A STUDY ON THE DERIVATION OF THE FIRE SERVICE VULNERABLE AREAS IN CHEONGJU CITY USING A GIS SPATIAL ANALYSIS METHOD

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Abstract - This study analyzes the fire service area in the integrated city of Cheongju city by spatial unit and derives the fire service vulnerable area through it. The purpose of this study is to propose comprehensive evaluation of firefighting in Cheongju city and basic layout of fire fighting force suitable for Cheongju city. For this purpose, fire protection access areas were derived through network analysis using GIS. Through the analysis of Kernel Density, illegal parking and high density areas were identified by analyzing the area density of illegal parking and stopping, Vulnerable areas. As a result, 118,033 buildings were derived from the five - minute zone service vulnerable buildings and 78,373 buildings were derived from the ten-minute zone vulnerable buildings. In addition, there is no adequate fire service for the integrated city of Cheongju, and it is derived that there is a difference in the ratio of service weak areas in the place where Cheongju city was located and Cheongwoncounty. In order to overcome the distribution of service area which is against this equality, it was judged that proper firefighting arrangement was needed in the place where Cheongwon - gun was located in the past, and It was judged that illegal parking enforcement should be strengthened in places where Cheongju city was located in the past. The results of this study are suggested as the base data of fire fighting force arrangement suitable for integrated city of Cheongju.

Keywords - Road, 119 Safety Center, Vulnerable Area of Fire Service, Illegal parking, Network Analysis, Kernel Density Analysis

I. INTRODUCTION

1.1. Background and Goals of Study

Modern cities are becoming more advanced and denser, which is leading to an increase in the scale of buildings and more complex uses of land. The increase in building scale and the density of the population within cities are accompanied by the risk that, when a fire occurs, it could spread and become a large-scale blaze which leads to a great deal of damage to life and property. Recently, large fires such as the MiryangSejong Hospital fire (January 26, 2018) and the Jecheon Sport Center fire (December 21, 2017) have become an issue, and this issue has created a great deal of fear and anxiety which goes beyond the risk of such fires. In addition, the problem of illegal parking and stopping which block fire engine access has recently identified as one of the major factors which hinder firefighting, and it is important to fight fires with methods that consider new obstacles caused by urbanization.The fire service areas for responding to fires when they occur within a city are generally organized by normal administrative area units (known as gu, gun, and dong) according to normal administrative safety ordinances. Problems with reduced the efficiency and equality of services occur due to problems with the personnel and cost required for such facility arrangements.

Urban fires are not only a great threat to the lives and safety of city residents, but also directly related to people's lives, thus, there must be efficiency and equality in providing services through a cautious arrangement of personnel and facilities. However, in urban-rural integrated cities in most areas, the firefighting personnel and facilities are dense to downtown areas. Because of this, proper services cannot be provided to outer areas, resulting in problems with being able to quickly fight fires. Cheongju, which is one of the urban-rural integrated cities created by integrating past administrative areas, has encountered problems in managing the entire city which has expanded without providing new arrangements or new facilities for the infrastructure that was provided in the past due to a rapid increase in the administrative area (an increase of 786.89 km2) accompanied by a comparatively small increase in firefighting facilities (an increase of 5 facilities). It has been, therefore, determined that there is a need to evaluate the appropriateness of the fire stations' jurisdiction areas.

This study aims to identify the vulnerable areas in fire services throughout the entire integrated Cheongju by analyzing fire service accessibility and the density of illegal parking/stopping points while considering the characteristics of actual Cheongju spatial data. In doing so, it aims to present basic data on a suitable arrangement of fire service personnel and facilities for integrated Cheongju.

1.2. Scope and Composition of Study

This study has selected the entire integrated Cheongju (July 2014) as its spatial range. For its analysis units, it has selected "dong" which is an administrative unit for the arrangement of actual fire service personnel and facilities. This study has selected the year 2017 as a reference point for analysis data, which is after the integration in 2014. Its range includes all places where a rescue teams have been placed according to the "Rule on Fire Service Standards" (an administrative safety ordinance), so all fire stations

and 119 safety centers are included in the study's range.

The composition of this study broadly includes a review of relevant literature, analysis data and methodology, analysis results, conclusions and limitations, and references. The review of relevant literature examines relevant legislation and previous studies. The section for analysis data and methodology describes the data used in this study, network analysis which uses GIS, and kernel density analysis theory . The analysis results section presents the results of the analysis and explains them in detail. Finally, the section for conclusions and limitations describes the study's conclusions and limitations, as well as future research.

II. REVIEW OF RELEVANT LITERATURE

2.1. Review of Relevant Legislation

The standards for the arrangement of fire services in Korea are based on Article 8 of the Framework Act on Fire Services (Law No. 6893, May 29, 2003) and they are set by administrative safety ordinances. However, the standards for these arrangements do not consider the actual distribution of population and housing within cities and were set according to administrative safety ordinances. There are difficulties in finding the fire service arrangements which are actually needed.

Legal content related to fire engine access when fighting fires is based on Article 21 of the Framework Act on Fire Services (Law No. 6893, May 29, 2003), and it states that fire engines should not be obstructed when they are fighting with fires and mobilizing for rescue/aid activities, and those who violate this law will be faced with prison or fines. Based on Article 21 Clause 2 of the Framework Act on Fire Services (Law No. 6893, May 29, 2003) and following Article 2 Clause 2 Item 2 of the Building Act, apartment building owners that have been specified by presidential decree must install "Fire Engine Special Use Areas" according to Article 16 Clause 1, and nobody is permitted to park the vehicle in the special purpose areas or engage in obstructive activities such as blocking entry to the special use areas.

2.2. Observations on Previous Studies

Studies analyzing fire service accessibility in Korea have used GIS network analysis to create data sets from actual road data starting with actual fire stations and 119 safety centers and analyzed the accessibility of fire service facilities in order to find fire service vulnerable areas and rescue team arrival vulnerable areas within cities. Based on this, this study attempted to select optimum locations and to propose policy proposals.

In the absence of any previous studies which directly analyze the density of points on illegal parking and stopping in South Korea, the focus was placed on the methodology which uses GIS-based density analysis. It was determined that studies employed density analysis through Kernel Density analysis were previous studies, and observations were made about these. In domestic studies, kernel density analysis was used to understand the spatial distribution characteristics of facilities and locations which were represented as points in GIS, and this was used to select optimal locations or to propose policies.

Table 1 below shows a summary of the previous studies' goals and analysis methods.

Table1: Summary of the previous studies` goals and analysis methods

Author	Goal of Study	Analysis Method
JeongKyudong et al. (2012)	To find fire service rescue team arrival vulnerable areas and suggest a plan of improvement through an analysis of the accessibility of each fire service area in the city of Daegu	Network analysis
Ku Seul et al. (2012)	To analyze fire service vulnerable areas in Jinju city based on fire mobilization times and propose an efficient method of adjusting fire service areas	Buffer analysis, OD cost matrix analysis
Kwan Pil et al. (2015)	To analyze vulnerable areas for emergency medical services in Daejeon Metropolitan City and present a plan for readjusting the service areas	Network analysis
Kim Yunhye et al. (2016)	To select the vulnerable points of fire stations in Ulsan Metropolitan City to ensure a safe residential life for its citizens	Network analysis, center point analysis
Choi Jinho et al. (2014)	To examine the shelters' locations and their spatial distribution characteristics in Cheongju and evaluate their suitability	Kernel density analysis, nearest neighbor analysis
KilHyemin(2015)	To analyze location selection factors for convalescent hospitals based on the spatial distribution of convalescent hospitals as they are currently located considering supply and demand factors in the Seoul metropolitan area	Kernel density analysis, LISA analysis
Park Kyeongyeol (2016)	To evaluate the expansion of tourist accommodations in terms of policy based on the spatial distribution of tourist accommodations using GIS spatial analysis methods	Kernel density analysis, GIS overlay analysis

2.3. Distinctiveness of the Present Study

In this study, GIS spatial analysis method was used to analyze the characteristics of the spatial distributions of fire stations and 119 safety centers as well as of illegal parking and stopping. Previous studies have analyzed the accessibility of fire engines using GIS network analysis starting at actual fire station to determine fire service areas and thereby ultimately analyzed the fire service vulnerable areas. However, there are no papers which discuss the problem of illegal parking and stopping, which acts as a direct obstacle to current fire engine access and firefighting.

The objective of this study is ultimately to find the fire service vulnerable areas through a fire service accessibility analysis based on actual road data in Cheongju as well as the density analysis of repeated illegal parking/stopping area using actual Cheongju illegal parking supervision data. Moreover, in existing studies, the vulnerable region was determined based on the area of and the number of buildings , but the scale of the buildings within the vulnerable areas was also considered in this study, and the total floor area of buildings which are vulnerable in terms of fire service was calculated as well. As a result, it was determined that this study was able to present data on a suitable arrangement of fire service capability for the integrated Cheongju, and this arrangement can provide fire services which are suitable for the integrate Cheongju.

III. ANALYSIS DATA AND METHODOLOGY

3.1. Analysis Data

To analyze the fire service accessibility, data such as national administrative boundary si/gun/gu data, eup/myeon/dong data, national road network node/link data, Chungbuk building data, and fire station location data were used. The time range of all data was based on the entire year 2017, and the data were processed as Cheongju-based data so that it could be used for the analysis goals of this study. A geocoding tool was used on Cheongju fire station and 119 safety center location data to project it as point data in GIS. The coordinate system for the GIS overlay analysis was processed by a Katech GRS80. Table 3 below contains the sources and descriptions of the data that were used.The coverage of fire service rescue team was derived from the data above, and service areas were used during network analysis. The standard for service areas was determined as the areas within 5 minute and 10 minute based on the 5 minutes which a “flash over” occurs when fighting with a fire.

For density analysis of the Cheongju illegal parking/stopping occurrence points, a geocoding tool was used on actual Cheongju illegal parking/stopping supervision point data to project it as point data in GIS. To find out the points that only act as factors in actually obstructing fire engine access when a fire occurs, the road width data of each road hierarchy in the Cheongju road data were used. Building data were also used to overlay it with the density data that were ultimately calculated.

3.2. Methodology

Arc Gis 10.1 software was used for the fire service accessibility analysis, and service areas were used during the network analysis.Network analysis has been used in many studies to analyze the connectivity and paths of networks such as roads and railways to examine their accessibility and usage areas. The analysis is performed based on the network data set, and the network data set is composed of nodes and links. Time weights can be added to links if distance and speed are added to each link. The shortest distance and the shortest time distance are calculated from the given distance and time properties, and this result is used to find the service areas.

Arc Gis 10.1 software was also used to perform kernel density analysis for the illegal parking/stopping occurrence point density analysis.The illegal parking supervision points were expressed in the form of dot in GIS. Therefore, in a small-scale map, the positions overlap and it is difficult to examine their visual and quantitative characteristics. To resolve this, kernel density analysis is used. Kernel density analysis is an analysis method which calculates density from the data of different characteristics in the study area. In the kernel density analysis process, the analysis radius is set, and the number of points included in the radius is estimated as a density and expressed by the kernel function (K).

$$K = \frac{1}{nh^d}\sum_{i=1}^{n}\left(\frac{x - x_i}{h}\right)$$

Here, K : Kernel density
n : number of points
h : bandwidth
d : data dimensionality
x : unknown point
xi :Ith point

Using data on the width and the number of lanes in roads, roads with a width of less than 8.5 m were selected as the road that fire engines cannot pass through when illegal parking is occurring. The selected roads and geocoded points were spatially overlayed, and the points where illegal parking/stopping was occurring on roads with less than 8.5 m width were selected. The kernel density analysis was used with the selected illegal parking/stopping points. Instead of population data, the number of illegal parking/stopping supervision was entered as a property along with the point’s location property. The analyzed raster file was reclassified as 9th level and polygonized. Such polygon data were overlayed with the building data, and the buildings were classified according to the level of illegal parking occurrences. Then the classified building data were overlayed again on roads with less than 8.5 m width to find the final data on buildings where large amounts of illegal parking/stopping occur and buildings that cannot be

entered by fire engines when illegal parking/stopping occurs.

To find out the final fire service vulnerable buildings in Cheongju, the Arc Gis 10.1 software was used to perform overlay analysis. Based on the fire service rescue team arrival vulnerable building data found through network analysis, the data on buildings at risk for a high density of illegal parking occurrences were added and overlayed.

IV. ANALYSIS RESULTS AND INTERPRETATION

4.1. Fire Service Accessibility Analysis Results

In the Cheongju fire service rescue team accessibility vulnerable area analysis results, 117,388 buildings (50.68%) out of a total of 231,610 buildings within Cheongju were included in the 5 minutes service area, and 39,655 buildings (17.12%). were included in the 5-10 minutes service area. 74,567 buildings were not included in a service area, which is 32.20% of all buildings in Cheongju. Table 2below shows the fire service accessibility analysis results for all of Cheongju.And Fig. 1 below shows the fire service accessibility analysis results for all of Cheongju.

Table2: Results of fire service accessibility analysis

Category	Number of Buildings	Ratio
All of Cheongju	231,610	100%
In 5 minutes areas	117,388	50.68%
In 5-10 minutes areas	39,655	17.12%
Outside Service Areas	74,567	32.20%

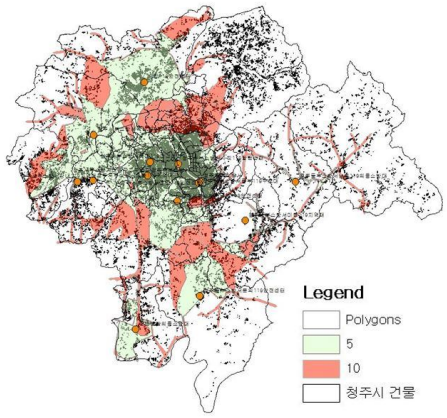


Fig.1. Fire service accessibility analysis results

In results of finding the vulnerable buildings by administrative boundaries such as eup, myeon and dong, the area with the highest ratio of 5 minutes area accessibility vulnerable buildings was Bugi-myeon, followed by Naesu-eup, Miwon-myeon, Nangseong-myeon, and Yullyang-Sacheon-dong. The highest ratio of 10 minutes area accessibility vulnerable buildings was in Bugi-myeon, followed by Miwon-myeon, Naesu-eup, Kadeok-myeon, and Hyeondo-myeon. In 15 out of the total of 43 eup/myeon/dong areas in Cheonju, the ratio of 5 minutes area accessibility vulnerable buildings was 40%, and in 8 eup/myeon/dong areas, the ratio of 10 minutes area accessibility vulnerable buildings was 40%.

However, in the results of calculating the buildings' ground area, the places with the largest 5 minutes area accessibility vulnerable building floor area was Naesu-eup, followed by Yongam 2-dong, Miwon-myeon, Namil-myeon, Kangnae-myeong, and Ochang-eup. The place with the largest 10 minutes area accessibility vulnerable building floor area was Naesu-eup, followed by Miwon-myeon, Kangnae-myeon, Yongam 2-dong, and Bugi-myeon. These results show some difference with the ratios of the number of vulnerable buildings.

4.2. Illegal Parking/Stopping Occurrence Area Density Analysis Results

In the Cheongju illegal parking/stopping high density occurrence area density analysis results, 784 buildings out of 231610 buildings in Cheongju were at density 9, the highest of the density levels. 1228 buildings were at density 8, and 2203 buildings were at density 7. Looking at this as a ratio of all the buildings in Cheongju, it is less than 8%, but there is a lot of density at fixed points, and there are clear characteristics of density mainly being distributed at a few points. As such, the risk that this can act as an obstacle when a fire occurs is considered to be high.

In the results of finding vulnerable buildings by administrative boundaries such as eup, myeon, and dong, the places with the highest ratio of high density buildings (7-9) were Kagyeong-dong and Bokdae 1-dong. The place with the highest ratio of medium density buildings (4-6) was Geumcheon-dong, followed by Sajik 2-dong, Tab-Daeseong-dong, Jungang-dong, Seongan-dong, and Yongdam-Myeongam-Sanseong-dong. Table 3 below shows a summary of the content above. And Fig, 2 below shows the Illegal Parking/Stopping Occurrence Area Density Analysis Results.

Table3: Results of Illegal Parking/Stopping Occurrence Area Density analysis

Eup/Myeon/Dong	All Buildings	Density 9 Buildings	Density 8 Buildings	Density 7 Buildings	High Density Building Ratio (%)
Kagyeong-dong	3767	555	649	328	40.7
Bokdae 1-dong	24555	224	486	213	37.6
Eup/Myeon/Dong	All Buildings	Density 9 Buildings	Density 8 Buildings	Density 7 Buildings	High Density Building Ratio (%)

Guemcheon-dong	3423	1146	882	874	84.8
Sajik 2-dong	2024	281	296	372	46.9
Tab-Daeseong-dong	2218	755	198	38	44.7
Jungang-dong	3699	396	398	760	42.0
Seongan-dong	3107	408	577	278	40.7
Yongdam-Meyongam-Sanseong-dong	2326	114	312	86	22.0

Eup/Myeon/Dong	All Buildings	Density 9 Buildings	Density 8 Buildings	Density 7 Buildings	High Density Building Ratio (%)
Yeongun-dong	1722	826	727	0	90.2
Mochung-dong	3716	1132	770	134	54.8
Sugok 1-dong	3095	177	1006	501	54.4
Bongmyeong 2-Songjeong-dong	3549	44	100	1712	52.3
Uncheon-Shinbong-dong	2074	0	261	751	48.8

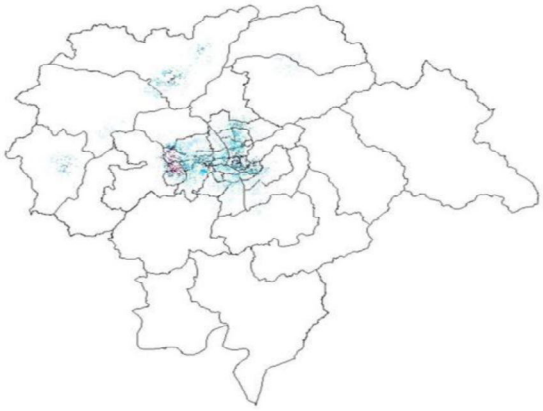


Fig.2. Illegal Parking/Stopping Occurrence Area Density Analysis Results(High Density)

4.3. Final Fire Service Vulerable Buildings

Fig. 3 below shows the results of finding the final fire service vulnerable buildings. Out of 231,610 buildings in Cheongju, there were 118,033 5 minutes service vulnerable buildings, and 78,373 10-minutes service vulnerable buildings.

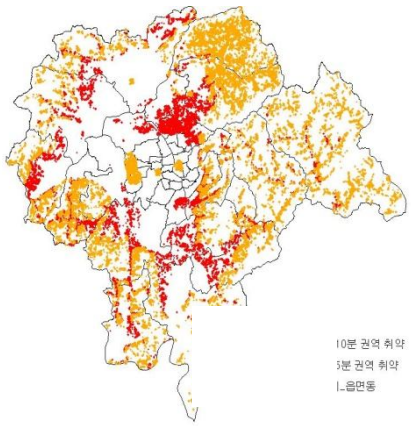


Fig.3. Final Fire Service Vulerable Buildings

4.4. Interpretation of Analysis Results

When the 5-minute and 10-minute area offire Service accessibility vulnerable buildings are calculated by ratio and by area, there was a difference in the order of places by degree of vulnerability. This was determined to be because the area of buildings is bigger in the place which was the site of Cheongju in the past. Also, the calculation method which uses the floor area can find the buildings which are vulnerable to the large fires somewhat more precisely. Looking at this, it was found that fire service accessibility vulnerable buildings are concentrated in the place which was the site of Cheongwon-gun in the past.

In the Illegal Parking/Stopping Occurrence Area Density analysis results, the eup/myeon/dong areas with a high ratio of high-density buildings were mainly areas with a lot of large shopping and commercial facilities. The eup/myong/dong areas with a high ratio of medium-density buildings were mainly areas with concentrations of multi-family housing and commercial facilities. Also, it was found that the eup/myeon/dong in places that were the site of Cheongju in the past had a high ratio of medium-density buildings.

CONCLUSIONS AND LIMITATIONS

Differences exist in the ratios of fire service vulnerable buildings according to administrative boundaries such as eup, myeon, and dong. As such, we have come to a conclusion that fire service which is appropriate for the integrated Cheongju cannot be provided. It was also found that the differences in fire service provision were large in Cheongju and Cheongwon-gun before integration. It has been determined that illegal parking supervision must be strengthened in the place which was once the site of Cheongju before integration, and the distribution of

fire service capabilities must be adjusted in the place that was once the site of Cheongwon-gun in the past. However, in the analysis of illegal parking occurrence area density, both the original data on illegal parking supervision points and the number of supervisions were used to confirm that the number of points where illegal parking occurs is more than the points where supervision occur, and there were limitations which made constructing these data difficult. Also, consideration must be given to differences in illegal parking/stopping occurrence characteristics according to the hour or day of week. This study is also limited in that it has not quantified the effect that illegal parking/stopping has on actual firefighting time. The problems with data construction and characteristics can be resolved in future research, and we aim to present basic data on the arrangement of fire service capabilities in integrated Cheongju through this study and future studies.

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REFERENCES

[1] Kim Kwon Sik, “Concepts and Measures of Accessibility”, Journal of Korea Transportation Research Society, vol.5,no.1,pp.1033–1046,1987.

[2] JeongKudong et al, “A Study on Deriving Vulnerable Area and its Reformation Way from Accessibility Analysis of jurisdiction of Daegu City Fire and Rescue Stations”, Journal of the Korean Institute of Fire Science and Engineering, vol.2012,no. 5,pp.170-173, May 2012.

[3] Ku Seul et al, “An Analysis of Fire Area in Jinju City Based on Fire Mobilization Time”, The Korean Society For Geospatial Information System,vol.20,no. 4, pp.127-134, December 2012.

[4] Choi Jin ho et al, “GIS Spatial Analysis base on the Distribution Characteristics and Location Suitability of Emergency Evacuation in Cheongju”, Research on regional policy,vol.25,no 1, pp.109-120, June 2014.

[5] Kwan Pil et al, “Rearranging Emergency Medical Service Region Using GIS Network Analysis-Daejeon Metropolitan City Case Study”, Journal of Korean Society for Geospatial Information,vol.23,no. 3,pp. 11-21, September 2015.

[6] KilHye min, “Analyzing the Location-Selecting Factors for Care Hospitals Using Kernel Density Function and LISA based on GIS-Focusing on the Demand and Supply Factors of the Metropolitan Area”, Residential Environment Institute of Korea,vol.13,no. 4,pp 283-299, December 2015

[7] Kim Yunhye et al, “Optimal Location Selection of Fire Stations using Geographic Information Systems : Focused on Ulsan Metropolitan Area”, Journal of the Korean Housing Association Spring conference,pp.221-224,2016.

[8] Park Kyeongyeol, “Evaluation of expansion policy of tourist accommodation facilities utilizing GIS Space Analysis Technique-Utilizing Density and Overlay Analysis”, The Korean Academic Society of Tourism and Leisure,vol. 28,no. 10,pp.249-266, October 2016.

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