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Models and Application of Firefighting Vulnerability

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Abstract

Geographic information systems (GIS) have been applied to analyze the efficiency and effectiveness of public facility services such as fire stations, police stations and day-care centers. Regardless of the scientific contribution of such an approach, there are numerous limitations to follow the rules or optimized suggestions due to high land price and other societal factors. In the present study, we narrowed the scope to firefighting services: how to decrease firefighting dismissals and help firefighters recognize the situation of fire events before arriving at the fire scenes. The absolute time from the fire station to the fire scene was considered to be the Mobility Kill Zone. Narrow roads and illegal parking were classified as the Operation Kill Zone. Areas with identified hazardous commodities and toxic substances were classified as the Identified Hazardous Zone. The areas cluttered with fire safety management objects were classified as the Fire Vulnerability Zone. Four models were suggested in our previous research and in the present study, we elaborated upon the models and examined new information technology (IT) to implement the models in rural and urban areas.

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Keywords: Firefighting Vulnerability, Mobility Kill Zone, Operation Kill Zone, Identified Hazardous Zone, Fire Vulnerability Zone, IoT

1. Introduction

Fire and water are very different elements of nature that are beneficial when controlled as well as dangerous to our lives if uncontrolled. People may imagine fires in the mountains in dry seasons or fires in buildings and industrial complexes. Regardless, firefighters are willing to fight fires despite the possible dangers. Exact situation awareness is inevitable and prediction of fire expansion is also critical, based on the wind direction. Geographic information systems (GIS) for fire divisions in Los Angeles have a long history of integrating all the databases for hazardous materials (HAZMAT) and real-time navigations and locations of fire-fighting engines with inbound telecommunication facilities. Contrary to well-prepared cities, densely-populated cities may be without detailed maps. However, even if the city is well mapped, it still might be too narrow to navigate for the firefighting engines.

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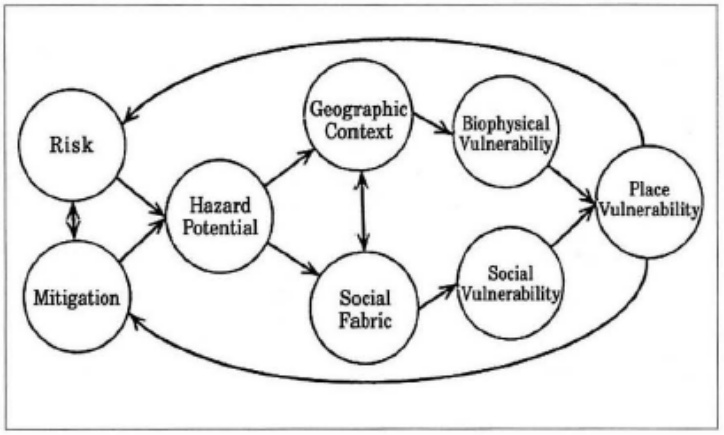


Fig. 1. The hazards of place vulnerability model (Susan Cutter, 1996)

GIS for public fire services have been investigated by many researchers (e.g., Lee and Lee, 2011, Cutter, 1996). Cutter suggested the concepts of social vulnerability (Fig. 1) in the context of place vulnerability.

Figure 1 shows a clear spatial dimension, but the temporal dimension appears accumulated or statistically treated. Fire incidences must be responded to in a timely manner, also called the golden time. Optimizing emergency facilities was another study topic indirectly related to fire services (Kim et al., 2002). Urban conditions were investigated in psychological terms to analyze the response to fire disasters (Parker et al., 2013). Indexing methods, overlapping analysis, mismatch analysis between serviced areas and uncovered areas, and network analysis were used for fire service analyses. A comprehensive study on critical factor analyses of fire damage in Korea was recently conducted (Chang et al., 2015). Since fire vulnerability was defined as the inability to withstand the effects of fire incidences in a general context, firefighting vulnerability was defined as inability to withstand the hindrances of firefighting or as the situation not to perform the firefighting activities properly in the Utilization and Excavation Practices of Firefighting Vulnerability Zone Model (Kim et al., 2014, Choi et al., 2014). In the latter 2 manuscripts, several concepts were introduced for applying the model to real situations. The evaluation of the models was tested in Daegu, Gyeongju, Jincheon and Incheon using GIS data.

2. Research Purpose

The firefighting models (Kim *et al*., 2014, Choi *et al.*, 2014) did not clearly show the role of GIS compared to previous studies in terms of life cycle. In the present study, we investigated the scope of the firefighting models in the context of applications in the system and showed further roles of GIS in new information technology (IT) environments utilizing state-of-the-art devices and extensive information around the fire scenes.

Figure 2 shows each stage of the response life cycle to either natural or human disasters. A different survey framework is planned for each step and the roles of GIS vary for each step. We did not show the reviews of all the stages, but instead focused on the response steps which could be divided into several substeps such as receiving a phone call, order to dispatch, going to the scene and approaching the fire scene.

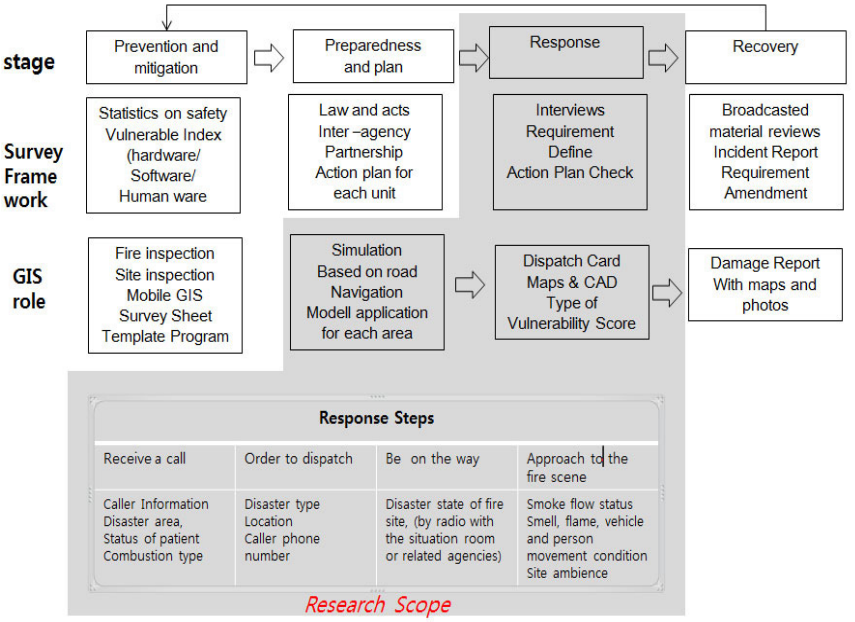


Fig. 2. A work scope of firefighting vulnerability study

3. Methods

To understand firefighting vulnerability, we reviewed the 3 studies which suggested the concept and tested the models briefly and then investigated the IT available in 2014 and 2015 in Korea to implement the concepts.

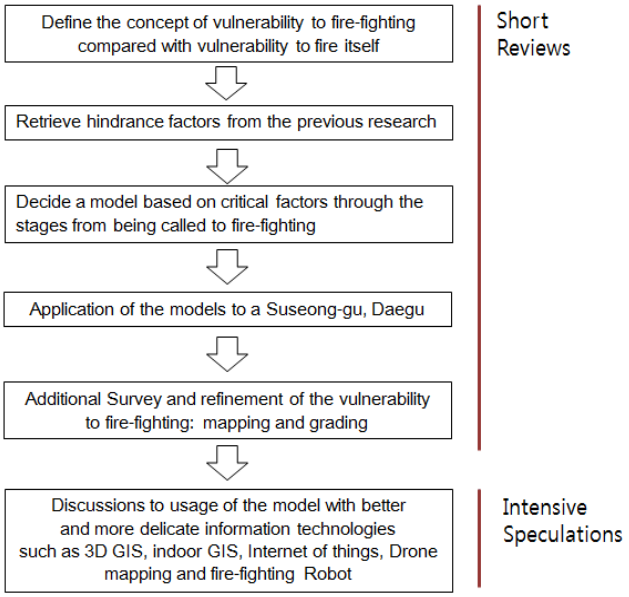


Fig. 3. Research Flow

Table 1. Fire vulnerability types

Fire vulnerability types	Characteristics
Mobility Kill Zone	temporal schemes: from the order to dispatch to the time of arrival at the scene spatial schemes: from fire station to fire scene preparing resources and driving vehicles and parking
Operation Kill Zone	temporal schemes: from arriving at the scene to leaving the scene spatial schemes: near the fire scene the most critical activities for fighting the fires and flames
Identified Hazardous Zone	temporal schemes: annual audit results or current update spatial schemes: near the fire scene
Fire Vulnerability Zone	Fire alert zone, fire safety management of objects, objects vulnera ble to large fire in legal terms

4. Firefighting vulnerability and critical factors through the stages

The absolute time from a fire station to the fire scene was considered to be the Mobility Kill Zone. Narrow roads and illegal parking were classified as the Operation Kill Zone. Spatial areas with identified hazardous commodities and toxic substances were classified as the Identified Hazardous Zone. Some areas where objects in need of fire safety management were numerous were classified as Fire Vulnerability Zone, such as old markets or public squares.

In this study, we mainly examined the urban areas and did not consider forest fires. However, the first 2 zones are also critical for forest fires. The last fire Vulnerability Zone appears to be the main target for fire preparedness, as the zones and objects have more experienced fires due to a higher chance to catch on fire and condensed distribution of significant fire damages. Fire prevention and escape practices are usually performed in the last fire Vulnerability Zone, as shown in Table 1.

Table 2. Goals and critical factors in main firefighting activities

Activities	Goals	Critical factors
dispatch the fire fight ers to the fire scene	reach the site within golden time	firefighting resources transportation to the scene
operation of resources	position the fire engines, extend lad ders and connect to hydrant	space (organize the resources), fire hydrants and tanks
save people and extin guish fire	extinguish fire, save and treat subje cts, send the wounded to hospital	information (fire characters, object s to be burnt, environments)

Critical factors for each step differ by location; however, the common items are classified in Table 2. Detailed attributes can be listed for each country. Mobility Kill Zones can be obtained with data, such as location and capability of both fire stations and small fire prevention houses, database of road conditions (length, width, average traffic velocity and speed limit), road and building DB for vulnerable access spots (road center line, boundary of road polygon, boundary of roadline, database of buildings, gap between road and building), hindrance DB for impeding fire engine approach (parking at night and daytime, building density, goods and objects in the streets) and real-time traffic information (open API service to show the traffic congestion situation at 4 levels: normal, light, heavy and jammed from traffic reports in real-time agency).

5. Application of the models to 4 cases

5.1. Selections of sample cases

The 4 models were applied to 4 Si-Gun-Gus of which the characteristics are plotted in Figure 4 for the average population, in Figure 5 for the average area size, in Figure 6 for the number of fire incidences and in Figure 7 for the average number injured from the fire. In the x-axis, 226 is the number of Si-Gun-Gu in Korea, Dalseo-gu belongs to Daegu Metropolitan City and Gyeongju is one of the old capital cities which include many cultural heritages. Incheon Yeonsu-gu is also a part of the metropolitan areas and Jincheon-gun represents the administration unit for rural areas.

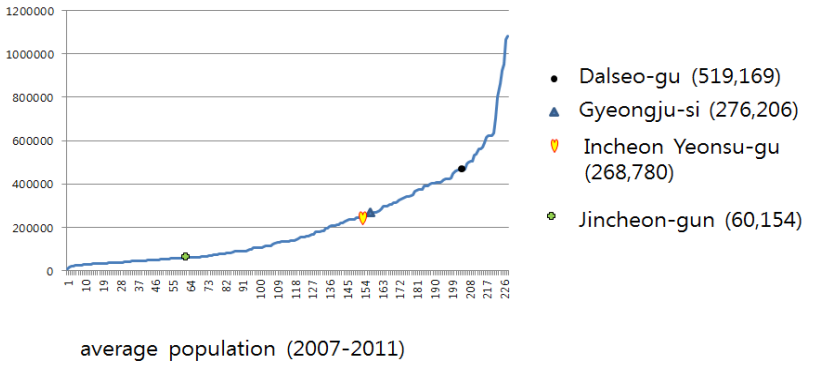


Fig. 4. Average population of the cities

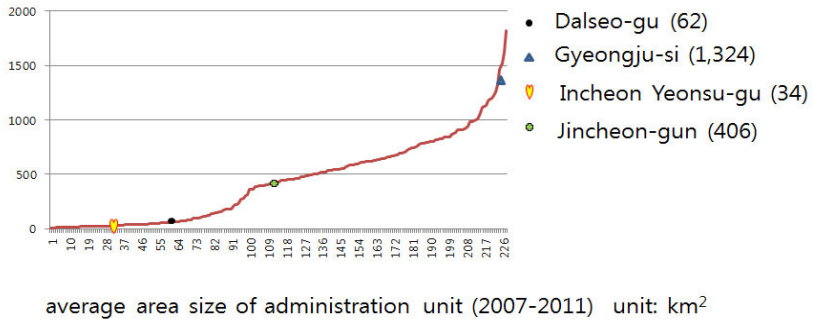


Fig. 5. Average city area size

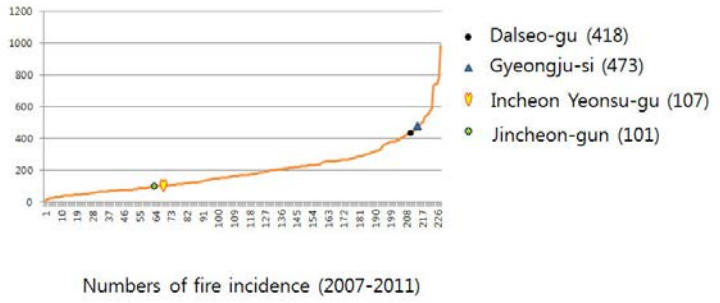


Fig. 6. Number of fire incidences

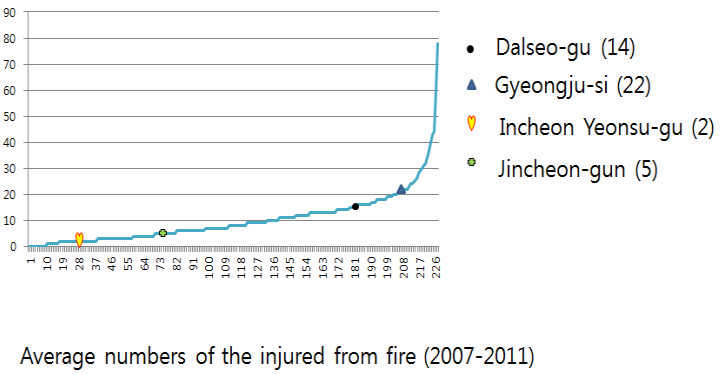


Fig. 7. Average number injured from fire

In Figure 8, the roads in Jincheon and Dalseo narrower than 4 meters were plotted in “a” and the roads whose shapes are too sharp-curved to drive are plotted in “b”. Contrary to Jincheon, the roads in Dalseo are narrower than 4 meters and distributed evenly. Each city may have different distribution patterns. Overlapping the locations of each vulnerable object may lead to a decision to allocate the proper size of fire engines. Time-Distance from fire station to the object which caught fire should be calculated in a previous study and thus, was not included when testing the models. A database for the speed limit, the average speed and unbreakable center dividers should be prepared.

Mobility Kill Zone		
	Jincheon	Daegu Dalseo
“a” Road with width of < 4m		

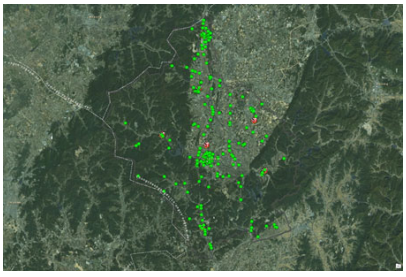
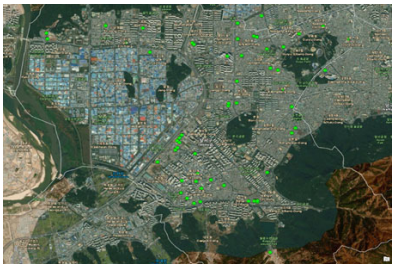
“b” Roads wit h a sharp turn f or fire-engine		

Figure 8. Results of Mobility Kill Zone Model for testbed cities

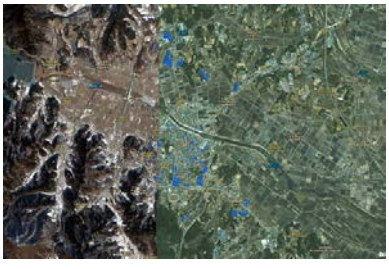
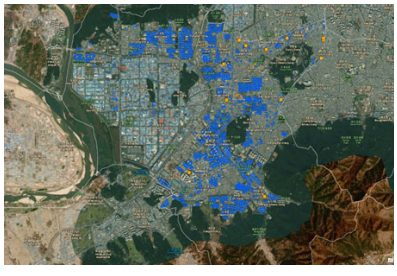
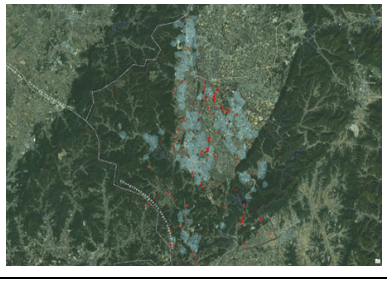
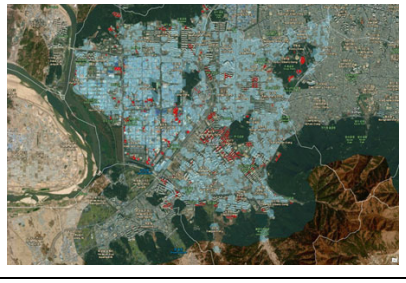
Operation Kill Zone		
	Jincheon	Daegu Dalseo
gaps between building and r oad		
hydrant		

Figure 9. Results of Operation Kill Zone Model for testbed cities

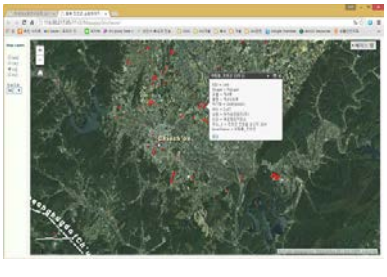
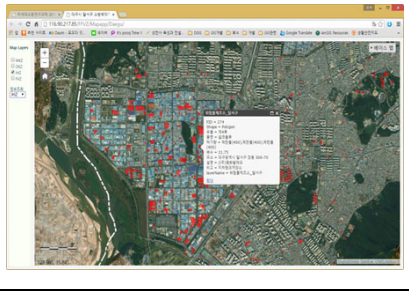
Identified Hazardous Zone		
	Jincheon	Daegu Dalseo
Hazardous materials		

Figure 10. Results of Identified Hazardous Zone Model for testbed cities

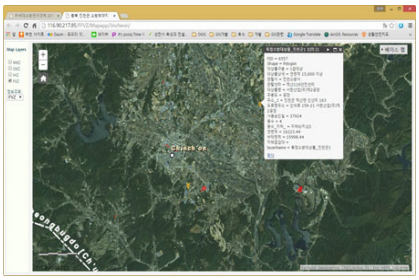
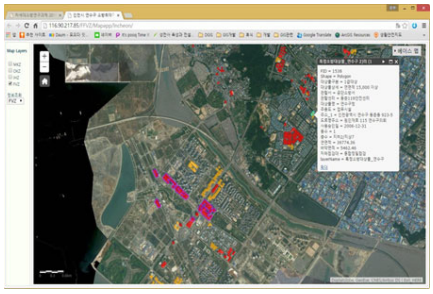
Fire Vulnerability Zone		
	Jincheon	Daegu Dalseo
Hazardous materials		

Figure 11. Results of Identified Fire Vulnerability Zone for testbed cities

6. State-of-the-art technologies to implement the models

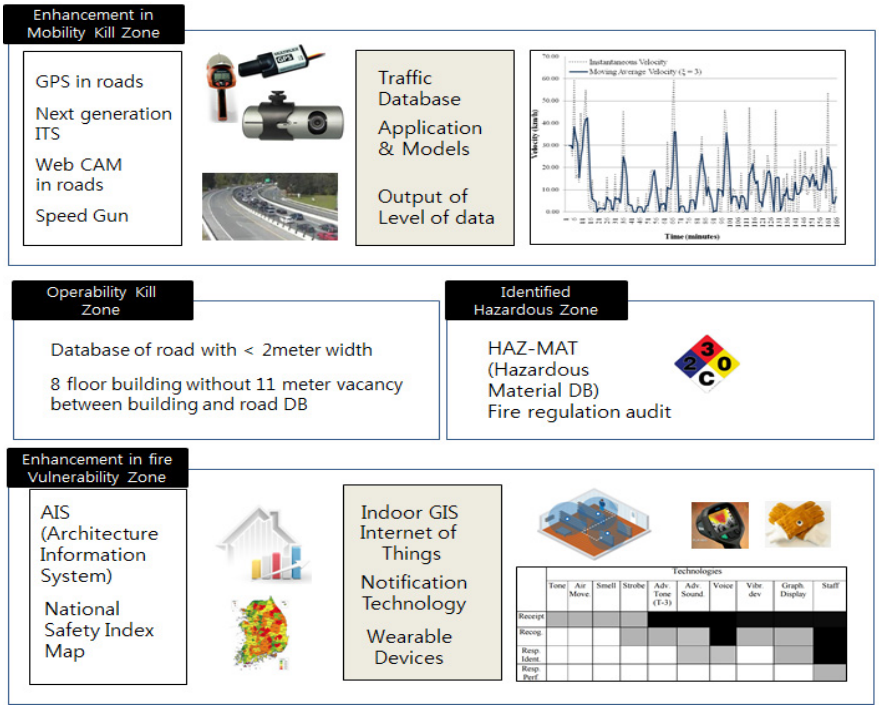


Figure 12. New technologies to implement the fire vulnerability models

Each city has begun to build a safety monitoring center where images taken by street cameras are monitored. GPS receivers are located in many devices, thus, all the information near the fire scene can be obtained in the monitoring centers. In the near future, the center will be able to receive traffic databases including simulated data. To manage and enhance the Mobility Kill Zone, HAZMAT data information and audit results should be delivered to the center and firefighting scenes. Currently, the information on all the structural characteristics of each building can be obtained, but exchanging information of the architectural information system (AIS) will enable the fire fighter to make a better decision. Indoor GIS is conceptually designed but not fully implemented in Korea in terms of database, at least for public buildings. Internet of things are extensively discussed to prevent a fire accident or to mitigate fire damage. These technologies will be applied to the fire Vulnerability Zone at first.

7. Conclusion

We investigated the scope of firefighting services such as how to decrease firefighting dismisses and help fire fighters recognize the situation of fire events even before arriving to the fire scenes. The absolute time from the fire station to fire scene was considered as the Mobility Kill Zone. Narrow roads and illegal parking were classified as the Operation Kill Zone. Areas where hazardous commodities and toxic substances were reported to exist were classified as the Identified Hazardous Zone. Areas cluttered with objects in need of fire safety management were classified as the Fire Vulnerability Zone. Four Models were suggested in our previous research. In the present study, we elaborated the models and examined new ITs to implement the models in rural and urban areas.

The results of the 4 fire vulnerability models may be loaded to graphic panels, on a dashboard in a situation monitoring room, mobile devices in a car or a fire engine to share proper information to prepare the resources for fire extinguishment and to set a priority to access the fire scene based on the object characteristics. If databases on hazardous materials were separately implemented or not updated properly, vulnerability increases. Firefighters should be knowledgeable of their service area and proud of the firefighting work they do (silent knowledge on a personal level) with experiences converted to awareness of common facts, even if a new firefighter is allocated to unfamiliar areas. ITs such as enhanced Intelligent Transportation Service (ITS) and GPS technology will provide more accurate and customized data for each fire incidence. With a limited budget, local government officers or governors will be able to make their own indices for the vulnerability based on the data.

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