Evaluating the Effects of Private EMS Through Urgency-Aware Emergency Simulation

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***Abstract*—Japan's aging population and declining birthrate have had a significant impact on emergency medical services(EMS). The rising number of emergency transports has led to longer response times. Some less urgent patient transfers additionally delay the provision of critical emergency care. The introduction of private EMS has been considered as a potential solution, but its effectiveness remains unverified. This study proposes a method to evaluate the impact of delegating less urgent patient transfers to private EMS on EMS quality, using data from Kobe City. Results show that over a year, the cumulative response time was reduced by approximately 170 million seconds, indicating the delegation of less urgent patient transfers to private EMS improves the quality of EMS.**

***Index Terms*—Aging Society, Emergency Medical Service, Bigdata, Simulation**

I. Introduction

In recent years, with advancements in ICT, companies, governments, and municipalities have been actively collecting and utilizing various types of data. There are various efforts worldwide to utilize diverse datasets to achieve more efficient and sustainable cities, smart cities [1]. In Japan, for example, ICT systems are being used to collect and record various data on emergency transport operations at fire departments. This datas is expected to be utilized in various directions, such as forecasting firefighting demand and optimizing the operation of emergency vehicles and other resources [2]. The Kobe City Fire Department, with which our laboratory is conducting joint research, also collects and records a vast amount of data related to emergency dispatches on a daily basis.

In addition, Japan has a chronically aging society with a low birthrate, which has significant social and economic impacts. The shortage of EMS is one of the most serious problems in Japan. The number of emergency transports is increasing every year, and the time required to arrive at the scene is also increasing proportionally. Some of these emergency transports are used for less urgent patient transfers, which may cause delays in providing emergency medical care to patients who need it as soon as possible.

Under these circumstances, private EMS, called private ambulance services, are attracting attention. The application of such services to less urgent patient transfers is one solution to the problem of concern. However, the actual effectiveness of private EMS has not been verified.

The purpose of this study is to quantitatively evaluate the effect of transferring less urgent patient transfers to private EMS on the quality of EMS using simulations. The following methods are proposed as specific approaches.

A1: Identification of less urgent patient transfers T.

Analyze Emergency Big Data and identify T by using labels of transport type and urgency.

A2: Create dispatch data D1 and D2 for comparison.

D1 is the original dispatch data extracted from the Emergency big data, and D2 is D1 minus T.

A3: Creation of algorithm A to simulate ambulance movement.

To create the algorithm, we use distance data that summarizes the distance between addresses within the jurisdiction,

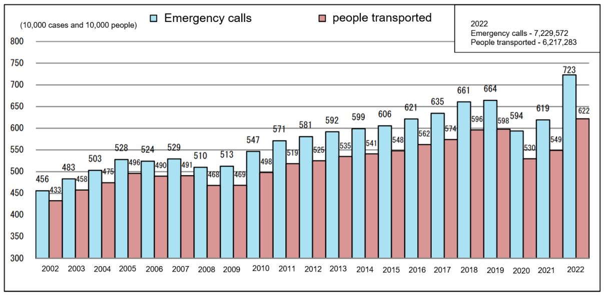

Fig. 1. Number of Emergency Calls by Ambulance and People Transported. [4].

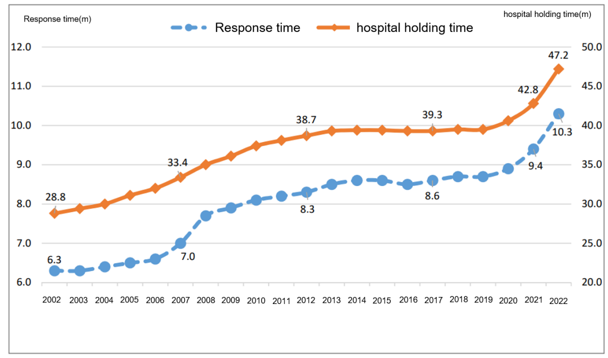

Fig. 2. Time Required to Arrive at the Scene and to Be Admitted to the Hospital. [4]

travel time, and information about the ambulance team.

A4: Apply D1 and D2 to A and compare the distribution and statistics of the data.

The total values are compared, and the effects on transports other than transfers to hospitals and the detailed changes in ambulance movements are analyzed".

We implemented this method using actual data from Kobe City, and conducted an experimental evaluation. The comparison between the presence and absence of private EMS shows a reduction in responce time by approximately 1.7 million seconds per year. In addition, the data excluding transfers to hospitals with low urgency, which were delegated to private ambulance services, also showed a reduction of approximately 230,000 seconds per year.

These results provide quantitative evidence that the quality of EMS improves when less urgent patient transfers are delegated to private EMS.

II. PRELIMINARIES

A. Aging Society and EMS Challenges

Japan has become a chronically aging society with a declining birthrate in recent years. According to the Cabinet Office [3], the number of people aged 65 and over has reached 36.23 million, and the ratio of the elderly to the total population (aging rate) is 29.1 percent. The effects of the declining birthrate and aging society are being felt across various sectors, including the medical field. According to the Ministry of Internal Affairs and Communications (MIC) [4], the number of ambulance calls in 2022 was 7,229,572 (up 1,035,991 or 16.7 percent from the previous year), an increase from the previous year as shown in Fig.1. This trend is expected to continue due to the aging population and declining birthrate. In addition to the increase in the number of emergency transports, the time required to arrive at the scene (responce time) has also increased. According to a 2023 report by the MIC [4], the average responce time in 2022 was 10.3 minutes, compared to 9.4 minutes in the previous year (Fig.2). The same trend can be seen in Kobe City, where we live, and the increase in responce time has become a major problem.

B. Emergency Big Data

Our laboratory is collaborating with the Kobe City Fire Department, which is collecting and recording data on emergency transports using an ICT system as part of its smart city initiatives. The emergency transport data (hereinafter referred to as emergency big data) includes basic information such as the dispatch team and vehicle names, temporal details like the call time and arrival time, information on the injured or sick person (age, gender, urgency), and spatial data such as the incident location and hospital destination A portion of the data is shown in TABLE I. This data has been collected since 2013 and now covers 10 years of data.

In the emergency big data, the dispatch dynamics of ambulances are recorded.

- Call Time: Time when the call is received at the fire station
- Dispatch Time: Time when the ambulance is dispatched
- Arrival Time: Time when the ambulance arrives at the scene
- Departure Time: Time when the ambulance leaves the scene
- Hospital Arrival Time: Time when the ambulance arrives at the hospital
- Hospital Departure Time: Time the ambulance left the hospital
- Return Time: Time the ambulance returned to the fire station

In addition, each transport is labeled to indicate the urgency of the patient. Fig.3 shows the urgency labels and their details in the Kobe City Fire Department. The urgency levels are classified from the top to the bottom as most urgent, urgent, semi-urgent, and other.

In the past, we analyzed this large amount of emergency big data to develop FD-CAST [5], a tool that calculates and visualizes fire truck ruresponcesh times to each town and street based on fire department composition. We also developed visualization system for ambulance movement [6], which has been used in actual emergency services.

C. Research Focus

According to an announcement by the Tokyo Fire Department [7], the number of patient transfers ,transporting a patient currently in a medical facility to another medical

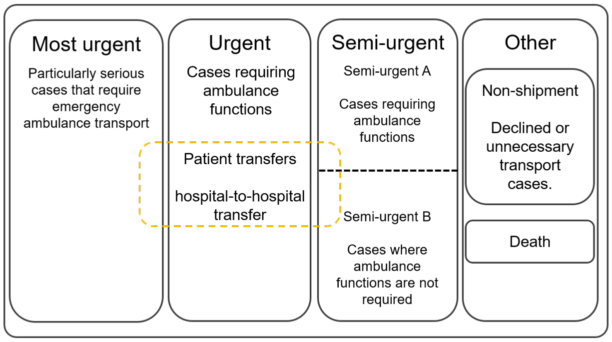

Fig. 3. Urgency Labels.

TABLE I
SAMPLE EMERGENCY BIG DATA."

	Call time	Illness	...	Age
1	14:52:22	Renal Failure	...	57
2	00:23:46	Pneumonia	...	58
3	23:31:05	Bruise	...	74

facility for medical reasons, by the Tokyo Fire Department's ambulance teams is increasing every year. Furthermore, it has been suggested that there is a certain percentage of patients with minor illnesses who have been diagnosed as not requiring hospitalization by the physician at the destination, and that if ambulances are used to transfer such patients, the response to emergency patients who need emergency medical care as soon as possible will be delayed, and lives that could be saved may not be saved. Thus, as the number of emergency transports rises, EMS quality declines due to the increase in less urgent patient transfers.

In some areas, Private EMS services have been introduced. Private EMS is an emergency service for people with minor injuries and minor illnesses [8]. The use of this private EMS is one solution to the problem mentioned earlier. In fact, the Tokyo Fire Department has been promoting the proper use of ambulances, as well as the use of the Tokyo Private Ambulance Call Center, which provides information on medical institutions and transportation to medical institutions on its website [9]. However, according to a survey conducted by the Fukuoka Prefectural Government on private ambulance services [10], 168 out of 360 respondents answered that they do not know or have never heard of such services, and 143 answered that they have heard of them but do not know the details. Thus, the existence of private ambulance services is not yet widely known to the public. Although private EMS have been introduced in some areas, it has not yet been proven what kind of effect the introduction of private EMS will have. This study addresses this issue.

III. Proposed Method

A. Goal and Key Idea

The purpose of this study is to quantitatively evaluate the improvement in the quality of EMS when less urgent patient transfers are delegated to private EMS. The key idea is to utilize emergency big data to simulate a dispatch without transfers and the original dispatch, and to compare the responce times of both dispatches. We propose the following method as a concrete approach to achieve the objective. Fig.4 shows a schematic diagram of the proposed approach.

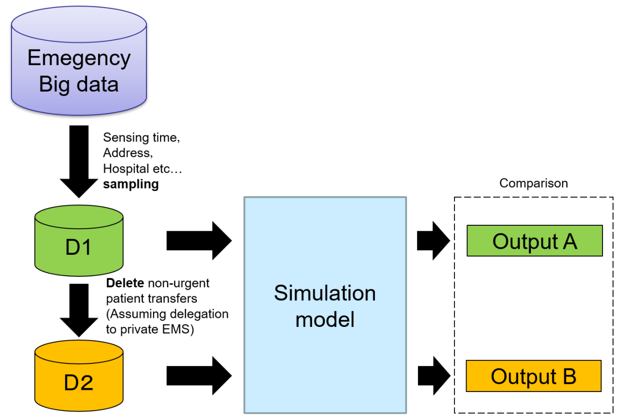

Fig. 4. Architecture of the Proposed Method.

A1: Analyze the emergency big data and identify the less urgent transfers T.

A2: Prepare original dispatch data D1 and data D2 excluding T from D1.

A3: Create an algorithm A to simulate the dispatch dynamics of ambulances.

A4: Apply D1 and D2 to A, calculate the responce time, and compare the data distribution and statistics.

B. A1: Identification of Less Urgent Transfer T

In order to simulate a dispatch without the transfer and the original dispatch, it is first necessary to define and identify the transfer to be removed. The term "remove" refers to that the emergency transports are assumed to be transferred to private EMS, so they must satisfy the following two conditions: (1) the emergency transport is intended for transfer to a hospital, and (2) the emergency transport is of low urgency.

For example, in the case of Kobe City from 2013 to 2023, as shown in Fig.5, we analyze the Emergency Big Data for transfers to hospitals with low urgency (in this case, transfers labeled as semi-urgent) to identify the transport T to be removed.

C. A2: Creation of Various Dispatch Data

The data to be input into the simulation is created from the Emergency Big Data. First, the following columns are extracted from the emergency big data to create the original dispatch data D1. The dynamics of ambulance dispatch is shown in chapter II-B.

- Address of the scene of the EMS
- Hospital Name
- Dynamics of ambulances

Next, data D2 is created by excluding the less urgent transfer transfers to be compared. The data D2 is created by removing

	Urgency level	Transport Type
0	urgent	patient transfers
1	other	sudden illness
...	...	...
912950	semi- urgent A	sudden illness
912951	semi- urgent A	sudden illness

Fig. 5. Urgency Level and Type of EMS in Kobe City from 2013 to 2023.

the less urgent transfer transfers T identified in A1 from the dispatch data D1.

D. A3: Create Simulation Algorithm

Create an algorithm for emergency transport simulation.

To create a simulation algorithm for ambulance transport, two sets of data are prepared: distance data and ambulance squad data. The former is information about the distance and travel time between each address in the fire department's area of jurisdiction, and the latter is information about the ambulance squads in that area. The details of each data are shown in TABLE II and TABLE III.

TABLE II
DISTANCE DATA

Column	Detail
Address of Scene	Addresses within the area of jurisdiction
Firefighter's Signature	Fire station in the area
Distance	Distance between the above two points
Travel Time	Travel time between two points

TABLE III
AMBULANCE SQUAD DATA

Column	Detail
Squad	First responders in areas
Firefighter's signature	Fire station to which squad belong
Vehicle Name	Name of the vehicle owned by that squad

Using the aforementioned data, we create an algorithm to simulate the dynamics of a series of ambulance dispatches for a certain emergency transport X. Fig.6 is shown as an image of the algorithm we have created. First, the following two assumptions are made. (1) The fire brigade of fire station S1, which is the nearest fire station that is not dispatchable at the time of the call, is on its way to the scene. (2) Time spent at the scene, travel time from the scene to the hospital, and time spent at the hospital are the same for all fire departments.

Here, the fire station that is not dispatchable in (1) is the fire station where all fire departments are mobilized and have not returned at the time of the call, i.e., the fire station where no fire department is present.

The algorithm is shown below. First, **call time** and **dispatch time** output the input data. Next, based on assumption, the fire station to be dispatched to the scene of X is determined. For example, in the Fig. 6, the distance data is retrieved from the site address of D1 and the nearest fire station, Central Fire Station, is obtained. Then, it searches the emergency team data to see if the emergency team of the Central Fire Station is available for dispatch. In this case, Central Fire Station No. 2 is available, so it is dispatched from the Central Fire Station. The travel time between the selected fire stations S1 and X is calculated from the distance data and added to the dispatch time to calculate and output **arrival time**. Next, since the time spent at the scene is the same for all fire departments based on assumption, the original time spent at the scene ,the difference between the departure time and the arrival time, is calculated and added to the current arrival time to calculate and output **departure Time**. The travel time between the scene and the hospital is also the same for all firefighting teams, according to Assumption. Therefore, as in the previous example, we output **hospital arrival time**. The same is done for **hospital departure time**. Finally, the travel time between fire station S1 and the hospital is calculated from the distance data and added to the time of illness onset to calculate and output **return time**. In addition, the ambulance teams of fire station S1 and the central second ambulance team in Fig.6 are overwritten so that they cannot be dispatched between the time of illness onset and the time of return from the fire station S1 in the simulation in X.

The above calculations are used to simulate the dispatch dynamics of ambulances.

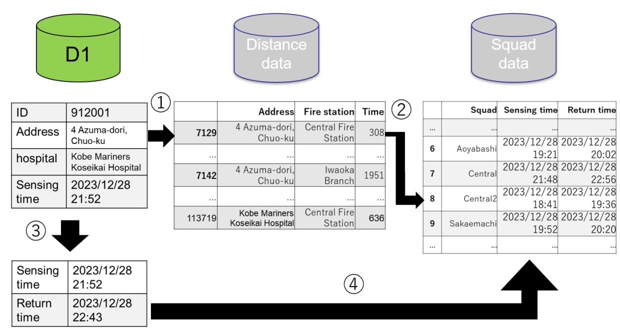

Fig. 6. Emergency Transport Simulation Algorithm.

E. A4: Analysis of Data

We analyze the effects of the transfer to private ambulance services on the responce times of the simulation cases A1 to A3. We analyze the difference in responce time before and after the transfer to private EMS, comparing the distribution of responce time and the total value, and the effect on transfers other than transfers with low urgency. Furthermore, we evaluate the simulation model by checking the accuracy of the simulation.

TABLE IV
DATA USED.

Data	Used Data
D1D2	Kobe City Emergency Big Data (2023)
Distance Data	Distance Data in Kobe City
Ambulance Squad Data	Kobe City Fire Department Emergency Team

IV. EXPERIMENT

A. Experimental Setup

Experiments were conducted using actual data based on the method proposed in Chapter III. Emergency big data and emergency team data were provided by the Kobe City Fire Department. Distance data was collected using Google's RouteApi. We used the data as shown in TABLE IV as the necessary data for dispatch data D1 and D2, and for A3. The number of transfers to hospitals in Kobe City in 2023 was 2,283, so D2 is the data of 2,283 cases removed from D1.

Python3 was used as the implementation language, pandas, numpy, re, seaborn, and matplotlib as libraries, and jupyter as a tool.

B. Results

The output simulation results were analyzed. First, a comparison of the distribution of each data D1 and D2 is shown in Fig.7. D2 is on the left and D1 is on the right. There are slight differences, such as the median being about 2 seconds smaller in D2, but there does not seem to be a significant change in the distribution.

Next, the total responce times for each transport were compared. The results are summarized in TABLE V. This is equivalent to about 19 days. Although there was not much change in the distribution, the total time saved was quite large.

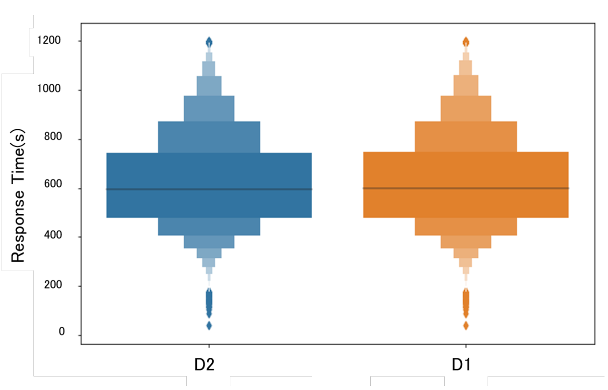

Fig. 7. Distribution of Responce Time.

TABLE V
TOTAL RESPONCE TIME

Data	Responce Time(s)
D2	62060812.0
D1	63768769.0

TABLE VI
IMPACT ON NON-TRANSFER TRANSPORT

Data	Responce Time(s)
D2	1603068.0
D1	1835636.0

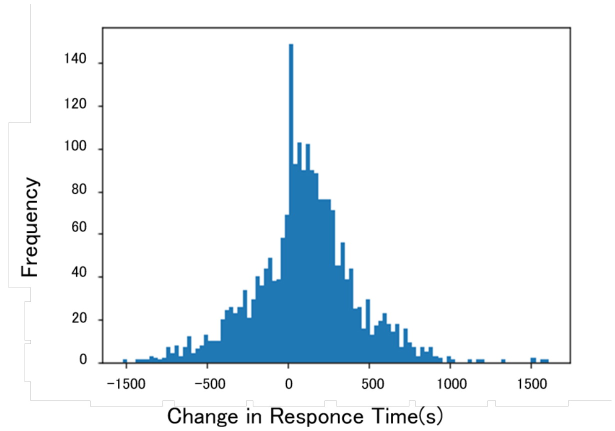

Fig. 8. Change in Responce Time for Non-transfer Transport.

The reduction in time includes the elimination of transfers that were delegated to private EMS, i.e., transfers with low urgency. The number of transfers that changed was 2,184. As before, a comparison of the total values was made, and the results are shown in TABLE VI. The comparison shows that the time saved is about 230,000 seconds, or about 2.6 days. In other words, the 1.7 million second reduction mentioned earlier consists of a 1.47 million second reduction due to the elimination of the transport itself and a 230,000 second reduction in transport time due to the effect of the elimination of the transport. The histogram plotted for each of the transfers that changed is shown in Fig.8. The horizontal axis indicates the responce time, and the rightward direction indicates the cases in which the introduction of private EMS has resulted in a faster responce time. The vertical axis indicates the number of cases. The histogram shows that there are both faster and slower cases, but the right side of the histogram favors the faster cases.

In order to confirm why some of the cases were shortened, we checked the specific changes that occurred in the changed transfers. An example is shown in TABLE VII.

In this example, the Nada Fire Department's resources were freed up by the elimination of the transfer to the hospital, and the fire department was assigned to the new fire department, resulting in a 5-minute faster arrival time. A further example

TABLE VII
SPECIFIC EXAMPLE OF CHANGED CONVEYANCE 1

Data	Call Time	Dispatch Time	...	Return Time	Fire Station
D2	16:55:48	17:09:07	...	18:57:31	Nada
D1	16:55:48	17:14:04	...	18:58:12	Aoyabashi

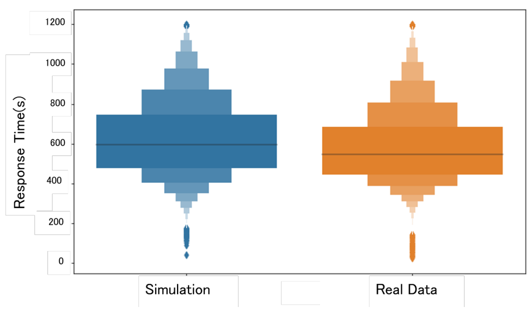

Fig. 9. Responce Time Violin Plot.

is shown in TABLE VIII. This example shows the simulation result of the same day as TABLE VIII, about 20 minutes later, and shows a case in which the responce time was delayed. It can be seen that the Nada Fire Department, which was supposed to be in charge of this case, is no longer able to take charge of the case due to the change of the Nada Fire Department, resulting in the opposite change from the previous case.

As a result, the opposite change is observed. As shown above, the loss of resources that should have been used by the Nada Fire Department results not only in an earlier response time, but also in a later response time. However, when considered as a whole, as shown in TABLE VI, the result is a reduction of approximately 230,000 seconds, and on average, a reduction of approximately 102 seconds per case.

The accuracy of the simulation was analyzed. Fig9 shows the distribution of responce time between D1 and the original. It was found that the overall distribution of the simulated responce time was longer than the actual responce time.

V. CONCLUSION

In this study, we focused on the problem of responce time, which is increasing in an aging society with a declining birthrate, and proposed a method to quantitatively evaluate the effectiveness of private ambulance services, which exist as a solution to this problem. Furthermore, we conducted an experiment using actual data from the city of Kobe to quantitatively demonstrate the impact of private ambulance services. It is expected that this method will be used to demonstrate the effectiveness of private ambulance services and lead to their further dissemination.

A. Discussion

The results of this study showed that transferring 2,283 less urgent patient transfers to private EMS reduced the responce time by approximately 19 days per year. An average of 102 seconds was also saved in 2,184 non-transfer cases. Since there are 2,184 transfers per year, this translates into a reduction of about 6 cases per day. In addition, 2,283 cases of transfers to hospitals will be transferred, which will also eliminate about 6 cases of EMS operations per day. The above results suggest that the transfer of EMS to the private sector will reduce the burden on EMS teams and improve the quality of EMS.

Regarding the accuracy of the simulation, the reasons for the lengthy simulation results include the fact that the algorithm is not capable of accommodating temporary ambulance teams, and the fact that it does not take into account the fact that the time spent at the scene varies depending on the ambulance team. As the name implies, a temporary ambulance team is an ambulance team that is formed on a temporary basis.

As for future issues, since the current analysis is based only on data for the year 2023, we are considering using data for the 10-year period from 2013 to 2023 and improving the accuracy of the simulation.

TABLE VIII
SPECIFIC EXAMPLE OF CHANGED CONVEYANCE 2

Data	call Time	Dispatch Time	…	Return Time	Fire Station
D2	17:14:34	17:32:03	…	18:06:04	Aoyabashi
D1	17:14:34	17:25:31	…	17:55:56	Nada

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