Proceedings of the 2017 Winter Simulation Conference
W. K. V. Chan, A. D'Ambrogio, G. Zacharewicz, N. Mustafee, G. Wainer, and E. Page, eds.

HYBRID, COMPOSABLE APPROACH TO SIMULATIONS IN HEALTHCARE OPERATIONS AND MANAGEMENT

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ABSTRACT

Simulation has been used for modeling in healthcare for many decades. Ranging from the modeling of physiological processes to group dynamics to the modeling of strategic and system-wide models of healthcare provision, simulation promises to be an effective approach to analyze healthcare operations. Effective application of simulations in healthcare operations requires that simulation deal with wide variability and unpredictability in workflow processes, the complexity of healthcare organizations and enables the participation of human experts in the modeling and operations processes. In this paper, based on requirements drawn from a participatory simulation with healthcare practitioners, we define a hybrid, composable approach to healthcare simulations. Both the participatory simulation and the composable simulation are applied in the context of the New Karolinska Solna hospital in Sweden, a highly specialized new hospital. Results point to the need to accounting for variability in workflow processes and integration with existing IT infrastructure in hospitals.

1 INTRODUCTION

The various areas of applications that have been pursued and documented make evident the potential and extent of simulation use in healthcare. Simulations have been used for applications ranging from investigating physiological processes at the cellular and organ level to modeling the spread of diseases at the public health level (Brailsford et al. 2009; Katsaliaki and Mustafee 2011; Günal and Pidd 2010). High fidelity simulations have found wide acceptance in medical education and training, both for individual and group training (Lasater 2007).

On the administrative side, simulations have been used to model hospitals, to estimate future resource needs, for resource optimization and so on (Griffiths et al. 2005; Harper and Shahani 2002). A large number of simulation applications focus on modeling patient flows, either in hospitals or at the department level to ensure high patient throughput, low waiting times while ensuring quality and safety (Jacobson, Hall, and Swisher 2006). These applications focus predominantly on patient-intensive areas such as emergency departments (Anagnostou, Nouman, and Taylor 2013). As pressure builds on healthcare to reduce costs and improve safety and quality, simulations for operational decision support could have enormous applications (Chahal and Eldabi 2008; Auerbach, Stone, and Patterson 2016).

However, such implementation for operational decision making has historically been weak, with little uptake from healthcare practitioners. Despite similar techniques being successfully applied in defense, manufacturing and other areas, the benefits of simulation on healthcare seem hard to define (Kuljis, Paul, and Stergioulas 2007; Sanchez et al. 2000). This could be because of the wide variability and unpredictability in healthcare workflow processes. This in turn leads to a lack of documentation for the same. A lack of standardized workflow processes that can be charted, a history that can be analyzed and steps that can be measured implies difficulty in modeling and simulating workflows. In such cases, knowledge and expertise on the management of unpredictability and workflows is embedded in medical practitioners. This could be especially problematic in the case of new hospitals, where new equipment, a lack of familiarity with new space and new operational parameters could make it hard even for seasoned medical practitioners.

In this paper, we attempt to define a hybrid, composable simulation architecture for simulating a wide variety of workflows in healthcare. The requirements for the architecture are derived from a participatory simulation with medical practitioners from hospitals around Stockholm. The participatory simulation addresses the case of distribution of care in the context of the opening of New Karolinska Solna (NKS), a highly specialized hospital in Stockholm. The results of the participatory simulation point to particular requirements for the simulation of healthcare processes, which are then realized in a composable simulation architecture. The architecture is implemented using a number of software components, mainly the AnyLogic simulation software (Capolongo et al. 2015; Dowdeswell, Beck, and Gjötterberg 2009).

The paper is structured in two parts. The first part describes a participatory simulation where co-ordination processes for organizing patient transfers across hospitals is investigated and designed. The problem formulation, the design of the participatory simulation and the experiment where the simulation was run is described. Results from the participatory simulation are then described. The results point to the need for a composable architecture for simulations, the implementation of which is then described. The participatory simulation, as well as the architecture for composable simulations is situated in the context of NKS, which has interesting implications for the distribution of healthcare in Stockholm.

In the following sections, we describe the operating model for the NKS hospital, which has unique implications and provides a unique case for simulations. We describe background work on simulations in healthcare, as well as the case for implementing composable architectures for simulations.

2 NEW KAROLINSKA SOLNA

The opening of the New Karolinska hospital (NKS), a super specialty hospital has raised interesting questions regarding the distribution of healthcare in the Stockholm county region. The hospital predominantly provides specialized care, and significantly alters the distribution of care in Stockholm. For instance, access to emergency care in NKS will be changed in order to conserve its resources of specialized care for those who need it. Patients who used to choose the Emergency Department (ED) of KS (the predecessor to NKS) will be forced to find other alternatives within Stockholm County (SLL), or require that NKS moves them to other hospitals for care. Similar models are envisioned for patients in other units of NKS, where patients who no longer need such specialized care will be redistributed to other hospitals in the region, to ensure that the resources of NKS are utilized for specialized care needs. This leads to questions on where patients will go, the capacities that are now needed in the different hospitals in Stockholm and operational procedures to steer patients to the right hospitals. Since the effect this will have on patients is unknown, resources and infrastructure, the process and operations around are yet to be designed.

Simulations seem well suited for the issue of process redesign around NKS. However, as mentioned earlier, given the lack of documentation on existing workflows and the new care delivery model being envisioned, creating appropriate simulations to enable this redesign remains a challenge. This lack of knowledge can be bridged through experts, essentially current medical practitioners who deal with such issues on a daily basis and including them in the modeling process and in the simulation. Using their expertise will help in constructing the right conceptual models, which could then be implemented in a composable simulation.

In the following sections, we describe a participatory simulation with medical practitioners where the goal was to investigate the bottlenecks and workflows around redistribution of patients requiring intensive care between hospitals. The results of the participatory simulation point to requirements for simulation architectures for the purposes of process redesign.

3 BACKGROUND WORK

A simple typology for healthcare simulations could be established based on their scale or unit of analysis. At the individual level, simulations are used for the analysis of diseases and people's health behaviors. They represent biological processes, either at the system or organ level. Such simulations are mainly used for training and education, as well as to model clinical or cost effectiveness of interventions, the biochemical effects of drugs and so on (Brailsford 2007).

Moving up a level, simulations are used for operational or tactical purposes. The unit of analysis is typically a care provision organization, such as a department in a hospital (cardiac, emergency etc.), a clinic, and an operating room and so on (Brailsford et al. 2007). A typical purpose for such simulations is to model patient flows in the unit to improve efficiency and safety. At a larger scale, models deal with long term strategic questions such as placement of hospitals, or logistics planning for emergencies (Lane and Husemann 2008).

A multitude of simulation approaches applied in healthcare. Discrete Event Simulations (DES), Systems Dynamics (SD) models, Agent Based Models (ABM) are all commonly used. Over the last couple of years, hybrid approaches combining two or more simulation paradigms are being applied, to facilitate complex, multi scale models. DES and SD approaches are combined to create rich, detailed models incorporating non-linear feedback loops at multiple scales. DES and ABMs are combined to investigate patient decision making and patient flows together (Jacobson, Hall, and Swisher 2006; Brailsford, Desai, and Viana 2010; Barnes, Golden, and Price 2013; Djanatliev and German 2013; Chahal and Eldabi 2008).

Many of these approaches have focused on some bounded aspects of healthcare, such as modeling patient flows or predicting patient arrivals and capacities to facilitate decision making and so on (Eldabi and Young 2007). There is a need to develop approaches in healthcare simulations that can facilitate the development of frameworks capable of modeling a range of scenarios. Such an approach must be able to handle the wide variability of processes and workflows in healthcare (even within a single unit, ward, clinic or hospital) and allow the participation of experts in the modeling process. The inclusion of expert practitioners is necessary because they hold a vast amount of tacit knowledge about processes, understand the uncertainties in the system extremely well (which would be very hard to capture and model) and could have conflicting perspectives on the system (Tako and Kotiadis 2015).

Component based modeling and simulation development is an approach towards developing integratable, interoperable and composable simulation models. It is aimed at addressing the challenge of developing large-scale, open simulations through the composition and reuse of predefined and preexisting validated simulation component (Benali and Ben Saoud 2011). While this approach is still restricted by domain, in that it leads to the development of domain specific models, with the careful development of simulation components for reuse, the approach can enable easy recombination of simulation components into different simulation systems for different purposes (Verbraeck and Valentin 2008).

A problem with composable simulation concerns the complexity of the components' interactions, which involves both conceptual modeling of each component, including modeling assumptions, model representation and definition and the implementation which involves communication protocols, data structures and so on. Despite its promise, composable simulations are not very prevalent in healthcare.

4 DISTRIBUTION OF CARE IN STOCKHOLM

The current system of co-ordination and transferring patients between hospitals is ad-hoc and organized on a case by case basis. Considering the new operating model of NKS, the hospital is interested in understanding how this increase in patient transfers will affect this system and the operations of other hospitals in the county. To investigate this, a participatory simulation approach was chosen. In the following sections, we describe the problem formulation, the simulation design, the experiment where the simulation was run and the results.

4.1 Problem Formulation

Following is the list of objects, processes and actors involved in patient transfers, restricted to the dispatching and receiving hospitals. This was discovered through a workshop involving relevant stakeholders.

1. Patient and patient information which could change over the course of a transfer, such as history, symptoms, treatment course, allergies etc. Typically described in Electronic Health Records (EHR) and transferred online.
2. Vehicle, which is an ambulance of several types. Depending on the health of the patient, other equipment might be required for the transfer, which the ambulance should be capable of accommodating. Stockholm has a fleet of ambulances (at the time of this study, approximately 80 ambulances, two intensive care ambulances and two helicopters). Ambulance fleet has to serve patient transfers, as well as attend to emergency cases.
3. Transport team, which again depending on the patient can be just the driver with a paramedic or include a full medical team of a doctor and a couple of nurses.

The following steps typically need to happen through the process of transfer. The transfer is typically initiated at the level of the unit, typically a ward or a department. All the steps are organized on a case by case basis:

1. Decision: The doctor in charge of the patients care has to decide whether the patient can be transferred. This is an autonomous decision by the doctor.
2. Negotiation on destination: The floor manager (called platskoordinator, one person per ward and usually a nurse with experience is in charge) has to co-ordinate with other hospitals and identify a hospital and ward willing to receive the patient.
3. Dispatch Preparation: All the resources necessary for transporting the patient has to be identified and gathered. This also depends on the patient's condition. The resources could be necessary equipment, a vehicle in which the equipment can operate and the personnel to monitor and treat the patient during the transport. Usually, none of these are readily available and has to be gathered from different places.
4. Transport: The actual movement of the ambulance between two hospitals. This usually happens as soon as the ambulance is ready with the necessary equipment and personnel.
5. Triage: A triage process at the receiving hospital. Most hospitals and wards operate at full, or near full capacity all the time. So in case the patient has to go into a specific ward at the receiving hospital, then a bed has to be cleared for the patient. This usually means sending a patient home, or in rare cases, transferring a patient to another hospital.
6. Transport: Any equipment and transport team (if it includes a doctor and nurses) need to be transported back to the origin hospital. This usually requires an ambulance as well, but can sometimes be achieved through regular vehicles such as taxis.

Two actors are critical to the entire process. Dispatchers are responsible for coordinating with other hospitals to transfer a patient, and assembling the right vehicle, equipment and team to transport the patient. Some hospitals may have dedicated personnel for this role, called a platskoordinator (placement coordinator), but it is usually performed by the floor manager or a lead nurse. The transport operator is responsible for operating and maintaining a fleet of ambulances. This actor maintains several classes of ambulances, and has to coordinate with the nurse as to the right class of vehicle to send based on the requirements. Assembling the resources required to transfer the patient typically takes a long time (on the order of several hours to a day), during which time the patient has to wait.

4.2 Participatory Simulation

Based on the problem formulation described previously, a simple participatory simulation was designed with the following elements and simplifications:

1. Participants in the simulation take on the role of either a hospital or an ambulance dispatcher.
2. A network of five hospitals named Central, North, South, East and West was created. They roughly correspond to the geographical locations of the major publicly run hospitals in Stockholm.
3. Three patient categories were created, low, high and critical. Critical patients require highly intensive care as compared to the other two. Critical patients transition to become high patients and then low patients over time. Low patients eventually leave the hospitals. In this simulation, time is measured through steps.
4. Corresponding to the categories of patients, three types of ambulances exist: ICU, High and Low. Critical patients can only be transferred in ICU ambulances. High patients can be transferred in either ICU of high ambulances while low patients can use any type of ambulance.
5. Each hospital has resources in terms of beds, with a certain number of beds of each category.
6. The simulation proceeds in time steps. At each time step, the hospital receives a certain number of patients of each category.
7. The hospitals have to decide whether to accommodate the incoming patients in their own beds, of which they have a limited number, or to transfer them to other hospitals.
8. When they decide to transfer the patient to another hospital, they have to talk to the participants corresponding to the destination hospital and negotiate with them on accepting that patient.
9. Once a destination hospital is identified, the hospital requests for an ambulance.
10. The dispatcher assigns a relevant ambulance to that hospital, following which the patient is transferred to the destination hospital.
11. A certain number of steps elapse before ambulances arrive at the origin hospital and patients arrive at the destination hospital.

The simulation was implemented using simple Google spreadsheets. Each hospital is given its spreadsheet with appropriate numbers for patients and beds, as shown in Figure 1. The spreadsheets for each hospital and ambulance dispatcher are linked. This linking enabled transfer of information between the participants. For example, if hospital Central agreed on a patient transfer with hospital North, then 1 patient would be listed at that time step in the appropriate column. Hospital North would see that patient on their spreadsheet as an incoming patient a few time steps later, assuming an ambulance was assigned. At the same time, an appropriate number would appear on the ambulance dispatcher's spreadsheet as request. The dispatcher would then have to assign an ambulance to that hospital, following which the patient would appear on the destination hospitals sheet. In Figure 1, the participant has to enter 1 in the Critical column of "Patients to Hospital North", to send a critical patient there. The same request would appear in the Ambulance dispatcher sheet.

The simulation was run with two parallel groups, of 12 participants each. Participants were all healthcare practitioners from the hospitals in Stockholm. Each role (the five hospitals plus ambulance dispatcher) was played by two participants together. Each role was played on separate laptops, and the sheets of each group were linked. The participants played out the simulation for approximately an hour, following which a debrief session was conducted with the two groups together.

Hospital Central	Beds Available		Patients Ready to Go			Patients to Own Beds		Patients to Hospital North			Patients to Hospital East			Patients to Hospital South			Patients to Hospital West		
	Low	High	Low	High	Critical	Low	High	Low	High	Crit	Low	High	Criti	Low	High	Criti	Low	High	Criti
Loading	200	40																	
Step 1	40	10	30	6	1	30	6	0	0	1	0	0	0	0	0	0	0	0	0
Step 2	26	7	30	6	1	26	7	4			5			4			3		
Step 3	17	3	30	6	1	26	7										4		
Step 4	9	0	30	6	1	9	6							4			12		1

	Ambulances			Hospital Central						Hospital North						Hospital East					
	Low	High	ICU	Exp. Low	Ass. Low	Exp. High	Ass. High	Exp. ICU	Ass. ICU	Exp. Low	Ass. Low	Exp. High	Ass. High	Exp. ICU	Ass. ICU	Exp. Low	Ass. Low	Exp. High	Ass. High	Exp. ICU	Ass. ICU
Step 5	20	4	2						1		0		0		1						
Step 6	16	0	0		16																
Step 7	4	4	2		4																
Step 8	16	4	2		16				1												

Figure 1: Snapshot of the hospital spreadsheet on top, ambulance dispatcher in the bottom.

4.3 Results

Game play and debrief was recorded, transcribed verbatim and translated. The debrief comments from the participants were coded inductively (Corbin and Strauss 1990), and categorized into themes relevant to the applicability of simulations to process redesign in healthcare. A summary follows:

1. Participants pointed out the wide range of events that commonly occur on the hospital floor on a regular basis, most of which are handled by personnel on a case to case basis. For example, the nurses in the simulation explained a common situation where borrowed or transferred gurneys and beds sometimes do not fit into doors or elevators.
2. In the same vein, they pointed out that while regular operations run smoothly on the hospital floor, such special and irregular events need to be planned for.
3. External pressures on cost and safety are driving hospitals to reconfigure and reorient their operations towards better production models. Simulations were identified as an effective way to support this orientation, and to explore different process configurations.
4. They also pointed out the difficulty in identifying bottlenecks in their processes. Considering the autonomy and agency of individual actors in resolving conflicts and issues, it becomes hard if not impossible to identify bottlenecks and inefficiencies in workflow processes. While one potential way would be to simulate in real world spaces with human actors, this is hard to accomplish regularly. This in turn makes it hard to simulate the same processes.
5. Following up on the previous insight, participants pointed out the need to identify and control certain elements, or the elements they do have control over.
6. This leads to the need to orchestrate and coordinate elements under their control, so they don't have to reconfigure their processes again and again. This is especially true considering shortage of resources, particularly people.
7. Participants also pointed to the fact that workflows and processes on every ward and floor will be different. In some respect this is normal and expected (considering that it is driven by the medical nature of the ward) but also makes optimizations and coordination mechanisms harder.
8. Along the same lines, participants also pointed to the difficulty in implementing central coordination mechanisms.

The insights gathered during the participatory simulation, combined with recent insights from literature, the lack of consistent processes and the lack of access to healthcare data all point to the need for a collaborative, integrative approach to modeling and simulation in healthcare.

5 SIMULATION ARCHITECTURE

The proposed architecture consists of three distinct layers, as shown in Figure 2. The first layer is a suite of simple, interoperable components representing discrete functional units in a hospital. The second layer contains control procedures to structure communication among components, and between the components and the database. The third layer contains class description of various concepts in healthcare, implemented as an ontology in Protégé (Gennari et al. 2003). This layer also contains a database, which maintains a record of all resources (of various types) being used in the simulation.

A sample actualization of the architecture is illustrated in Figure 3. Hospital X is a model created by structuring components, as is hospital Y. The hospital control room represents the control layer in the architecture, while the database is not shown.

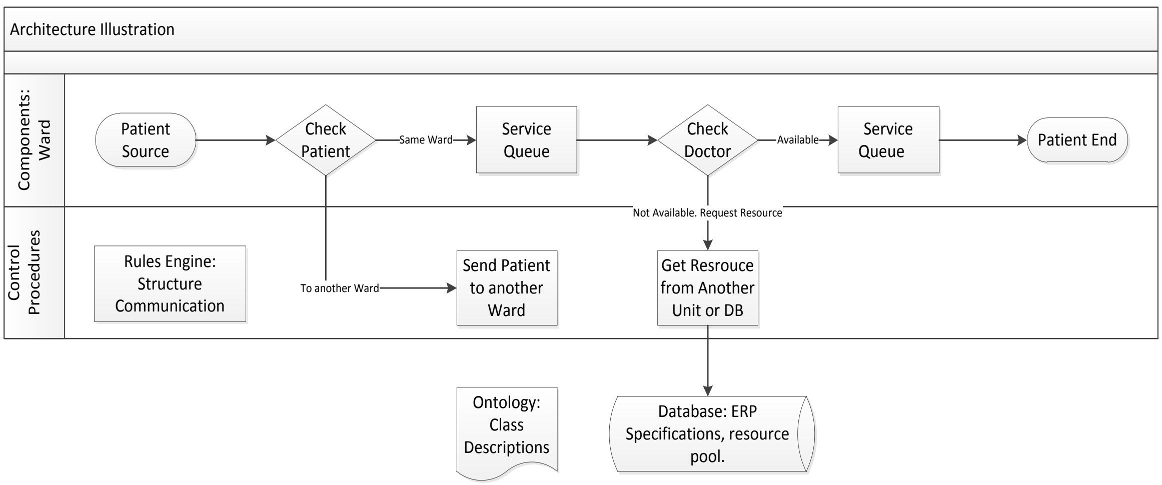

Figure 2: Architecture illustration.

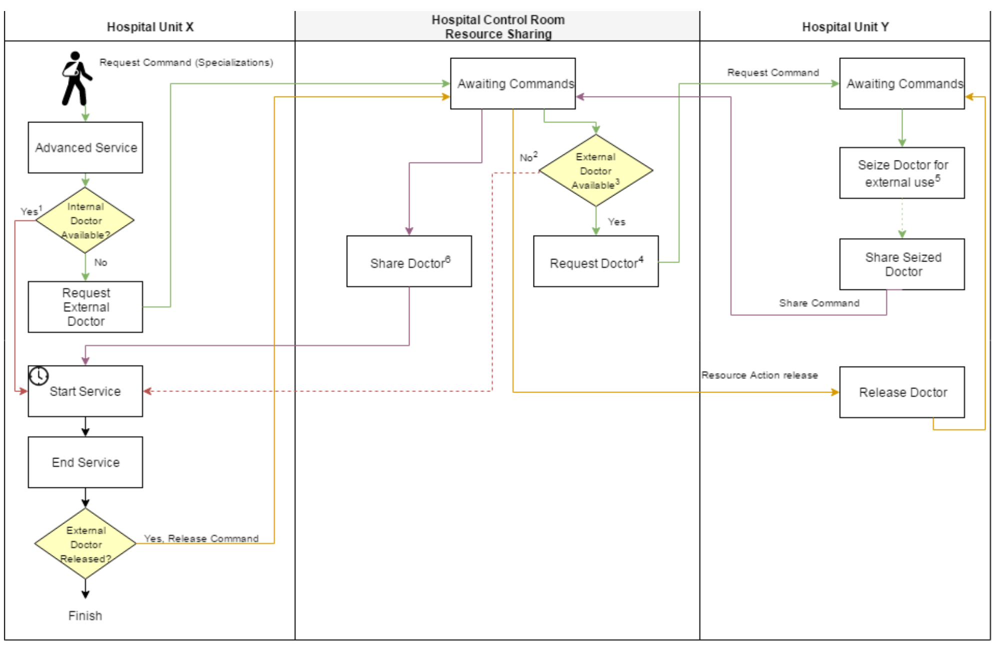

Figure 3: Sample implementation of the architecture.

As mentioned earlier, the challenge in creating composable simulations lies along two dimensions, the implementation and conceptual modeling. Here, we describe the architecture along those dimensions.

5.1 Implementation

5.1.1 Components

The first layer in the architecture is a suite of simple, interoperable and self-contained components. Each component is either a single behavior, or composed of simple modular behaviors. Each behavior represents a single task, function or activity carried out at the hospital. Every component is completely self-contained, in that it represents a complete, consistent piece of logic and has access to all resources it requires.

The individual components in the suite are realized using AnyLogic simulation software. As shown in the figure, each component represents a simple piece of logic such as waiting in a queue, or checking for a resource, or performing a task and so on. The components can be strung together into an overall process structure, also realized using AnyLogic. The process structure represents a unit in a hospital, for example a ward. This process structure is essentially a Discrete Event Simulation, where events are triggered either based on patient arrival or other process.

Components can also be agents. For example, the Patient Source spawns patients of different severity depending on configuration. Patients pass through the process, stopping at each component and take decisions on their own or wait for external stimulus (in this case to be processed by the component).

Depending on external stimulus (for example events generated through data or other simulation models), different modules and their subsequent behaviors are triggered. This process structure can be changed easily through simple rules, without re-implementing any models or the process structure.

5.2 Control Procedures

Using the AnyLogic API, a runner skeleton was created to enable running the models in an environment outside the simulation software (using the AnyLogic runtime libraries). The skeleton is able to run multiple models (a model is a set of components strung together in a process, the ward in the above illustration) concurrently and handle communication between them. The skeleton is also able to keep track of resource values of the models through the database.

This component is implemented in Java and is uses the Model-View-Controller design pattern to clearly discern the functionality between the different classes. It also uses the mediator design pattern to reduce the communication complexity between the objects and to keep the logic and communications limited to one place, enabling easy maintenance.

A rule engine implemented using the Drools library is used to route and monitors all communication between the components. The rules are external to the logic, and can be changed without implementing further changes in programming logic. A rule is essentially a statement in programming logic, and can be attached to different classes. This layer contains “facts” which are essentially Java classes that encapsulate data. Every fact invoked on the rule engine is saved for monitoring purposes.

5.3 Database

The data layer contains an ontology and a database. The ontology is implemented in Protégé, and contains the knowledge base for the entire architecture. The ontology can be accessed via a library, and the classes and instance used to populate parameters in the components.

The database contains a simple Enterprise Resource Planning (ERP) specification, again linked to the ontology. The control layer maintains a record of total resources as well as all the resources being used in the different running components. Whenever a component needs a resource, such as equipment or a doctor, it invokes a procedure in the control layer, which then checks the database for the resource and either satisfies the request or denies it. Logistics processes and planning is delegated out of the components, reflecting the current institutional agency in the hospitals.

5.4 Composability

The composability in the architecture is facilitated through two main functionalities. The first is the suite of self-contained components, which can be rearranged in a process depending on the scenario. This rearrangement doesn't require any programmatic effort, and is facilitated through the use of the Drools library. The second is the externalization of the entire suite, including the Drools library from the supporting simulation package. This facilitates the development of a software application that can be used within a participatory exercise.

The ontology is used to (sometimes) instantiate components and populates them. The ontology ensures conceptual consistency and integrity, since it contains data definitions and classes that have already been agreed upon by the medical community. This ontology was built based on previous models and through interviews with experts in Stockholm.

Using the rules engine, and the external application, a user (in this case a medical practitioner) can create their own models by changing the sequence of components in a process. The user effectively composes their own simulations using the components and the rules engines. In this way, the approach enables the user to simulate of different workflows and a wide range of scenarios.

6 DISCUSSION

We described a composable simulation architecture that combines discrete event and agent based simulation approaches that can facilitate process redesign and operational planning in hospitals. The requirements for the architecture in terms of flexibility and inter-operability were derived from a participatory simulation experiment that investigated the coordination process around patient transfers in Stockholm.

Decision making or operational considerations in healthcare is varied, and requires a lot of coordination and orchestration among multiple actors and stakeholders. For simulation to be applicable in this context, it needs to be able to support the modeling of processes from the perspectives of all of these stakeholders. Creating models for all actors is infeasible. However, the reusable, composable approach described in this paper could potentially address this pluralism issue by enabling all stakeholders to create their own models from the same validated building blocks.

By modeling only basic behaviors, it is easier to investigate the system and validate it as well. Validating complex models is hard. By breaking down a complex system into its most basic constituent parts, it is possible to investigate each component, either in isolation or by combining that component with others, and iterating over these combinations. Validation of simpler components is also easier, especially since they can be created through ontologies. Validation of the larger, complex processes can be accomplished by creating those processes with experts. The experts can be enabled to model processes based on their knowledge and experience, achieving validation, stakeholder engagement and knowledge capture at the same time.

Hybrid simulation is able to explore healthcare systems at multiple scales. However, this requires additional design consideration to be usable for practitioners. Software design practices and design patterns have proved beneficial in this exercise, not least deriving requirements from use cases. Other design patterns, such as MVC, mediator and fact based patterns facilitate maintainable, easily modifiable simulation architectures (Bell et al. 2016). The software is carefully implemented and documented to ensure reuse and composability at the software level, not only at the conceptual level, and based on design guidelines for composable components (Verbraeck and Valentin 2008).

Using a rule based engine such as Drools enables both forward and backward chaining, as well as flexibility in the architecture. Used predominantly in cases of complex business logic which changes often, rules engines serve to externalize complex business and domain logic, to facilitate easy modifications (Greenes et al. 2004). These modifications can be bottom up, driven by facts (which can be driven by the database and ontology in this instance) or driven top down (through user control of the component and process structures).

The composable approach is still domain specific. Creating a suite or library of components and composing them with stakeholders has the potential to create a large number of simulations. Methods to manage this library, as well as to manage the simulations that will be created are needed. Further research is also needed on the evaluation of these simulations.

Conceptual modeling is achieved through engagement with stakeholders and effective software design which enables them to model their own processes. Ontological frameworks ensure semantic integrity to some extent; resource planning is achieved through databases. The architecture for healthcare simulations combines a multitude of technologies and simulation approaches. Conformity to common interoperability standards in simulation or software such as High Level Architecture (HLA) or Base Object Model (BOM) is a desirable future step.

7 CONCLUSION

Composable simulations could have enormous potential to support process redesign, validate complex simulations and address the need for pluralistic models and simulations in complex systems. As compared to other domains, because of the wide variability in healthcare processes, the unit of integration must necessarily be smaller, at the behavior and individual level as opposed to the model level. Once the suite or library of components becomes standardized, the units can become larger and more complex. Hybrid approaches combined with effective software design provide promising ways forward for simulation in healthcare. Simulation in healthcare needs to integrate in tighter ways with stakeholders to enable uptake and increase the use of simulations in healthcare. The value created by such approaches is based on the need for pluralism and close collaboration among the stakeholders and the simulation community. It is imperative to leverage expert knowledge and to strive to include this knowledge in the simulation development process, enriching both communities.

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