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Hybrid simulation modeling for analyzing the impact of RFID scrubs'distribution in operating rooms

Yasmina Maïzi*, Ygal Bendavid

Department of Analytics, Operations and Information Technologies (AOTI), Case postale 8888, succursale Centre-ville, Montréal, QC H3C 3P8, Canada

*Corresponding author. Email address: maizi.yasmina@uqam.ca

Abstract

In this research study, we propose an overview of a hybrid agent-based and discrete-event simulation model to improve medical uniforms' (Scrubs) distribution system in hospitals located in Montreal region. This study is important since it allows the assessment of health and safety required conditions that guarantee a safe working environment for medical personnel in hospitals, and particularly vital in the current COVID-19 pandemic. Indeed, it assesses operational conditions for minimizing the spread of disease due to a) uniforms' exposure to germs and pathogens, directly related to the distribution process of these uniforms b) insufficient inventory level due to personnel's unusual behaviors in the pandemic context, involving extended use of potentially infected uniforms due to a shortage of uniforms on distribution shelves. We propose a framework for hybrid simulation model to evaluate the impact of using an automated RFID-based scrubs distribution system in order to control, from one side, scrubs' contamination and implicitly the contamination of any person or object in contact with employees, and from another side, scrubs' overuse - thereby leading to an inefficient scrubs' inventory management. This study is part of a pilot project conducted in one of the largest hospitals in the province of Quebec.

Keywords: Simulation, IoT, RFID, Health Care, COVID-19.

1. Introduction

The hospital in this research study is one of the largest hospital in the province of Quebec. Among the ongoing hospital initiatives, the improvement of uniforms' (Scrubs) distribution process specifically for operating rooms (OR) is under study. Unfortunately, this process is quite often overlooked (Bendavid et Maïzi, 2020), although considered as essential to the proper functioning of the hospital. While these uniforms protect medical personnel, they are also a possible vector of contamination and their sound management is of crucial importance. However, as in many hospitals, scrubs' management is inefficient and induces several problems:

1. Inefficient uniform replenishment system,
2. High level of inventory for OR uniforms,
3. Shortages of specific sizes or models,
4. Messy and disorganized shelving area
5. "Squirrel phenomenon" by staff who keep uniforms in their lockers in case of shortage
6. Non-compliancy with infection control regulations, which is increasingly important with the emergence of the COVID-19 Pandemic where these problems are exacerbated.

The hospital is therefore exploring innovative solutions for the distribution of uniforms that would meet the indicated challenges. In recent years, uniforms' distribution systems in the form of "smart cabinets" supported by Internet of Things (IoT) / RFID (radio frequency identification) technologies have attracted growing attention. However, there are various options on the market. Indeed, in the last few years, RFID uniforms' distribution systems have been implemented in hospitals, and few cases are available. In these cases, scrubs are equipped with RFID tags which allow real time automatic detection in the cabinet. This technological option seems promising but raises many questions related to (a) the most appropriate design for the hospital, (b) realistic impacts on operations, and (c) realistic impacts on staff health and safety.

In order to assess the impacts of implementing an RFID uniforms' distribution system for managing medical personnel's scrubs in operating rooms, in this research study, we present a hybrid simulation framework that integrates advantages, from one side, of discrete-event simulation modeling approach to represent operational rules and procedures inherent to hospital operations and processes, and from another side, of agent-based modeling approach to represent human behavior, namely surgeons and nurses in this particular business case of scrubs' utilization and how these behaviors impact scrubs' distribution process management.

The reminder of this paper is organized as follows: in section 2, we review the existing literature on RFID technology applications in scrubs' management and on hybrid simulation modeling in healthcare operations management. Section 3 describes the design science approach followed to investigate the business case of smart shelves RFID-based scrubs' distribution system in operating rooms. We first, describe the problem from the field, second define the objectives of the solution with respect to the hospital requirements; and third suggest the framework for a hybrid agent-based and discrete-event simulation model that assesses the impact of the proposed solution. We conclude this section by listing the expected outcomes of using our hybrid simulation model. These outcomes will be provided in the longer version of this paper. Finally, section 4 presents our concluding remarks.

2. Literature review

2.1 RFID solution literature review

In recent years, uniforms' (scrubs) distribution systems in the form of "smart cabinets" supported by RFID (radio frequency identification) technologies have been implemented in several hospitals. In this particular case of scrubs' distribution systems, the scrubs are equipped with RFID tags which allow real time automatic detection in the cabinet. In fact, the first generation of "smart cabinets" of this type was offered in 2007 (Bahelor, 2007), but the market was not ready at that time. Since then, the technology has evolved (e.g. Swedberg, 2018), several suppliers now offer various more reliable RFID solutions (e.g. ABG Systems, ImageFIRST, Tagsys, etc.), and we find various deployments in the middle hospital (e.g. Swedberg, 2017). If this track seems promising, it raises many questions. Indeed, apart from the studies proposed by the sellers, there are few scientific studies in the field, mainly interested in logistical processes (e.g. Salayong et al, 2019; Shim et al, 2016) and none of them explore the design of the most appropriate solutions to support logistics from the laundry department to the shelves on the floors. Additionally, apart from great numbers provided by vendors, the realistic impacts of such solutions on the performance of operations is still fuzzy: (a) the choice of the design of the most appropriate solutions from the laundry room to the distribution on the floors (b) with realistic impacts on the performance of operations (c) and even less with the opportunities to reduce contamination and the impact on staff health and safety. Indeed, because a virus like the COVID-19 can survive on surfaces several hours to days, contaminated personal protective equipment (PPE) such as scrubs may, in turn, serve as a vehicle for transmission of the virus, contributing to the spread of the outbreak. Although healthcare facilities are aware of this possibility, many hospitals still struggle to improve infection control and prevent contamination by ensuring that employees make good use of their uniforms. Looking at more efficient scrubs-distribution systems and preventing inappropriate use of uniforms by employees (e.g. manipulating the scrubs in the shelving areas, bringing them outside the hospital or hiding spare uniforms in their lockers) is a promising opportunity to explore (Bendavid and Maïzi, 2020). This is where RFID solutions may help with scrubs' distribution systems; still there are many analysis to perform to really assess the impacts.

2.2 Hybrid simulation modeling in healthcare operations management

Simulation modeling has been used to design, observe, understand, analyze and improve large-scale complex systems (Mei et al, 2015). Undeniably, its ease to grasp complex behaviors, interactions and operations makes it a powerful tool for analyzing and improving large scale healthcare operational management's issues. Moreover, there is a wide range of methods used to build simulation models, each of these methods/paradigms are predominantly used in their domain (Scheidegger et al, 2018). However, there are three paradigms that are widely used in operations management and industrial engineering community and related areas to model and resolve associated issues: Discrete-Event Simulation (DES), Agent-Based Simulation (ABS) and System Dynamics (SD). The inherent complexity of processes related to modern organizations as well as human behaviors impacting the performances of these processes has led managers and researches to combine these paradigms and use hybrid simulation approaches. Brailsford et al, (2019), define hybrid simulation as a modelling approach that combines two or more of the following paradigms: discrete-event simulation, system dynamics and agent-based simulation. In the last decades, hybrid simulation modeling has been successfully used to model several processes related to manufacturing, supply chain and healthcare (Brailsford et al, 2019), most of them using a combination of discrete-event simulation and system dynamics modeling. Likewise, Scheidegger et al (2018) conducted a thorough literature review regarding hybrid simulation methods used by the industrial engineering community and related areas. The results of the study show that the combination of SD and DES have more than 40 years of history while the integration of ABS in hybrid simulation modeling has a recent history, but successful applications in healthcare operations management in combination with DES modeling. The motivation to use a hybrid modeling approach is derived by the complexity of the modeled system and hence the difficulty to grasp its inherent characteristics by using one modeling paradigm that could lead to limited modeling abilities. Hybrid simulation applications were particularly successful in healthcare due to the multidimensional complexity inherent to healthcare operations. Some examples of applying hybrid simulation modeling to healthcare are interesting to mention : Djantiliev and German (2013) present a remarkable hybrid simulation modeling approach for large scale healthcare modeling needs using AnyLogic software, and a case study for stroke therapy is used to present the applicability of such a framework for large-scale problems. Abdelghany et al, (2016) develop a DES/ABS modeling approach for healthcare systems modeling and analysis and validate their modeling approach with a case study in a radiology centre. Viana et al, (2018) develop a hybrid DES/ABS model to improve patient flow at the outpatient pregnancy clinic in Norway, given the uncertainty associated with the demand. Although the literature shows intensive research studies using hybrid simulation modeling approach, the majority of them combine discrete-event simulation modeling and system dynamics. Few of them combine ABS and DES modeling. Therefore, leaving the door open to many opportunities to develop simulation frameworks that combines ABS and DES modeling paradigms.

3. Methodological approach

In order to select and analyze the impacts of deploying an efficient scrubs' management system for OR, we adopt a Design Science approach (Hevner et Chatterjee, 2010; Peffers et al, 2007). More specifically, we follow the Design Science Research Methodology (DSRM) process model as presented in Fig.1 and detailed in what follows.

The identification of the research problem and the motivation for the research (Phase 1) started before the Covid-19 pandemic, when the hospital under study had raised significant concerns regarding scrubs' management (see Fig. 2). In this figure, part a) displays the actual scrubs' distribution process where personnel have free access to the uniforms displayed on the shelf. Part b) of Fig. 2 displays the same free access shelf after a day. One can note that there is no control on personnel's movements (searching, multi-picking, preference picking, etc.). It is important to mention that in the specific case of COVID-19 pandemic: (a) the shelves are completely "robbed", forcing the laundry management department to re-stock urgently; (b) the remaining scrubs are considered contaminated due to uncontrolled personnel's movements.

In Phase 2, we defined high-level objectives for (a) improving the logistic performance of the OR uniforms' distribution system used by the medical personnel (see Fig.3), by (a) helping the hospital select the most appropriate RFID scrubs management system for the OR and (b) designing and developing a simulation model to better assess the potential impacts on scrubs' logistics processes. This will allow better decisions for the future pilot project.

In the following Phase (3) we:

(a) Identify potential RFID solutions used to improve scrubs management. An initial benchmark analysis is being conducted in order to understand the existing offer on the market. This allows leveraging on existing knowledge, targeting the right system and formalizing our hypothesis for the hybrid simulation model. A more exhaustive professional review is planned to explore previous RFID initiatives in the sector and identify specific KPIs that will be used for building the case. We also plan to explore information from professional conferences such as RFID journal live and the *The Clean Show* to have a more comprehensive understanding of such solutions (linens tracking) used in laundry, hotels, hospitals, etc. At this stage, there is no more doubt that RFID technology is the dominant design.

(b) Select specific designs (solutions) in order to reduce the number of scenarios to test and prototypes to develop.

(c) Design and develop RFID-simulation models and retained RFID prototypes at the ESG/UQAM Internet of Things (IoT) lab, where we have access to simulation software, RFID equipment to build smart shelves and RFID equipped scrubs provided by the hospital.

(d) Propose a preferred solution according to the impacts on operations performance.

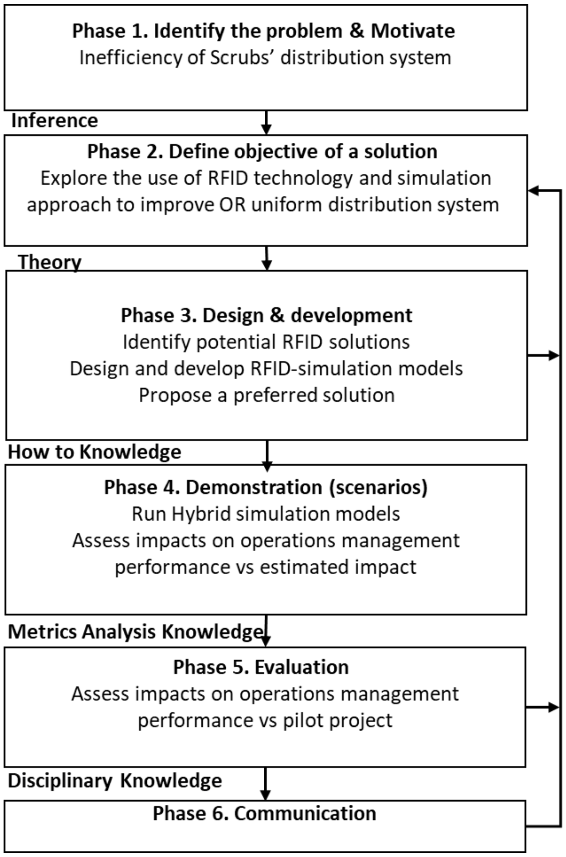

Figure 1. Design Science Research Methodology (DSRM) process model followed in the research (Peffers et al, 2007)

For the Phase 4 - Demonstration and the assessment of the solution (vs. the projects requirements), our hybrid simulation models will be tested at the ESG/UQAM IoT lab. The hybrid simulation models will be developed using data from the laundry management department. The framework of the simulation model is presented in the following subsection.

In Phase 5, in order to "observe how effective and efficient is the solution", we intent to participate in a pilot project of one system (e.g., smart cabinet, smart shelves, or else) in the OR department of the hospital. The results of a real implementation will provide data against which we will revise the simulation model inputs and align it to make it more reliable for further deployments.

a) Shelf at the beginning of the day and b) Shelf at the end of the day

Figure 2. Uniform actual distribution system (self-service with limited control)

Figure 3. Uniform distribution system: from laundry to OR department for medical personnel.

It is important to note that although the five phases were presented sequentially, in reality they include several feedback loops between the ESG/UQAM IoT lab and the hospital.

3.1 Hybrid simulation framework

In this subsection, we give an overview of the hybrid simulation framework to be developed in this research study. The reader can note that this is an ongoing research work that started before the COVID-19 pandemic. At the beginning of this pandemic, we were in a data collection phase. Due to the change of the situation, the data collection phase is now including a new situation related to the pandemic that will allow us to better validate our ABM modeling paradigm used in the hybrid model. The complete version of the model and the simulation results will be presented in the longer version of this paper.

3.1.1 Model development

The multidimensional complexity of healthcare operational processes are a perfect motivation for choosing a hybrid modeling approach. More specifically, in our business case, there is a need for comprehensive and accurate modeling of operational processes and business rules as well as personnel's behaviors impacting the correct functioning of these processes and rules.

The hybrid simulation model is developed in our IoT lab at ESG/UQAM and will assess the impact of using some RFID equipment to build smart shelves. Several scenarios will be run in order to choose the most appropriate technology. The model is developed using AnyLogic (AnyLogic, 2018) since it allows the integration of both ABS and DES paradigms.

Agent-Based Simulation Modeling

Generally speaking, there is no doubt that human resources' behaviors have a direct impact on operations management (Bendoly et al, 2015). More specifically, in a hospital environment, personnel's behaviors have a direct impact on scrubs' distribution management. Indeed, some employee have preferences regarding specific categories of scrubs, they have tendency to take more scrubs than required, they hide them, they wash them at home, they don't bring them back to the laundry collecting points, etc. The list of odd behaviors is long. In the context of the COVID-19 pandemic, these behaviors have considerably increased and raised new challenges to hospitals' managers, concerning scrubs' inventory management but more critical issues of scrubs' potential contamination factor due to their over manipulation on the shelves, from one side, and from another side, due to the fact that these scrubs are manipulated outside hospitals areas. Consequently, it is obvious that an ABS paradigm is the most appropriate approach to model these behaviors. In the specific case of our model, the ABS modeling components are summarized in Table 1.

Table 1. ABS components of the hybrid simulation model.

Characteristics	
Agents	Surgeons, anesthesiologists, nurses, technicians, residents, students and cleaning resources.
	All laundry resources affected to different tasks.
Behaviors	Agent decisions and their reactivity to environmental conditions and to their interactions with other agents.
	Agent future decisions in reaction to environmental changes.
States	Passive/Active states of each agent.
	Agents' mood or emotional state. (NB: will affect agents' behavior and therefore their interactions with processes and procedures of the DES model)

Discrete-Event Simulation Modeling

The Discrete-Event Simulation paradigm is used to model scrubs' flow within the laundry facility, procedures as well as to represent the scrubs' distribution process and inventory management policy.

An overview of the hybrid simulation framework is presented in Fig. 4.

3.1.2 Model data collection and future scenarios

Data collection is still a work in process. From one side, data related to scrubs flow process: namely, different arrival channels, arrivals rates, cleaning steps and process times, specific protocols for scrubs coming from specific channels. Data related to equipment downtime and resources unavailability. Scrubs' distribution frequencies and points of distribution. From another side, personnel's behaviors regarding scrubs picking frequencies at different points and scrubs' returning frequencies at different points. Qualitative data collections through surveys regarding personnel's behaviors with respect to COVID-19 pandemic situation and in response to other colleagues' reactions. Finally, specific data related to contamination rates of different viruses and pathogens and related to scrubs free manipulation on the shelves.

A first simulation model will be built to represent the actual mode of operation that takes into account a free access to scrubs displayed on shelves. Once the model is verified and validated with hospital data, a second model representing a desired future mode of operation will be built and will integrate smart shelves as scrubs' distribution system for OR. Primary to simulation modeling, several tests will be conducted at the IoT lab in order to come up with the best RFID-based solution for smart shelves. Scenarios will be run to assess the impact of using these smart shelves on daily operations management as well as on staff health and safety.

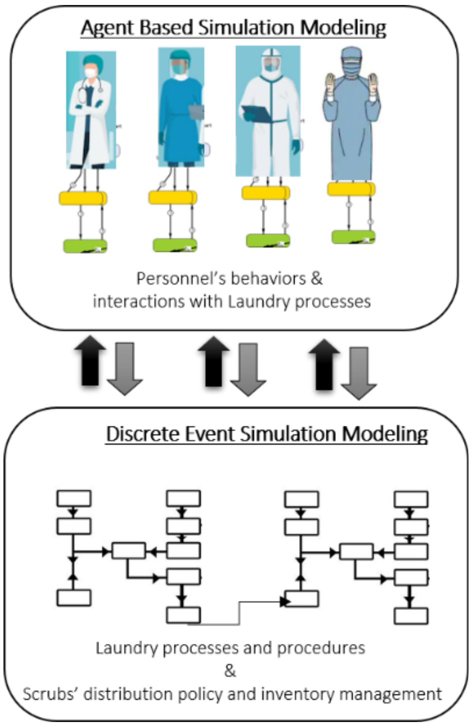

Figure 4. Hybrid simulation framework.

3.1.3 Expected outcomes

We expect to show that RFID-based smart shelves scrubs' distribution system will help hospital managers achieve several goals. Between them two goals expected by our partner in this study (hospital):

- Align scrubs' demand according to the needs (e.g. create a balance availability vs level of inventory, create incentives to return uniforms after use, prevent loss / theft and ensure availability of all sizes at all times for all staff)
- Improve infection control and prevention of contamination by staff (i.e. reduce handling of scrubs on shelves - prevent movement of scrubs outside the hospital - prevent illegal storage of scrubs in the staff locker)

4. Conclusion

RFID technologies have been widely used across industries and have enabled a variety of applications. Among the research's interests related to RFID innovative solutions, we can mention the application of such technologies to improve scrubs' distribution systems. The methodological contribution of this paper is multiple:

a. Combine the usage of physical prototyping and simulation modeling for an RFID-based project.

b. Define a realistic hybrid simulation framework (based on tested RFID technologies) that integrates processes' and procedures' dynamics and rules as well as resources behaviors that impact these dynamics. We strongly believe that each of these behaviors that are certainly different among categories of personnel affects operational performances which will likewise affect resources' performances. We expect to quantify these impacts through our simulation scenarios.

c. Assess the impact of RFID-based smart shelves on inventory management policy and iteratively validate the robustness of the model against the real implementation with a pilot project at the hospital.

d. Quantify the impact of using RFID-based smart shelves on health and safety required conditions that guarantee a safe working environment for medical personnel in hospitals, and particularly in the current COVID-19 pandemic, since we expect that simulation scenarios will quantify the potential spread of disease due to uniforms' exposure to germs and pathogens, directly related to the scrubs' distribution process.

This study is an ongoing research work. We are in a gathering data phase that has been extended due to COVID-19 pandemic. We expect to present our ESG/UQAM IoT Lab tests and simulation results in the extended version of this paper.

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References

Abdelghany, M., Eltawi, A., (2016). A Discrete-Event and Agent-Based Hybrid Simulation Approach for Healthcare Systems Modeling and Analysis. (2016). International conference on Industrial Engineering.

AnyLogic, 2018. AnyLogic (version 8.2.3). www.anylogic.com.

Bahelor, B. (2007). Tagsys Unveils Smart Cabinet to Help Hospitals Manage Surgical Scrubs, RFID Journal; Retrieved from http://www.rfidjournal.com/articles/view?3400

Bendavid, Y., Maïzi, Y., (2020). An Overlooked Use of RFID at Hospitals. Retrieved from https://www.rfidjournal.com/an-overlooked-use-of-rfid-at-hospitals

Bendoly., E., Wezel., W., V., Bachrach., D.G., (2015).

The handbook of behavioral operations Management. OXFORD University Press.

Brailsford, S.C., Eldabi, T., Kunc, M., Mustafee, N., Osorio, A.F. (2019). Hybrid simulation modelling in operational research: A state-of-the-art review, European Journal of Operations Research 278 pp. 721-737.

Djanatliev, A., German, R., (2013). Large Scale Healthcare Modeling by Hybrid Simulation. In Proceedings of the 2013 Winter Simulation Conference, pp. 1881–1892.

Galvão Scheideggera, A.P., Fernandes Pereirab, T., Moura de Oliveirac, M.L., Banerjeea, A., Barra Montevech, J.A., (2018). An introductory guide for hybrid simulation modelers on the primary simulation methods in industrial engineering identified through a systematic review of the literature, Computers & Industrial Engineering 124, pp. 474-492.

Hevner, A., Chatterji, S., (2010). Design science research in information system. In book: Design Research in Information Systems, pp. 9-22.

Mei, S., Zarrabi, N., Lees, M., & Sloot, P.M.A. (2015). Complex agent networks: an emerging approach for modeling complex system. Applied Soft Computing, volume 37, December, 311-321

Peffers, K., Tuunanen, T., Rothenberger, M. A., and Chatterjee, S. (2007). 'A design science research methodology for information systems research'. Journal of Management Information Systems, 24 no 3, pp. 45-77

Salayong, K., Phaebua, K., Lertwiriyaprapa, T., Boonpoonga, A., Chaiyasang, L. et Kumjinda, A. (2019). Linen Laundry Management System in Hospital by Using UHF-RFID. Research, Invention, and Innovation Congress (RI2C) pp. 1-4.

Shim, S. J., Kumar, A. et Jiao, J. R. (2016). Computer simulation for reengineering the linens delivery process with RFID in a hospital. International Conference on Information Society (i-Society) pp. 122-125.

Swedberg C. (2017). RFID Solution Cuts Scrubs Costs for Virginia Hospital, available online Retrieved from http://www.rfidjournal.com/articles/view?16626

Swedberg C. (2018). Super-Slim RFID Tags for Linen Tracking, available online: Retrieved from http://www.rfidjournal.com/articles/view?17541

Viana., J., Simoensen., T.B., Dahl.,F.A., Flo., Kari. (2018). A hybrid discrete event agent based overdue pregnancy outpatient simulation model. In proceeding of the 2018 Winter Simulation Conference.