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DESIGNING A DIGITAL TWIN PROTOTYPE FOR IMPROVING VACCINATION CENTERS' DAILY OPERATIONS

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ABSTRACT

In this research paper, we propose a digital twin prototype to improve mass vaccination centers in the Montreal region. This research is important because is it always challenging to define an optimal layout/capacity for healthcare operations, especially in an emergency mode (e.g., pandemic mode). Indeed, in such stressful situations, all managers are more concerned about the effectiveness of daily operations, regardless of their efficiency. Following a "design science" research approach, we developed (i) an IoT prototype for real-time patient tracking, (ii) a simulation model, and (iii) integrated them to build our digital twin prototype. Our institution's IoT lab was used as a testbed research environment for developing the IoT infrastructure and simulating the vaccination center. While the prototype was developed for vaccination centers, the approach can be used in any other multi-patient/multi flow operational environment where real-time visibility and simulation are required.

1 INTRODUCTION

Back in 2020, like several other provincial governments, the Quebec government has set up vaccination centers with the aim of massively vaccinating its citizens. However, due to the shortage of vaccines and both human and material resources, it was essential that these centers were efficient and able to adjust quickly to changing needs. To do so, vaccination centers' managers have tried to implement various strategies to optimize the use of their resources and succeed in this race against time.
Among these strategies, the use of the Digital Twin (DT) came up as an innovative option to support them in real-time decision making. Although the DT is a concept initially developed in the manufacturing sector, its potential in the service sector, and more specifically in the healthcare field seems very promising and could be very useful to improve operations management.

2 DESIGN OF THE DT PROTOTYPE

Our approach for designing the prototype can be summarized as follows: first, we identified the inefficiencies of the COVID-19 vaccination centers and raised the importance of having high-grained visibility on the performance of each workstation. Second, we formalized the objectives to design and develop an RFID/IoT prototype that would be used to support decision-making; for instance, by allowing real-time visibility on operations and the ability to dynamically reallocate resources where needed (i.e. according to real-time workstation occupancy and line-up behavior). We then collected data on patient flow, resource utilization, and facility settings. This was used to select the most appropriate technology for tracking patients at various stages of the process from their arrival at the vaccination center to their discharge. To reduce the risk of contamination, we bet on a simple, low-cost solution using a passive UHF RFID label worn as a badge or attached to the patient's clothing. Various fixed RFID readers/antennas were also selected for identifying the patient presence and tracking its direction. The next step was to build the connected prototype at the IoT Lab in Montreal, where several RFID-IoT technologies are available. The data captured is then filtered and transferred to a data base, using PTS Mobile Clearstream platform. For the simulation model, we used AnyLogic software and developed a hybrid model based on the ABM and DES approaches. The ABM approach represents patients and administrative staff, while the DES approach represents the entire operational process of the vaccination center. We used the "pedestrians" library because it not only allows us to model mass movements, but also provides tools for modeling queues, servers (e.g., medical and administrative staff), and managing patient movements between them. Interaction with the model is dynamic, allowing the vaccination center manager to enable or disable access to a service point. For example, the manager can disable one of the RFID checkpoints and view the model's behavior. Similarly, the manager has access to a dashboard that provides an overview of the vaccination center's workflow. As a key part of the DT, once the physical IoT infrastructure was set up and the pre-process data transferred to the simulation model, the two components were integrated into the AnyLogic software. Figure 1. illustrates the digital twin architecture.

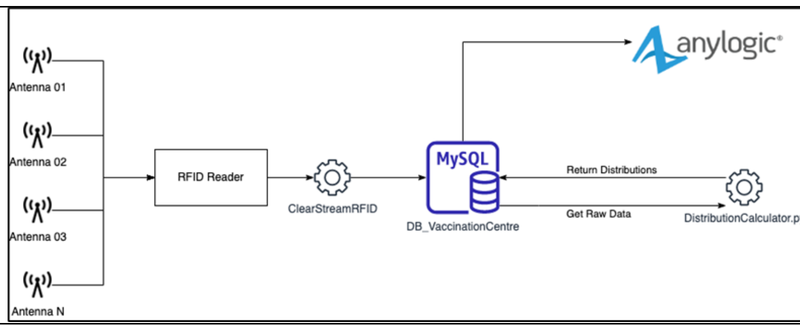

Figure 1: DT prototype architecture.

The prototype was developed during the lockdown period of the pandemic. Access to vaccination centers was very limited, so we decided to build and test our prototype in the IoT lab at the School of Management Sciences. To demonstrate the usefulness of our artifact, we simulated the vaccination process for different patients in different areas of the UQAM IoT lab. This exercise allowed us to validate the performance of the automated data collection and evaluate the response of our artifact. First, we were able to test and validate the operation of the IoT infrastructure, from capturing the RFID tag to storing the information in the database. Next, we were able to test and validate the simulation model using the data captured in real-time. Finally, we tested the operation of the digital twin, which integrates both physical and virtual components.

3 CONCLUSION

During the SARS-CoV-2 vaccination campaign, the government devoted many resources to accelerate the pace of vaccination and quickly vaccinate a large number of citizens. However, the vaccination centers were not efficient, raising the interest in assisting decision-makers in their strategies to massively vaccinate the population while considering the improvement of all vaccination centers. To answer this question, we designed and built a DT prototype that ensured the tracking of real-time patient dynamics in a COVID-19 vaccination center, allowing an effective and efficient patient-handling process. The results of this work can be reused in different hospital environments, such as testing centers, emergency rooms, or in any area of the service sector. Since the goal of the digital twin is to mimic its physical twin, it will be necessary to adapt or develop a new simulation model and physical infrastructure, but easily. It's important to keep in mind that while everyone now thinks the pandemic is behind us, the experts don't. A recent study published in the journal Nature explains that due to global warming, we are likely to see more pandemics in the coming years.