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A HYBRID DISCRETE EVENT AGENT BASED OVERDUE PREGNANCY OUTPATIENT CLINIC SIMULATION MODEL

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ABSTRACT

This paper provides an overview of a hybrid, discrete event simulation (DES) agent based model (ABM), simulation model of the overdue pregnancy outpatient clinic at the Obstetrics department of Akershus University Hospital, Norway. The model is being developed in collaboration with clinic staff. The purpose of the model is to better plan resources (e.g. staffing) to improve patient flow at the outpatient clinic given the uncertainty associated with demand. The uncertainty is due to an increase in the size of the hospital's catchment area, changes to overdue pregnancy guidelines in Norway and that women can give birth before their appointments. The ABM model component represents the human parts of the system, the women and the clinic staff. The DES component represents the outpatient clinic's physical location and processes/pathways that operate within it. The technicalities of the model are presented along with some illustrative results.

1 INTRODUCTION

This paper present a hybrid simulation model of the overdue outpatient clinic at Akershus University Hospital, Norway (AHUS). Overdue pregnancy outpatient clinics are challenging to plan for due to the probability of women not requiring their appointments as they have given birth, physiological and psychological differences between mothers, changing demographics due to immigration patterns, and population growth, and policies and protocols associated with this group. The Health Services Research Unit (HØKH), the data acquisition group, part of the analysis department and the obstetrics department at AHUS have collaborated to develop simulation and statistical analysis tools, to analyze patient flow and resource utilization and to plan for future changes in demand and operating procedures.

The paper is structured as follows. Section 2 provides additional information about overdue pregnancies. Section 3 provides a concise explanation of the technical aspects of the model, how the data was collected and incorporated into the model, why a hybrid approach was adopted and how the model was developed and validated. Section 4 discusses an illustrative use of the model with three hypothetical experiments. Section 5 concludes the paper summarizing the model, its strengths and weaknesses, and the development process which have been discussed throughout the document.

2 OVERDUE PREGNANCY

2.1 Definition of an Overdue Pregnancy

Definition 1 A pregnancy is post term when the gestation period exceeds gestational week (GW) 42 (>294 days). (WHO 1977)

Definition 2 Post term pregnancy guidelines in Norway, recommend an additional clinical exam in GW 41, 7-9 days after term, including a clinical examination, ultrasound and cardiotocography (CTG) (Norwegian Society of Gynecology and Obstetrics 2014)

2.2 Overdue Outpatient Clinic

Patient flow and resource utilization in the outpatient clinic are affected by staff and appointment scheduling and women not requiring appointments due to birth. An overview of the process is provided in the green boxes Figure 1.

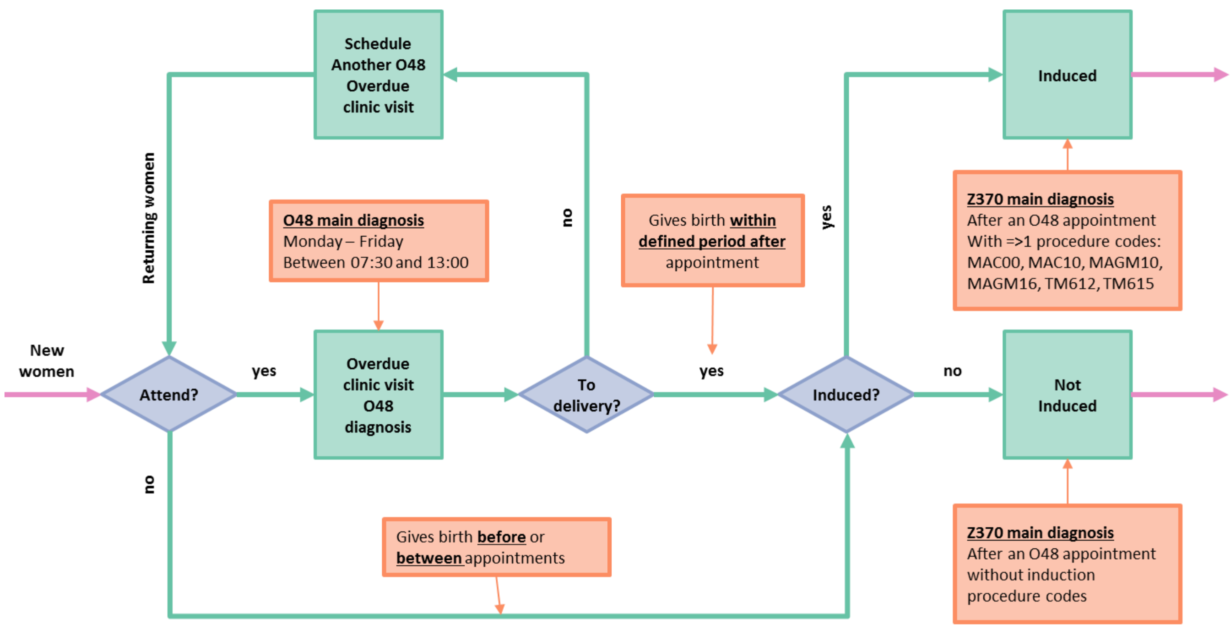

Figure 1: An overview of the overdue pregnancy outpatient clinic. The orange boxes with bold underlined text summarize the diagnostic codes use to classify/group the patients in the data extraction exercise.

2.3 Demand

The demand for the overdue pregnancy clinic has increased in recent years, illustrated in Figure 2 which shows the number of scheduled appointment and the number of women who arrived per week from 2010 to 2017. The noticeable increase from 2011 is due to an increase in the size of the AHUS catchment area and changes to the overdue pregnancy guidelines in July of 2011 (The Norwegian Directorate of Health 2011). During this period the number of births has not increased substantially, despite the change in the size of the catchment area. The increase is due to the new guidelines.

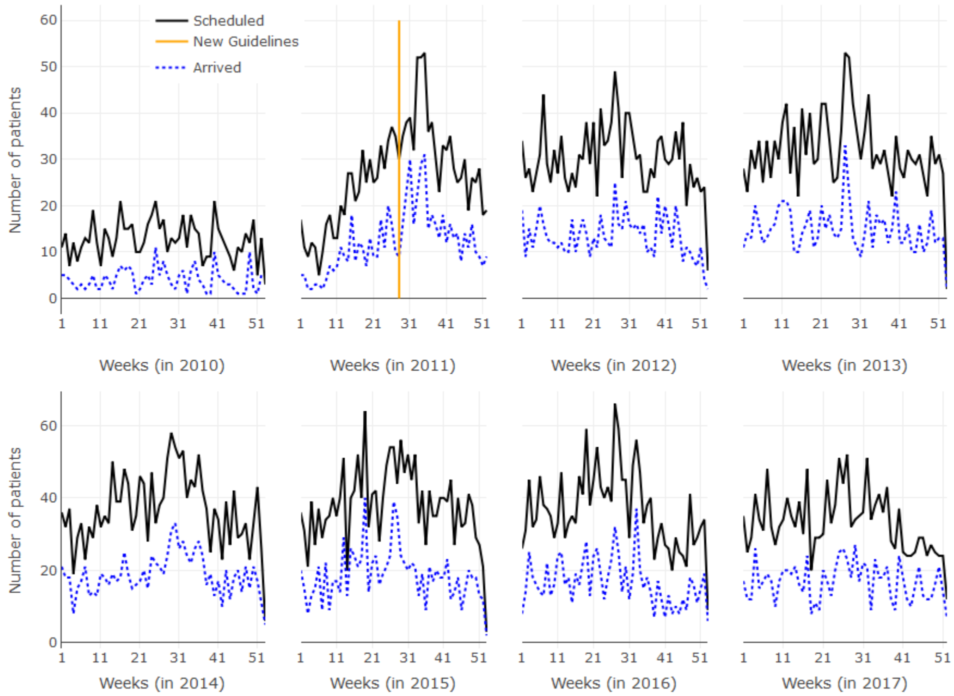

Figure 2: Changes to demand over time (Births: 2010=4647, 2011=5135, 2012=5265, 2013=4665, 2014=5089, 2015=5051, 2016=4971, and 2017=4640).

3 MODEL DEVELOPMENT

The model was developed in AnyLogic (AnyLogic 2018), and interfaces with R. The model runs over any time horizon. Currently Monte Carlo runs of the model consisting of batches of 50 runs are conducted. This section provides an introduction to the key technical aspects of the model, including how the data was collected and incorporated into the model, and a simplified overview of the model.

3.1 Model Data Collection

We discussed with clinic staff: admin, midwives and doctors, the scope of the system, which is illustrated in Figure 3. The simplified system illustrated covers the majority of the overdue outpatient clinic appointments. To compliment the boundary setting exercise, we discussed with staff and the hospital administration the availability of data relating to outpatient visits. The hospital has excellent data relating to inpatient visits, but less outpatient data is routinely collected, with the exception of arrival times and whether the patient attended their appointment and the outcome of the appointment. We received data relating to overdue appointments for the period 01/01/2010 to 31/12/2017 from hospital information systems (DIPS and PARTUS). We requested this period because of the increase in catchment area size in 2011 and the introduction of the new overdue policy, discussed in section 2. To model staff planning effectively we required information relating to the key processes that take place in the clinic during a woman's visit, as shown in Figure 3. The hospital did not have the resources to audit the clinic for a prolonged period of time, so staff were asked to provide estimates. A program was developed in VBA to elicit estimates from staff, see Figure 3 (Leal et al. 2007). From discussions with staff, they stressed that there was no seasonality with respect to the service times. An R script was written to automate the analysis process, import the staff estimates, summarize the individual estimates, aggregate the estimates for specific processes and to fit parametric distributions to the estimates. If a parametric distribution fitted the data they were assigned to the relevant model distribution object. Otherwise empirical data is used to create custom distributions using internal AnyLogic functionality. An example of the fitted data is shown in Figure 3. Data were collected from five doctors, six midwives and five reception staff. They were asked to base their estimates for the relevant processes in Figure 3 part 1, for the last 2 days.

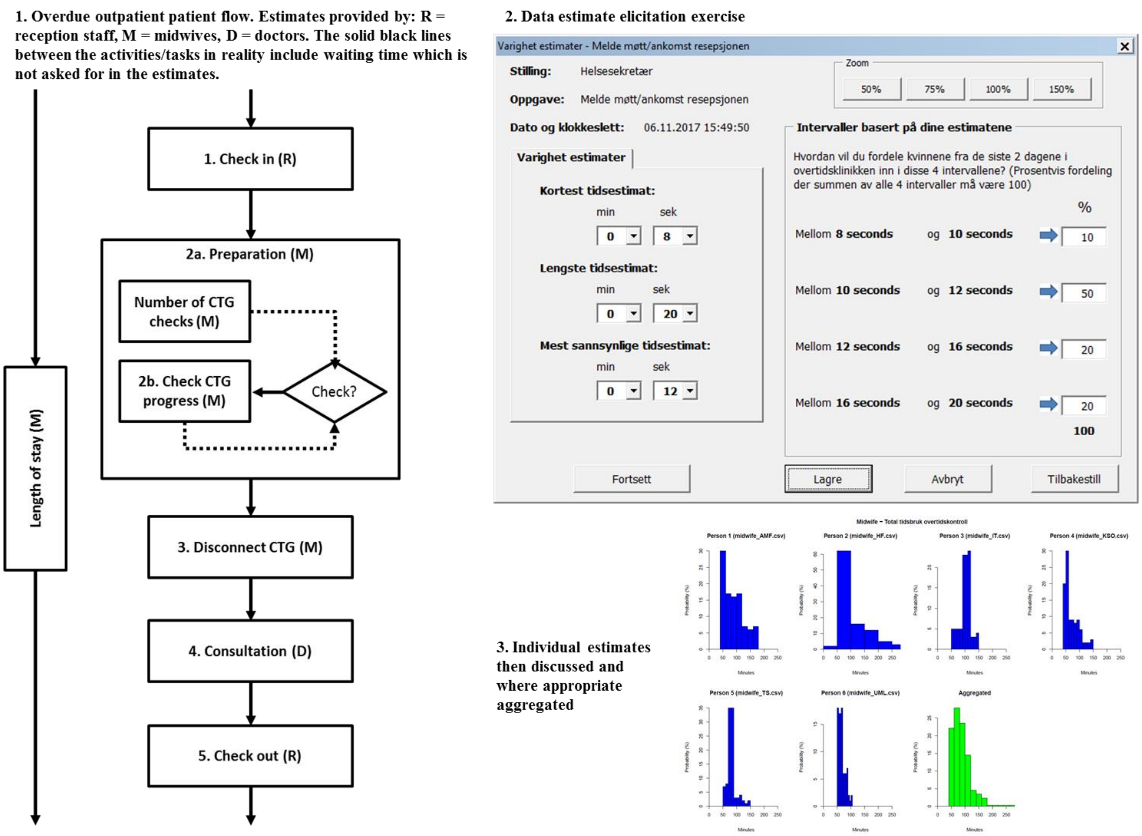

Figure 3: Model development. Part 1. Conceptual model. Part 2. Data estimation program (in Norwegian). Part 3. Example of the estimates [blue = individual estimates, green = aggregate].

3.2 Simplified Model Overview

The model focuses on the overdue pregnancy outpatient clinic, but also incorporates other clinics which run in parallel to the overdue pregnancy clinic and compete for resources, i.e. reception staff and waiting area space. The other clinics relate to pregnant women or postnatal women. The other outpatient clinics are modeled in a simplified way, see Figure 3, part 1 with boxes 2 and 3 removed. The simulation model could be considered a hybrid DES ABM model (Djanatliev et al. 2012; Eldabi et al. 2016), as the overdue clinic is constructed as a DES model, and the women and various characteristics of the model are modelled as agents. R is used to analyze the raw data from hospital systems, prior to incorporation into the model, and to perform analysis on the raw simulation output. A simplified technical illustration of the model is provided in Figure 4. The model is developed in AnyLogic which refers to everything as an agent which may be confusing. The components illustrated in Figure 4 include the main variables (including types, e.g. double, int etc.) and functions (indicated with "()"). Sections 3.2.2 – 3.2.9 explain briefly the components presented in Figure 4. The model presented in this paper is related to a previous modelling study with the obstetrics department (Viana et al. 2016).

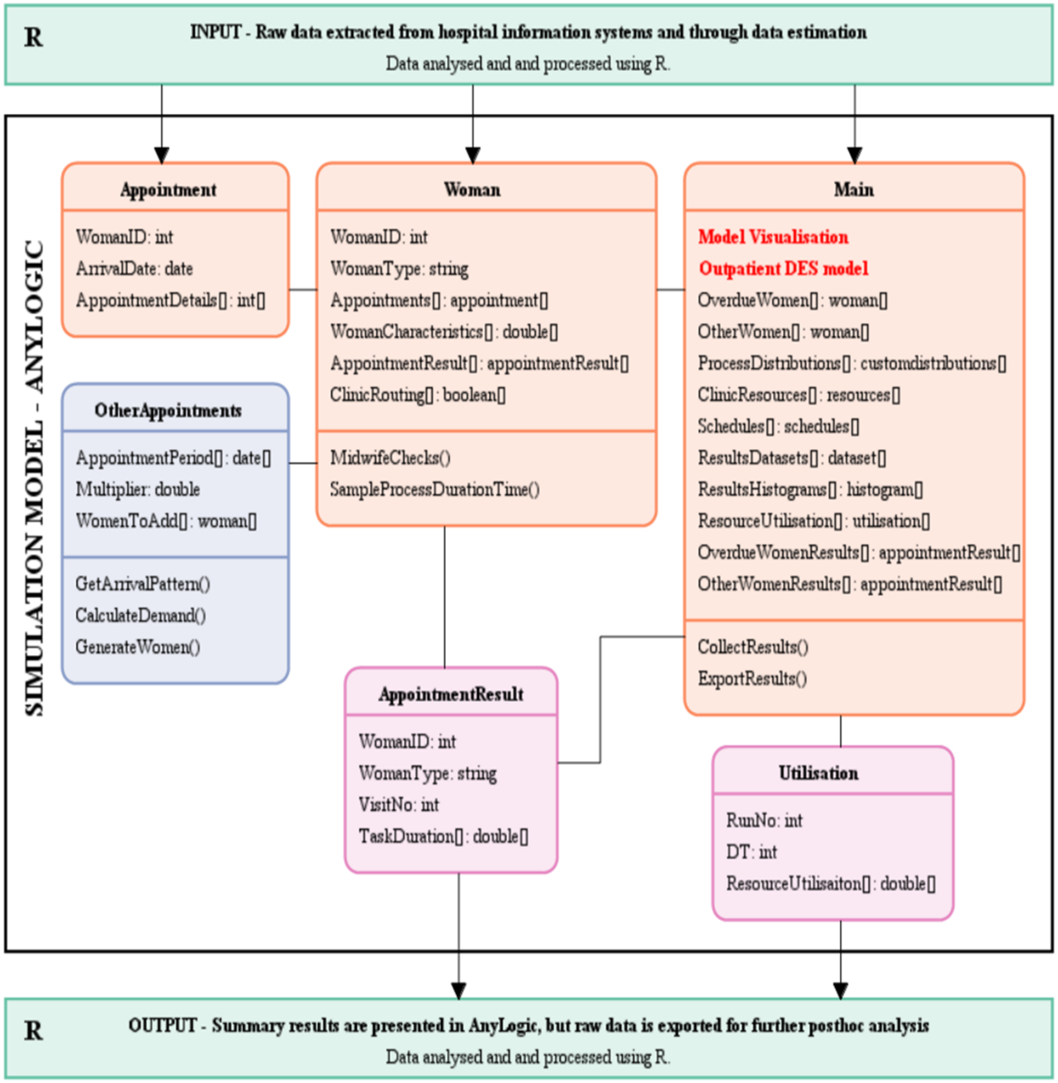

Figure 4: A simplified presentation of the interrelationship between model components.

3.2.1 Type of Hybrid Model and Main Data Exchanged between ABM and DES

The DES outpatient clinic model and the population of women agents who use the clinic which are both located in the main environment. The interactions are illustrated in Figure 4. Distributions representing the process durations, patient pathways, and clinical and demographic characteristics of the women stored in the main environment are sampled each time an appointment is generated for a woman. The woman level characteristics determine the route the woman takes through the clinic, who she sees, and how long it takes. The women interact with each other by competing for clinic resources. If one were classifying the model it could be considered as a pragmatically hooked ABM DES model (Eldabi et al 2016). The women have been modelled as agents to allow future development and provide a base for future expansion of the model. One could argue that the women in this model are simply entities in a DES model, or that the model itself is a hierarchical DES model.

3.2.2 Input

The input component was introduced in section 3.1. Data relating to arrival patterns from hospital information systems were extracted by the data acquisition group and manually by Tone Breines Simonsen. Any identifiable information is removed from the extracted data for data protection reasons.

3.2.3 Main

The main component is the core "agent" in an AnyLogic context of the model, acting as the environment that all the other agents are placed in. It contains the outpatient clinic DES model logic, including the clinic visualization which is used to validate the model with clinic staff, and result collection functionality. A simplification of the clinic DES model which is located in the main environment is presented Figure 5.

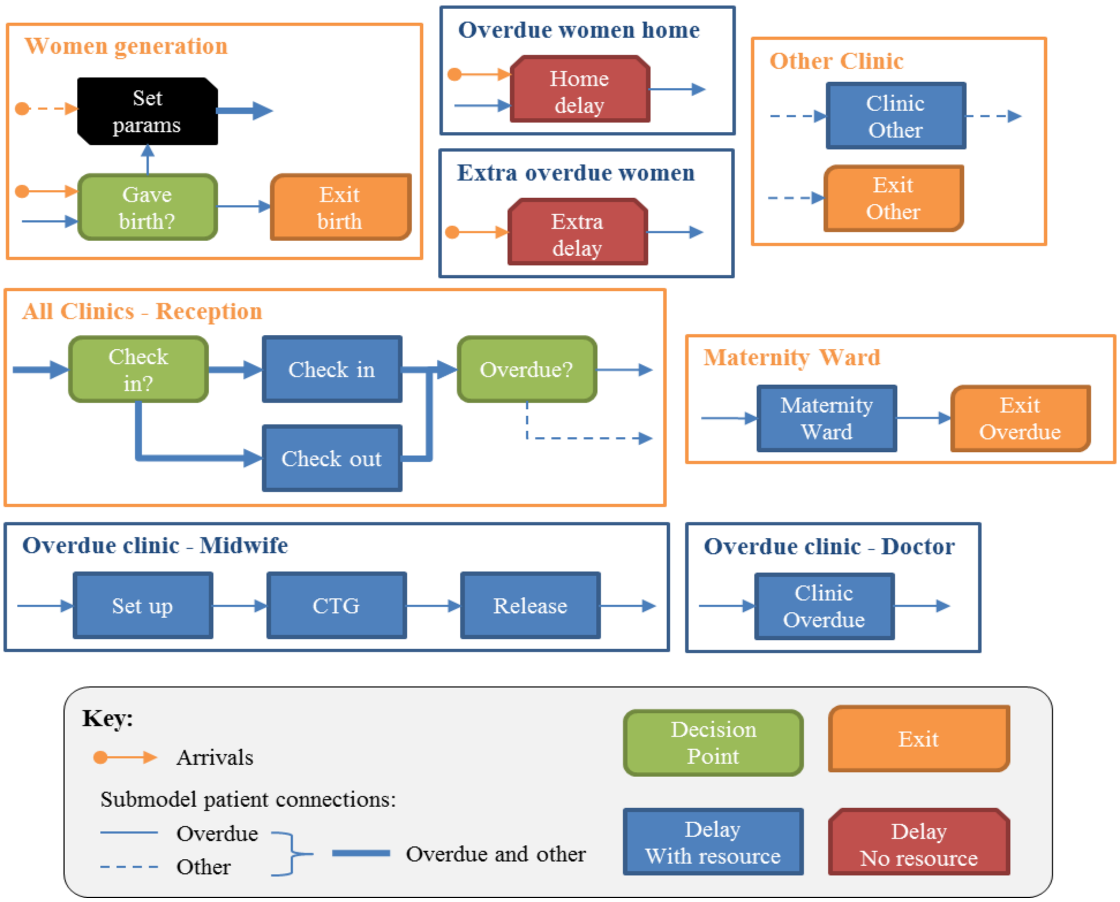

Figure 5: DES clinic component of the "Main" environment. Visualization and results are excluded.

The DES model is based on the conceptual model presented in Figure 3. The agents that interact with the clinic model are of type Woman (section 3.2.3). The model can currently use three different arrival mechanisms:

1. Deterministic - based on historical arrival patterns,
2. Partly stochastic - variation around the historical arrival times, or additional demand generated based on historical arrival patterns,
3. Completely stochastic - not based on historical arrival patterns.

Overdue women and other clinic women are generated in the "Women generation" part of the DES; all overdue women are created at the beginning of a model run, and are moved to the "Overdue women home" part of the DES. Each woman is assigned one or more Appointment (section 3.2.4) agent, which is used to schedule her arrival time in the DES clinic model. The other women who attend the other clinics are generated randomly based on a Poisson arrival pattern with a specified rate, which can vary over time. We use the partly stochastic arrival method of generating additional overdue clinic demand following historical arrival patterns. In order to achieve this we create a population of OtherAppointments agent (section 3.2.5) to represent each day for which we increase demand.

When an overdue woman or an other clinic woman is generated, they are assigned various characteristics and methods, including an appointmentResult agent to collect results about each clinic visit (section 3.2.6). When a woman arrives for her appointment she enters the "All Clinics – Check in/out" part of the clinic DES. This represents the check in and check out processes, which are conducted by shared reception staff resources, and the allocation of the clinic capacities and waiting resources. Women can only arrive when the clinics are open, and the schedule is shown in Table 1.

Table 1: Selected Main level parameters, including clinic times.

	Shared					**Overdue clinic**					**Other clinics**				
	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri
Arrival rate/h						**Based on historical demand**					25	25	25	25	25
Waiting/people															
Room	10	10	10	10	10										
Corridor	10	10	10	10	10										
Resources (No.)															
Admin staff	2	2	2	2	2										
Doctors						2	1	2	2	2	9	9	9	9	9
Midwives						2	2	2	2	2					
Midwife beds						3	3	3	3	3					
Opening times															
Lists start	08:00	08:00	08:00	08:00	08:00										
Lists end	10:30	10:30	10:30	09:30	10:30										

After check in the overdue and other women are routed to the "Overdue Clinic – Midwife" or the "Other Clinics" part of the model, respectively. The other clinic women go through a simple representation of the other clinic where the entire visit is condensed into a single sampled length of stay. Upon completion of their consultation the other clinic women return to the "All Clinics – Check in/out" part of the model to check out and exit the model.

The overdue outpatient clinic women go through the detailed midwife processes, which reflect the stages indicated in Figure 3. A woman is set up in a midwife bed and connected to a CTG machine by an available midwife. The midwife may need to stay with the woman, or may be able to set up, check on, release or set up another woman in another midwife bed. The midwife then checks back in on the woman a number of times, estimates for the number of checks were provided by midwives, until the woman's scan is complete. The midwife then releases the woman, who can proceed to the "Overdue Clinic – Doctor" part of the model.

When a doctor is free, they will call the woman in for their consultation. Upon completion of their consultation the woman returns to the "All Clinics – Check in/out" part of the model to check out. Depending on the woman's characteristics, she may return to the "Overdue women home" or to the "Maternity Ward", if she is referred for induction.

The DES model periodically collects utilization results (section 3.2.7) for all model resources: staff, waiting areas, rooms and equipment each defined time step (15 minutes). The time step can be adjusted, but setting it too low, will affect the models execution time.

3.2.4 Woman

The Woman agent, see Figure 4, represents all women who visit the overdue pregnancy clinic and the other clinics, represented in the Main agent (section 3.2.2). The agent contains parameters and functions relevant for decision making in the model. Each woman has a non-empty population of Appointments (section 3.2.4), and a population of Visits (section 3.2.6) equal to the number of appointments.

The agent contains parameters that relate to their visit, including service times (e.g. time to check in, time with midwife, consultation time etc.), the number of checks and routing parameters, that control the movement of the agent through the DES clinic model at specified points. The service times, number of checks and routing parameters are updated when the patient arrives at the clinic. Their distributions are defined in the Main agent.

3.2.5 Appointment

Appointment agents (class) see Figure 4, are used to generate events that are pre-planned and scheduled according to historical data. Each Woman (section 3.2.3) in the deterministic and partly stochastic variants of the model contains a population of Appointments. The Appointment agent consists of the patient's ID, the appointment date/time, and flags that indicate whether the patient made the appointment or not, they were a new patient or a returning patient, they gave birth before there appointment, and whether they were induced after the appointment and if this induction was planned. If the model is being driven entirely or partly by historical data, then the appointments are generated for each patient during the model startup. If the model is run in the entirely stochastic setting, then appointments are not used.

3.2.6 Other Appointment

The OtherAppointment agent population (a collection of class OtherAppointments), see Figure 4, is located in the Main agent (section 3.2.2) and contains functionality to generate additional demand based on the historical appointment data imported into the model through R. This agent allows the user to specify the days and periods (start and end times) that the additional demand arrives over. The additional demand can vary day by day e.g. 20% higher on specified days, and 100% higher on others. There are two options for generating this demand, randomly over the specified period, or weighted by the historical arrival pattern ("scheduled"). This agent then generates additional women, each consisting of one appointment and routing parameters that will result in single visits to the clinic, to compete for resources with the historical demand and the other clinic women.

3.2.7 Appointment Result

Each woman (section 3.2.3) contains a population of AppointmentResult agents (a collection of class AppointmentResults); see Figure 4, corresponding to the number of visits (appointments) to the clinic. This agent records activity (e.g. check in, CTG set up, consultation etc.) waiting and process times, and the total length of stay of their visit. Additional for overdue women the number of CTG checks is collected.

3.2.8 Utilisation

The Utilisation agent (class), see Figure 4, is based in the Main agent (section 3.2.2) and is responsible for collecting utilization results for each resource in the DES model every defined number of model time units (time step). It records, the runNo, for multiple runs of the model, the time stamp, the number of doctors, then the utilization of the following resources, over the defined time step: reception staff, corridor waiting area, waiting room, midwives, doctors (the aggregate utilization of the overdue clinic doctors, FØD1, FØD2, ØHJ, and ExtraDoctor), OtherDoctor (the other clinics resource), Room 026 and Room039 (the rooms where the midwife beds are located), and AfterClose, which is a resource used to sweep through the model to clear any women that remain after the normal opening hours.

3.2.9 Output

A new Utilisation agent (instance of class utilisation) is created and added to a collection of Utilisation agents each time step. At the end of the model run, a function is called to iterate through these Utilisation agents and to populate model datasets and histograms to produce the appropriate utilization graphs over time and histograms for visualization purposes.

Every time a woman completes an appointment, whether it be an overdue or an other clinic woman, her appointmentResult is added to a corresponding collection of appointmentResult agents. Like the Utilisation agent collection discussed previously, a function is called at the end of a model run to iterate through these collections to update histograms associated with the wait and service times for each process and the total length of stay.

The process described above is used to update collections during the Monte Carlo experimental runs. At the end of each of the 50 runs, the results are collated and the raw data is written out as text files to be analyzed in R.

3.2.10 Model Validation

Arrival patterns replicated historical demand. Length of stay (Los) information is not collected for the clinic, so the model is validated against LoS estimates provided by the midwives. The LoS results depicted later in Figure 8 were judged by clinic staff as being accurate. Extreme value testing was carried out with respect to arrivals and resources and the model visualization was used to validate the model.

4 ILLUSTRATIVE EXPERIMENTS

This section presents a very simple use case of the model over the period from 19.06.2017 to 05.08.2017. The four scenarios presented in Table 2, are to give the reader an idea of what the model can be used to assess. Figure 6 illustrates the appointment profile during the modelling period. The focus of this paper is the technical aspects of the model and not the results per se.

Table 2: Illustrative scenarios.

Scenario	**Description**
Base	The status quo. Historical data. Original estimates from clinic staff
S1 – Demand	100% increase in the arrivals of Overdue clinic patients. Based on Figure 6.
S2 – Midwife	Increase the number of midwives from 2→3
S3 – Both	S1 + S2

The outpatient clinic in this example operates most days between 08:00 and 10:30. There is no warm period as the clinics start from empty each day in the illustrative experiments.

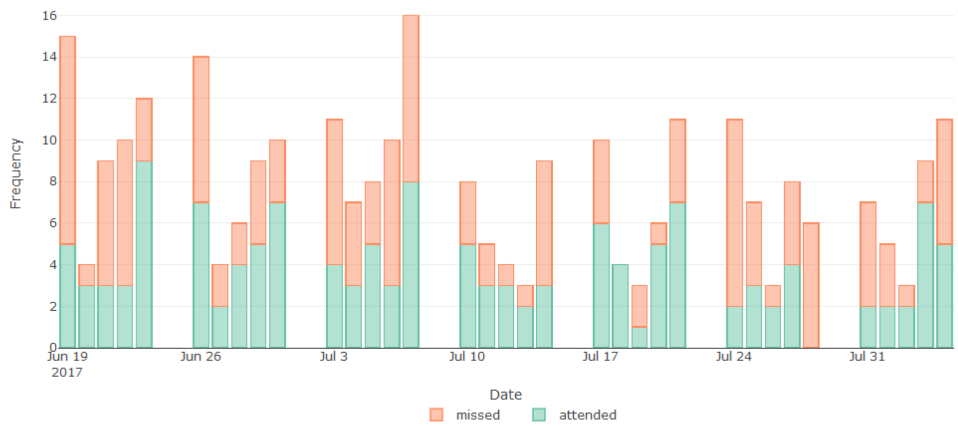

Figure 6: Appointment profile (x-axis = days of the week. y-axis = number of appointments).

4.1 Results

The scenarios were evaluated using Monte Carlo runs of the model (consisting of 50 runs). The model collects many detailed results that were mentioned in sections 3.2.6 and 3.2.7. We present selected results with respect to the four scenarios. All results collected can be presented over time in addition to specified points; individual run results can also be presented.

Figure 7 presents the average utilization for: the reception staff, the waiting room, the midwives and the overdue clinic doctors. The x-axis corresponds to the scenarios and the y-axis to the average utilization over the seven week model time horizon. The reception staff are not affected by any of the scenarios, with the utilization remaining fairly constant. The doubling of the overdue women arrivals (S1) has the most noticeable influence on the utilization of the selected resources. Also as expected adding an additional midwife (S2) reduces the midwife utilization. Combining scenarios S1 and S2 (S3) reduced the utilization of midwives, but this additional midwife coupled with the increased demand, led to an increase in the doctor utilization. It should be noted that these results are the average over the modelling period, and that during the period at multiple points resources are utilized 100%. Also what is not shown here is how often clinics overrun. This functionality will be added to the model.

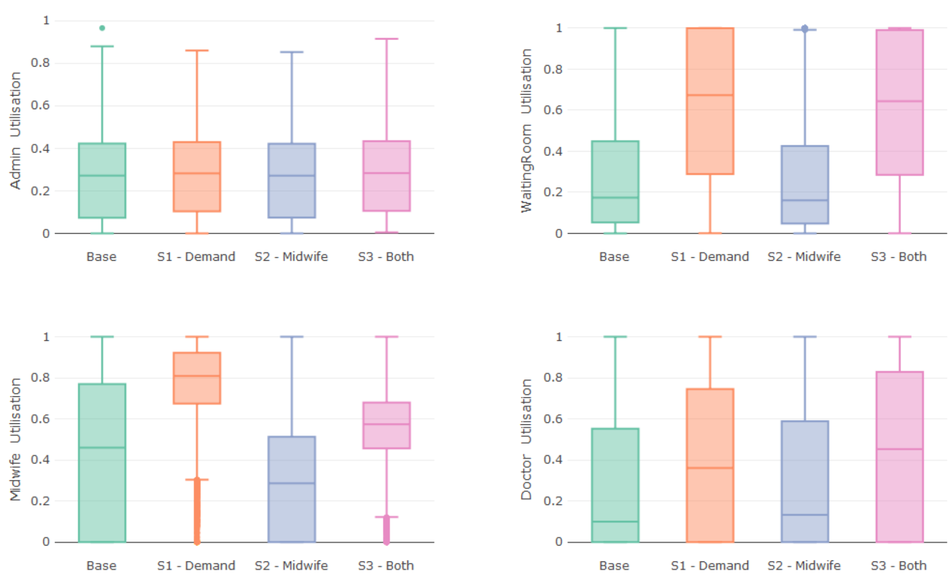

Figure 7: Selected resource utilization results. Averages from Monte Carlo experiments (50 runs).

Figure 8 provides selected average durations for: total length of stay, time spent checking in and out, time spent with midwife and time spent with doctor. All of the times presented in Figure 8 include waiting time and service time. It shows that it is the total time spent with the midwife that drives the increase in length of stay in S1 and S3. The time a patient spends checking in and out is hardly affected by the scenarios, as the overdue patients make up a fraction of the demand for the reception staff resource. The doctors cannot see an overdue patient in the scenarios presented here until the patient has gone through the midwife processes. The midwives act as a buffer/bottleneck, shielding the doctors from the increase in demand.

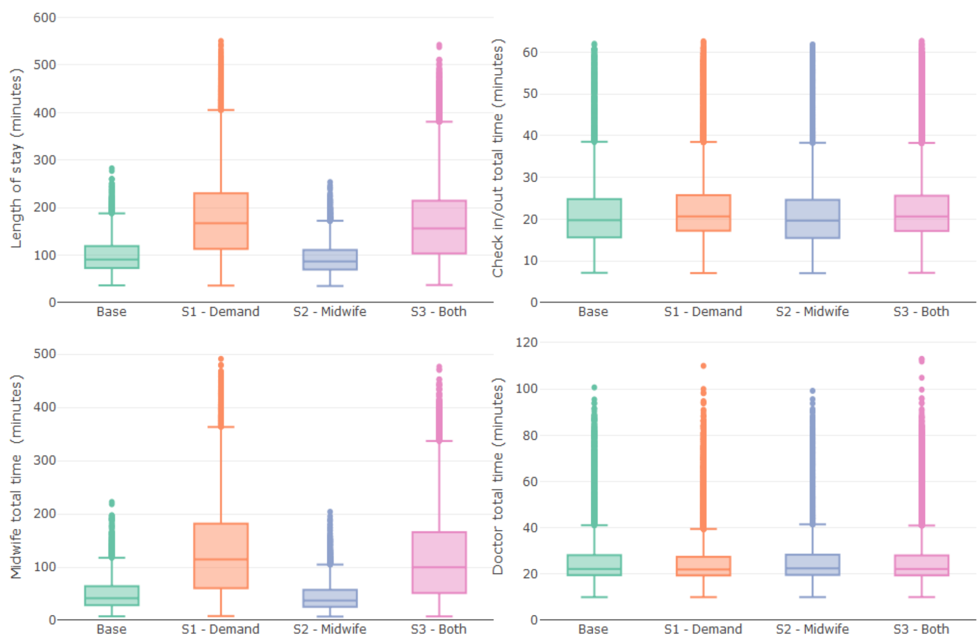

Figure 8: Selected duration results. Averages from Monte Carlo experiments (50 runs) for thefor the 7 week modelling period.

5 CONCLUSION

This paper provides a technical overview of a hybrid model of an overdue pregnancy outpatient clinic in a large Norwegian hospital. A DES model of the outpatient clinic is linked with agent based representations, of women, and crude agent based elements to collect results and drive the model. The model interfaces with R to receive input data and to export to R for post hoc analysis, and to be analyzed in a perhaps better suited environment following a key principle of modelling, including hybrid modelling, using the appropriate tool or representation to do the job.

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