figure 1: Home Hospital Services provided for children by Oslo University Hospital (OUS), the orange catchment area and Akershus University Hospital (Ahus) the blue catchment area. The white circles are patients, the blue houses are hospitals and the grey vehicles are home hospital vehicles.

The advanced home hospital service at OUS (OUS-AHS) is organized by the Ullevål hospital (which is part of OUS). OUS-AHS provides services for children and adolescents (0-18 years) including treatment and care at home rather than in hospital. The service is delivered by experienced nurses, specialist nurses, a nursery nurse and a doctor. The aim is that when it is safe and feasible, children and adolescents requiring hospitalization, who are Oslo residents, can receive hospital level care at home, with the support of home nurse visits. The severity of the condition and the wishes and ability of the patient and their family are major factors determining receipt of a service. The service operates between set times, but telephone support from a nurse who knows the child and family is available out of hours.

At Ahus advanced home hospital service (Ahus-AHS) is organized in the Department for child and adolescent medicine. As OUS-AHS it provides services for children and adolescents 0-18 years of treatment and care at home rather than in hospital. Ahus-AHS consists of experienced nurses, specialist nurses and a specialist doctor in close cooperation with the hospital ward. The criteria for transfer to Ahus-AHS is that the patient is in a stable phase and the parents are in a position to provide adequate care.

From the descriptions above of the OUS-AHS and Ahus-AHS they appear quite similar but when you look closer there are significant differences in the structure of the systems, how the services are organized, and the types of patient groups included. We aim to model these differences and to assess the different systems, to share best practice and improve service delivery, but as this is preliminary work and given space constraints we shall present a proof of concept model from an Ahus perspective in this paper. The key assumptions and limitations of this work are presented in Table 1. It is anticipated that a more comprehensive model of the OUS-AHS and Ahus-AHUS systems would be completed before Winter Simulation Conference.

Table 1: Model assumptions.

No.	Assumption	Description
1	AHS appointments "First come first served"	This is unrealistic as geographical distances between appointments are not taking into consideration.
2	Simplifying Seasonality	Seasonality is represented through adjustments to the arrival rates and service time distributions over the time horizon of the model.
3	Duration of AHS service	Patients are generated for each week. Some patients may receive home hospital services for a number of weeks, which is not reflected in the model.
4	Hospital care	Currently very simple, consisting of an arrival point, and a delay (service) to capture the patients' length of stay.
5	Simplified patient groups	Different patient groups e.g. oncology, blood tests, antibiotic course, are not explicitly represented
6	AHS staff (skill mix)	All staff and vehicle combinations are able to treat all conditions.

2.3 Ahus initial data

The modelling work as stated is in development and as such what data that we currently have access to will be summarized before we discuss the initial model. Figure 2 presents the number of patients receiving AHS and the associated number of visits from healthcare professionals from Ahus from December 2015 through to August 2016. It can be seen that patient often receive more than one visit as part of the service.

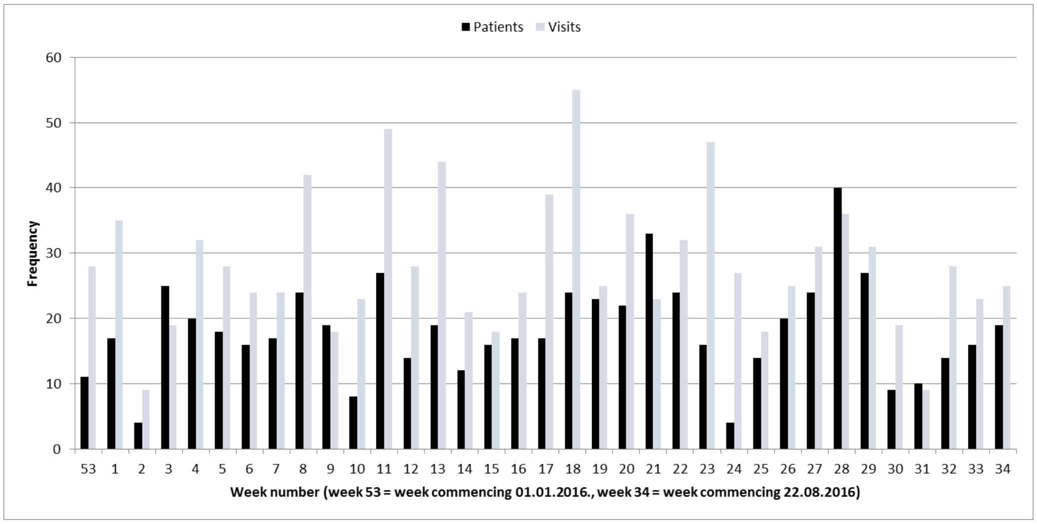


Figure 2: Number of patients and visits, per week from December 2015 until August 2016.

Figure 3 provides a breakdown of the time the healthcare professionals spend travelling versus the time they spend with the patient. The data suggests that slightly more time is spent with patients then travelling. We shall revisit this in section 4.

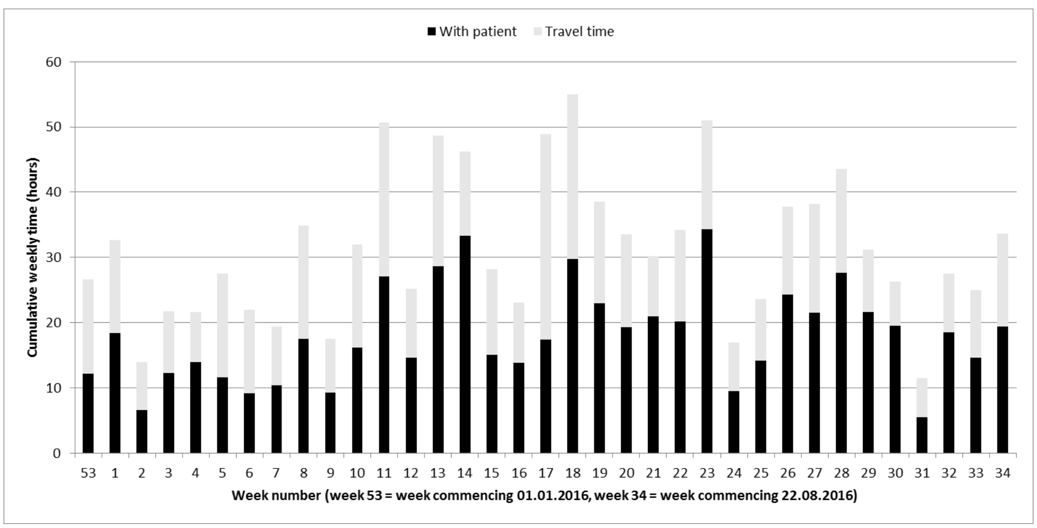


Figure 3: Time (in hours) spent with patients and travelling, per week from December 2015 until August 2016.

From figures 2 and 3 very crude estimates were made for the arrival patterns, the number of visits each patient has per week, also the municipality within the Ahus catchment area (data not shown), and a distribution for visit duration. All of these estimates are questionable at this stage. More detailed data analysis is planned following approval from ethics and privacy ombudsmen.

3 METHOD

The model is being developed in AnyLogic (2017). It builds upon the senior author's previous modeling work (Viana et al. 2016; Rand-Hendriksen et al. 2016). It follows the principle of using the best method for the job at hand. Of course this is a subjective decision, and is based on the senior author's experience with certain modelling methodologies. One could of course build this model in any single paradigm if they so wished.

Figure 4 provides an overview of the model as it currently stands. The sections highlighted in grey are the focus of this paper. The AnyLogic model consists of several agents; conceptually AnyLogic treats everything as an agent. These agents can have different levels of behavior from very active behavioral rules and communication within the agent and between other agents, to very passive entity like agents.

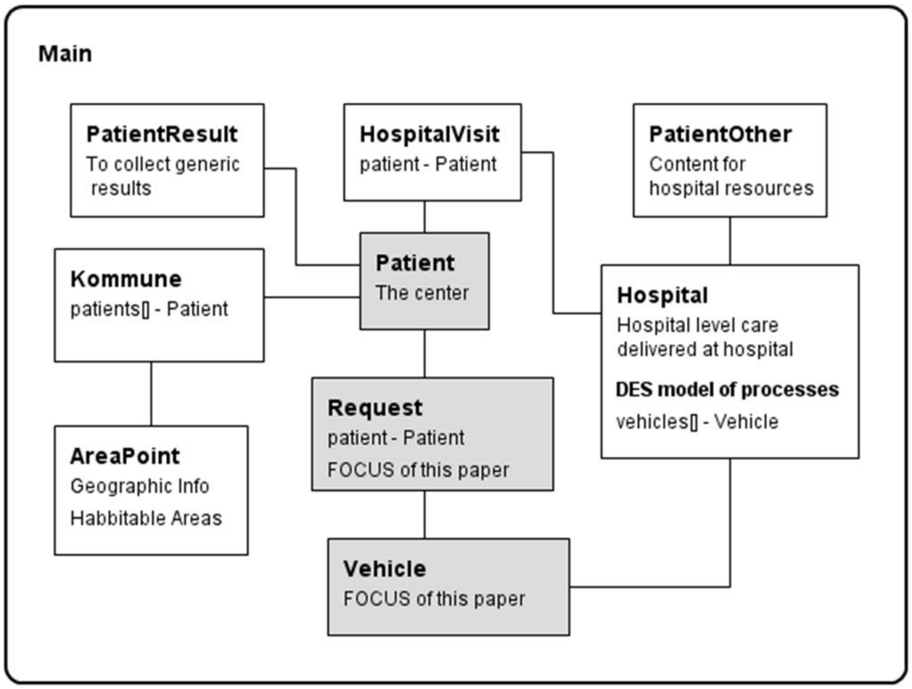


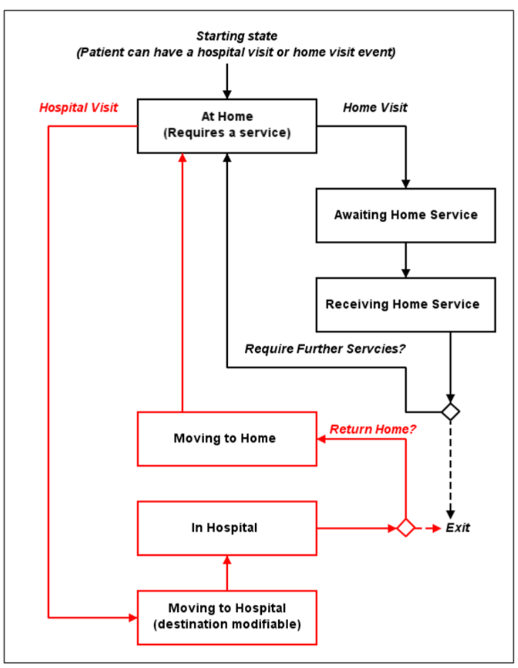
Figure 4: Conceptual model illustrating the interaction of the main components of the model. The components in grey are the focus of this paper.

The agents currently included in the model are:

- Main – contains the geographical visualization and drives the model, it contains all of the other agents which are discussed below and illustrated in Figure 4.
- Kommune (Municipality) – Oslo is a municipality. The Ahus catchment area consists of 21 municipalities. The population, the patients, are generated from within the municipalities.
- AreaPoint – Derived from Geographic analysis outside of AnyLogic to derive areas and co-ordinates of habitable areas, there are fjords, forests where people cannot live.
- Hospital – the hospitals OUS and Ahus are based on the same generic agent, with the ability to make parametric change, e.g. no. of beds, number of vehicles available for home hospital service. Two types of patient visit the hospital, "Patient" (those who also receive home hospital services) and "PatientOther" those who content for the same hospital resources.
- HospitalVisit – is a tool for passing the visualization of the Patient between the Main and the Hospital levels. It is also used to start the physical process of identifying the best route to get to the hospital, through the interaction with OSM map servers or other routing algorithms.

- PatientOther – has been briefly mentioned. This is a "Patient" lite agent that is used to compete with Patient agents for resources. It does not contain all the traits and characteristics of a Patient agent, e.g. geographic location and the state charts for movement to the hospital.
- Patient Result – collects basic results for the patients, wait times, treatment time, time until treatment, outcomes etc.
- Patient – contains potentially detailed information about a patient, e.g. age, gender, address, illnesses. The patient triggers home hospital service and hospital visit events, which lead to the scheduling of an AHS visit and a hospital visit respectively.
- Request – is similar to the HospitalVisit agent, it provides a copy of the Patient agent to the vehicle which is bringing the person to provide the AHS. This enables the vehicle to travel to the patient's location. We shall discuss this further in the results and discussion sections.
- Vehicle – this is the resource that carries the agent which provides the home hospital service. The vehicle resource is kept in the hospital level models, so OUS and Ahus can have their own fleets of vehicles, but the visualization of the vehicles is at the Main level.

Figure 5 provides two state charts which control the movement of agents within the model. The state chart on the left relates controls the movement of the Patient agent from within the Patient to the hospital. This states chart also keeps track on status of AHS if the patient is receive a service. The state chart on the right of Figure 5 controls the movement of the vehicles between the hospital and the patient and between patients. The Patient agent generates a request which is sent to the appropriate hospital which is based on the municipality the patient resides in. In the DES model representation of the appropriate hospital will dispatch the vehicle to the patient. At present this process is rather rudimentary and will be improved in due course. The vehicles are currently routed out on a "first come first served" process, which leads to unnecessarily long travel times.



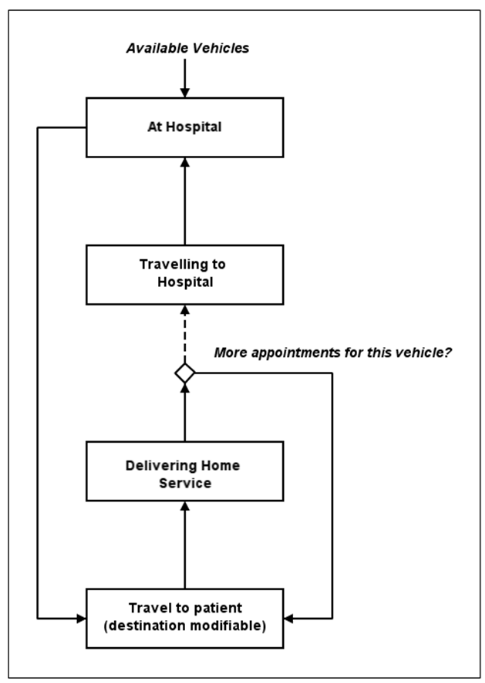


Figure 5: The state chart on the right is embedded in the vehicle agent and controls its operation. It interacts with the patient and hospital agents. The state chart on the left controls the movement of the patient agent to the hospital and requesting a home hospital visit.

Figure 6 presents the hospital agent model, which contains discrete event simulation DES representations of visits to the hospital of AHS patients and non-AHS patients. The “vehicle”, “beds_Stroke” and “beds_Neurology” represent resources that are contented for. These are some of the policy levers in the model. The AHS patients who visit the hospital arrive at the “patientArrival”, the moveToQueue is to control the visualization at the hospital level. The “takeBed” point take the bed resource, if a bed resource isn’t available then the patient queues. The moveToDelay, moves the agent to the bed location, the patient then stays for a time sampled from a distribution based on the patient’s characteristics. Following this the patient then exits the DES model and if they remain in the model they travel back to their home location, if not they are removed from the model completely.

The almost identical flow beginning with “source” and ending in “sink2” handles the non-AHS patients, the “PatientOther” agents, not the “Patient” agents. The “takeBedOther” and “takeBed” contain for the same bed resources. Results collected at the hospital level include the “PatientOther” agents as they impact upon waiting time and length of stay of the AHS patient who visit the hospital.

The bottom collection of icons from “processRequest” to “sink”, control the movement of AHS vehicles from the hospital to the patients requesting a service. This DES function interacts with the Patient agents who generate “requests” which are captured by “processRequest”. At “takeVehicle” if there is an available vehicle then it is sent to the patient. When it arrives at the patient the duration of the service is sampled, based on the patient’s characteristics. If there are no vehicles available the request queues until a vehicle becomes free. Currently the system works on a “first come first served” process, this is not correct, for example if a vehicle is in the North of the Ahus catchment area and the next request is in the queue, it will take roughly 90 minutes to drive back, depending on the traffic.

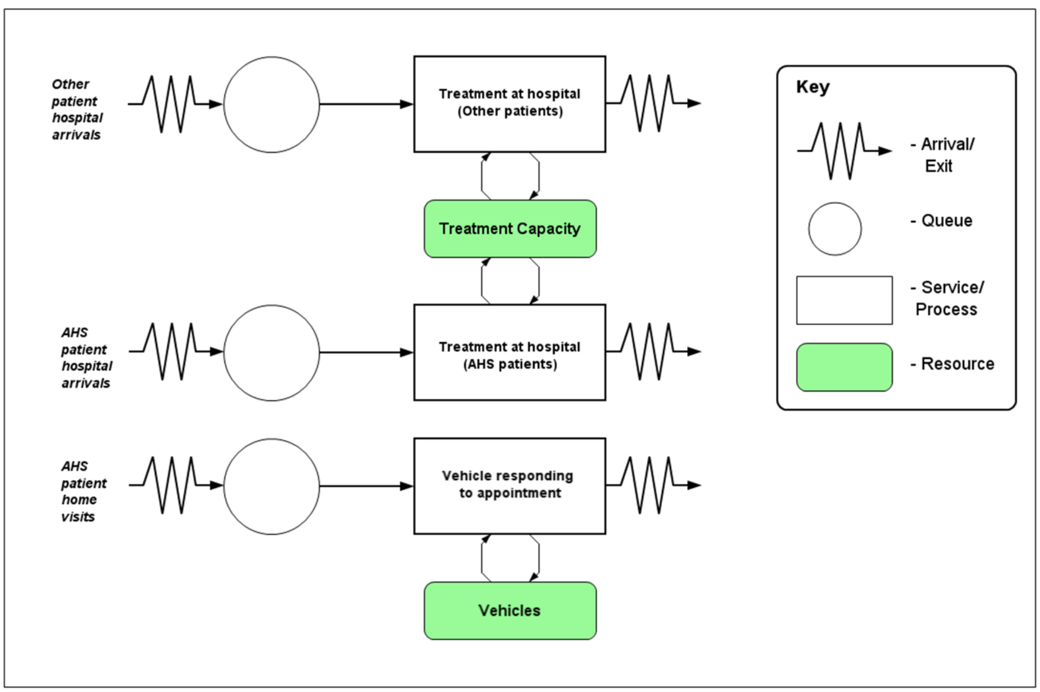


Figure 6: Simplified hospital agent activity cycle diagram. Two broad categories of patient arrive at the hospital non AHS patients, “other patients” and “home hospital service” patients, which share hospital treatment capacity. “Home hospital services” are delivered by vehicles shown at the bottom of the figure.

4 PRELIMINARY RESULTS

What follows are illustrative results, based on the limitations that have previously been mentioned. The amount and quality of the summary data that the arrival patterns and process distributions were based and the way in which AHS vehicles are routed between AHS patient requests. The model runs for the same duration as the historical data was collected, from 01/01/2016 to 28/08/2016. The model results included in the upcoming graphs are based on 50 simulation runs.

Summary results are collected and collated over a week. This decision was to assess the model in terms of the data that was available. The current modeling limitations have been stated in table 1. All of the limitations stated in Table 1 will be addressed in future. It is anticipated other results will be collected in future iterations, including costs, patient outcomes, utilization of specific staff, to examine skill mix and different competence levels.

Table 2 lists the criteria that will be used to optimize the model, following verification and validation of the base model. It is anticipated that following further discussion with model stakeholders that the criteria stated in Table 2 may be revised.

Table 2: Proposed optimization criteria.

No.	Criteria	Min/Max	Description
1	Patients seen	Max	Number of patients receiving the service
2	Time travelling	Min	Reduce time travelling between patients.
3	Continuity of care	Max	Patients seen by the same healthcare professional
4	Cost	Min	Costs of delivering the service
5	Hospital Readmission	Min	Number of readmissions prevented by the service.

Figure 7 presents the number of patients receiving AHS per week. As can be clearly seen the model at present is not a good fit. Possible explanation for this include a rough approximation of the number of visits per patient per week. Patients were assigned a number of visits based on a Poisson distribution with a lambda of 2. Once the patients had its number of visits met the patient then leaves the system. It is very likely that patients have more visits, and would remain in the system longer.

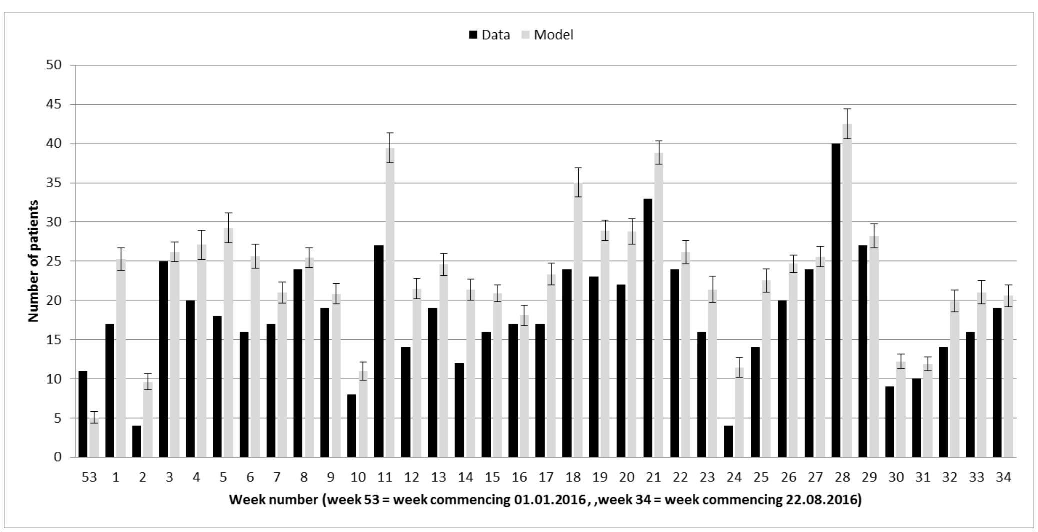


Figure 7: Number of patients per week from December 2015 until August 2016. Preliminary model results (with 95% confidence intervals) compared to historical data.

Figure 8 illustrates a closer fit between the model and the historical data with respect to the number of visits per week. This closer fit is not an indication the model is an accurate representation of the system.

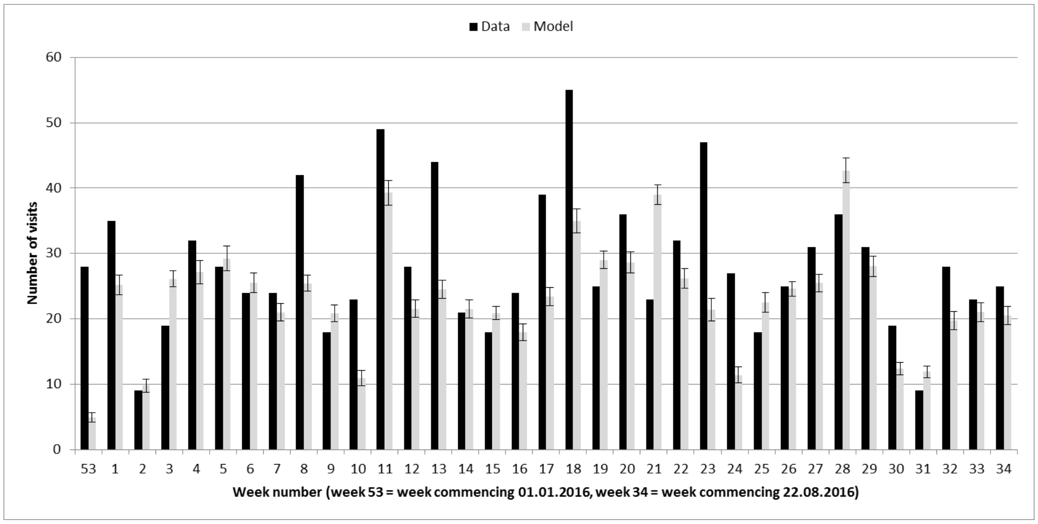


Figure 8: Number of visits per week from December 2015 until August 2016. Preliminary model results (with 95% confidence intervals) compared to historical data.

Figure 9 highlights some discrepancies between the model and the historical data. An exponential distribution with a rate of 38 minutes was derived from the available data. This is the average for the entire Ahus-AHS population. It is likely that there would be variation between different types of AHS users. E.g. Chemotherapy, wound management, palliative care, administering an IV.

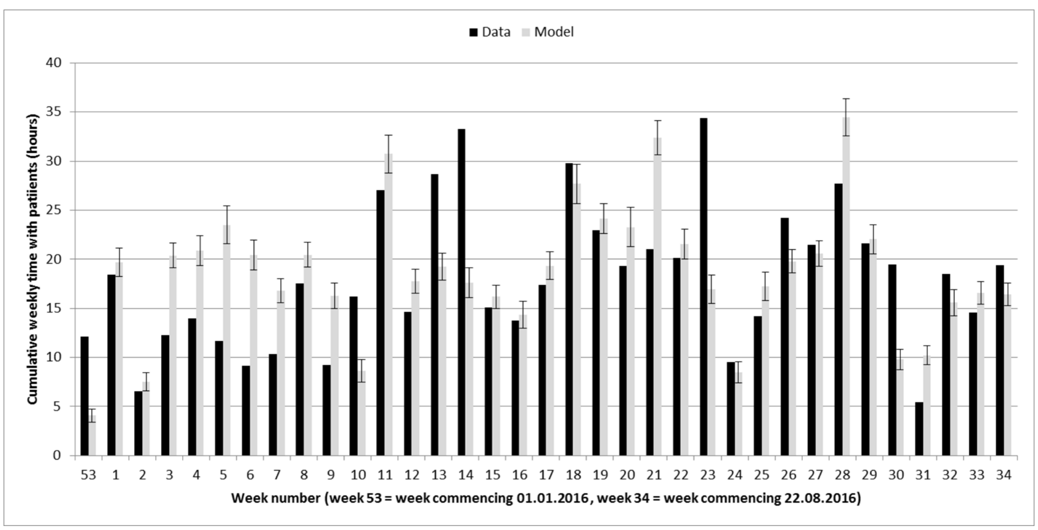


Figure 9: Home hospital services, time spent with patients in hours per week from December 2015 until August 2016. Preliminary model results (with 95% confidence intervals) compared to historical data.

Figure 10 highlights one of the major weaknesses of the current model, the cumulative travel time per week. As previously mentioned it is highly likely that vehicles have to travel extreme distances in the current first come first serve bias. The Ahus-AHS vehicles in the model travel much further than the historical data suggests. It is likely that the Ahus catchment area has been subdivided into smaller geographical areas which may have been assigned a specific vehicle(s). This would significantly reduce the travel time. Investigating this matter is a priority for upcoming data collection efforts and meetings.

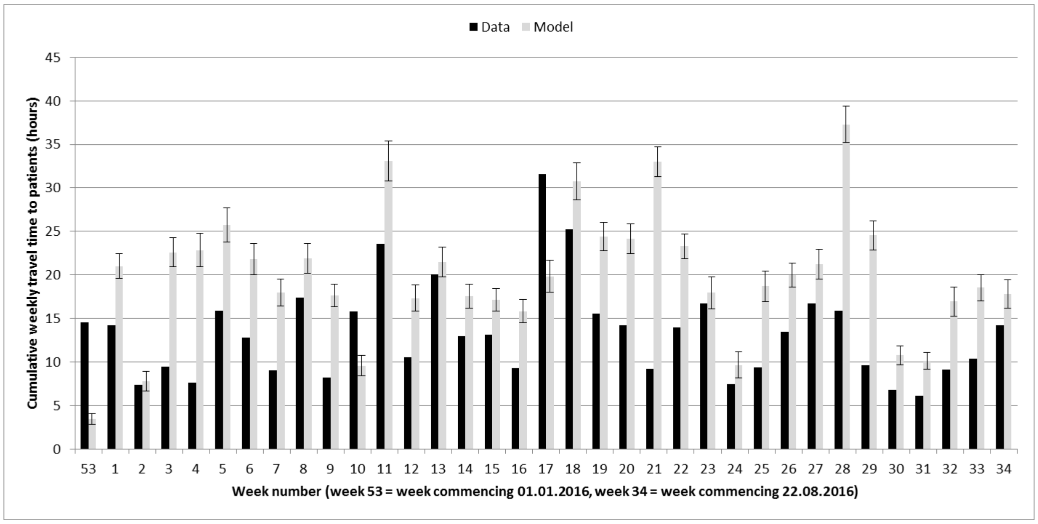


Figure 10: Home hospital services, time travelling in hours per week from December 2015 until August 2016. Preliminary model results (with 95% confidence intervals) compared to historical data.

It is possible to get more detailed results from the model, relating to a variety of model variables, but the quality of data that the model uses needs to be improved and the model needs to be evaluated with stakeholders and subject matter experts.

5 DISCUSSION AND CONCLUSIONS

This hybrid model builds upon the authors previous work, and adds to the growing hybrid literature (Brailsford 2015; Djanatliev and German 2013). However is it a hybrid model? Is combining an ABM or several ABMs with one of more DES model a hybrid. A very interesting panel discussion took place in Washington DC last year, about what hybrid simulation modelling is. Robert Sargent and Richard Nance, pointed out that when the Winter Simulation conference was founded the call for papers requested papers that are discrete, continuous or combined (Eldabi et al. 2016). My take on the discussion was that ABM and DES modelling were subsets of one another and that if one should build a model using the two it should be called a combined or composite model.

Does it matter which approach is used? If you can address a problem is that not enough. Does the debate arise due to the nature of research? Would an academic, a practitioner in a consultancy company and lay person view a problem in the same way.

The model created is in a very early stage of development, but it has support from stakeholders within the hospitals, and a rich data source that once permission has been received will be used to improve almost every aspect of the model. The team is particularly interested in the hospital admission pattern of those patients who use the AHS to assess the effectiveness of the service to prevent admissions.

We are particularly interested in exploring the sensitivity analysis with models that contain multiple models, and various levels of stochasticity (Rossiter, 2015). To that end we are exploring methods to combine simulation software with packages specifically designed for statistical analysis such as R.

It is likely that the model will go through one or two iterations before the Winter Simulation conference. We are excited to present a more developed model with selected case studies that have been specified by OUS and Ahus.

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