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SYSML FOR CONCEPTUAL MODELING AND SIMULATION FOR ANALYSIS: A CASE EXAMPLE OF A HIGHLY GRANULAR MODEL OF AN EMERGENCY DEPARTMENT

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ABSTRACT

Continual improvements to the efficiency of patient flow in emergency departments (EDs) are necessary to meet patient demand. Discrete Event Simulation (DES) is commonly employed for this purpose, but validation and verification is daunting in that many stakeholders – clinicians, administrators, and engineers – need to understand the system's processes in a unified manner. Therefore, knowledge transfer between stakeholders requires a unified formal approach. We describe the use use of System Modeling Language (SysML) to this end, as well as the results of model validation by comparing hourly census in many areas in the real-world ED with those predicted from simulation, before and after a process intervention. The accuracy of these comparisons provides evidence that a methodologically rigorous DES model, incorporating our method for model verification using SysML, is a valuable decision making tool for judging the utility of interventions to improve patient flow.

1 INTRODUCTION

Nationwide, emergency departments (EDs) are demonstrating increased interest in analytical methods to improve patient flow and to reduce crowding (Connelly 2004, Hung at al. 2007). ED visits continue to increase while the number of EDs has decreased, causing ED crowding, longer wait times, and rising health care costs, according to the CDC's National Center for Health Statistics (McCaig and Nawar 2006). Crowding (patient volume in excess of functional capacity) results when the system is not able to accommodate the demand; this is commonly thought by healthcare practitioners to result from inadequate number of beds, but in fact may result from inefficient processes for patient care and hospital admission. Implementing changes to the physical system can be very expensive, and the target outcomes are not guaranteed. Moreover, there are significant opportunity costs; failed interventions are likely to degrade morale and sandbag further attempts at process change. Discrete-event simulation (DES) may provide a reliable means of mimic the real-world system in a computer model, in order to provide the best chances for success in the real-world intervention. Experimenting with different scenarios in such a computer model could be the cheapest, fastest, and most reliable approach for such highly complex and dynamic systems.

Building a validated and verified DES model for an ED is not a trivial task. An important early step is accurate characterization of patient flow, which medical personnel may best understand, but simulators may best be able to formally describe, as simulation analysts do not often have the medical background to fully comprehend and describe clinical processes. Because of this disconnect, it is important that clinical stakeholders transfer a considerable amount of practical and historical knowledge about their ED processes to system analysts in the most transparent and efficient manner. A formal and unified medium between ED process owners (clinicians and administrators) and simulation analysts must be sought for to reduce effort and error in the process of knowledge translation. *Ad-hoc* methods, such as documents, diagrams and databases, have been traditionally used to transfer system owners' inputs to the simulation analysts in order to understand the system scope for analysis. We propose a better approach in this paper which originates from the model-based system engineering. In our example, we use System Modeling Language, or SysML (http://omgsysml.org/), as a unified platform to model the ED processes and operations.

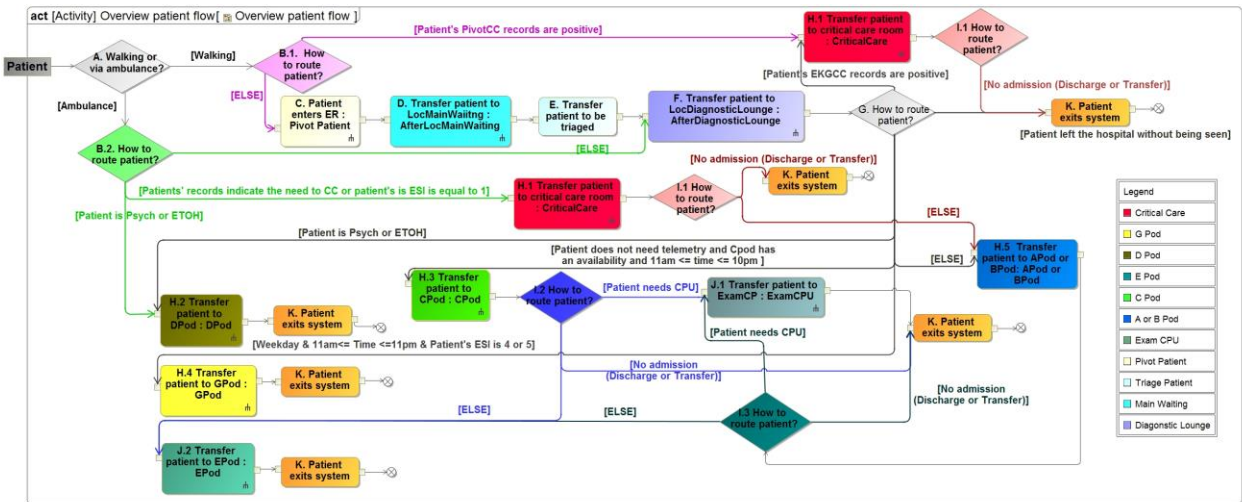


Figure 1: Overview of patient flow in the Anderson Emergency Center, as represented in SysML

The above diagram illustrates the use of SysML to characterize the actions involved in patient care in the Anderson Emergency Center (AEC) (http://www.rhodeislandhospital.org/services/emergency-department), which we describe herein as a case example of this knowledge translation process. In this SysML diagram, one action might expand to become another activity diagram, which then describes the that action in further detail. All such diagrams are inter-connected to describe the overall process. Creating this set of nested diagrams as a single formal language between the stakeholders involved in the process has accelerated the process by which stakeholders mutually understand both the real and simulated system. Furthermore, the verification of simulation model logic was completed by all the stakeholders through the revisions of these SysML diagrams. Traditionally, the simulation analysts (who understand the simulation model but not the clinical process) will verify the simulation logic, even though they are the least experienced in the systems' real-world correlates; our method allows clinical stakeholders to continue to participate in the verification process and thereby improve the accuracy of the model.

The simulation model in our example was used to test whether addition of a new Pod (a discrete unit of beds and dedicated staff within a clinical department) for low acuity patients along with other clinical changes (explained in Section 4.2) would alleviate patients' waiting times to be seen by health care providers. A MedModel simulation model was utilized to examine if this strategy will decrease waiting times, increase throughput, and decrease the number of patients who left without being seen after long waiting times.

This paper is organized as follows: A background about discrete-event simulation in modeling ED operations is provided in Section 2, along with an introduction about SysML. Section 3 discusses the conceptual modeling of the patient flow in the ED, and in particular at the AEC, as well as development and structure of the simulation model. Output analyses are explained in Section 4. Section 5 provides a summary of conclusions from our methods of conceptual modeling.

2 BACKGROUND

2.1 Discrete Event Simulation in emergency department operations

Jun, Jacobson, Swisher (1999) present a comprehensive literature review on the use of simulation in healthcare systems, covering the twenty years prior to its publication and including 117 references for clinic models alone. This survey shows the large amount of research which has been conducted on patient flow and resource allocation in health care delivery. The authors found that the common theme of these publications is the attempt to understand the relationship between various inputs into a health care system (e.g., schedules, resource availability) and output performance measures from that system, (e.g., resource utilization metrics, patient throughput and waiting times). In addition, the survey by Mustafee, Katsaliaki, and Taylor (2010) revealed at least 50 papers published between 1970 and 2007 that discuss the application of DES to problems related to healthcare. Specifically, emergency department (ED) operations are addressed in Takakuwa and Shiozaki (2004) and Sinreich and Marmor (2004), among others.

EDs are an important source of medical care in the US healthcare system, and the high variability of care within and between EDs warrants the use of DES for system analysis, for a number of applications. Reduction in ED length of stay was explored by Samaha et al. (2003) by modeling the current system and exploring possible alternatives. The relationship between major ED resources (e.g., healthcare providers, nurses, and beds) and key performance measures (typically waiting times and length of stay) was investigated by Komashie and Mousavi (2005). Improvements in the ED via allocation of new resources were also explored by Duguay and Chetouane (2007).

Scheduling of ED resources is a critical managerial decision. DES has been also used to optimize staff schedules without hiring additional resources. For instance, Draeger (1992) studied the effect of ED nurse workload on the average number of patients waiting and their waiting times, and thereby identified an improved nurse schedule without increasing costs. In similar efforts, Evans et al. (1996) recommended the optimal number of nurses and technicians in an ED to reduce patients' length of stay.

A new concept called "Team Triage" was first examined in a simulation model before its implementation in a real-world system by Ruohonen et al. (2006). Team Triage suggests the presence of a healthcare provider (and potentially other staff members) along with the traditional nurse during triage, in order to reduce patient waiting times, especially for low-acuity patients. The concept of a "Fast-Track" (i.e., a dedicated patient flow pathway for low-acuity patients) has also been explored as a means of reducing waiting times of these patients (Rodti el al. 2006; Sanchez et al. 2006). As mentioned above, the current paper also describes studies into the impact of implementing a similar track in the AEC.

2.2 System Modeling Language, SysML

The Unified Modeling Language (UML) is an industry standard modeling language for object-oriented software development, maintained by the Object Management Group, OMG (http://www.uml.org/). OMG has created the System Modeling Language, SysML, as an extension of UML, to support modeling of complex systems that involve humans and hardware as well as software components. SysML reuses a subset of UML and provides additional modeling capabilities for requirements and parametric relationships, and augments the UML activity, block definition, and internal block diagrams.

SysML offers seven diagrams to model the four views about the system; structure, behavior, requirements and analytics (Friedenthal et al. 2008). The diagrams are interconnected to represent a complete model of the system. SysML semantics are very expressive and flexible. Domain-specific languages (e.g., ED operations) can be built in SysML using model libraries or profiles (Selic 2007).

The simulation literature has largely addressed the computer models used for healthcare applications, and is fairly expansive, as explained in Section 2.1. Conversely, conceptual modeling to facilitate communication between stakeholders has received little attention. Lehaney and Hlupic (1995) believe failure to complete simulation studies is often due to inefficient communication between the simulation experts and the stakeholders. Conceptual modeling clarifies the problem objectives, inputs, outputs, content, assumptions and simplifications of the model, all of which are key to a successful simulation study. A few studies have discussed conceptual modeling in DES studies (Lehaney and Paul 1996; Lehaney et al. 1999). These studies investigate the use of standardized modeling process to support seamless conceptual modeling.

Accurate communication between all stakeholders in production of a simulation model, and in particular, characterization of the system under simulation, remains a challenge. The most prevalent reason to this problem is the lack of a unified formal modeling platform. Tako et al. (2010) highlighted this continuing problem and proposed a participative modeling framework for developing conceptual models in healthcare simulation studies. The purpose of this framework was proposed to engage stakeholders in a structured and participative way, as a crucial and essential component of the associated simulation study. Furthermore, the Winter Simulation Conference hosted a panel in 2011 which recognized the importance of conceptual modeling, and drew attention towards the great potential for conceptual modeling to impact the success of simulation studies (Van der Zee et al. 2011).

3 SIMULATION MODEL

The simulation model presented in this paper was built in MedModel (ProModel Corp 2007). The scope of this model is large and intricate, incorporating a highly granular set of processes performed in the ED in question, and warrants significant description herein to understand the scope of the problem of communication between stakeholders.

In the present study, SysML activity diagrams were mainly used to model patient flow in the ED. These diagrams were shared among the stakeholders to conceptualize the model in a unified formal approach. As a result, these diagrams showed an impact on the simulation model verification process: it simplified the ability of physicians and engineers to clearly describe any particular process, compared with the use of multiple *ad-hoc* platforms. We used MagicDraw (No Magic 2012) as the SysML editor.

3.1 Conceptual Modeling of the Anderson Emergency Center

The Anderson Emergency Center of Rhode Island Hospital is an academic, Level I Trauma Center with over 105,000 patient visits annually). Like typical EDs in the United States, it continues to increase in volume, with an average increase over 1%, and with daily variations in volume topping 10%. The AEC has recently employed DES to improve its ED operations as, like many EDs, it faces continual pressure to improve the system with minimal cost.

To this end, MedModel was employed to develop a high-fidelity simulation model that captures the very detailed processes executed upon patients' arrivals to the ED, such as X-rays, CT scans and lab tests. The processes modeled, and described below, reflect practices as of October 2011, when the model was originally commissioned; changes to both real-world and simulated processes have also been implemented but are not described here.

Upon arrival, ambulatory patients receive a quick assessment by the "pivot nurse" as their first point of interaction with the patient, at which an Emergency Severity Index (ESI) from 1 to 5 is assigned, to indicate their acuity level and estimated risk of decompensation over time (http://www.ahrq.gov/professionals/systems/hospital/esi/index.html) Patients with high acuity (ESI 1 and some ESI 2) are moved immediately to Critical Care rooms (known more generally as resuscitation bays), while patients with lower acuity levels (most ESI 2 and ESI 3-5) are transferred to the main waiting area to be further triaged.

Triage is the process of determining the priority of patients' treatments based on the severity of their condition, and is completed in the AEC by a dedicated triage nurse. During the peak hours of patient arrival (11am to 11pm), the AEC employs Team Triage, wherein a dedicated physician or midlevel provider, registrar, and a technician (as needed) concurrently evaluate the patient along with the triage nurse, and subsequently have physican orders (predominantly labs, medications, EKG, and/or X-rays) processed within the triage area. After triage, the patients wait again in public waiting area, to be seen by healthcare providers in one or more of several clinical care areas: Urgent Care Areas (A, B, and C Pods), the Behavioral Health Unit (D Pod), the Chest Pain Unit, Critical Care rooms, and an informal area for admitted patients awaiting bed assignment (E Pod). A description of how patients are assigned and re-assigned rooms follows.

Depending of the patient's medical condition (e.g., ESI, vital signs, and chief complaint), the decision points shown in Figure 1 will determine where the patient is destined for initial and terminal phases of care. Patients will be directed into critical care room upon arrival if their condition requires close monitoring or resuscitation. Patients solely presenting with psychiatric complaints or intoxication will be escorted to D Pod; the remainder (and majority) of patients are seen in the Urgent Pods, prioritized first by acuity and secondly by arrival time. Subsequently, if a patient may be transferred to the D Pod for further psychiatric care, discharged to home, transferred to another facility, or admitted to the hospital. Of the admitted patients, a number are admitted to the Chest Pain Unit (CPU) for overnight observation; this unit remains within and is managed by staff of the AEC, and therefore is included in the model. Moreover, patients admitted to the hospital, and for whom an inpatient hospital bed is not available within 30 minutes, may be transferred to the CPU (if a CPU bed is available) or to E Pod temporarily, until their inpatient bed becomes available.

The AEC serves as the access point to one of the nation's busiest Level I trauma centers. Hence, capturing the high-level and low-level abstractions of the system requires the involvement of many stakeholders with diverse backgrounds, including clinical medicine, business, engineering, and public health (and particularly patient safety). Moreover, the system itself involves many clinical actors, making complex decisions: patients arrive with a wide spectrum of complaints, some requiring immediate transfer to "critical care rooms" (i.e., resuscitation bays), while other patients require less urgent evaluation, or even minor or non-urgent care. The coordination of resources and services to meet all patients' needs and expectations is a very challenging mission.

Given the spectrum of needs of the AEC's patients, there is great variation in the processes to be completed by each clinical resource. Moreover, the processes are highly interconnected across locations within the AEC and require shared resources. For example, one physician is assigned to care for all patients in a set of beds divided between A and B Pods, while each Pod nurse is designated to care for a different set of 4 patients within a single Pod. Furthermore, patients throughout the ED are transferred to numerous locations for lab tests, CT scans, X-rays, and other medical orders. Figure 1 represents the overview of flow for patients in the AEC. This is an activity diagram described in SysML as "call actions". Some of these actions point to other activity diagrams that represent a fully detailed patient flow submodel. This interconnectivity between the flow diagrams in SysML and the ability to capture all processes in one platform have simplified communication among stakeholders of the simulation project.

We generated 22 activity diagrams to describe the patient flow in the AEC. Two of these model arrivals to the ED (walk-in vs. ambulance arrivals); others represent the "Pivot" (pre-triage) process upon arrival, the triage process, and the waits to be called to a room Additionally, patient care in each primary treatment area ("Critical Care" and the "Urgent Pods") is unique and distinct, and each has been described separately in SysML. Finally, patients' records and resident physician reports at different locations are handled in special manners, and have their own corresponding SysML diagrams. The different medical orders called for the patient such as medications, X-rays, CT scans, lab tests and/or others entail different processes and resources to be completed, also characterized in SysML diagrams.

The experience of building one SysML model, composed of 22 interconnected activity diagrams to represent operations in the AEC, has streamlined modeling and simulation efforts. The SysML diagrams are both detailed and flexible, and are designed to be adapted easily to future needs as well. The use of one platform to conceptually model such a complex system, and thus obviating the use of the *ad-hoc* methods, has proved efficient and effective. These diagrams have been used for clinical stakeholders to verify that the model is accurately replicated in the MedModel logic. For the most part, all the stakeholders found it easy to follow the activity diagrams in SysML (as in Figure 1); this has allowed them to swiftly confirm that the key aspects of patient flow are accurately captured in these diagrams (or note in which aspects they are not), and thereby aided in verifying the simulation model. Weyprecht and Rose (2011) have argued that SysML is well-suited as a meta-model for general purpose simulation solution. They focused on the activity diagram as the most relevant diagram for simulation purposes. Our experience suggests that, in the case of a highly granular simulation of a busy ED, the semantics of such activity diagrams can be sufficiently analogous to the behavior of the system described in a simulation model.

The objective of this section was to introduce the readers to our approach of building the conceptual model of the system for simulation using SysML. Our experience has been fruitful during the brainstorming sessions and the verification of the simulation model. The following section discusses the technical perspective of the simulation model.

3.2 Development of Simulation Model

The simulation model in MedModel is depicted in Figure 2. The model's animation has been also used to verify the simulation logic.

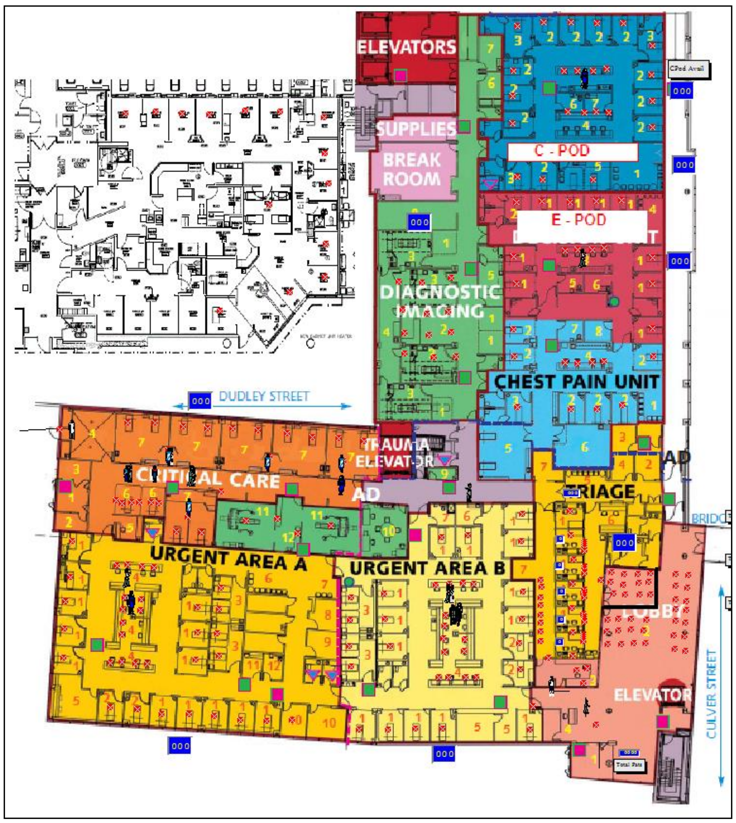


Figure 2: Snapshot of Simulation Model in MedModel

In this model, there are 152 real and virtual locations where the patient (and other entities, such as medical records) and clinical resources can travel to or from. A total of 54 resources are modeled, including registrars, nurses, attending, patient care technicians (i.e., nursing technicians), and other clinical staff. The processes involved in the model are captured in templates referred to as "macros" in MedModel. Such macros can be considered as functions in a library that can be reused by calling them.

Input data has been collected from the real system by time-clocking the service times of the different operations. In most cases, such data were collected by trained research assistants; rarely, we relied on expert opinion for uncommon or time-consuming processes intractable to direct measurement. In addition, arrival patterns to the ED were abstracted over the days of the week and the hours of the day, and characterized as heterogeneous Poisson distributions for the inter-arrival times for every 2 hours. The AEC utilizes the MEDHOST Inforamtion System (MedHost 2013) to track patients from their arrival times until their disposition from the ED; data were abstracted from MEDHOST for arrival data or whenever infeasible by the above means to calculate directly. Stat::Fit (Geer Mountain Software Corp., 2011) was used to determine a best-fit distribution function for each of the datasets for input distributions thus obtained. Finally, the simulation model makes some assumptions and deliberate omissions; we mention here the most important:

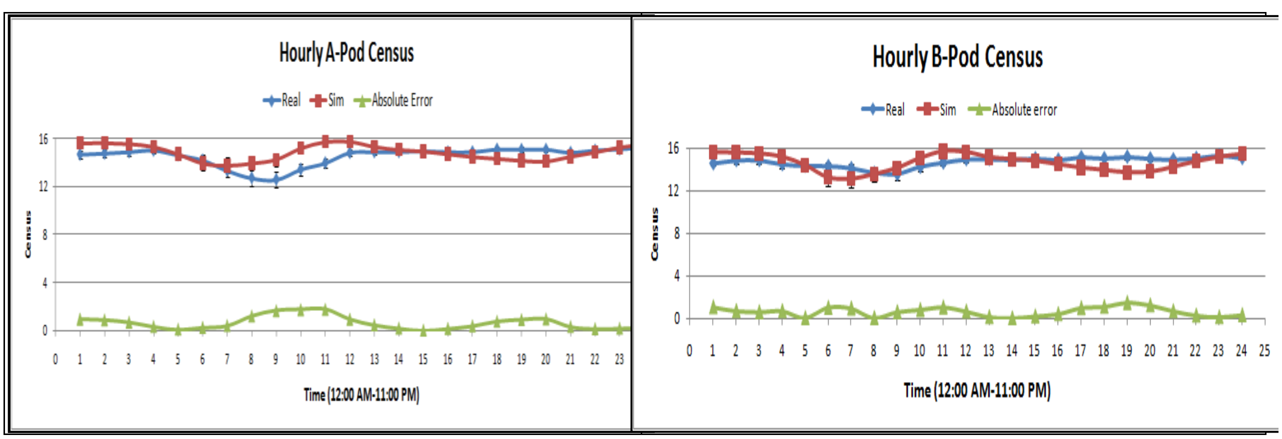
- Certain bed movements, which occur for less than 5% of the patients, were not tracked in the model. This is in accordance with common industry standards for such modeling. For example, a patient's apparent condition may worsen and warrant immediate transfer to a "Critical Care" bed from other clinical areas in the ED. This occurs uncommonly and rarely to the detriment of clinical care; we elected not to incorporate this into the model.
- Some patients (~2-4%) elope prior to evaluation, but only from waiting areas after triage; a small percentage (<0.1%) leave from other locations, before the completion of care. Elopements were not included in this iteration of the model.

4 OUTPUT ANALYSIS

The "base-case scenario" – i.e., a simulation of normal patient flow under routine conditions during the validation study period – was run as a part of model validation. Simulation performance metrics were compared to the expected numbers from the real-world data, as described below, and as described elsewhere (Goldlust 2013). In addition, the simulation model was used to add an area ("G Pod") designated to serve patients with lower acuity levels (ESI 4-5) on weekdays from 11am till 11pm.

4.1 Base-Case Scenario

Extensive analysis has been performed to validate that an accurate model is produced. The hourly censuses at the key locations in the ED were compared to the expected results. In addition, daily times for completion of critical tasks, such as time from arrival till triage, and time from arrival to admit or discharge, were also included in the validation efforts. Real data was extracted from MedHost for three months in different seasons: October 2011, January 2012, and April 2012. For comparison, the simulation model was run for fifty 2-week replications; the first week was a warm-up period to remove the bias of an empty system, and was not included in analysis. The model was treated as a terminated system, as it will never reach steady-state, due to the volatile arrival patterns. The performance metrics are presented by comparing the simulation results to the expected values extracted from the historical data. In addition, the absolute error obtained from subtracting the simulation results to the actual data is provided for each performance metric. Figure 3 shows the hourly census in some key locations. Figure 4 displays the daily turnaround times to complete triage and times till discharge or hospital admission.



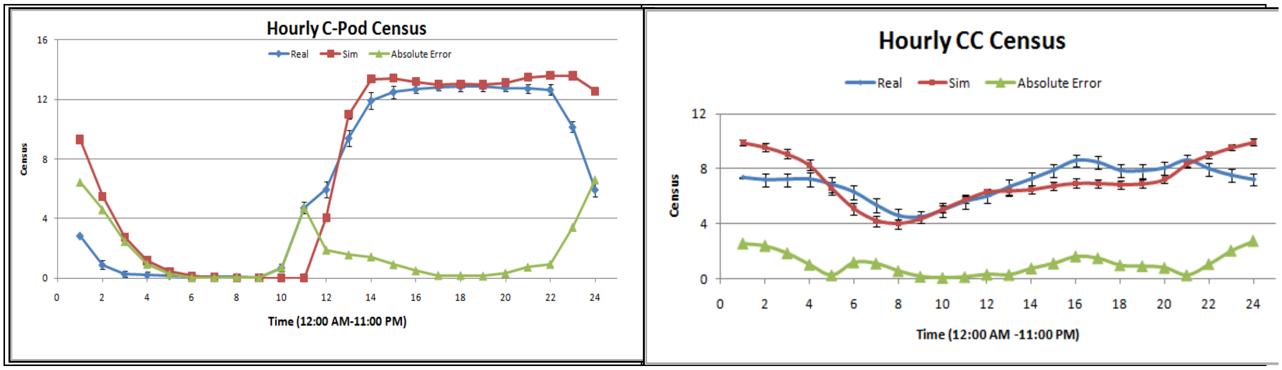
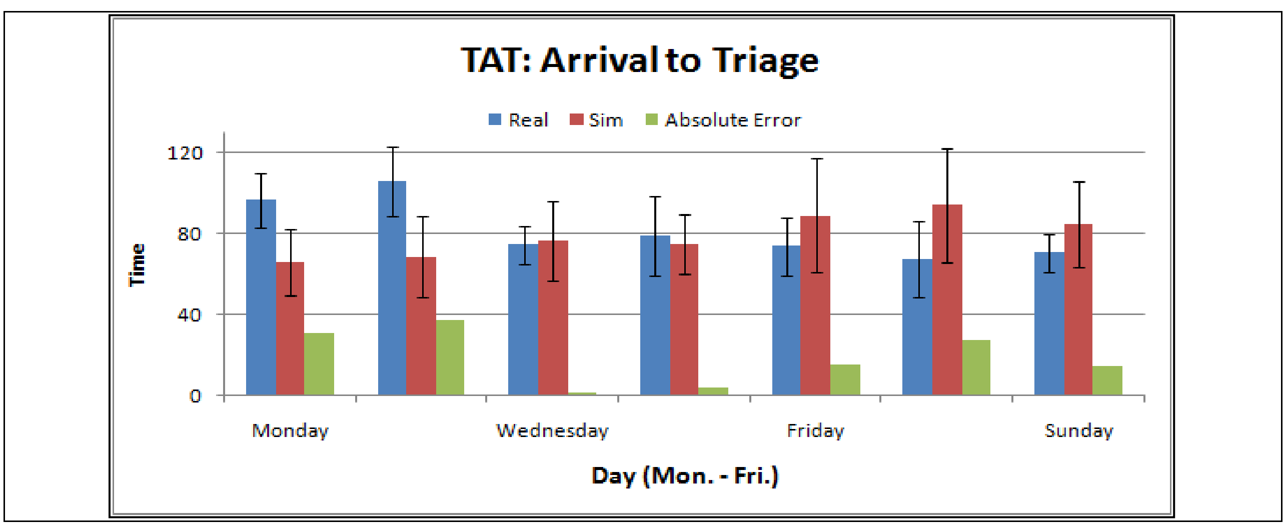


Figure 3: Actual and predicted mean patient census within different locations of the AEC, by hour of day. Error bars represent 95% CI on the mean.

The hourly censuses in the locations displayed in Figure 3 illustrate how the simulation data matches the real-world data. The absolute errors are close to zero in most instances, and are never off by more than 5 patients. The greatest discrepancy is seen in the hourly census of C-Pod, towards the end of the day (after C Pod closure) and at the early part of the day (shortly after C Pod opening). C-Pod closes at 12 am, in real life, patients are expediently moved to other available beds, but in the simulation, such movements are not prioritized. As a result of the analysis shown, this variation between the simulation and real-world ongoing was targeted for further improvements on the model, with good effect (*unpublished data*).; it highlights the discrepancy between planned (predicted) and actual behavior, and the effects of inaccurately characterizing the real-world process as an ideal state.

In Figure 4, the daily turnaround times for triage and disposition from the ED (discharge or hospital admission) are shown. The simulation model appears to perform well, according to the real-world data with respect to these metrics. The differences in these times are not statistically significant and believed to be of marginal clinical significance. Of note, this was not chosen as a primary outcome measure for validation of the model, as it is a known phenomenon that simulations of such processes commonly outperform their real-world counterparts in this regard. Nevertheless, this analysis has further validated the simulation model performance against the real-world data; the discordances noted have prompted further investigation and refinement of the model. This allows us to experiment new scenarios in the model, as suggested in the following section.



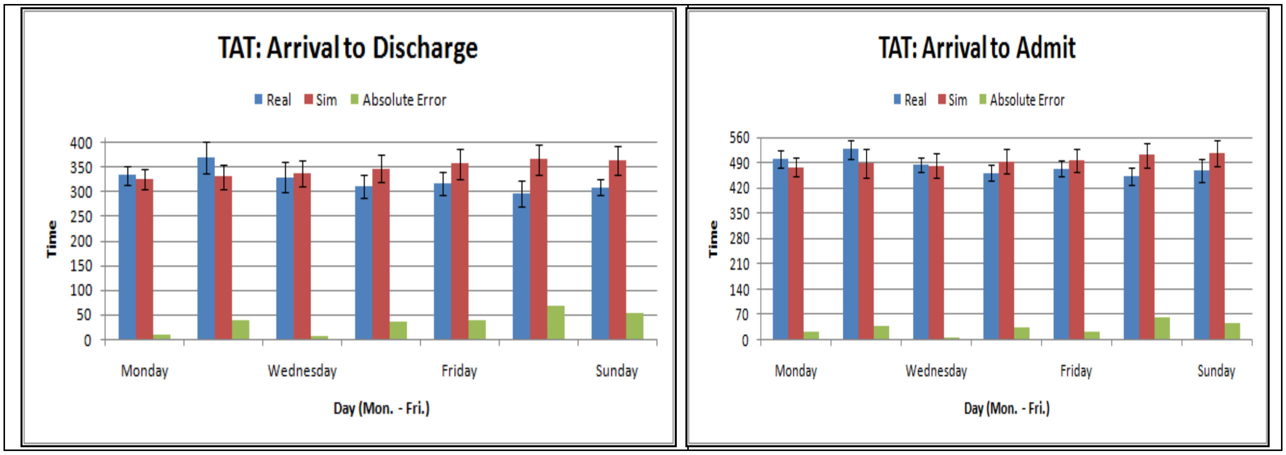


Figure 4: Actual and simulation-predicted turnaround times between (A) patient arrival and completion of triage, for all walk-in patients; (B) patient arrival and discharge, for patients being discharged; and (C) patient arrival and hospital admission, for patients being admitted. Error bars represent 95% CI on the mean.

4.2 Analysis of Process Change: Addition of "G Pod" and changes to staffing patterns

A new "G Pod" was planned by the ED managerial team to be implemented in January 2013. This Pod operates under similar principles of the "fast track" described in the literature review; namely, low-acuity patients (ESI 4-5) are preferentially seen here. The G Pod is staffed on Monday through Friday, between the hours of 11 am and 11 pm, by dedicated staff including one physician, one nurse, and one midlevel provider. Additional changes to patient flow were adopted at that same time, including extending the open hours of one patient care area (C Pod) by one hour and removal of one physician, who previously staffed 5 out of 16 rooms from each of A and B Pods, from 11 am to 7 pm.

The simulation model was used to predict the ED performance with these changes. A SysML activity diagram characterizing the patient flow in G Pod is presented in Figure 5. Patients with ESI 4 and 5 are now directed into the G Pod, where they are first assessed by the dedicated nurse in that area. Then, based on availability, the patient will be seen by either the midlevel provider or the physician. By definition, ESI 4-5 patients are seldom expected to have labs or imaging beyond that obtained in triage (http://www.ahrq.gov/professionals/systems/hospital/esi/esi4.html).

It is worth mentioning that adding these changes to the SysML master model has helped understanding of the impact of such changes to the related simulation model. The alignment between the SysML and the simulation models makes it easier for systems modelers to conceptualize the changes and implement them in the simulation model, and similarly for clinical stakeholders to conceptualize the potential effects on real-world correlates. For example, the flow in G Pod is described in Figure 5 is connected to the other activity diagrams, which are all part of one over-arching SysML model. This interconnection of patient flow in one unified formal platform has eased the task of adding the necessary code of this new flow to the simulation model.

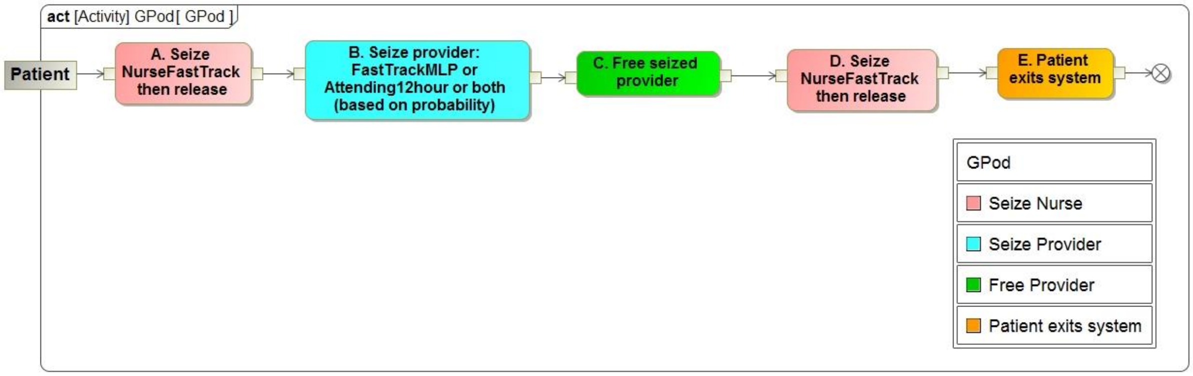


Figure 5: G Pod flow

Preliminary analysis of the putative impact from adding G Pod (along with the other changes mentioned) was performed with the simulation model thus suggested by the new SysML flow. The performance measure of interest for this preliminary analysis was the time from arrival to completion of clinical care (i.e., declaration of disposition). The analysis stratifies patients according to their ESI level. Table 1 demonstrates the numbers obtained from the simulation model that incorporated the changes in January 2013. These numbers appeared, frankly, unbelievable to clinical staff, prior to real-world implementation. Table 2 shows the performance measures prior these changes (baseline case); the gains from the changes are huge as the difference between the numbers in the two tables show. However, skepticism has been mitigated after experiencing the effects of changes in patient flow since January 2013, which have borne out the simulation outputs. Statistical analysis against real-world data has not been completed as of yet, ongoing investigation will compare the performance of the first three months (January – March 2013) to the performance predicted by the simulation model.

Table 1: Comparison of simulated turnaround times (arrival until completion of care) between baseline conditions and several process changes (addition of G Pod, changes in nursing and physician room coverage)

		Mean	**Standard Deviation**	**Median**	**75th Percentile**	**90th Percentile**
Baseline Scenario	**ESI 1**	280.6	199.2	235	365	550
	ESI 2	345.5	220.1	309	309	592
	ESI 3	351.0	221.6	317	317	592
	ESI 4	372.8	277.0	323	323	613
	ESI 5	336.6	180.1	308	308	576
Post-Interventional Scenario	**ESI 1**	267.2	161.3	235	347	481
	ESI 2	270.6	180.2	238	346	477
	ESI 3	274.5	202.0	238	347	488
	ESI 4	101.6	108.0	63	122	216
	ESI 5	97.4	122.4	51	91	213

Subsequent to this data analysis, the G Pod and other changes were implemented. At the time of this writing, preliminary data from the performance of the real-world department appear to qualitatively reflect the results of the simulation model; the magnitude of the improvements, particularly in low-acuity patients, appears to be similar *(unpublished data)*.

The simulation model presented in this paper has been highly useful in predicting the performance of the AEC under baseline conditions, and after proposed changes to care, with respect to the metrics of interest. The model has incorporated fine details of the care provided to patients in the AEC, to a degree which is rarely (if ever) reported in our review of the literature. Future use of this simulation model is ongoing; e.g., to examine the effects of downtime for the CT scanners, X-ray suites, etc. In addition, this model demonstrates a system engineering approach in the conceptual modeling efforts by the use of SysML. This new implementation of SysML in modeling the patient flow in the ED has tremendously facilitated communication between the stakeholders and the verification of the simulation model.

5 CONCLUSION

This paper first reviews the implementation of discrete event simulation in healthcare, and particularly in emergency medicine. We highlight the importance of employing a formal modeling language, such as SysML, in these efforts. Based on our case example, we found the gains in efficiency to the process of model development, relative to the use of *ad-hoc* methods common in simulation practice, to be highly significant for such a complex simulation. The efficiency of this method allowed for the development of a reliable decision-making tool, and thereby justifies the investment in DES to model and simulate the AEC. SysML proved to be advantageous in examining process changes prior to real-world system implementation, and ferreting out design flaws in the simulation which might otherwise have led to poor process recommendations. This work appears to justify ongoing work to improve this model and to incorporate some of the nuances that were not prioritized previously.

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