The Ninth International Symposium on Operations Research and Its Applications (ISORA'10)
Chengdu-Jiuzhaigou, China, August 19–23, 2010

Effect of Ambulance Station Locations and Number of Ambulances to the Quality of the Emergency Service

Keisuke Inakawa[1,*] Takehiro Furuta[2] Atsuo Suzuki[3]

[1]Department of Management Science and Engineering,
Akita Prefectural University, Yurihonjo, 0150055, Japan
[2]Department of Management Science,
Tokyo University of Science, Tokyo, 1628601, Japan
[3]Department of Information Systems and Mathematical Sciences,
Nanzan University, Seto, 4890862, Japan

Abstract In this paper, we consider ambulance systems by the aspect of their response time using queueing simulation. We introduce the actual situation for ambulance system of Seto City in Japan, and propose a queueing simulation model. This simulation model enables us to compute the mean response time, loss ratio and the other several important indices. Using the simulation model, we present 2 simulation experiments. One is about the decision-making for restructuring of the ambulance system, the other one is about relation between ambulance locations and the number of ambulances. From these simulation results, we discuss appropriate ambulance systems.

Keywords Emergency Medical Service; Simulation; Location problem

1 Introduction

Recently, there is a growing interest in emergency medical services in Japan for the reasons such as the progress of aging society and the deteriorating condition of public safely. The number of calls for ambulances tends to increase in Japan. The number of calls in 2007 is about 5.29 million. The value of 5.29 million calls means that one of the 26 people in Japan is transported by ambulance within a year[3].

In this situation, the fire and disaster management agency (FDMA) in Japan starts several improvement strategies. Firstly, they perform a revision to the law (Emergency Life-Saving Technician's Act) and progress to develop human resources for emergency life-saving technician. Secondly, they propose a basic guideline about the size of ambulance systems. Currently, every city in Japan runs own ambulance system. The guideline encourages the resize of these ambulance systems. By the guideline, small ambulance systems will merge and become new ambulance systems that take care of about 500 thousand people[8]. For this reason, restructuring plan for ambulance systems are discussing in Japan.

*Corresponding author, Email: inakawa@akita-pu.ac.jp

Previous research treated ambulance systems applying the classical location-allocation problems assuming deterministic conditions. The typical p-median problem or p-center problem is included in such a problem. Brotcorne et al. [2] summarize these location problems. However these problems can not directly represent the stochastic feature of ambulance systems. Carter et al. [1] analyzed a case of two ambulances and two fixed ambulance home stations. They assumed a simplified cooperation between the two ambulances by the aspect of queueing theory. Larson [7] developed the HYPERCUBE queueing model with N ambulances. Inakawa and Suzuki[4] proposed a location problem applying a continuous-time Markov chain. These models are useful to deal the stochastic feature but there are complex and time consuming calculations.

In these contexts, we discuss ambulance systems by the aspect of their response time using queueing simulation. A response time is a waiting time of the clients for an ambulance arrival. In this research, firstly, we introduce the actual situation for the ambulance system of Seto City in Japan, and propose a queueing simulation model. This simulation model enables us to compute a mean response time, a loss ratio and the other several important indices.

Using the simulation model, we present two simulation experiments. One is about the decision-making for restructuring of the ambulance system. We do simulations assuming four cases of restructuring ambulance system. Comparing these results of the simulation, we consider an effective plan for ambulance systems. The other one is about relation between ambulance locations and the number of ambulances. We show a lower bound of mean response time, and introduce a fact that the bound affects an improvement plan. From these simulation results, we consider appropriate ambulance systems.

2 Present Data Analysis

In Japan, the number of calls for ambulances tends to increase rapidly. The number of calls in 2007 is about 5.29 million, although the number of calls in 1998 is about 3.70 million. Figure 1 shows the increase of calls in Japan from 1998 to 2007. In the last decade the number of calls increases by more than 1.5 million. The growth rate of calls is 1.43 but that of the number of ambulances is 1.07. It means that the growth rate of the number of ambulances is considerably lower than that of calls.

To make matters worse, a mean response time is increasing every year. Figure 2 shows the increase of mean response time in Japan. The mean response time in 2007 is 7.0 minutes, while the mean response time in 1998 is 6.0 minutes. This situation should be suspected decreasing a life-saving rate.

We introduce an ambulance system of Seto City in Japan. Seto City is a medium scale city located in Chubu area of Japan. The population of the city is about 130 thousand [9]. Figure 3 shows the number of calls in Seto City. The number of calls tends to increase in Seto City as in the whole Japan. The number of ambulances in the city does not change in the period although the growth rate of calls is 1.6. Seto City is a typical city in Japan.

Figure 4 is a graph of calls which is classified according to each hour and each day. The figure shows that there are many calls in the morning and there are the most calls in Monday morning. Relatively, the number of calls in day time is stable, and there are fewer calls in late-evening and early morning. From a result of cluster analysis, we

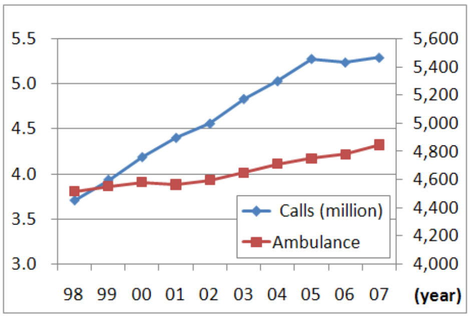

Figure 1: Annual cals in Japan

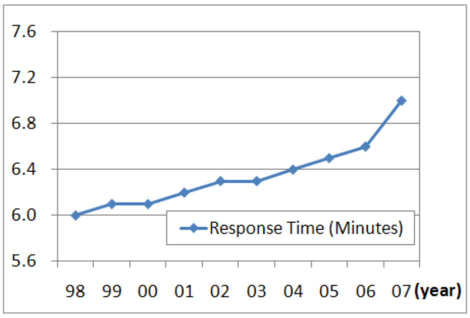

Figure 2: Mean Response Time in Japan

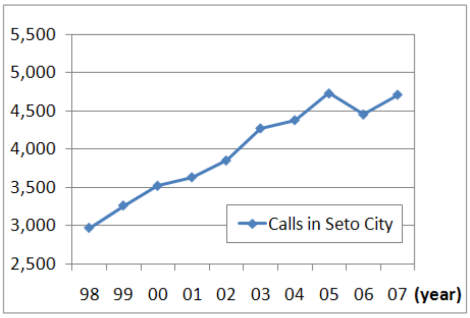

Figure 3: Annual calls in Seto City

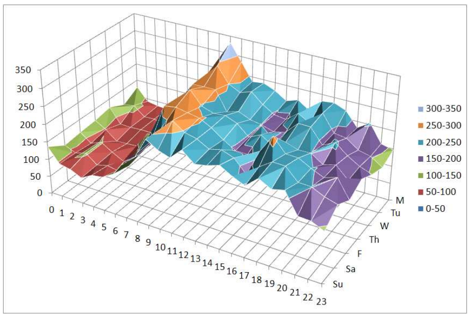

Figure 4: Calls of each day and each hour

separate these periods with 3 time periods. That is morning period, day time period and late-evening period. In this paper, we discuss the day time period.

The width and the breadth of Seto City are about thirteen kilometers and twelve kilometers respectively. Seto City has 4 ambulances and 3 ambulance stations. Figure 5 shows an overview of the city and the place of 3 ambulance stations. Station 1 has 2 ambulances, and the other stations have one ambulance each. The lines in the figure are road network of the city. Thick lines express the main roads, and thin lines express the other roads. Ambulances can run on the road network obeying the speed limit of the road. We assume the actual speed of main road is 46.34 km/hour and that of the other road is 27.51 km/hour [5, 6]. Figure 6 shows the actual places of occurrence of demand calls. We can see bias of the places, the bias are related to the population.

3 Simulation Model

In this section, we present our simulation model. We assume that demand blocks in our model are Zip-code areas in Seto City. An overview of Zip-code areas is in Figure 6. There are 361 demand blocks. Calls are generated from these demand blocks in a Poisson manner with rate which depends on population.

In our simulation model, ambulance is on standby at its home station until a call occurs. When a call occurs, then the nearest ambulance moves to the demand point. After they finish the service, it comes back to own home station. During the service, it cannot

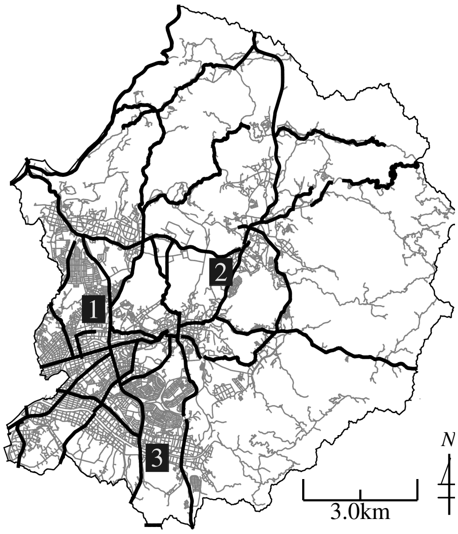

Figure 5: Seto City and ambulance stations

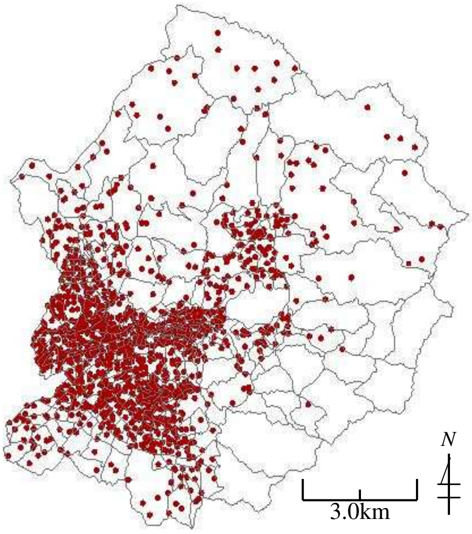

Figure 6: Calls of Seto City in 2007

respond to the other calls. We define a period from departure of ambulance to return of it as a service time. Service times are assumed to be exponentially distributed. Their means depend on response time. When all ambulances in the city are busy, we assume that new demands will be served by the backup vehicle or ambulance from other city. It means that this simulation model is loss system in queueing theory.

A response time is a waiting time of the clients for the ambulance arrival. It is the sum of a mean lead time and a mean travel time from the ambulance station to the demand point. In our model, a mean response time is computed from 100 simulations. The number of trials in a simulation is 5,000, and we repeat that simulation by 100. Because the number of annual calls in Seto City is about 5,000, it means that we assume 100 year cases of the city.

Figure 7 is an overview of our simulation model. In the step of "Initial setting" in the figure, we set next arrival times of calls to all blocks using random numbers in a Poisson manner. In the step of "Arrival" in the figure, we follow the left arrow, if the next event is an arrival. In the step of "Search the nearest ambulance" in the figure, we search the nearest ambulance. And if all ambulances are busy, we set dummy ambulance as the nearest ambulance.

In the step of "Dummy ambulance", we follow the arrow to record a loss event if it is a dummy ambulance. In this case, they cannot serve the call because all ambulances are already in service. If it is not a dummy ambulance, we change ambulance state to 'in service', and record their response time. In the step of "Event 5,000" in the figure, we follow the left arrow if the number of recorded events is 5,000. Otherwise, we go back to the step of "Search the next event" in the figure.

In the step of "Arrival" in the figure, we follow the right arrow if the next event is not arrival. In this case, we set a service time using random numbers. In the next step,

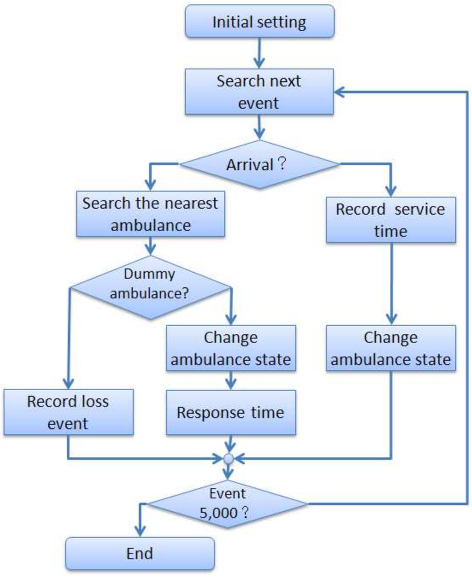

Figure 7: Simulation flow

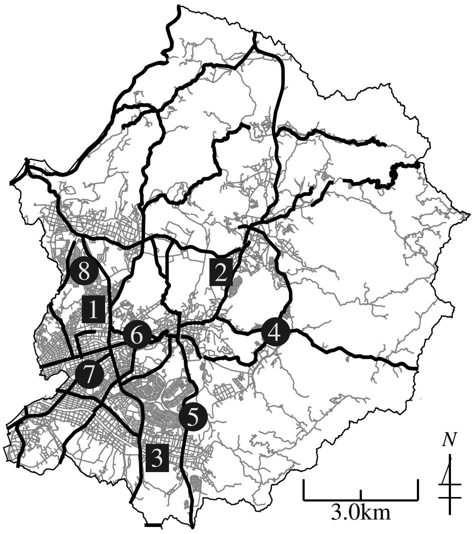

Figure 8: Candidates for a new station

we record the service time, and change the ambulance state to available. We repeat this simulation flow, and we can compute a mean response time using simulation record.

4 Simulation Experiments

In this section, we apply the simulation model to Seto City and 2 simulation experiments are executed. In the first simulation experiment, we assume four cases. These four cases are tabulated in Table 1. The first case is a simulation of the present ambulance system of Seto City. In the second case, we assume that a new ambulance station is constructed. In the third case, we assume that a new ambulance is added to the ambulance system. In the final case, we assume that a new ambulance station is constructed and a new ambulance is added to the system. We compare these cases, and discuss efficient decision-making for restructuring of this ambulance system.

In the second simulation experiment, we fix the number of ambulance stations and change the number of ambulances. And we see the minimum limit of mean response time.

Table 1: Four cases of simulation experiment 1

Case 1:	Present ambulance system
Case 2:	Constructing a new ambulance station
Case 3:	Adding a new ambulance
Case 4:	Constructing a new ambulance station and adding a new ambulance

4.1 Simulation Experiment 1

In the first simulation experiment, we assume four cases. The first case is a simulation of the present ambulance system of Seto City. In this case, we execute simulations for all combination of 3 stations and 4 ambulances, and we confirm the present location of ambulances is the optimal location when the present facilities are given.

We denote the present location of ambulances as 1, 1, 2, 3. It means that first ambulance is located at station 1, the second ambulance is also located at station 1, the third ambulance is located at station 2 and the fourth ambulance is located at station 3. Main results of these simulations are tabulated in Table 2. From the Table 2, we can confirm that the present location is the optimal location. The response time for present location is 5.3081 minutes.

In the second case of experiment 1, we assume that a new ambulance station is constructed. In present location, 2 ambulances are located into station 1. We try to make the ambulance system more efficient by constructing a new station and assigning an ambulance to each station. We assume that there are 5 candidates for a new station. Figure 8 shows places of these 5 candidates. We execute simulations for all combinations of 3 stations and 5 candidates. Main results of these cases are tabulated in Table 3, and the optimal location is 1, 2, 3, 6. The mean response time of this location is 4.9358 minutes. Comparing Table 2 and Table 3, we can find that the effect of constructing a new station is 0.3723 minutes (22.34 seconds).

In the third case, we assume that a new ambulance is added to the system when present stations are given. That is, there are 3 stations and 5 ambulances. We execute simulations for all combinations. Main results of these cases are tabulated in Table 4, and the optimal location is 1, 1, 2, 3, 3. The mean response time of this location is 5.1281 minutes. Comparing Table 2 and Table 4, we can find that the effect of adding a new ambulance is 0.1799 minutes (10.80 seconds). Therefore, the effect of adding a new ambulance is lower than the effect of constructing a station.

In the final case, we assume that a new ambulance station is constructed and a new ambulance is added to the system. That is, there are 4 stations and 5 ambulances. Main results of these cases are tabulated in Table 5, and the optimal location is 1, 2, 3, 6, 6. The mean response time of this location is 4.7550 minutes. Comparing Table 2 and Table 5, we can find that the effect of this plan is 0.5531 minutes (33.19 seconds). Naturally, this case gives the minimum mean response time in these four cases.

From the simulation results of four cases, we can find that Seto City should select the restructuring plan of case 4 if the city has enough budget. However, this plan might be most expensive. Therefore, the plan of case 2 or case 3 might be selected because of budgetary restrictions. In such a situation, the city should select the plan of case 2 because we know that the plan of case 2 is twice as effective as the plan of case 3.

4.2 Simulation Experiment 2

In the simulation experiment 1, we can find that adding a new ambulance might give relatively few effects to reduce a mean response time. Especially, constructing a new station is twice as effective as adding a new ambulance. So, in simulation experiment 2, we fix the number and the location of ambulance stations and vary the number of ambulances.

Table 2: Main results of case 1

Location	Response Time	Loss ratio
{ 1, 1, 2, 3 }	5.3081	0.0031
{ 1, 2, 3, 3 }	5.4727	0.0032
{ 1, 2, 2, 3 }	5.5354	0.0033

Table 4: Main results of case 3

Location	Response time	Loss ratio
{ 1, 1, 2, 3, 3 }	5.1281	0.0004
{ 1, 1, 2, 2, 3 }	5.1499	0.0004
{ 1, 2, 3 }	5.8324	0.0218

Table 3: Main result of case 2

Location	Response time	Loss ratio
{ 1, 2, 3, 6 }	4.9358	0.0033
{ 1, 2, 3, 7 }	5.0838	0.0034
{ 2, 3, 6, 6 }	5.1767	0.0032

Table 5: Main results of case 4

Location	Response time	Loss ratio
{ 1, 2, 3, 6, 6 }	4.7550	0.0004
{ 1, 1, 2, 3, 6 }	4.7899	0.0004
{ 1, 2, 3, 3, 6 }	4.8260	0.0004

Figure 9 shows a relation between the number of ambulances and its mean response time. In the cases of which the number of ambulances is 1 and 2, the mean response times are 11.1982 minutes and 8.2839 minutes. We omit these cases in figure 9 because these response times are too long to write the same figure. From the figure, mean response time decreases whenever an ambulance is added. However, the effect of which an ambulance is added decreases when the number of ambulances becomes large. For example, if the number of ambulances changes from 4 into 5, the effect is 0.1799 minutes (10.80 seconds). It is described in the case 3 of simulation experiment 1. If the number of ambulances changes from 9 into 10, the effect is only 0.0079 minutes (0.47 seconds).

Additionally, we suppose that the number of ambulances is infinite. In this case, the nearest ambulance must assign to calls, because there are no congestions in ambulance system. So the mean response time can compute simply. That is just a mean lead time and an average of travel time, and that is 4.8926 minutes. We describe this time as a lower bound of mean response time, and we denote this bound as break line on figure 9. We can see that mean response times are getting closer to the bound of mean response time whenever the number of ambulances becomes large.

On the other hand, the case 2 of simulation experiment 1 shows us a possibility that location 1, 2, 3, 6 with 4 ambulances makes the mean response time 4.9358 minutes. We denote the mean response time as a black circle on Figure 9. The mean response time is almost the same as a case of which the number of ambulances is 10. In addition, the value is close to the limit of mean response time. We think that it is because a new number six ambulance station breaks the limit of mean response time. Therefore, constructing a new station is efficient in this city.

5 Summary and Conclusions

In this paper, we provided a simulation model for ambulance systems and introduced two simulation experiments. In the first simulation experiment, we can find that constructing a new station is twice as effective as adding a new ambulance for Seto City. This result means that it is important to evaluate restructuring plans concretely. In the second simulation experiment, we show a lower bound of mean response time. Value of this bound greatly influences for an efficient system improvement. We think that these results become helpful in ambulance location planning.

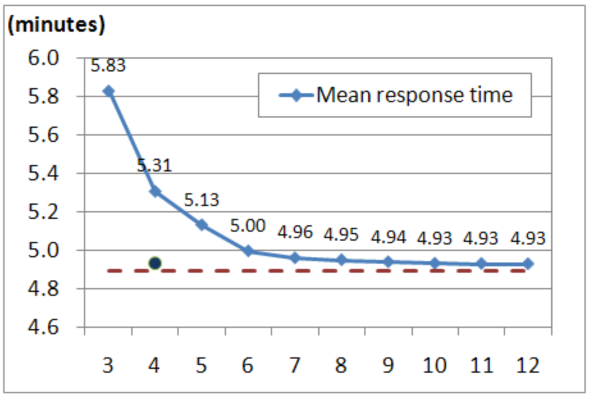

Figure 9: The number of ambulanes and mean response time

Acknowledgements

This research was partly supported by Japan Society for the Promotion of Science Grant-in-Aid for Young Scientists (B), 20710123, 2010.

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