Simulating Hospitals’ Intake of COVID-19 Patients with Arena

Team #13

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1. Introduction

COVID-19 wrecked the economy of the United States and while health-care systems were often at or over capacity with COVID-19 patients, they did not escape the financial burden brought on by the virus. The American Hospital Association (AHA) undertook an extensive investigation of the financial impact COVID-19 had on American hospitals, and found that in a four month period, American hospitals and health systems faced a total loss of $202.8 billion ($50.7 billion per month on average). The AHA attributed hospitals financial loses to four factors:

1) The effect COVID-19 had on hospitalization costs.
2) The large number of cancelled and forgone services, caused by COVID-19.
3) Additional costs associated with protective equipment and sanitation.
4) Additional costs to support hospital workers and staff members.

Hospitals, in a response to COVID-19, had to cancel non-emergency procedures; these elective procedures accounted for over 48%, on average, of American hospital's revenues. Moreover, future patients will also be heavily impacted by the financial burdens hospitals faced during the outbreak. In order to help recover from expenses and loss, many experts are worried about the decrease in quality, increase in costs, and longer wait time for health care services after the outbreak. The AHA forecasts that hospital wait times will be longer, costs for previously inexpensive elective procedures will skyrocket, and service quality may decrease for all future patients admitted to hospitals. Combatting this issue for a potential future surge of the pandemic will be critical to the viability of the future of the healthcare system. Hospitals will need to find a balance between caring for patients who need critical care after being exposed to the virus while also maintaining a limited offering of elective procedures to continue to support the system financially [1].

2. Problem Description

This project will simulate the basic operations of a hypothetical hospital under a health crisis situation like COVID-19, which if happens again in future can disrupt the basic operations of the healthcare sector. During such a health crisis, hospitals have to cancel non-emergency procedures to accommodate the surge of patients. This can have a debilitating financial impact on the hospital. Therefore, the hospitals need to be prepared and have a plan in place for allocating resources if such a situation arises in future.

For the project, a two story hypothetical hospital was considered where each floor has three units: general care, moderate care and intensive care (ICU). Floor one is primarily dedicated to the medicine patients and floor two for the surgical patients as shown in figure one.

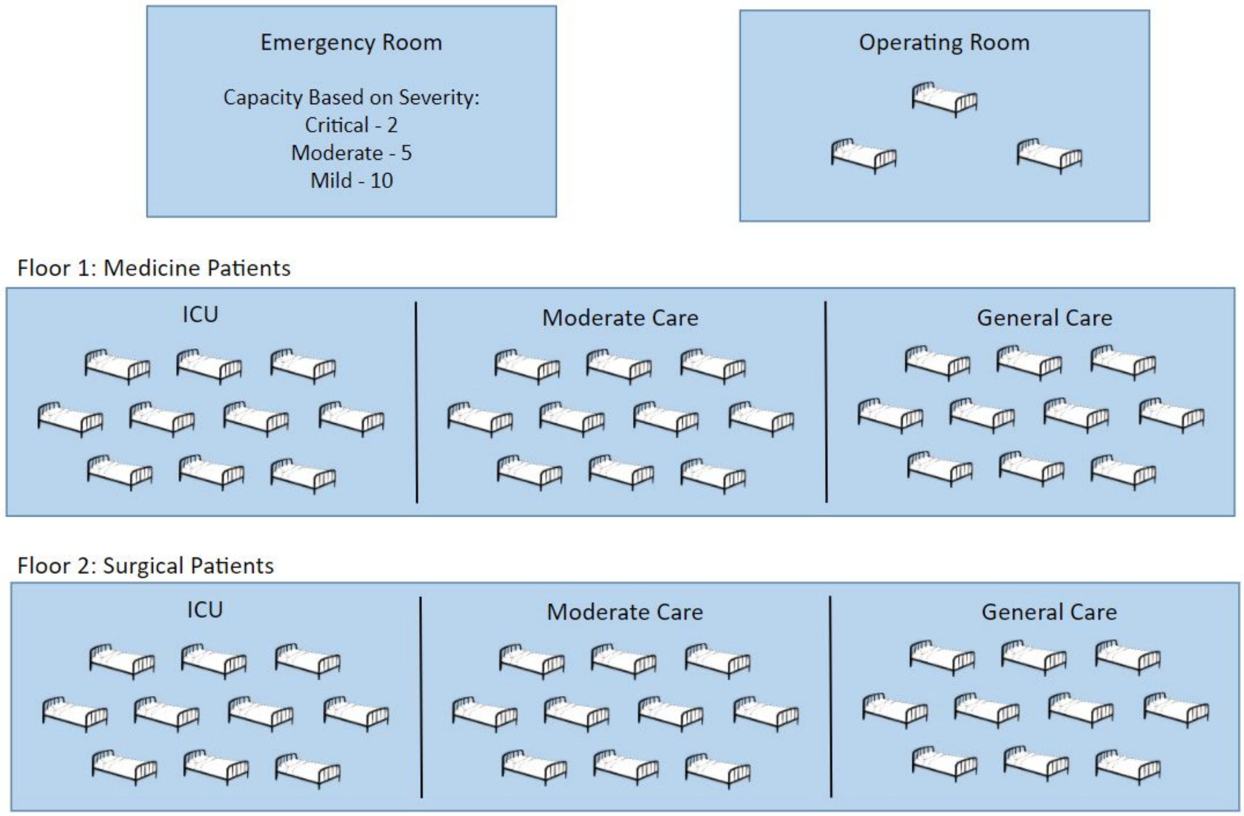

Figure 1: Hospital Layout

The hypothetical hospital is assumed to perform three major revenue generating surgeries which are cardiac surgery, orthopedic surgery and cesarean surgery. The ongoing COVID-19 pandemic has overwhelmed the hospital with an unexpected surge of medicine patients. Under normal operation the hospital would keep the two floors dedicated to the two different types of patients. However, due to a surge of COVID-19 patients the hospital had to quickly adapt to the needs of the incoming patients which required the hospital to use many of the surgical floor beds for COVID-19 patients. This led to the hospital canceling many procedures resulting in a large loss of revenue.

Now after months of caring for COVID-19 patients and better treatment options, the hospital is better able to control how many COVID-19 patients they will admit. Because the hospital relies on the revenue from procedures, the hospital would like to understand all options for treating as many COVID-19 patients as possible while minimizing the lost revenue from canceling procedures. This will help the hospital in planning for any future surges in COVID-19 or any other infectious disease.

3. Solution Approaches

The model will be controlled using doctors, nurses, and beds as resources as shown in table 1. Beds will be allocated specifically to each unit on each floor. Doctors will be allocated based on their specialty, for example only cardiologists are able to perform cardiac surgery and care for cardiac surgery patients post operation. Nurses, on the other hand, are able to float between units and between floors.

Table 1: Resource Allocations

Resource Type	**Number of Resources**
Beds	20 beds between two ICUs 20 beds between two moderate care units 20 beds between two general care floors
Doctors	3 Cardiologist 3 Orthopedic Surgeon 3 Obstetrician 10 General Medicine
Nurses	30 for the whole hospital

Patients will be placed in a specific unit based on the patient type. The patients will then follow the flow for the patient type as shown in figure 2. Procedure patients have their own queues based on procedure type and all COVID-19 patients will enter the system through queues signifying the emergency room. COVID-19 patients will be directed to a specific queue based on their severity.

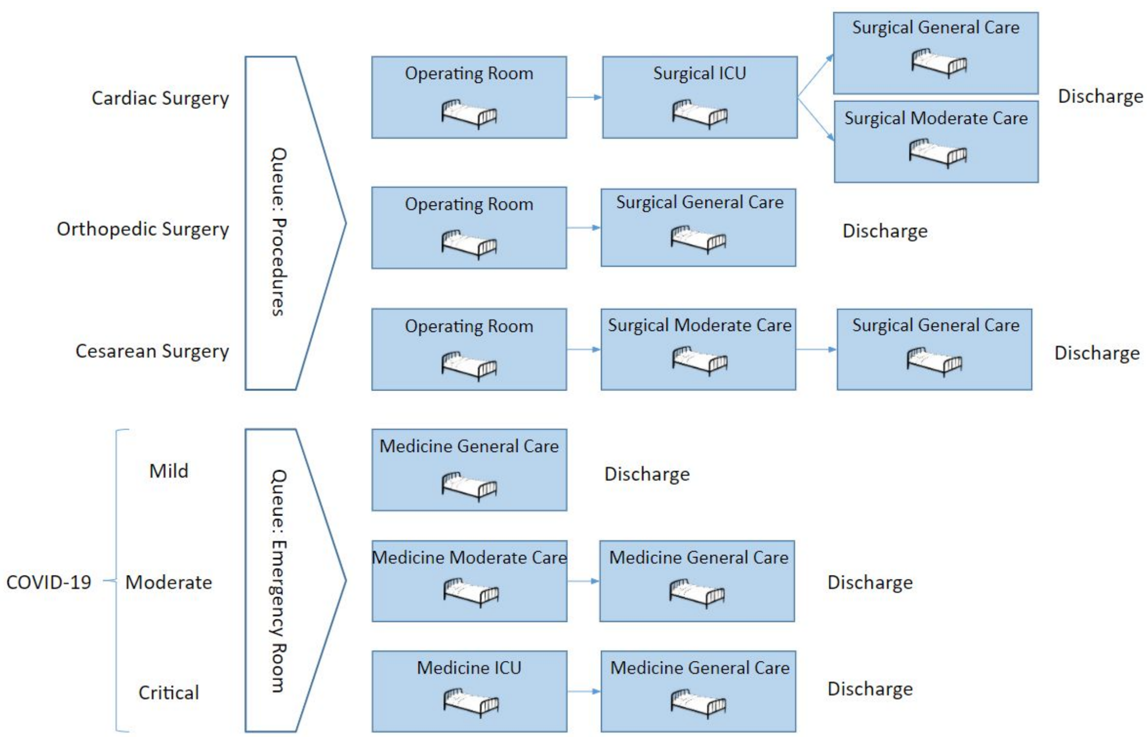

Figure 2: Patient Flows

Processing times through each phase of care will be based on table 2 for each job type. Table 2 also shows the average revenue which will be used to calculate total revenue for all patients that are admitted to the hospital.

Table 2: Job Types and Average Processing Time

Job Type	Description	Average Treatment Time	Average Revenue
1	Cardiac Surgery	● ICU (1 Day) ● General/Moderate Care (4 Days)	$48,571 [2]
2	Orthopedic Surgery	● General (1-2 Days)	$36,278 [3]
3	Cesarean Surgery	● Moderate (2 Days) ● General (2 Days)	$17,004 [4]
 4 5 6	*COVID* Mild Moderate Critical	● Mild: General Care (1-5 Days) ● Moderate: Moderate Care (3-5 Days) ● Moderate: General Care (2-3 Days) ● Critical: ICU (8-12 Days) ● Critical: General Care (2-3 Days)	$13,297 $26,757 $40,218 [5]

As the number of nurses and beds can be adjusted to meet medical patients' (i.e. COVID-19) and procedure patients' needs, these are the two variables that will be changed to find an optimal solution. To maximize revenue the project team will experiment by assigning different numbers of beds and nurses to each floor which will determine how many patients end up being admitted to the hospital versus being rejected.

4. Simulation Modeling

The project team designed a simulation model that allows for adjusting of resources to understand the most optimal ratios of COVID-19 patients to planned procedure patients. The model creates six different patient types reflecting the three procedure types and the three COVID-19 severities. Cardiac surgery patients arrive at an interval reflecting two scheduled surgeries per day, orthopedic surgery patients arrive at an interval reflecting four scheduled surgeries per day, and cesarean surgery patients arrive at an interval reflecting eight scheduled surgeries per day. COVID-19 patients arrive once per every two hours and then are assigned a severity type with a 20% chance of being critical, 30% chance of being moderate, and 50% chance of being mild.

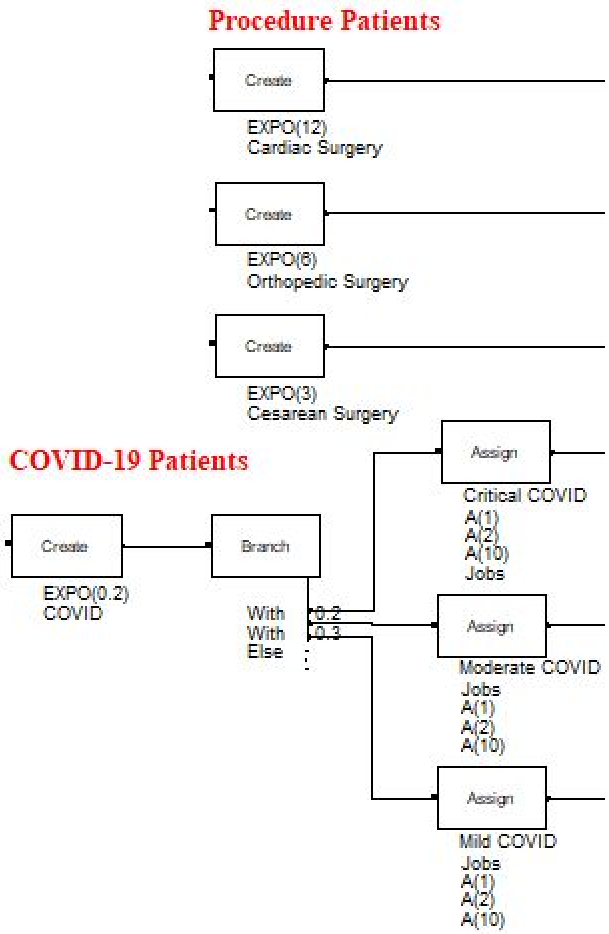

Figure 3: Creation of Patient Types

For all three procedure types, when the patient arrives at the hospital, if the queue has one person waiting, the patient's surgery will be rescheduled for the following day, in other words they will experience a delay of 24 hours before returning to the queue. If the patient is rescheduled more than 3 times, the patient will seek another hospital for their surgery and will be disposed from the system. All rejected patients will be counted to understand missed opportunities. Once a patient has been accepted to the queue, they will wait until the specified operating room is available and then will complete their procedure. Once the procedure has been completed, the patient will hold on to the resources until a bed is available in the next phase of their care. If a patient stays in the operating room without being to move on due to bed constraints, the patient will be discharged from the operating room after they have been there for the length of their total expected stay. This pattern continues for each step of the patient's flow through the hospital.

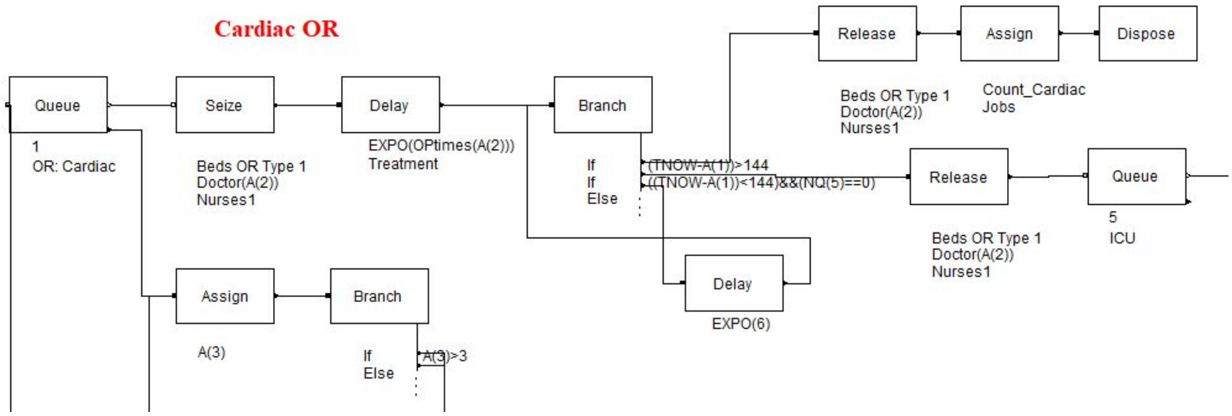

Figure 4: Example of procedure patient flow using cardiac patients moving from the queue to the operating room to the ICU. If the patient tried to get in the queue more than 3 times they will be disposed. If the patient stays in the OR for more than 6 days they will be discharged from the OR, otherwise they will move on to the ICU when a bed is available.

Patients with COVID-19 with a critical severity will immediately go to the ICU, however, if the queue, which has a capacity of two, is full the patient will be transferred to another hospital and disposed from this system with a 90% chance. Otherwise, the patient will experience a delay and try to revisit the queue. Patients experiencing moderate or mild cases of COVID-19 will be transferred to another hospital and disposed of from this system with a 50% if their respective queue is full. Once a COVID-19 patient, of any severity, is admitted to the hospital they will follow their flow in the same way in which the procedure patients did.

When patients seize resources at their respective units, they seize one bed and the respective percentages of nurses and doctors needed to care for them. A patient in the operating room requires one doctor and two nurses. In the ICU a nurse is able to care for two patients and a doctor is able to attend to five patients. In a moderate care unit, a nurse is able to care for three patients while a doctor is able to attend to five patients. Finally, in a general care unit, a nurse is able to care for four patients while a doctor is able to attend to ten patients.

5. Design of Experiments

The objective of the project is to find the optimal allocation of the hospital resources which can maximize the revenue generated by the hospital under this unprecedented COVID-19 crisis. The experiment has been designed to fulfill that objective. As mentioned earlier there are three major categories of resources

- Hospital beds
  - ICU
    - Floor Zero
    - Floor One
  - Moderate Care
    - Floor Zero

        - Floor One
    - General Care
        - Floor Zero
        - Floor One
- Doctors
    - Cardiologists
    - Orthopedic Surgeons
    - Obstetricians
    - General Medicine
- Nurses
    - Assigned to Floor Zero
    - Assigned to Floor One

First, the project team created a baseline situation trying to replicate the scenarios of early March and April 2020 when hospitals barely had a resource allocation plan to tackle the impending crisis. To replicate that scenario, the project team allocated 90% of resources to the floor designated for COVID treatments. Under that situation, out of 20 beds in ICU, moderate care, and general care 18 beds from each care were allocated for COVID treatment. Only 2 beds from each care were allocated for procedure patients. Out of 30 nurses, 25 were assigned to the COVID floor. Since there is no sharing of doctors between floors, the doctors with specialization in procedures were allocated to floor one while the general medicine doctors were assigned for COVID treatment. Table 3 shows the allocation of hospital resources under the baseline condition. The outcome of the baseline simulation is the revenue under the baseline conditions. The objective of the project is to improve this revenue by optimal allocation of hospital resources.

Table 3: Resource Allocation for Baseline Simulation

Resources	Floor Zero (COVID)	Floor One (Procedures)	Total
ICU Beds	18	2	20
Moderate Care Beds	18	2	20
General Care Beds	18	2	20
Cardiologists	´	3	3
Orthopedic Surgeon	´	3	3
Obstetrician	´	3	3
General Medicine	10	´	10
Nurses	25	5	30

In the next step, the project team has performed an optimization process using the OptQuest for Arena Simulation. Without an appropriate tool, finding an optimal solution for a simulation model generally requires searching in a heuristic or ad hoc fashion. This usually involves running a simulation for an initial set of decision variables, analyzing the results, changing one or more variables, re-running the simulation, and repeating this process until a satisfactory solution is obtained. This process can be very tedious and time consuming even for small problems, and it is often not clear how to adjust the controls from one simulation to the next. OptQuest overcomes this limitation by automatically searching for optimal solutions within Arena simulation models.

As mentioned earlier, the objective of the optimization was to maximize the revenue generated. The generated revenue is a function of the resources allocated for different types of treatments in the hospital. OptQuest requires users to mention the range of possible values for each control variable. Table 4 shows the ranges of each variable.

Table 4: Control Variables and Their Ranges

Control Variable	Type	Lower Bound	Suggested Value	Upper Bound
Doctor1	Integer	1	3	4
Doctor2	Integer	1	3	4
Doctor3	Integer	1	3	4
Doctor4	Integer	5	7	10
General Care Beds Floor 0	Integer	1	10	20
General Care Beds Floor 1	Integer	1	10	20
ICU beds Floor 0	Integer	1	10	20
ICU Beds Floor 1	Integer	1	10	20
Moderate Care Beds Floor 0	Integer	1	10	20
Moderate Care Beds Floor 1	Integer	1	10	20
Nurses0	Integer	1	15	30
Nurses1	Integer	1	15	30

Different constraints were introduced for the control variables. The constraints are introduced to conform to the existing capacity of each resource type. The objective function and the constraints are shown in the following equations.

Objective Function:

Maximize (Revenue) (1)

Subject to,

ICU beds allocated to floor zero + ICU beds allocated to floor one = Total ICU beds (2)

Moderate care beds allocated to floor zero + Moderate care beds allocated to floor one = Total moderate care beds (3)

General care beds allocated to floor zero + General care beds allocated to floor one = Total general care beds (4)

Nurses allocated to floor zero + Nurses allocated to floor one = Total nurses (5)

The capacity of each resource type is shown in table 1. Based on equation (1) to (5) the optimization was performed. The outcomes are explained in the next section.

6. Results

From the baseline model, we had conducted a convergence test to evaluate the revenue achieved for when COVID-19 was at its most severe case; the baseline model is where almost all hospital beds are allocated to COVID patients, and most elective procedures were canceled. For testing the convergence of revenue, the baseline model achieved a revenue of $2,770,115, -$884,539 short of the optimal solution. The increase of revenue for the optimal solution can be attributed to the increased number of patients served for elective procedures. The figure below shows the converge test for the baseline model. The model was simulated twenty different times, starting at fifty replications in increments of fifty.

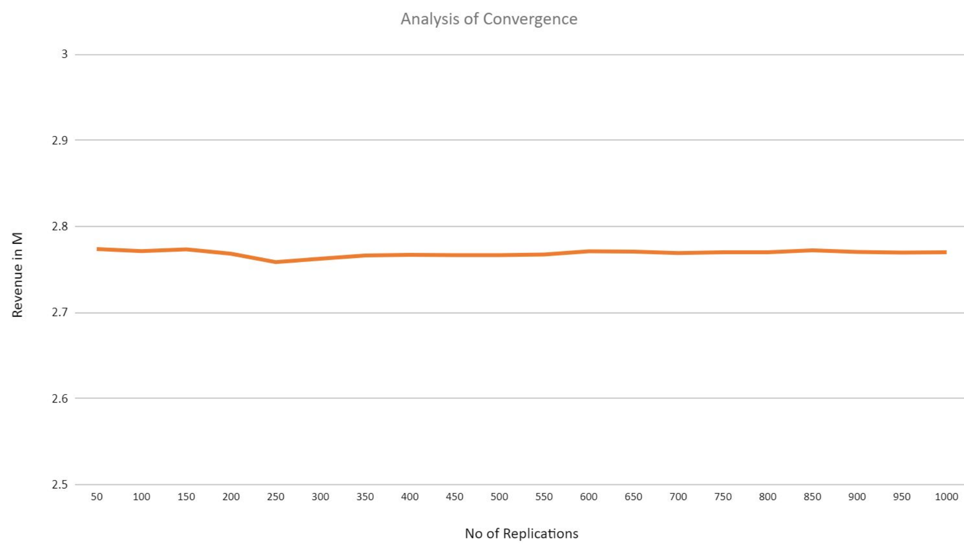

Figure 5: Convergence Test for Baseline Model

After the creation of the baseline model using Arena, optQuest was used to find the optimal utilization of resources to maximize revenue. Two hundred scenarios, each replicated fifty times, were simulated with different combinations of doctors, nurses, and beds to find the optimal allocation of resources to maximize revenue. Figure 6 below provide some visual details of our findings:

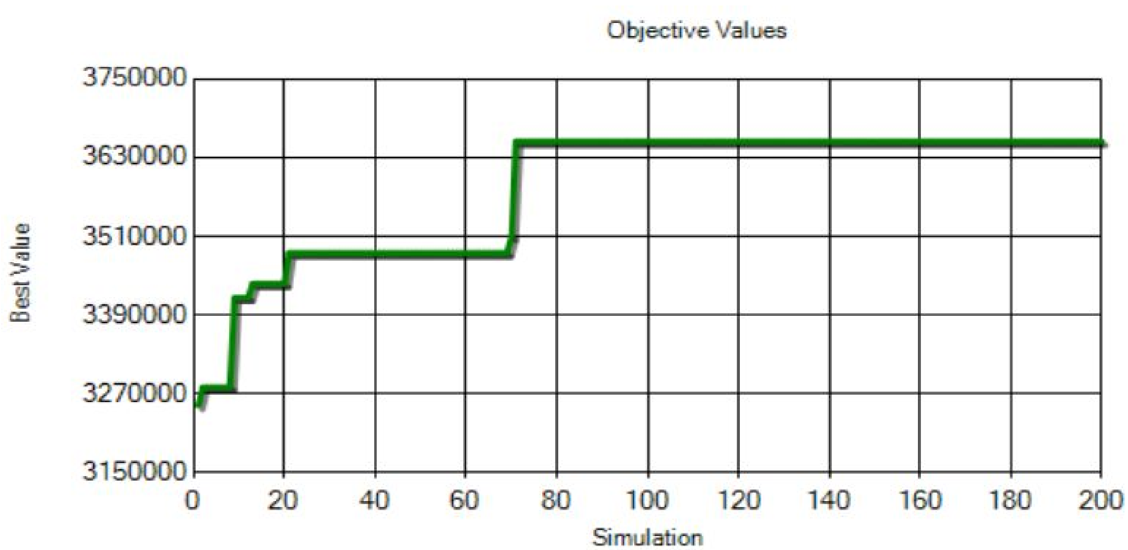

Figure 6: Graph of Revenue Vs. Simulation Run

From our findings, we were able to find that the most optimal revenue is achievable in six different scenarios; scenarios 1-6 shown in table 5. The differences between these scenarios is the number of nurses for both floors, one and zero. All six scenarios achieved a maximum revenue of $3,654,654. Table 5 below provides the figures for the number of resources allocated for doctors, beds, and nurses for the six scenarios and the baseline model.

Table 5: Allocation of resources for optimal scenarios (in bold) and baseline model.

Scenario	Doctor 1	Doctor 2	Doctor 3	Doctor 4	Nurse 0	Nurse 1	GC 0	GC 1	MC 0	MC 1	ICU 0	ICU 1	Revenue
Baseline	3	3	3	10	25	5	18	2	18	2	18	2	$2,773,861
Scenario 1	**1**	**1**	**3**	**10**	**14**	**16**	**4**	**16**	**10**	**10**	**16**	**4**	**$3,654,654**
Scenario 2	**1**	**1**	**3**	**10**	**15**	**15**	**4**	**16**	**10**	**10**	**16**	**4**	**$3,654,654**
Scenario 3	**1**	**1**	**3**	**10**	**16**	**14**	**4**	**16**	**10**	**10**	**16**	**4**	**$3,654,654**
Scenario 4	**1**	**1**	**3**	**10**	**17**	**13**	**4**	**16**	**10**	**10**	**16**	**4**	**$3,654,654**
Scenario 5	**1**	**1**	**3**	**10**	**18**	**12**	**4**	**16**	**10**	**10**	**16**	**4**	**$3,654,654**
Scenario 6	**1**	**1**	**3**	**10**	**19**	**11**	**4**	**16**	**10**	**10**	**16**	**4**	**$3,654,654**

GC = General Care, MC = Moderate Care

7. Conclusions and Discussion

The rise of COVID-19 cases in the past few months have been quite drastic. With hospitals giving more attention to COVID-19 patients it has been quite challenging for health caregivers to generate revenue for their hospitals, this is primarily due to the fact that priority of treatment is given to COVID patients thereby giving less attention to non-emergency procedures which actually generate more revenue to the hospitals.

As stated earlier in the introduction, the American Hospitals Association discovered that many hospitals encountered financial challenges due to the negative impacts brought about by the virus. According to Levitt et al, at least 20-60% of people will be infected with coronavirus, and the likelihood that 15% of them will require intensive care hospitalization is very high [5]. Additional costs will be incurred to provide COVID patients with adequate sanitization, protective gear, and equipment. At the same time, there will be patients who may not have health issues related to COVID-19 but will still be in need of critical care. It is imperative that hospitals should figure out a seamless and proficient way to stabilize the generation of their revenue through caring for patients who need elective procedures and also patients that are in dire need of critical care due to the negative implications caused through the exposure of the grotesque virus.

The main aim of the project was to simulate the basic flow of operation and to depict the primary form of function of a hospital experiencing catastrophe and pandemic situations like COVID-19, and also to create an optimized situation where hospitals can efficiently generate sufficient and satisfactory revenue while seamlessly attending to the healthcare needs of their patients.

The simulation mimics a real hospital in a real-life crisis scenario with two floors and 3 units on each floor. The units are general care, moderate care, and intensive care (ICU) as further described in the problem description section. The solution approaches and simulation model sheds more light on the procedures and the nitty-gritty actions taken to carry out and advance the simulation model. The result of the simulation revealed that the increase of elective procedures in hospitals can definitely contribute positively to the rise of revenue using the optimal solution simulated in this project. This model shows that 80% of ICU and general care beds should be allocated to COVID-19 patients and 50% of moderate care beds should be allocated to COVID-19 patients. 47-63% of nurses should be allocated to the care of COVID-19 patients according to the model optimization. The model also showed that both cardiac surgeons and orthopedic surgeons can be reduced to 30% of a normal operation during the COVID-19 crisis.

Some of the limitations encountered in the projects were with the constraints, in a real-life situation the number of rejects would have been a constraint as a healthcare system should be interested in retaining their patient population rather than losing them to competitors. However that was not taken into consideration in the situation of this simulation. Another major limitation was the version of Arena used to create the simulation model. The student version of the arena is not quite versatile or multifaceted therefore in some cases, it was not the most efficient in adapting it to this simulation model. Because of this reason, a maximum of 150 batches, or patients, was implemented in the simulation. Additionally, the team controlled the number of patients in the system through maximum batches during creation which limited the extent of which the ratio of procedure patients to COVID-19 patients could be optimized. A more robust model would have allowed for the two types of patients to share resources across floors, however, that would have made the model significantly more complicated. Although the main aim of the project was to maximize revenue for hospitals, the cost for doctors and other healthcare providers were not incorporated in the simulation. If simulating for a real-life hospital, the team would recommend incorporating these constraints into the model.

8. References

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