Accessibility vulnerability analysis of fire-fighting response service using network analysis in Seoul, Korea

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Abstract

In order to reduce the damage from fire accident, it is very important to secure the golden time of the fire-fighting response. However, dense building and traffic congestion are the major obstacles to secure golden time for fire-fighting. This study analysed the accessibility vulnerability of fire-fighting response service of Seoul in Korea. We analyzed accessibility vulnerability using service area search method among the network analysis in GIS program based on the level of traffic congestion such as optimal, low, middle, high level. Also, we additionally considered the level of fire risk such as occurrence, economic damage, human injury based on hotspot analysis and cluster and outlier analysis (COA). Finally, we deducted the regions which simultaneously are vulnerable to access and dangerous at fire accidents. As a result of research, there are the general tendency that as the level of traffic congestion becomes higher, more regions become vulnerable to access of fire-fighting response services. Also, the areas where accessibility vulnerable areas and fire risky areas overlap. We found that there are areas which need to be managed to enhance accessibility of fire-fighting response services in Seoul and other alternatives are supplied to solve the problems. To manage these areas, smart services which can rapidly access accident areas, such as smart fire drone, can be appropriate alternatives.

Keywords: Fire-fighting response service, Accessibility vulnerability, Network analysis, Hotspot analysis, Cluster and outlier analysis, Smart fire response service

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Introduction

Korea government have implemented an efficient urban spatial structure by designing the location of buildings compactly through the process of rapidly urbanization and industrialization. In addition, the government have promoted the efficiency of the urban structure by designing various land-use zones for multiple locations in terms of land use plan. However, recent fire accidents in urban areas have been increasing in the frequency of accidents that cause more property and human injuries from fires due to dense and complex urban structures. In other words, changes in the urban structure caused by urbanization and industrialization tend to serve as factors such as enhancing the possibility of fire, obstacle of fire-fighting response services. Especially, it tends to obstruct fire-fighting response services from arriving the accident site within golden time.

For the recent 10 years, the economic damages and human injuries per occurrence have been getting larger (Figure 1). Especially, the level of increase has become rapidly from 2016. This means that the level of risk from fire accidents is increasing. Especially, this phenomenon tends to occur more seriously in urban areas.

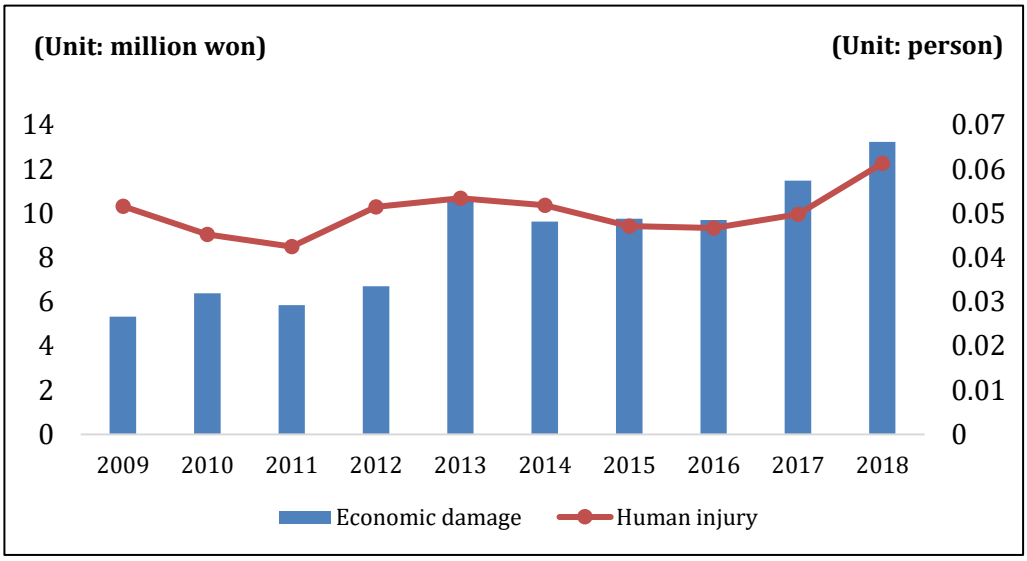

Figure 1: Economic damages and human injuries per occurrence of fire accidents (2009-2018)

Table 1: Economic damages and human injuries per occurrence of fire accidents (2009-2018)

Division	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Economic damages	5.323	6.373	5.847	6.694	10.614	9.620	9.748	9.689	11.474	13.221
Human injuries	0.052	0.045	0.042	0.051	0.053	0.052	0.047	0.047	0.050	0.061

For all disasters, the level of initial response activity immediately after an accident determines the level of property damage and human injury reduction from disasters. In particular, the fire accident can reduce the damages depending on how fast the fire is extinguished after the fire and can prevent the occurrence of secondary damages. In this respect, it is very important to keep the golden time of response activities in a fire accident.

The countries have established the standard of the placement of fire-fighting response services and arranged them based on the standard.

Japan government established the standards based on the time which fire-fighting response services can arrive within 6 minutes or 8 minutes. The government considered the real possibility of arriving time within golden time as most important factors to establish standard. In case of UK government, the standards were established based on the analysis of fire risk modelling. The government made the method for evaluating level of fire risk by each building, regions and applied them to arrange the fire-fighting response services. In Korea, the government have established the standards for placement of the fire-fighting response service based on the population and area by each region. However, they aren't scientific and analytical standards, moreover the standards are too simple to arrange fire-fighting response services. In other words, there are limitations that is difficult to reflect regional characteristics, and the efficiency has decreased due to uniform placement standards because the Korean government uses only population and area as placement variables.

In this background, this study tried to analyze the accessibility vulnerability of fire-fighting response service in terms of placement of fire-fighting response services in Korea. For the research, we selected the Seoul with the most urbanization and industrialization in Korea as research target area.

Theory

Fire-fighting response service (FFRS)

There have been lots of fire accidents and they have caused severe damages in Korea. In this process, various limitations and problems with Korean fire-fighting response service (FFRS) were raised. The limitations and problems can be said to have been improved to some extent, but the problems are still revealed in recent fire accidents in Korea such as Jaecheon sport center fire accident (2017), Milyang hospital fire accident (2018). In this background, Korean government have tried to make efficient arrangement criteria of FFRS and the government decided to arrange FFRS based on the region's population, areas to manage. But the limitations on the FFRS are continuously presented, and the 'delayed arrival of FFRS' have been frequently presented as a major problem.

Accessibility vulnerability of fire-fighting response service (FFRS)

The definitions of FFRS have been conceptualized in various way by each country. In Korea, FFRS is defined as the ability to how quickly and to what extent fire-fighting equipment and personnel can arrive in the accident site and how efficiently the fire can be extinguished. In Japan, FFRS is conceptualized as three components such as personnel, equipment, water resource capacity. Generally, most countries defined FFRS as trained personnel, sufficient equipment and water resource for fire-fighting (Je, 2008).

Fire-fighting response service (FFRS) is generally defined as 'how efficiently fire-fighting equipment and personnel can arrive in the fire accident site, so that the fire can be extinguished (Yoo et al, 2013). Also, the level of FFRS is comprehensively assessed in terms of time of arrival at the site, scales of FFRS, efficiency of response activities (Je, 2008; Koo and Yoo, 2012).

It is very important to consider the adequacy of the location of the FFRS, in that we must consider not only the sufficiency and quality of the fire-fighting personnel, equipment, but also the appropriate accessibility to accident sites. There have been previous studies which studied about optimal location of FFRS center. Simon (1943) argued that it is necessary to arrange FFRS according to the region's risks, taking account variables such as level of fire risk, economic level, physical level (buildings). In other words, he presented the method of fire damage risk analysis which can consider physical, socio-economic factors.

Also, there have been studies which anlayzed the accessibility vulnerability of FFRS. In these studies, accessibility vulnerability (fire-fighting service vulnerability) was commonly defined as the degree to which FFRS is difficult to arrive the accident sites within golden time (Lee et al, 2011; Yoo et al, 2013; Choi et al, 2014). Lee et al (2011) and Yoo et al (2013) analyzed the accessibility vulnerability of FFRS using network analysis of GIS program. Yoo et al (2013) deducted areas which are vulnerable to FFRS's accessibility using service area search method by network analysis (GIS) and presented the ways to eliminate vulnerability. Lee et al (2011) also analyzed the accessibility vulnerability using service area search by network analysis (GIS) and calculated this vulnerability with other risk factors related to FFRS

using overlay method by GIS. Choi et al (2014) analyzed vulnerability dividing into four sections such as mobility kill zone, operability kill zone, identified hazardous zone, fire vulnerability zone. This study deducted final level of vulnerability by each section using 'Fire-fighting vulnerable zone' model. In addition to the FFRS, previous studies about emergency rescue services (119) were also actively conducted (Jeong, 2012; Choi et al, 2015; Jeon et al, 2018). Jeong (2012) deducted vulnerable regions and buildings for emergency services accessibility and presented the ways to eliminate vulnerability factors. Choi et al (2015) also, analyzed vulnerability by each building in Busan and deducted the regions which are necessary to be improved. Jeon et al (2018) tried to analyze the vulnerability about all the urban and rural regions in Korea using network analysis of GIS.

As a result of literature reviews like above, most studies which analyzed accessibility vulnerability commonly seemed to use network analysis of GIS program. More specifically, service area analysis method was used in most studies and other analysis methods were used such as optimal route search, shortest route search. However, most studies tend to only concentrate the results from network analysis of GIS and tend not to consider about regional characteristics such as socio-economic, physical factors well. Also, most studies only analyzed the aceessibility vulnerability and didn't connect with the level of fire risk. So, there can be limitations that the results of those research cannot be considered the real vulnerability.

In this background, we analyzed both the accessibility vulnerability and fire risk and considered two factors in the process of analysis. We tried to analyze the accessibility vulnerability of FFRS by connecting level of accessibility vulnerability and level of fire risk. That is, we thought the real accessibility vulnerability means 'hard to access of FFRS in fire risk areas' and this concept is the differentiation with previous studies.

Methodology

For the analysis, we defined administrative district 'Dong' of Seoul as research target. We analyzed the level of risk from fire accidents and accessibility vulnerability of FFRS. Moreover, we focussed on Seoul which have most traffic congestions, level of density.

Prior to the analysis, we defined the concept of accessibility vulnerability of FFRS. We conceptualized the vulnerability based on two perspectives such as vulnerability of accessibility of FFRS and risk level by each region. That is, we defined regions which have risky factors such as, economic damages and human injuries, occurrences and are vulnerable to access as 'accessibility vulnerable region'.

To analyze risk regions from fire accidents, we collected historic data about economic damages, human injury and occurrences of fire accidents for the recent 5 years (from 2014 to 2018). Using these data, we made average data by each administrative district and deducted more risky regions using 'hotspot analysis' and 'cluster and Outlier analysis' method. These analysis methods are the analysis methods for effectively figuring out the cluster areas among various areas about specific factors. Through these analysis methods, we figured out 'high-high' regions. These regions mean the areas where the level of historical risk from fire accidents is distributed by forming spatial clusters and we defined them as fire risky regions.

And then, we made four road network of Seoul such as optimal, low, middle, high level of traffic congestion for deducting service areas by each traffic congestion. In this study, the criteria of dividing the level of traffic congestion is the travel speed. So, we differently set the travel speed by each road network such as optimal (max speed), low (max speed/2), middle (max speed/3), high (max speed/4). Using these road networks, we implemented service area analysis based on 119 safety centers in Seoul and deducted three areas such as within 5 minutes, 8 minutes, over 8 minutes by each analysis. Based on above results of analysis, we deducted 9 maps about accessibility vulnerability of FFRS in Seoul.

Finally, we analysed about the areas which are risky from fire accidents and vulnerable to be accessed by overlaying the maps deducted.

Results

'Hotspot analysis' and 'cluster and outlier analysis (COA)'

As a result of COA, most high-high clusters of human injury were distribued in center of seoul such as jung-gu, jongro-gu. On the other hand, most high-high clusters of economic damage were distributed in gangnam-gu. In case of occurrence, high-high clusters were distributed in gangnam-gu (Figure 2).

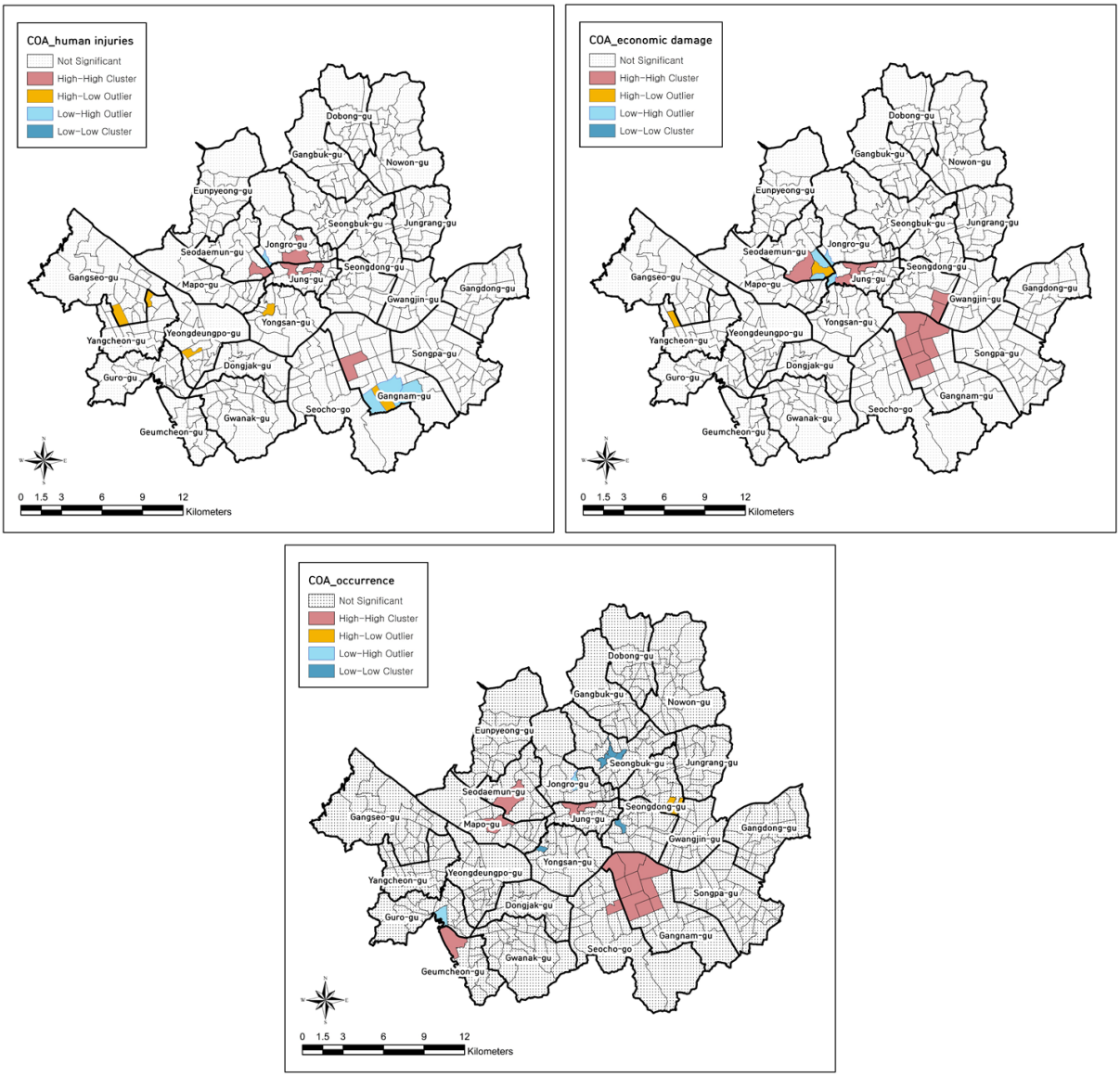

Figure 2: Results of Cluster and outlier analysis (COA) by each fire risk factor

In case of hotspot analysis, the results of analysis were similar to the results of COA. Most hotspots of human injury, economic damage were distributed in jung-gu, jongro-gu, gangnam-gu, seodaemun-gu, mapo-gu. Also, most hotpots of occurrence were distributed in gangnam-gu like hotspots of economic damages. On the other hand, coldspots are less distributed than hotspots in seoul. Furthermore, most of regions are analyzed as hotspot of fire accidents in each risk factors and spatial statistical significance was analyzed to be higher in hotspots that in coldspots (Figure 3).

Figure 3: Results of Hotspot analysis by each fire risk factor

These results show that fire risk areas are distributed in spatial clusters like above figure 2 and figure 3. In the north of the Han river, the center regions such as jung-gu, jongro-gu, seodaemun-gu are more risk from fire accidents. In the south of the Han river, most risk regions are contained in gangnam-gu, seocho-gu. Also, although the spatial clusters are different by risk factors such as human injury, economic damage, occurrence, gangnam-gu commonly seems to be risk areas in all risk factors. Moreover, the level of spatial statistical significance is higher in most areas of gangnam-gu than the other.

Service area analysis

Each space means the area where FFRS can arrive within 5 minutes (green), 8 minutes (pink), and over 8 minutes (red) by differently setting the travel speed of each road. In optimal level of traffic congestion, most of regions are contained in service areas within 5 and 8 minutes. However, as the level of traffic congestion increase, service areas within 5 minutes and 8 minutes are reduced. In case of high level of traffic congestion, more regions were analyzed not to belong to the service areas within 8 minutes than

low, middle level. Also, although the areas where road networks aren't constructed were commonly didn't less belong to the service areas, (Figure 4).

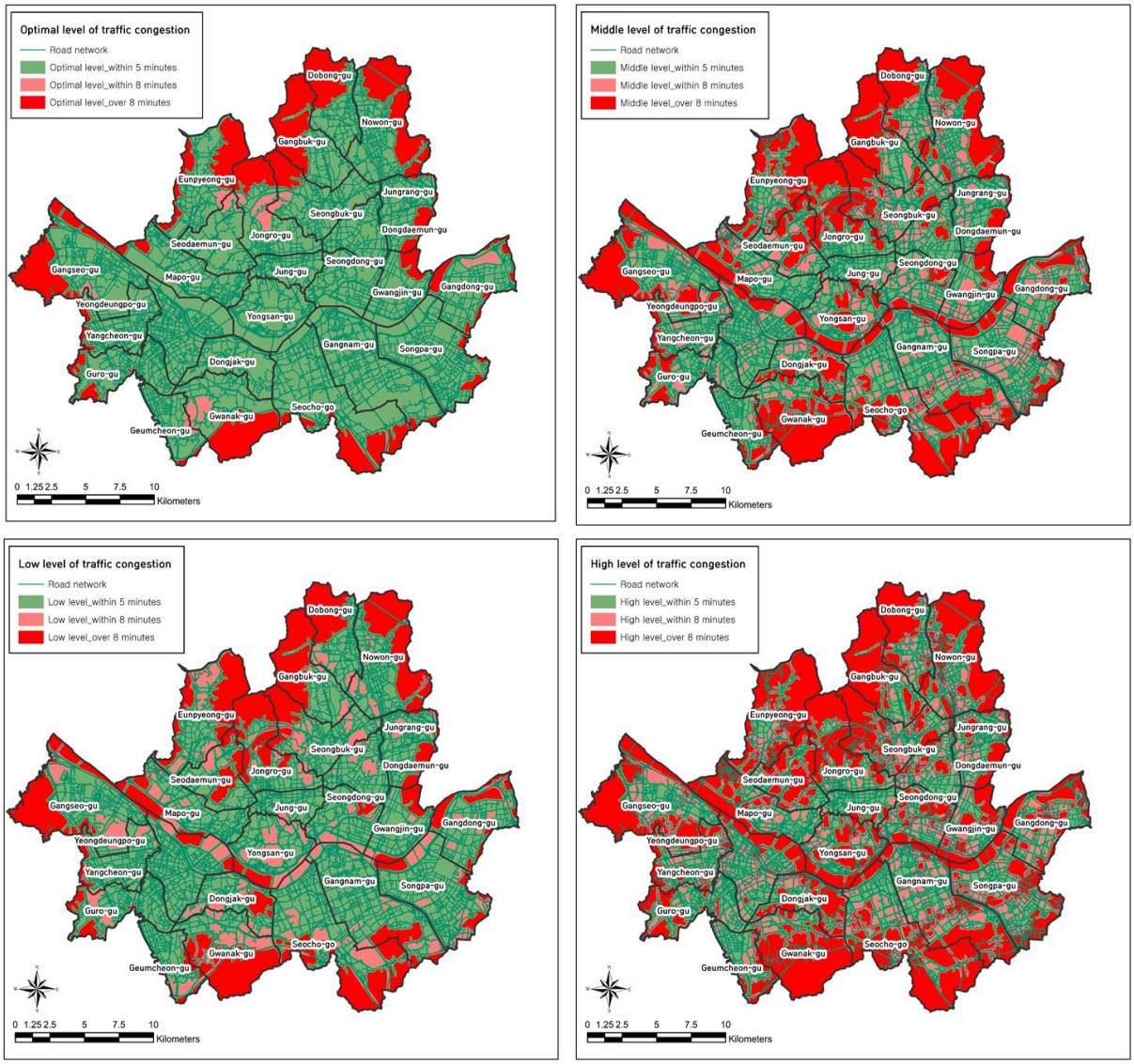

Figure 4: Results of Service area analysis by each level of traffic congestion

Comprehensive analysis

Finally, we tried to figure out the areas where both the level of fire risk and accessibility vulnerability are high. For this, we overlaid the hotspot map of fire accidents with the service area map. According to figure 5, the blue checked areas mean the hotspots of each fire risk factor and the green, pink, red areas mean the service areas by each minute. We made nine maps for comprehensive analysis. According to this result, as traffic congestion increase, the areas where fire risk regions and accessibility vulnerable regions overlap become wider. Especially, in case of high level of traffic congestion, most of fire risk areas are contained in accessibility vulnerable areas. That is, this result shows that if traffic congestion gets worse, those areas can be more risky from fire accidents because accessibility of FFRS decreases (Figure 5).

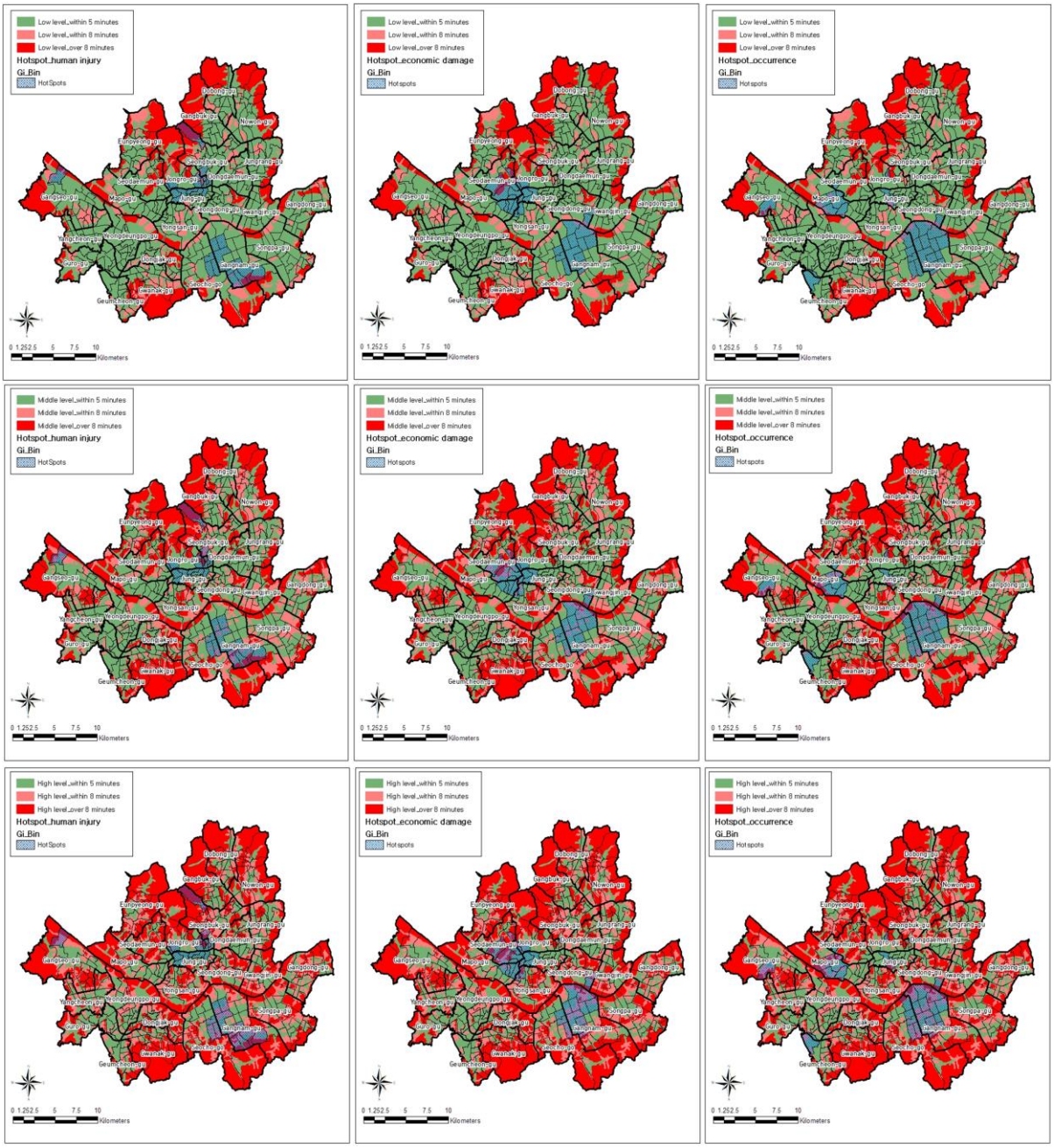

Figure 5: Overlay of Service area analysis and Hotspot analysis by each traffic congestion

Conclusion

This study analyzed the accessibility vulnerability of FFRS of Seoul in Korea. As a result of this research, service areas of FFRS analyzed to become smaller and the areas where fire risk regions and accessibility vulnerable regions overlap become wider by increasing the level of traffic congestion. Also, the areas where fire risk regions and accessibility vulnerable areas overlay tends to be wider by increasing the level of traffic congestion. This result means that if fire accidents occur in time or areas where traffic is crowded, accessibility of FFRS become more difficult and the damages can be exacerbated. Also, this is more critical to Seoul in Korea, because arrangement of FFRS is simply based on population and areas to manage in Korea.

Discussion

The results of this study imply that there is limitation about the arrangement criteria of FFRS in Korea. Current criteria of arrange which consider about only population and areas to manage cannot effectively response to fire accidents. Moreover, it is hard to solve the problems by reorganizing the service areas or filling the resources for FFRS in fully complicated and dense urban area, such as Seoul in Korea. Those solutions cannot produce maximum effects unless accessibility is improved. So, the governments need to find the alternatives for effectively enhancing the accessibility of FFRS from newly perspective such as smart technologies for cities. In that sense, we think that smart fire-fighting technologies such as fire-fighting drone can be effectively used for solving the limitation of current system.

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