A Discrete Event Simulation-Based Model to Optimally Design and Dimension Mobile COVID-19 Saliva-Based Testing Stations

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Summary Statement: The present COVID-19 brief report addresses: (1) the problem of optimal design and resource allocation to mobile testing stations to ensure rapid results to the persons getting tested; (2) the proposed solution through a newly developed discrete event simulation model, experienced in on-campus saliva-based testing stations at the University of Illinois at Urbana-Champaign; and (3) the lessons learned on how 10,000 samples (from noninvasive polymerase chain reaction COVID-19 tests) can be processed per day on campus, as well as how the model could be reused or adapted to other contexts by site managers and decision makers.
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Key Words: Discrete event simulation, COVID-19, testing stations, optimization, resource efficiency, resource allocation.

PROBLEM: CONTEXT AND OBJECTIVE

Fast, scalable, cost-effective, and reproducible COVID-19 testing processes are needed. According to the Centers for Disease Control and Prevention, sufficient testing capacities are indeed essential to flatten the curve on coronavirus. On the one hand, with an increasing number of students back to campus or employees to their workplace, mobile testing stations seem to be a suitable solution to enable convenient, rapid, and frequent testing. On the other hand, with thousands of persons being tested on a daily basis, it is of the utmost importance to handle and process the samples in a time-efficient fashion to provide rapid feedback and monitor the COVID-19 situation. For instance, the University of Illinois is providing free COVID-19 diagnostic walk-up saliva-based testing on campus. Here, the objective is to be able to collect and test more than 10,000 samples in a given working day, ie, within a 10- to 12-hour time window. Although there was no preexisting model available to process a significant number of tests on campus on a daily basis, an initial process flow has been proposed by a team of researchers and healthcare professionals at the University of Illinois, the “COVID-19 SHIELD: Target, Test, Tell” team. On this basis, a discrete event simulation (DES) model has been proposed to optimally design and dimension the on-site laboratory infrastructure and process in terms of resource (machines, operators) number and allocation. The DES model developed and illustrated in this report can be easily adopted and applied broadly, providing operational support to achieve the takt time required to perform a significant number of tests per day. It is made available (see DES model, Supplemental Digital Content 1, http://links.lww.com/SIH/A640, which provides the complete DES model) for researchers, site managers, practitioners, and decision makers who want to reuse or adapt it in other situations.

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SOLUTION (1/2): MODELING PHASE

A DES model has been developed to run different scenarios in terms of process configuration and resource allocation. It aims to find the optimal testing process configuration to reach the testing objective while minimizing the resources—operators and machines—deployed. To foster its dissemination and uptake, the freely accessible personal learning edition version of AnyLogic software has been used to build and run the DES model and to provide the user with a clear visual interface to understand and modify the model quickly (see Figure, Supplemental Digital Content 2, http://links.lww.com/SIH/A641, which gives a snapshot of the DES model of the COVID-19 testing process for saliva samples). The pools of resources to allocate and optimize are also depicted (see Figure, Supplemental Digital Content 3, http://links.lww.com/SIH/A642, which illustrates these resources within the DES model). All the tasks, time distributions for each event, and initial resource allocation are available in the DES model file (see Table, Supplemental Digital Content 4, http://links.lww.com/SIH/A643, with is based on the inputs provided by healthcare professionals from the “COVID-19 SHIELD: Target, Test, Tell” team). Note that while a constant time is used for the machines, a triangular distribution has been chosen, based on experts' knowledge and experience, to model the variability of performance among the operators (with a repartition of ±20% around the mean value).

SOLUTION (2/2): SIMULATION PHASE

To evaluate the performance of different realistic scenarios, the DES has been run 10 times for each of these different configurations to find out the optimal one, ie, minimizing the number of resources used while achieving the time objective of 10,000 samples being tested in 1 working day. Three key hotspots have been identified on the process flow, as highlighted through the dotted frames (see Figure, Supplemental Digital Content 2, http://links.lww.com/SIH/A641, which illustrates the process flow through a DES model). These hotspots correspond to bottlenecks, where an accumulation (queue) of vials to be tested occurs, leading to slow down the overall testing process flow. The first bottleneck is noticed when the number of operators allocated to the preparation of the vials is insufficient to deal with the number of vials collected for testing. The second one is also related to the number of operators allocated to the task "opening and pipetting," which needs to be performed individually for each sample. The third one is due to the time required (1 hour and a half) to complete the "test-RT-qPCR" for a batch of 384 vials.

LESSONS LEARNED: RESULTS AND IMPLICATIONS

Results (see Figure, Supplemental Digital Content 5, http://links.lww.com/SIH/A644, which outlines the time distribution for testing 10,000 samples times under different scenarios with 10 replications for each scenario, with the optimal configuration highlighted in bold) clearly show that 2 measures have a significant impact on testing times: adding more operators for preparation to a certain extent and having sufficient testing machines available. Of course, the more operators and machines there are, the more time efficient the process will be, but resources not only have to be optimized because of cost constraints but also to limit the number of operators working together in the same workplace or station to further prevent the spread of the virus. For the present process flow, the optimal resource allocation depending on the number of samples to be tested in a single day has also been computed (see Table, Supplemental Digital Content 6, http://links.lww.com/SIH/A645, which provides the optimal resource allocation for different sample sizes). Through the present DES model to proceed saliva-based samples for COVID-19 testing, it has been found that with a process flow well designed and optimized in terms of resource use and allocation, it is feasible to achieve the goal of collecting, transporting, and testing 10,000 samples on-site per day with a reasonable amount of resources mobilized. In practice, the University of Illinois has publicly released a data dashboard that displays daily information about the University's on-campus COVID-19 testing program, available here: https://go.illinois.edu/COVIDTestingData. An average of 10,118 daily tests has been monitored for the first 2 weeks of class on campus (academic year 2020/2021), which is well aligned with the objective of the present DES model. Broadly, mobile testing station managers can benefit from the use of such a DES-based model to change and improve their processes and procedures in response to the pandemic. This DES model can be launched quickly for scenarios exploration. It can also be easily modified whether some parts of the process flow evolve or a new machine is implemented on the testing center.

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