Business Simulation A4 Report

By Wesley van der Horst and Nando Beijaard

This report aims to find the optimal placement of 20 ambulances in a certain region. This region consists of seven subregions, a single middle region 0 and 6 regions which surround the middle region. The middle region contains a fictional hospital whereas the 6 surrounding regions all have “docking stations” in the middle of each region, where the region bound ambulances come back after completing an accident. All regions have a hexagonal shape and fit inside a circle with a diameter of 10 kilometers. The placement of 20 ambulances is optimised by using the number of emergency calls that must wait 15 minutes before an ambulance arrives. This total wait time is calculated by taking the time before an ambulance responds to the call and the time it takes for this ambulance to arrive at the accident.

Initially, we consider all regions to have the same exponentially distributed arrival rate of 1/15 for the accidents. The locations of these accidents are chosen uniformly random within the respective region it occurs by generating a random coordinate within a rectangle surrounding the hexagonal region and checking whether it is inside the region, if not a new random coordinate is created.

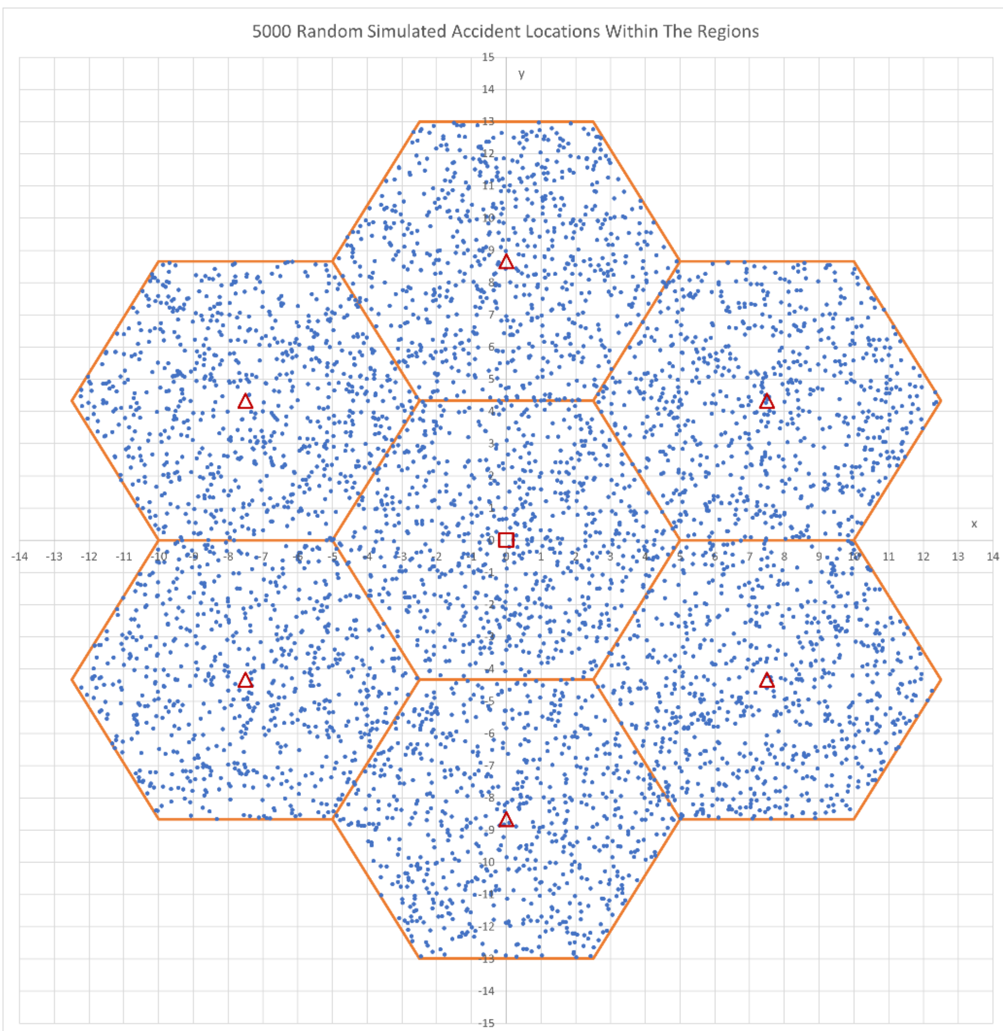

Figure 1: Map of 5,000 randomly generated accident locations.

As you can see in figure 1, each hexagon represents the aforementioned regions, the hospital is represented by the red square at coordinate (0,0). Each regions docking station coordinates are calculated from this point and are represented by the red triangles. The whole system is represented in the same coordinate system (instead of a coordinate system per region). Initially, we consider only the situation where each ambulance can only respond to emergency calls in their respective regions. Later, we also consider the situation where idle ambulances respond to nearby calls from neighboring regions that are placed in the queue as well as different arrival rates.

The travel distance for ambulances is calculated by using the Euclidean distance from the docking station to the coordinates of the accident in kilometers. The travel time is then calculated by assuming the ambulances speed is 1 kilometer per minute. This travel time is vital for the calculation of the waiting time of the emergency caller. The waiting time of an accident is the time until the arrival of an ambulance, thus the travel time and the time between the arrival of the accident and departure of the ambulance from its docking station. These times are, however, not the only times that have to be calculated since the ambulance can only be used after it arrives back at the docking station after dropping the patient off at the hospital. The time between arrival at the place of the accident and the arrival at the docking station consists of the travel time between the accident and the hospital (at 0,0) and the travel time between the hospital and the docking station. The service time considered in this report is the time from arriving at the accident until arrival back at the docking station. Ambulances must first return to their docking station after responding to an emergency, this is done for replenishment. We assume that the replenishment happens instantaneously. If, after arrival at the docking station, there is no emergency call in the queue; the ambulance goes into idle mode.

Standard model

The optimal solution of ambulance placement is found using local search, to keep the simulation time manageable we have chosen to cap the maximum ambulances at the outer regions at 5, while the maximum number of ambulances at the hospital is 14 as well as a minimum of 1 ambulance at each dock. These boundaries result in a total of 10,374 different solutions of which the total number of ambulances is 20. Due to the total amount of ambulances having to be 20 and considering every possibility of one of the seven regions having +1 or -1 ambulances, each solution had at most 43 neighbors. A budget of 20,000 simulations was chosen to still have a reasonable simulation time which could take several minutes while having enough simulations to be able to run over large parts of the solutions within the list. The value which the local search decides the best value is the percentage of calls that had to wait less than 15 minutes. The local search found the following three solutions to be the three best solutions within the constraints from top to bottom ranking 1, 2, 3 respectively:

Region	0	1	2	3	4	5	6
# of ambulances	1	3	4	3	3	3	3

Region	0	1	2	3	4	5	6
# of ambulances	1	3	3	3	3	3	4

Region	0	1	2	3	4	5	6
# of ambulances	1	3	3	3	4	3	3

This result is not very surprising, the ambulances can only respond to calls in their respective region and all arrival rates are equal, so you would want to have as many ambulances per region as possible, so all regions want to have 5 ambulances. Due to the maximum number of ambulances being 20 this will not be possible. Our expectation was for solution (2,3,3,3,3,3,3) to come out on top since all regions would want the most ambulances per region as possible and less due to the service times for the middle region with the hospital. This region has the lowest average travel time between accident and hospital. Moreover, this region has no travel time between the hospital and docking station. Thus, ambulances are available sooner than the ambulances in the outer regions and thus the waiting time for callers will be smaller. The results of this solution however were very close to the top 3, with an only about 0.5% lower average. It does make sense however that these solutions are performing so well but purely due to randomness of the accident arrivals one of them comes out on top since the solutions are very similar and having either 1 or 2 ambulances based at the hospital might not be as significant as expected. The optimal solution leads to the following statistics:

Solution (1,3,4,3,3,3,3)	# Observations	Min	Max	Average	St. Dev.
Waiting time	4736	0.085	23.377	3.785	2.646
Service time	4736	3.5E-4	24.439	13.494	5.711
% Arrival within target	4736	0.000	1.000	0.988	0.111

So, 98.8% of the emergency callers get help within 15 minutes after they have called in their emergency. This would mean between about 55 to 59 people (depending on the unrounded average) do not get help within the target time.

Allow ambulances to work in neighboring regions

Next, we will find the optimal solution when ambulances are allowed to help emergency calls that are in the queue of neighboring regions. Upon the arrival of an accident when the region it is in has no available ambulances the nearest available ambulance will be sent if there is one, as well as when an ambulance returns to its base location and there are no waiting accidents within its own region it checks for the nearest waiting accident and drives there if there is one.

We consider our previously mentioned expected best performing solution. Since region zero has the most neighbors and the least travel time between responding to an accident and being able to handle a new accident, thus region zero does not need a lot of ambulances. The solution produces the following statistics:

Solution (2,3,3,3,3,3,3)	# Observations	Min	Max	Average	St. Dev.
Waiting time	4592	0.035	18.675	3.523	1.808
Service time	4592	6.7E-4	27.145	12.875	5.766
Waiting time arrival within target	4592	0.000	1.000	1.000	0.021

The table above tells that 100% of the callers get help within 15 minutes, however, one might notice that the maximum waiting time is still 18.675 which is higher than the considered target time of 15. This could be explained by just a couple of observations being above the target time which would make the percentage around 0.9995 and result in 1.000 when rounded to 3 decimals. Comparing this with the percentage of the situation where ambulances can only provide help within their own region the percentage of people that get help within 15 minutes is significantly higher. Allowing ambulances to help in other regions does improve performance in general also for solutions that previously were not performing very well. So, our recommendation would be to allow ambulances to work in neighboring regions to increase overall performance.

One might even consider placements such as (14,1,1,1,1,1,1) which results in the following:

Solution (14,1,1,1,1,1,1)	# Observations	Min	Max	Average	St. Dev.
Waiting time	4720	0.095	13.182	6.065	3.242
Service time	4720	1.1E-3	23.141	6.690	6.903
Waiting time arrival within target	4720	1.000	1.000	1.000	0.000

Or even (20,0,0,0,0,0,0) not even needing docking stations.

Solution (20,0,0,0,0,0,0)	# Observations	Min	Max	Average	St. Dev.
Waiting time	4678	0.164	13.193	8.052	3.00
Service time	4678	1.1E-4	10.678	1.006	1.021
Waiting time arrival within target	4678	1.000	1.000	1.000	0.000

Both of these still have a target achievement of 100% and greatly reduce the service times which could be a great cost reduction depending on location usage costs as well as ambulance usage, especially the second one since the docking stations would not be necessary, and service times are minimal. However, both of these also have a significant increase in average waiting times, where ethics and morality come into play.

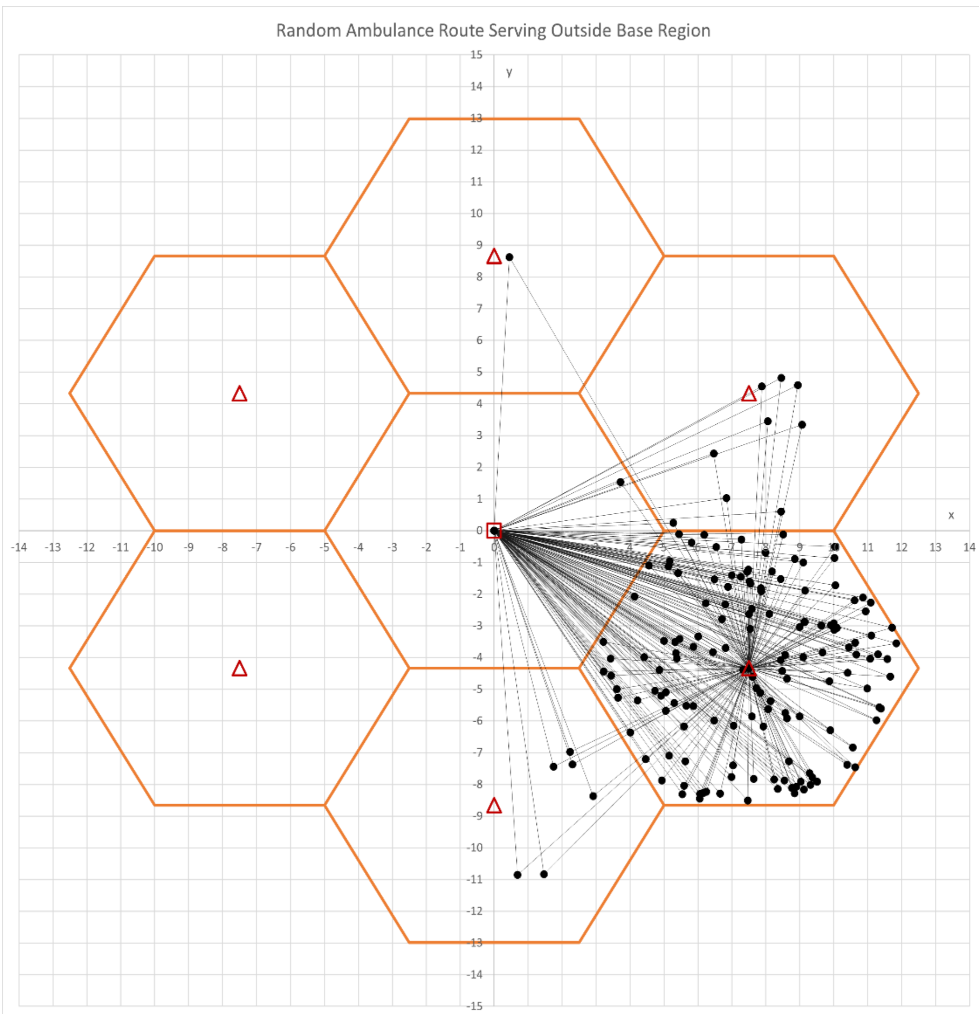

Figure 2: Handled accident route of a random ambulance over one simulation.

Different arrival rates

Next, we will check whether the optimal solution changes when different regions have different arrival rates. Purely theoretically one would assume that if the arrival rate of accidents in a single region increases the number of ambulances should also increase depending on the factor of increase of course. The arrival rates are changed by us for testing purposes from:

{1/15, 1/15, 1/15, 1/15, 1/15, 1/15, 1/15}

To:

{3/15, 1/15, 1/15, 1/15, 2/15, 1/30, 1/15}

So, the arrival rates for regions 1, 4 and 5 are higher/lower. The optimal solution for the situation where ambulances cannot help in other regions and its statistics are:

Region	0	1	2	3	4	5	6
# of ambulances	2	3	3	4	3	2	3

	# Observations	Min	Max	Average	St. Dev.
Waiting time	6309	0.036	37.732	4.235	3.704
Service time	6309	1.6E-5	24.422	11.091	7.125
% Arrival within target	6309	0.000	1.000	0.972	0.166

The optimal solution of the standard model produces a rate of arrival within the target of 97.2% with these arrival rates, whereas the other solutions previously mentioned in this report drop a lot regarding their hitting percentages. This is a great performance considering there are also nearly 2,000 more accidents being served and the percentage is not significantly lower than with the old rates. The new optimal solution generates more ambulances on the rates we have increased while lowering the number of ambulances in the regions with lower rates. So, changing the arrival rates do influence the answer for the optimal solution.

The situation where ambulances are allowed to help other regions gives the following statistics for the previously mentioned solution:

Solution (2,3,3,3,4,2,3)	# Observations	Min	Max	Average	St. Dev.
Waiting time	6432	0.061	18.286	3.750	2.067
Service time	6432	6.7E-4	24.117	10.422	6.837
Arrival within target	6432	0.000	1.000	0.999	0.037

With an average of 99.9%, nearly all accidents are reached within the target time for this solution with a good average waiting time. However, when considering again solution as (8,2,2,2,2,2,2) or (14,1,1,1,1,1,1), these do perform better in this scenario with an average of 100%. However, the same situation with sacrificing average waiting time for service time and a slight improvement of target hitting comes to mind.

Solution (8,2,2,2,2,2,2)	# Observations	Min	Max	Average	St. Dev.
Waiting time	6496	0.086	15.971	4.282	2.534
Service time	6496	3.7E-4	22.942	8.610	7.141
Arrival within target	6496	0.000	1.000	1.000	0.018