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Designing a RFID/IoT prototype for improving COVID19 test centers daily operations

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Abstract

In this research paper, we propose a hybrid agent-based and discrete-event simulation model coupled with a RFID/IoT infrastructure for improving COVID19 test centers located in Montreal region. This study is important, since defining an optimal capacity for healthcare operations is always a challenge, especially in a pandemic mode. Indeed, in such situations, all managers are more concerned by the effectiveness of daily operations regardless their efficiency. Even though, this can be meaningful and largely acceptable, it could lead to critical situations depending on how the current situation may evolve. To improve the performance of COVID19 test centers, it requires a good understanding of logistics flows and a visibility on daily patient inflows and different resource utilization. We propose a RFID/IoT infrastructure that captures test centers real time data and make them available to be used by our hybrid simulation model. The model uses real time data to continuously adjust test centers capacity. This study is part of a bigger project conducted in Montreal region where we design and develop Digital Twins modules to assist different healthcare units such as emergency departments, COVID19 vaccination centers as well as COVID19 test centers.

Keywords: Simulation; IoT, RFID, COVID19 test centers, healthcare operations management.

1. Introduction

In March 2020, the World Health Organization (WHO) declared that the COVID19 outbreak became a pandemic (WHO, 2020). In the province of Quebec, the first cases of COVID-19 infection have been diagnosed at the end of February 2020. On March 13, 2020, the state of health emergency was declared throughout the province of Quebec. Today, the virus continues its frantic progression and to date (beginning of May 2021), the province of Québec has 361,820 confirmed positive cases and unfortunately 11,025 deaths, (INSPQ, 2021).

The sudden increase in cases and hospitalizations has set an enormous burden on a healthcare system already strained and weakened by an elderly population suffering from chronical diseases.

Even with the development of new vaccines and a hope of herd immunity against the COVID19, testing, tracking, tracing and isolating quickly and on a large scale continues to be vital to public health policy responses to the COVID19 pandemic (OECD, 2020). This implies COVID19 testing strategies that combine different technologies but also managing COVID19 test centers effectively and efficiently to ensure a quick adjustment of tests centers' capacities in response to sudden raise of cases.

In situations of extreme emergency such as the current pandemic, healthcare operations managers are focused on achieving the critical daily operations, thus unintentionally neglecting data collection essential to process analysis and improvement approaches.

In this research work, we aim to develop and design a RFID/IoT infrastructure (prototype) to improve COVID19 tests centers daily operations. Indeed, this infrastructure monitors daily operations within these tests centers and capture patients' and resources' information that will be used for adjusting test centers capacity if needed. We first determine the appropriate technologies that can be implemented at different levels of a COVID19 test center. Second, we test our physical prototype within our lab. Finally, we develop a hybrid simulation model that will use real time captured data from COVID19 tests centers in order to adjust their capacities with respect to predicted increase of patients' inflow.

The remainder of this paper is organized as follows: in section 2, we explore the existing literature regarding: i) RFID/IoT in healthcare; ii) hybrid simulation modeling in healthcare operations management and iii) simulation-based modelling cases related to COVID19 pandemic. Section 3 describes the design science methodological approach followed to develop the physical prototype. In section 4, we describe the hybrid simulation model that was developed to use RFID/IOT prototype gathered data. Given this model, we run two scenarios to show how it is crucial to adjust the COVI19 tests centers capacities in anticipation of a sudden patients' inflow increase. This is achieved by using the real time data captured by the RFID/IoT infrastructure.

2. Literature Review

As the COVID19 pandemic continues its frightening progression, the scientific community has addressed (and is still doing so) several issues raised by this global situation. Moreover, government authorities have heavily relied on decision support tools, among them those using a simulation based modeling approach to address challenges and concerns induced by this global pandemic (Currie et al., 2020). In what follows, we address literature review regarding: i) RFID/IoT in healthcare; ii) hybrid simulation applications in healthcare operations management; finally, iii) simulation modeling related to COVID19.

2.1. RFID/IoT in healthcare at the time of COVID19

IoT technologies have been widely explored to help authorities in managing various challenges in the recent outbreak of COVID19. For instance, IoT technologies are used for contact tracing and social distancing applications (Shahroz et al., 2021). IoT based wearable monitoring device have also been proposed to measure vital signs related to COVID19 as well as compliance to quarantine for potentially infected patients (Bassam et al., 2021; Otoom et al., 2020). Other researchers have started to explore future "smart connected community scenarios" as blueprints for the development of "smart and intelligent infrastructures" (including smart testing centers) against COVID19 as well as for helping manage future pandemic outbreaks (Gupta et al., 2021). Although a part of IoT literature concerns indoor tracking applications (e.g., for mobile assets or patients), in regard to the extant literature, the research on "RFID, simulation and tracking" (co-occurrence key words) has mainly been explored in logistics and supply chain management (Rejeb et al., 2020). In the present research we borrow the same themes and use them to explore the outcomes of using a RFID/IoT infrastructure that ensures tracking real time patients' dynamics in a COVID19 test center.

2.2. Hybrid simulation modeling in healthcare operations

Simulation modeling has been used for decades to design, observe, understand, analyze and improve large-scale complex systems including several applications in healthcare(Salleh et al., 2017), (Mei et al., 2015).

There is a wide range of methods used to build simulation models, each of these methods/paradigms are predominantly used in their domain (Galvão et al., 2018). However, there are three major paradigms: discrete-event simulation (DES), agent-based modeling (ABM) 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 modeling. 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, Galvão 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 has more than 40 years of history, while the integration of ABM 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/ABM 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/ABM model to improve patient flow at the outpatient pregnancy clinic in Norway, given the uncertainty associated with the demand.

2.3. Simulation modeling related to COVID 19 pandemic

In this specific context of the COVID19 pandemic, simulation modeling has contributed to address many different issues. We observe several epidemiological simulation modeling of the COVI19 outbreak. One can cite the worldwide very well known (SEIR) model that describes the evolution of the proportion of susceptible/exposed/infected/recovered individuals within a given population. Kemp et al. (2021) use an extended (SEIR) model including social interaction, undetected cases and patients' progression through hospitals, intensive care units and deaths to describe the impact of the COVID19 pandemic and its evolution. Gostic et al. (2020) address the issue of traveling and how limiting these travels can have a considerable impact on pandemic progression. (Cuevas, 2020) uses an agent based model to evaluate the COVID19 transmission risks in facilities. The model includes an individual profile for each agent, which defines its main social characteristics and health conditions used during its interactions. The achieved experimental results provide useful information to elaborate public health strategies for reducing the transmission risks of COVID19 within facilities. Silva et al. (2020) suggest an agent based model to simulate health and economic effects on social distancing. Different scenarios of social distancing interventions are analyzed, with varying epidemiological and economic effects. The scenarios' outputs deliver a useful tool to assist health authorities in planning different actions against COVID19 spread. Asgary et al. (2021 a) combine artificial intelligence to a hybrid DES/ABM simulation model that assists mass vaccination planners in order to assess the outcomes of different types of drive-through mass facilities. Finally, Asgary et al. (2021 b) use an agent based model to analyze the outcomes and effectiveness of different testing strategies and scenarios in schools, with various number of classrooms and class sizes. They use a modified version of the (SEIR) model that includes symptomatic and asymptomatic infectious populations as well as feasible public health measures. The results of the simulation modeling show that even though testing cannot eliminate contamination risks, it can certainly control outbreaks. In this same vein, this study, offers to emphasize on how we can assist COVID19 tests centers in order to quickly adjust their capacities in response to sudden patients' inflow increase.

3. Methodological approach

For this research paper, we followed a Design Science Research (DSR) approach (Peffers, et al., 2007), presented in **Figure 1**.

In phase 1 we identified the inefficiencies of covid-19 testing centers and raised the importance of having high grained visibility on the performance of each workstation (vs a high level number of people tested/day). In phase 2, we formalised to the objectives of designing and developing a RFID/IoT prototype that would be used to support the decision making for improving the performance of the center (e.g., by allowing a real time visibility on operations and ability to re-assign resources where required. In phase 3, we gathered data on patient flow, resource usage and facility settings to document the COVID19 centers. This was used to select the most appropriate technology for tracking patients at different stages of the process. Since we looked for high detection performance-low value-disposable IDs, we selected passive UHF RFID tags (from Avery Dennison and Zebra) using a badge form factor. Various fixed readers were also identified as potential candidates to track patient's presence and directions. The next step was to build the connected prototype at the Montreal-based IoT lab, where various RFID technologies are available. In order to facilitate the integration of the data capture we used the same line of products from one vendor (Impinj, 2021) using various passive RFID UHF fixed readers: (a)xPortal to detect patients in a zone such as a waiting area (b)a multi antenna R420 fixed reader to detect patients in different subzones (c) a xSpam fixed reader equipped with a technology to detect patients movements from one zone to another **(Figure 2).** All captured data is then streamed to a specific database using PTS ClearStream software (PTS, 2021). At phase 4, testing the RFID/IoT infrastructure in our IoT lab allowed us to validate the choice of the main technologies required that ensure tracking

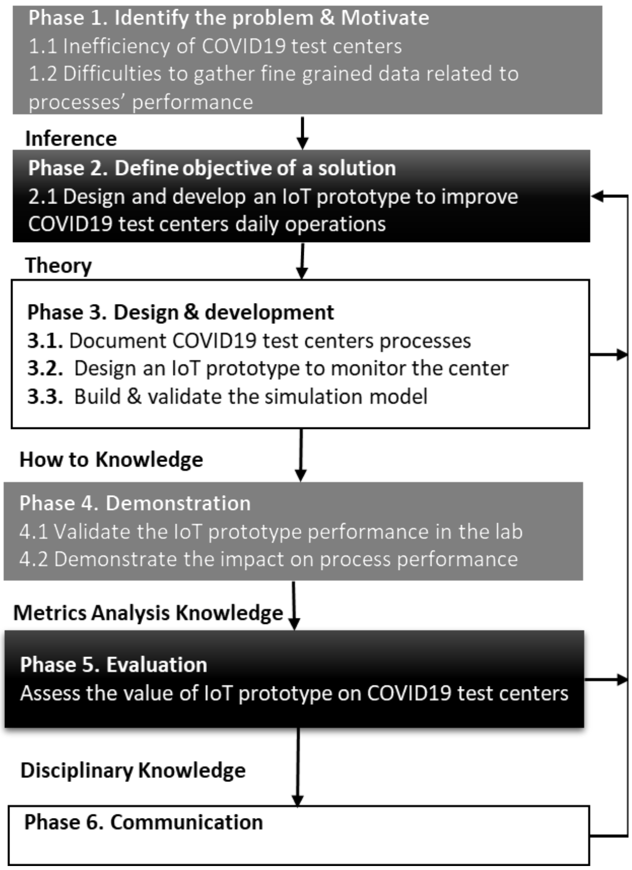

Figure 1. Methodological approach.

patients' dynamics from one side, and from another side, real-time transmission of gathered data to be used by our simulation model. Once the RFID/IoT infrastructure was tested and validated in our lab, we built a simulation model designated to use real time captured data from our IoT prototype, and demonstrate impacts on process performance. Within this paper, the scope of the research is limited to phase 4 – but the next step will be to fully evaluate the prototype onsite.

4. Solution Design for improving COVID19 tests centers

4.1 Physical prototype

As presented in **Figure 2**, various readers (R) are disposed in specific areas where patients are located, i.e: 1) in the lineup, 2) at each desk of the evaluation area, 3) in the first waiting area, 4) at each desk of the registration area, 5) in the second waiting area and finally, 6) at each desk of the testing area.

4.2 Simulation modeling for COVID19 tests centers

For this research paper, we develop a hybrid modeling approach integrating a discrete-event simulation paradigm and an agent based modeling paradigm, using AnyLogic (AnyLogic, 2021). The discrete-event Simulation paradigm is used to model the testing process within a COVID19 test center, while the agent based modeling paradigm is used to model the patient behavior and states as well as used resources.

We develop first, one base case model that represents the COVID 19 test center before the second wave (end of summer time). We verify and validate this model. Then, by running two scenarios, we suggest a better staffing policy in order to anticipate the impact of patient inflows increase in COVID19 test centers, in prevision of the second wave or any other successive wave at that time.

The testing process is divided in three major activities, each of these activities requires specific resources. The COVID19 test center under study takes walking patients. Patients are first triaged, they are then sent to the registration area in order to take their information, and finally they are sent to the testing area where a nurse will proceed with testing. The process end at this step.

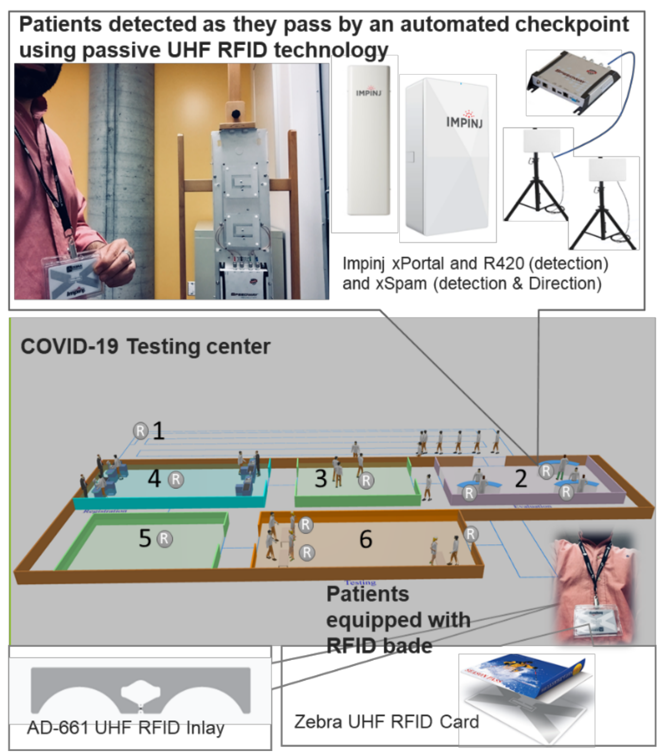

Figure 2. RFID Prototype for capturing real time data.

Figure 3. represents a 2D view of the COVID19 test center simulation model, while Figure 4. represents a 3D view of it.

In order to assess the performance of the COVID19 test center, the following key performance indicators (KPIs) are used:

- **Average length of stay**. This KPI is designated in the results as: **Avg Leng Stay**.

- **Resources percentage of utilization** per category of resources. These KPIs are designated in the results as:
  - **% Util Admin**: for resources assigned in the registration area
  - **% Util Triage**: for resources assigned in the evaluation area.
  - **% Util Test**: for resources assigned in the testing area.
- **Total number of tests performed in a day**. This KPI is designated in the results as: **# Tests**.

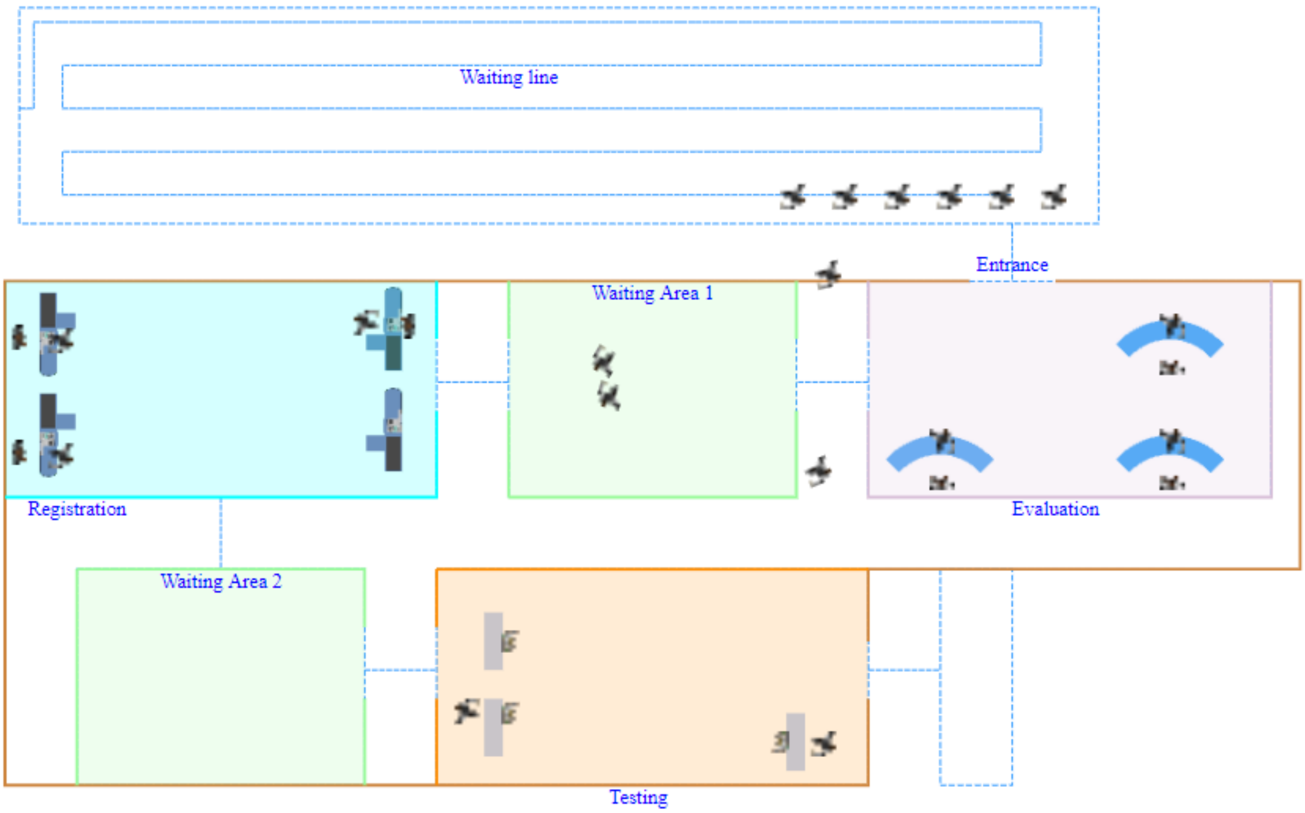

Figure 3. A 2D view of the COVID19 test center simulation model.

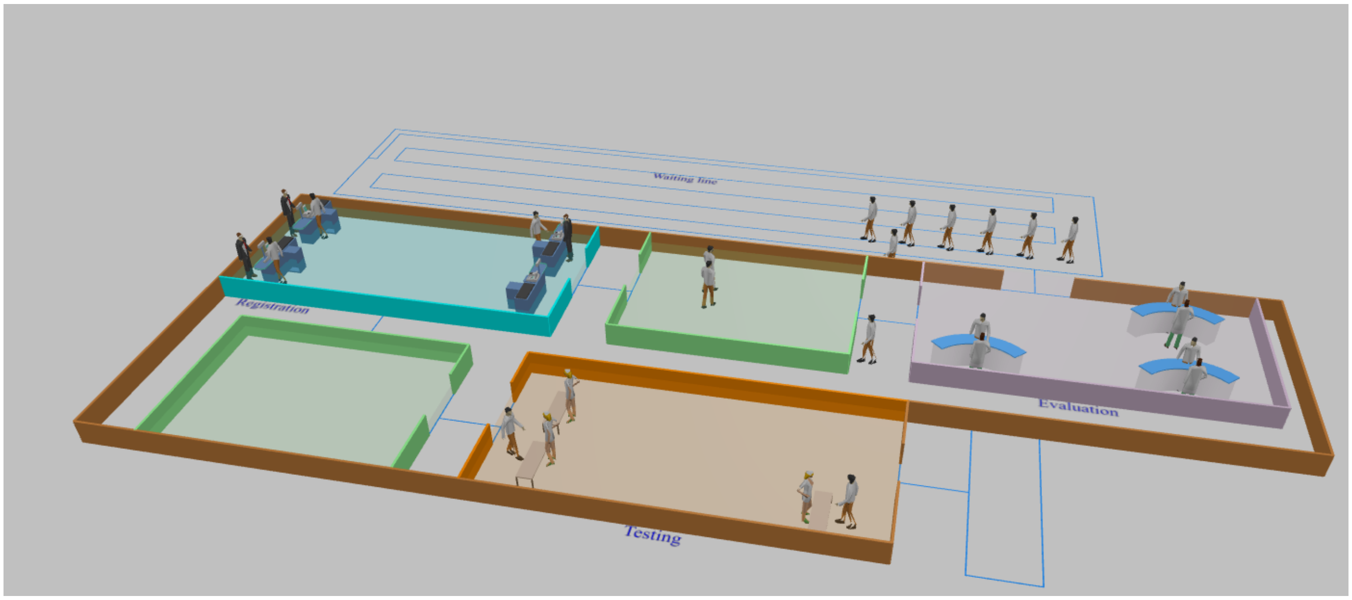

Figure 4. A 3D view of the COVID19 test center simulation model.

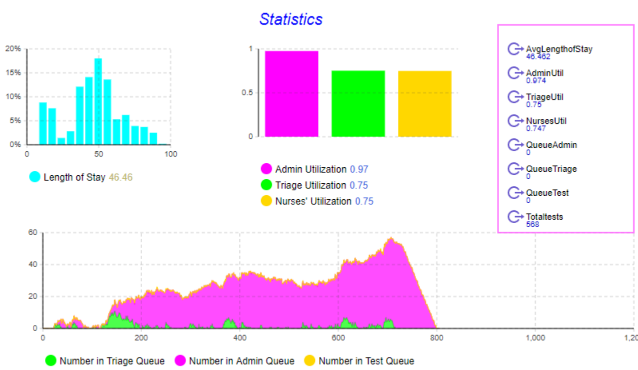

Figure 5. Results for one replication.

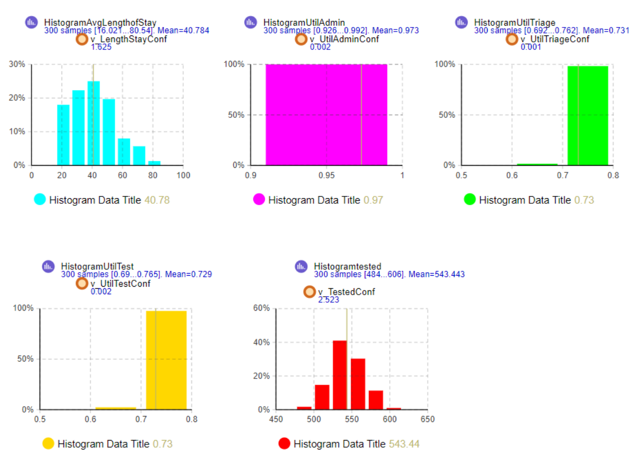

Figure 6. Parameters variation experiment.

The simulation model runs over a day (8:00 am to 8:00 pm) and is repeated 300 times, in order to generate statistically significant results. Figure 5 shows a screenshot of the simulation results for one replication, while Figure 6 shows the results for parameters' variation experiment with a random seed and 300 replications. Table 1 summarizes the results.

Table 1. Summarized results for parameters' variation experiment.

KPI	Value	Half-width
Average Length Stay (min)	40.78	1.62
% Util Admin	97.30%	0.002
% Util Triage	73.10%	0.001
% Util Test	72.90%	0.002
# Tests	543.44	2.52

The rounded number of test gives an average of 543 performed test per day.

To validate the simulation model, we compared two KPIs provided by the simulation model to the corresponding one in the COVID19 test center: the average length of stay and total number of tests performed in a day. The observed KPIs in this test center, for the specific analyzed period were as follows: an average length of stay, μ_1=38 minutes and an average total number of performed tests per day, μ_2=541 tests.

The simulation results show:

- An average length of stay of 40.78 min with a 95% confidence interval:
IC1 = [39.16, 42.4]. Where, LB1= 39.16 min is the lower bound and UB1 = 42.4 min is the upper bound.

- A total number of performed tests of 543.44 with a 95% confidence interval:
IC 2 =[540.92, 545.96]. Where, LB2 = 540.92 is the lower bound and UB2 = 545.96 is the upper bound.

If we consider a reasonable error (ε_1= 5 min, for the average length of stay and ε_2 = 5 tests, for the total number of performed tests per day), we can say that the simulation model is valid for the COVID19 test tester under study. Indeed, Table 2 displays the relative variation between the simulation model's KPIs and the COVID19 test center KPIs by comparing the lower and upper bounds differences with the acceptable errors.

Table 2. Comparison of simulation results with COVID19 tests center KPIs.

Measure	Value	Comments
UDif1 =$\lvert UB1 - \mu_1 \rvert$	1.16	$\mu_1 \notin$ IC1 but
LDif1 =$\lvert LB1 - \mu_1 \rvert$	4.4	LDif1 < ε_1
UDif2 =$\lvert UB2 - \mu_2 \rvert$	4.96	$\mu_2 \in$ IC2 and
LDif2 =$\lvert LB2 - \mu_2 \rvert$	0.08	LDif2 < ε_2

Once the simulation model validated, we then analyze its outputs. The results displayed in Table 1 show a high % of utilization of registration resources (administrative resources). Consequently, a small increase in patients' inflow in prevision of the second wave or any other subsequent waves would be very damageable. Hence, it will induce an increase of the average length of stay, from one side, and from another side, putting people a risks to be contaminated due to their long stay in a same closes area (even if all protective measures are taken, there is always a small contamination risk).

Hence, in this perspective, we optimized (using OptQuest optimization tool) the simulation model capacity considering an increase of 25% and 50% respectively in patients' inflow. One can note that for our COVID19 test center, this increase in patients' inflow will be detected with the RFID/IoT infrastructure.

Table 3. displays simulation results for an increase of 25% of patients' inflow with adjusted capacity, while Table 4. displays simulation results for an increase of 50% of patients' inflow with readjusted capacity consequently.

Table 3. Summarized results for parameters' variation experiment with a 25% increase in patients'' inflow.

KPI	Value	Half-width
Average Length Stay (min)	12.36	0.06
% Util Admin	68.80%	0.003
% Util Triage	77.90%	0.003
% Util Test	77.60%	0.003
# Tests	720.43	3.18

The rounded number of test gives an average of 720 performed test per day.

Table 4. Summarized results for parameters' variation experiment with a 50% increase in patients' inflow.

KPI	Value	Half-width
Average Length Stay (min)	12.93	0.09
% Util Admin	86.30%	0.003
% Util Triage	78.10%	0.003
% Util Test	77.70%	0.003
# Tests	902.81	3.35

The rounded number of test gives an average of 903 performed test per day.

The adjusted capacity in both scenarios (increase of 25% and 50% in inflow patients) ensures an average length of stay of 12-13 minutes. Let's recall that the key here is to be able to detect the quick change in patient inflows and adjust the capacity consequently. The RFID/IoT infrastructure is designed to continuously feed the simulation model for this purpose.

5. Conclusion

In this research paper we designed and built a RFID/IoT infrastructure that ensures tracking real time patients' dynamics in a COVID19 test center, as well as tracing process' flows. A tag encoded with a unique (24 digit) Id is used to identify each patient and stream real time data that can be used in a simulation model to continuously adjust COVID19 tests centers capacities when required. The advantage of such a technology is certainly its affordable price, but more importantly, it is a disposable tag that avoids any contamination since the data is captured automatically at each point of interest where RFID readers are installed. Additionally, the infrastructure addresses privacy concerns that are always important in such implementations. Indeed, patients remain anonymous, which is a very important aspect, since people tend to resist to invasive technologies that identify them (such as face recognition using vision technology and AI, or applications on their cell phone). This concern was raised while the COVID19 tracing application was launched in Canada with limited success. The scope of this paper was limited to phase 4 of our methodological approach. This study is part of a bigger project conducted in Montreal region where we design and develop Digital Twins modules to assist different healthcare units such as emergency departments, COVID19 vaccination centers as well as COVID19 test centers. The next phase will be to deploy the infrastructure in a test center.

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