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The Study for the Optimal Location of Fire Stations in Seoul

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Abstract

Disasters are the phenomena that we have to prevent the occurrence in order to keep the safety to human lives and properties, and if occurred, we have to minimize the economic, social, and mental costs of the occurred disasters or incidents. This research analyzes the optimal location of fire stations in terms of served population maximization in Seoul. This research introduces "the maximal covering location problem(MCLP)," one of the optimization techniques, as the primary research method. This research also applies a geographic information system into spatial distribution analyses of existing fire stations and observed fire incidents. Results from the analyses show that the existing location of fire stations and branches need to be improved. The dispatch location of fire engines should be reconsidered for rapid services of fire fighting.

Key words : Covering Location Problem, Optimization Method, Fire Station Location, Geographic Information System

요 지

재해는 인간의 생명과 재산을 안전하게 보호하기 위해서 발생을 사전에 예방하고, 불가피하게 발생하였을 경우 그 경제적, 사회적, 정신적 손해를 최소화하여야 하는 모든 현상을 의미한다. 본 연구는 인위재해중 교통사고 다음으로 발생빈도가 높은 화재를 연구의 대상으로, 서울시를 연구대상지역으로 하여 서울시 주민들이 가장 최적의 소방서비스를 받을 수 있는 소방서 입지를 분석하였다. 연구의 방법으로는 최적화분석기법의 일종인 "최대수용입지문제"를 주요 연구방법으로 적용하였으며 지리정보시스템을 적용하여 현행 소방서와 화재발생의 입지적 분포를 관찰하였다. 연구의 결과로 현행 서울시 소방서 및 소방파출소의 입지는 개선의 여지가 있으며 보다 신속한 소방서비스를 받기 위해 소방차 출동지역에 대한 일부 조정이 필요할 것으로 분석되었다.

핵심용어 : 최대수용입지문제, 최적화기법, 소방서 입지, 지리정보시스템

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1. INTRODUCTION

Disasters are the phenomena that we have to prevent the occurrence in order to keep the safety to human lives and properties, and if occurred, we have to minimize the economic, social, and mental costs of the occurred disasters or incidents. Fire incidents are the second member of man-made incidents next to traffic incidents in terms of both occurrence and life/property damage in Seoul, and have increased due to the development of Korean economy and cities during the last 30 years. Thus, the immediate response of fire fighters is very important to reducing human life rescue and property damage from fire incidents. Consequently, the location of fire stations becomes a key factor in hazard mitigation of fire incidents.

Urban planners and urban system analysts have applied various techniques including facility location theories, geographic information systems, transportation modeling to provide guidelines for optimal fire station location. Among them, a number of urban planners and mathematical programmers have insisted that mathematical location modeling can identify "optimal" location patterns on the basis of some realistic objective to be identified, and by some measure quantified (Church and ReVelle, 1973). In their modeling techniques, the concept of a maximal service distance which any user would have to travel to reach a public facility would reflect the worst possible performance of the public facility system in the urban and regional location of emergency facilities such as fire stations, ambulance dispatching stations, or police stations. A mathematical modeling approach of maximal covering location problem (MCLP) is evolved from this maximal service distance concept.

The objectives of this research are: (1) to investigate the applicability of the maximal covering location problem to the optimal location identification of fire stations in terms of served population maximization in Seoul, and (2) to obtain "covered" administrative Dongs and population amount within the jurisdictional region of Seoul. The 6.1 version of LINDO (Linear, INteractive, and Discrete Optimizer) software is applied to solve the location set covering problem over a range of values of distance in Seoul's case. Population data and fire station addresses of year 1999 are used as primary input data sets.

2. Literature Review

Existing research in the fields of natural hazard, disaster events, and emergency management planning, especially in Korea, can be classified into three groups: (1) studies for policy development and administrative organizations for disaster management, (2) studies for hazard factor identification and disaster impact analysis for natural and man-made disasters, and (3) evaluation of emergency response facilities. The studies for policy development and administrative organizations for disaster management were begun by Jung and Shin(1994), inducing the Seoul metropolitan government to build up an emergency management system. Their research included forecasting basic needs for disaster management by surveying Seoul residents disaster preparedness and risk assessment, determining prioritization for emergency management policies, and providing policy directions for emergency response systems of medical services and administrative emergency management institutions.

The disaster management programs and policies have been extended to a study on the emergency management of the Seoul metropolitan government II (Jung, 1995), the project report for policy directions of emergency medical systems and the applicability evaluation of geographical information systems to safety management systems of Seoul underground facilities (Jung, 1995b), the study for improvement plans of Korean disaster management systems through existing disaster management systems and their problems (Yim, 1996), the study for problem identification and policy development of disaster management planning (Ko, 1997), the research for establishing emergency response plans through disaster-type characteristics and case studies (Yim, 1997), and improvement plans for disaster management for flood impact mitigation (Shim, 1997).

The studies for hazard factor identification and disaster impact analysis for natural and man-made disasters began with the study of risk assessment for major accident from hazardous industries in urban areas by Roh and Paek (1993). Studying hazard factor identification and disaster impact analysis has been followed by the research of disastrous urban hazard factors in the old built-up area (Kang, 1998), the study of disastrous man-made urban hazard factors in the small cities of Korea (Kim and Kang, 1999a), the study on the assessment of the regional vulnerability to urban disasters (Kim and Kang, 1999b), the study for community risk prioritization from large scale LPG storages through hazard assessment (Roh and Seo, 1999), the estimation of risk and optimal route of transporting hazardous materials applied to the Seoul metropolitan area (Cho and Oh, 1999), and the development of earthquake response modeling in Seoul (Kim, et. al., 1999).

Church and Revelle (1974) introduced the evaluation method for the location of emergency response facilities by solving the maximal covering location problem. Their early research was followed in the study of siting ambulances and fire companies by Revelle (1991), and the study on location model of emergency medical services in Chinju city (Kim and Kim, 1995).

3. Mathematical Formulation of the Maximal Covering Location Problem

According to Church and ReVelle (1974) and Revelle (1991), the maximal covering location problem identifies the maximum population that can be served within stated service distances given a limited number of fire stations. Defined on a network of nodes and arcs, a mathematical formulation of this problem can be stated as follows:

Maximize $Z = \sum_{i \in I} a_i y_i$

Subject to $\sum_{j \in N_i} x_j \geq y_i$ for all $i \in I$ (1)

$\sum_{j \in J} x_j = P$ (2)

$x_j = (0, 1)$ for all $j \in J$ (3)

$y_i = (0, 1)$ for all $i \in I$ (4)

where

I = denote the set of demand nodes;

J = denotes the set of fire station sites;

S = the distance beyond which a demand point is considered "uncovered" (the value of S can be chosen differently for each demand point if desired);

d_{ij}= the shortest distance from node I to node j;

x_j= 1 if a fire station is allocated to site j, 0 otherwise;

$N_i = \{j \in J | \ d_{ij} \leq S\}$;

a_i= population to be served at demand node i;

P = the number of fire stations to be located.

N_i is the set of fire station sites eligible to provide "cover" to demand point i. A demand node is "covered" when the closest fire station to that node is at a distance less than or equal to S. In this, problem, we determine S to be "2㎞" that is computed from an assumption of a peak-hour travel speed of 24㎞/hr times a minimum response time of 5 minutes. A demand node is "uncovered" when the closest fire station to that node is at a distance greater than S (2㎞).

The objective of this problem is to maximize the number of administrative Dong residents served or "covered" within the desired service distance of 2㎞. Constraints of type (1) allow y_i

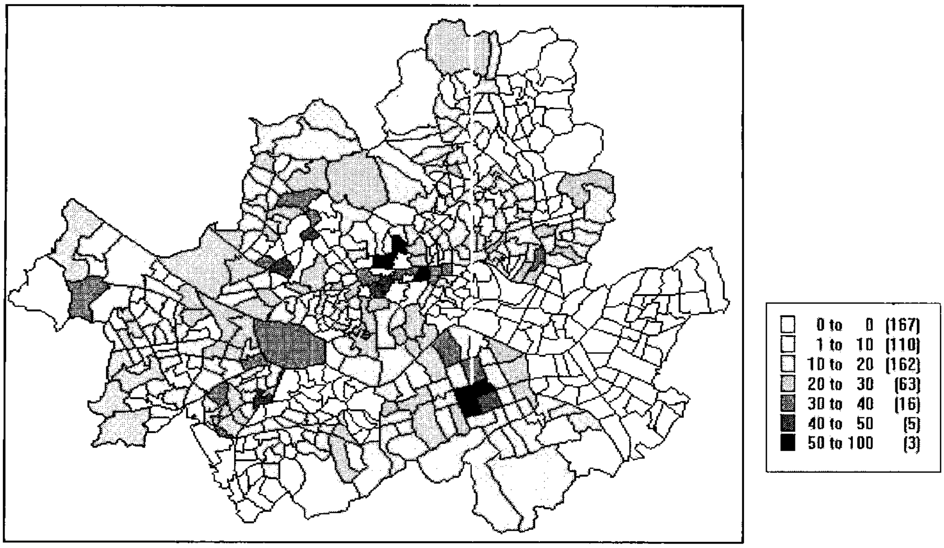

Figure 1. The Spatial Distribution of 1998 Fire Incidents in Seoul

to equal 1 only when one or more fire stations are established at sites in the set N_i. In other words, one or more fire stations are located within S distance (2㎞) units of demand point i. The number of fire stations allocated is restricted to equal P in constraint (2). The solution to this maximal covering location problem specifies not only the largest amount of population that can be covered, but the number of P fire stations that achieve this maximal coverage.

4. Analyses and Results

4.1 Spatial Pattern Analysis

The Seoul city consists of twenty-five self-governing jurisdictions of Kus, and is further divided into five hundred twenty two primary administrative districts of Dongs. The information of population and fire station address in the year of 1999 is obtained from statistical yearbooks of city and local governments, local government reports for fire incidents, and statistical yearbooks of the Korean central government for fire.

This research first investigates the spatial pattern of 1998 fire incidents using the geographic information system in Seoul. Figure 1 shows the spatial distribution of fire incidents. A significant number of fire incidents is observed in Chongro-Ku, Chung-Ku, Yoeuido, and Seocho-Ku areas of Seoul. Figure 2 presents the location of fire stations, fire station branches, and emergency rescue teams in Seoul. The spatial distribution map of Seoul fire stations shows that most stations are located in central areas of Seoul, though fire incidents frequently occurred in outside city areas.

4.2 Optimal Location Analysis

The optimal location analyses for fire stations require three input data sets: 1) a set of distance data between two zones, 2) a set of "covered" fire station sites, and 3) a set of existing fire station location. This research computes the set of distance data between two zones by applying a x-y coordinate concept. Average travel speeds of cars in Seoul are within the range of 20.90㎞/h from the year of 1993 to 25.41㎞/h of the year 1998 according to annual speed measurement reports of Seoul city. The average travel speeds of buses during the same period are within the range of 17.02㎞/h to 20.07㎞/h. Thus, this

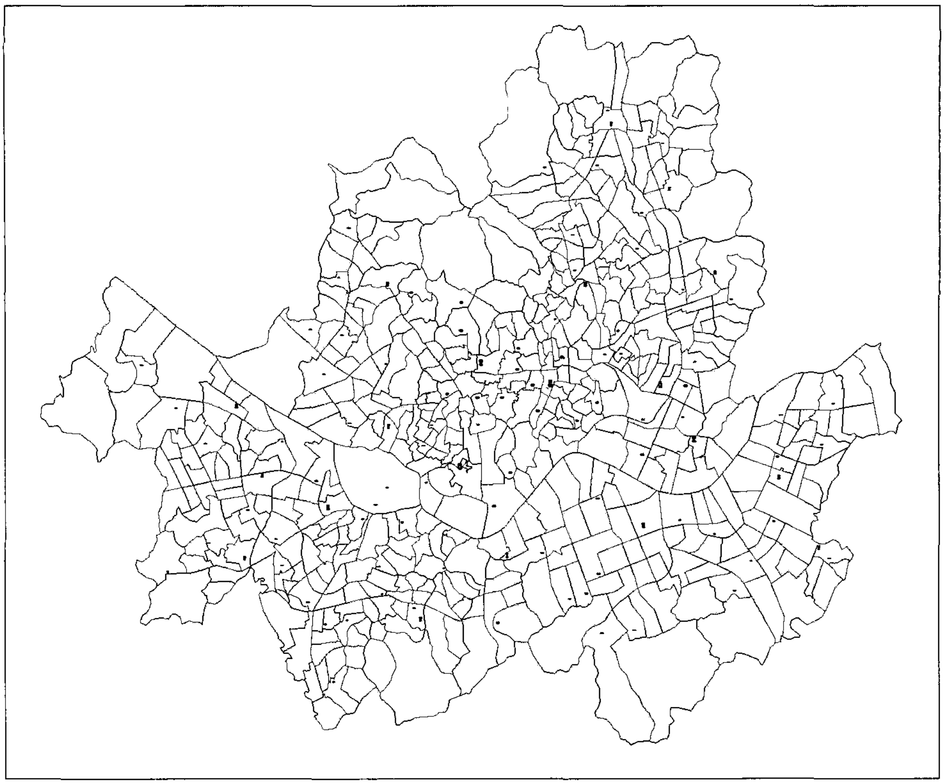

Figure 2. The Location of Fire Stations, Branches, and Emergency Rescue Teams in Seoul

research determines the average travel speed of 24km/h as the study travel speed.

Jarvis, et. al.(1977) provided that the average emergency response time of ambulance services in Bel-O-Mar region is 6 minutes. Consequently, this research determines the average emergency response distance of fire engines to 2km, using the five minute response time and 24km/h travel speed. The set of "covered" fire station sites is found by applying the 2km response distance.

There are 109 different fire stations including fire stations and fire station branches in Seoul. This research develops three study cases: 1) the optimal location case of 109 no-predetermined sites, 2) the existing location case, and 3) the minimum fire station case. Results from the three case studies are shown in table 1.

The result from case 1 shows that all Seoul residents are covered if sites of 109 fire stations and branches are not pre-determined. However, the existing fire station sites only cover 10,166.6 thousand residents based on the study assump-

Table 1. Three Case Study Results for Fire Station Location

Study Case	Case 1(No-determined)	Case 2(Existing)	Case 3(Minimum)
No. of Facilities	109	109	27
Covered Pop.	10,321,449	10,166,600	10,321,449
Status	Optimal	Optimal	Optimal
Iteration No.	606	658	94,088
Branches	0	0	19
Elapsed Time	1 second	2 seconds	6 minute 57 seconds

tions. Ten administrative Dongs are not covered. They are: Yi-Moon 1 Dong in Dongdaemun-Ku, Shin-Nae 1 Dong in Chungrang-Ku, Su-Yoo 4 Dong in Kangbuk-Ku, Han-Kang-Ro 3 Dong in Yongsan-Ku, Jung-Gok 1 Dong in Kwangjin-Ku, Jung-Reung 4 Dong in Sungbuk-Ku, Eung-Am 4 Dong in Eunpyung-Ku, Shin-Weol 7 Dong in Yangcheon-Ku, and Mun-Jung 1 and 2 Dongs in Songpa-Ku. If we do not pre-determine the sites of fire stations and branches, only twenty-seven sites are needed.

5. Conclusions

Man-made disasters such as fire incidents are neither frequently observed nor accurately predictable. In addition, fire incidents result in a wide range of damage that affect residents' quality of life. Results from the analyses show that the existing location of fire stations and branches is not optimal. the dispatch location of fire engines should be reconsidered for better services of fire fighting.

Further research is recommended to the detailed study in modeling the association between fire incident location and fire station location, factor analyses for fire occurrence cause, and the development of effective disaster management systems for fire fighting. The research area is needed to be extended to the Seoul metropolitan region. Other public facility location applications including hospitals or police stations need to be considered to evaluate the applicability of this approach.

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