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Design of Campus COVID-19 Testing Using Modeling and Simulation

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Abstract: Due to the COVID-19 pandemic, large institutions, such as Binghamton University, have required widespread testing of students returning to campus. This project uses the simulation software, Simio, to design and test the student move-in process. For the move-in model, an optimal ratio of employees was found. Afterwards, a series of 20 scenarios were run, each varying in the number of move-in days, operating hours per day, and student arrival intervals. Based on the simulation results, a move-in schedule of three days, eight hours of operation per day, and half-hour student arrival intervals is recommended to be implemented in the fall 2021 semester at Binghamton University. This schedule yields an average completion time of 31.3 minutes. Additionally, this move-in model has been standardized to be utilized by other universities for the COVID-19 pandemic or a similar situation in the future.

Keywords: COVID-19, Move-in Testing, Modeling and Simulation

1. Introduction

Due to the ongoing COVID-19 pandemic, the need for widespread testing is essential. On March 11, 2020, the World Health Organization (WHO) declared COVID-19 a pandemic (WHO, 2020). Since then, there have been over 140 million cases worldwide, including over 30 million in the United States (Johns Hopkins University & Medicine, 2021). Although most cases of COVID-19 display mild symptoms, the disease can cause severe illness and in the most extreme cases, death. An effective way to decrease transmission of the virus is with widespread testing coupled with contact tracing (CDC, 2021). To delay the spread, many universities, including Binghamton University, have required on-campus students to be tested upon arriving and throughout the semester.

COVID-19 testing was first implemented at Binghamton University during the fall semester of 2020. There were many factors and alternate scenarios to consider since more than 6,000 students returned to campus. These factors include the amount of staff needed, parking availability, length of the operation in terms of number of days and hours, as well as the time window that students should arrive in. Therefore, a simulation model was created with the intended goal of optimizing the move-in process. This paper describes the simulation model by comparing the alternative scenarios and providing the analysis necessary to derive the most effective move-in process.

2. Background

Thorough background research was required to achieve an efficient and effective move-in. First, Binghamton University's incomplete 2020 fall semester move-in model was analyzed. The team's senior project called for the development of a simulation model that built off this preliminary effort. To receive advice and guidance, two ISE professors and an ISE graduate student, who worked on the incomplete fall model, were consulted. In addition, various universities were researched to examine their move-in processes in order to construct an efficacious simulation model. Two universities that stood out because of their use of Simio were the University of Central Florida and Cornell University. These universities helped gauge the project as their models were designed to move in a similar number of students. UCF's model was designed for 6,000 students (University of Central Florida, 2020). In addition, Cornell's model was designed for 6,500 students, which was more comparable to the 7,000 students that Binghamton's model was designed to accommodate (Cornell, 2020). A contrasting feature found between the universities' move-in processes was the duration. Cornell and UCF's processes spanned over five days and 16 days, respectively. In comparison, Binghamton's 2020 process spanned seven days (Ellis, 2020, p.1). The in-depth research done on the different universities provided several guidelines and solutions to incorporate into the simulation model that was developed and showed that simulation can be used to efficiently design the move-in testing process.

3. Methodology

3.1 Simio Simulation Model

The simulation model was created using Simio, an object-oriented simulation and modeling software (Simio, 2020). A baseline model was created based on preliminary research which was used for the 2020 fall semester move-in. The main process flow of the entire testing operation followed a basic seven-step process: check-in, data collection, sample collection, sample preparation, incubation, analyzing, and data entry. The corresponding times to these stations can be seen below in Table 1. These processes all followed a different triangular distribution, except for the incubation time which was a strict 15 minutes. Triangular distributions were chosen to represent the processes since there was no significant variability in the data that was collected. The distributions were determined by a few different factors including previous data that was collected during last year's fall move-in process.

Table 1. Time Distribution per Station

Station	Time Distribution
Check-In	Tri(10, 20, 30) sec.
Data Collection	Tri(1.5, 2.0, 2.5) min.
Sample Collection	Tri(2.0, 2.5,3.0) min.
Sample Prep	Tri(2.0, 2.5, 3.0) min.
Incubation	15 min.
Analyzer	Tri(0.5, 1.0, 2.0) min.
Data Entry	Tri(1.0, 1.5, 2.0) min.

The model simulates the entity movement throughout the system. The entity, or student, starts by entering the system in their car. The car is parked, and the student makes their way to the front entrance of the Event Center. Once the student enters the door, they are checked-in to ensure they have arrived in the correct time slot. The student then follows a lined path to the stairs where they go down and enter the queue for the data collection process. After exiting, they are directed towards the sample collection station where they get the nasal swab antigen test. Tested students will then go to the West Gym to get their dorm key and other needed supplies. After, the student will wait in their car for approximately 16 minutes until their test results are back and they can safely move into their dorm. This process in Simio can be seen depicted in Figure 1.

Figure 1. Simio Entity Flow

The first step of designing the entity model described above was to create the overall process flow in Simio. This was done using Simio objects that included sources, sinks, servers, combiners, and separators. All of these objects were connected inside the model using connectors and paths. Add-on process triggers were used to define the model logic. This is where Simio enables customization for model specific needs. State variables were used to track process parameters, and this is where data

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on the key performance indicators (KPIs) were collected. Once an experiment on a specific scenario was run, the data collected on the KPIs could be exported from Simio to be analyzed.

3.2 SketchUp

SketchUp, a 3D modeling software, was utilized to create a representation of the Events Center, West Gym, Parking Lot F, and Parking Lot F3. This is the location the fall semester move-in took place and is where the upcoming student move-in with COVID-19 testing is expected to take place. SketchUp's compatibility with Simio was a main reason why it was chosen to facilitate the visual needs of the model. The SketchUp model was designed to be a replica of Binghamton University's Events Center. Using tools such as Google Maps and blueprints, a model with the exact dimensions of the Events Center was constructed. The detailed view of the system gives practitioners and decision-makers a clear understanding of the design and analysis that was performed. This is necessary because, in the absence of the 3D model, those that have no previous experience working with Simio would have a difficult time understanding the functionalities of the simulation.

3.3 Optimization of Employees

The first goal of analysis was finding the optimal ratio of workers at the data collection, sample collection, and sample preparation stations. By finding the optimal ratio of workers, it was then possible to find which multiple of the ratio best fit the system for completion time while not having an excess of workers. Four measures were used to track the ratio test, these being: average completion time (minutes), max queue between data and sample collection, max wait time for sample preparation (minutes), and max queue for sample preparation (per station). To start the ratio test replications, 10 workers were added to each station. Based on utilization, and the fact that it had the longest run time, sample collection needed to have the most workers. Therefore, the experiment was set up by decreasing the number of workers at the data collection station and sample preparation station by one, for each new row of experiments. The results from the experiments, along with the optimal scenario (highlighted), can be seen in Table 2.

Table 2. Data from the Optimization of Employees Experiment in Simio

Resource			**Measure**			
Data Collection	*Sample Collection*	*Sample Preparation*	*Avg. Completion Time (min.)*	*Max Queue Sample Collection*	*Max Wait Time for Sample Prep (min.)*	*Max Queue for Sample Prep (Per Station)*
10	10	10	36.96	10	2.178	9.3
9	10	10	37.32	10	2.273	9.4
8	10	10	37.5	8.6	1.979	8.2
7	10	10	64.98	3.6	0.649	3.3
8	10	9	59.28	8.6	45.8	178.8

Using this table, as well as the corresponding graphs, a ratio of 8:10:10 was determined to be the optimal configuration for data collection, sample collection, and sample preparation, respectively. Using the Max Waiting Time graph, seen in Figure 2, it was determined that the 7:10:10 ratio produces the least amount of waiting time for test samples to be passed through the system. However, it was necessary to make sure the time students spent in the system was not unfeasibly long. Therefore, the data was compared against the average completion time. For the average completion time graph, seen in Figure 2, a limit was set at one-hour - per move-in coordination staff - for the amount of time a student will spend in the system, and from this, it can be seen that the 7:10:10 ratio was unfeasible since it passed the one-hour threshold. The conclusion was then drawn that the 8:10:10 ratio was the optimal resource allocation ratio because it produces the least amount of time waiting for samples to pass through the system while also minimizing the average completion time of students getting their tests done to an acceptable degree.

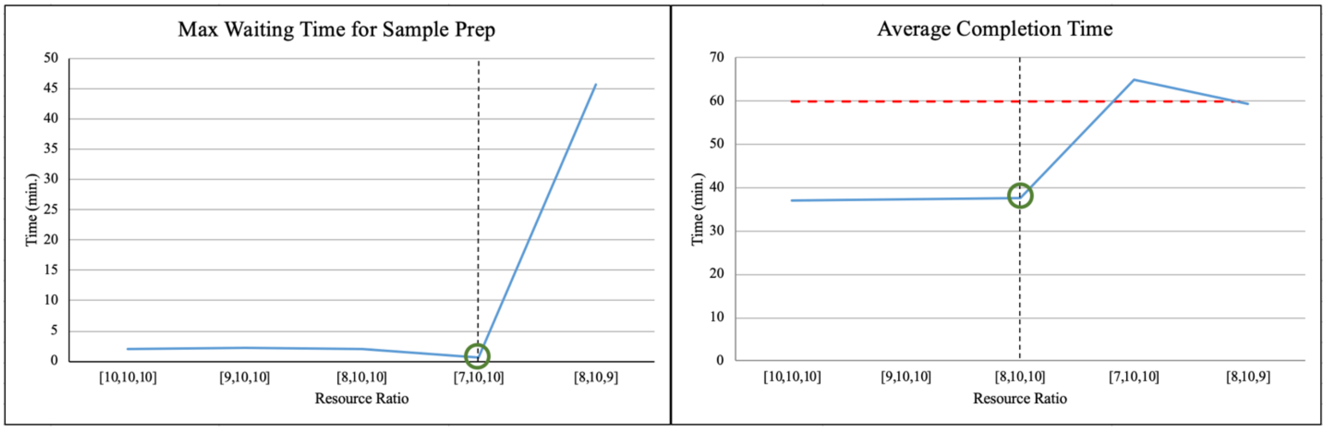

Figure 2. Employee Optimization Graphs

4. Results and Analysis

4.1 Scenarios

After finding the optimal ratio of testing staff, the focus turned to scenarios. Each scenario was made up of three parameters: total days, hours of operation, and the arrival window students would be given to show up for their test. These parameters were adjusted in Simio based on each scenario. With these three parameters being altered within the constraints of the process, 20 possible combinations were tested as individual scenarios. The constraints on the parameters were set by the move-in coordination staff. Table 3 shows a summary of the three parameters that were altered for each scenario. The arrival window is a crucial variable that influences the entity flow throughout the system. Based on data collected from last fall's move-in process, it was recorded that, on average, 50% of students arrive in the first 10 minutes of their allotted arrival window. In a one-hour process, this would cause a significant backlog in the system, therefore, a half-hour arrival window was considered in an effort to space out student arrivals.

Table 3. Considered Scenario Combinations

Total Days	Hours of Operation	Arrival Window
• 2 Days • 3 Days • 4 Days • 5 Days • 6 Days	• 8 Hours • 10 Hours	• 1/2 Hour • 1 Hour

There were seven key performance metrics used to compare all scenarios: hours worked by testing staff, number of tested students, entrance queue length, sample collection queue length, estimated cars in parking lot, time waiting for test results, and total completion time. These seven KPIs were identified by the move-in coordination staff as the parameters that would have the most impact on the move-in testing process, and therefore, are what the final recommendation was based on. With the direction of the team's advisor, Dr. Kwon, thresholds were set on the seven KPIs. If any scenario did not meet the criteria, it would not be considered. There were 10 scenarios, of the 20 tested, that fit the thresholds set on the KPIs. These 10 scenarios were plotted in Figure 3, which compares completion time to staffing hours. To balance these competing criteria, a trendline was found that represents the optimal balance of completion time (plotted on the y axis) and staffing hours (plotted on the x axis). The data point that was closest to this line was from the three-day, eight hour/day, half-hour interval schedule. Therefore, this scenario was deemed the best option due to its proximity to the trendline.

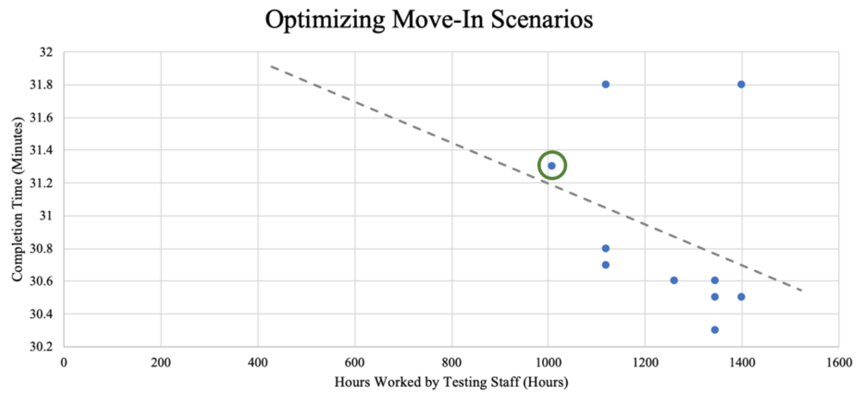

Figure 3: Optimizing Move-in Scenarios

4.2 Recommended Design

The final model was chosen based on the data that was collected and analyzed across the 20 scenarios. The recommended model has 12 employees working at the data collection station, 15 employees working at the sample collection station, and 15 employees working at the sample preparation station. Alongside these employees, other workers in the system include those at the check-in table, data analysis and entry stations, and residential life staff at the West Gym. With this system, there will be 2,337 students tested each day. This process will take place over a three-day, eight hour/day, and half-hour interval schedule. Table 4 shows a summary of the data collected on the seven KPIs. The most important takeaway from this table is that the average completion time for a student to go through the whole process is 31.3 minutes. With this completion time, the process would be able to operate efficiently while maintaining all social distancing guidelines as well as meet all requirements that were set by the university.

Table 4: Recommended Scenario KPIs Summary

Scenario: 3-day, 8 hour/day, 1/2-hour interval	
KPIs	*Scenario Outputs – Max (Avg)*
Hours Worked by Testing Staff	1008
Tested Students	2337.6
Entrance Queue	28.8 (3.6)
Sample Collection Queue	5 (0.4)
Estimated Cars in Parking Lot	190.5 (135.3)
Waiting for Test Results (min.)	20.4 (17.9)
Completion Time (min.)	36.4 (31.3)

4.3 Model Verification and Validation

After collecting and analyzing the data from the Simio model, verification was necessary. This was done using queueing theory. The Simio model can be looked at as a queueing network; specifically, a Jackson network. All service times within a Jackson network are independent exponential, so each node can be analyzed as a stand-alone M/M/c queue (Askin & Standridge, 1993). Figure 4 shows the Jackson network that represents the steps of the process the students go through. λ represents the arrival rate, μ represents the service rate, c represents the servers at a node, and ρ represents sever utilization. The first step taken to verify results was calculating the server utilization rate at each node in the network. The other step that was taken to verify results was to find the average time (W) at each node in the network (Askin & Standridge, 1993). To do this, not only were the calculations for W necessary, but p(0) and W_q had to be calculated as well.

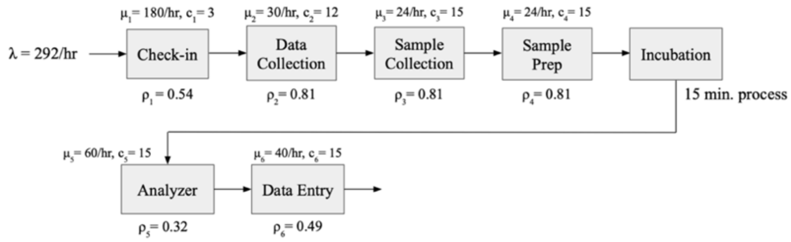

Figure 4. Jackson Network of Student Testing Process

After completing all necessary calculations, the average time for a student to go through the whole process was found to be W = 25.85 minutes. This value does not account for the walking time in-between stations. The team walked through the system and it took an average of 7.1 minutes, which brings the calculated time to W = 32.95 minutes. This value verifies the average time in the recommended Simio model being 31.3 minutes. The slight difference can be attributed to the fact that an M/M/c queue follows the exponential distribution, while the model was run with triangular distribution inputs.

Next, the model had to be validated. To do this, data was collected from the actual move-in process that took place at the start of the fall semester. After gathering data across a few days, the times recorded fell within the acceptable range of the simulation values. This acceptable range was set at plus or minus three minutes. With the model verified and validated, it was concluded that the simulation model was a strong representation of the actual move-in process.

5. Conclusions

An effective move-in process is essential to making sure Binghamton University has a safe start to the semester for all staff and students. Simio, SketchUp, and various ISE techniques and methodologies have been used to design a simulation model, run scenarios, recommend a solution, verify these results, and finally validate them. The most effective move-in scenario was found to have three days, eight hours of operation per day, and half-hour student arrival intervals, with 12 employees at the data collection station, 15 employees at the sample collection station, and 15 employees at the sample preparation station. The system would have the ability to test 2,337 students per day, and it would take an average of 31.3 minutes for students to go through the process. To further the outreach of the project, a universal Simio move-in model with step-by-step guidelines will be made available to all other SUNY schools. The instruction guideline walks the school through a step-by-step process on how to make the model customizable for their own use. Eventually, COVID-19 testing on campuses will come to an end, but having this simulation model is a valuable resource to allow for schools to be prepared for a similar scenario in the future.

6. References

Askin, R. G. & Standridge, C.R. (1993). *Modeling and Analysis of Manufacturing Systems*. John Wiley & Sons.
COVID-19 Testing and Cases Statistics. (2020). University of Central Florida. Retrieved November 23, 2020, from https://www.ucf.edu/coronavirus/
COVID-19 Contact Tracing. (2021, February 25). CDC. Retrieved April 12, 2021, from https://www.cdc.gov/coronavirus/2019-ncov/daily-life-coping/contact-tracing.html
COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University. (2021). Johns Hopkins University & Medicine. Retrieved April 15, 2021, from https://coronavirus.jhu.edu/map.html
COVID-19 Tracking Dashboard. (2020). Cornell University. Retrieved November 24, 2020, from https://covid.cornell.edu/testing/dashboard/
Ellis, K. (2020, August 19). *Seven-Day Move-In Starts With COVID-19 Testing*. Binghamton University State University of New York. https://www.binghamton.edu/news/story/2602/seven-day-move-in-plan-starts-with-covid-19-testing
Rolling Updates on Coronavirus Disease. (2020). WHO. Retrieved March 15, 2021, from https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen
The Story of Simio. (2020). Simio. Retrieved February 20, 2020, from https://www.simio.com/about-simio/

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