Article

A study on GIS-based spatial analysis of emergency response for disaster management: Focusing on Seoul

Hyun Soo Park, Seol A Kwon

National Crisisonomy Institute, Chungbuk National University, 1 Chungdae-ro, Seowon-Gu, Cheongju, Chungbuk, Korea

Abstract: This study aims to analyze the operation of fire emergency dispatch, understand the impact of golden time on fire emergency dispatch, and identify factors and improvement measures for effective fire emergency dispatch within prime time. According to the results of the study, rescue dispatch activities varied depending on the nature of the incident. The summer season had a higher number of calls than other seasons, and Saturday was the day of the week with the highest number of calls. When analyzing the spatial distribution of rescue incidents, we found that rescue incidents were concentrated in some areas. In particular, the arrival time tended to be relatively long in areas south of the Han River and in areas where some fire stations or safety centers were not deployed. We also found that rescue incidents dispatched by stations other than neighboring stations were also concentrated in certain points. Based on these findings, the following policy implications can be drawn: First, the location of fire stations or safety centers should be adjusted; second, dispatch personnel and equipment should be strengthened; third, inter-agency cooperation should be strengthened; and fourth, prevention and education programs should be strengthened. Implementing these policy recommendations will improve fire emergency services' efficiency and response capabilities and minimize the occurrence and damage of life-saving events.

Keywords: spatial autocorrelation; travel time; distance by road ; emergency response; GIS

1. Introduction

Emergency dispatch plays a pivotal role in safeguarding lives and property during fire incidents, disasters, or emergencies in a firefighting organization. The efficient management of emergency response time is critical for the success of rescue operations and the overall survival rates. This necessitates the timely execution of rescue operations through prompt responses and actions within a specific time frame referred to as the "golden time" (Xiao-tao & Li-ping, 2011; Hwang, et. Al., 2018; Seo, et. Al.,2022).

The golden time for emergency response in firefighting is characterized by a highly restricted timeframe, which is subject to variation based on the intricacy and gravity of the emergency situation. Delayed responses to emergencies significantly diminish the prospects of survival for individuals requiring rescue, while concurrently exacerbating the magnitude and scope of the disaster. Consequently, it is imperative for fire and emergency services to optimize this limited golden time by executing swift and efficient rescue operations, thereby maximizing their effectiveness. (Weinholt & Andersson Granberg, 2015; O'Grady, 2014; Jaldell, 2017).

Conducting research on EMS response times in the context of firefighting holds paramount significance for fire and disaster management agencies, first responder organizations, and relevant professionals. Such research endeavors enable a comprehensive comprehension of the impact of the golden time in fire emergency dispatch on real-life emergency scenarios. Furthermore, by identifying pertinent factors and implementing enhancement strategies pertaining to efficient fire emergency dispatch, the efficacy and triumph rates of emergency rescue operations can be markedly improved. (Koester & Greatbatch, 2020; Chen, et. Al., 2020; Wang, et. Al., 2013).

The primary objective of this study is to conduct a comprehensive analysis of the operational dynamics of fire emergency medical services (EMS) and to acquire an extensive comprehension of the ramifications of prime time on fire EMS. Through this investigation, the study aims to identify the critical factors and propose improvement measures that effectively optimize the provision of fire EMS services within prime time. The findings and recommendations derived from this research endeavor are anticipated to substantially enhance the overall performance of fire emergency services and mitigate the adverse consequences in emergency situations. (Hao-wei, et. Al., 2011; Murphy & Greenhalgh, 2016).

2. Data and Method

2.1. Data

This study focuses on investigating the spatial patterns of dispatch to arrival times for critical life-saving incidents in the city of Seoul. Firefighting operations play a pivotal role in ensuring public safety, often necessitating prompt response times. Consequently, the duration between dispatch and arrival at the incident scene holds significant importance.

Therefore, the aim of this research is to analyze the spatial distribution of rescue dispatch times in Seoul and identify regions characterized by comparatively delayed response times. Such analysis is crucial for identifying areas where improvements are needed to enhance the efficiency and timeliness of emergency rescue operations.

For this purpose, we used information from the 500m×500m grid map of Seoul (3,227 grids) provided by the Geospatial Information Platform Geo-statistical Map (https://map.ngii.go.kr/) to identify the characteristics of space in Seoul.

Next, to examine the rescue dispatch of fire-fighting, we used the "Seoul Rescue Dispatch Status" data from the Fire Safety Big Data Platform (https://www.bigdata-119.kr/). This data is based on 846,384 disaster rescue reports from 2017 to 2022 and contains various information such as the cause of the accident, report, dispatch, and arrival date, coordinates of the arrival point, and the dis-patching fire station or safety center. From these data, we excluded data that did not contain the co-ordinates of the arrival point. The results of each call were safety measures (593,676), life search (14,895), and life rescue (83,701). The purpose of this study is to identify areas where there is a relative delay in arriving at the scene, centered onincidentss that require urgent arrival, so the data corre-

sponding to life saving is selected from the pro-cessing results. In addition, in the case of incidents in mountains or rivers, the time required to arrive at the scene is relatively long due to the characteristics of the location or because it is mainly handled by mountain rescue teams or water rescue teams. Therefore, it is difficult to treat it together with other incidents, so it was excluded. In addition, there are cases where two or more fire departments or safety centers respond to the same incident to-gether, so in these cases, we selected only the data that arrived at the arrival point the fastest, and fi-nally analyzed 56,514 cases in the study.

For the locations of fire stations, safety centers, and rescue teams in Seoul, we used 'Seoul Fire Sta-tion, Safety Center, and Rescue Team Location In-formation' from the Open Government Data portal (https://www.data.go.kr/). We excluded incidents that occurred in mountains or rivers from the rescue dispatch status data, so we excluded information on mountain rescue teams and water rescue teams from this data.

2.2. Method

In order to examine the time taken from rescue dis-patch to arrival at the scene in Seoul by region, the coordinates of the arrival point in the rescue dis-patch data were linked to the grid data to be in-cluded in the grid corresponding to the arrival point, so that the number of rescue dispatches and related information per rescue dispatch could be identified for each grid.

Ideally, the fire department or safety center that re-sponds to an incident will be the closest station. However, if that station has just responded to an-other incident, they may have to respond from a dif-ferent station. In this situation, the time from dis-patch to arrival at the scene is likely to be longer. In this study, we want to assume that this is also a fac-tor that can affect travel time. To examine this, we selected the second closest fire station or safety cen-ter in a straight line from the centroid of each grid, and defined "non-neighboring stations" as stations other than the second closest station. This allows us to compare the proportion of rescues within each lattice that were responded to by neighboring de-partments to those that were responded to by non-neighboring de-partments.

Spatial understanding is necessary to obtain a va-riety of information about a space. Among them, "spatial autocorrelation" is a concept that indicates the degree to which the values of a particular region are similar to the values of its neighborhood. This allows us to identify spatially consistent patterns. Spatial concentrations, such as clusters or hotspots, which are common in many distributions that can occur in space, indicate a pattern of clustering of phenomena in a particular space. This is related to Tobler's (1970: 236) first law of geography ("Eve-rything is related to everything else, but near things are more related than distant things").

The first method to identify these patterns of spa-tial distribution is Global Moran's I. This method can test whether there is spatial autocorrelation across the space, i.e., it can analyze whether local distribution patterns are clustered or random. This method can verify whether there is spatial autocor-relation throughout the space, i.e., it can an-alyze whether the local distribution pattern is clustered or random (Lim et al., 2017).

Although the global Moran I can give an idea about the self-correlation of the target area, it is dif-ficult to see which areas are clustered when the size of the target area is very large. Therefore, Anselin (1995) developed the Local Indicator of Spatial As-sociation (LISA) metric to measure spatial autocor-relation at the local level, and one of these methods, Local Moran's I, can reveal the spatial clustering pattern in detail by exploring the clusters of hot and cold spots where observations are concentrated (Jung & Son, 2009).

3. Result

Let's take a look at the status of rescue activities by occurrence characteristics. First, <Table 1> shows the status of rescue dispatch by season. By season, summer accounted for 27.7%, which is rel-atively high compared to other seasons. The lowest season was fall with 23.2%.

<Table 1> Rescue Dispatch Status by Season

Season	n	%
Spring	13,189	23.3
Summer	15,652	27.7
Autumn	13,128	23.2
Winter	14,545	25.7
Total	56,514	100.0

The following <Table 2> shows the status of res-cue calls by day of the week. By day of the week, Saturday is the most common day of the week (14.9%), but there is not much difference between the days except Sunday.

<Table 2> Rescue dispatch status by day of the week

Day	n	%
Monday	8,183	14.5
Tuesday	7,976	14.1
Wednesday	8,213	14.5
Thursday	8,062	14.3
Friday	8,082	14.3
Saturday	8,443	14.9
Suday	7,555	13.4
Total	56,514	100.0

The breakdown of rescue calls by time of day is shown in Table 3. First of all, when looking at the total number of cases, the percentage of rescue calls from 00:00 to 07:00 was within 4%. From 08:00 to 21:00, the rate was relatively high compared to the previous time period, ranging from 4 to 6%, and from 22:00, the rate decreased again.

<Table 3> Rescue dispatch status by time of day

Hour	Total number of cases		Number of arri-vals over 7 minutes	
	n	%	n	%
00	2,081	3.7	90	4.3
01	1,638	2.9	58	3.5
02	1,422	2.5	61	4.3
03	1,146	2.0	53	4.6
04	1,102	1.9	36	3.3
05	1,158	2.0	44	3.8
06	1,560	2.8	63	4.0
07	1,971	3.5	93	4.7
08	2,338	4.1	112	4.8
09	2,733	4.8	118	4.3
10	2,842	5.0	129	4.5
11	2,652	4.7	137	5.2
12	2,685	4.8	128	4.8
13	2,658	4.7	138	5.2
14	2,710	4.8	183	6.8
15	2,735	4.8	166	6.1
16	2,802	5.0	191	6.8
17	2,913	5.2	157	5.4
18	3,346	5.9	173	5.2
19	3,090	5.5	151	4.9
20	2,851	5.0	110	3.9
21	2,863	5.1	132	4.6
22	2,780	4.9	122	4.4
23	2,438	4.3	96	3.9
Total	56,514	100.0	2,741	100.0

Next, we looked at the incidents that took more than 7 minutes to arrive, and found that they were generally within 7%. When looking at the time of day, from 00:00 to 10:00, it was within 5%. From 11:00 to 18:00, the percentage is relatively high compared to other time periods, around 5-6%, and from 19:00, the percentage tends to decrease again. The proportion of rescues taking longer than 7 minutes is higher from 14:00 to 16:00 than from 08:00 to 09:00 and 18:00 to 19:00, which are the peak commuting hours. These results suggest that traffic is not the only factor affecting the time it takes to respond.

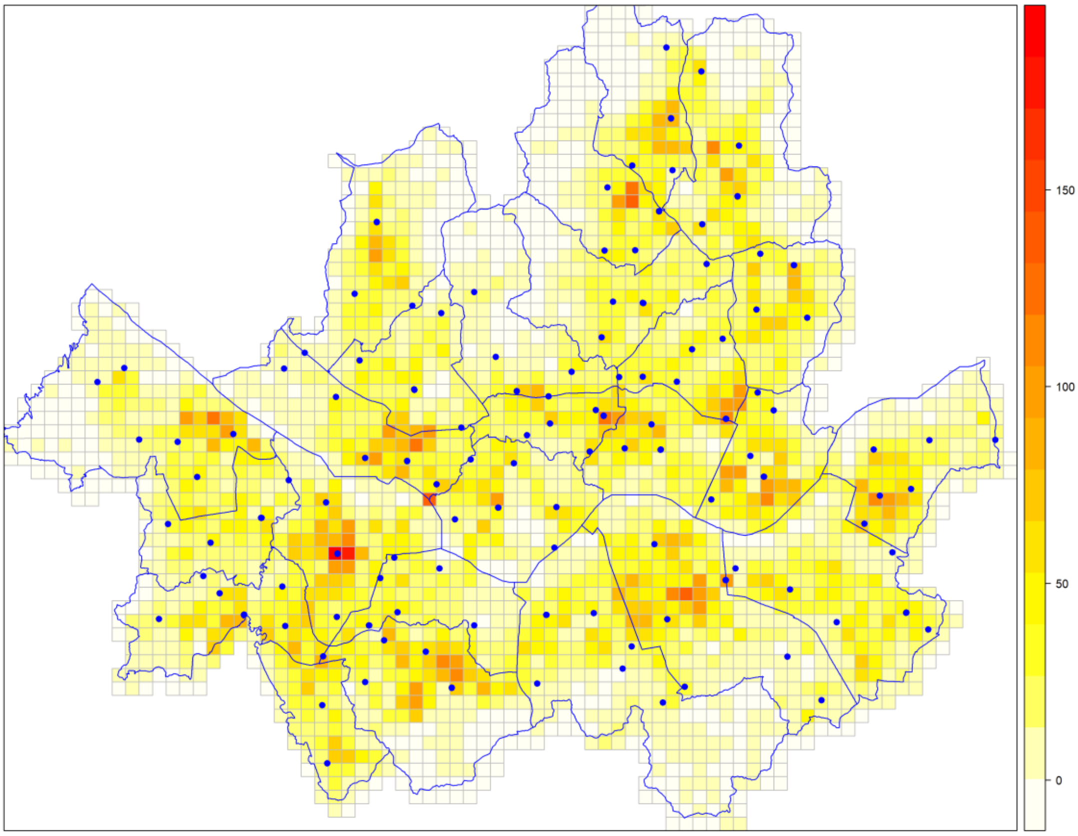

Figure 1. Distribution of all lifesaving events

Therefore, it is necessary to analyze the spatial characteristics of the occurrence area and the loca-tion of the dispatching fire station or safety center.

The spatial distribution of life-saving events is shown in Figure 1. The points in the figure are fire stations or safety centers. The maximum number of lifesaving events within a grid was 184, with an av-erage of 26.88. As shown in the figure, life-saving events are not evenly distributed across all regions, but are concentrated at certain points (Moran's I=0.45, $p < .000$).

Next, the distribution of rescues with arrival times of 7 minutes or more among all rescues is shown in Figure 2. Within a grid, the maximum number of calls with arrival times greater than 7 minutes was 15, and the average was 1.08. As shown in the fig-ure, the distribution of dispatches with arrival times of 7 minutes or more appears to be clustered in cer-tain neighborhoods (Moran's I=0.26, $p < .000$).

Upon examining the grid-based analysis, it becomes evident that certain areas exhibit a considerable frequency of incidents with arrival times exceeding 7 minutes. Notably, these areas encompass both locations that are situated far away from fire stations or safety centers, as well as those that are in close proximity to such facili-ties.

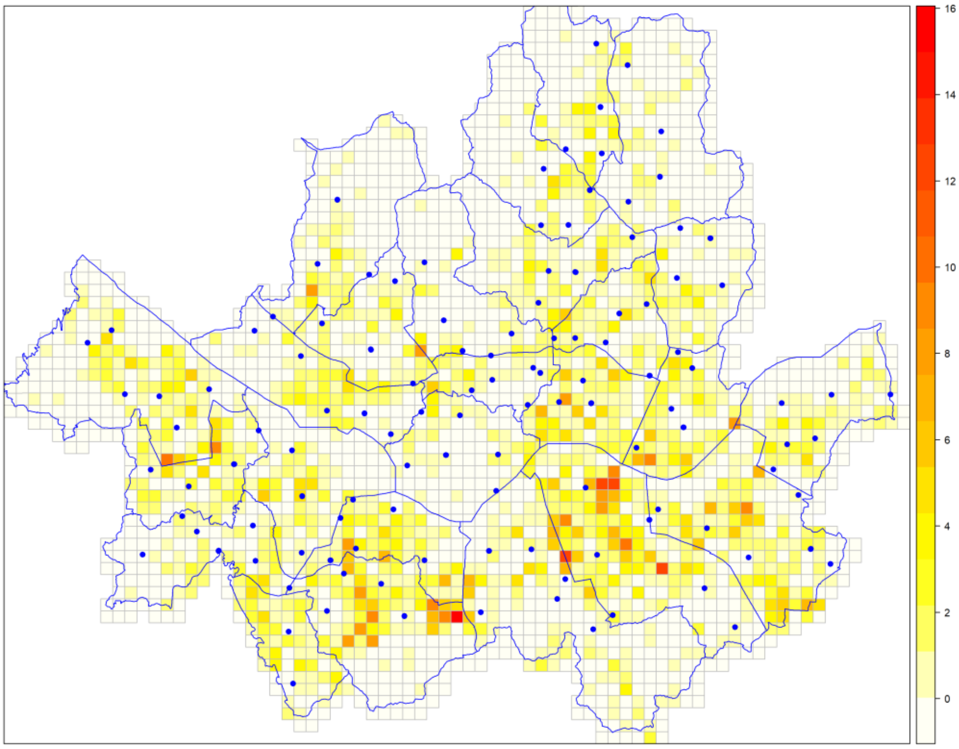

Figure 2. Distribution of lifesaving events 7 minutes or more after arrival

Next, we looked at the clustering patterns of re-gions within the grid by the number of rescue inci-dents with arrival times greater than 7 minutes, as shown in Figure 3.

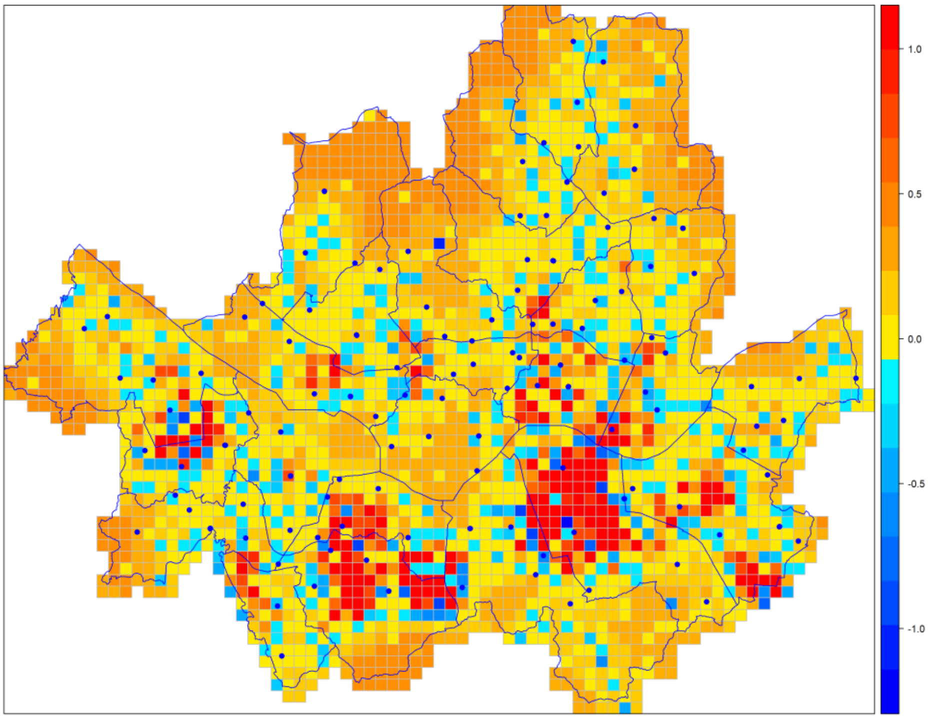

Figure 2. Local autocorrelation of lifesaving events >7minutes of arrival.

Looking at the spatial pattern of life-saving in-cidents that took more than 7 minutes from dis-patch to arrival at the scene, it is generally found that they are relatively distributed in areas south of the Han River. In particular, the hotspots in Gangnam-gu are widely distributed. While it can be assumed that this is a high-traffic area that takes longer to reach, it is also possible that there are not many fire stations or safety centers in the area.

Also, in the case of Songpa-gu, this result can be attributed to the relatively wide spacing between fire stations or safety centers. In particular, in the southern part of Songpa-gu, the distance to the fire station or safety center is considerable enough that it can be seen as a blind spot.

In other parts of the world, the spacing between fire stations and safety centers tends to be concen-trated in relatively large areas.

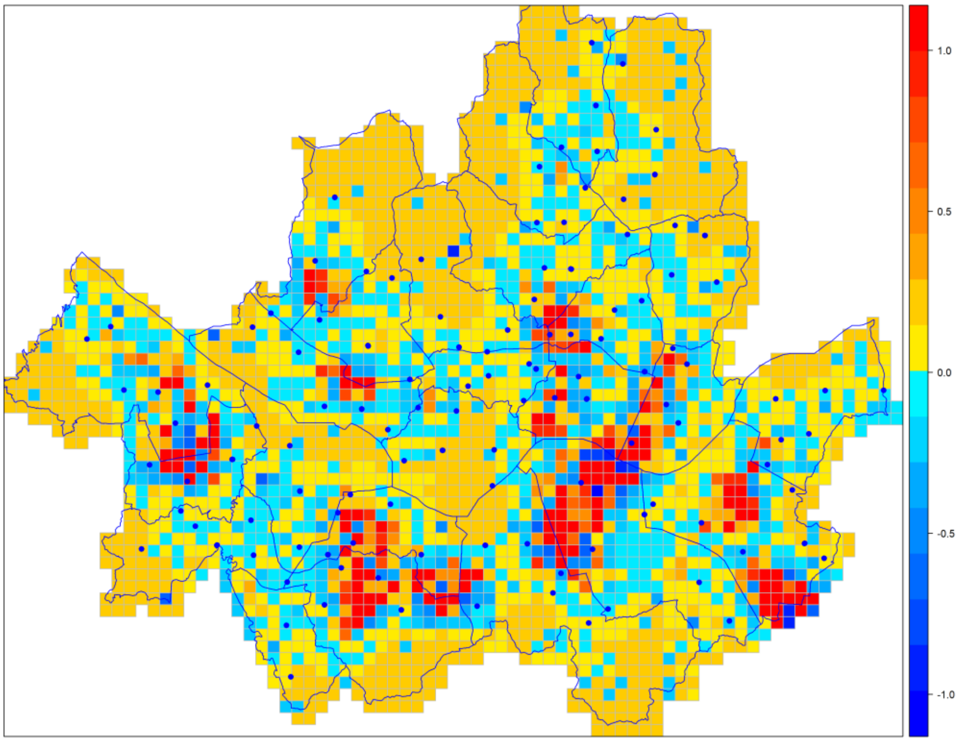

Figure 3. Local autocorrelation of life-saving incidents 7 minutes or more from

For the purposes of this study, we assumed that the time to scene would be af-fected if the call came from a location other than the nearest fire station or safety center. The results of this study are shown in Figure 4. For each grid, the maximum number of calls from non-adjacent sta-tions was 12, with an average of 0.57. The number of lifesaving incidents from non-neighboring sta-tions is not evenly dis-tributed across all neighbor-hoods, but is concentrated at certain points (Moran's I=0.19, $p < .000$).

Compared to the results in Figure 3, we don't see a significant difference for re-gions with a wide distribution of hotspots.

4. Conclusions

The purpose of this study is to analyze the ac-tual operation of firefighting emergency medical services, broadly understand the impact of golden time on firefighting emergency medical services, and identify factors and improvement measures for effective firefighting emergency medical services within golden time.

The results of the study show that rescue call activity varies depending on the characteristics of the occurrence. By season, the number of rescue calls was relatively high in summer compared to other seasons, and by day of the week, the most rescue calls occurred on Saturdays. By time of day, the number of rescue calls was higher from 08:00 to 21:00, and the rate of rescue calls was higher from 14:00 to 16:00 during rush hour.

In addition, when we analyzed the spatial distribution of life-saving incidents, we found that rescue dispatch incidents were concentrated in some areas. In particular, the arrival time tended to be relatively long in areas south of the Han River and in areas where some fire stations or safety centers were not deployed.

In addition, we found that life-saving incidents from non-neighboring stations were concentrated at certain points.

Based on these results, it is necessary to analyze the spatial characteristics of the incident area and the location of the dispatching fire station or safety center, and to take supplementary measures, especially for areas with long arrival times. In addition, it was found that traffic volume alone does not affect the arrival time, so it is necessary to explore measures to improve the efficiency of rescue dispatch by considering various factors.

The policy implications of our conclusions can be summarized as follows.

First, the location of fire stations or safety centers.

As a complementary measure for areas with longer arrival times, additional fire stations or safety centers should be built or existing facilities should be relocated to suit the area. This will minimize dispatch times and allow for faster response times to life-saving incidents.

Second, we need to increase the number of responders and equipment. It is necessary to strengthen the firefighting personnel and equipment that respond to times and areas with a high number of rescue calls. In particular, response capabilities can be improved by appropriately deploying responders during rush hours and in areas where life-saving incidents are concentrated.

Third, strengthen cooperation between stations.

As life-saving incidents involving responders from non-neighboring stations are concentrated at certain points, it is important to strengthen cooperation between stations.

Establishing systems and processes for information sharing and effective collaboration in emergency situations can improve the efficiency of rescue dispatch.

Fourth, strengthen prevention and education programs. Since rescue calls are reactive, it is necessary to minimize the number of life-saving incidents through prevention and education. It is important to activate prevention campaigns and safety education programs to strengthen citizens' ability to recognize and proactively deal with dangerous situations. In addition, education on fire prevention and response should be provided to help citizens recognize fire hazards and respond appropriately.

Implementing these policy implications can improve the efficiency and responsiveness of fire first responder dispatch and minimize the occurrence and damage of life-saving events.

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Profile

Hyun Soo Park (chaos51@hanmail.net)

He received his Ph.D. from Korea University, Korea in 2008. He is a Leader of Center for Citizen Safety Research of National Crisionomy Institute(NCI), Chungbuk National University.

Seol A Kwon (@chungbuk.ac.kr)

She received her Ph.D. from Chungbuk National University, Korea in 2017. She is a Leader of Center for Disaster Safety Innovation of National Crisisonomy Institute(NCI), Chungbuk National University.