The evaluation reduced the total travel time of emergency transport by reorganization of fire stations in Kyoto Otokuni Area.

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1. Introduction

The population of Japan has been declining since 2004 and the average age of the population is expected to become increasingly older.[1] Consequently, the number of people aged 15 years and younger and the working-age population (aged 15 to 64 years) is expected to decline. Therefore, the formation of sustainable local communities is required in each region and ensuring the sustainable provision of administrative services to support these communities is an important issue. [2] [3] [4]

In this study, we consider the issue of one of these administrative services—emergency services provided by fire departments. The number of emergency calls in Japan has been increasing every year and has doubled in the past 20 years even though the population has been decreasing. [5] Emergency services must continue to fulfill their responsibility to protect the lives, health, and property of residents by promptly responding to changes in the environment affecting emergency services, such as the diversification and scale of disasters and accidents, the increasing complexity of urban structures, and the diversification of residents' needs.

In order to solve these various problems, we think that it is very important to first quantify and demonstrate the burden of work undertaken by fire departments. A qualitative discussion will tend to follow existing policies, which will increase the possibility that discussions regarding the reorganization and integration of fire stations will not proceed. Moreover, in the case of multiple fire stations, it is important to think quantitatively about how to balance and distribute the work. This is important from the viewpoint of risk diversification and as well as to maintain the motivation of those who are engaged in the work. In addition, it will provide very meaningful basic data for making policy decisions related to the reorganization and integration of fire stations. Based on this background, the purpose of this study is to quantitatively discuss the topics outlined below, focusing on the Otokuni Fire Department, which has jurisdiction over the Otokuni area and includes two cities and one town—Muko City, Nagaokakyo City, and Oyamazaki Town—in Kyoto prefecture in Japan. [6][7]

Chapter 2 provides an overview of the study area and the data used.

In Chapter 3, a schematic of the road network for the Otokuni area is presented to calculate how the on-scene arrival time changes depending on the reorganization of fire stations. The first step is to calculate which fire station is closest to the requested emergency transport location, that is, which fire department can be dispatched to arrive at the location in the shortest time. This catchment area of the requested emergency transport is called the Emergency Medical Services Area (EMS area).

In Chapter 4, the current status of emergency transport operations (number of emergency transports, on-scene arrival time, on-scene treatment time, and hospital transport time), staffing, and emergency vehicles is described based on actual operation data in 2016. Based on the concept of the nearest EMS area in Chapter 3, the number of emergency transports that the EMS team should receive is then calculated, and the difference from the current actual operation is ascertained. In addition, when there is a request for emergency transport in a section in the Otokuni area, and for some reason, the nearest emergency team is unable to respond, another emergency team is required to provide support. In this study, this is defined as "EMS supporting transports" and the ratio between the number of EMS supporting transports and the total number of emergency transports is defined as the ratio of support emergency transports to the total number of emergency transports. We will calculate the value and analyze the factors that cause such emergency transports to occur.

In Chapter 5, based on the above, we estimate the number of emergency transports and total on-scene arrival time for each emergency team when the current three fire stations are reorganized into three new fire stations and the ratio of emergency transports to support these stations is set.

Chapter 6 shows that a decrease in total on-scene arrival time compared to the current situation leads to an increase in the rate of lives saved. The social benefit resulting from this is generally referred to as the benefit of improving the EMS survival rate. This section discusses how the benefit of improving the EMS survival rate changes when the ratio of EMS transports in support of a patient is changed.

In Chapter 7, we estimate the decrease in annual personnel costs, building maintenance costs, and general administrative costs when three fire stations and one branch station are reorganized into three fire stations.

Chapter 8 summarizes the issues involved in reorganizing and consolidating fire stations.

2. Overview of study area and emergency transport data

2.1 Overview of study area

As shown in Figure 2-1, the study area was the Otokuni area, consisting of Muko City, Nagaokakyo City, and Oyamazaki Town in Kyoto Prefecture. The area of this district, consisting of three cities and towns, is 32.86 km^2 and the population is approximately 154,681 as of April 2021. The Hankyu Kyoto Line and JR Tokaido Main Line run parallel to each other, and the Meishin Expressway and Kyoto Jukan Expressway also run through the district to form a wide traffic network area. The area forms a suburban residential city with an excellent natural environment and historical culture; as a bedroom community for the Kyoto-Osaka metropolitan area, the construction of low and medium-rise housing has been progressing.

As shown in Figure 2-2, the district currently has one fire station headquarters, three fire stations, and one branch fire station. These include the Muko Fire Station, Nagaokakyo Fire Station, Oyamazaki Fire Station, and East Branch Station, with the Otokuni Fire Headquarters located in the East Branch Station.

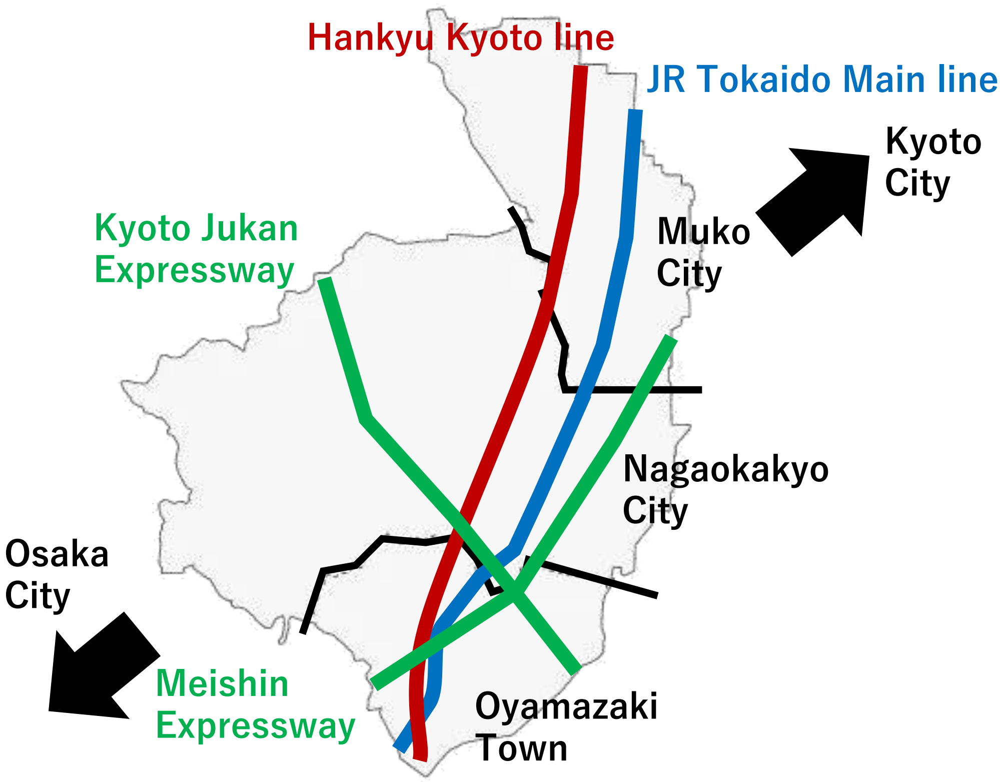

Figure 2-1: Study Area

Figure 2-2: The location of fire stations in the study area

2.2 Overview of EMS data

In this study, emergency transport data was provided by the Otokuni Fire Department. [8)] The attributes of the data are as follows: destination address, date of incident, type of incident, time of incident, time of arrival at the scene, time of arrival at the hospital, dispatched emergency unit, age, sex, and name of the transporting agency.

3. Calculation of on-scene arrival time from fire station using the road network

3.1 Creation of road network data

In Figure 3-1, a road network was created based on map data for the Otokuni area. The number of links is 22,632. There are four fire stations in the network created in this study. In Muko City, there are 181 sections, in Nagaokakyo City there are 78 sections, and in Oyamazaki Town there are 80 sections. The center of each section and fire station location data were inputted as node data in the road network link data.

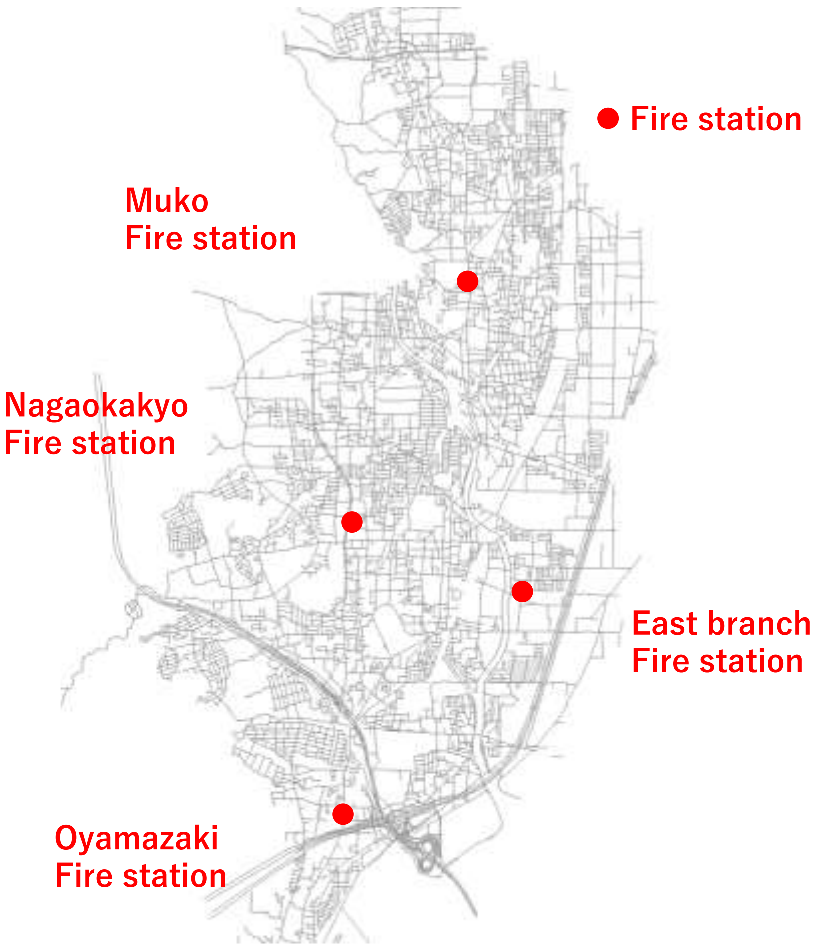

Figure 3-1: Map of road network data and fire stations

3.2 Calculation of the shortest time required from fire station to section

The shortest travel time between four fire stations and 339 sections was calculated using the road network FORTRAN. The link times were calculated under the condition that the ambulance travels at the speed limit.

3.3 Calculation of EMS area

Using the results in 3.2, the area associated with a fire station that can provide the quickest service was defined as the EMS area. These results are shown in Figure 3-2.

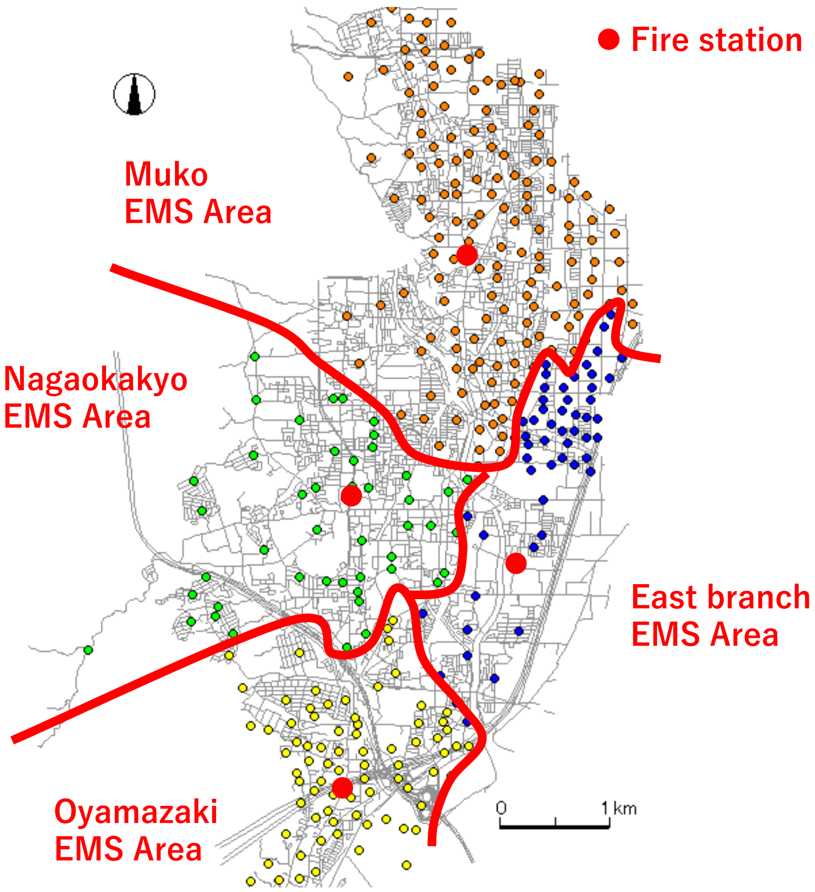

Figure 3-2: Map of EMS area

3.4 Equation relating theoretical time to on-scene arrival time

In 3.2, the shortest time to travel from the distress location to the nearest fire station was calculated using the road network, but this shortest time is a theoretical time and is shorter than the actual time because it does not take railroad crossings and traffic conditions into account.

By regression analysis, we estimated the relationship between on-scene arrival time in the actual transport data and theoretical time (Equation 1).

$$\text{On-scene arrival time (minutes)} = 0.012 \times \text{theoretical time (seconds)} + 4.26 \text{ (minutes)} \tag{1}$$

3.5 Calculation of on-scene arrival time in Otokuni Fire Department

Using 3.2 and 3.3, we calculated the theoretical on-scene arrival time for each EMS team to the nearest point for each EMS area. The weighted time by the population of each section was calculated. The results are shown in Table 3-1.

Table 3-1 Theoretical times from fire station to EMS area (seconds)

	Muko Fire station	Nagaokakyo Fire station	East branch Fire station	Oyamazaki Fire station
Muko EMS area	146.22	380.91	381.45	557.05
Nagaokakyo EMS area	337.29	131.12	282.41	292.29
East branch EMS area	327.03	247.55	142.84	315.37
Oyamazaki EMS area	504.94	274.65	310.32	139.63

Table 3-1 shows the theoretical time from the fire station to EMS area

The theoretical times in Table 3-1 were converted to on-scene arrival times using Equation (1), and the results are shown in Table 3-2.

Table 3-2 On-scene arrival times from fire station to EMS area (minutes)

	Muko Fire station	Nagaokakyo Fire station	East branch Fire station	Oyamazaki Fire station
Muko EMS area	6.01	8.83	8.84	10.94
Nagaokakyo EMS area	8.31	5.83	7.65	7.77
East branch EMS area	8.18	7.23	5.97	8.04
Oyamazaki EMS area	10.32	7.56	7.98	5.94

4. Analysis of the current status of EMS transport operations at the Otokuni Fire Department

4.1 The number of staff, emergency transport, and emergency vehicles at each fire station

Table 4-1 shows the number of staff, emergency transport, and emergency vehicles at each fire station. The East branch fire station has a larger number of employees because it is combined with the Fire Department Headquarters. Therefore, compared to other fire stations, the number of staff is considered to be more than sufficient for the number of emergency transports.

Table 4-1 Number of staff, emergency transports, and emergency vehicles at fire stations[3)]

	Muko Fire station	Nagaokakyo Fire station	East branch Fire station (combined with the Fire Department Headquarters)	Oyamazaki Fire station
Staff	40	41	42 (28)	26
Emergency transports	2,111	2,042	1,027	1,088
Emergency vehicles	1	1	1 (1)	1

4.2 Distribution of on-scene arrival times in the Otokuni Fire Department

Figure 4-1 shows the on-scene arrival times of emergency transport operations in the Otokuni Fire Department. In this study, we use Kahler's lifesaving curve[9)] shown in Figure 4-2 to understand the current status of emergency transport services in the Otokuni area.

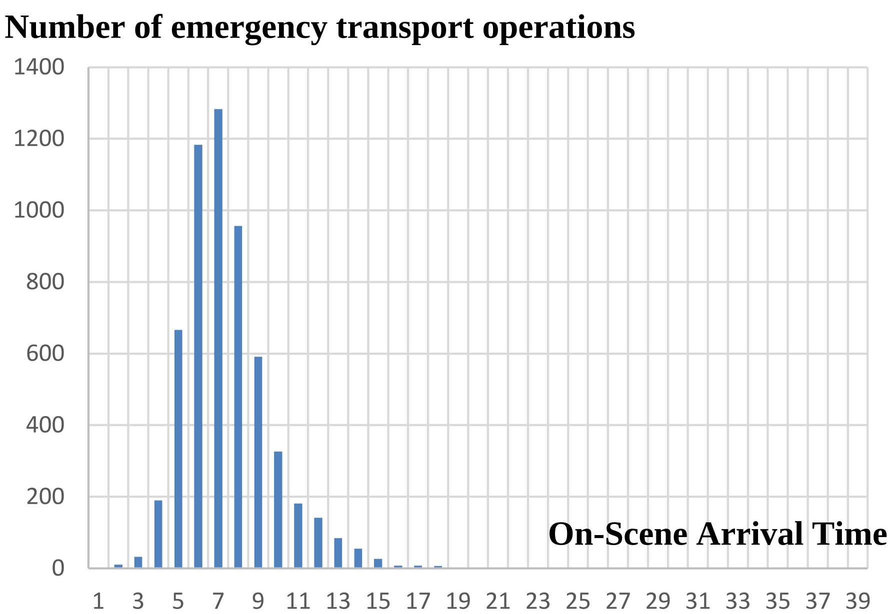

Figure 4-1 Distribution of on-scene arrival times in the Otokuni area

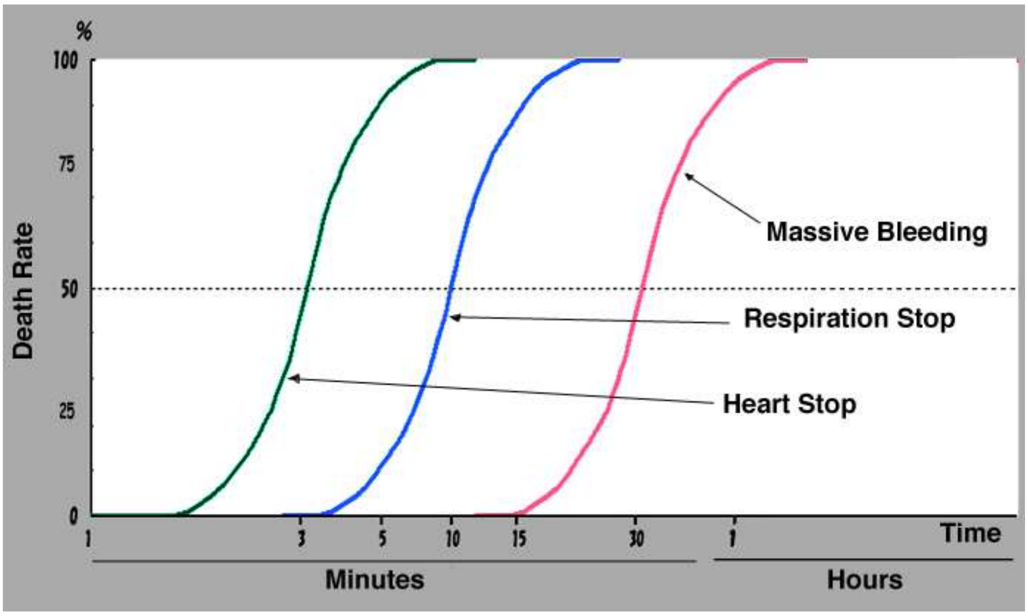

Figure 4-2 Kahler's lifesaving curve[9)]

Overall, the average on-scene arrival time was 6.5 minutes. In contrast, the national average on-scene arrival time is 8.7 minutes[9)]. According to Kahler's lifesaving curve, the mortality rate is approximately 50% at 10 minutes after respiration stops, but in the Otokuni area, approximately 94.1% of all patients were able to benefit from an ambulance arrival within 10 minutes.

4.3 Calculation of EMS transport time in the Otokuni area

Table 4-2 shows the total time taken for EMS transport (including the on-scene arrival time, treatment time at the scene, and hospital transport time) for each EMS team in the Otokuni area, and Table 4-3 shows these times divided by the number of transports. Table 4-4 below shows the average on-scene arrival time for all EMS teams inside and outside their own EMS area.

Table 4-2 Total EMS transport time in the Otokuni area (minutes)

EMS team	Total EMS transport time		
	On-scene arrival time	treatment time	Hospital transport time
Muko EMS team	12,288	28,713	17,564
Nagaokakyo EMS team	12,573	29,803	15,704
East branch EMS team	6,545	14,711	7,184
Oyamazaki EMS team	6,827	15,444	9,570

Table 4-3 Average time required per EMS transport in the Otokuni area (minutes)

EMS team	Average time required per EMS transport			
	On-scene arrival time	Treatment time	Hospital transport time	Total time
Muko EMS team	6.17	14.41	8.82	29.40
Nagaokakyo EMS team	6.63	15.73	8.29	30.65
East branch EMS team	6.92	15.55	7.59	30.06
Oyamazaki EMS team	6.60	14.94	9.26	30.79
Entire Otokuni area	6.58	15.16	8.49	30.16

Table 4-4 On-scene arrival time inside and outside the local EMS area (minutes)

	On-scene arrival time		
	All EMS areas	**Inside the local EMS area**	**Outside the local EMS area**
Muko EMS team	6.17	6.04	7.66
Nagaokakyo EMS team	6.63	5.68	8.09
East branch EMS team	6.92	5.88	8.33
Oyamazaki EMS team	6.60	5.65	7.95
Entire Otokuni area	6.58	5.81	8.01

Comparing the three sections of time required in Table 4-2, the on-scene arrival time, hospital transport time, and on-scene treatment time were each increasingly longer. Table 4-3 compares the EMS transport time for each EMS team and suggests that the Muko EMS team is more efficient in transporting. Table 4-4 shows that the Muko EMS team has the longest on-scene arrival time inside their local EMS area. Considering all EMS areas, the East branch EMS team took the longest. The reason is thought to be due to the high ratio of emergency transports by support EMS teams.

4.4 Calculation of the number and percentage of support EMS transports in the Otokuni Fire Department

Table 4-5 summarizes how many emergency transports are performed by each fire station in the nearest EMS area in the Otokuni area and the percentage of transport cases that each EMS team supports outside their local EMS area.

Table 4-5 Number of emergency transport operations and EMS support ratio by fire station

	Muko EMS team	Nagaokakyo EMS team	East branch EMS team	Oyamazaki EMS team	Total
Muko EMS area	1,959	627	148	60	2,794
Nagaokakyo EMS area	78	1,248	251	235	1,812
East branch EMS area	70	87	587	148	892
Oyamazaki EMS area	4	80	41	645	770
Total	2,111	2,042	1,027	1,088	6,268
EMS support ratio	6.2%	38.9%	42.8%	40.7%	29.2%

The EMS support ratio was calculated by dividing the sum total of EMS transports provided to non-local EMS areas by the total number of EMS transports for each EMS team.

The total number of emergency transport operations conducted by the Muko EMS team was 2,111, 2,042 for the Nagaokakyo EMS team, 1,088 for the Oyamazaki EMS team, and 1,027 for the East branch EMS team. However, the total number of emergency transports that occurred for each EMS area was 2,794 in the Muko EMS area, 1,812 in the Nagaokakyo EMS area, 892 in the East branch EMS area, and 770 in the Oyamazaki EMS area. The highest number of emergency transport operations occur in the Muko EMS area, followed by the Nagaokakyo EMS area, the East branch EMS area, and the Oyamazaki EMS area. The Muko EMS team has the lowest EMS support ratio, while the ratios of other EMS teams are approximately 40%. This suggests that the Muko EMS team is not able to handle all of the emergency transports that occur in the nearest EMS area, and it is clear that many cases are transported by the Nagaokakyo EMS team and other EMS teams as support. The total number of support emergency transports in the Otokuni area was 1,829 out of 6,268 transports. Therefore, the ratio of emergency transports provided as support was 29.2%.

5. Change in total on-scene arrival time by percentage of EMS supporting transports

The benefit of wide-area firefighting [7] is that firefighting capabilities are strengthened, and specifically, the services provided to residents are improved through:

- Enhancement of the number of initial dispatches
- Reinforcement of the support system under unified command
- Enhancement of initial firefighting capability and the reinforcement system by enabling response to large-scale disasters and special disasters
- Appropriate station allocation for the entire jurisdiction
- Shortening the on-scene arrival time by unifying the command, which enables the nearest vehicle to go directly to the scene
- Efficiency in personnel deployment, integration of headquarters functions, and joint operation of command
- Generous deployment of personnel to the field
- Strengthening of firefighting capabilities by upgrading and specialization of preventive and emergency services to increase field personnel and expertise
- Reduced number of off-duty dispatches due to improved disaster response capabilities and enhanced systems

Some of the improvements to the fire stations achieved by strengthening the infrastructure of the firefighting system include:

- Efficient operation and maintenance through sharing and joint maintenance of vehicles, materials, and equipment by improving advanced firefighting equipment and facilities
- The organization is revitalized through appropriate personnel rotation, which increases the number of places of employment and makes it easier to secure personnel as the organization grows in size
- Human resource development through training, etc., is also possible

Based on these benefits and the current situation, we believe that it is necessary to take steps toward the consolidation and reorganization of public facility layouts such as fire stations.

In terms of the number of emergency transports and the total on-scene arrival time, the average on-scene arrival time is calculated and discussed based on the ratio of emergency transports by the support team when the current four fire stations are reorganized into three fire stations.

5.1 Calculation of total on-scene arrival time for the four current fire stations

In calculating the total on-scene arrival time, we used the actual number of transports in 2016. Table 5-1 summarizes each EMS team's transports to the nearest EMS team areas.

Table 5-1 Number of EMS transports (2016)

	Muko EMS team	Nagaokakyo EMS team	East branch EMS team	Oyamazaki EMS team	Total
Muko EMS area	1,959	627	148	60	2,794
Nagaokakyo EMS area	78	1,248	251	235	1,812
East branch EMS area	70	87	587	148	892
Oyamazaki EMS area	4	80	41	645	770
Total	2,111	2,042	1,027	1,088	6,268

Table 5-2 shows the results when the average on-scene arrival time and the number of transports calculated in Table 4-2 are multiplied by each EMS team and each EMS area.

Table 5-2 Total on-scene arrival time (minutes)

	Muko EMS Team	Nagaokakyo EMS Team	East branch EMS Team	Oyamazaki EMS Team	Total
Muko EMS area	11,783	5,537	1,308	657	19,284
Nagaokakyo EMS area	648	7,280	1,920	1,825	11,673
East branch EMS area	573	629	3,507	1,191	5,899
Oyamazaki EMS area	41	604	327	3,828	4,802
Total	13,045	14,051	7,062	7,501	41,659

Compared to the actual total on-scene arrival time of 41,486 minutes, the measurement error is less than 1%.

The ratio of the number of cases transported by each emergency team is approximately 2:2:1:1 (Muko: Nagaokakyo: East branch: Oyamazaki), which is similar to the 2:2:1:1 ratio of the total on-scene arrival time.

5.2 Calculation of total on-scene arrival time for ideal transport at the four current fire stations

We considered the ideal case of the current transports at the four fire stations. In this case, the ideal transport occurs when each fire station is able to handle 100% of the transports that occur in the nearest EMS area, (i.e., when the ratio of EMS supporting transports is 0%).

Table 5-3 Number of emergency transports when ideal transports are performed

	Muko EMS team	Nagaokakyo EMS team	East branch EMS team	Oyamazaki EMS team	Total
Muko EMS area	2,794				2,794
Nagaokakyo EMS area		1,812			1,812
East branch EMS area			892		892
Oyamazaki EMS area				770	770
Total	2,794	1,812	892	770	6,268

The total on-scene arrival time was calculated using the same method as in 5-1, and the results are shown in Table 5-4.

Table 5-4 Total on-scene arrival time when ideal transports are performed

	Muko EMS Team	Nagaokakyo EMS Team	East branch EMS Team	Oyamazaki EMS Team	Total
Muko EMS area	16,805				16,805
Nagaokakyo EMS area		10,570			10,570
East branch EMS area			5,329		5,329
Oyamazaki EMS area				4,570	4,570
Total	16,805	10,570	5,329	4,570	37,274

In the ideal case, the total on-scene arrival time of 37,274 minutes is 4,385 minutes less than the current on-scene arrival time of 41,659 minutes.

The burden ratio changes when transport is ideal, and a comparison of the total time required at the scene for each EMS team shows that the Mukai EMS team has a higher burden.

5.3 Establishing the location of the new fire station when reorganizing from four fire stations to three fire stations

We established the location of the new fire station by reorganizing from the current setup of four fire stations to three fire stations. The analysis up to 5.2 shows that there is increased burden on the Muko Fire Station and the Nagaokakyo Fire Station; therefore, both stations remain unchanged in the proposed setup, and we propose that the East Branch Fire Station and the Oyamazaki Fire Station are merged into a new fire station. This analysis will examine the change in total on-scene arrival times. Figure 5-1 shows the location of the new fire station when reorganizing from four fire stations to three fire stations. Based on a previous study[12)], the location of the new fire station was set at 2-Chome, Shonetsu, Nagaokakyo City (near the Hankyu Nishiyama-Tennozan Station).

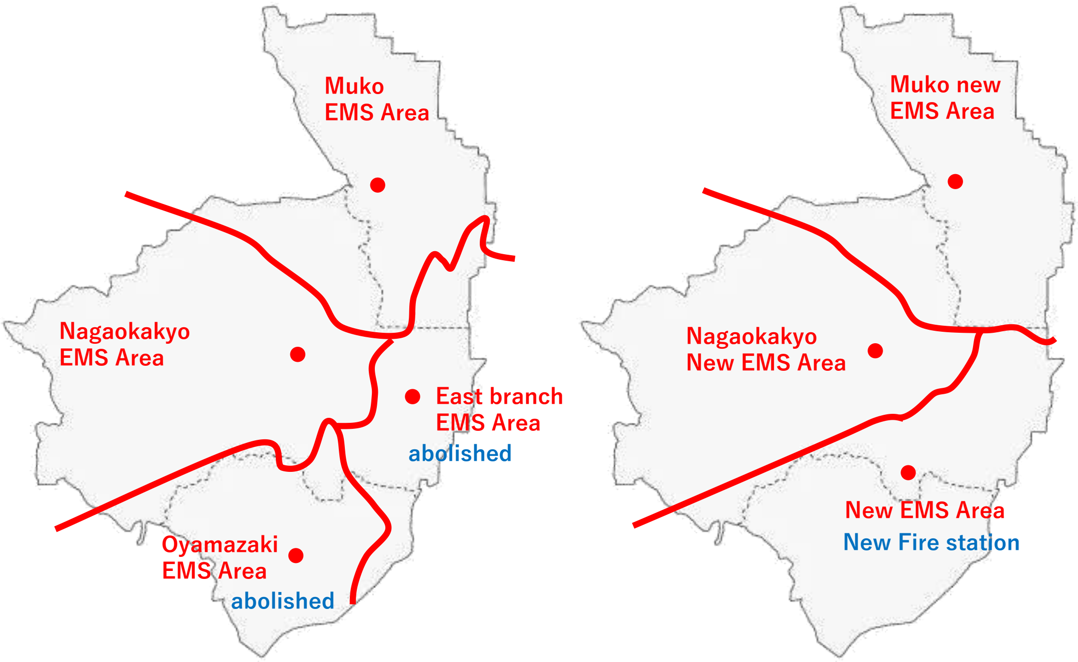

Figure 5-1 Map of the potential location of the new fire station when reorganizing from four fire stations to three fire stations

5.4 Calculation of on-scene arrival time when reorganizing from four fire stations to three fire stations

When the new fire station is located in its proposed location, the average on-scene arrival time at the three fire stations is calculated as shown in Table 5-5. The area of the nearest EMS team was recalculated and classified according to the road network when the three fire stations were used.

Table 5-5 On-scene arrival time for the three new fire stations

	New Muko EMS team	New Nagaokakyo EMS team	New EMS team
New Muko EMS area	6.10	8.73	12.50
New Nagaokakyo EMS area	8.61	6.33	9.18
New EMS area	10.92	8.21	6.02

5.5 Calculation of total on-scene arrival time at the three new fire stations after reorganization

To calculate the total on-scene arrival time, the number of EMS transports in the three fire stations after reorganization was calculated. The results are shown in Table 5-6.

The calculation here assumes that the ratio of backup emergency transports will remain the same as the current state with four fire stations.

Table 5-6 Number of emergency transports with three fire stations

	New Muko EMS team	New Nagaokakyo EMS team	New EMS team	Total
New Muko EMS area	2,085	667	221	2,974
New Nagaokakyo EMS area	77	1,233	480	1,790
New EMS area	67	151	1,286	1,505
Total	2,229	2,051	1,988	6,268

When the total on-scene time was calculated from Tables 5-5 and 5-6, the results are shown in Table 5-7.

Table 5-7 Total on-scene arrival time for three fire stations

	New Muko EMS team	New Nagaokakyo EMS team	New EMS team	Total
New Muko EMS area	12,712	5,826	2,768	21,306
New Nagaokakyo EMS area	663	7,806	4,408	12,878
New EMS area	732	1,242	7,738	9,712
Total	14,107	14,875	14,915	43,896

This total on-scene arrival time of 43,896 minutes is an increase of 2,237 minutes compared to the current total on-scene arrival time of 41,659 minutes. Although the current ratio of emergency transports to support teams was taken into account, the number of transports and total on-scene arrival time required by each EMS team shows that the difference in burden is approximately 10% in all cases, which suggests that the burden is relatively evenly distributed at the current ratio of emergency transports to support teams.

5.6 Calculation of total on-scene arrival time for ideal EMS supporting transport at three fire stations after reorganization

The ideal case of EMS supporting transport at the three fire stations was examined. In order to calculate the total on-scene arrival time, the number of EMS transports was first calculated for the ideal case of transport at the three fire stations. The results are shown in Table 5-8.

Table 5-8 Number of emergency transports under ideal conditions with three fire stations

	New Muko EMS team	New Nagaokakyo EMS team	New EMS team	Total
New Muko EMS area	2,974			2,974
New Nagaokakyo EMS area		1,790		1,790
New EMS area			1,505	1,505
Total	2,974	1,790	1,505	6,268

The total on-scene arrival time was calculated using the same method as in 5-1, and the results are shown in Table 5-9.

Table 5-9 Total on-scene arrival time when transportation is ideally performed by three fire stations

	New Muko EMS team	New Nagaokakyo EMS team	New EMS team	Total
New Muko EMS area	18,130			18,130
New Nagaokakyo EMS area		11,334		11,334
New EMS area			9,051	9,051
Total	18,130	11,334	9,051	38,515

This total on-scene arrival time of 38,515 minutes is 3,144 minutes less than the current total on-scene arrival time of 41,659 minutes. When ideal transport operations are performed, the burden ratio for each EMS team will decrease, but the Muko EMS team will have a higher burden ratio than under the current situation, which assumes the presence of backup EMS transports. Since the occurrence of transports in the Muko area cannot be reduced, we think that efforts to compensate for the burden on the Muko EMS team are necessary.

5.7 Change in total on-scene arrival time by EMS support ratio with the four current fire stations

This study was conducted using emergency transport data collected in fiscal year 2016. Based on this data, we considered what would happen if the number of support emergency transports changed from the current situation. The total on-scene arrival time was calculated for the situation where the ratio of emergency transports in support changed in 5% increments from 0% to 30%; the difference from the total on-scene arrival time calculated in Table 5-2 was also calculated. The results are shown in Table 5-10.

Table 5-10 Change in total on-scene arrival time by EMS support ratio with the four current fire stations

EMS support ratio (%)	Total on-scene arrival time (min)	Difference from the total on-scene arrival time (min)
0	37,274	-4,385
5	38,021	-3,638
10	38,768	-2,891
15	39,514	-2,145
20	40,261	-1,398
25	41,008	-651
30	41,754	95

With four fire stations, the total on-scene arrival time would change significantly if the current ratio of EMS transports to the scene was reduced to 0%, from the current ratio of 29.2%. The table shows that a 10% decrease in the ratio of backup transports leads to a reduction in on-scene arrival time of under 1,500 minutes, which translates into a reduction of approximately 0.24 minutes per EMS transport. Therefore, the lifesaving rate is expected to increase by that amount as per Kahler's lifesaving curve.

5.8 Change in total on-scene arrival time by EMS support ratio with three fire stations after reorganization

Table 5-11 shows the change in total on-scene arrival time as a function of the percentage of EMS transports provided by three fire stations after reorganization, using the same method as in 5.7. The total on-scene arrival time was calculated for each 5% change in EMS support ratio from 0% to 30%, and the difference from the total on-scene arrival time calculated in Table 5-2 was also calculated. The results are shown in Table 5-11.

Table 5-11 Change in total on-scene arrival time by EMS support ratio at three fire stations after reorganization

EMS support ratio (%)	Total on-scene arrival time (min)	Difference from the total on-scene arrival time (min)
0	38,515	-3,144
5	39,523	-2,136
10	40,530	-1,129
15	41,538	-121
20	42,546	887
25	43,553	1,894
30	44,561	2,902

The table shows that the difference from the current total on-scene arrival time is less than 0 when the ratio of support transport is less than 15%. The table shows that a 10% decrease in the ratio of backup transports leads to a reduction in on-scene arrival time of about 2,000 minutes, which translates into a reduction of approximately 0.31 minutes per EMS transport. The reduction in the ratio of emergency transports to support three fire stations is greater than the reduction in the ratio of emergency transports to support four fire stations. This indicates that the importance of individual fire department functions is high when the number of fire stations is reduced to three.

6. Calculation of benefits from increased emergency lifesaving rate by improving the EMS support ratio

6.1 Methodology for calculating the benefits from increased emergency lifesaving rate by improving the EMS support ratio

The current ratio of EMS supporting transports is 29.2%, and we believe that reducing this ratio will enable more efficient transport operations in the area nearest to the EMS team. Efficient transport operations can be expected to reduce the total on-scene arrival time, leading to an improvement in the emergency lifesaving rate for those being transported. In this study, we calculated and quantified the actual emergency lifesaving rate benefits.

The benefit calculation formula actually used by Yamanashi Prefecture Office can calculate the benefits of increased emergency lifesaving rate by improving the EMS support ratio. [10)]

Equation (2) shows the benefit of reducing the amount of human loss and the number of fatalities by reducing on-scene arrival time through efficient improvement of emergency transport operations by appropriately staffing and reorganizing projects.

$$B = LR\,(To - Tw) \cdot CN \cdot AP \cdot \sigma \quad (2)$$

B: Benefit from increased emergency lifesaving rate (yen/year)

LR: Lifesaving improvement per minute (3%/minute)

50% increase in the lifesaving rate in 15 minutes at Kahler's lifesaving curve (massive bleeding)

To: Current on-scene arrival time (minutes)

Tw: On-scene arrival time at reorganization (minutes)

$\therefore$ $(To - Tw)$: On-scene arrival time reduced by realignment (minutes)

CN: Per-capita per-carriage mortality rate (0.0559%)

Calculated from FY 2018 number of deaths during transport/population = 82/146,775 = 0.0559%.

AP: Population of Otokuni area 146,775

σ: Human losses due to deaths (226 million yen/person)

Calculated from the Ministry of Land, Infrastructure, Transport and Tourism's "Technical Guidelines for Cost-Benefit Analysis of Public Works Evaluation (Common Edition)"[11)]

6.2 Benefits from increased emergency lifesaving rate by improving the EMS support ratio for the four current fire stations

Table 6-1 below shows the benefit of increased emergency lifesaving rate when the EMS support ratio changes in 5% increments from 0% to 30% using the difference between the total on-scene arrival time calculated in Table 5-10 and Equation (2).

Table 6-1 Benefits from increased emergency lifesaving rate by improving the EMS support ratio for the four current fire stations

EMS support ratio (%)	Benefits from increased emergency lifesaving rate (100 million yen)
0	3.89
5	3.23
10	2.57
15	1.90
20	1.24
25	0.58
30	-0.08

The social benefit increases with a decrease in the EMS supporting ratio from the current ratio of 29.2%, because the social benefit depends on the difference in on-scene arrival time due to the ratio of EMS supporting transports.

6.3 Calculation of benefits from increased emergency lifesaving rate by improving the EMS support ratio for three fire stations after reorganization

Table 6-2 shows the benefits of increased emergency lifesaving rate when the EMS support ratio changes in 5% increments from 0% to 30% using the difference between the total on-scene arrival time calculated in Table 5-11 and Equation (2).

Table 6-2 Benefits from increased emergency lifesaving rate by improving the EMS support ratio for three fire stations after reorganization

EMS support ratio (%)	Benefits from increased emergency lifesaving rate (100 million yen)
0	2.79
5	1.90
10	1.00
15	0.11
20	-0.79
25	-1.68
30	-2.58

Compared to the benefits in the case of four fire stations, the benefit of 279 million yen when the EMS support ratio was 0% for three fire stations was lower. However, since the benefit per EMS transport is higher for three fire stations, it can be said that if the ratio can be reduced below 15%, the current EMS service can be maintained.

7. Calculation of annual per-year cost savings after reorganization

Based on the results up to Chapter 6, the benefits of eliminating one fire station are calculated. Specifically, we consider the case where the functions of the East Branch Fire Station and Fire Department Headquarters are transferred to a new fire station, and the Oyamazaki Fire Station is abolished. In this chapter, we focus on the expenditures of the Otokuni Fire Department and assume that personnel costs, building maintenance costs, and general administrative costs will be reduced. Table 7-2 shows the expenditure data of the Otokuni Fire Department in 2020 from the Otokuni Fire Association's publication[11)]. In addition, the cost of transferring the functions of the East Branch Fire

Station and the Fire Department Headquarters to the new fire station and the cost of building a new fire station are not taken into account.

Personnel costs are calculated by dividing the total expenditures by the total number of employees to obtain per capita income, which is then multiplied by the number of employees that could be reduced. The Otokuni Fire Department currently has 186 firefighters, of which the two in charge of general affairs at the Oyamazaki Fire Department could be reduced. Other emergency personnel are not reduced because they are considered necessary in the reorganized fire department.

The general administration and building maintenance costs will be reduced by the ratio of the total area of the Oyamazaki fire station to the total area of the four fire stations in the Otokuni Fire Department. The table below shows the percentage of total floor space. Table 7-1 shows that the Oyamazaki Fire Station occupies 15% of the total floor space, which can be reduced by this percentage. The amount of possible reduction is calculated from the above expenditure amounts.

Table 7-1 Ratio of total floor area at each fire station in the Otokuni District [12)]

	Total floor area (m^2)	Ratio (%)
Muko fire station	1,644	23.0
Nagaokakyo fire station	1,458	20.5
East branch fire station	2,966	41.5
Oyamazaki fire station	1,075	15.0
Total	7,143	100.0

Table 7-2 Reduction of costs after reorganization

	Costs (thousand yen)	**Reduction of costs** (thousand yen)
Personnel costs	1,541,616	16,576
General affairs costs	35,540	5,348
Office maintenance costs	36,060	5,426
Total costs	1,629,396	27,352

The total expenditure for the Otokuni fire department in 2020 was 1,629,396 (thousand yen), and we consider a possible reduction of 27,352 (thousand yen) after reorganization.

8. Conclusion

We are faced with the question of how fire departments should be reorganized, integrated, and maintained from the viewpoint of protecting the lives, bodies, and the property of residents. Such activities must still ensure the level of services to residents, such as emergency transport, with limited personnel, facilities, equipment, and vehicles under severe financial conditions. In order to solve such problems or to lead the fire department in a better direction, we believe that it is very important to first quantify and demonstrate the workload that fire departments face. Qualitative discussions tend to follow existing policies, which increases the likelihood that discussions about restructuring and consolidation of fire stations will not proceed. In the case of multiple fire stations, it is important to quantitatively consider measures to distribute operations in a well-balanced manner. This is important from the perspective of risk diversification and to maintain the motivation of those engaged in the work. Therefore, in this study, the burden of emergency transport operations was assessed and evaluated.

The number of personnel and vehicles of the EMS team at the fire station is 42, which is almost the same as the number of personnel at the Muko Fire Station and the Nagaokakyo Fire Station because the fire station is currently located in the Nagaokakyo East Division, which has less workload. We believe that the allocation of staffing may be considered in line with the number of transports. The total number of transports by area shows that the Muko area has the largest number of EMS transports and that the processing rate for each EMS team is 92.8% for the Muko EMS team and approximately 60% for the other EMS teams, suggesting that the burden on the Muko EMS team is being covered by the other EMS teams. Since the current EMS support ratio is 29.2%, we believe that reducing the ratio of emergency transports in support through appropriate staffing and vehicle allocation will lead to a reduction in the overall burden on the area.

In Chapter 4, a comparison of the total on-scene arrival time of an ideal transport situation in the current four-station structure and the actual situation shows a possible reduction in transport time of 4,385 minutes, which is equivalent to 675 cases since the average total on-scene arrival time is currently 6.5 minutes. This translates into a reduction of approximately 42 seconds per case.

Furthermore, when the on-scene arrival time was examined when the fire stations were reorganized into three fire stations, the total on-scene arrival time was calculated to be 43,896 minutes, which is an increase compared to the current total on-scene arrival time for four fire stations; therefore, if the ratio of emergency transports for support is not reduced, the current emergency transport time will increase. The situation means that the current EMS level cannot be maintained. Therefore, it is necessary to consider the deployment of personnel to reduce the number of backup EMS transports when the number of fire stations is reduced to three. The total on-scene arrival time would be 38,515 minutes if all EMS transports at the three fire stations could be performed in an ideal manner, which is 3,144 minutes less than the current total on-scene arrival time. This translates into a reduction of 484 cases in terms of the number of transports. However, even in this case, the burden on the Muko

EMS team is the highest, and the total arrival time of the new EMS team is nearly double the expected time. We believe that the level of EMS transport at the current four fire stations can be increased by decreasing the EMS support ratio. When the number of fire stations is reduced to three, the total on-scene arrival time will be reduced to 15% or less compared to the current level.

In Chapter 6, we determined that the annual benefit of improving emergency lifesavings is 279 million yen/year when the EMS support ratio is 0%, which is less than the 389 million yen/year benefit when the ratio of emergency transports to support services is 0% with four fire stations. However, since the benefit per support transport ratio is higher with three fire stations, it can be said that if the ratio can be reduced below the current ratio of 15%, which is the ratio that can maintain the current state of transport operations, the effect on the EMS support ratio is higher than if the current EMS support ratio of 29.2% with four fire stations is reduced.

In Chapter 7, the annual cost reduction effect of reorganizing to three fire stations was examined. In this chapter, the cost reduction was examined in consideration of the actual expenditure amount, resulting in a reduction of 27 million yen/year, or 1.67% of the total expenditure. This value is equivalent to about 2% in the case of four fire stations and about 1.5% in the case of three fire stations when considering the decrease in the ratio of backup transports to increase the benefits of emergency lifesavings. So, the decrease in the ratio of backup transports is considered to be highly important.

In conclusion, we have quantitatively clarified that the effect of the reduction in the ratio of emergency transports by support staff, i.e., the optimization of staffing according to the status of emergency transports, is much greater than the effect of various cost reductions. Although this study evaluated the burden through network analysis, it has yet to be analyzed with actual staffing under review. Therefore, we would like to conduct a study of the optimal allocation of ambulances, an analysis of transports when the allocation of ambulances is taken into consideration, and proposals and analysis of work schedules that take into account the current low number of transports during the late-night hours.

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