Improving Emergency Medical Services with Time-Region-Specific Cruising Ambulances

Jiun-Yu Yu and Kwei-Long Huang

Abstract This study aims to propose a dynamic resource allocation policy for Emergency Medical Service (EMS) of New Taipei City, Taiwan. Response time is one of the major key performance indicators in EMS system since rapid ambulance response provides patients better chances of recovering or surviving. Ambulances in New Taipei City used to park in separate fire stations and wait for the calls from emergency medical dispatch center (EMD). As an alternative, a dynamic resource allocation policy is designed and proposed by dispatching ambulance to patrol on the streets or stay at specific locations in the areas with high emergency events demand time slots. These areas and time slots are determined by statistical analysis of the historical emergency medical service data. The main idea of this dynamically allocated ambulance policy is to increase the probability that an ambulance will be on stand-by at the nearby area when an emergency event occurs. In addition, this policy is investigated under the condition that no extra EMS resource is available. A simulation model is developed to evaluate this dynamic resource allocation policy, and the results of this study show that time-region-specific ambulance cruising policy can significantly reduce the EMS response times.

Keywords Response time · Resource planning · Resource allocation Healthcare

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1 Research Objective

This study aims to achieve two goals. First, reduce the response time without substantially increasing the amount of or significantly changing the allocation of the current emergency medical service (EMS) resources. Second, propose a time-region-specific cruising ambulances system which dispatches ambulance(s) to patrol on the streets or stay at some specific locations in the high EMS demand areas and time slots. This study is conducted based on the historical EMS data provided by the fire department of New Taipei City, Taiwan.

2 Literature Review

Brotcorne et al. [1] review many OR/MS models for ambulance location and allocation. These models usually focus on minimizing the number of ambulances with the location set covering model (LSCM) or on maximizing the demand covered with the tools such as the maximal covering location problem (MCLP) model and the double standard model (DSM) subject to two covering constraints. Many models that contribute to location research afterward are introduced in this paper.

Green and Kolesar [2] conclude that emergency medical service system (EMSS) has been significantly influenced by operations research and management science (OR/MS) after reviewing the related literatures published from 1960s. Many papers on EMSS management appear in 1970s, leading to implementation of new policies in firefighting and policing. Lots of the practices and experiences from New York City are then adopted by many other cities. Green and Kolesar also discuss how original models affected EMSS, investigating the pace of new models in OR/MS area and suggesting the future potential of OR/MS application.

Ingoldsson et al. [3] develop a discrete event simulation model to evaluate the impacts of the different deployment scheme. In the simulation models, ambulances having completed their missions are to be directed to certain location according to the proposed "park search" algorithm. "Park search", consisting of a prioritized list of locations where ambulances should park, is conducted after ambulances transfer patients to hospitals. The system allows ambulances to be available near the area with high EMS risk.

3 Problem Description

New Taipei City is the most populated region in Taiwan, roughly 4 million people living in a donut-shaped area of 2,000 km^2. The north part of New Taipei City is coastal area while the south part of it is covered by mountains more than 1,000 m high. Due to the unique geographic characteristic, the inhabitants are densely living

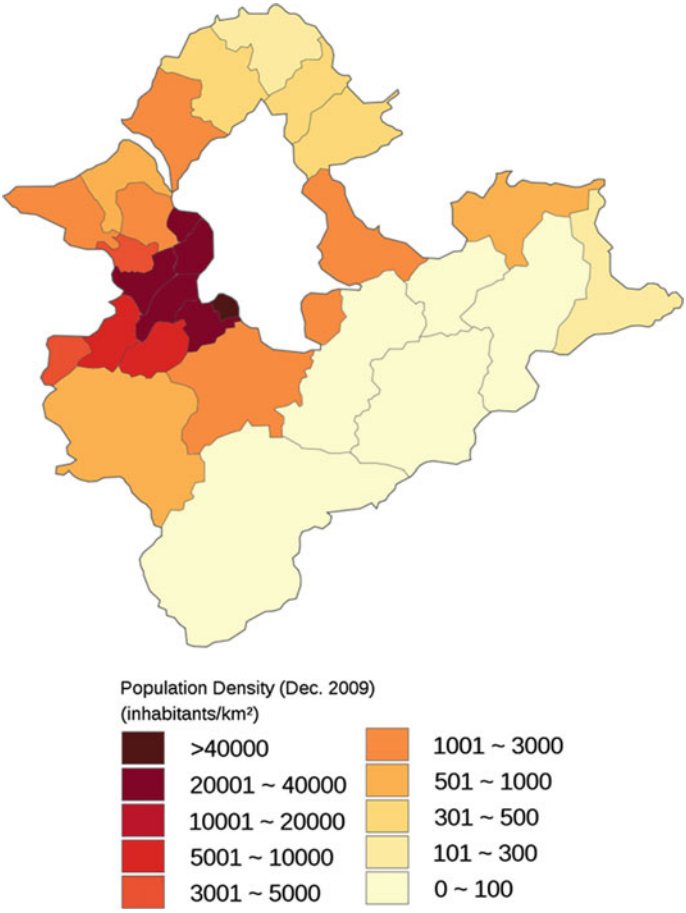

Fig. 1 Population density of New Taipei City

in the small west region, and the medical resources such as hospitals and fire stations are unevenly distributed (Figs. 1 and 2). In sum, there are currently 66 EMS units within the 29 districts in New Taipei City.

The original ambulance operation is that each ambulance is standing-by at its designated fire station. Once an emergency call is dispatched to a specific fire station, its standing-by ambulance will be sent to the scene to execute the task. After completing the task, the ambulance returns back to its designated fire station for posted cleanup and then become ready for the next task. The historical data of emergency medical service studied in this research is the record of location and time of every emergency event occurred in New Taipei City. There are seven steps of handling an incoming emergency call:

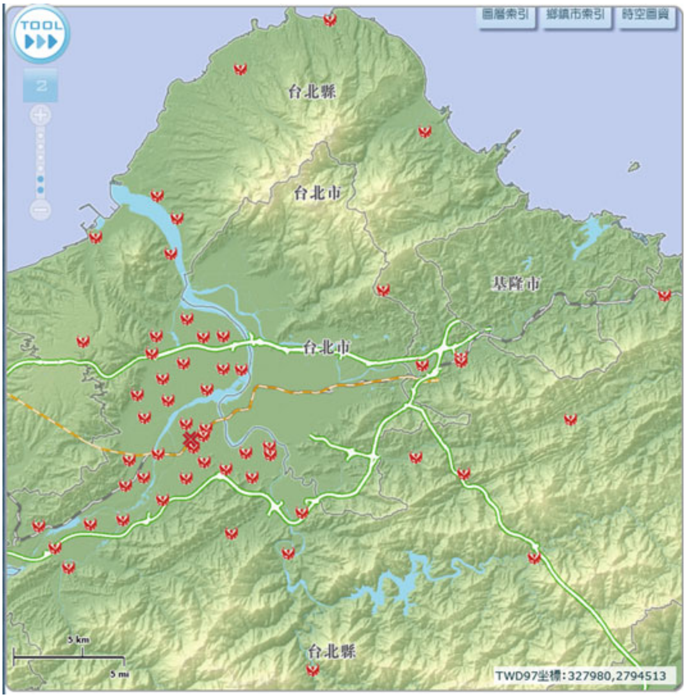

Fig. 2 Fire station locations in New Taipei City

1. Dispatch Center receives a call from an emergency scene.
2. Dispatch Center dispatches an available ambulance from the fire station which is the nearest to the scene.
3. The ambulance arrives at the emergency scene.
4. After the EMTs finish the first aid emergency treatments, the ambulance leaves for the nearest hospital or the hospital requested by the patient.
5. The ambulance arrives at the hospital.
6. The ambulance leaves the hospital and returns back to the fire station.
7. The ambulance arrived at the fire station and the task closes.

Due to the physical locations of fire stations, response times for some events may be longer than the required standard and are not improvable inherently under the current configurations and resources. Subjected to the resource constraint (e.g., without adding new ambulances and emergency medical technicians (EMTs)), new ways of dynamically deploying the ambulances must be investigated and proposed.

Under the time-region-specific cruising policy, one or more ambulances will patrol on some certain routes or stay at a specific location during a certain time slot instead of residing at its designated fire station. It is expected that the dynamically deployed ambulance(s) can more rapidly respond to the emergency events and provide instant care to patients simply through the re-allocation of the current resource.

4 Research Methods

In this study, a set of heat maps based on the Geographical Information System (GIS) is developed to show the frequency of emergency events spread over in each district in New Taipei City. Figure 3 is generated based on the data of emergency events collected from 2010 to 2011. In this figure, New Taipei City is divided into small grids, each 450 m^2. The grid colored in red denotes the higher frequency of events while the blues ones denotes the lower frequency.

After analyzing the historical data from the 29 districts, three busiest regions, Banqiao, Sanchong, and Zhonghe, are selected for further investigation with the time-region-specific cruising policy using simulation modeling. Since the EMS demand is not time invariant on hourly base, each region is only simulated for two time slots with high EMS event frequencies, namely, 17:00–19:00 and 21:00–23:00. This simulation setting in fact increases the practicality of the time-region-specific cruising policy under investigation as the ambulance(s) will only have to be re-deployed in these time slots, if this policy is proved to be significantly better and is then implemented in real practice.

The simulation model is developed using AnyLogic software, and the input parameters used for simulation settings include (1) arrival rate of EMS events, (2) location of each EMS event, (3) delay time between the call from EMD and the ambulance leave the fire station, (4) ambulance average driving speed, (5) duration

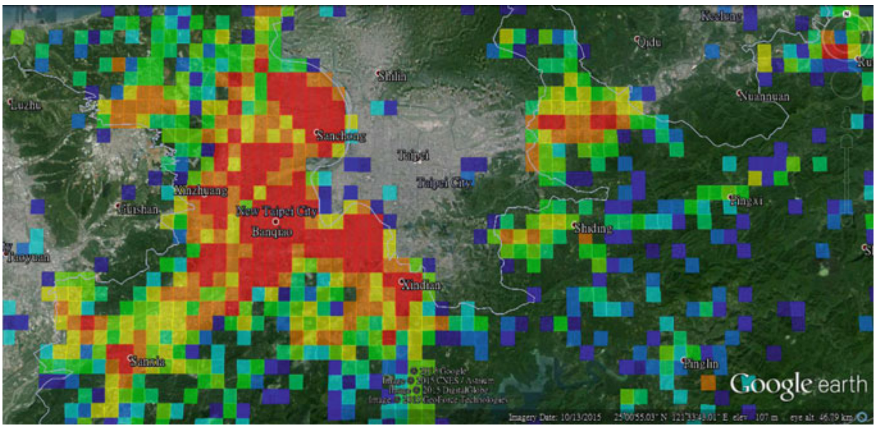

Fig. 3 Example of heat map for New Taipei City

Region & time slots	Banqiao 17:00-19:00	Banqiao 21:00-23:00	Sanchong 17:00-19:00	Sanchong 21:00-23:00	Zhonghe 17:00-19:00	Zhonghe 21:00-23:00
K-S test p-value	0.0068	0.0154	0.1155	0.0509	0.0507	0.4585
Paired t-test p-value	0.5190	0.8738	0.8091	0.0670	0.2354	0.8488

Fig. 4 Simulation model validation resutls

time EMT stay at the scene, (6) duration time of paper work and patient transfer at the hospital, and (7) number of ambulance in each fire station.

The simulation model is validated by comparing the simulated results with the historical EMS data. Simulation results are obtained by random generation of EMS events, the locations of which are based on historical data. Ambulances in the simulation model are operated according to the original operations: standing-by in the fire station and waiting for the calls from dispatch center. Kolmogorov-Smirnov test and paired t-test are conducted to examine the difference between the simulation results and the historical response time. The test results show that there are no significant differences between the result generated by simulation model and the historical response time (Fig. 4).

5 Simulation Analysis

In this study, two types of ambulance dynamic allocation policies are proposed and investigated. In the Guarding mode, the ambulance is on standby at the gravity location determined from the historical EMS events. In the Cruising mode, the ambulance patrols on either a short or a long routes that are specifically designed around the gravity location. Since vehicles are driving on the right-hand side in Taiwan, making right-turn is more convenient and efficient than turning left. Thus, in the Cruising mode the ambulance patrols on the designed routes clockwise. Moreover, as some of the fire stations are equipped with two ambulances, it is also good to know if the response times would be reduced if both ambulances are operated under the proposed dynamic allocation policy. Figure 5 summarizes the ambulance operation policies studied in the simulation.

Figure 6 demonstrated the simulation example of Banqiao region, in which the dotted blue line illustrates the shorter route while the solid black line the longer route. There are actually 6 fire stations in Banqiao region, locations of which are also indicated in Fig. 6.

For each of the “One” ambulance operation policies listed in Fig. 4, Banqiao region may have 6 possible arrangements as there are 6 stations; only one ambulance is needed to run on this policy. Therefore, 18 different settings are to be

Plans	Description	
Original Operations	Ambulance standing-by in the fire station, waiting for the calls from dispatch center.	
Dynamic Allocation One Ambulance	Guarding Mode	Standing-by at the gravity location
	Cruising Mode	Cruising on (shorter) Route 1 clockwise
		Cruising on (longer) Route 2 clockwise
Dynamic Allocation Two Ambulances	Guarding Mode	Standing-by at the gravity location 1
		Standing-by at the gravity location 2
	Cruising Mode	Cruising on (shorter) Route 1 clockwise
		Cruising on (longer) Route 2 clockwise

Fig. 5 Ambulance operations policies studied via simulation

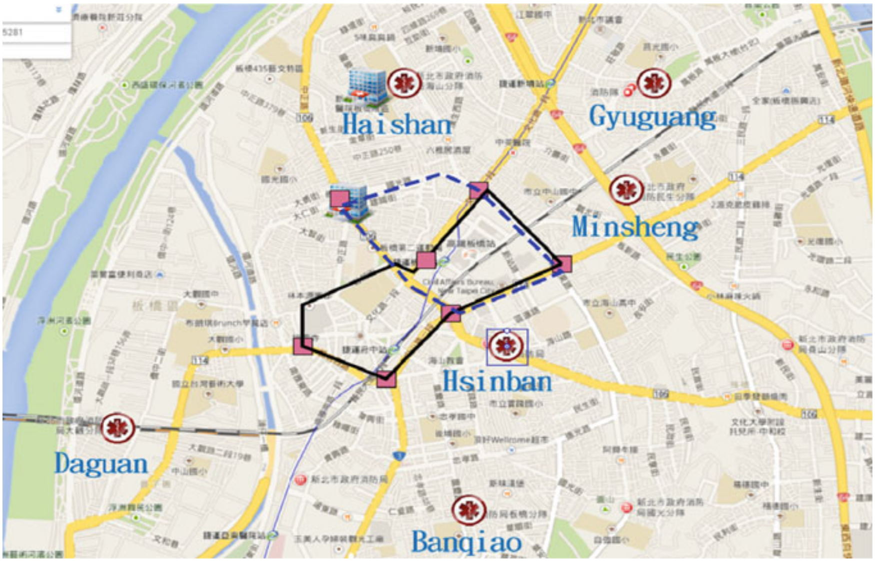

Fig. 6 Demonstration of simulation model for Banqiao region

simulated and examined in the model. Similarly, for each of the "Two" ambulance operation policies, Banqiao region will have to choose from the 6 stations and the 4 policies, resulting in total 180 possible arrangements to be simulated.

In the time slot 17:00–19:00, the simulation results with "One" ambulance operation policy for Banqiao is shown in Fig. 7. It is obvious that the response

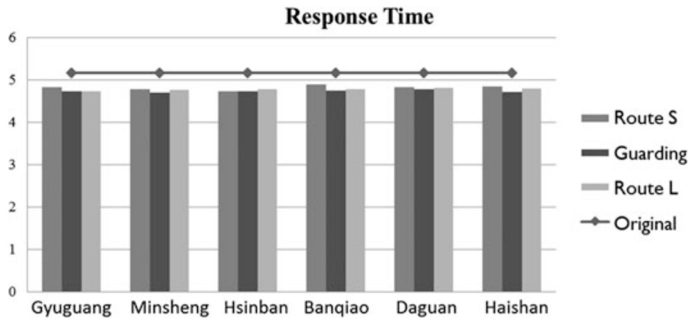

Fig. 7 Simulation results with One ambulance policy for Banqiao region, 17:00–19:00

Fig. 8 Policy combinations for Two ambulance policy for Banqiao region

A	Gravity 1 & Route 1
B	Gravity 1 & Route 2
C	Gravity 2 & Route 1
D	Gravity 2 & Route 2
E	Gravity 1 & Gravity 2
F	Route 1 & Route 2

times for the 3 proposed "One" ambulance policy are all shorter than those of the original practice. The average reduction in response times is 7.56%.

In the same time slot, the "Two" ambulance operation policy are examined under 6 different combinations, shown in Fig. 8. The simulation results of these 6 combinations are compared using Tukey's Honest Significant Differences (HSD) Test, which shows that the combinations C and D are significantly better than the other four combinations (Fig. 9). This result suggest that in Banqiao for the time slot 17:00–19:00, sending one ambulance to stay at gravity center 2 and the other ambulance to patrol on either shorter or longer route will significantly reduce the response time, from 5.16 to 4.36 min, in average. Further simulation investigations reveal that any two of the six stations can be chosen to implement these C or D combination as the simulated performances are similar.

The same simulation investigation is conducted for Banqiao for the time slot 21:00–23:00 as well. The results show that again combinations C and D are significantly better than the other four combinations. However, the performances are not the same across the six stations. Tukey's HSD Test shows that only the following practice produces significant reduction in response time: one ambulance

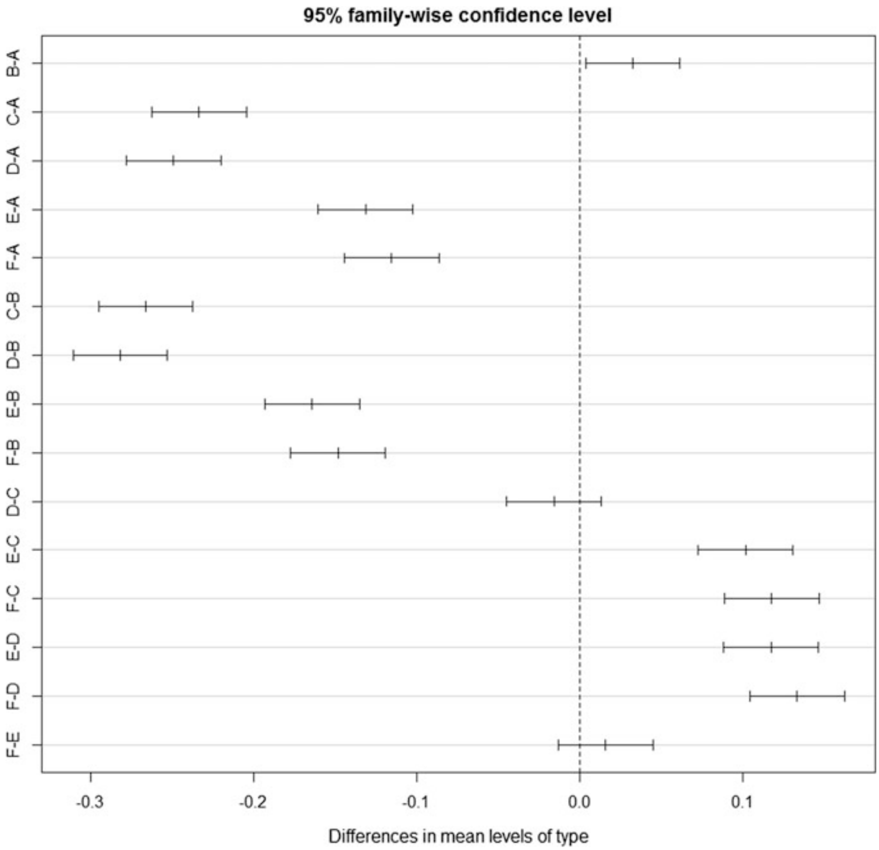

Fig. 9 Tukey's honest significant differences (HSD) test results for Two ambulance policy for Banqiao region, 17:00–19:00

from Minsheng station stay at gravity center 2 and the other ambulance from Daguan patrol on route 2 (Fig. 10). This set of collaboration reduced the average response time from 4.74 to 3.82 min, 19.35% of reduction.

In sum, the simulation study shows that for Banqiao region, both One and Two ambulance dynamic allocation policies generate significant reduction in response time. But if the Two ambulance policy is to be implemented, different time slots required different set of stations to collaborate to achieve the best result.

Similar simulation modeling and experimentations for the other two chosen regions, Sanchong and Chonghe, are conducted as well for the two chosen time slots, 17:00–19:00 and 21:00–23:00. The optimal ambulance dynamic allocation policies for these time-region-specific combinations are all different, and significant reductions in response time are all achieved.

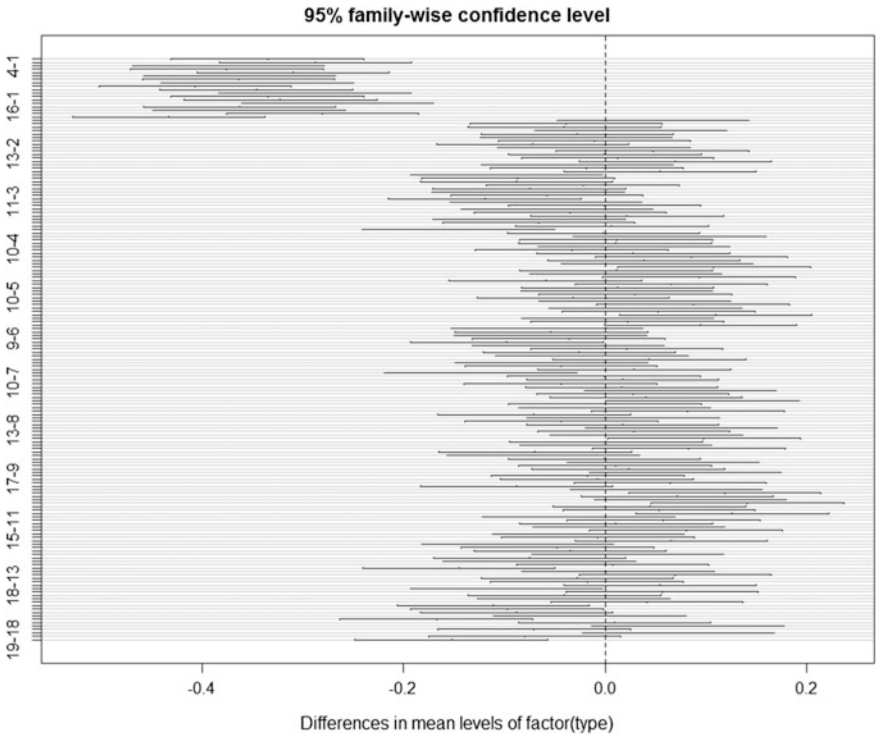

Fig. 10 Tukey's honest significant differences (HSD) test results for Two ambulance policy for Banqiao region, 21:00–23:00, six stations collaboration

6 Conclusion

This simulation study successfully achieved the two aforementioned aims. Given the same limited amount of EMS resources, the time-region-specific cruising ambulance scheme proposed and tested in this study helps to significantly reduce response times for the chosen fire stations in New Taipei City. These dynamically allocated ambulances help to reduce the EMS covering areas of every station. The simulation model developed in this study is the prototype and can be suitably extended to different time-region combinations.

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