Helicopter Emergency Transport in Upstate New York
ORIE 5580 Report

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• Executive Summary

Background and Problem Statement

Helicopter emergency medical services as an integral part of worldwide emergency medical services provided prehospital services for emergency patients nowadays are widely used in many industrialized countries. In order to meet the timely response to emergencies and at the same time to consider all the uncertainties, how to implement an effective allocation plan and adequate service for helicopter emergency medical services is a basic requirement for helicopter emergency medical services. For example, a helicopter working in an uncertain environment and weather should be the first and foremost condition to be considered before it is dispatched. Secondly, the demand of emergencies is assumed to be stochastic. The incident can occur at any time and place, also the condition of the patient is another factor deciding if a helicopter should be deployed. Also, helicopters and installing helicopter bases are very expensive. To reduce the cost, it influences the number of helicopters or bases. Consequently, the assignment of the location for each helicopter can be complicated. When a call arrives, the helicopter department needs to dispatch the closest helicopter, if that closest helicopter is already dispatched before, then the next appreciated base's helicopter needs to be dispatched. Therefore, cost, environment, the dynamic of the assigned process and stochastic services demand are all the high impact factors of the final decision of the helicopter allocation plan. Therefore, our project proposes a simulation-based optimization method for helicopter allocation by using the historic data from upstate New York helicopter emergency transport as reference to capture the complicated operational process and different sources of uncertainty. Our simulation model investigates how to choose the location and number of helicopters for Upstate New York. The goal is minimize the total cost for installing and maintaining these facilities but also assuring the stochastic demand of emergencies.

Soluiton

We build simulation models to predict helicopter rescue service dynamics and implement several methods to ensure plausibility and credibility of our model. Our model is able to generate and mimic a real world helicopter rescue service system and will perform several crucial performance measurements for companies to compare different scenarios and make decisions. The model provides output analysis including: average response time of each urgent call, fraction of helicopter dispatched, fraction of urgent call response and helicopter utilization. Those four performance measurements will be explained in detail in the Model Analysis part, which will stress how those measurements can reflect scenarios and can help companies to make decisions.

Recommendation

This study not only outputs a simulation model but also concludes several recommendations of bases and number of helicopters assigned choices. In the Model Analysis part, this model will provide an interpretable table of different scenarios, each with indicated bases and number of helicopters selection, and corresponding performance measurements statistics, in addition, statistics interpretation will also be stressed in the final recommendation part to better help companies make decisions.

• Problem Description

Current Situation

Helicopter transportation's dynamic interface is a crucial problem in the city environment. Especially when an urgent accident occurs, the efficiency of helicopter rescue is an increasingly important measurement of emergency response plans. When the Helicopter Dispatch (HD) center receives an emergency call from a patient at the scene, HD will manage to assign a helicopter to the scene and transport the urgent patient to the hospital. There are a lot of uncertainty factors which can impact the performance of helicopter rescue performance and emergency response timeliness. Intuitively, when a call is received at Helicopter Dispatch center, HD should determine whether there is an available helicopter within reachable distance of the scene since, due to expensive helicopter transportation and limit number of helicopter availability, it is not actually possible to dispatch helicopter for rescue to a scene very far away from helicopter base location. What is more, HD also needs to check whether it is safe to fly due to factors like bad weather or the repair of helicopters. Then HD will gain more detail about the urgent patient, such as the precise location of patient, severity of the accident, specific treatment needed. HD facilities also need to check which hospital should the patient be delivered to, if the patient does not have specific treatment, then the patient will be delivered to the nearest medical facility, while if the patient is severely injured and needs special treatment, then the patient will be delivered to specific Trauma based on treatment needed. After the HD finished calling, a helicopter should be assigned and prepared for departure, where preparation includes processes such as clearance, safety check, awaiting for departure, etc. After preparation, helicopters are ready to dispatch HD and be on the way to the scene. However, an event might be canceled at any time before the helicopter reaches the scene, i.e, the death of a patient or rescue no longer needed, if the event is canceled, then the helicopter will return to the base after it is dispatched and be ready for the next assigned rescue. If Helicopter reaches the scene, it spends some time on the scene and transports the patient to a medical facility or Trauma as fast as possible. After reaching the medical facility/Trauma, the helicopter spent some time at the hospital waiting for the patient to be transferred to medical facility or trauma and then go back to its base, then ready for next rescue. This is roughly the transportation dynamics for each helicopter.

Goal of Study

Since helicopter maintenance is expensive, the number of helicopters is limited, the real situation is complex and various, HD needs to make many decisions in order to optimize the handling of energent accidents. The goal of this study is to use simulation to mimic helicopters responding to urgent calls in upstate New York region and consider where the helicopters should be based around and the number of helicopters in each base. Simulation approach and logic will be explained in detail in the following part. At the end, this study will recommend several choices of helicopter base location and number of helicopters assigned.

• Model Approach and Assumption

Model Approach

Simulation

This study uses a simulation model. Simulation modeling is the process of creating and analyzing a mimic situation of a physical model to predict its performance in the real situation. Simulation modeling can be used to help managers to make decisions on optimization of targeted performance.

Simulation Process

The logic of this simulation model is to use assumptions drivened from previous given data to create a helicopter rescue interface model to predict real world situations and help make decisions to optimize the overall helicopter response of emergency performance. Assumptions will be theoretically discussed in the following part. The complete simulation process conducts several events:

Call Arrival: This is the beginning event of one emergency call. We will use the distribution and parameters obtained from assumption to generate call interarrival times, until the cumulative time reaches the end of time, i.e 365 days. Immediately, we generate a cancellation time based on assumptions for each call. Next step is to decide whether a helicopter is available within 180 km. If so, we then generate a HD call processing time and compare to cancellation time, to decide whether this call is ready to fly or is canceled during HD call processing. If no helicopter is available, then we mark this call as no response and deal with the next call.

Call Cancelled: This event happens when a call is canceled. There are two situations when a call is canceled. First, the call is canceled before the helicopter departure, that is, the call is canceled when the assigned helicopter is still waiting clearance or in preparation state, then this helicopter is marked as returning to base immediately and ready for use. Second, the call is canceled after the helicopter departure, that is, the call is canceled when the helicopter is flying on its way to the scene. In this case, the helicopter needs to return to its original base, the arrival base time should be calculated according to its current location, and this helicopter is only available for use after its arrival base time.

Call Finishes At HD: This event happens after the HD finishes call processing. If a call reaches this event, then we first generate a random probability of safe to fly based on assumption, if the result is not safe, then mark the helicopter as return to base and be ready for use immediately, if it is safe to fly, then the helicopter enters preparation for fly. In this step, we also generate a random preparation time based on assumption, and compare the preparation time with cancellation time to decide whether the call is canceled during helicopter preparation. If canceled, helicopter returns to base and be ready for use immediately, if not, helicopter successfully departs to scene

Helicopter Departs For Call: This event happens when a helicopter successfully departs HD and is on its way to the scene. Based on the arrival scene time assumption, we generate an arrival time. However, we still need to check whether the call is canceled when the helicopter is flying to the scene. Therefore, comparing arrival scene time with cancellation time, if the helicopter is canceled on its way to the scene, the helicopter returns to its original base from its current location, calculating arrival base time after which the helicopter can be ready for use. Else, the helicopter will arrive at the scene and ready to transport the patient to hospital.

Helicopter Arrives At Scene: This event happens when a helicopter arrives at the scene. Then we record the current time and mark it as the response time for this urgent call. Still, we need to generate a random time spent at a scene, add this scene duration to record current time, then helicopter departs the scene, on its way to hospital.

Helicopter Departs From Scene: When a helicopter departs from the scene, several cases and decisions need to be made. First, calculate the nearest medical facility/Trauma of that scene, if the nearest hospital is one of the four Trauma, then transport the patient to the nearest Trauma. While the nearest hospital is not one of four Trauma, generate a random probability based on assumption of transporting to Trauma. If transport to Trauma, transfer to nearest Trauma, if not, transfer to nearest medical facility. Second, compute the time of arriving at the hospital based on distance and speed.

Finish Repond: When helicopter arrive at hospital, we will generate a random time spent at hospital based on assumption, then, after helicopter spending at hospital, it return to base, record the time of arrival base after which helicopter can be ready for use

Model Assumption: Above simulation process should be conducted based on reasonable assumptions on distribution and parameters. We use a random number generator to ensure that each individual call arrival is independently randomly generated from a non-homogeneous poisson process, arrival rate function is hour-based, varying from 24 hours per day, and we do not consider weekly and seasonal influence in arrival rate. Also, we assume cancel time, HD call processing time, helicopter preparation time, scene spent time and hospital spent time all follow specific distribution and parameters which can be pre-calculated from given data. What is more, probability of safe flight and probability of transport to Trauma when nearest hospital is not Trauma are Bernoulli distributed with fixed probability. Finally, since we have spoken with firefighters, paramedics and other first responders with an existing helicopter service, we assume helicopters within 180km from the scene as available and helicopters fly at an average speed of 160km/hour.

Data Analysis

We need to obtain distributions and parameters for the above model assumption. Since we have a given data about helicopter service over one year, we can assume that this data provides a trustable real situation, therefore we obtained the following distributions and parameters from statistically analysis of the given data:

- **Call Arrival Rate**: Non Homogeneous Poisson Process: Hourly Rate Table:

Hour	Rate	Hour	Rate	Hour	Rate
1	0.723	9	1.70	17	3.56
2	0.618	10	2.75	18	3.20
3	0.374	11	3.19	19	3.05
4	0.319	12	3.72	20	2.28
5	0.266	13	3.96	21	1.40
6	0.277	14	3.67	22	1.17
7	0.489	15	3.81	23	0.881
8	0.777	16	3.68	24	0.813

Table 1: Rate (calls per hour)

- **Cancel Time**: Exponential Distribution: Mean = 4.87 Hour per Call
- **HD Call Processing Time**: Triangular Distribution: Minimum: 5, Mode: 7, Maximum: 10
- **Helicopter Preparation Time**: Triangular Distribution: Minimum: 5, Mode: 7.5, Maximum: 10
- **Time Spent on Scene**: Beta(a = 2.95,b = 11072,scale = 1302.6) or Gamma(a = 2.95,scale = 0.12)
- **Time Spent at Hospita**l: Beta Distribution: (a = 2.90, b = 812, scale = 141) or Gamma (a = 2.91, scale = 0.17)
- **Probability of Safe to Fly**: Bernoulli Distribution: Probability = 0.899

- **Probability of Go To Trauma When Nearest Hospital Is Not Trauma**: Bernoulli Distribution: Probability = 0.193

Model Verification

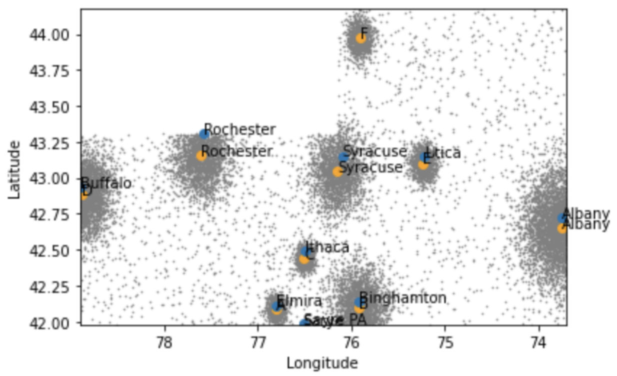
Since a model is complex and includes several steps, in order to make sure the model is correct and trustable, we implement several steps to check model correctness.

Verify One Simulation per Scenario

To ensure each call arrival follows the procedure correctly with different random generated situations. We create several helpful tables to track real time helicopter dynamics flow, for example, we created a table for helicopter capacity remaining information, so that in one scenario, for each call arrival, we can keep track of the real time helicopter remaining number, helicopter chosen information, during which steps was the call canceled, and when would this helicopter return to base. Therefore, for each scenario simulation, we can manually check if the helicopter availability update is correct since this is the most important part in the simulation model and has a large impact on the overall result. After making sure all call arrival flows correctly on logic, we might have a simple intuition check on the overall helicopter service dynamics. For example, we can set the number of helicopters in each base to be 1 or set only one or two bases as helicopters, comparing statistics performance measurement such as average response time, fraction of response to get an insight on whether this model system works intuitively correctly.

Verify Overall Correctness

We use a batch size as 13, so that we are generating 13 of a 2-week length timeline, which can help us to check correctness within each batch and also calculate a more confident performance measurement. After generating simulation data, we compare this simulated data with the data provided, compute several statistics i.e, average response time to convince our simulation mode to predict a plausible helicopter service flow. Finally, we check model credibility by intuitively comparing it to real world situations. For example, from the scene location, hospital location and bases location plot, we slightly alter the number of helicopters in crucial bases, and then compare whether model statistics changes in a correct trend as the it should be in real world, i.e, average response time is supposed to increase as we remove helicopter from busy bases, and decrease if we assign more helicopters near busy scene location and busy hospital location.



- ## Model Analysis

Performance Measures and Objective:

Objective

Our objective is to assess how many helicopters should have and where to input in order to reach the minimum average response time per urgent call. Average response time is a critical performance measurement since it can reflect on average, how long would one urgent call be responded to, that is, the average time from call arrival at HD facility to the time that a helicopter arrives at the scene. We aim to minimize the average response time as low as possible so that our helicopter rescue service is more efficient.

Performance Measurements

Since our problem is a performance related question and can be answered through the help of model statistics, choosing the correct performance measures is essential to performance analysis. For our problem, we choose four performance statistics to compare the scenarios.

Average Response Time: For those cells which have a helicopter arriving at the scene. The response time for a call is the time interval from the moment the call is received at the HD to the moment the helicopter arrives at the scene.

Percentage of Calls Dispatched: The percentage of calls where a helicopter is dispatched.

Response Fraction: Fraction of calls received at the HD where a helicopter arrives at the scene.

Utilization of Helicopters: This measures, on average, how many calls are delivered to hospital by each helicopter per day. It is computed as the number of cases reaching the hospital divided by the product of number of days simulated and number of helicopters.

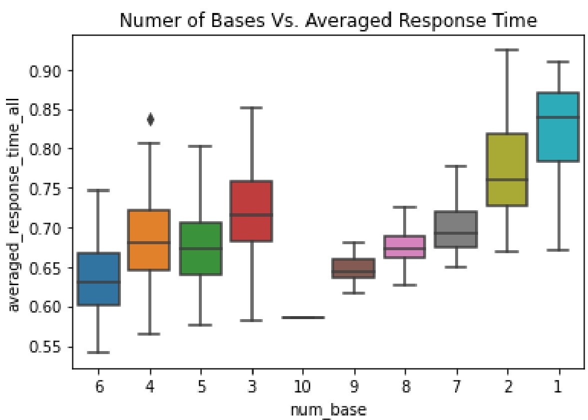
- ## Model Selection:

Optimization of simulation models is always considered as the hardest and trickiest part. Based on the enormous size of combinations of the number of helicopters and its related bases, it is nearly impossible to simulate all the possible combinations. According to this situation, we decide to implement the random search techniques to find the best solution for the simulation model. To be clear, the best solution for our model is not the optimal solution. While in the process of base selection, our solution is to yield better results step by step by comparing the result of the last step and making a statistical decision for next steps.

In the first step, we aim to find the best number of bases that should be installed in the helicopter emergency system. The approach is to set all bases having the same number of helicopters. For example, for choosing 4 bases in 10 bases, there are 210 combinations. For each combination, we set the number of helicopters as 3 for each base. Then, we run our simulation model for these 210 different scenarios and gather all four performance measures. There are 10 choices of choosing the number of bases, and each choice follows the above logic. The following table is the number of bases that should be installed and the related combinations of choosing for different cities.

# Bases	1	2	3	4	5	6	7	8	9	10
# Combinations	10	45	120	210	252	210	120	45	10	1

We combine all the combinations for all the 10 choices of bases' numbers, and get 1023 different scenarios. To compare these scenarios, the following plot is the number of bases choosed with it's related averaged response time.



From the plot, we can see, the minimum averaged response time has a large probability in the cases of the bases 3,4,5,6. Therefore, for the next step, we select the 3 best scenarios with the smallest averaged response time for base 3,4,5,6, and the total scenarios are 12 which is shown in the following table.

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	averaged_response_time_all	num_base
0	2.0	2.0	2.0	0.0	0.0	0.0	2.0	2.0	0.0	2.0	0.541381	6
1	2.0	2.0	0.0	2.0	2.0	0.0	2.0	0.0	0.0	2.0	0.542400	6
2	2.0	2.0	0.0	2.0	0.0	0.0	0.0	2.0	2.0	2.0	0.551211	6
3	3.0	3.0	0.0	3.0	0.0	0.0	3.0	0.0	0.0	0.0	0.564949	4
4	2.0	2.0	2.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.575709	5
5	3.0	3.0	3.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.576297	4
6	0.0	0.0	0.0	0.0	3.0	0.0	3.0	3.0	0.0	3.0	0.578363	4
7	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	0.0	4.0	0.582952	3
8	0.0	0.0	0.0	2.0	0.0	0.0	2.0	2.0	2.0	2.0	0.584026	5
9	2.0	0.0	0.0	2.0	0.0	0.0	2.0	2.0	0.0	2.0	0.591132	5
10	0.0	0.0	0.0	4.0	0.0	0.0	4.0	0.0	0.0	4.0	0.622886	3
11	4.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	4.0	0.623584	3

After the optimization of the total base number and related cities, the next step is finding the best helicopter number of each base. It separates two approaches: one is having no limit of 5 bases and another one is considered the cost of installing the bases so the bases will be limited to only 5.

Not Limited to 5 Approach:

From the first step, we already have the decision of the number of bases and which city should be chosen to install the bases. By choosing the best helicopter number, we design an algorithm for choosing the random number for each decided installed base and make sure for each scenario, the total number of helicopters cannot exceed the number of 12. The algorithm chooses 286 scenarios for a random number of helicopters. We also include the situation that assigns 0 helicopters for some chosen bases to make the whole approach completed. After getting the simulation results from the model, for each number of helicopters from 1 to 12, we select the top 3 best scenarios for the final part analysis.

The following table is the selection in the second step. There are 12 tables for 12 helicopters with three different bases assignments and 12 related boxplot.

```
Total Helicopter = 1
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.66	[0.64, 0.68]
Scenario 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.67	[0.63, 0.7]
Scenario 3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80	[0.77, 0.82]

```
Total Helicopter = 2
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.67	[0.65, 0.7]
Scenario 2	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.66	[0.63, 0.69]
Scenario 3	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.64	[0.62, 0.66]

```
Total Helicopter = 3
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.67	[0.64, 0.69]
Scenario 2	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.65	[0.64, 0.66]
Scenario 3	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.70	[0.68, 0.72]

```
Total Helicopter = 4
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	2.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.66	[0.64, 0.67]
Scenario 2	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.67	[0.66, 0.68]
Scenario 3	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.65	[0.64, 0.67]

```
Total Helicopter = 5
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	1.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	2.0	0.67	[0.66, 0.69]
Scenario 2	2.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.67	[0.66, 0.69]
Scenario 3	1.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0	1.0	0.69	[0.68, 0.7]

```
Total Helicopter = 6
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	0.0	3.0	0.66	[0.65, 0.67]
Scenario 2	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	0.0	3.0	0.67	[0.66, 0.68]
Scenario 3	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	0.0	3.0	0.66	[0.65, 0.68]

```
Total Helicopter = 7
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	1.0	0.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0	1.0	0.67	[0.65, 0.69]
Scenario 2	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.0	0.0	1.0	0.66	[0.65, 0.66]
Scenario 3	1.0	0.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	1.0	0.67	[0.65, 0.68]

```
Total Helicopter = 8
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	1.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.63	[0.62, 0.64]
Scenario 2	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.0	0.0	3.0	0.64	[0.63, 0.65]
Scenario 3	1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	0.67	[0.65, 0.68]

```
Total Helicopter = 9
with three best senarios for different bases assignment
```

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	3.0	2.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.63	[0.62, 0.64]
Scenario 2	3.0	2.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.63	[0.62, 0.64]
Scenario 3	1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	0.62	[0.61, 0.64]

Total Helicopter = 10
with three best senarios for different bases assignment

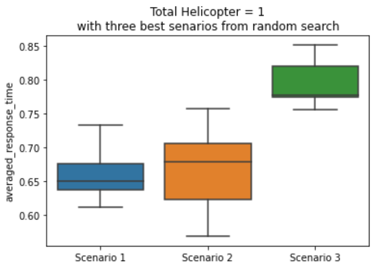
	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	2.0	2.0	2.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.60	[0.59, 0.61]
Scenario 2	1.0	2.0	0.0	1.0	1.0	0.0	4.0	0.0	0.0	1.0	0.60	[0.58, 0.61]
Scenario 3	0.0	0.0	0.0	2.0	0.0	0.0	2.0	2.0	2.0	2.0	0.59	[0.58, 0.6]

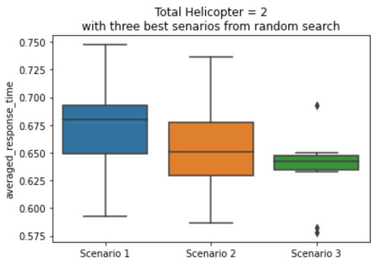
Total Helicopter = 11
with three best senarios for different bases assignment

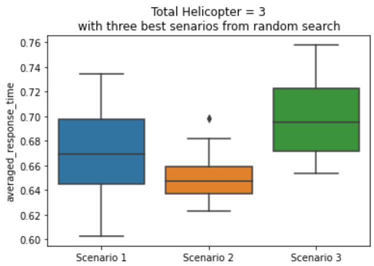
	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	5.0	1.0	1.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.63	[0.62, 0.63]
Scenario 2	2.0	2.0	0.0	3.0	0.0	0.0	4.0	0.0	0.0	0.0	0.59	[0.58, 0.6]
Scenario 3	5.0	1.0	1.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.61	[0.61, 0.62]

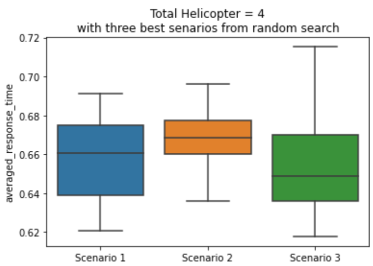
Total Helicopter = 12
with three best senarios for different bases assignment

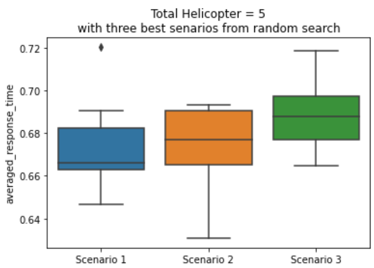
	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	Averaged_response_time	reponse_time_ci
Scenario 1	2.0	2.0	2.0	0.0	0.0	0.0	2.0	2.0	0.0	2.0	0.56	[0.54, 0.57]
Scenario 2	2.0	2.0	0.0	2.0	2.0	0.0	2.0	0.0	0.0	2.0	0.56	[0.55, 0.57]
Scenario 3	2.0	2.0	0.0	2.0	0.0	0.0	0.0	2.0	2.0	2.0	0.57	[0.56, 0.58]

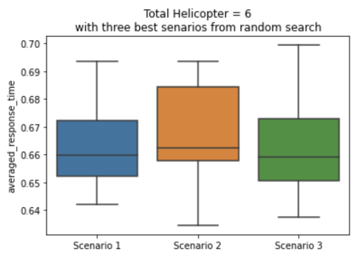


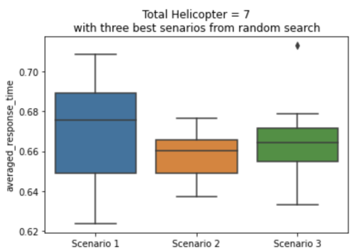


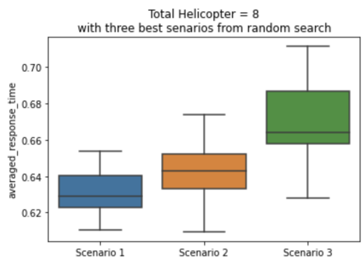


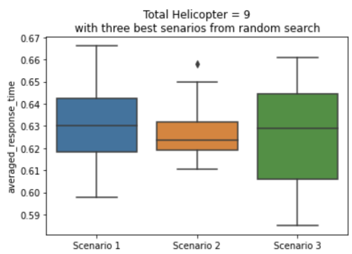


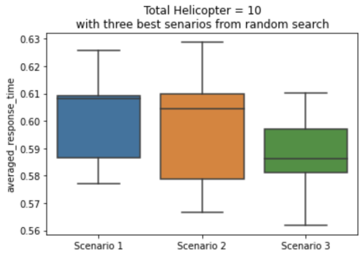


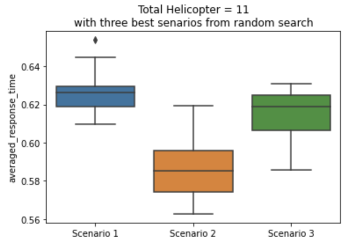


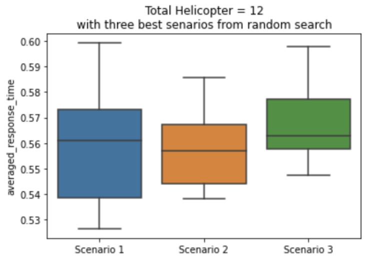












After having all 36 scenarios for 1-12 helicopters in the system, the last step combines all the results and gives the statistically confidence interval for all best selection for four measurements. The following table is our recommendation result.

Heli_num	1	2	3	4	5	6	7	8	9	10	11	12
Buffalo	1	1	3	4	1	0	1	1	3	0	2	2
Rochester	0	0	0	0	0	0	1	1	2	0	2	2
Elmira	0	0	0	0	0	0	1	0	0	0	0	2
Ithaca	0	0	0	0	1	0	1	1	2	2	3	0
Sayre PA	0	0	0	0	0	0	1	1	0	0	0	0
Watertown	0	1	0	0	0	0	0	0	0	0	0	0
Syracuse	0	0	0	0	0	2	1	1	2	2	4	2
Binghamton	0	0	0	0	1	1	0	1	0	2	0	2
Utica	0	0	0	0	0	0	0	1	0	2	0	0
Albany	0	0	0	0	2	3	1	1	0	2	0	2
Averaged_response_time	0.66	0.64	0.65	0.655	0.675	0.66	0.655	0.63	0.63	0.59	0.59	0.555
reponse_time_CI	[0.64, 0.68]	[0.62, 0.66]	[0.64, 0.66]	[0.64, 0.67]	[0.66, 0.69]	[0.65, 0.67]	[0.65, 0.66]	[0.62, 0.64]	[0.62, 0.64]	[0.58, 0.60]	[0.58, 0.60]	[0.54, 0.57]
percentage_of_calls_dispatched	0.115	0.115	0.215	0.235	0.54	0.57	0.69	0.745	0.675	0.745	0.74	0.84
dispatched_CI	[0.11, 0.12]	[0.11, 0.12]	[0.21, 0.22]	[0.22, 0.25]	[0.53, 0.55]	[0.56, 0.58]	[0.69, 0.69]	[0.73, 0.76]	[0.66, 0.69]	[0.73, 0.76]	[0.73, 0.75]	[0.83, 0.85]
response_fraction	0.105	0.105	0.185	0.21	0.475	0.505	0.61	0.67	0.61	0.68	0.67	0.765
response_frac_CI	[0.10, 0.11]	[0.10, 0.11]	[0.18, 0.19]	[0.20, 0.22	[0.47, 0.49]	[0.49, 0.52]	[0.61, 0.61]	[0.66, 0.68]	[0.60, 0.62]	[0.66, 0.69]	[0.66, 0.68]	[0.76, 0.77]
Utlization_of_helicopter	4.295	2.22	2.67	2.16	4.065	3.47	3.625	3.475	2.885	2.88	2.51	2.665
utilization_CI	[4.12, 4.47]	[2.10, 2.34]	[2.54, 2.80]	[2.02, 2.30]	[3.89, 4.24]	[3.36, 3.58]	[3.43, 3.82]	[3.41, 3.54]	[2.75, 3.02]	[2.78, 2.98]	[2.41, 2.61]	[2.53, 2.80]

As we can see from the table result, the total of helicopters is 12 will give the best optimization simulation solution with 6 bases. The smallest averaged response time is around 0.55 and the 95% confidence interval is (0.54,0.57). From the result we can also find the trend of the less number of helicopters, the more averaged response time needed for one scenario. Therefore, the recommendation of no limit of bases is for Buffalo, Rochester, Elmira, Syrancuse, Bingamton, Albany six bases we equally assign 2 helicopters.

Limited to 5 Approach:

If a company is interested in limiting the number of bases to five in order to reduce the fixed base cost, we also use a simulation model to predict how many helicopters and where to put in five bases to reach the minimum average response time. Hence, the first step is to decide which 5 bases are possible to be the best base selection. Second, for each choice of base combination, we implement a random search algorithm to decide how many helicopters in total and how are these helicopters distributed to each base so that to realize a minimum average response time.

Base Selection:

We use combinations to permutate on all possible combinations of 5 bases, choosing from 10, hence, there are 252 combinations of 5 bases in total. Since this is the first generally selected step, we set each base to have 2 helicopters. Then, implement simulation on each combination, and record all four performance measurements.

Number of Helicopter Selection

After deciding base selection, we need to decide how many helicopters to put in each base to achieve minimum average response time. To realize this, we implement a random search algorithm to permute different helicopter number combinations on each base selection. Specifically, for each of two base selections, we use a random search algorithm to permute different helicopter number combinations, and use a simulation model to obtain a simulated prediction result.

• Output Analysis

There are two types of simulation models, terminating and steady-state. It's very clear that the helicopter simulation model has the feature of without any natural stopping condition, thus, it is a steady-state simulate model. The first most challenging part of the steady-state model can be the initial transient problem. The initial segment of simulation is not representative of the stadt-state behavior. In our case, the response time will be small since there is no dispatched helicopter yet. To get rid of this initial transient period, we introduce a warm up period for the simulation model which means the output analysis will not include any information of the warm up period. Given that we have to run the simulation model for a finite period of time, we need to identify the time range for the warm up period. To make a more robust process, we select to run to use 12 weeks as the warm up period.

To get rid of the wate of computation effort, we will not repeat deleting the initial period many times, instead, our simulation model will run a long period which here we choose is half a year. Then we divide it into 12 batches and each batch has a 2 weeks period. By using batch mean technique, we only have one warm up period for each replication.

• Recommendation

Limit to 5 Bases Recommendation

Base selection Recommendation

This is the result of permutation on choose 5 from 10 bases, this table suggests that these three choice of 5 bases are worth of further consideration

base5_df

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	averaged_response_time_all	percentage_of_calls_dispatched_all	response_fraction_all	Utlization_of_helicc
2	2.0	2.0	2.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.5757085758540680	0.7274778134089050	0.6408568871653370	2.496428571
245	0.0	0.0	0.0	2.0	0.0	0.0	2.0	2.0	2.0	2.0	0.5840261783297950	0.7639498585503850	0.6850307287093940	2.971428571
108	2.0	0.0	0.0	2.0	0.0	0.0	2.0	2.0	0.0	2.0	0.5911317082820610	0.7917013725419190	0.7183648402322580	2.960714285
239	0.0	0.0	0.0	2.0	2.0	0.0	2.0	0.0	2.0	2.0	0.5931353243652330	0.7591812186787830	0.681597561628323	
53	2.0	2.0	0.0	0.0	0.0	0.0	2.0	2.0	0.0	2.0	0.5972244032550860	0.8143179761535130	0.7266066391208700	3.18571428
119	2.0	0.0	0.0	0.0	2.0	0.0	2.0	0.0	2.0	2.0	0.5973636519876290	0.8312510850839350	0.7518129248520950	2.93928571
125	2.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	0.6021016010019080	0.8096962220799280	0.7396402249927810	2.98214285

Then, our further step helps select the top two base selections decided as the best 2 base selections: {Buffalo, Rochester, Elmira, Ithaca ,Syracuse} & {Ithaca ,Syracuse, Binghamton, Utica, Albany}

base5_select_compare

	Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	averaged_response_time_all	percentage_of_calls_dispatched_all	response_fraction_all	Utlization_of_helicopter_all
0	3.0	3.0	3.0	3.0	0.0	0.0	3.0	0.0	0.0	0.0	0.5340770608770630	0.7465444413256750	0.685458584641505	1.7642857142857100
1	0.0	0.0	0.0	3.0	0.0	0.0	3.0	3.0	3.0	3.0	0.5474725672863580	0.7737010297076580	0.7032982206967290	1.6857142857142900
2	3.0	0.0	0.0	3.0	0.0	0.0	3.0	3.0	0.0	3.0	0.5537529034852300	0.8597892143443750	0.7825431152477420	2.2547619047619000
2	2.0	2.0	2.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.5757085758540680	0.7274778134089050	0.6408568871653370	2.4964285714285700
245	0.0	0.0	0.0	2.0	0.0	0.0	2.0	2.0	2.0	2.0	0.5840261783297950	0.7639498585503850	0.6850307287093940	2.9714285714285700
108	2.0	0.0	0.0	2.0	0.0	0.0	2.0	2.0	0.0	2.0	0.5911317082820610	0.7917013725419190	0.7183648402322580	2.9607142857142900
2	1.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	1.0	0.6639128373746610	0.5924329635518860	0.5273012153504250	4.2785714285714300
1	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	1.0	1.0	0.6924365888003710	0.5690195133702720	0.491001550445058	3.992857142857140
0	1.0	1.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.700100746773972	0.558679772415591	0.48400647164828700	4.107142857142860

Number of Helicopter Selection Recommendation

This table records all manually random search methods on the number of helicopter selection results, suggesting these top five scenarios have the smallest average response time. Therefore, these five scenarios will be our recommendation for limiting 5 bases selection. Manually random selection tends to give a better model since we use interpretation and intuition to slightly alter the number of helicopters.

base5_recommendation_all

Buffalo	Rochester	Elmira	Ithaca	Sayre PA	Watertown	Syracuse	Binghamton	Utica	Albany	averaged_response_time_all	percentage_of_calls_dispatched_all	response_fraction_all	Utlization_of_helicopter
0	0	0	2	0	0	4	2	2	2	0.5493396645276350	0.7725686119651370	0.7004872648294930	2.2232142857142
2	2	2	3	0	0	3	0	0	0	0.5597142525388630	0.7443044760117930	0.6784898558493470	2.366071428571
0	0	0	2	0	0	3	2	3	2	0.5639923366567700	0.7704216477342340	0.7072459582611330	2.4642857142857
0	0	0	4	0	0	2	2	2	2	0.5685098733742910	0.7799482761794320	0.7122747436817790	2.419642857142
0	0	0	5	0	0	1	2	2	2	0.5687843078632290	0.7964787252845470	0.7289312119201100	2.3779761904761

Conclusions

In the construction of a simulation model on helicopter urgent response service prediction, we correctly build the simulation model through reasonable assumptions and progressly check the correctness of the simulation model through various aspects of evaluation. After confirming the credibility of the model, we use the theoretical combination method and random search to permute a large number of possible different scenarios of simulation, and analyze model performance by four important performance measurements and statistical statistics. In the part of output analysis, we compare measurements and confidence intervals to determine the best scenario and provide recommendations with respect to company requirements. Finally, in the Appendices, Python simulation code and a description of how to implement and replicate the simulation model are provided.

- ## Appendices

For those simulation specialists who want to implement our model, we make many detailed comments in each line of code. Here we give the summary where consists eight main parts:

- **Import libraries**: The python libraries needed are some basic for construct and calculation of numerical data like numpy and pandas. For statistical reference calculation like confidence interval, we apply the scipy library and math library. For data visualization of the output analysis, we use matplotlib and seaborn for plots.
- **Data Initialization**: The simulation model needs some initialization like the longitude and latitude of bases and hospitals. Before we go into the optimization of the objective of the simulation model which is related to optimize the number of the helicopters and bases, we need to give some initial number of helicopters and bases to test the model if correct which is also defined in this part.
- **Data Reference**: There are some distributions and probabilities we need before we start the simulation model, we use the simulated historical data that our professor generates. From historical data, we treated the whole process as a non-stationary poisson process, and then estimated the call arrival rate for each hour in a day. Also, the probability of when to go to trauma but not the closest hospital are also calculated from this dataset. By plotting all call arrival samples, we can get a common sense of the distribution of the call locations which is very crucial for us to conduct the alternative scenarios to find the best solution.
- **Simulation Events:** We already describe the details of the model in the section of model approach and model assumption. This part includes all the events functions.
- **Testing(For One Scenario)**: This part is very crucial for the model verification. By looking for the results that generated from the model, we did some error analysis, then editing the event functions and improving it simultaneously.
- **One Senario's Simulation**: This part's code basically is the same as the testing part. The only difference is we run the period that we need for one simulation and introduce the 13 batches, and use one batch as the initial warm up state.
- **Simulation for Different Scenarios**: In this part we conduct the alternative system of different scenarios. By random search, we design the algorithm of how to randomly choose the number of helicopters and bases.
- **Output Analysis**: This part includes the final choice of some best scenarios and the calculation of the related confidence interval and boxplots for the four measurements.