New York upstate helicopter emergency transportation modeling report

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Executive summary

In our experiment, by allocating at most 12 helicopters among up to 5 helicopter bases, we are going to minimize the average response time of our emergency transportation system and at the same time keep the fixed cost at a low level. The empirical analysis gives us 10 potential base candidates: Buffalo, Rochester, Elmira, Ithaca, Sayre PA, Watertown, Syracuse, Binghamton, Utica, and Albany. During the experiment, we use the data of one year to estimate input parameters, including the arrival rate, cancellation rate, etc. And we build a simulation model that covers 15 months to get the estimated performance of different base-helicopter-allocation combinations. In making the final recommendation, we output the average response time of successfully handled calls to check for the average response time minimization goal, and we also output the total number of helicopters needed and average flight time of each flight to check for the costs in operating such a system. Apart from these two main goals, we also make sure the system is viable by checking the percentage of calls dispatched, response fraction, and utilization of helicopters.

With the goals and methods mentioned above, we finally come up with two alternatives with their average response time approximately equal to 31.8 minutes, and the final decision can be made based on the cost of fuel and individual helicopter:

Plan 1	Plan 2
Total number of helicopters: 12	Total number of helicopters: 11
Buffalo, 1; Sayre_PA, 2; Albany, 2; Syracuse, 4; Rochester, 3	Binghamton, 2; Buffalo, 1; Albany, 3; Syracuse, 3; Rochester, 2

Plan 2 requires one less helicopter than Plan 1, but from our analysis, Plan 2 has 100 hours more than Plan 1 in the total annual flight time of all helicopters, hence Plan 2 may incur higher fuel costs. Given the cost of an individual helicopter (H), the approximate life of one helicopter (L) and the cost of fuel in a 100-hour flight (F), we choose Plan 1 if $H<L*F$, otherwise Plan 2.

Problem description

Helicopter ambulance transportation is efficient but expensive to transport extremely urgent patients. Successful helicopter ambulance transportation relies on multiple conditions: weather condition, availability of helicopter at a certain base, remaining flight mileage considerations, etc.

We build our simulation model according to the following procedure to handle a call for helicopter ambulance transportation. At any time an instance arises, firefighters, who react as the first responder, will assess whether helicopter transportation is needed at the scene. If the patient needs helicopter transportation to get further health aid, a call will be placed to the helicopter dispatch to request a helicopter transportation service. The first step for the HD is to assess the safe condition of sending out helicopters, as extremely windy and raining weather can put both the pilot and patient's safety at risk. After the safety assessment by HD, a helicopter will be dispatched to the scene if there is an available helicopter within the service range of the base. The helicopter will perform preparation before taking off and flying to the scene. Then the helicopter will transfer the patient to the nearest hospital or trauma center depending on the degree of injury and return to its base. If the patient passes away before the helicopter arrives, the call will be canceled and the helicopter will return to its base.

Modeling approach and assumptions

To model the procedure described in the previous section, we make a few assumptions to help us build the simulation model. For our simulation, we have modeled a simplified version of helicopter ambulance transportation. We assume that helicopters do not need to refuel between calls, and crews are always available when the helicopter is ready with no handover time between shifts. In addition, we assume that helicopters need to fly back to base every time before they go on to the next call. In reality, it is usually the opposite since flying to the next destination will be more energy and time-efficient than returning to the base after each call.

With the assumptions above, we model our simulation as follows. We divided our simulation model into two major parts: simulation experiments to confirm our model, and output base location selections, and the number of helicopters at each base using the model. From our analysis of historical data (details of analysis is shown in the following section), we are able to build the model with our parameter of choice, and then we test the model to find out which set of parameters will give us the best performance on the average response time. Using the parameters with the best performance, we are able to find out the base locations and helicopter assignments that minimize the average response time.

Data analysis

From the historical data of helicopter transportation, we explore the distribution of interarrival time between each event and the probability distribution of call locations. As we need to generate call arrivals before we perform the helicopter simulation, we first find the distribution of calls within a day. We compute the rate of call arrivals for each hour without the day-of-week and seasonality effect (Figure 1).

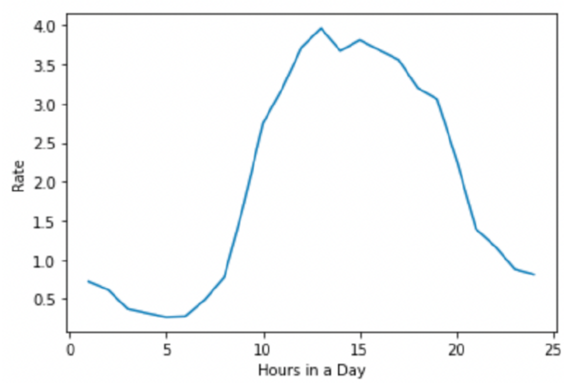

Figure 1: Distribution of call arrivals

We estimate the fraction of unsafe conditions where the helicopter is not dispatched due to unsafe weather conditions. We observe the fraction of calls not handled equals to 0.101±0.005 within a 95% confidence interval.

Then, we analyze the cancellation delay time. Nonzero values in the column “Cancel Delay” represent the time the call is first received and then canceled. Since a call is canceled when the helicopter is on the way to the scene, it can never be canceled when the helicopter arrives. From the maximum likelihood principle, we estimate the rate parameter of the exponential distribution and mean of the cancellation time. The mean time of the cancellation time from historical data is estimated to be 4.87 hours. Thus, we use exponential distribution to estimate the cancellation time with mean 4.87.

For scene time and hospital time, we fit the data to different distributions and compare the statistics. To get a rough comparison in the beginning, we plot the data in a histogram and overlay with distributions that we think are the most likely to fit. In the first attempt, we try distributions Gamma, Beta, Lognormal, Exponential, Pareto, and Weibull. Among all distributions, we observe that Gamma, Beta, Lognormal and Weibull have similar shape to our histogram. To have a more precious estimation of distribution, we perform Q-Q plots of historical data against Gamma, Beta, Lognormal and Weibull distributions to compare the goodness of fit. For both scene time and hospital time, we observe a best fit in Q-Q plots plotted against Gamma distribution (Figure 2 and Figure 3). Then in our later simulation model, we use Gamma distribution with shape parameter 2.95 and scale parameter 0.12 for scene time, and Gamma distribution with shape parameter 2.91 and scale parameter 0.17 for hospital time.

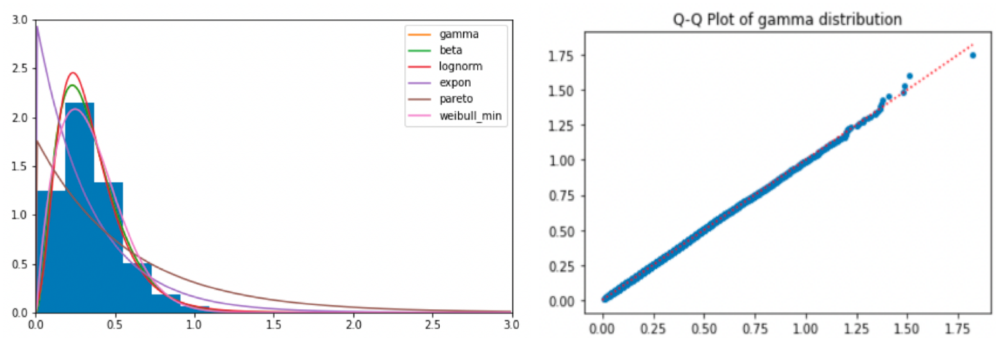

Figure 2: Distribution of scene time and fitted Q-Q plot of Gamma distribution

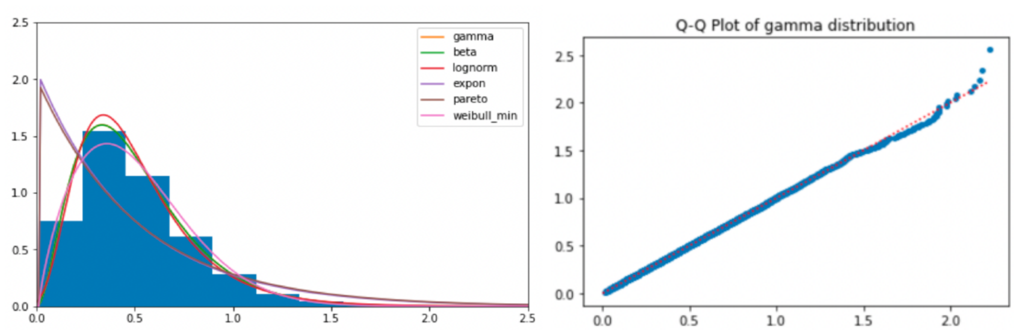

Figure 3: Distribution of hospital time and fitted Q-Q plot of Gamma distribution

The most important part is to estimate the call density from each location in upstate New York to aid our decision on helicopter base locations and assignment of helicopters in each base. We first plot the call location with a scatter plot and we can see some clustering on the plot. This indicates that the clustering area has more calls generated. To have a more concrete visualization, we plot the call density in small squares, with deeper color representing larger call density.

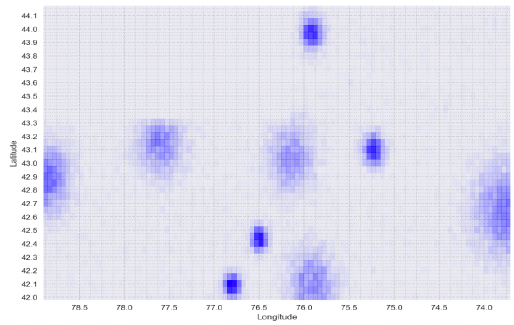

Figure 4: Call density map

Since the helicopter can either transfer the patient to hospital or to the trauma center, we need to analyze the proportion of patients that are transferred to the hospital and to the trauma center. From our analysis of historical destinations of helicopter transportation, helicopters mostly fly to the hospital that is the closest and the remaining fly to a major trauma center to take care of the serious injury. However, there are some exceptions. When patients are closer to one of the four trauma centers than any other hospital regardless of degree of injury, they are transferred to the trauma center automatically. We estimate the portion of patients that are transferred to one of the trauma centers to be 0.193.

For flight preparation time and safety assessment time, there is no clear historical data recorded. With the given time range and recorded most likely and least likely data, we use triangular distribution to approximate the interarrival time. Since the flight preparation time often takes between 5 to 10 minutes, we choose to take the average time 7.5 minutes as the most likely value. Similarly, the safety assessment time is modeled with triangular distribution with the most likely value 7 and ranges from 5 to 10 minutes.

Call Arrival	Non Stationary Poisson
Scene Time	Gamma(2.95, 0.12)
Hospital Time	Gamma(2.91, 0.17)
Cancellation Time	Exponential(4.87)
Safety Assessment Time	Triangular(5, 7, 10)
Flight Preparation Time	Triangular(5, 7.5, 10)
Probability of Unsafe Condition	10.1%
Probability of Transferring to Trauma Center	19.3%

Table 1: Summary of Parameters

Model verification

Details of the logic of our model will be provided in the Model analysis section. Here we only discuss the results of the model under some simple cases for verification.

To make sure our model works and provides a reasonable result, we set the initial parameters with a simulation time length of 1 month with 1-day warm-up and limited the number of helicopters to be 1 and the total number of bases to be 3 (since in our model we decide to have 3 fixed bases, which received the most calls in historical data and are trauma centers at the same time). Here we only have 5 replications.

We expect the helicopter to be assigned in Syracuse since it is the trauma center closest to the middle of upstate New York.

Output is given below.

	Helicopter Bases	Number of Helicopters	Average Response Time
0	[Albany, Syracuse, Rochester]	[0, 1, 0]	48.693884

This agrees with our expectations.

Then we tried another case where we looked for 5 bases with 12 helicopters. For simplicity, we limited the simulation time period to be 1 day without warm-up. We expect there is no extreme assignment that the helicopters should be assigned almost evenly among the 5 bases from our best pick.

Output is given below.

	Helicopter Bases	Number of Helicopters	Average Response Time
18	[Binghamton, Buffalo, Albany, Syracuse, Roches...	[3, 2, 2, 3, 2]	30.878034

It gives our best pick and it agrees with our expectations.

As mentioned above we believe our model works well and provides reasonable results.

Below we compared the performance measures of our final global optimal result from full time-length simulation with relative statistics of original data and found our result convincing.

Performance Measures	**Mean Results**	**95% Confidence Interval**
Average Time Response	31.85 (min.)	[31.76, 31.94]

Percentage of Calls Dispatched	86.15%	[86.04%, 86.27%]
Response Fraction	0.7906	[0.7888, 0.7924]
Utilization of Helicopters	2.89	[2.87, 2.91]

Table 2: Optimal Result's Performance Measures

Performance Measures	**Results from Data**
Average Time Response	Cancellation Time censored at 30 min.
Percentage of Calls Dispatched	81.20%
Response Fraction	0.7328
Utilization of Helicopters	3.11

Table 3: Statistics from Original Data

Comparing the tables above, we can see the average time response of our model result is very close to our assumption in data that cancellation time will not exceed 30 minutes, based on which we fit the cancellation time distribution. This assumption is equal to having a constant time response of 30 minutes.

For the percentage of calls dispatched, response fraction, and utilization of helicopters, our model results are also close to data, but with better performance. With our optimization, we get a larger percentage of calls dispatched and a higher response fraction, even with lower utilization of helicopters, which means our model is working reasonably and efficiently to distribute the helicopters and make decisions on base locations.

Model analysis

From the sample data we observe Albany, Syracuse and Rochester are the top 3 busiest among all of the hospitals, and the frequencies that patients are transferred to these three locations are strictly much higher than to the rest .

Location	**Number of Visits in the Sample Data**
Albany	2431
Rochester	2035
Syracuse	2020
Buffalo	1329
Binghamton	1163
Utica	861
Watertown	805
Ithaca	630
Elmira	622
Sayre_PA	558

Table 4: Base Choice Analysis

With this observation, we decide to run separate tests for the number of bases equals 3, 4, and 5, and have these three busiest locations always in our base choice to see whether adding another one or two bases will significantly decrease the average response time of the system.

For each round, we are going to allocate H helicopters over N bases. We allocate the helicopters one by one, by checking the utilization of a potential new helicopter over N bases and adding this new helicopter to the place where it will attain the highest utilization.

As our goal is to minimize the average response time, we also considered using response time as the standard to allocate helicopters, but this criterion does not perform as great as utilization. With utilization as the standard, we can reduce the average response time to below 40 minutes, while response time functioning as the criterion will always lead to more-than-50-minute results.

The graph above shows our simulation results in terms of average response time. Because the number we got is so big from the 12-helicopter-3-base scenario, we did not test fewer helicopters with 3 bases.

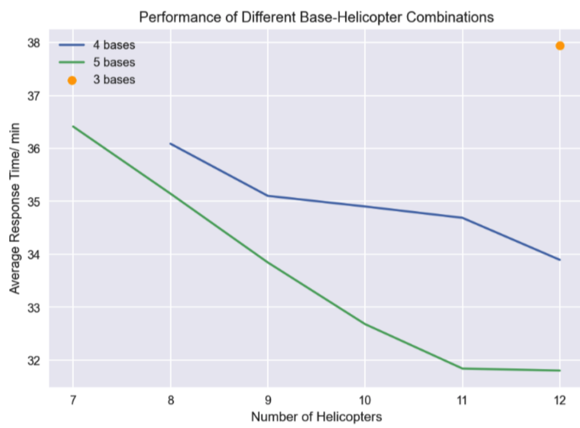

Figure 5: Performance of Different Base-Helicopter Combinations

In this analysis, we only focus on the 4-base and 5-base cases. We can check the sensitivity of the average response time to the number of helicopters by observing the slope of each line, and to the number of bases by the vertical gap between the two lines. And our observations are as follows:

1. Horizontally, in the 5-base situation, though we attain the lowest average response time at H=12, the marginal efficiency brought by the 12th helicopter is only 0.03-minute improvement and thus the lowest among all the helicopters.
2. Horizontally, in the 4-base situation, we attain the lowest average response time at H=12, and as we can see from the changes in the slope, the 12th helicopter reduces the average response time much more (0.8 minutes) compared to the previous two (0.3 minute and 02 minutes, respectively).
3. Vertically, between the two lines, the largest gap lies at H = 11, which means with 11 helicopters, the 5-base strategy is strictly overperforming the 4-base one (by 0.9 minutes).

Observations above can give the decision-makers some hints about the efficiency of different allocation of helicopters with the average response time taken into consideration. To put the strategy into production, except for the expenses on helicopter purchases, we also need to consider the mileage of the helicopters, as the fuel costs cannot be ignored in helicopter operations.

The minimum average response time is about 31.8 minutes, and if there are some chances that we can save on the fuel, we assume a 2.2-minute indifference zone on average response time, so we collect all combinations with their average response time below 34 minutes and check the average mileage traveled for each dispatched call. As we assume the helicopters are always traveling at a constant speed, we can compare helicopters' average flight time instead.

The statistics table below ranks the combinations according to the average response time. The top combination has the minimum average response time as well as the lowest average flight time, however, it requires 12 helicopters. In this case, we want to see whether some combinations only require 11 helicopters but also have an approximately great performance. And the third combination is exactly what we are looking for. The average response time of this combination is only 0.05 minutes behind the optimal result, and the average flight time is 0.3 minutes/call higher than the optimal result.

	Bases Selection	Heli Allocation	Average Response Time	CI(ART)	Percentage of Calls Dispatched	CI(PCD)	Response Fraction	CI(RF)	Utilization of Helis	CI(UH)	Average Flight Time	CI(AFT)
17	[Buffalo, Sayre_PA, Albany, Syracuse, Rochester]	[1, 2, 2, 4, 3]	31.810	[31.793, 31.827]	0.855	[0.855, 0.856]	0.786	[0.785, 0.787]	2.666	[2.658, 2.675]	26.528	[26.506, 26.551]
16	[Ithaca, Buffalo, Albany, Syracuse, Rochester]	[2, 2, 3, 2, 3]	31.839	[31.815, 31.863]	0.865	[0.865, 0.866]	0.794	[0.794, 0.795]	2.680	[2.674, 2.687]	26.769	[26.729, 26.808]
9	[Binghamton, Buffalo, Albany, Syracuse, Roches...	[2, 1, 3, 3, 2]	31.860	[31.829, 31.891]	0.859	[0.859, 0.86]	0.789	[0.789, 0.79]	2.870	[2.862, 2.879]	26.734	[26.691, 26.777]
19	[Ithaca, Watertown, Albany, Syracuse, Rochester]	[2, 1, 3, 3, 3]	32.034	[32.01, 32.058]	0.863	[0.863, 0.864]	0.793	[0.792, 0.793]	2.648	[2.641, 2.654]	26.830	[26.796, 26.864]
18	[Watertown, Binghamton, Albany, Syracuse, Roch...	[1, 2, 2, 4, 3]	32.135	[32.11, 32.159]	0.858	[0.857, 0.858]	0.787	[0.786, 0.787]	2.650	[2.642, 2.658]	26.955	[26.919, 26.991]
20	[Elmira, Buffalo, Albany, Syracuse, Rochester]	[2, 1, 3, 3, 3]	32.264	[32.227, 32.301]	0.867	[0.866, 0.867]	0.794	[0.793, 0.794]	2.658	[2.65, 2.665]	27.118	[27.068, 27.169]
11	[Ithaca, Watertown, Albany, Syracuse, Rochester]	[2, 2, 2, 2, 3]	32.453	[32.425, 32.482]	0.847	[0.846, 0.848]	0.776	[0.775, 0.776]	2.791	[2.781, 2.801]	27.211	[27.174, 27.247]
10	[Watertown, Binghamton, Albany, Syracuse, Roch...	[2, 2, 2, 2, 3]	32.624	[32.599, 32.65]	0.852	[0.851, 0.852]	0.779	[0.779, 0.78]	2.854	[2.846, 2.863]	27.509	[27.465, 27.553]
23	[Utica, Binghamton, Albany, Syracuse, Rochester]	[3, 2, 2, 3, 2]	32.642	[32.612, 32.672]	0.851	[0.85, 0.851]	0.778	[0.777, 0.779]	2.621	[2.612, 2.629]	27.450	[27.41, 27.49]
4	[Binghamton, Buffalo, Albany, Syracuse, Roches...	[3, 2, 2, 2, 1]	32.696	[32.668, 32.723]	0.841	[0.84, 0.841]	0.770	[0.77, 0.771]	3.089	[3.077, 3.101]	27.619	[27.578, 27.66]
13	[Elmira, Buffalo, Albany, Syracuse, Rochester]	[2, 2, 3, 2, 2]	32.701	[32.672, 32.73]	0.856	[0.855, 0.857]	0.785	[0.784, 0.785]	2.883	[2.874, 2.892]	27.681	[27.65, 27.712]
21	[Ithaca, Binghamton, Albany, Syracuse, Rochester]	[2, 2, 3, 2, 3]	32.720	[32.689, 32.75]	0.864	[0.864, 0.865]	0.792	[0.791, 0.792]	2.660	[2.652, 2.668]	27.537	[27.503, 27.571]
22	[Watertown, Elmira, Albany, Syracuse, Rochester]	[2, 2, 3, 3, 2]	32.722	[32.684, 32.759]	0.855	[0.854, 0.855]	0.782	[0.781, 0.782]	2.604	[2.597, 2.611]	27.504	[27.465, 27.544]
15	[Watertown, Sayre_PA, Albany, Syracuse, Roches...	[2, 2, 2, 2, 3]	32.858	[32.836, 32.881]	0.847	[0.847, 0.848]	0.775	[0.775, 0.776]	2.844	[2.837, 2.852]	27.666	[27.638, 27.694]
12	[Watertown, Buffalo, Albany, Syracuse, Rochester]	[1, 2, 2, 4, 2]	32.983	[32.959, 33.006]	0.851	[0.851, 0.851]	0.778	[0.777, 0.778]	2.838	[2.83, 2.846]	28.056	[28.031, 28.082]
14	[Ithaca, Buffalo, Albany, Syracuse, Rochester]	[1, 1, 2, 5, 2]	33.002	[32.962, 33.042]	0.851	[0.851, 0.852]	0.779	[0.779, 0.78]	2.868	[2.858, 2.879]	27.827	[27.779, 27.875]
5	[Elmira, Buffalo, Albany, Syracuse, Rochester]	[2, 1, 2, 3, 2]	33.099	[33.07, 33.127]	0.846	[0.845, 0.846]	0.772	[0.772, 0.773]	3.127	[3.116, 3.138]	27.951	[27.915, 27.987]
6	[Buffalo, Sayre_PA, Albany, Syracuse, Rochester]	[1, 1, 2, 4, 2]	33.414	[33.387, 33.44]	0.845	[0.845, 0.846]	0.772	[0.771, 0.773]	3.110	[3.1, 3.119]	28.263	[28.236, 28.291]
24	[Ithaca, Sayre_PA, Albany, Syracuse, Rochester]	[2, 1, 3, 3, 3]	33.452	[33.425, 33.48]	0.862	[0.862, 0.863]	0.788	[0.787, 0.788]	2.671	[2.662, 2.681]	28.166	[28.133, 28.198]
7	[Watertown, Sayre_PA, Albany, Syracuse, Roches...	[1, 2, 2, 2, 3]	33.693	[33.653, 33.732]	0.842	[0.841, 0.843]	0.767	[0.766, 0.768]	3.092	[3.083, 3.101]	28.553	[28.505, 28.601]
0	[Ithaca, Albany, Syracuse, Rochester]	[3, 3, 3, 3]	33.906	[33.88, 33.931]	0.864	[0.863, 0.864]	0.787	[0.787, 0.788]	2.633	[2.627, 2.64]	28.672	[28.642, 28.702]
2	[Binghamton, Buffalo, Albany, Syracuse, Roches...	[1, 1, 2, 3, 2]	33.925	[33.882, 33.969]	0.836	[0.835, 0.836]	0.762	[0.761, 0.763]	3.398	[3.385, 3.411]	28.838	[28.787, 28.889]

Table 5: Statistics for Combinations with Average Response Time < 34 minutes

Conclusion

With our analysis above, there are two candidates for the final consideration:

To make a specific decision, we need to estimate the total cost in the long term. From the simulation, we get 16994 calls within one year. Assume we use the model Eurocopter/Airbus AS350 B2 for helicopters, which on average burns 47 gallons of fuel per hour. And we approximate the cost of jet fuel by $4.5/gallon.

1) 5 bases with 12 helicopters:

Locations	Helicopter Allocation	Average Response Time/min	Percentage of Calls Dispatched	Response Fraction	Utilization of Helicopters	Average Flight Time/min
Buffalo	1	31.810 [31.793,31.827]	0.855 [0.855,0.856]	0.786 [0.785,0.787]	2.666 [2.658,2.675]	26.528 [26.506,26.551]
Sayre_PA	2					
Albany	2					
Syracuse	4					
Rochester	3					

Total flight time of all helicopters in one year = 6424.14 hours

2) 5 bases with 11 helicopters:

Locations	Helicopter Allocation	Average Response Time/min	Percentage of Calls Dispatched	Response Fraction	Utilization of Helicopters	Average Flight Time/min
Binghamt	2	31.860	0.859	0.789	2.870	26.734

on		[31.829,31.891]	[0.859,0.86]	[0.789,0.79]	[2.862,2.79]	[26.691,26.777]
Buffalo	1					
Albany	3					
Syracuse	3					
Rochester	2					

Total flight time of all helicopters in one year = 6504.31 hours

So the gap in the fuel cost between these two strategies is around $3600/year. With this number in mind, if the price of a helicopter is high enough to overwhelm the extra cost in fuel, we would recommend the second strategy with 5 bases and 11 helicopters. Otherwise, the first strategy will be better. And of course, the calculation represented in this part is only a rough scratch, the fuel consumption and fuel price can be different depending on the company's choice. Overall, if the cost of fuel is high, maybe the first strategy will help the company profit more, and vice versa.

Appendix

The model that we use to select helicopter bases and determine the distribution of helicopters among these bases can be separated into two parts. The first part of the model is focused on the simulation process. In this part, our goal is to use simulation experiments to derive the expected average response time when bases are chosen and the number of helicopters in each base is given, and also output other key performance measures at the same time. The second part of the model aims at using the output of the previous part to find out the optimal solution of helicopter bases and distributions, which minimizes the expected average response time. We analyze the historical data to predetermine some of the bases so that we can narrow down our choices, and then enumerate all possible combinations and distributions of helicopter bases and the number of helicopters in each base to observe the minimizer of average response time.

To obtain the average response time of each scenario, where a combination of bases and the corresponding helicopter distribution among these bases are fixed, we simulate the process of calls arriving at the HD.

A few assumptions are made based on our analysis of the historical data.

The arrival of calls follows non-stationary Poisson distribution, where the arrival rate differs within each different hour of the day. In each hour, the arrival rate is constant and is listed in the chart below.

Hour of the Day	Arrival Rate	Hour of the Day	Arrival Rate
0	0.722527473	12	3.96428571
1	0.618131868	13	3.673076923
2	0.373626374	14	3.813186813
3	0.318681319	15	3.684065934
4	0.266483516	16	3.56043956
5	0.277472527	17	3.197802198

6	0.489010989	18	3.054945055
7	0.777472527	19	2.28021978
8	1.695054945	20	1.395604396
9	2.747252747	21	1.1703296
10	3.192307692	22	0.881868132
11	3.71978022	23	0.813186813

The cancellation time follows an exponential distribution with a mean of 292 minutes. The safety assessment time follows a triangular distribution with a minimum of 5 minutes, a maximum of 10 minutes, and most likely 7 minutes. With 10.1% probability, it is unsafe to fly and the call is abandoned. The flight preparation time follows a triangular distribution with a minimum of 5 minutes, a maximum of 10 minutes, and most likely 7.5 minutes. The time spent at the scene follows Gamma distribution with A equals 2.95 and scale equals 0.12. The time spent at the hospital follows Gamma distribution with A equals 2.91 and scale equals 0.17. Our run length is 31 days with a one-day warm-up period. This warm-up period is determined by our first few experiments, where we discovered that the average response time converges to its steady-state after about 1 day.

The workflow of our model runs like this. When a call arrives at the HD, a cancellation time is generated immediately. With each ongoing step, we compare the future cancellation point with the current time. If cancellation happens before the assigned helicopter takes off, the status of the helicopter is reset to available at the point of cancellation and the call is abandoned. If cancellation happens between take-off and arriving at the scene, the status of the helicopter is reset to available after it returns to base and the call is abandoned. Otherwise, the cancellation cannot happen. After arrival, safety assessment time is generated and added to the current time. A variable uniformly distributed on (0,1) is generated and compared to the unsafe rate to determine whether it is safe to fly. We use the resampling method to generate the call location from the historical data, and then determine whether there are helicopters available within the 180 km range. If it is safe, we search for the closest available helicopter at that time and generate the time it needs to prepare, arrive at the scene, and spend at the scene, then add it to the current time. Next, we decide which hospital to go to by using a uniform variable again, and calculate the time needed for transportation and return to base, and current time leaps forward. When the helicopter returned to base, this call was completed.

The python implementation of the simulation experiment part of our model consists of a class and three main functions.

We first generate a class of helicopters, assign their ID, base, and next available time. The initial next available time is set to 0.

The first function is the ***call*** function, which defines the activities of each call and is the core of our simulation. In this part, we reconstruct our workflow from the previous part and record the responses we need. One tricky aspect of our code requires special attention. Instead of setting up a Boolean property of availability for each helicopter, we create the next available time. This is because, for each call, the call function has to be finished before the next call executes the call function. Therefore, changing the status of helicopters by True or False is not going to affect the next call, since all helicopters assigned must be reset to available after the termination of each call. Therefore, we use the next available time to solve this problem. When a helicopter is assigned to a call, the next available time is set to infinity. If the call is canceled, the next available time is reset to the cancellation point or the time it returns to the base, depending on when the cancellation happened. When a call is successfully transported, the next available time is reset to the time the helicopter returns to the base. In this way, for each new call waiting to be assigned a helicopter, we can compare the current time with the next available time of each helicopter. If the current time is larger, it means this helicopter is available.

The second function is the ***simulated*** function. In this part, we generate calls according to our assumptions and run *the* ***call*** function on each call. Then we calculate the mean response time for each call satisfying the performance criteria and obtain the average response time. We also keep records of other performance measures which we are interested in.

The third function is the ***replicate*** function. We use the Replication_Deletion method to wipe out the initial transient effects, by running 15 replications and setting the warm-up period to 1 day. We then calculate the mean of the average response time to derive the final average response time for the given combination of bases and helicopter distribution. Other performance measures also proceed in this way.

After we run the simulation with the defined function ***Call***, we define ***hospPick*** to determine the best location of each base and additional utility that an additional helicopter will bring to the specific base, and ***replicate*** to choose the best combination of bases and number of helicopters at the base according to our designed metrics. Within the ***replicate*** function, we iterate through the number of bases and calculate and store average response time, percentage of handled calls, response fraction and utilization of helicopters for each iteration in four separate lists. For our algorithm to pick location for hospital ***hospPick***, we observe there are three trauma centers with the most number of receiving patients and this indicates we have to include these three centers as our base to maximize our performance. Therefore, to make our algorithm more computationally efficient, we fix these three trauma centers in our choice of bases. Since we are comparing based on the performance of helicopters, we calculate the utilization of a single helicopter at each one of the bases, and assign the helicopter to the base that has the largest utilization. With helicopter assignment, we can choose the remaining two bases by iterating through the combination of the remaining seven locations and number of helicopters at the base. Then we choose based on the performance measure, prioritizing the average response time.

By the end of the first part of our model, we would be able to simulate the average response time, percentage of calls dispatched, response fraction, and utilization of helicopters.