Journal of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography
Vol. 37, No. 5, 293-302, 2019
https://doi.org/10.7848/ksgpc.2019.37.5.293

ISSN 1598-4850(Print)
ISSN 2288-260X(Online)
Original article

Developing a Method to Define Mountain Search Priority Areas Based on Behavioral Characteristics of Missing Persons

Yoo, Ho Jin [1] · Lee, Jiyeong [2]

Abstract

In mountain accident events, it is important for the search team commander to determine the search area in order to secure the Golden Time. Within this period, assistance and treatment to the concerned individual will most likely prevent further injuries and harm. This paper proposes a method to determine the search priority area based on missing persons behavior and missing persons incidents statistics. GIS (Geographic Information System) and MCDM (Multi Criteria Decision Making) are integrated by applying WLC (Weighted Linear Combination) techniques. Missing persons were classified into five types, and their behavioral characteristics were analyzed to extract seven geographic analysis factors. Next, index values were set up for each missing person and element according to the behavioral characteristics, and the raster data generated by multiplying the weight of each element are superimposed to define models to select search priority areas, where each weight is calculated from the AHP (Analytical Hierarchy Process) through a pairwise comparison method obtained from search operation experts. Finally, the model generated in this study was applied to a missing person case through a virtual missing scenario, the priority area was selected, and the behavioral characteristics and topographical characteristics of the missing persons were compared with the selected area. The resulting analysis results were verified by mountain rescue experts as 'appropriate' in terms of the behavior analysis, analysis factor extraction, experimental process, and results for the missing persons.

Keywords : Missing persons behavior, Search and Rescue, Probability of Area, Spatial Multi-Criteria Decision Making, Weighted Linear Combination

1. Introduction

According to the disaster year books for the past 5 years. (Ministry of the Interior and Safety, 2013, 2014, 2015, 2016, 2017) statistics, the 6,831 times missing person incidents among total 37,115 mountaineering accidents occurred (around 18%) from 2013 to 2017. In particular, the total number of mountaineering accidents in 17 years was 6,767, which is down from 7,472 in 2016 and 7,940 in 2015. However, the number of distresses and missing person incidents increased by 341 from the previous year. Furthermore, more of these incidents are expected to occur in the future.

As the number of accidents increases in mountainous areas, the number of firefighters who handle and handle accidents is not enough. In particular, the number of specialists for mountain rescue is 105 organizations in nine

Received 2019. 03. 18, Revised 2019. 04. 18, Accepted 2019. 10. 24
1) Member, Dept. of Geoinformatics (GSE), University of Seoul (E-mail: yoo0928@hanmail.net)
2) Corresponding Author, Member, Dept. of Geoinformatics, University of Seoul (E-mail: jlee@uos.ac.kr)

nations in 2018 (National Fire Agency, 2019). In addition, 70% of the country's land is very mountainous compared to flat areas. Therefore, it is necessary to scientifically and systematically establish the operation, conduct, and command of search and rescue operations in order to quickly recognize the situation of rescuees by replacing the shortage of manpower in the increasing number of rescue sites, and to expedite the exploration and safe emergency rescue activities. Therefore, the National Fire Protection Agency, together with the Ministry of Public Administration and Security, which are responsible for the safety of the people, are in charge of conducting search sites by incorporating LBS (Location-Based Service) and GIS GIS (Geographic Information System) based on advanced ICT (Information & Communication Technology). These agencies are constructing various systems that can increase the success rate of operations within the Golden Time. One strategy is to establish an operation plan based on a real-time map and to give operation instructions to search and rescue personnel, and to reduce the waste of manpower such as duplicate search by reporting and inputting the real-time status of search area. This means that the concerned agencies have established a national lifesaving search system, but the problem of the search structure by the national lifesaving search system is that the search area is selected on the map based on the subjective judgment of the commander. It is very difficult to rescue missing persons in the search and rescue Golden Time in mountainous areas with high risk factors such as steep slopes, hills, rocks, and rapidly changing weather, based solely on the experience of a particular commander. With these, this study analyzes the methods of finding missing persons based on probability in mountainous areas through previous studies to find the missing person's age, gender, migration statistics according to the missing person's age, and mental and physical state when a person is suddenly lost. We analyze the patterns of behavior according to the status of the resident, derive analysis elements by combining topographic factors such as the slope of the missing area and vegetation environment, and provide objective information when searching for missing persons through the analysis results according to the type of missing persons through selecting priority search area. This aims to support the efficient operation of the searchers, as well as the rescue of missing persons within Golden Time.

2. Previous Studies

This study utilizes the pattern of behaving according to the mental and physical condition of missing persons and the statistics of disappearance events and selects the areas where the missing persons are expected to be. Koester (2018) is examined the probability of missing persons based on personal behavior and statistics. A preliminary study on the models of predicting missing person were conducted based on various models including Ring models (Syrotuck, 2000; Koester, 2008), Watershed models (Doke, 2012), Bayesian models (Lin and Goodrich, 2010), Mobility models and Agent-Based Lost Person Movement Modelling (Mohibullah, 2017).

The Ring model is based on the crow's-flight distance statistics provided by Syrotuck (2000) and Koester (2008). Distances for 25%, 50%, 75%, and 90% are shown in circles based on the location of the missing persons. However, this model uses Euclidean distance, which does not take into consideration elevation and slope to calculate actual distances.

The Watershed model divides the terrain according to the watershed to indicate the search area. This model was used by Doke (2012), which showed that about 75% of Wildland Search and Rescue accidents occur in mountains. The probability for a watershed is determined by the probability calculated by the watershed adjacent to the watershed containing the IPP (Initial Planning Position), divided by the total area of the watershed. This model, however, produces large areas for its watersheds that may not be ideal for search operation procedures.

Lin and Goodrich (2010) proposed a Bayesian model that automatically generates a probability distribution map from topographic feature data such as topology, vegetation, and altitude data. This is the first study to integrate the GIScience techniques to evaluate the mobility model for missing parts in human search. However, this model requires actual path data from past events. Without the GPS (Global Positioning System) location log, the travel path will not be exactly determined.

The mobility model predicts the movement of the missing person for a certain period of time through a highly mobile route. In GIS, the cost of raster data is calculated by applying a least-cost path algorithm with cost-distance modeling. This also utilizes Tobler's hiking function (Tobler, 1993) to calculate the anisotropic cost surfaces that predict the speed of the missing persons but does not consider the variety of walking speeds for different types of hikers.

Finally, Mohibullah (2017) examined the use of UAV (Unmanned Aerial Vehicle) to find missing persons through an actor-based missing person movement model. Based on the behavior of the missing persons, the study adds variables such as surrounding environment and spatial data, evaluates the model, and finds the missing persons through the predictive model more accurately. This study also has the considers limitations of the actual path data for real missing persons, such as Bayesian models, which requires a large amount of time and money to produce a large amount of sample data and generate predictive models.

Similarly, this study utilizes information and statistics on past disappearances. However, in this paper we consider the information on the location and behavioral characteristics of the missing persons and topographical features of the area in order to supplement the limitations of the five missing persons prediction models discussed above.

3. Research Methodology

MCDM (Multi-Criteria Decision Making) is used to find a solution to a problem, considering various criteria to present a model for selecting search-priority areas for missing persons based on their behavioral characteristics (Oh, 2008). This study uses integrates GIS and SMCDM (Spatial Multi-Criteria Decision Making) methodologies as a methodology used to select one or more alternatives ranked according to spatial arrangements based on the results analyzed through multiple criteria. The overall flow of research on this methodology is shown in Fig. 1, which includes four steps: selection of decision rules, set of evaluation criteria, weighting of evaluation criteria, and spatial decision making.

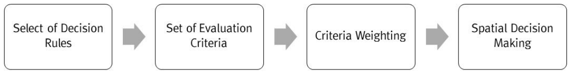


Fig. 1. General methodology

3.1 Selection of decision rules

First, an SMCDM method for the selection of a missing person's search priority area must be selected. The decision rule used in this study is WLC (Weighted Linear Combination) . This technique is also called Simple Additive Weighting or Scoring Method. This method is based on the concept of weighted averages and is widely used in a raster-based GIS environment.

$$A_i = \sum_{j=1}^{J} w_j \cdot x_{ij} \ (i = 1,2,\cdots,I,\ j = 1,2,\cdots,J) \quad (1)$$

The WLC can be expressed as an equation by Eq. (1). When overall evaluation standard (j) for all methods (i) are calculated, the method with the highest total weight is selected. The result of the selection of the survey area (A_j) is calculated by multiplying the index (x_{ij}) of the analysis element of each missing person by the weight value (w_i) of the analysis element.

3.2 Set of evaluation criteria

In SMCDM, each evaluation criterion is constructed as a layer with attribute values, called a criterion map. These evaluation criteria differ in measurement scale according to each criterion's characteristics. Objective phenomena that can be interpreted generally are measured by Natural-Scale, and If a unit of measurement is defined by the decision maker's subjective judgment, it is measured as a Constructed-Scale. If the attribute does not clearly express the degree of achievement of the purpose, it can also be indirectly measured to construct a criterion. Therefore, there is no optimal way to standardize the evaluation criteria, and it is applied in an appropriate way according to the characteristics and problems of variables. The method of measuring the evaluation index for selecting the search priority area is as follows. Extract analysis elements from the behavior characteristics of the missing person. We consider topographical information for missing information, behavior characteristics of missing people, and missing regions for each element. The subjective assessment of the survey leader is reflected via an index with a value between 0 and 10 (Lee and Lee, 2011).

We used a methodology from previously performed analysis to extract the analysis factor from the behavioral characteristics of the missing person. Perkins *et al.* (2003) integrated the results of research on the behavior of the existing missing person and the results of analysis of the case of the missing person in the United Kingdom. Behavior and rescue methods for missing persons are classified into Characteristics, Where, and How.

This study analyzes only Characteristics and Where, in relation to missing person behavior and location. The analysis of Characteristics for this study is shown in Table 1. We analyze the content of different actions of the missing person and extract geographical keywords such as location and position and analysis elements of mountain topography that can be analyzed by GIS. "Hill" is defined as "a place where the ground is slightly high" and can extract the element of "elevation". In Table 1, an objective geographical keyword "hill" is extracted from the statement "Often head for a scenic location or well-known beauty spot such as a hill, which may overlook civilization".

Table 1. Extracting analysis element based on behavioral characteristics of missing persons

Division	Behavior Content	Geographic keywords	Analysis element
Characteristics	Frequently located at the interface of two types of terrain and/ or vegetation boundary.	vegetation boundary	vegetation boundary
	Often head for a scenic location or well-known beauty spot such as a hill, which may overlook civilization	hill	elevation (contour)
	Rarely found in dense under-brush or trees	dense under-brush or trees	vegetation, forest density

As described above, the analysis elements are extracted by using common geographic keywords through the analysis of the characteristics of missing persons' behavior for each type.

We determine the index definition according to type of missing person of the extracted element from a method used in a previous research to find the enemy's optimum penetration area considering the topographical factor. This is derived from detection risk index setting method of the ISRID (International Search and Rescue case Database) that was used in analysis for search area (Bang *et al* 2006, Shin *et al*., 2009).

Based on topographical information, using risk of search area prediction model, topographical information such as height and slope was used based on the area of the missing person, like setting detection hazard index to select the most suitable penetration area. As shown in Table 2, according to the method of setting the detection risk index by inclination (Shin *et al*, 2009), the index is divided into 10 levels and the index is divided into 5 levels. The highest index is set to 10 with an interval of 2.

Table 2. Detection risk index by slope

Division	Range (%)	Index
0% Slope	0≤Slope≤10	2
10% Slope	10≤Slope≤20	
20% Slope	20≤Slope≤30	4
30% Slope	30≤Slope≤40	
40% Slope	40≤Slope≤50	6
50% Slope	50≤Slope≤60	
60% Slope	60≤Slope≤70	8
70% Slope	70≤Slope≤80	
80% Slope	80≤Slope≤90	10
90% Slope	90≤Slope≤100	

The method using the ISRID is to set a value of 10 times the probability of missing persons based on ISRID statistics, for each range as shown in Table 3.

Table 3. Index setting based on ISRID statistics

Probability of missing persons	ISRID(m)	ISRID Range (m)	Index
25%	50	0≤Range≤50	2.5
50%	100	51≤Range≤100	5
75%	238	101≤Range≤238	7.5
95%	424	239≤Range≤424	9.5

3.3 Evaluation criteria weight calculation

The third step in SMCDM is to estimate the weights for the analytical elements defined in the evaluation criteria setting. The weight of each element is defined using the AHP (Analytical Hierarchy Process) pairwise comparison method (Saaty, 2005). AHP data is easy to analyze and is applicable for both quantitative and qualitative criteria. For this study, a total of 11 specialist groups consisting of eight 119 Special Rescue Teams in the central rescue headquarters and three Dobongsan Mountain rescue teams.

3.4 Spatial decision

The final step in the methodology is SMCDM. This interprets the result of GIS analysis superposition analysis using the set evaluation criteria, and weights created for the WLC method.

The scale of the raster data and the result is generated with a size of10m by 10m, which is the minimum grid used by the search function of the national rescue system. To extract search areas using data sets generated for each missing person, we use the Local Function, Tomlin's cartographic modeling language (Tomlin, 1990). This method is illustrated in Fig. 2 in contrast with Focal and Zonal functions.

The raster data created by the product of index and weight by analytic element according to missing person type were analyzed by the Map Algebra function of ArcMap10.3. In the resulting raster, the area with highest index is selected as the search priority area.

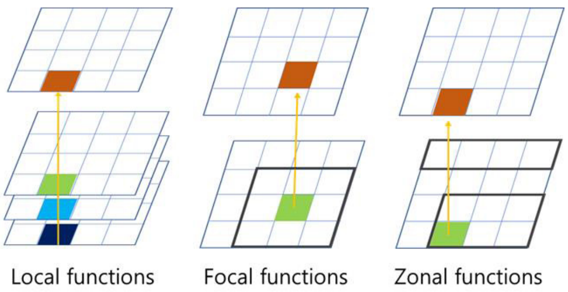


Fig. 2. Map Algebra Functions (Tomlin, 1990)

4. Experimental Analysis

To demonstrate the proposed methodology, we conduct an experiment to identify priority search areas. Because there was no record of a recent distress and missing accident common to the expert group, we constructed a virtual missing situation and conducted the experiment.

4.1 Set-up of experiment area and situation

In this study, Bukhan Mountain (called Bukhansan) located at Seoul in Korea, which has the highest number of mountain accidents and rescue operations (Seoul Metropolitan Government, 2018), was selected as the mountainous area for the experiment. In order to see Seoul at a glance, the detailed test area includes the Bukhansan summit and Insu Peak, a region where many hikers come and go for rock climbing (Fig. 3).

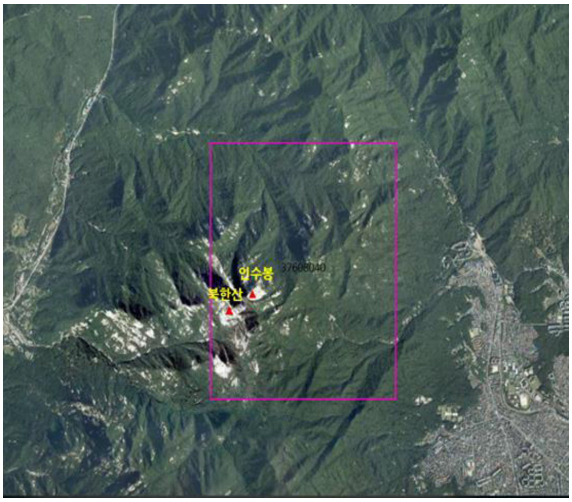


Fig. 3. Experimental area

For this scenario, the missing person is characterized as a male with age in his 60s and was reported missing at time 16:00. Based on the statistics of mountain accidents published by Seoul Metropolitan Government in 2017 (Seoul Metropolitan Government, 2017), the likelihood of occurrence of each characteristic is at 61% for the gender, 33.4% for the age, and 25.9% for the time frame.

The missing person's last identified location and missing time are set arbitrarily, and the missing location is assumed to be the latitude 37° 39' 50.5" longitude 126° 58' 40.0" and the is already missing for about 2 hours.

4.2 Set of evaluation criteria

The behavioral characteristics of the five types of missing persons are analyzed and a total of seven elements are extracted and defined as shown in Table 4, including Travel distance, Vegetation types, Vegetation density, Slope, Height, Hiking trail, and Shelter.

Table 4. Definition of mountain terrain elements through analysis of missing behavior

Element	Description
Travel distance	Factor that can determine how far away a person has been missing from the last location.
Vegetation	Factor that indicate the environment surrounding the missing person (forest, grassland, rock) and where they might have moved.
Vegetation density	Factor that determine the extent of the forest around the missing person.
Slope	Factor that can determine if a missing person is moving in a hurry or on a flat surface.
Height	Factor that determine if a missing person has moved to a higher or lower destination.
Hiking trail	Factor to determine how far away a person is missing from a trail.
Shelter	Factor that can determine if a missing person is moving or hiding in a place that has a shape like a temple, a shelter, or a sperm.

For the analysis elements extracted above, the information of the missing persons, the missing terrain, and the behaviors of the missing persons are analyzed and are indexed according to characteristics. The index setting for the moving distance factor uses the age-specific walking speed of Satoh *et al.* (2006). The age of the missing person is 50, and the age-specific walking speed is 3.40 km/hr., which is 50-64 years old in Table 5.

Table 5. Walking speed by age

Age	Walking speed (km/hr.)	Walking speed (m/min)
5~9	2.17	36.17
10~14	3.39	56.50
15~49	4.00	66.67
50~64	3.40	56.67
65~74	2.82	47.00
75 or more	2.51	41.83

Based on this, the moving distance section according to the missing time is divided into a range of 1 to 10 hours. The virtual missing time is 2 hours that defines an Index value 10 of the moving distance section corresponding to 2 hours missing time and is defined with a difference of 2.

The Height elements use the Natural Breaks (Jenks) classification scheme. The height range of the survey area appears from 150m to 833m, which is classified into 10 levels. Index values are defined in accordance with the statistics of the characteristics that move to the higher or lower part of the typed behavior of the missing person and ISRIDs.

The Slope range of the searching area is from 34% to 336%, and the slope elements are classified into 10 stages in the same way as the elements of height. The definition of the Index value of the slope element is defined in accordance with the characteristic of moving to a high or low slope position in the action of the missing person.

Vegetation elements define the Index value according to the behavior characteristic that a missing person moves to a forest, grassland, and rock. The range of vegetation elements is defined by selecting six classifications of land cover map: hardwood-forest, coniferous forest, mixed forest, rock stone, natural grassland, and other grassland.

Vegetation density is set to three levels of - small, medium, and high using the vegetation density attribute value in the forest map. Index values are defined as 3, 6, and 10, which are different from other elements. This factor is defined according to whether the missing persons tend to move towards dense forests or behave in the opposite way.

The Hiking trail criterion is defined according to the distance the missing persons are found in the trail. The range setting for this criterion sets the range for each missing person type because the statistics for the Track Offset of the ISRID are different for each missing person type. Index values range from 25%, 50%, 75%, and 95% of the Track Offset to 2.5, 5, 7.5, and 9.5 in descending order of probability.

The Shelter elements use data from the main points of the hiking trail. The setting of the range of this element is 30 meters in radius. The index defines 10 as the missing persons who have a behavioral characteristic of the capability to find shelter or hide in a building, and 5 as the missing persons who do not have this capability.

4.3 Calculation of criteria weights

In order to define the weight through pairwise comparison for AHP, a total of 11 specialist groups consist of eight 119-special rescue teams in the central 119-rescue headquarters and three Dobongsan rescue teams in the Seoul City 119-special rescue team are configured.

Of the 11 experts, 10 responded. Analysis of the results of the questionnaire are tabulated in a spreadsheet. The CR (Consistency Ratio), which can determine that the AHP questionnaire responses, are consistent and the results can be evaluated as "reliable" because all 10 people have scores of 0.1 or less. As a result of weight extraction in Table 6, the moving distance element of weight 0.178 is the most important element, and the height has been defined as with the least weight of 0.100.

Table 6. Search priority analysis element weight

Ranking	Element	Weight
1	Travel distance	0.178
2	Hiking trail	0.163
3	Shelter	0.161
4	Slope	0.135
5	Vegetation	0.132
6	Vegetation density	0.131
7	Height	0.100
Total		1

4.4 Spatial decision

The search priority area selection analysis uses each missing person's analytical data set created through the basic data set. The Map Algebra analysis tool of ArcMap10.3 used by Eq. (2) to generate analysis data for each missing person.

$$A_j = \sum_{j=1}^{7} w_j \cdot x_{ij}$$

$$\left(\begin{array}{l} A_{j = jSearch\,area\,selection \in dex[=1...10]} \\ x_{1j = j\,Travel\,distance \in dex[=1...10]} \\ x_{2j = jHiking\,taril \in dex[=1...10]} \\ x_{3j = jShelter \in dex[=1...10]} \\ x_{4j = jSlope \in dex[=1...10]} \\ x_{5j = j\,Vegetation \in dex[=1...10]} \\ x_{6j = j\,Vegetation\,density \in dex[=1...10]} \\ x_{7j = jHeight \in dex[=1...10]} \\ \quad w_1 = Travel\,distance\,weight[0.178325719] \\ \quad w_2 = Hiking\,trail\,weight[0.163316308] \\ \quad w_3 = Shelter\,weight[0.160876616] \\ \quad w_4 = Slope\,weight[0.135038236] \\ \quad w_5 = Vegtation\,weight[0.131536996] \\ \quad w_6 = Vegtation\,density\,weight[0.130686649] \\ \quad w_7 = Hight\,weight[0.100219476] \end{array}\right) \quad (2)$$

4.4.1 Search priority area analysis by missing persons

The search priority area according to the different behavior characteristic of the missing person is selected as an area where the sum of the product of the index value of all the elements and the weighted product is high. By overlapping the analysis and movement data of the missing person in time units, select the priority area for each section may be selected corresponding to the time of disappearance.

As a result of comparing and analyzing the different behavioral characteristics of the missing person and the feature of the topography of the selected area, five types defined in the experiment: Despondent shown in Fig. 4(a), Psychological Illness shown in Fig. 4(b), Developmental Problems shown in Fig. 4(c), Miscellaneous Adults shown in Fig. 4(d), Hikers / Walkers shown in Fig. 4(e) are all well-represented information and behavioral characteristics of the missing person. The results are presented in Fig. 4.

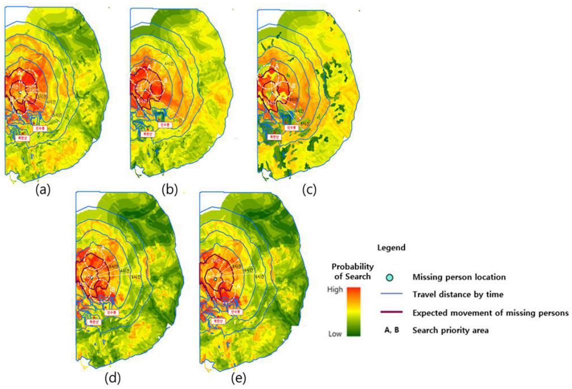


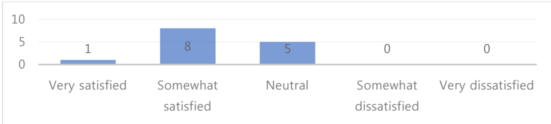
Fig. 4. Search results for missing persons

4.5 Validation of results through expert questionnaire

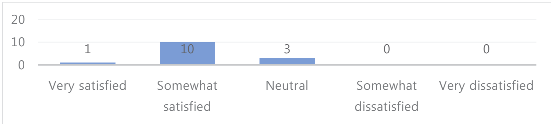
The search and rescue experts were asked about the qualitative evaluation of the experimental process and the experimental results about the search priority area selection results of the missing persons. The group of experts consist of 14 119 special rescue teams in the central 119 rescue headquarters and 5 Dobongsan rescue teams in the Seoul city 119 special rescue team.

Table 7. Expert verification survey results

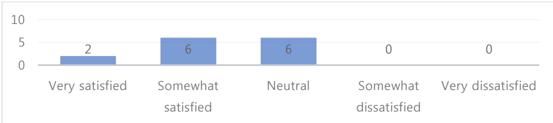
1. Do you think the analysis of the behavioral characteristics of missing persons is good?



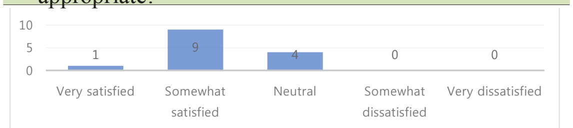
2. Do you think the element of behavior analysis is well extracted?



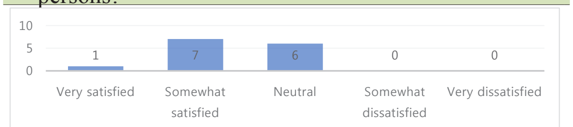
3. Do you think that the index score of each element according to the behavior characteristics of each missing person is properly set?



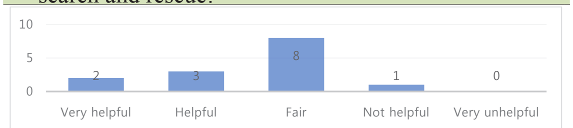
4. Do you think the test area and disappearance were appropriate?



5. What do you think about the results of the search area selection for behavioral characteristics of missing persons?



6. Do you think this study will be helpful in establishing search and rescue?



Before the questionnaire was handed, the background and purpose of this research were explained, and explanatory materials of experimental procedures, methods, and results were distributed. Questionnaires were made up to a total of six questions, and the order of the questions was ordered according to the experimental method, and the results of the questionnaires are as shown in Table 7.

There is no evaluator who selected 'Somewhat dissatisfied' and 'Very dissatisfied" for the experiment process from 1 to 4, and it is concluded that the behavior analysis, index setting, experiment area setting, disappearance setting for missing persons is appropriate. The number of experts who selected "Very satisfied", "Somewhat satisfied" in Question 5 is eight, more than half of the respondents. From these results, it is considered that the missing person search priority area is appropriately selected

5. Conclusion

In this paper, in order to assist in ensuring the to rescue a missing person within the critical time, we proposed a method to select the search priority areas for missing persons by integrating missing person behavior characteristics, disappearance information, and topographical information in missing areas and using SMCDM technique.

Seven elements were extracted by analyzing the behavioral characteristics of the missing persons of Despondent, Psychological Illness, Developmental Problems, Miscellaneous Adults, Hikers / Walkers five types according to the procedure of the SMCDM method. Indices were defined to set evaluation criteria for analysis elements according to the behavioral characteristics of missing persons. The weight of the analysis factor was defined using AHP pairwise comparison questionnaire for mountain rescue professionals. Using the defined index values and weights, each analysis layer for each missing person type was calculated and then overlay analysis was performed by Map Algebra. Based on the results of the overlay analysis, the priority areas for searching for missing persons were selected, and the behavioral characteristics and topographical characteristics of the missing persons were compared with the selected regions.

Finally, to determine whether the results of the selection of priority search area are meaningful, we selected a search rescue specialist group and conducted a verification questionnaire. As a result of the questionnaire, the behavior analysis, the factor extraction, the experimental process, and the results of the missing persons were mostly evaluated positively, and this reflected on the applicability of the research.

Using the proposed method, we can make a more accurate judgment about the search area through information about the user's mental status, age, sex, and reason of disappearance. However, this study does not consider the effects of weather, such as temperature and humidity on a missing person's behavioral patterns in missing areas. In the future, collecting more cases of distress and disappearance, improving results of statistical analysis and observations behavior patterns for various environmental conditions would enable incorporating these factors so missing persons may be found more accurately and quickly.

Acknowledgement

This work was supported by the 2018 Research Fund of the University of Seoul.

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