Understanding the impact of whiteboard on A&E department operations using hybrid simulation

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ABSTRACT

This paper uses hybrid simulation to evaluate the impact of a whiteboard on the workflow of an A&E department. Hybrid simulation in this context is defined as the integrated use of discrete event simulation and system dynamics; we illustrate how discrete event simulation and system dynamics, by themselves, are incapable of meeting the objective. “Parsimonious” and “divide and conquer” principles for model-building have been followed. We also highlight how a slight modification to the “divide and conquer” approach can assist multi-method users. This paper has deployed novel approach of hybrid simulation in the context of healthcare. It attempts to link value proposition of information system(whiteboard/ electronic patient tracking system) to workflow of A&E department. Due to technical limitation with respect to automatic exchange of information between system dynamics and discrete event simulation, potential of hybrid simulation could not be deployed to maximum level.

Keywords

Simulation, system dynamics, discrete event simulation, accident and emergency department, hybrid simulation, schedule pressure, Whiteboard/ electronic tracking board

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Introduction

There has been continuous increase in waiting times in British hospitals for many years (Audit Commission, 2001). In 'The NHS Plan', government pledged that by 2004 no one should wait for more than four hours in the Accident and Emergency (A&E) department (The NHS Plan, 2000). Certain exceptions were made since January 2005; from 100% it has been modified to 98% (Department of Health, 2003). Approximately 13 million people attend around 200 major A&E departments in England every year, with no restrictions on attendance. Around 80% of the attendees are discharged home, rest are admitted to in-patient beds. The 4-hour target is a major national performance indicator for receiving significant increase in funding. It was important to give evidence of attaining such improvement targets; however how to reduce waiting times remained unclear (Cooke et al, 2004).

In many cases, planned improvements are being linked to demanding service targets and hospitals that do not achieve those targets could face financial and other penalties. Many hospitals made strenuous efforts to meet these targets by allocating additional staff or other resources to A&E departments, changing emergency patient management or in other ways (Mayor, 2003). Many effective approaches from operations and management science such as simulation have been applied to improve A&E operations to achieve targets. There is also evidence of deployment of information technology to automate and improve clinical and operational services in A&E (Levin et al,2006; France et al, 2005;Aronsky et al;Boger and Vincennes,2003).

The management of a London district general hospital (LDGH) is interested in implementing an electronic white-board to improve A&E operations. As this is expensive investment, prior to implementation, management wanted evidence of its impact on A&E operations in the virtual environment. The most important indicators of A&E performance to them are throughput, time-in-system and breaches. Breaches represent the number of people who fail to meet the 4-hour target. The main objective of this study was to capture the impact of implementing an electronic white-board on A&E processes. This is an example of evaluation of the value proposition of information systems in healthcare setting (Green and Young, 2008). Despite the intangible nature of benefits associated, this paper has attempted to provide potential solution.

The structure of the paper is as follows: the next section provides description of background and research question. Section three provides elaborate discussion on scoping phase, followed by section on modelling. The last section discusses the results, limitations and potential future work.

Background and Research Problem

A&E departments have a high public profile: media stories about waiting times and inappropriate care such as readmissions are quite common. Demand for A&E services in England and Wales has increased. The increased demand is due to demographical changes in absolute numbers as well as in aging. These have an additive effect on demand. An increase in population increases the volume of patients while aging augments the complexity of the required services. Information technology (IT) has educated customers of healthcare services, leading to increased expectations. These factors put pressure on healthcare providers to improve the services.

In respond to these pressures the government has committed to improve the health services and to this end has committed extra resources to NHS for operational improvements. Planned improvements are linked to demanding service targets. The NHS Plan (2000) stated that "by 2004 no one should be waiting more than four hours in A&E department from arrival to admissions, transfer or discharge". Responding to certain clinical exceptions, this target was modified from 100% to 98%, since January 2005. Hospitals were put under intense pressure to meet these targets; hospitals that do not achieve those targets can face financial and other penalties.

Hospitals are part of the service sector. The major difference between service and other sectors is that both servers and customers are humans. Humans, unlike machines, respond to the changing work environment. Another major difference is that services are supplied instantaneously; there is no buffer of finished goods to protect against changing demand. Thus, in order to maintain the quality of services, it is vital to match demand with supply. The high level of uncertainty associated with demand makes the task of aligning demand with supply more difficult. This difference in demand and supply builds up schedule pressure. Unlike machines, servers in service industry, e.g. doctors and nurses in A&E, respond to this schedule pressure by changing their performance and behaviour. For timely and appropriate response from the human service agents, it is important to have the accurate information about the status of the system where status of the system is ever-changing. A&E is an example of such an ever-changing system.

The A&E department is a challenging and dynamic environment from a clinical and operational perspective (Nemeth et al, 2008) as its state changes continuously. Like other service sectors such as banking, hospitals have also sought solutions from IT. There are many opportunities for IT in healthcare (Mendonca et al, 2004; Berglund et al, 2007). However, successful adoption of new IT in healthcare settings has been limited in many instances. A number of barriers against IT adoption have been well documented in literature (Broome and Adams,2005; Riet et al, 2001). One of these barriers is a lack of understanding about how IT adoption relates to workflow. Due to its inability to show a tangible impact on workflow, such initiatives struggle to get support from senior management (Wong et al,2008).This is the problem LDGH was facing. A&E management was aware that whiteboard has been successfully deployed in many emergency departments, and was able to considerably improve the processes. Due to the lack of reported studies demonstrating the impact of whiteboard on workflow, the LDGH approached our modelling team to provide the requisite analysis.

Scoping Phase

As the major function of whiteboard is to provide information about the dynamic status of the A&E department, the objective of this research project was to capture the impact of information flow on workflow (process of patient flow). Simulation was chosen as the method. Several papers have emphasized the suitability of simulation for patient flow research (Connelly and Blair, 2004; Bagust et al, 1999; Eldabi et al 2007, Brailsford et al, 2004; Brailsford and Hilton,2001; Wolstenhome, 1999; Lane et al 2000). Two simulation techniques, discrete event simulation and system dynamics have become quite popular in the healthcare domain. A fair amount of literature is available on use of both discrete event simulation (DES) and system dynamics (SD) for the purpose of A&E improvements.

Although an early decision of deploying simulation was made in the initial stages of the project, the main challenge was whether to adopt a DES or SD approach. Patient flow in A&E has more resonance with process, DES due to its process stance, was decided as the method of choice. While SD struggles to capture the stochastic and sequential nature of the process, DES's inherent capabilities easily represent the process without compromising on the simplification of reality (Martin and Raffo, 2000). Another important factor which influenced the selection of DES was the expertise of modelling team, given that modellers feel comfortable with what they know best and tend to use the method they know rather than the method dictated by the problem (Brailsford and Hilton 2001; Chahal and Eldabi, 2008).

In the initial stages of conceptual modelling it became evident that although DES due to its process stance was able to capture the A&E patient flow and provide resolution up to the individual patient level which was necessary to meet the objective, it was struggling to model the impact of information flow, which is the main output of electronic whiteboard. As the objective was to find the impact of white board on workflow, it was necessary to capture the dynamic relationship between information displayed by whiteboard and its impact on A&E processes. The whiteboard displays the information regarding the real time status of A&E department and backlog of patients. Backlog is built up when there is a difference in supply and demand. This imbalance in supply and demand is responsible for long waiting times and eventually breaches (patients failing to meet the 4-hour target). Since the production and consumption of services is instantaneous, the imbalance in supply and demand manifests itself in the form of schedule pressure. The performance (productivity) and behaviour of human resources is affected by the schedule pressure (Oliva,2002; Dierks et al; Arboleda et al, 2007). Further, LDGH's physicians indicate that the relationship between schedule pressure and productivity is a hump shaped curve – i.e. the doctors' productivity increases in response to schedule pressure slowly and after reaching a peak starts decreasing.

In order to capture the impact of whiteboard on services, it was essential to capture the dynamics of complex relation between information flow, schedule pressure and productivity. As DES has been initially adapted from manufacturing, where productivity of machines is not sensitive to the changes in environmental factors such as schedule pressure, DES modellers normally don't view the process from these perspectives. SD, due to its stance on non linear relations and feedback, lends itself naturally to capture this type of dynamic complexity. Hence, SD was selected as method of choice for analysing the impact of white board on productivity. However the ultimate objective was not to analyse the relationship between information flow (whiteboard), schedule pressure and productivity, but a step further – the influence of this relationship on workflow process of A&E. As one of the main indicators A&E performances for LDGH is number of breaches, it is vital to use a method which is capable of tracking individuals.

SD, due its stance on aggregates, does not provide individual level resolution. In order to meet the objective it was necessary that modelling tool not only capture the dynamic complexity of relation between information flow, schedule pressure and productivity but is also capable of capturing the process view of patient flow and detailed resolution up to individual level. From the above discussion it is quite clear that where both SD and DES were capable of capturing only certain aspects of the system, both were struggling to capture other aspects. As the limitation and strengths in terms of capturing the information required to meet objective were complementary, it was decided to use hybrid simulation, which is proposed in literature as the potential solution capable of capturing both detailed and dynamic complexity of healthcare domain (Chahal & Eldabi, 2008; Brailsford et al, 2003). By hybrid simulation in this context, we imply the integrated use of SD and DES. The following sections provide information about development of SD, DES and hybrid models.

Modelling

The model development process follows the “Divide and conquer” and parsimonious Principes (Pidd, 2001).

Divide and Conquer principle

This is also known as decomposition of main purpose (Powell, 1995). The main objective is divided into small objectives and then models for each objective are developed. The method for development is selected before the decomposition of objective. However we have modified this ideology slightly – we argue that instead of committing to method before decomposition, it is better to commit after decomposition. This modification is well placed in context of contemporary trends towards use of multiple and hybrid methods for problem solving (Minger, 2002; Brailsford et al ,2003; Chahal and Eldabi, 2008; Eldabi et al, 2007). As it was decided to use the hybrid simulation for solving this problem, applying “divide and conquer” approach the main general objective “capture of the impact of whiteboard on process” was divided into three separate objectives:

1. Develop a model to represent the variation in performance (productivity) in response to white board information flow.
2. Develop a model which captures the detailed activities of A&E processes with high resolution.
3. Link them to achieve main objective (which is impact of object1 on objective2).

As discussed in previous section, it was agreed that SD is more appropriate for first objective and DES for second objective, both SD and DES models were developed. In order to meet the third objective it was important to link and execute SD and DES in an integrated manner (hybrid simulation).

Parsimonious principle

Pidd (2001) has advised that rather than attempting to build a complete model from scratch, it is advisable to start with simple small model followed by gradual extensions. As Majors area and physicians were described as the main bottlenecks, we limited our first version of model development to Majors and physicians only. Majors is a part of A&E where patients with high (but not life threatening) severity are seen. are seen. As this was first attempt of deploying hybrid simulation in healthcare, it was important for us to see the feasibility of this approach on simple SD and DES models. This factor further advocated the use of the parsimonious approach. The idea was that if the first phase passes the feasibility test, the model can be easily extended to include other areas and more detail. The following sub-sections provide the description of model development for each of the above objectives.

Development of SD Model

The main objective of the SD model was to represent the variation in productivity (performance) in response to information flow from white board. Whiteboard provides the information regarding backlog and number of people waiting over 3 hours (thus indicating the number of people to be discharged in the next hour or the desired discharge rate). LDGH team maintain that instead of the overall backlog, it is the number of people waiting over three hours (conveyed to them by red dots on a white board) which causes pressure in the system. The interactions between variables such as backlog, number of people over 3 hours and schedule pressure are captured with feedback loops. Feedback refers to information about behaviour returning to affect subsequent behaviour (Gillespie, 2004). These feedback loops can be balancing or reinforcing.

In Figure 1, the feedback loops represents the relation between information flow (backlog, number of people over three hours) ‘schedule pressure’ (SP) and productivity. In this SD model, SP is the core endogenous variable which affects productivity. Schedule pressure is defined as ratio between desired discharge rate and normal discharge rate. According to expert opinion from LDGH, the relationship between SP and productivity is hump shaped. Productivity increases in response to increase in SP and after reaching a plateau, starts decreasing. The hump shape relationship is avoided by splitting the effect of SP on productivity into two variables (Sterman, 2000): motivational productivity and overwork productivity. Motivational productivity forms a S-shaped curve in response to SP for increased productivity whereas overworked productivity forms a S-shaped curve with respect to SP to decrease productivity. Look-up tables have been used for these variables (Sterman, 2000).

<<Insert Figure 1 about here>>

Figure 1 shows the relation between these variables in the causal loop diagram. Increase in SP increases the motivational productivity (intensity of work) which increases discharge rate, discharge rate decreases backlog which subsequently decreases the number of people waiting over three hours. The relationship is represented by the balancing feedback loop. On the other hand the relationship between backlog, number of patients waiting over three hours, SP and overwork productivity is represented by the reinforcing loop. The reinforcing loops destabilises the system. An increase in SP can decrease the productivity, which subsequently decrease the discharges rate, leading towards an increase in the backlog and the number of patients waiting over 3 hours with a subsequent increase in SP. Dominance of these loops is sensitive to SP. Up to a certain level of increase in SP, the balancing loop dominates. Beyond that level, the reinforcing loop becomes dominant leading the system towards greater backlog. In order to quantitatively analyse these relationships, the causal loop diagram was converted into a mathematical model. Simulation experiments with different scenarios were performed for validation and experimentation. Software Vensim was used for experimentation.

Development of DES Model

The main objective of DES model was to capture the detailed activities of A&E processes and provide information such as throughput, time-in-system and number of breaches. DES models of A&E are quite common. The models reported in literature examine patient routing and flows, scheduling of resources, staff planning and reengineering of A&E processes and policy design (Kamoshi and Mousavi, 2004; Cooke et al, 2002, Fletcher et al, 2007; Kolker,2008;Gunal and Pidd (2007); Blake and Carter, 1996; Centeno et al, 2003; Mahapatra et al, 2003; Miller et al 2004; Gunal and Pidd, 2007).

We used Simul8 for the development of the DES model. For the purpose of understanding the flow of patients through Majors department a flow chart of the process was developed. The basic elements of DES model are:

- Flow chart: represent the flow of patients from arrival to exit
- Entities: items to be processed, patients in this case with their attributes and arrival distribution
- Activities: the various task patients go through from arrival to exit
- Resources: agents or equipment required for performing activities, in this case doctors, nurses and cubicles
- Entity routing: The logic for flow of entities under various conditions

As the main driver for this whole project was whiteboard, we emphasised the inclusion of whiteboard in the DES model. DES modellers have been criticized that rather than representing the preference of clients, modellers focus more on the technicalities of model. Whiteboard provides information about patients who are still in the system. This feature of whiteboard is imitated by a queue which contains information such as time-in-system for all patients still being processed. It provides us information about total backlog and number of patients who have been is system for more than three hours. We noticed that the inclusion of whiteboard enhanced the engagement and interest of clients in the process of model building.

A screen shot of the simul8 model is shown in Figure 2. It shows the overview of flow of patients through Majors area in A&E. Most of the data required was gathered from observations, expert opinion and the LDGH database. As accuracy was not of prime concern, expert opinion was used to generate most of the data. In the baseline model, real data from LDGH for a ‘quiet week’ was used. In other scenarios exponential distribution was used for walk-in and ambulance arrivals. Activity durations were modelled using triangular distribution. The main outputs of interest are time-in-system and number of breaches.

<<Insert Figure 2 about here>>

Development of Hybrid Model

We have already discussed that neither DES nor SD on their own were capable of meeting the objective; hence hybrid simulation was proposed as the potential solution. The main objective was divided into three objectives defined in a previous section. The first and second objectives were achieved by SD and DES models respectively. However in order to achieve the third and main objective, the SD and DES models were required to integrate with each other. For successful integration of SD and DES there were two main challenges:

- Through what and how would SD and DES be linked/mapped to each other?
- At what frequency would SD and DES component of the hybrid model interact to exchange information with respect to their run time?

In order to overcome first challenge, it was important to figure out the information/data which is transferred from DES to SD and vice versa.

From DES to SD

In the literature, it is reported that productivity is affected by schedule pressure and schedule pressure increases with backlog. LDGH A&E physicians maintain that it is the number of people over three hours in A&E which causes pressure, not the actual number of people in A&E. We quote one of the senior physicians – "it is number of red dots (patients waiting over three hours) that puts the system under pressure". SD model on its own is not capable of calculating this number accurately, in hybrid this information about the timely value of this variable is acquired from DES. Hence DES passes down the information regarding number of people over three hours to SD.

From SD to DES

From interviews, it was clear that variation in productivity due to schedule pressure affected the performance of the whole system. Connecting this variation in productivity (output of SD) to the rest of the process was a challenge. After careful observation and analysis of A&E processes, we identified that this variation in productivity was actually manifesting itself into the process in the form of variation in activity duration. Martin and Raffo (2000) have applied the similar ideology in the hybrid model of software project management. There is an inverse relationship between productivity factor and activity duration. During high productivity (increase in SP up to a certain level) physicians were taking less time to perform the tasks.

In the absence of SP, the productivity factor is taken as 1. In such a situation, the activity duration of tasks in the DES model is not affected. Productivity factor and number of people waiting over three hours is the main information which exchanged between two models. SD uses number of people over waiting three hours, which also represent the desired discharge rate (as in order to meet four-hour target, number of people waiting over three hour needs to be discharged in the next hour) along with other variables such as normal discharge rate, etc. To calculate SP and subsequently productivity, DES uses productivity as input to calculate the duration of activities.

This answers what is linked but still does not explain how they are linked. As the models are validated on their own in order to justify their adequacy and ability to capture their respective objectives before they are linked to form the hybrid, it is important that the variables which are exchanged are defined in the respective SD and DES models. This is prerequisite for mapping/linkage between SD and DES elements of hybrid. For example in this scenario, even though the SD model is not able to calculate the number of people waiting over 3 hours accurately, however contains this variable as an endogenous variable. Similarly, the DES model describes the productivity factor in the model. As discussed before, duration of activities on process is inversely proportional to productivity factor; it is included in DES in the form of following equation:

Duration of activity = fn. (Triangular distribution (based on expert opinion)) / productivity factor

The next challenge was to decide when (with respect to their run-time) SD and DES components of hybrid are going to interact with each other for exchanging information. From the previous literature on hybrid simulation, we identified three ways how people have tried to exchange information between SD and DES components.

- Cyclic Interactions
- Planetary Interactions
- Parallel Interactions

Cyclic Interactions: Here SD and DES are run separately and the information is exchanged between consecutive runs. There is no interaction during the run time. The results of the SD model are fed into the DES model as an input. The DES model is run and its output fed back into the SD model. This cycle continues till SD and DES align with each other. Chatha and Weston's (2006) framework for management decision making provides an example of cyclic interactions.

Parallel Interactions: Simulation for both SD and DES are run at the same. The information is exchanged during the run-time. Continuously changing elements represented by SD, such as productivity causes changes in the discrete events. Similarly, discrete elements represented by DES, such as number of people waiting over 3 hours, influences continuous parameters (schedule pressure). Martin and raffo's (2000) work in software process management fits well in to the description of parallel interactions.

Planetary Interactions: In this hybrid simulation (SD+DES), the total run time of SD+DES is equal to total SD run-time and dt of SD is equal to DES run-time. In the whole SD+DES (hybrid) cycle, SD runs once whereas DES runs for n times where n is equivalent to total SD+DES or SD time divided by dt or DES time. Data is exchanged between models after each dt. In these interactions one SD model interact with number of DES models. Helal et al's (2007) paper on synchronisation between system dynamics and discrete event simulation provides an example of planetary interactions.

The selection of interaction mechanisms depends upon the objective of the problem. In this case the purpose was to find the impact of the variation in productivity on the process. For this purpose, productivity factor and the number of people waiting over 3 hours are exchanged between two models. Both parameters depend upon each other and change their values dynamically. In this the SD model represents the environment and the DES model represents the process; both process and environment continuously feed in to each other. This can only be achieved if both SD and DES run in parallel. This was why we decided to have parallel interaction between both models.

The information between SD and DES is exchanged after regular intervals. In order to capture minor disturbances, it is advisable to reduce this interval. In our experiments, as the data was exchanged manually, the information was exchanged after every hour. Both models run for 24 hours and information between them is exchanged 23 times.

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Validation of models

Pidd (1999) discussed black box and open box approaches to validation. In case of the SD model, accuracy was not the objective – most of the data was based on expert opinion, so open box approach to validation was used. After development, the models were shown to the client and different scenarios with changing arrival rate were executed to analyse the effect of increasing schedule pressure on productivity. Results showed that productivity increased with SP up to a certain level before starting to decline. They also show that the increase was gradual, whereas decline in productivity was steeper. This behaviour was validated by the client.

In case of the DES model, again open box approach to validation were used. The model was shown to the client to validate the patient flow and its logic. As many details of the A&E processes were not modelled, black-box approach on its own was not sufficient. However when compared with hospital data, there was not much significant difference in hospital data and model results . Real arrival data for a quiet week was used for the purpose of DES model validation. In a quiet week the SP on system is almost negligible, so it was expected that DES model on its own will be sufficient to represent the real system as there won't be noticeable change in productivity of physicians in response to SP.

Hybrid model was validated using an open box approach. It shows the impact of information flow of whiteboard on the productivity, which subsequently affects the performance of system. The output of the hybrid model was compared with that of the DES model. It was observed that in absence of SP, there was no difference in the output of DES and Hybrid (Figure 3). In the scenario where system is exposed to SP by increasing the inflow of patients, the hybrid model performs better than DES (Figure 4). In the third scenario, the system is put under enormous schedule pressure. This affected performance in an adverse manner. The LDGH team validated the model saying this is exactly what they observe in real life. The next section provides discussion on results.

Results and Discussion

The overall objective of the project was to capture the impact of whiteboard on patient flow. For this purpose it was essential to build a model capable of representing processes incorporating individual level detail as well as the impact of information flow (electronic whiteboard). As mentioned before we have adopted a parsimonious approach (Pidd, 2001) to model development. Parsimonious approach was more important here as we felt this was more appropriate for developing a hybrid model in healthcare setting. Before developing elaborate details covering different aspects of the processes, we tested the utility of this proposed technique on a smaller scale.

<<Insert Figures 3 and 4 about here>>

Two sets of experiments were carried out. The first set was to evaluate the effect of information flow (whiteboard) on process flow. For this, the hybrid model was created with 'quiet week' data where there was no schedule pressure, hence the output of the hybrid model is same as that of the DES model (Figure 3). In order to see the impact of schedule pressure on process activities, it was vital for the system to experience it. So another scenario using exponential distribution to represent an increased inflow of patients was investigated. In this scenario, there is a significant difference in the outputs of the DES and Hybrid models (Figure 4). Although both models are given the same throughput, there is a significant difference in number of patients treated between 180 - 240 minutes and number of breaches. This clearly indicates that performance of systems is sensitive to schedule pressure. In order to experience the schedule pressure, accurate information about the status of the system is vital. Whiteboard provides that information. The information conveyed by the whiteboard has an impact on the workflow by influencing the response of physicians to the changing status.

The second set of experiments was conducted to show the impact of increased frequency of whiteboard update. In order to capture the real added value of electronic whiteboard over manual whiteboard, it was important to see the difference in productivity in response to schedule pressure in both scenarios. For this it is important that information between two models is exchanged in real time. That can be achieved only by automating the exchange of data. Due to technical limitations, in this study, data between the models was exchanged manually. For simplicity, data between two models was exchanged after every hour. As with respect to schedule pressure, the main advantage of electronic board over manual is its frequency of update. In order to show the impact of frequency of update on process, we have used two scenarios: 1) the whiteboard is updated every hour and 2) the whiteboard is updated every two hours. In view of understanding the impact of update frequency on process, data between SD and DES of corresponding hybrid models has been also exchanged after one hour and two hours.

<<Insert Figure 5 about here>>

Figure 5 shows the comparison between the output of the DES and, hybrid models representing update and exchange after two hours, while Figure 4 shows the results of update and exchange after one hour. It is quite clear from the Figure 5 that frequency of information update affects the response time of physicians in the form of enhanced productivity. Timely response to an increase in schedule pressure improves the performance of the system. In the service industry the way service organisations respond to work pressure is a critical determinant of service quality, satisfaction and overall performance of the service organisation (Oliva, 2001)

This study shows the applicability of hybrid simulation in healthcare domain by attempting to translate the impact of intangible benefits of information system in to tangible business process improvement. It also shows the benefit of an electronic whiteboard over a normal whiteboard. It is clear that in service industry, servers respond to pressure by increasing their performance and this increase in performance is subjected to the availability of information. Electronic whiteboard not only provides real-time information about the status of the system, but also improves the response time of servers.

However there are certain limitations as well. The models focus only on Majors and physicians, thus, the scope of the model is very limited. Due to technical limitations with respect to automation of exhange, the time between consecutive exchanges is very large. The model is run for only one day. Another major drawback is that the capability of DES of multiple runs could not be deployed.

In future work we are planning to extend the model to include other areas of A&E and other factors affecting productivity such as time-based fatigue, communication loss, etc. In this limited version, the impact of schedule pressure on performance has been analysed. Schedule pressure also affects the behaviour of people, for example servers in the service industry adopt coping policies such as discharging patients to inappropriate destinations. This is also in our future plans. We will also investigate to how to shift resources from one department to another without having an adverse impact. We believe that this can also be evaluated by exploring the relationship between schedule pressure in different areas and its impact on productivity of the resources of that area. We are planning to automate the information exchange between SD and DES components of the hybrid model. The automation will extend the capabilities and utilities of hybrid simulation to a higher level.

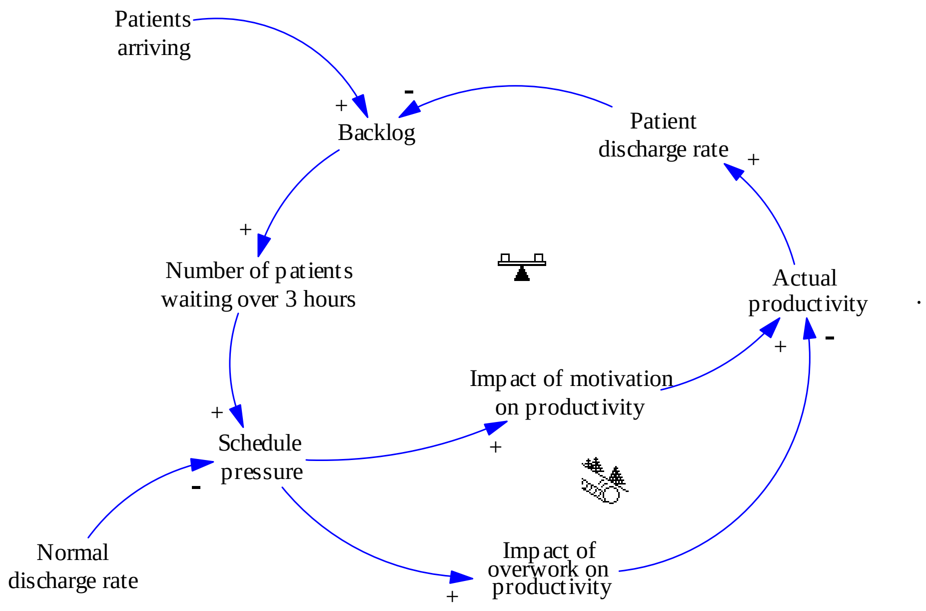


Figure1: Causal loop diagram describing the feedback loops between different variables

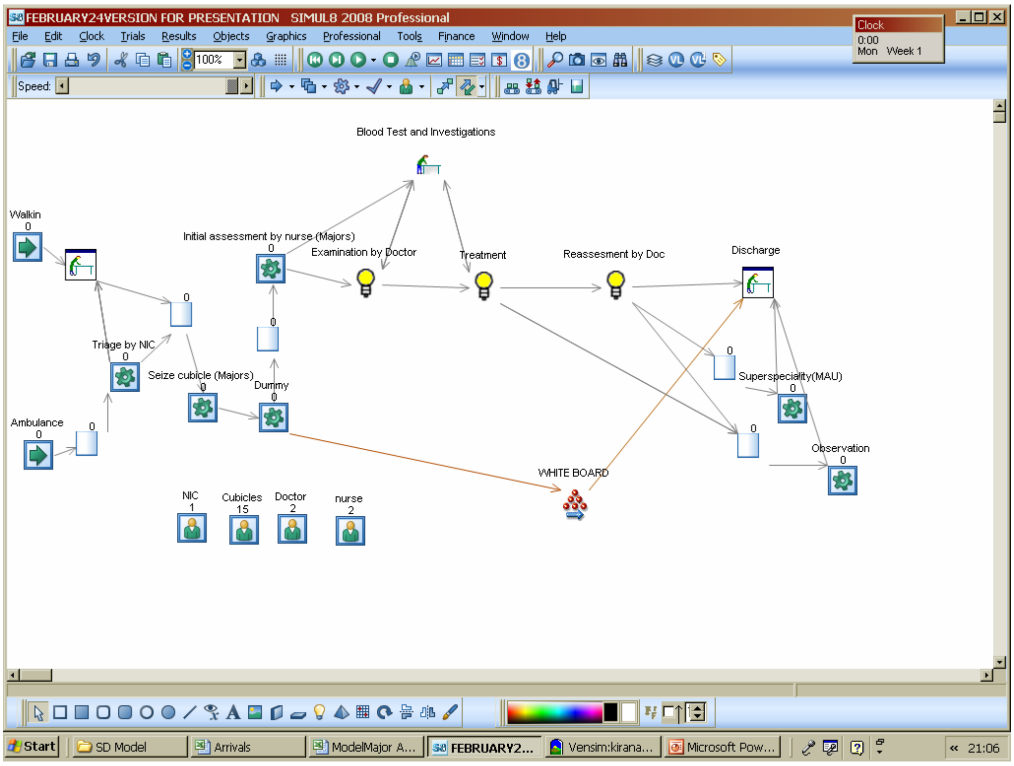


Figure 2: DES model representing the flow of patients in Majors

Figure 3: Comparison between DES model and Hybrid model of a quiet week

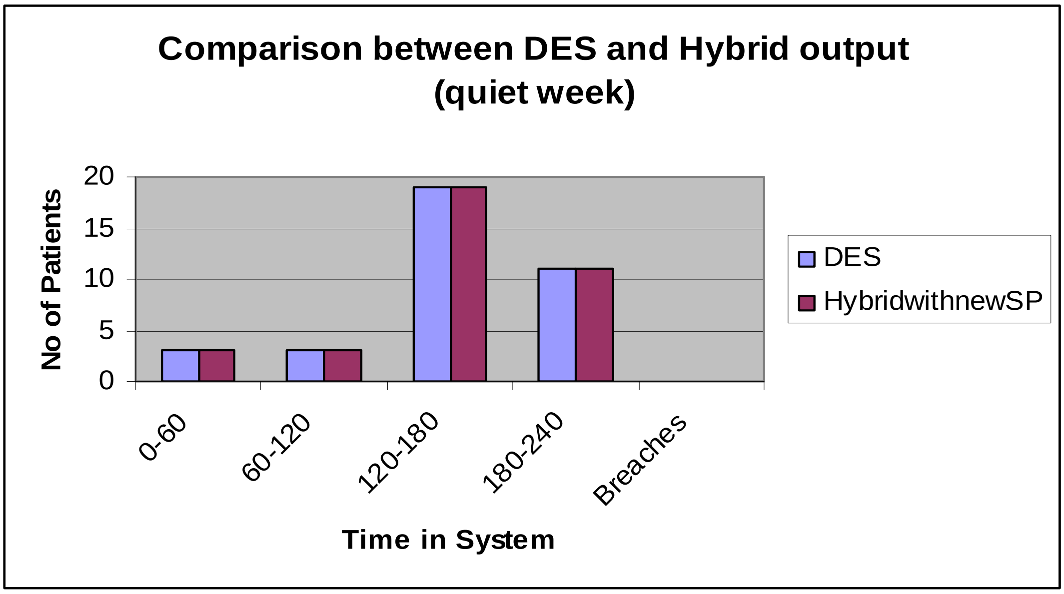


Figure 4: Comparison between output of DES and Hybrid (increased inflow of patients)

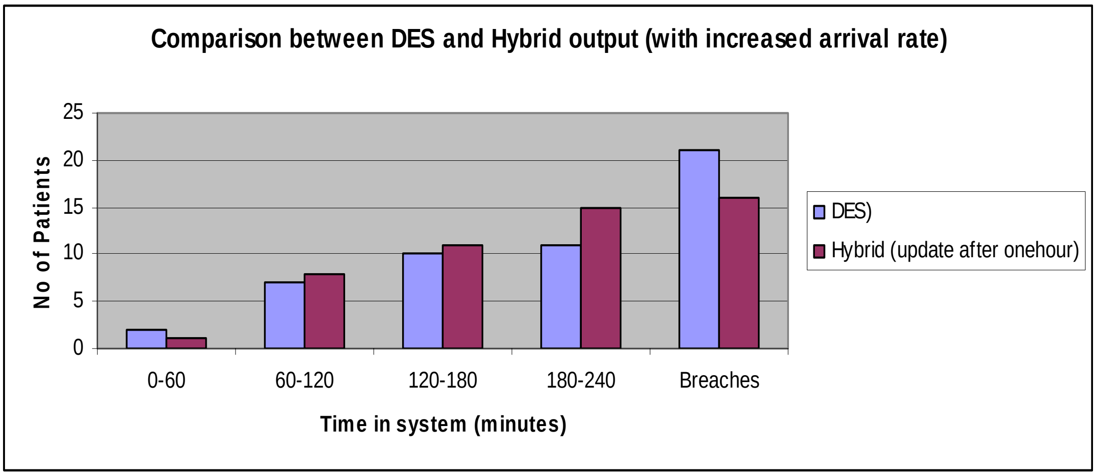
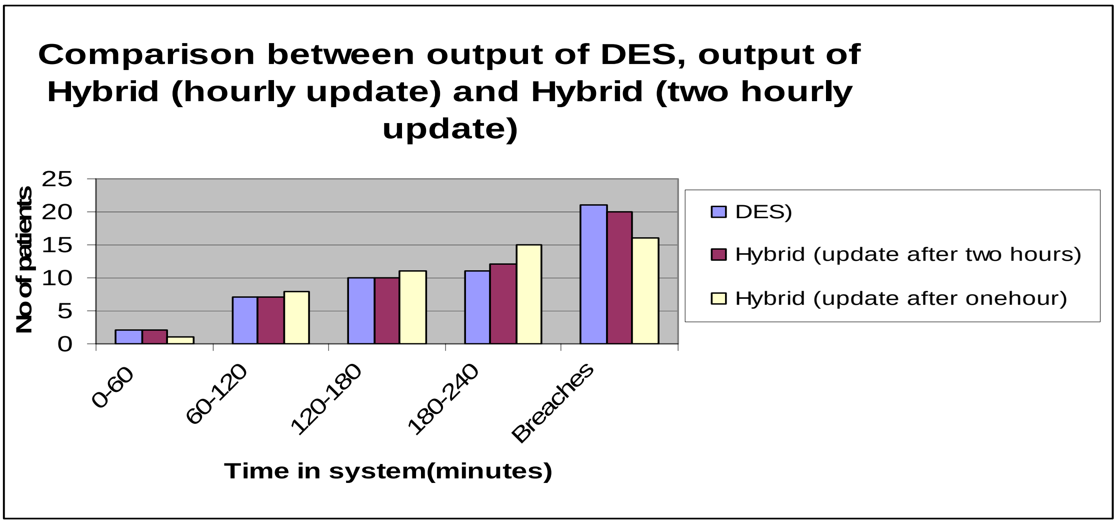


Figure 5: Comparison between output of DES, output of Hybrid (hourly update) and Hybrid (update after two hours)



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