ORIE 5580 Final Project - Fall 2021

Helicopter Emergency Transport in Upstate New York

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Executive Summary

A simulation-based approach was taken to address the problem of helicopter base location selection and helicopter assignment in Upstate New York. Out of the 10 locations being considered, the towns of Utica, Albany, Ithaca, Rochester and Syracuse were selected as base locations to maximize coverage. Due to redundancy requirements, configurations where at least two helicopters were assigned to each base and the remaining two available helicopters were each placed in two locations were explored through discrete-event simulation. The best configuration based on percent dispatched, response fraction, and helicopter utilization has 3 helicopters placed in helicopters in Albany and Ithaca.

Background and Problem Definition

Emergency responses sometimes require air-lifting the patients to the nearest appropriate definitive care sites. Aviation operations are inherently expensive and the ability to conduct a flight is often subjected to safety considerations such as weather conditions. Upstate New York is a region where helicopter transport operations are conducted to meet urgent patient needs.

The client seeks to determine the most appropriate helicopter base locations from a pool of 10 towns in Upstate New York and how many helicopters to assign to each of the selected bases. The 10 towns under consideration are Buffalo, Rochester, Elmira, Ithaca, Sayre, Watertown, Syracuse, Binghamton, Utica, Albany. The number of rotary-wing aircraft available for assignment to the bases is 12. Each aircraft travels at a ground speed of 160 km/hr and has a maximum service range of 180 km from their assigned base.

A cycle of an emergency call response can be summarized as follows:

1. Call is received
2. Safe-to-fly assessment and assignment to base and helicopter if safe
3. Helicopter crew performs flight preparation and depart
4. Helicopter spends some time at scene with patient
5. Helicopter travels from scene to nearest appropriate definitive care center
6. Helicopter drops off patient and returns to base

In the case that the conditions are unfit for flight, the response request is not granted.
There is a chance that a dispatched helicopter response is canceled while the helicopter is en route to the scene. The helicopter simply returns to its base.
There are five metrics that the client uses to evaluate a solution’s performance:

1. Percentage of calls dispatched: percentage of dispatched calls to total calls received
2. Average response time: average time between call receival and arrival at scene
3. Time to definitive care: average time between call receival and arrival at hospital
4. Response fraction: fraction of calls received where helicopters arrive at the scene
5. Utilization of helicopters

Modeling approach and assumptions

The Simulation model

The appropriate modeling framework for the problem is discrete event simulation. Given that each service call follows the same set of events such as helicopter assignment, arrival to scene and arrival back at base, the simulation can be driven based on the nearest upcoming event in the event list.

The overarching driver of the simulation is our event list, in which we keep a list of events to happen at different times. At the start of the simulation, we start with 1 event (a caller event)l in our event list. From there, certain events can trigger the generation of a new event to be added to the event list, for example at the time the call is received, we generate the next call event to happen at time T based on historical poisson distribution. A more detailed breakdown of our simulation logic will be included in the next section.

The simulation model is scripted with python, having a clear and concise code structure with the simulation going on in main.py, supporting functions in util.py, and classes for helicopters, bases, calls, etc. sitting in a class folder.

Simulation Logic

Included below is a succinct description of our simulation logic, please refer to our code submission for the complete simulation model.

1. Start by initializing the hospital locations, helicopter bases location and helicopter assignment in the bases.
2. Initialize first call event in our event list
3. While current time is smaller than end time:
   a. Update state with the current event
   b. Get the next event from the event list
   c. Update time to the time of the next event to take place

In step 3.a) there are a lot more complications with detailed handling of different events, such as helicopter arrival, departure to hospital, etc. The precise event handling, parameter updates, and generation of new events for each of the different events to take place can be found in the code appendix.

Assumptions

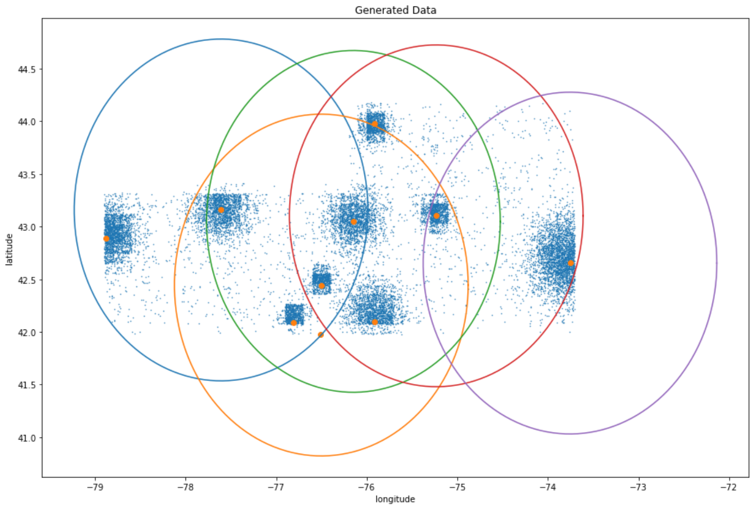
In the modelling process, the observations of the helicopter service has led us to the following assumptions:

- Ambulance crews naturally want to live in a reasonable-sized population center. Accordingly, helicopter bases are being considered in Buffalo, Rochester, Elmira, Ithaca, Sayre PA, Watertown, Syracuse, Binghamton, Utica and Albany.
- We can have up to 12 helicopters.
- We can have up to 5 helicopter bases.

- Helicopters travel at a speed of 160 km/hr and can respond to calls within 180 km of their base.
- We will assume that helicopters do not require refueling and servicing between calls.
- Helicopter crews are restricted in how many hours they can fly in a single shift, but we will not consider that complexity.
- Shift handovers from one helicopter crew to the next can be complicated, since HD is reluctant to dispatch a helicopter that is close to the end of their shift. We will ignore this complexity and allow helicopters to be dispatched at any time.
- The decision on whether it is safe to fly or not depends on the path a helicopter takes from its base to the scene, but we will assume the decision is made without regard to base or scene location.
- In reality a helicopter returning to base can be redirected to a new call assuming sufficient fuel and remaining duty time for the crew, but in our modeling we will not allow this; helicopters must reach their base before being considered available for the next call.
- Calls requiring the transport of multiple patients are very rare. We will assume each call requires transport of a single patient.

The solution search space

It is simply infeasible to conduct simulation for all combinations of helicopter placement across the 10 possible locations. Five candidate towns where the bases should be located in the region can be selected by visualizing the radii of helicopter service range from each location and their respective coverages.



It is suitable to leave out bases where there is significant overlapping of service range from bases in other locations. Bordering locations to adjacent states, Canada and bodies of water are also not ideal base locations and should not be selected unless there is no coverage from another location. For example, consider the city of Buffalo. A base in Rochester covers most of Buffalo's region. Having a base in Buffalo will waste the effective coverage of aircrafts since it borders Canada and has a number of bodies of water around its proximity. On the other hand, although Albany borders Massachusetts and New Hampshire, a base in the closest location being considered, Rochester, will not be able to cover part of Albany's region.
Five selected locations (Utica, Albany, Ithaca, Rochester and Syracuse) with coverage range illustrated in the plot above provide reasonable coverage while being in close proximity to denser population centers.

The number of aircrafts to assign to each candidate base was also narrowed down. For redundancy, no base should be assigned less than two aircrafts (eliminating the cases where the sole aircraft of a base requires an unexpected servicing, driving that base out of service). On the other hand, no single base should have more than three aircraft, since no base location exhibits population density in a different order of magnitude to the others. Therefore, the solution search space is further narrowed down to which two bases the two additional aircrafts should be assigned to, having assigned two aircrafts to each base as default.

Data Analysis

The simulation derived a lot of its assumptions from a data set of calls spanning across a period of one year. Within the data set, information about call location, flight safety status, helicopter availability, cancellation delay, scene time, hospital location and hospital time were provided for each call that was logged.

To provide an input for scene time and hospital time to the simulation, various distributions were fitted on the respective fields of the data set provided. The best distribution and corresponding parameters were selected based on their fit (histogram overlay and QQ plot) and used in the discrete event simulation model.

- Interarrival times for calls were assumed to be a non-stationary Poisson process with different rate parameters across each hour of the day.
- The cancellation time (prior to censoring) was fitted as an exponential distribution with the rate parameter estimated through maximum likelihood estimation.
- Delay experienced at the dispatch office which introduces a lag between call receival and call assignment was modeled as a triangular distribution since the usual value, minimum and maximum are known.
- Whether the weather condition is safe to fly for each call was modeled as a binomial distribution with one trial and a probability of success derived from the one year call data.

*Distribution parameter derivation retrieved from earlier analysis (Project Homework)

Item	**Distribution**	**Parameters**
Scene time	Beta	a=2.95, b=11072, scale=1302.6
Hospital time	Beta	a=2.9, b=812, scale=141
Call interarrival time	Poisson process with 1 rate parameter per hour of day	rate = [0.723,0.618,0.374,0.319,0.266,0.277,0.489,0.777,1.70,2.

		75,3.19,3.72,3.96,3.67,3.81,3.68,3.56,3.20,3.05,2.28,1.40,1.17,0.881,0.813]
Cancelation time	Exponential	Lambda = 4.87
Dispatch delay time	Triangular	Min = 5, max = 10, mode = 7
Condition is safe to fly	Binomial	k = 1, p = 0.899
Patience requires trauma care	Binomial	k = 1, p = 0.193

Configuration Generation

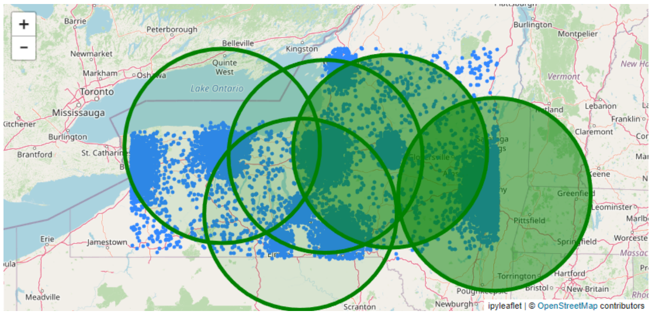
In previous sections we have justified our solution search space to the five selected bases. And from the result of running the simulation with only 2 helicopters compared with 12, we show that more helicopters will improve our desired metrics since they will increase the efficiency. Therefore, we now consider how to fit 12 helicopters in the 5 bases that we have. To make the number of helicopters equally spread out in the bases, we set a minimum of 2 helicopters per base. This is the same as choosing two out of the five bases to have 3 helicopters while the rest have 2. So our problem becomes assigning the 2 extra helicopters. Thus, we are left with 5C2 number of configurations to experiment.

Configuration Results

In the below configuration results, we show a comparison of the 10 different configurations and their corresponding metrics.

Configuration 1

Description: Three helicopters in Utica and Albany. Two helicopters in the other three bases.
Map:



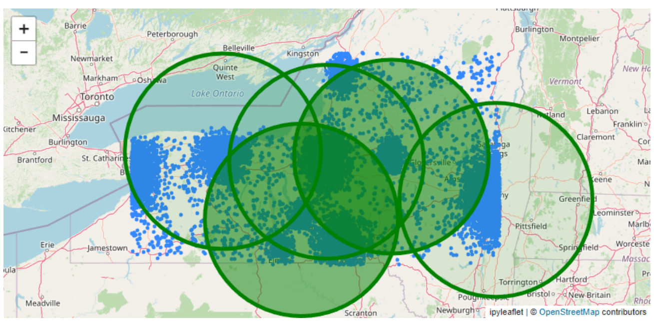
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.795532	0.279226	0.638324	0.671663	1.484726
std	0.001252	0.003123	0.005006	0.003717	0.018658

Configuration 2

Description: Three helicopters in Utica and Ithaca. Two helicopters in the other three bases.

Map:



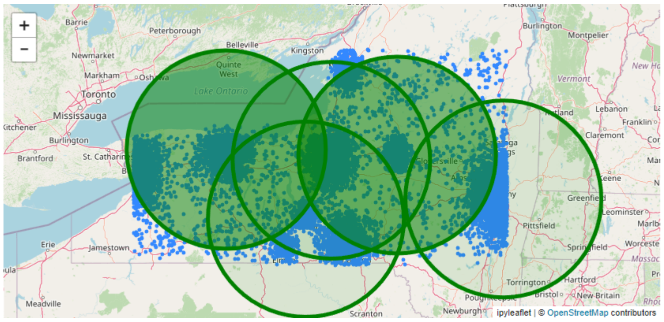
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.792654	0.277635	0.635191	0.668695	1.476872
std	0.003825	0.004736	0.007665	0.005421	0.033460

Configuration 3

Description: Three helicopters in Utica and Rochester. Two helicopters in the other three bases.

Map:



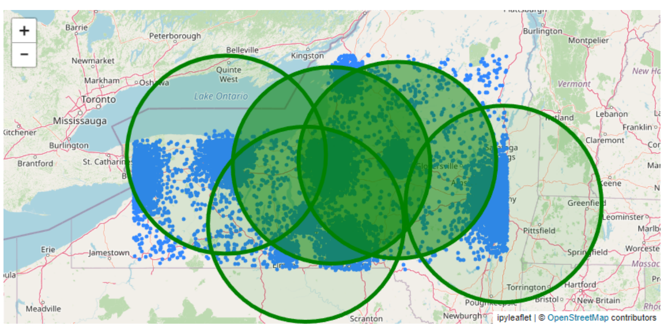
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.795487	0.279790	0.639267	0.671571	1.486986
std	0.001669	0.001829	0.005689	0.004063	0.023601

Configuration 4

Description: Three helicopters in Utica and Syracuse. Two helicopters in the other three bases.

Map:



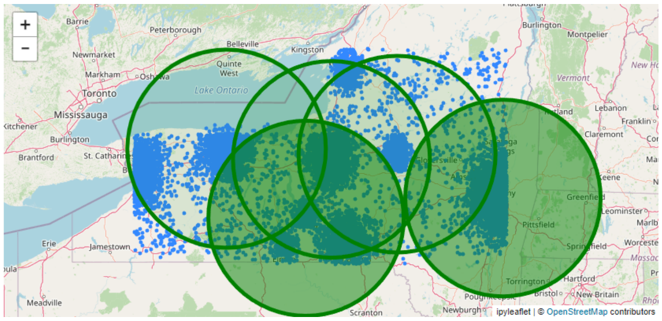
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.794851	0.277661	0.637620	0.669814	1.479155
std	0.006002	0.002844	0.006071	0.004630	0.020547

Configuration 5

Description: Three helicopters in Albany and Ithaca. Two helicopters in the other three bases.

Map:



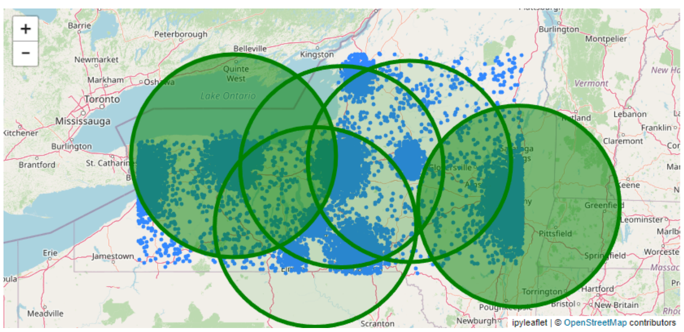
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.796401	0.278587	0.638264	0.672938	1.500068
std	0.002915	0.002272	0.004265	0.002777	0.026633

Configuration 6

Description: Three helicopters in Albany and Rochester. Two helicopters in the other three bases.

Map:



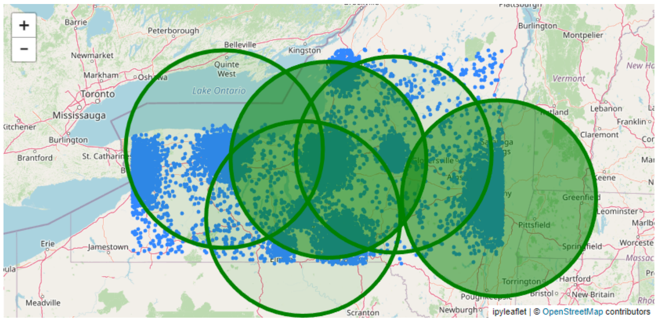
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.792438	0.277110	0.635939	0.66964	1.479064
std	0.002868	0.003376	0.006542	0.00486	0.015674

Configuration 7

Description: Three helicopters in Albany and Syracuse. Two helicopters in the other three bases.

Map:



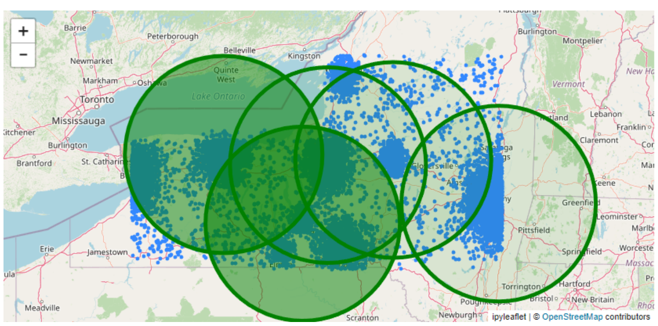
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.788186	0.277345	0.634323	0.666647	1.479521
std	0.004681	0.002442	0.005821	0.005405	0.034801

Configuration 8

Description: Three helicopters in Ithaca and Rochester. Two helicopters in the other three bases.

Map:



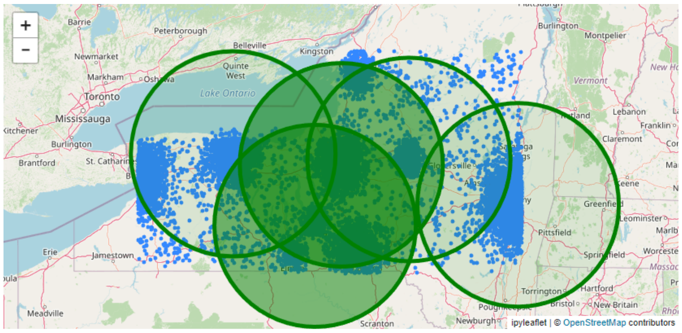
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.794742	0.275986	0.633523	0.668969	1.482580
std	0.003374	0.003150	0.006754	0.004774	0.022473

Configuration 9

Description: Three helicopters in Ithaca and Syracuse. Two helicopters in the other three bases.

Map:



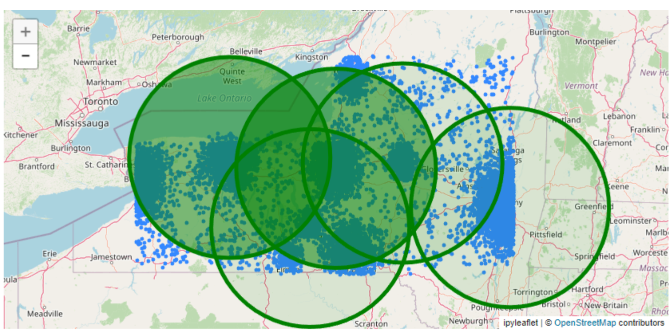
Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.793855	0.275293	0.634156	0.669983	1.489863
std	0.006684	0.002464	0.005782	0.006645	0.019714

Configuration 10

Description: Three helicopters in Rochester and Syracuse. Two helicopters in the other three bases.

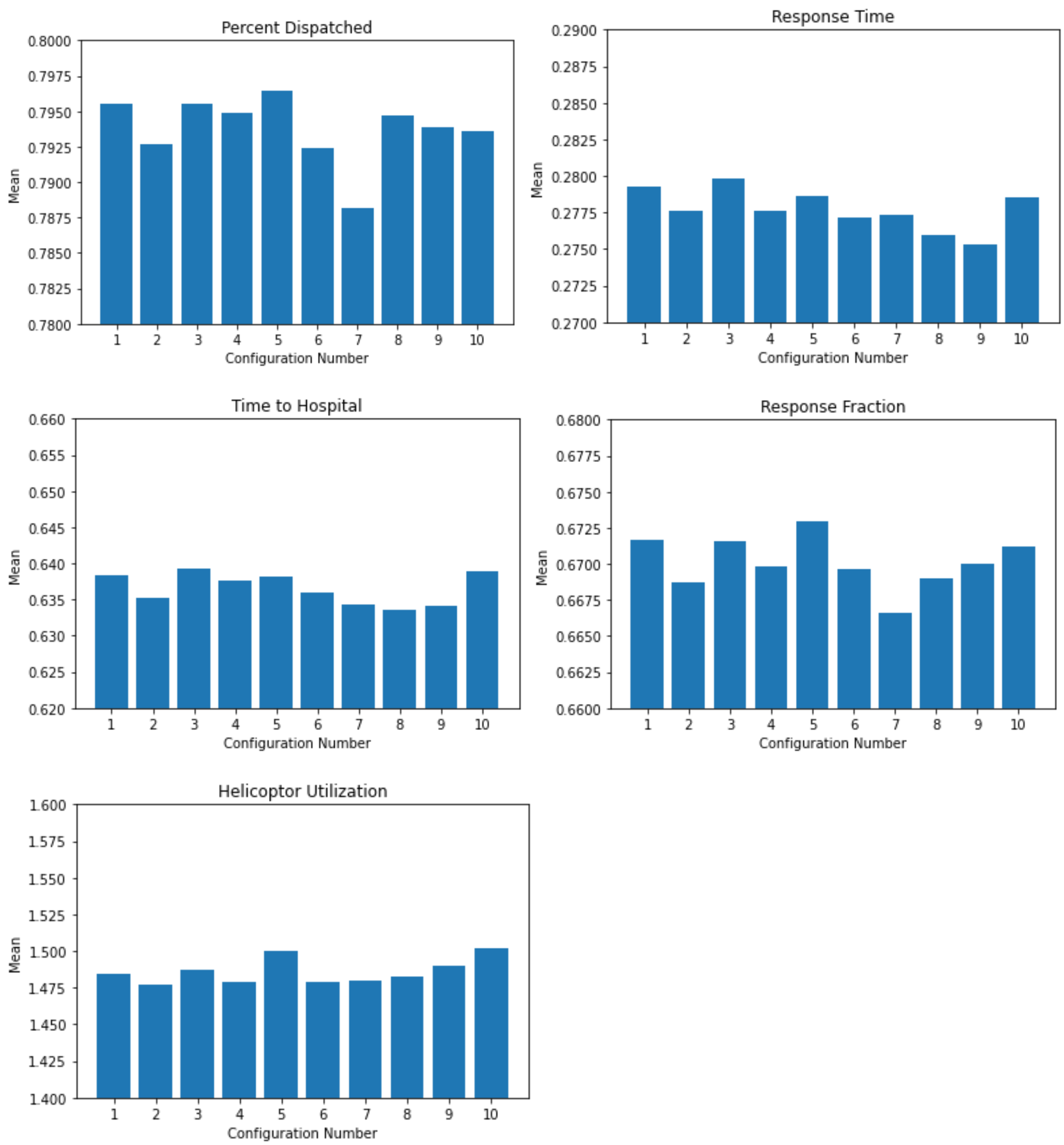
Map:



Results:

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.793626	0.278499	0.638856	0.671213	1.501895
std	0.004043	0.003800	0.008956	0.004441	0.032147

Configuration Comparison



Configuration 5 (Three helicopters in Albany and Ithaca. Two helicopters in the other three bases.) has the best Percent Dispatched, response fraction, and helicopter utilization. Moreover, it's time to hospital an dresponstime metrics are also above average. For this reason, configuration 5 stands out to be the best assignment of helicopters and bases.

Therefore, the final result of our simulation yielded the following assignment of helicopter bases and helicopters:

- Utica: 2 helicopters
- Albany: 3 helicopters

- Ithaca: 3 helicopters
- Rochester: 2 helicopters
- Syracuse: 2 helicopters

Verification

To verify our simulation model is set up correctly and our chosen configuration is indeed optimal, we came up with an intuitively bad assignment: Having only 1 helicopter base at Albany and all 12 helicopters in that base. The results of this deliberately bad assignment is indeed a lot worse, which proves that our model is working as expected.

	Percent Dispatched	Response Time	Time to Hospital	Response Fraction	Helicoptor Utilization
mean	0.793914	0.353992	0.711278	0.472792	1.052785
std	0.002760	0.003725	0.008328	0.003821	0.014011

Conclusion

In this simulation model, we utilized a number of tools and methods to come up with a robust model implemented using object oriented programming. Our discrete event simulation involved different distributions and characteristics drawn from historical data. After running numerous configurations we have concluded the final recommendation, which is 2 helicopters in each of Rochester, Syracuse, and Utica; and 3 helicopters in Albany and Ithaca.

Limitation

In real life situations, helicopters require refueling and servicing, we should take it into account. In addition, flight time limitations and rest requirements should be considered in our model. Furthermore, we assume the decision made on whether Safe-to-fly without the consideration of the path from base to scene.

Future work

Due to limited computing resources, we did not exhaust every possible combination of one to twelve helicopters assigned to five bases. Instead our scope was guided by selecting certain combinations and using those to draw insights to move our search space forward. As a future work on this project, we might want to exhaust all the combinations of helicopter numbers and bases and compare the resulting metrics to select the best assignment.

Appendices

- Github repo link (https://github.coecis.cornell.edu/pw273/ORIE_5580_project)
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