Simulation to Optimize Functionality

of

Emergency Rooms

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1 The Problem

We live in a country where immediate access to top-notch healthcare is viewed as a given - despite one's ability to pay or level of health insurance. With such high expectations and demands for healthcare, Hospital Emergency Rooms (ERs) are nearly always busy with wide ranges of emergencies and non-emergencies alike. Further, as the population, average lifespan, and insurance costs increase, we expect ERs will become even busier. So, if ERs will become busier, then how can we make them more efficient? We have two goals in this paper. First, we must accurately model an emergency room. We do this by taking real-world input data, applying it to a model, then comparing the results to real-world averages to ensure that our model achieves real world-results (based on the real world data). Secondly, we attempt to improve upon our base model by implementing improvements proposed by our reference paper (see reference A), where emergency departments are divided into two components, emergencies and urgent care. This second goal is where we attempt to answer our original question of how to make emergency room operations more efficient (given certain staffing/space requirements).

2 Conceptual Model

To start, we must first describe our base-case (model of an emergency room). The conceptual model is relatively simple as it tracks entities (patients) through the ER as follows:

- Patients arrive either via ambulance or walk-in based on arrival rates were described in the reference study (schedule based on arrival at UK ER over 1 year).
- Patients are immediately triaged according to criticality (Patient Triage Index = 1-critical, 2-urgent, or 3-non-urgent).
- The entities are then given priority (through condition-based decide and condition-based hold modules) based on their criticality where they are assigned a room (a resource).
- After patients are assigned a room, they are awaiting a nurse (resource). The nurse is delayed according to patient criticality. These delay times are adjusted from the reference paper data (modified to make more practical sense).
- After a nurse is assigned, a doctor (separate resource) is assigned and delayed again according to criticality. We assume that the doctor either treats or orders a discharge of the patient and is released.
- After an additional delay, the nurse is released, a record module counts the entity, and the room is released (and is IMMEDIATELY available for another entity - room cleaning/turnaround is not considered in our models).

Our model follows these general assumptions.

- All patients who enter the ER *will be seen* by a doctor (no balking or patient mortality)
- Patients must be assigned a room before being assessed
- Weekdays and weekends follow the same distribution
- We do not incorporate additional specialists into our model.
- Administrative matters, (paperwork, sterilization of rooms after use, patient transport, etc) handled by support staff, are not accounted for in our model
- Though our model does not factor in the cost (of a doctor compared to a nurse), we assume that doctors cost more than nurse practitioners (important for advances to the base model), which costs more than nurses.

2.1 Arena Model – Base Case

Now that we have described the generalities of our base case system, we will describe the specifics.

2.1.1 Inputs

Inputs (data) are described as we describe the processes below.

2.1.2 Simulation Components for the Based :

Entities: Patients

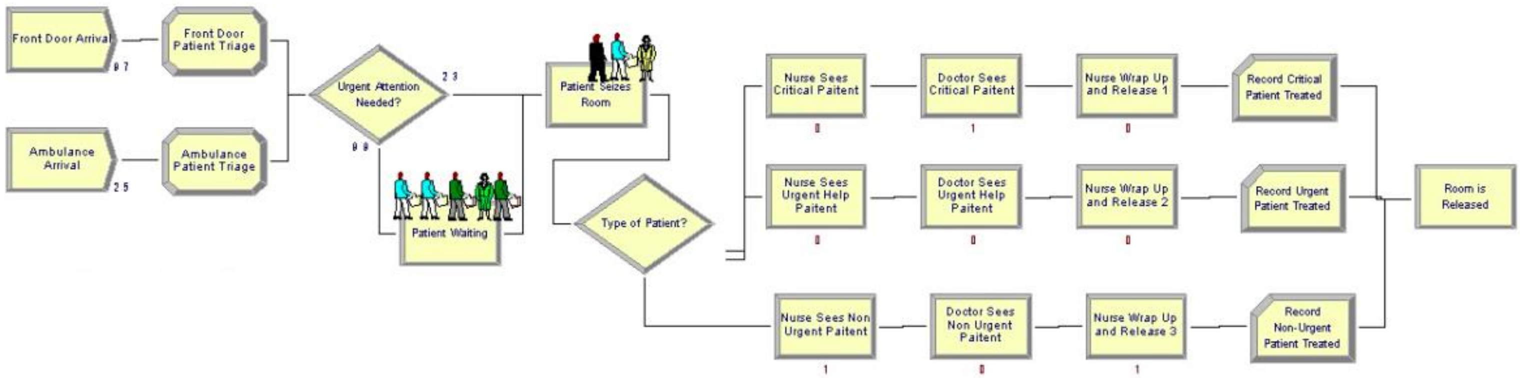
Resources: Rooms, Nurses, Doctors

Variables: No. of rooms, No. of doctors, No. of nurses, Non-Critical Patient Waiting Queue, Room Seize queue, Nurse Seize Queue, Doctor Seize Queue

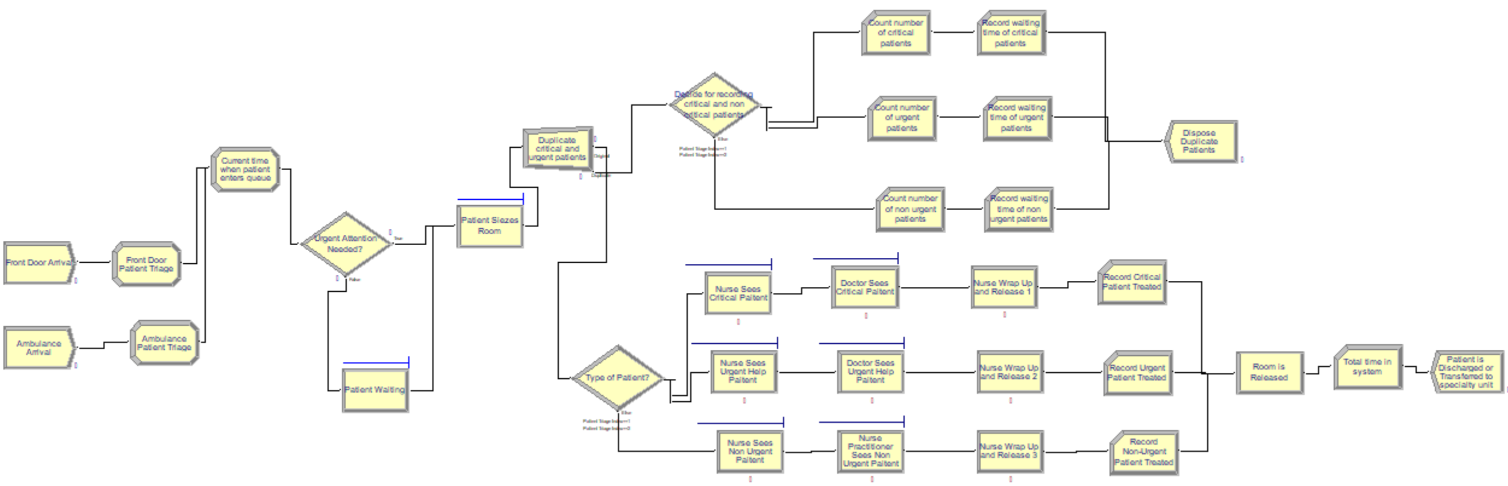
Statistical Accumulators: No. of Critical Patients Treated, No. of Urgent Patients Treated, No. of Non-Urgent Patients Treated, Patient Waiting Times

Base Model:

We quickly determined that our base model did not produce the granularity in waiting/processing times

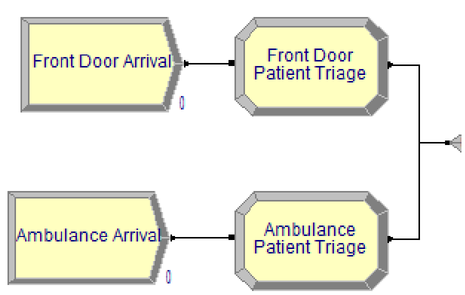


for each level of patient. Therefore, we upgraded our base model to include additional record modules:



2.1.3 Logical Flow:

2.1.3.1 Arrival and Triage



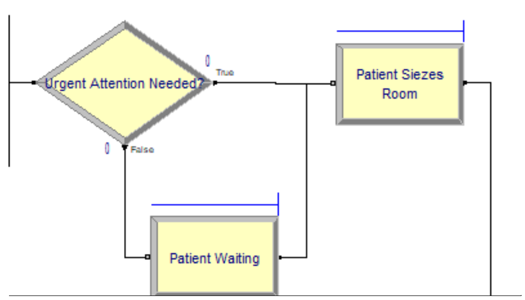
Patients arrive either via the front door (83%) or an ambulance ambulance (17%) as described by https://www.acepnow.com/article/emergency-medical-services-arrivals-admission-rates-emergency-department-analyzed/ . Arrival rates were described in the reference study (schedule based on arrival at UK ER over 1 year). The schedule for arrival is as follows:

- Front door arrival distributions for subsequent 6 hours of the day
  - 0000-0600 = NORM(1.58,0.63)
  - 0600-1200 = NORM(0.5,3)
  - 1200-1800 = NORM(6.59,4.9)
  - 1800-2400 = NORM(4.7,1.45)
- Post that they were assigned triage value using DISC(.009, 1, .343, 2, 1, 3)
- Ambulance arrival distributions for subsequent 6 hours of the day
  - 0000-0600 = NORM(.32, 0.13)
  - 0600-1200 = NORM(1.02,0.61)
  - 1200-1800 = NORM(1.35, 0.10)
  - 1800-2400 = NORM(0.96, 0.30)
- Post that they were assigned triage value using DISC(.093, 1, .922, 2, 1, 3).

Triage value (patient index) - Triage distribution is based on an Iranian study (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4437092/). We modified the triage distribution to assign a higher level of criticality (3 times more likely to be critical) to ambulance arrivals (https://www.acepnow.com/article/emergency-medical-services-arrivals-admission-rates-emergency-department-analyzed/).

1) Critical/Life-Threatening which can include resuscitation, heart attack, stroke, unconsciousness, etc
2) Critical/Non-Life-Threatening like broken bones, etc
3) Non-Critical/Non-Life-Threatening conditions like the common cold, strep throat that could be treated by a primary care physician or Nurse Practitioner

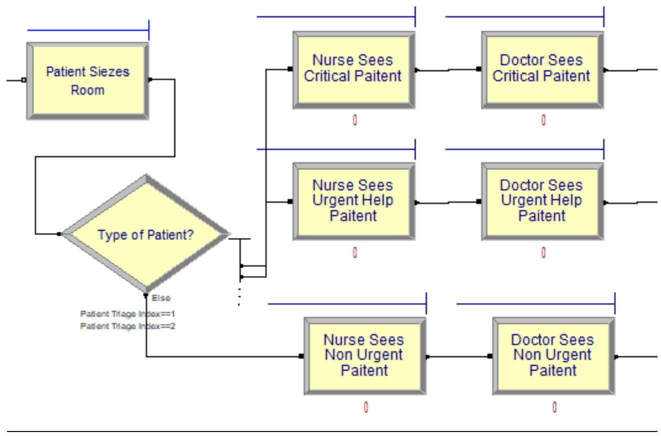
2.1.3.2 Room Assignment



- If a patient is Critical, the room is assigned immediately, else the patient waits in the waiting room. (‘Urgent Attention Needed?’ decide module checks criticality)
- The non-critical patients are held back till one of the rooms is empty and there is no critical patient waiting for a room.

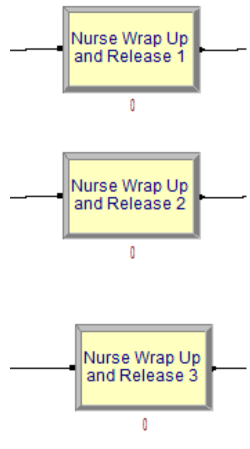
- The ‘Patient Waiting’ Hold module checks for condition (NQ(Patient Seizes Room. Queue)==0) before assigning a non-critical patient a room.

2.1.3.3 Nurse Seize/Delay & Doctor Processes



- Nurses are assigned to the patients based on their Patient Triage.
- Nurses first prepare the patients for treatment before they are seen by the doctor.
- The doctor then treats the patient and the treatment time is based on the patient's Triage.
- Patient Processing/ Treatment Times
-
- Time spent by nurses for preparation before seeing the doctor
  - Critical: 2*(BETA(10,10) + TRIA(3,4,5))
  - Urgent : (BETA(10,10) + TRIA(3,4,5))
  - Non-urgent: (BETA(10,10) + TRIA(3,4,5))
- Time spent by doctors to operate different categories of patients
  - Critical: TRIA(20,30,60)
  - Urgent: TRIA(15,20,40)
  - Non Urgent: TRIA(8,10,20)
- The numbers on the reference paper, didn’t seem very realistic. Thus, we retained the distributions and changed the most likely, minimum and maximum values to make the data more suited for our study.

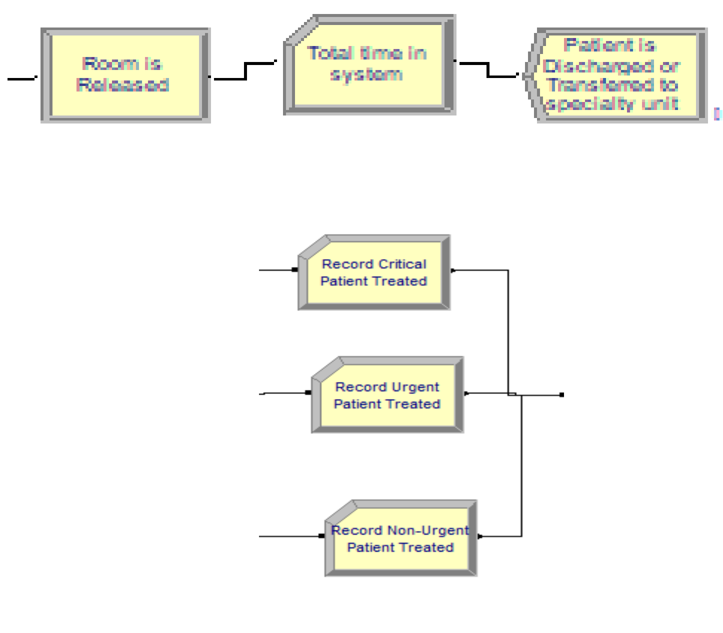
2.1.3.4 Nurse Delay and Release



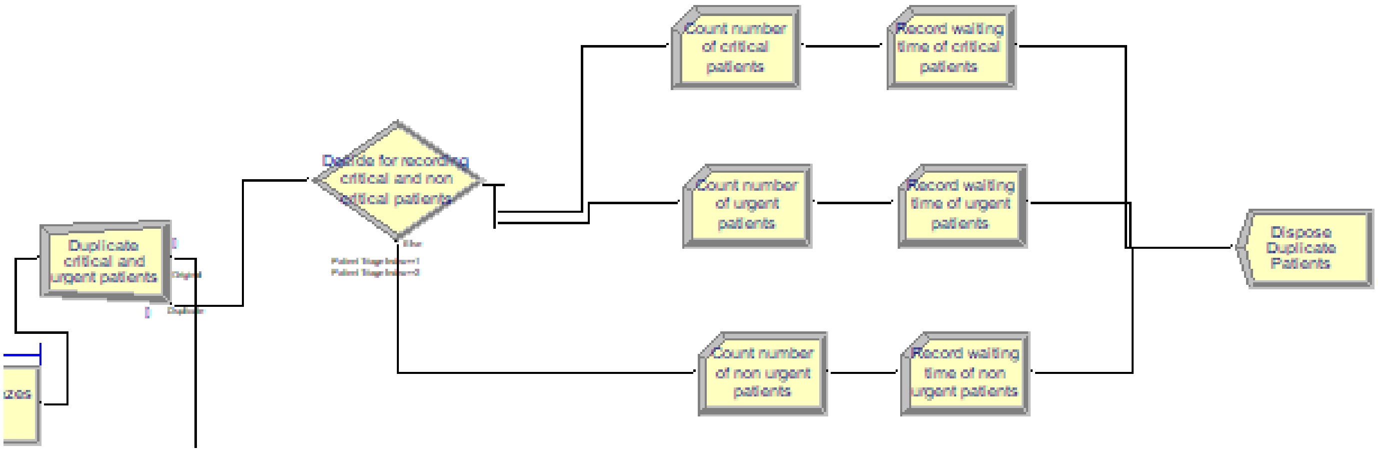
There is an additional delay present for the nurse to “out process” patient after the treatment. The patient is then prepared for discharge from the room. Following this process, the nurse gets released as follows:

- Same for all: TRIA(8,10,12)

2.1.3.5 Record Patients, Release and Dispose



Once the patients are treated, a record module counts the number of patients treated, for each type. After the patient's treatment has been recorded, the room is then released and total time in system is recorded as time interval between arrival and treatment and the patient entity is disposed from the system.



To count the critical, urgent and non urgent patients and their respective waiting times record modules are used as follows:

- Separate module is used to duplicate the patient entities.
- Decide module is used to send the duplicate entities to appropriate record module based on patient triage index.
- First one counts the number of patients of that particular category.
- Second record module records the waiting time of each category of patient until she gets the room.
- After this is done the duplicate patient entity is disposed.

3 Results

In order to see the compounding impact of round-the-clock operations, we ran the simulation for a 10 day period. We established the final resource allocation (6 rooms, 5 nurses, and 3 doctors) because it gave total system time results (202 minutes) closest to the US ER time average of 3.7 hours (https://medicalconnectivity.com/2006/06/01/average-length-of-stay-in-eds-nationwide-too-long/). We reasoned that our base scenario should mimic the real world in that our model should generate results in line with current averages (since we used real data).

Our results showed that critical patients were admitted (to a room) within 3 minutes of arrival while, urgent and non-urgent patients waited for 162 and 167 minutes, respectively. Again, these results mimic what we expect to see in the real-world (essentially no wait for critical patients). While our main priority of minimizing the queue times of critical patients is achieved with the results, the waiting time for non-urgent and (especially) urgent patients it too long. So, how do we minimize the waiting time for urgent patients without sacrificing the current waiting time of critical patients, for roughly the same costs?

Once in a room, patients must wait to see a nurse as follow:

- Critical = 3.5 minutes, Urgent = 6 minutes, Non-Urgent = 6.7 minutes

And then, to see a doctor, patients wait as follows:

- Critical = 1 minute, Urgent = 2 minutes, Non-Urgent = 2.2 minutes

Again, any adjustments to our model cannot come at the cost of increasing these times for critical patients.

3.1 Model Improvements Based on Results from Base Model

Several hospitals in the UK have reconfigured their ERs into two sections, an A&E (accident and emergency) and UCC (urgent care centers). The basis for this reconfiguration is simple; if patients can be immediately categorized into emergency or non-emergency, then they could follow either of the two pathways within the ER. The UCC side would be staffed accordingly with nurses, nurse practitioners (NPs), and general practitioners (GPs) while the A&E side would be staffed with trauma specialists (both doctors and nurses). The implications of the division are rather intuitive for the following reasons (not all inclusive):

- Resources (i.e., medical personnel) could be used more effectively. For example, a trauma specialist would not be misusing his/her expertise in diagnosing the flu.
- In light of efficient resource utilization, hospitals would save money by not over-paying a specialist to perform jobs beneath his/her specialty
- Wait times (queue lengths) would be shorter. While it is clear that life-threatening emergencies have little-no wait times, those with non-emergencies would be in a queue separate from the emergency queue (and would avoid being continually pushed to the back of the queue).

Therefore, we decided to adjust our model by adding an urgent care center (UCC) to the ER department. We assumed that the UCC would use a nurse practitioner (NP) to ONLY treat non-urgent patients.

To create the UCC, we decided that we could not increase the costs (i.e., add more personnel, without taking away other personnel) or increase the number of rooms. We created multiple different models in an attempt to improve our base case. Our attempts involved the following changes:

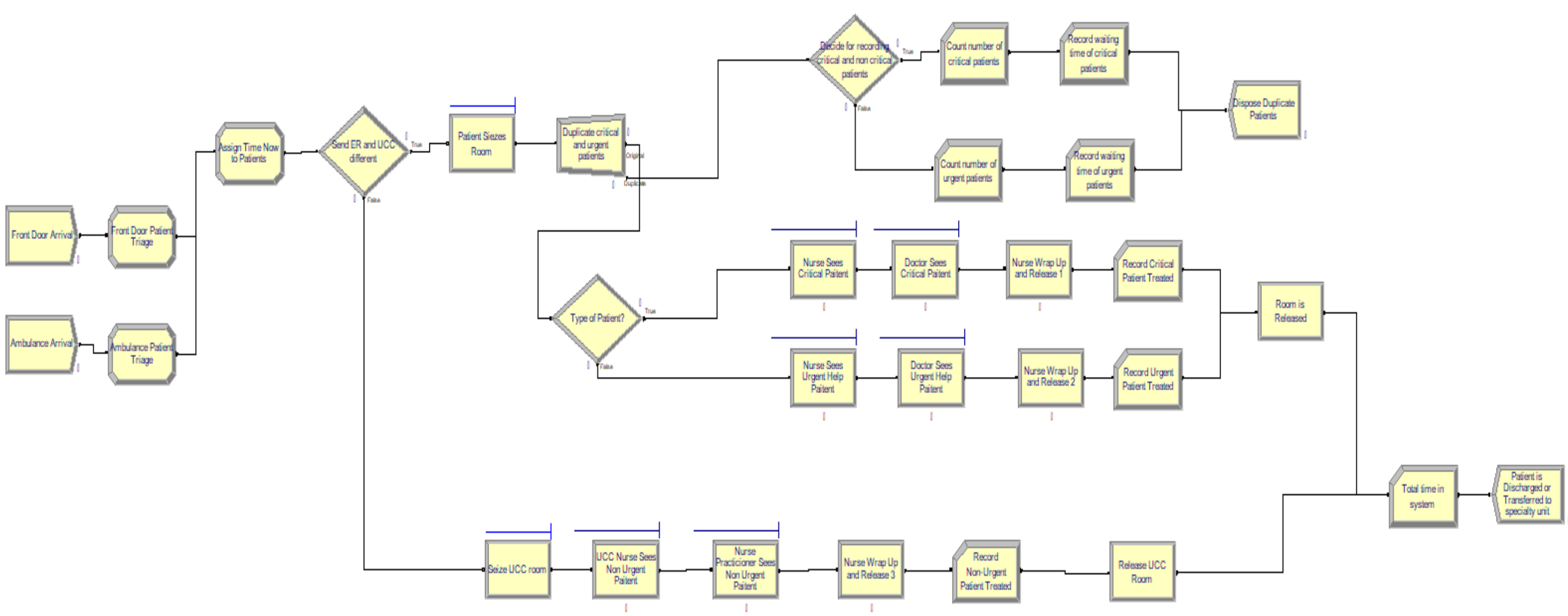
- Physically separating the UCC from the ER (i.e, the UCC would have 2 rooms and the ER 4 and nurses were not shared between the two)

- Sharing the nurses while specifically allocating rooms for the ER or the UCC (not shared)
- Sharing nurses and sharing rooms

The last scenario, in which the UCC and ER shared nurses and rooms, was the most successful. In the model, patients were still prioritized as before. We reasoned that if we reduced the doctor amount from 3 to 2, then the cost savings would allow the ER to hire an NP and an additional nurse WITHOUT increasing the cost. Therefore, our final model had 6 rooms, 6 nurses, 2 doctors (which only treated critical and urgent patients) and 1 NP (which only treated non-urgent patients).

The model is the same in terms of all delay times and arrival rates. The only difference is that critical and urgent patients get dedicated rooms and doctors. Non critical patients are now seen by nurse practitioners instead of MDs. This essentially saves the cost of hiring an MD who would treat non critical patients too, this is based on our real world observation that an MD costs more than a nurse practitioner.

Model with UCC/A&E separated:



Though successful, the results did not improve on our base model. In fact, the results summarized in the table below show a surprising decline in nearly every metric.

	ER Only	ER + UCC	% Change	
Total Patients Through	1409	1240	-12%	Worse
Critical	30	25	-17%	Worse
Urgent	561	478	-15%	Worse
Non-Urgent	818	737	-10%	Worse
Total Time in System	203	211.8	4%	Worse
Room Utilization	0.6726	0.6762	1%	Better
Nurse Utilization	0.6825	0.6762	-1%	Worse
NP Utilization	N/A	0.6519		N/A
MD Utilization	0.5945	0.4409	-26%	Worse
Critical Patient Wait	3.07	6.09	98%	Worse
Urgent Patient Wait	162.3	159.7	-2%	Better
Non-Urgent Wait	167.9	175.1	4%	Worse

In this case (specific room/staff constraints and input data), the versatility of a doctor is worth far more than an additional nurse and a nurse practitioner.

4 Conclusion

Of course, we cannot definitively conclude that the UCC/ER model will always be worse. In fact, there may be situations where the UCC/ER model are superior to that of the ER. What we can conclude is that we can easily compare models given a set of constraints. In other words, hospital managers need only insert their specific data, staffing and space constraints in order to ascertain which model would be right for them.

Therefore, we conclude that, while the UCC/ER model did not improve efficiency in our case, efficiencies may be gained in certain situations. We hypothesize that the size of our emergency department did not allow for the benefits that specialization would bring. More specifically, a doctor is far more valuable (in this situation) than an additional nurse and nurse practitioner would be. We concede that this may not always be the case.

5 Appendix

5.1 References

A - USING SIMPLIFIED DISCRETE-EVENT SIMULATION MODELS FOR HEALTH CARE APPLICATIONS, *Proceedings of the 2011 Winter Simulation Conference; S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, eds.*

https://www.acepnow.com/article/emergency-medical-services-arrivals-admission-rates-emergency-department-analyzed/ - Describes ER arrivals from ambulance or front door