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Research paper

Development and Verification of Fire Service Area Re-division and Fire Fighter Deployment Methodologies using Census Spatial Data

Ji-Soo Lee[1], Yoon-Ha Lee[2], Hyun-cheol Seo[2] and Won-Hwa Hong[3]*

[1] Assistant Professor, Department of Fire Safety, Kyungil University, Gyeongsan, Korea
[2] Doctor's course, School of Architecture, Civil, Environmental and Energy Eng.
Kyungpook National University, Daegu, Korea
[3]Professor, School of Architecture, Civil, Environmental and Energy Eng.
Kyungpook National University, Daegu, Korea
**Corresponding author: hongwh@knu.ac.kr*

Abstract

The South Korean fire service force deployment criteria have insufficient considerations compared to the US, the UK, and Japan, and even when compared with OECD countries, the national criteria for fire service forces should be improved. In particular, the criteria for division of fire service areas are concentrated on administrative districts so that the response times of actual front line fire houses cannot but be much different among regions. In addition, since the numbers of residents under each fire fighter's charge show larger differences among lower organizations, technical methodologies to respond to such differences should be urgently developed. Therefore, in this study, fire service areas were redivided based on accessibility utilizing census polygon data and fire fighters were reorganized using the population attribute information embedded in the data. The methodology presented in this study was applied to the target area to quantitatively evaluate the degrees to which the differences in the numbers of residents under one fire fighter's charge and the accessibility were improved.

Keywords: *Census Spatial Data, Fire Service Area, Deployment Methodology, GIS*

1. Introduction

Recently, urban fires have been becoming more complex and larger and accordingly, studies intended to improve the criteria for the deployment of fire service forces in charge of relief services have been conducted steadily.

In particular, in the case of South Korea, a survey indicated that the number of persons under each fire fighter's charge reached 1,579 as of last year. According to the domestic criteria for fire fighter deployment, the number of fire fighters for field activities should be at least 51,714 arithmetically and there is a shortage of 19,254 fire fighters based on the minimum standard. In addition, with regard to the deployment of fire service forces, the existing fire service areas were divided with the boundaries of administrative districts and the numbers of fire fighters were calculated based on the numbers of fire engines.

To solve these problems, previous studies have presented population, areas, distances between 119 safety centers, the number of buildings, and the number of dangerous articles as variables that must be considered for the criteria for fire service forces. However, since actual operation of domestic fire service forces is delegated to local governments, the abovementioned variables have remained as long-term alternatives due to the lack of practical budgets and technical limitations.

In previous studies, we have verified by engineering that the imbalance in fire service areas might be shown to be larger among the spatially lower ranked areas. Therefore, in this study, based on the verified data, a methodology was presented to minimize differences among areas by optimizing accessibility through the reorganization of the current fire fighters and areas without any increase in the number of fire fighters or establishment of new centers and adjusting the number of residents under each fire fighter's charge. In particular, a bottom-up method that enables expansion to upper ranked areas through adjustments among minimum spatial units constituting the fire service force deployment area was presented with a view to fundamentally solving the existing problems. In the reorganization of the fire service areas, it was verified that the adjustment among areas could be made in the smallest units utilizing the population census data.

In this study, the spatial scope was set as one district which is the minimum unit of fire service force areas, but it can be expanded to the scale of a city. Accordingly, the scope of the content is based on the areas of 119 fire houses, and qualitative characteristics such as fire fighters, equipment, and operation were excluded from the study.

2. Consideration of criteria for fire service force deployment

Domestic organizations refer to the fire houses, 119 fire houses, rescue fire fighting aviation units, fire fighting vessel units, and 119 regional units that conduct fire fighting by mobilizing fire fighting equipment or fire fighters. The criteria for deployment of fire engines to fire fighting organizations are determined considering the disaster risk factors, population, area, and the

characteristics of the targets of fire-fighting in the jurisdictions. Accordingly, the fire fighter deployment criteria for 119 fire houses currently in force are as Table 1.

However, the National Fire Agency introduced criteria for fire fighting organization rating and fire fighter calculation considering demand for fire fighting and regional characteristics in January 2018, which came into effect in February 2018. The details of the criteria present criteria for minimum numbers of fire fighters to deployed to 119 fire houses and the content is set forth as Table 2.

Table 1. Criteria of firefighter placement for 119 safety center

Fire Pumper Truck (1st)		Fire Pumper Truck (2nd)		Water Tank Truck		Ladder Truck		Chemical Truck		Command car		Ambulance	
A	B	A	B	A	B	A	B	A	B	A	B	A	B
3	9	3	6	3	3	3	6	3	9	3		3	9

A : Drive B : Extinguishment

Table 2. Deployment criteria for minimum numbers of fire-fighters

		1st Grade	2nd Grade	3rd Grade
Criteria	Population	More than 500,000	More than 250,000~Less than 500,000	Less than 250,000
	Number of target	More than 20,000	More than 10,000~Less than 20,000	Less than 10,000
	Safety Index	More than 300	More than 200~Less than 300	Less than 200
Fire Fighter		24	21	18

As for the methodology of this study, the range that can be reached by each fire house within the shortest time is derived regardless of the currently set fire service area. Through the foregoing, a methodology to reorganize the jurisdictions of individual fire houses based on the shortest arrival time is presented. The results derived through this process and the results from a certain target area for which access vulnerability was derived in an existing study are compared to verify the improvement effect.

That is, the method of analyzing the accessibility of the currently set fire house areas derives the arrive times only from the demand points within the designated area. However, the method of deriving the improved plan is to calculate the minimum times to reach a specific demand point from different fire houses to redivide the ranges of jurisdictions of the fire houses so that the fire house that shows the shortest arrival time has jurisdiction over the demand point.

As a technical method for carrying out this series of processes, the network analysis tool of Arc GIS is used to derive the arrival times to the demand point from individual fire houses. Here, the 119 fire house location information is used as the supply points. The centers of gravity in the census data that were accumulated with the minutest space division units among the demographic data constructed thus far were used as demand points.

Census data are the data in which the land of South Korea was divided into areas where around 500 to 1,000 reside by the National Statistical Office of South Korea considering physical environments such as terrains and roads through population and housing censuses. Therefore, individual census boundaries do not consist of the same population numbers.

3. .Method of Research

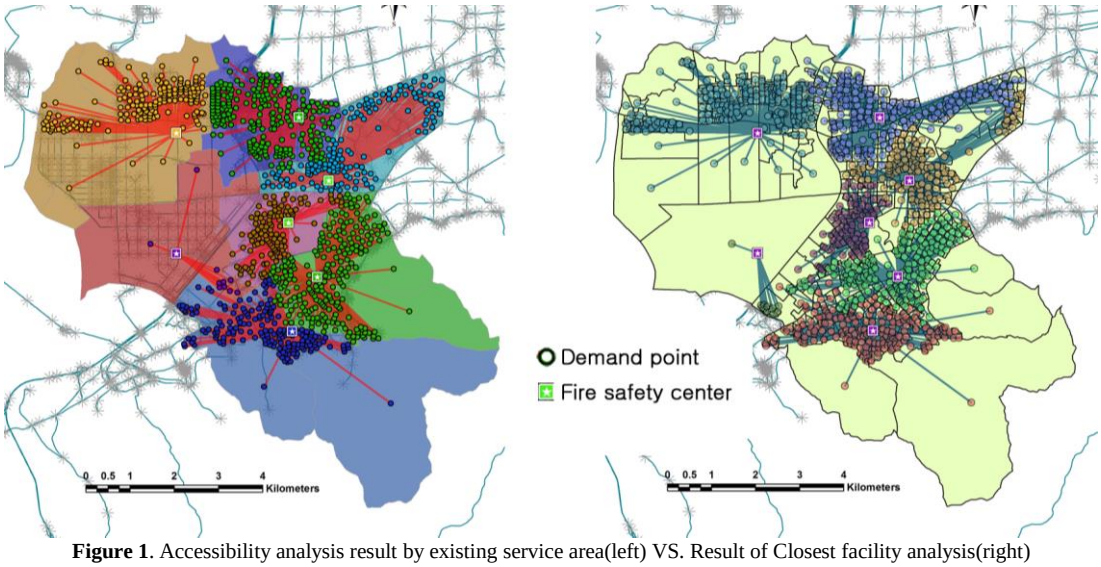

Figure 1. Accessibility analysis result by existing service area(left) VS. Result of Closest facility analysis(right)

The left figure in the Figure 1 is the results for analysis of the accessibility of existing fire houses and only the accessibility of the fire houses to the demand points existing in the ranges divided by colors is analyzed.

On the contrary, in the case of the right figure, multiple demand points that can be reached within the shortest time by each fire house are selected without any space restriction and the demand points assigned to individual fire houses do not overlap.

As described above, each demand point represents a census boundary and the concept of re-division of areas according to the census boundaries is expressed in the following Figure 2.

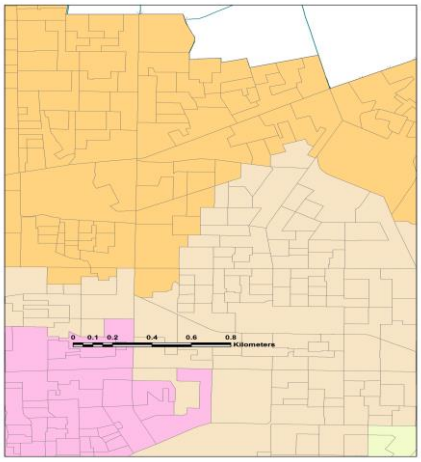

Figure 2. Detailed illustration of segmentation using Census spatial data

The fire fighting demand populations in relevant areas were calculated using the resultant data on the jurisdictions of 119 fire houses divided according to the accessibility analysis as described above and the degree to which the differences in the numbers of residents under each fire fighter's charge among the areas decreased when fire fighters were redeployed according to the demand populations was verified.

4. Analysis and Discussion

The resultant improvements by fire service area according to accessibility analysis were organized as shown in the following Table 3. When seen from the viewpoint of the entire target areas, the arrival time could be reduced by around 30 seconds on average. In particular, the reducing effects were identified in all areas so that the methodology can be judged to be appropriate as a methodology to reduce arrival times.

The results of application of the improvement plan to deploy fire fighters according to the demand populations in the areas redivided without increasing the numbers of fire fighters in the current target areas based on the results of re-division as such were set forth as shown in the following Table 4.

Table 3. The resultant improvements by Fire Service Area Re-division using Census spatial data

AVG. Travel time (min'sec")	Weol-sung	Song-hyun	Bon-ri	Sung-seo	Juk-jun	Dae-chun	Do-won	Total
Present (A)	1'18''	1'51''	2'33''	2'13''	2'05''	3'48''	1'44''	2'01''
Improvement Suggestion(B)	1'03''	1'29''	1'17''	2'13''	2'00''	2'32''	1'29''	1'41''
(A-B)	15"	21"	1'16"	0	5"	1'16"	25"	20"

Table 4. Improvement plan of firefighter deployment according to the demand populations

		Weol-sung	Song-hyun	Bon-ri	Sung-seo	Juk-jun	Dae-chun	Do-won	Std. Dev.
Number of fire fighter	Present	49	19	19	19	19	16	17	11.7
	Improvement Suggestion	18	29	20	33	31	18	29	4.4
Population per fire officer (person)	Present	1,342	6,613	4,156	4,835	6,861	310	5,474	2524
	Improvement Suggestion	3,008	3,741	3,741	3,741	3,741	323	3,741	1521

According to the results of analysis, for the majority of fire houses in the targe areas to be in charge of the same numbers of residents, some areas where the deployment of fire fighters fewer than the legal standard numbers of fire fighters is appropriate may appear. This is a problem appearing even now depending on areas. In the case of the relevant areas, investigations indicated that fire houses were being operated with the minimum legal number of fire fighters or slightly fewer fire fighters. Therefore, in this study, a fire fighter adjustment plan was composed under the condition that the minimum legal numbers of fire fighters per 119 center should be satisfied.

As major results, it could be seen that the methodology presented in this study showed high improvement effects with a reduction in the difference in the numbers of fire fighters from 11.7 to 4.4 and a reduction in the difference in the numbers of residents per fire fighter from 2,424 to 1,521.

5. Conclusion

This study was conducted to reduce regional differences in individual factors in the deployment of fire service forces utilizing responding time and fire fighting demand population as quantitative elements. According to the results of the study, practical problems remain such as the way to satisfy the legal numbers of population in some areas with extremely small numbers of residents under charge. However, it was identified that following the application of the methodology presented in this study, great effects to reduce differences in average arrival times and the number of residents per fire fighter could appear. In particular, it was quantitatively verified that in the deployment of fire service forces, fire service areas can be readjusted and fire fighters can be deployed according to fire fighting demand using census data.

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