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Development of Demand for Evacuation Forecasting Methods for Shelters Using Accessibility Analysis

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Abstract: In the present study, accessibility analyses were conducted based on actual pedestrian paths to derive the catchment areas of shelters with a view to forecasting the demand for evacuation that would occur for the currently designated shelters and defining the ranges of evacuees that can be accommodated by the shelters. In addition, the results of the accessibility analysis and city space information were combined to forecast demand for evacuation that might occur in an emergency. The results of the study indicate that the accommodation capacities of the currently designated shelters can sufficiently accommodate the population residing in the administrative district when the area occupied by each person is applied but evacuees may be concentrated on some shelter when evacuees would evacuate to the nearest shelters in principle. In addition, the results indicated that 18.76% of the population residing in the subject area would take at least 5 min to evacuate to the nearest shelters. Therefore, resident's evacuations should be forecasted through the forecasting of demand for evacuation and evacuation plans should be established based on the results. In the present study, accessibility analyses were conducted based on actual walking routes to secure practicality. The present study is meaningful in that the results can be utilized as a methodology to review demand for designated shelters and as a tool for designation of shelters later.

Key words: Evacuation, forecasting, shelter, accessibility anaylsis, walking speed, population

INTRODUCTION

The purpose of the present study is to forecast the demand for evacuation occurring for the current designated shelters and define the range of evacuatees that can be accommodated by the shelter. Currently to respond to various kinds of accidents, civil defense shelters at various grades have been designated and operated. In addition, although, information on the number of persons that can be accommodated by each shelter is disclosed, the information is based on a simple calculation formula that applied the area occupied by each person to the area that can be secured.

However, since, evacuees may be concentrated on certain evacuation facilities when an actual civil defense emergency has occurred leading to problems such as the shortage of supplies, prior evacuation plans are considered necessary. In fact, according to the contents of some press reports (NEM., 2011), the resident accommodation rates of evacuation facilities in four border areas in Gangwon-do except for Chuncheon-si and Cheolwon-gun are lower than 100% (Park and Kim, 2012). While, the capital of Korea, Seoul's shelter capacity can hold 285% of its population (Kim *et al*., 2015).

Therefore in this study, the levels of accessibility to shelters according to actual pedestrian paths were analyzed to derive catchment areas of the shelters. In addition, the results of the accessibility analysis and city space information were combine to forecast demand for evacuation that may occur in the case of evacuations. The results of the study are meaningful in that they can be utilized as a methodology for review of demand for the currently designated shelter and a tool for designation of new shelter.

Literature review

Review of laws regarding evacuation facilities: Civil defense evacuation facilities are facilities designated to efficiently operate underground evacuation facilities in order to protect resident's lives and properties when a civil defense emergency has occurred including underground structures such as independent shelters, basements of buildings (such as subway stations) underground shopping centers, pedestrian underpasses and underground parking lots and incidental facilities for performance of the functions of the underground structures (NEM., 2011).

Government supported facilities refer to that facilities that have been installed with government subsidies and publicly used facilities refer to those privately owned or public agency owned underground facilities that have been designated as emergency evacuation facilities.

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Table 1: Classification of civil defense evacuation facilities (NEM., 2011)

Category/Installation object	Scales of facilities	Requirements
Government aid facilities		
Government office building	Area: over 660 m^3	
	Wall thickness: over 1 m	
	Equipping facilities that can protect in CBR situation	1.43 m^3/person
Five islands in the Western sea and border areas	Area: 1.43 m^3/person	
	Wall thickness: over 0.5 m	
	Blast door, Gas filter, Emergency exit	
Publicly used facilities		
Government/local government or public organization's basement facilities	Equipping broadcasting equipment, emergency exit (floor area: over 60 m^3)	3.3 m^3/4 people (0.825 m^3/person)

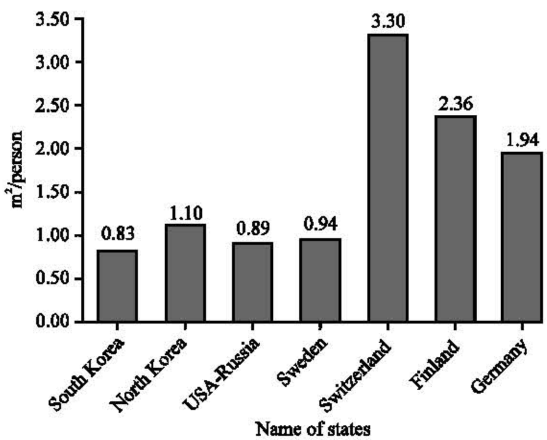

Fig. 1: Standard of area for evacuees

Central government and local government buildings are evacuation facilities for general affairs command that are different from resident evacuation facilities in nature and scale, etc. and cannot be used for resident evacuations in cases of emergency.

Resident evacuation facilities can be divided in those installed in 5 islands in the Western sea and border areas with particularly high risks of Northen Korean attacks and those installed in other areas and the criteria for the scales of facilities and requirements are different as shown in Table 1.

On reviewing the criteria for the number of evacuees of South Korea, it can be seen that the areas of evacuation facilities are smaller compared to the USA and european countries and the standard area per person is smaller than even that of North Korea (Mok, 2015) (Fig. 1).

Meanwhile, resident evacuation facilities in South Korea can be divided into short-term evacuation facilities for emergency evacuation for less than one day and long-term evacuation facilities where long-term evacuations for one day or more based on whether those evacuation facilities have essential incidental facilities or not.

Table 2: Essential facilities and equipment (NEM., 2011)

Category	Contents
Essential facilities	Communication facilities
	Emergency water supply system
	Sanitation facilities
	Emergency power plant
	Fire extinguishing facilities
Essential equipment	Placing an emergency article in each evacuation facilities (Under 100 people-1/over 100 people-2)
	Emergency article: flashlight, radio, First-aid kit, candle, match (lither)
	Placing CBR (chemical, biological and radiological) mask-1 number/person
	Equipping an emergency light (Using a battery or storage battery)

Table 3: Evacuation ratings (NEM., 2011)

Category	Contents	Note
1st	Underground facilities that can be protected in CBR situation	Command center
2nd	Subway, tunnel, basement of high-rise building	Public area
3rd	Underground shopping area, basement parking lot, underground road way passage, basement of multiple-layer building	Public area (Over 660 m^3)
4th	Basement of detached house	Basement (Over 60^3)

In addition, evacuation facilities are classified into grades 1~4 based on the locations where the facilities have been installed, the uses and areas of the facilities.

Evacuation facilities should be designated considering crowd gathering places (densely populated areas), evacuation spaces and accessibility as well as evacuation capacities by area (Table 2 and 3).

MATERIALS AND METHODS

Spatial data construction method: In the present study, Arc GIS was used for accessibility analysis and demand for evacuation forecasting. Spatial data for Arc GIS can be largely divided into 3 types.

The first type is those spatial data that indicate evacuation facilities in the form of points and require location information and facilitie's capacities to accommodate populations. Although, the capacities to accommodate populations can be calculated through a general method according to a manual used for calculation in South Korea in the present study those data that were announced by local governments through their home pages were used.

The second type is those data that were made by spatially visualizing evacuation demand information. To construct these data in the present study, the demand for

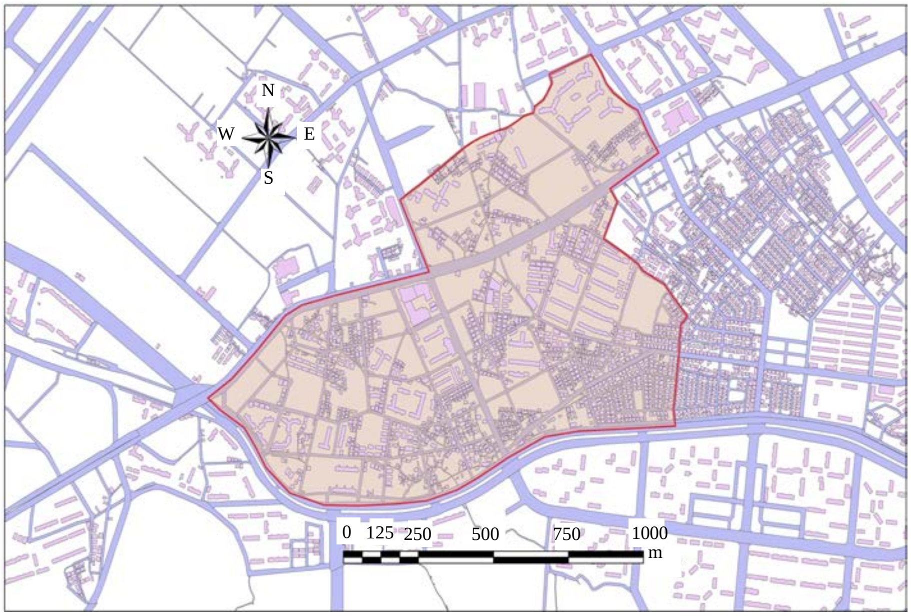

Fig. 2: Spatial data construction

populations residing in buildings was estimated and the results were summed up in units of individual blocks partitioned by streets. That is each block is a concept that include the information on the total population residing in multiple buildings existing in it. Here, the demands in building units were estimated using a method that combined city space information and statistical information which showed errors of approximately 3% when applied to a metropolitan city in previous studies (Lee and Hong, 2016).

Theoretically, the levels of accessibility to individual buildings can be analyzed. However, in the present study, the units of demand for evacuation were set to blocks to expand the range of subjects to the entire city. In addition to visually show the catchment areas of shelters for provision of practical information that can be utilized, analyses of block units divided by streets were judged to be desirable.

The above data are for residential buildings extracted from the subject area and the populations to be evacuated from individual buildings utilizing the gross areas and statistical information entered into the topographic information. There after, route data were constructed for network analysis. Walking lines were drawn using CAD and network data sets were established to conduct analyses in Arc GIS.

In the network data sets, the lines indicate walking lines and the points indicate nodes where turning and route changes can be made.

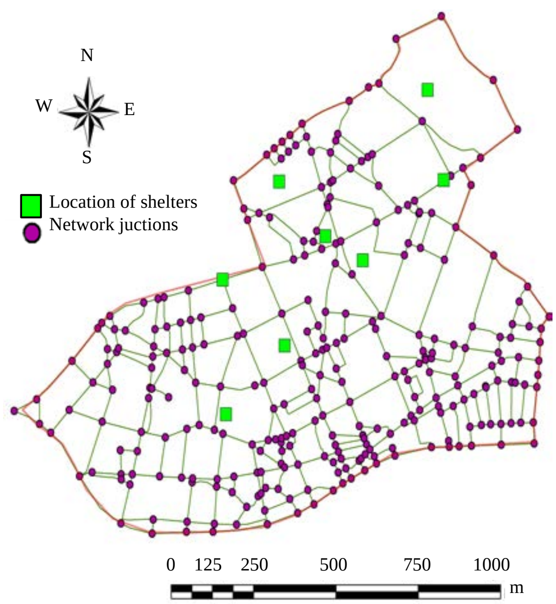

Fig. 3: Network data set construction

In Fig. 3 lines indicate walking lines and the points indicate nodes where turning and route changes can be made. Based on a series of information constructed as such results of forecasting of demand for evacuation were derived utilizing the location-allocation analysis technique to ensure that individual demand points do not overlap each other and the nearest evacuation facilities on the can be selected (Fig. 2-4).

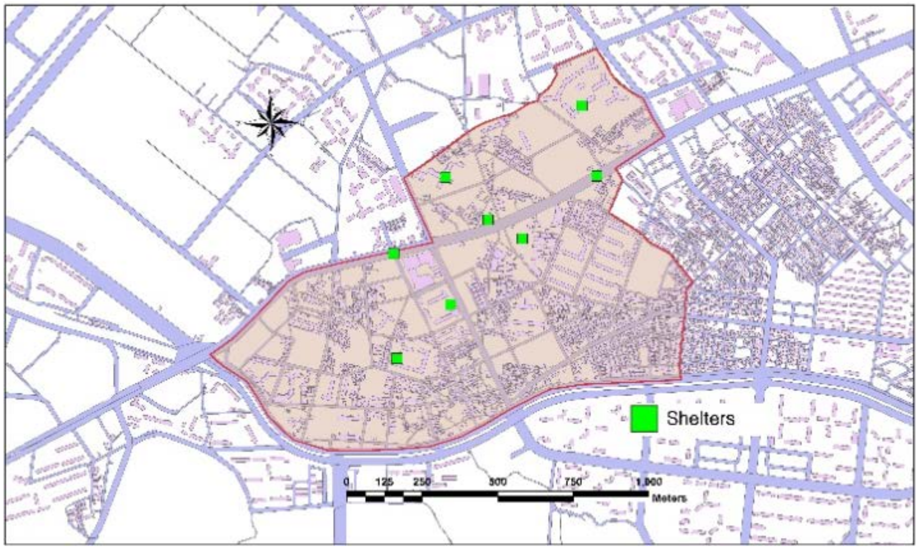

Fig. 4: Status of the site and location of shelters

RESULTS AND DISCUSSION

In the present study, 'Jincheon-dong' which is the most densely populated among 'dong' units of Daegu-si (area: 884.15 km^2, population: 2,492,724). The general present situations of the study subject area are as follows (Table 4).

In addition, the data on the locations and present situations of shelters designated in the subject area are as follows. A total of 8 shelters are located in the subject area and two of them are publicly used facilities and Grade 2 facilities. The remaining 6 shelters are private facilities and grade 3 facilities.

The areas of individual shelters vary greatly in a range of 396~31,775 m^3 and the numbers of persons that can be accommodated also vary greatly a range of 160~17,000. Therefore, the possibility for the numbers of persons evacuated to shelters that can accommodate small numbers of evacuees to exceed the maximum numbers of evacuees that can be accommodated, so that, some of the evacuees should move to other shelters is judged to be high (Table 5 and Fig. 5).

The results of location-allocation analyses conducted under the assumption that evacuees from the 135 blocks in the subject area would evacuate to the nearest shelters indicated that the numbers of evacuees to four shelters would exceed the maximum numbers of evacuees that could be accommodated and the predicted excessive accommodation rates were shown to be 13.96~218.13% (Fig. 6 and 7).

In the case of the shelter with the highest predicted accommodation rate, populations exceeding three times

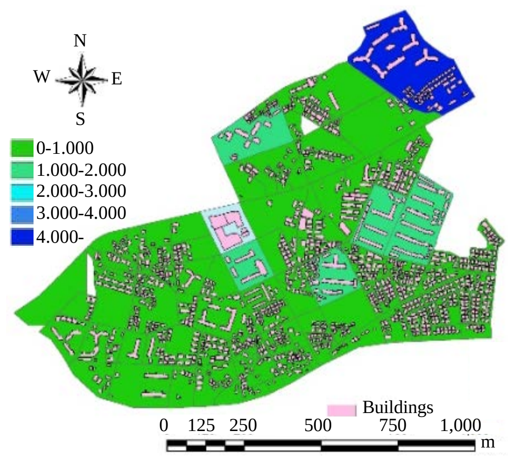

Fig. 5: Population status of the site

Table 4: General status of the site

Categories	Contents
Area	5.95 km^2
Population	64,348 (2015.06)
Number of residential buildings	1,508
Number of blocks	135

Table 5: Shelters status of the site

Category	Grade	Area (m^3)	The number of persons to be accommodated	Area/population (m^3/person)
A1	2nd	4,907	5,950	0.82
A2	2nd	5,016	6,000	0.84
B1	3rd	6,672	7,850	0.85
B2	3rd	1,980	2,200	0.90
B3	3rd	4,392	4,280	1.03
B4	3rd	7,702	9,327	0.83
B5	3rd	31,775	17,000	1.87
B6	3rd	396	160	2.48

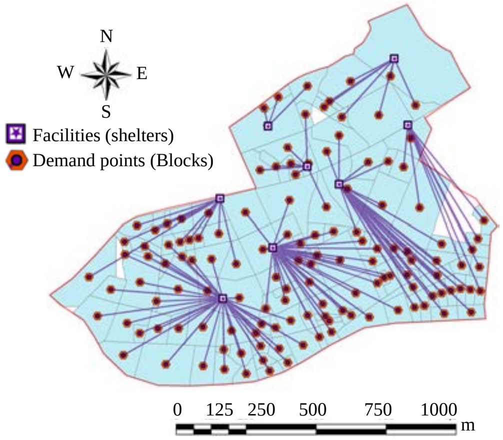

Fig. 6: Location-allocation analysis result

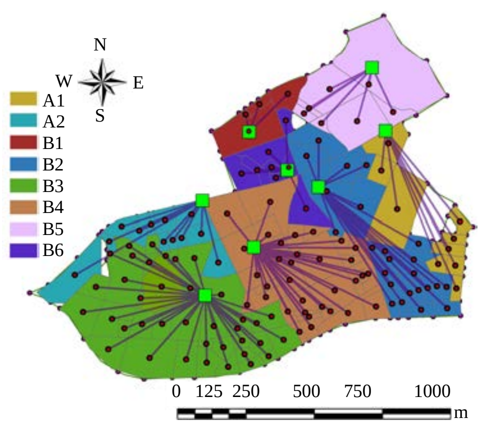

Fig. 7: Result of zone division

of the maximum numbers of evacuees that could be accommodated were expected to be concentrated on it.

The average travel distances to individual shelters in cases where evacuees from the 135 blocks in the subject area would evacuate to the nearest shelters were identified to be 106.74~580.66 m.

Therefore when the average walking speed is assumed to be 1.5 m/sec, the average time required for evacuation to each shelter is expected to be 1.19~6.45 min.

The population that would take 5 min or more to evacuate to the nearest shelter is estimated to be a total of 6,077 which corresponds to 18.76% of the total number of evacuees. Since, this is a result without considering situations in emergencies, route characteristics (gradients, etc.) and the gait characteristics of evacuees (age, degree of disabilities), the lengths of evacuation time are judged to increase further when such characteristics are reflected (Table 6-8).

Table 6: Prediction refugee population of each shelters

Categories	Grades	The number to be of persons accommodated	Evacuation forecasting population factor (%)	Forecasting demand
A1	2nd	5,950	3,360	56.47
A2	2nd	6,000	529	8.82
B1	3rd	7,850	1,904	24.25
B2	3rd	2,200	4,877	221.68
B3	3rd	4,280	4,956	115.79
B4	3rd	9,327	10,629	113.96
B5	3rd	17,000	5,633	33.14
B6	3rd	160	509	318.13
Total		52,767	32,397	61.40

Table 7: Evacuation distance to each shelters

Categories	The shortest distance (m)	The longest distance (m)	Average distance (m)
A1	15.46	848.16	580.66
A2	53.00	572.58	265.48
B1	0.00	286.82	106.74
B2	0.08	865.46	539.76
B3	17.42	562.99	318.26
B4	9.40	660.26	324.49
B5	26.11	295.37	183.58
B6	41.43	253.46	158.21

Table 8: Population that would take 5 min or more

Categories	Average required time (min)	The population that would take 5 min or more	The population ratio that would take 5 min or more (%)
A1	6.45	2,829	86.54
A2	2.95	0	0.00
B1	1.19	0	0.00
B2	6.00	1,917	40.37
B3	3.54	697	15.10
B4	3.61	634	5.96
B5	2.04	0	0.00
B6	1.76	0	0.00
Total	3.44	6,077	18.76

CONCLUSION

In the present study, accessibility analyses were conducted based on actual pedestrian paths to derive the catchment areas of shelters with a view to forecasting the demand for evacuation that would occur for the currently designated shelters and defining the ranges of evacuees that can be accommodated by the shelters. In addition, the results of the accessibility analysis and city space information were combined to forecast demand for evacuation that might occur in an emergency.

The results of the study indicate that the accommodation capacities of the currently designated shelters can sufficiently accommodate the population residing in the administrative district when the area occupied by each person is applied but evacuees may be concentrated on some shelter when evacuees would evacuate to the nearest shelters in principle. In addition, the results indicated that 18.76% of the population residing in the subject area would take at least 5 min to evacuate to the nearest shelters. Therefore, resident's evacuations should be forecasted through the forecasting of demand for evacuation and evacuation plans should be established based on the results.

The average length of evacuation routes from the 135 blocks to the nearest shelters estimated to be 349.46 m and the standard deviation was shown to be 212.78 indicating that the appropriateness of shelter location selection was not sufficiently considered.

In the present study, accessibility analyses were conducted based on actual walking routes to secure practicality. The present study is meaningful in that the results can be utilized as a methodology to review demand for designated shelters and as a tool for designation of shelters later.

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