Mapping of the Rescue Equipment Mobilization Potential: A Decision Support Tool for Emergency Management

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Abstract

On a managerial perspective, pre-diagnosis of emergency response potential and decision support during rescue operation are essential for improving emergency response capability. Toward this end, this paper introduced a novel index to measure equipment availability at a certain location and time: Rescue Equipment Mobilization Potential within Standard Emergency Response Time ($\text{REMP}_{\text{SERT}}$), which was estimated and visualized in a map based on the geographic information system (GIS). It was shown that the accuracy of the proposed map was in highly acceptable range (i.e., 92.4%), compared with commercialized navigation system (i.e., *NAVER map navigation*). Using the validated map, two case studies were presented: (i) the pre-diagnosis of response potential (case: Seoul) and (ii) the decision support for optimal dispatching of rescue equipment (case: Mauna Ocean Resort collapse), through which the utility and efficacy of the proposed map in emergency management were verified.

Keywords: *Novel approach; Emergency response agency; Rescue equipment; Mobilization potential; Standard emergency response time; Geographic information system.*

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Introduction

Research background and objective

The overriding duty of an emergency response agency (ERA) (e.g., 911 services in the United States and 119 services in South Korea) in saving a life is to mobilize appropriate rescue equipment to the scene of the emergency in a timely manner (Alireza & Wen, 2012; Sunarin et al., 2014; Victorian Auditor-Generals, 2015). This is because the emergency response time (i.e., the elapsed time between the first call of an emergency and the arrival of the first responder unit at the scene) exerts a profound influence on the survivability of the injured people (Jonathan, 1979; Thomas & Jay, 2002; Lie, 2014).

Toward this end, several emergency organizations around the world have regulated the standard emergency response time (SERT) for the rapid and effective mobilization of rescue equipment (e.g., 8 minutes for the World Health Organization (Peter & Vincent, 2002), 10-15 minutes for Colorado (Colorado Resource Mobilization Working Group, 2009), 12-15 minutes for California (San Diego Coutry Grand Jury, 2014), and 10 minutes for Wales (The Fire Brigades Union, 2015)).

In the case of South Korea, the Ministry of Public Safety and Security (MPSS) has established the *Emergency Rescue & Response Plan* and has regulated the SERT to 10 minutes as the primary duty of the ERAs in South Korea (Ministry of Public Safety and Security of South Korea, 2015a). According to the *Emergency Response Statistics Report 2015* of MPSS, however, the percentage of the cases in 2015 where rescue equipment was mobilized within the SERT was only about 58.52% of all the emergency cases (Ministry of Public Safety and Security of South Korea, 2015b).

In a managerial perspective, the poor response capability of the ERAs is mainly due to the following two reasons: (i) the lack of diagnosis tool for non-service areas of ERAs; and (ii) the lack of decision support tool regarding equipment mobilization in an emergency.

Firstly, the service area of an ERA (i.e., the regional scope where an ERA can mobilize its rescue equipment within the SERT) is determined in accordance with the geographic position of the ERA and the road network condition of the adjacent area. The problem is that non-service areas of ERAs always exist due to the insufficient number of ERAs to cover all populated area. In these sense, the additional establishment of ERAs has been high on the agenda in South Korea, highlighting the need for an appropriate diagnosis tool for decision makers.

Secondly, the effect of emergency response highly depends on the on-scene manager's sense of situational judgement. Figure 1 shows the current emergency management process of South Korea. Just after the first call of an emergency, on-scene manager mobilizes the first responder unit, considering the contents of the call. However, in many cases, it might be insufficient to fully cover uncertain conditions of an emergency, which eventually requires additional on-scene judgements on a new rescue strategy and its required equipment from an on-scene manager. In the current practice, the judgement is determined solely depending on an on-scene manager's personal experience and instant intuition. Furthermore, the manager cannot but relies only on the contextual information of a scene in making the decision. This may contain high possibility of human errors, which worsen a rescue plan. For example, an on-scene manger may require additional equipment and draw up rescue strategy based on his/her own scene understanding. However, it is not guaranteed that the equipment will be mobilized in time as hoped by manager, and if this is the case, the hasty decision may significantly deteriorate the rescue plan because the golden-time can be already passed. Therefore, to enhance the manager's sense of situational judgement and reduce the human errors, the intuitively understandable and easily recognizable information on equipment availability should be provided to on-scene managers in advance. Given the availability information on rescue equipment (e.g., equipment location, immediately available quantities, and travel time to the scene), an on-scene manager may strengthen the insight to identify which equipment is useful or useless in a particular condition. This support will lead an on-scene manager to establish well-coordinated rescue strategy with accessible equipment in time.

Regarding the issues above, this research devised a novel index that can measure equipment availability at a certain location and time: Rescue equipment mobilization potential within the standard emergency response time ($REMP_{SERT}$). The $REMP_{SERT}$ value represents the number of rescue equipment that can be mobilized within the SERT.

This research aims to estimate and visualize the $REMP_{SERT}$ of South Korea for the diagnostic and supportive tasks needed in emergency management. Further, the case study for each task was conducted in which the utility and effectiveness of the proposed map were demonstrated. The following aspects were considered in estimating the $REMP_{SERT}$: (i) the SERT of 10 minutes (i.e., the South Korea standard) was established as a time constraint; (ii) all sorts of rescue equipment of the ERA in South Korea (e.g., ambulance, command car, and pump car) were considered as evaluation targets; and (iii) actual-measurement GIS data were collected and applied for reflecting accurate road network conditions.

The remainder of this paper is organized as follows. Related works regarding the emergency management were discussed, in which the approach gap from previous efforts were discussed. The next section presents a detailed explanation on the materials and methods for developing the $REMP_{SERT}$ map, followed by the accuracy evaluation of the proposed map. In sequence, to demonstrate the proposed map's utility and effectiveness, two case studies are presented. Lastly, the concluding remarks and the future research directions are presented in conclusion.

Related works

There have been various studies regarding the rescue equipment mobilization on managerial aspects. Table 1 presents the summary of the previous efforts.

First, many studies estimated the impact of emergency response time on survivability of injured people as well as investigated the impact factors of the response time. These efforts have shown that the survivability is the matter of response time rather than the quality of emergency care. Lam et al. (2015) examined the underlying risk factors that can possibly affect emergency response time for the purpose of deriving interventional measures which can shorten the emergency response time. They revealed that the most significant factor affecting emergency response time was traffic followed by location of the scene, and weather. Clark et al. (2013) developed Weibull and weighted Cox models for estimating the effect of emergency care and emergency response time on survivability of injured people at traffic crashes. This study concluded that the mortality was mostly independent of emergency care but was highly affected by the emergency response time.

On the other hand, relocation of emergency facilities has been studied as an effective strategy in shortening the response time. Nogueira Jr et al. (2014) developed an optimization model for determining the optimal set of ambulance bases location and ambulance allocation scenario using AMPL/CPLEX with the object of shortening the emergency response time. This study pointed out that only with the reallocation of ambulances to the original bases, the entire emergency response time in a city could be improved. Daskin & Dean (2004) modeled the location problem of emergency medical services to find the minimum number of facilities required in meeting the medical service demand. Marianov & ReVelle (1996) proposed a probabilistic mathematical model for determining the optimal location of emergency service facilities. Shi et al. (2015) presented a scenario-based stochastic mixed-integer, non-linear program model for integrating facility disruption risks, en-route traffic congestion, and in-facility queening delay in an integrated facility location problem. Sigrid et al. (2014) presented a three-stage mixed-integer stochastic programming model for a location and routing problem of local distribution centers.

Moreover, some studies presented methods for predicting demand of relief-goods for response to large-scale disasters. Jiuh-Biing (2010) presented a dynamic relief-demand management model for emergency relief goods logistics under imperfect information conditions and Yuxuan & Nan (2015) developed a modified susceptible-exposed-infected-recovered model for predicting or forecasting the time-varying medical relief demand.

The previous efforts have contributed in emergency management in various ways as discussed above, especially for large-scale disaster. Most of the studies have focused on temporary facility (e.g., warehouse for relief logistics) and its optimal location; however, very few concerns were given to permanent facility (i.e., ERA) and its non-service areas. Moreover, the means for directly supporting on-scene manager with equipment information were investigated very rarely. In a managerial aspect, this research focuses on locating new ERAs as permanent facilities than relocating temporary or existing facilities and also the way to enforce on-scene manager's situational awareness and insight for better decision making rather than forecasting demand of equipment.

Development of the REMP$_{SERT}$ map

Data collection

A set of actual-measurement GIS data required for evaluating and mapping the REMP$_{SERT}$ of South Korea was collected. The GIS data consist of spatial data representing an object on the map and attribute data showing the information of the object. The spatial data take the form of a point, line, and polygon, and the attribute data display a series of information in the form of a table. The purpose and source of the GIS data that were used in this study were as follows (refer to Table 2 and Figs. 2 to 6).

- Administrative division data: Polygon-type spatial data that can be distinguished by administrative division was collected to configure the basic frame of the REMP$_{SERT}$ map. In this study, the administrative division data provided by the Ministry of Public Administration and Security was used. In this data, the administrative division of South Korea is divided into three levels (i.e., the Si-level, which is analogous to the county level of the U.S.; the Gu-level, which is analogous to the city level of the U.S.; and the Dong-level, which is analogous to the town level of the U.S.) (refer to Fig. 2). Based on this, an analysis can be performed at various levels.

- Land use data: Polygon-type spatial data that includes land use information was collected to select the target region. This study used the data which was processed by the Biz-GIS Corporation, Ltd. with the Landsat images provided by the Water Resource Management Information System. This data divides the land of the nation by a 30*30m polygon, and includes land use information for each polygon (i.e., water, wetland, grassland, forest, paddy field, try field, and populated area) as attribute data (refer to Fig. 3).
- National standard node-link data: Point- and line-type spatial data representing the shape of a road network were collected for generating the road network on GIS. In this study, the national standard node-link data provided by the National Transportation Information Center were used. This data consists of a link that represents the section of a road and a node that indicates the start and end points of the road, and includes attribute data, such as the standard code (i.e., node ID and link ID), the number of lanes, turn information, and regulation speed (refer to Fig. 4).
- Urban Traffic Information System (UTIS) traffic data: Actual-measurement traffic data were collected to reflect the accurate traffic conditions (i.e., the traffic speed of each link) to the road network. The UTIS is the advanced traffic information system that collects and distributes the nation’s real-time traffic information through wireless communications between road-side equipment and on-board equipment (e.g., navigation). The traffic information at five-minute intervals can be provided via a private line and a URL scheme.

In this study, the monthly average traffic speed of UTIS traffic data with five-minute intervals, from April 1 to 30, 2015, was used to represent the road network traffic.

- ERA and its rescue equipment data: ERA and its rescue equipment data were established through the *Rescue Equipment Statistics* provided by MPSS. Point-type spatial data were created to express the exact position of the ERA, and the information (i.e., the contact information of each ERA, the location of each ERA, the type and the number of rescue equipment which is under control of each ERA) was included as attribute data (refer to Fig. 5). In South Korea, a total of 224 ERAs and 15 kinds of rescue equipment are in operation (refer to Table S1 in the Supplemental Data).
- Census data: To support the decision making on the establishment of additional ERAs, census data were used in this study. Census data depending on the location (i.e., point-type spatial data) rather than administrative districts (i.e., polygon-type spatial data) were collected to be more accurate. As for the census data, this study used the data which was processed by the Biz-GIS Corporation, Ltd. with (i) the new address system database of the Ministry of Public Administration and Security and (ii) the census output area database of the National Statistical Office. This data includes the numbers of households and people within a 100*100m around the point as attribute data (refer to Fig. 6).

Map organization

A basic map for evaluating the $REMP_{SERT}$ was established. In this study, Arc-GIS 10.3 was used, and the detailed steps of the study were as follows (refer to Fig. 7): (i) the selection of target region; (ii) the establishment of a network dataset; and (iii) origin-destination setting.

- The selection of target region: According to the *ERA Performance Report 2014* of MPSS, the mobilization boundary of the ERAs in South Korea is mostly included in populated areas; 89.9% of all the emergency calls in 2014 were from populated areas (e.g., residential areas, construction sites, on the road, and downtown areas). Accordingly, the populated area (21.3% of the entire country) was selected as the target region in this study based on the land use data (refer to Fig. 7).

- The establishment of a network dataset: A network dataset was established by processing the national standard node-link data using Arc-Catalog 10.3. The road network was designed by connecting each link based on the standard code, and turn information and UTIS traffic data (i.e., monthly average traffic data) were reflected in it (refer to Fig. 7).
- Origin-destination setting: The locations of 224 ERAs were set as the origins of the rescue equipment. With respect to the target region, a 300*300m fishnet was generated, and the centroid of each cell was set as the destination of the rescue equipment (refer to Fig. 7). A detailed snapshot of a Si-level division (i.e., the capital of South Korea, Seoul) was included in Fig. 7 to express the origin and destination of the rescue equipment in detail.

The estimation of $REMP_{SERT}$

Based on the basic map, the $REMP_{SERT}$ of 598,555 destinations was evaluated. The detailed steps were as follows: (i) origin-destination cost matrix (O-D CM) analysis; and (ii) calculation of the $REMP_{SERT}$.

- O-D CM analysis: Through Arc-GIS 10.3, it is possible to perform a variety of network analyses (e.g., new-route analysis, O-D CM analysis, and service area analysis) based on the Dijkstra algorithm, an algorithm for finding the shortest path. Among them, O-D CM analysis is used to analyze the travel time according to the possible paths from an $origin_{(k)}$ (i.e., $ERA_{(k)}$) to a $destination_{(i)}$, and to derive the minimum travel time, $OD\text{-}Time_{ik}$. In addition, O-D CM analysis can derive the $OD\text{-}Time_{ik}$ between several $origins_{(k)}$ and $destinations_{(i)}$ at once, in the form of a matrix. In this study, the $OD\text{-}Time_{ik}$ from 224 $origins_{(k)}$ to 598,555 $destinations_{(i)}$ were derived using O-D CM analysis.

- Calculation of $REMP_{SERT}$: Based on the derived $OD\text{-}Time_{ik}$ results, the $REMP_{SERT\ ij}$ for each destination$_{(i)}$ of the rescue equipment$_{(j)}$ can be evaluated (refer to equation (1)). The $REMP_{SERT\ ij}$ is the number of rescue equipment$_{(j)}$ that can be mobilized to destination$_{(i)}$ within the SERT (i.e., 10 minutes, South Korea Standard). By comparing the SERT and $OD\text{-}Time_{ik}$, it is possible to determine whether the $ERA_{(k)}$ can mobilize their rescue equipment within the SERT or not. $SERT\_F_{ik}$ is set to 0 if $OD\text{-}Time_{ik}$ is longer than the SERT, whereas it is set to 1 if not. Through this, the $ERA_{(k)}$ that can mobilize their rescue equipment to the destination$_{(i)}$ within the SERT can be identified. The $REMP_{SERT\ ij}$ can be calculated by adding the number of rescue equipment$_{(j)}$ in $ERA_{(k)}$ that meets $SERT\text{-}F_{ik}=1$ (refer to Table S2 in the Supplemental Data).

$$REMP_{SERT\ ij} = \sum_{k=1}^{t} R_{kj} * SERT\_F_{ik} \tag{1}$$

where *i* is the destination ID (1-598,555), *j* is the rescue equipment ID (1-15), *k* is the origin (i.e., the ERA) ID, *t* is the total number of ERAs (224), $REMP_{SERT\ ij}$ is the mobilization potential within the SERT of destination$_{(i)}$ for rescue equipment$_{(j)}$, R_{kj} is the number of rescue equipment$_{(j)}$ managed by $ERA_{(k)}$, and $SERT\_F_{ik}$ is the SERT factor, which is 0 if the travel time from $ERA_{(k)}$ to destination$_{(i)}$ is more than the SERT, or 1 if the travel time is less than the SERT.

The $REMP_{SERT}$ map was developed by mapping the $REMP_{SERT\ ij}$ of rescue equipment$_{(j)}$ (j: 1-15) for the destination$_{(i)}$ (i: 1-598,555) (refer to Fig. 8 and Figs. S1 to S8 in the Supplemental Data).

The accuracy evaluation of the estimated $REMP_{SERT}$

As illustrated in the previous section (refer to equation (1)), the $REMP_{SERT}$ is determined based on the OD-Times (i.e., travel times) between a destination and ERAs. Accordingly, to ensure the accuracy of the proposed $REMP_{SERT}$ map, this study evaluated the results of the OD-

Time by comparing it with the ground truth. Since measuring numerous travel times between the destination and ERAs manually is almost impossible in reality, the estimated OD-Time was compared with the travel time calculated from the most widely used navigation system (i.e., *Naver map navigation*) in South Korea. Being used by more than ten million users per month, the *Naver map navigation* is one of the most accurate systems reflecting real-time traffic data in South Korea.

Table 3 shows the summary of the evaluation result. The destination (i.e., identification number 3,029) was selected randomly from 3,920 destinations in Seoul as the target destination, and adjacent 13 ERAs which can arrive at the destination within 20 minutes were selected as origins. The travel times from each ERA to the target destination were calculated using the *Naver map navigation* for one entire day (i.e., from 12 AM to 9 PM with three hour intervals on February 13, 2017), which in turn were calculated into the average values.Considering the fact that rescue equipment is mobilized faster than normal vehicle on the road, the average travel time from the *Naver map navigation* was calibrated to offset the differential. Towards this end, both the annual average speed of rescue equipment (i.e., 40 km/hr) and that of normal vehicle (i.e., 25.7km/hr) were considered for the calibration (Fire Fighting Development Conference, 2011; Seoul Statistics, 2014). That is, the average travel time calculated using the *Naver map navigation* was multiplied with the emergency factor (i.e., 25.7/40) to represent rescue equipment's mobilization time.

As a result, it was shown that the mean absolute percentage error (MAPE) between the OD-Time (i.e., the travel time of the $REMP_{SERT}$ map) and the calibrated travel time from the *Naver map navigation* was 7.6% on average. On a timely manner, there was 1.32 minutes difference between them on average. This result demonstrates that the OD-Time can represent the mobilization time of rescue equipment in acceptable range compared to the ground truth. However, to effectively support a decision making in an emergency situation, the small errors should not be overlooked. The future research plan for improving the accuracy of the proposed map was further discussed in the conclusion section.

Case Studies

To demonstrate the efficacy of the proposed $REMP_{SERT}$ map in emergency management, case studies regarding two aspects were conducted: (i) the pre-diagnosis of response potential for emergency preparedness and (ii) the decision support for optimal dispatching of rescue equipment during emergency response. The $REMP_{SERT}$ map can support decision makers in following ways:

- Pre-diagnosis of response potential: The $REMP_{SERT}$ itself can be used for intuitive diagnosis of response potential on a regional basis. To be specific, vulnerable areas along with their population can be analyzed, and further, the order of supplementary urgency among the areas can be inferred. This should lead decision makers toward right direction with the obvious scientific ground.
- Decision support for optimal dispatching of rescue equipment: The major function of the proposed $REMP_{SERT}$ map in rescue operation is to provide information on equipment availability to an on-scene manger in a very intuitive way. In this manner, an on-scene manager's insight to understand the given situation may improve and a more feasible rescue strategy can be created. Moreover, once the judgement made from an on-scene manager, the $REMP_{SERT}$ map will find the optimal dispatching plan of additional rescue equipment based on the OD-time. Although the optimal dispatching is the outcome of the $REMP_{SERT}$ map, basically, it is a supportive model and accordingly involves a man-made decision indispensably. As such, to validate the efficacy of the proposed $REMP_{SERT}$ map, first, it needs to be applied to real scenes for reflecting the human decision as an input of the map. The scientifically acceptable validation could be made with the enough samples of real scene

applications. In this study, to gain a foothold, we demonstrated the application of $REMP_{SERT}$ map in emergency response through hypothetical case study, in which its efficacy was verified.

Pre-diagnosis of response potential: Case study of Seoul, South Korea

The capital of South Korea, Seoul, has the highest population density (17,219 persons/ km^2) among all the Si-level divisions in South Korea; its population density is roughly eight times higher than that of both New York (2,050 persons/km^2) and Sydney (2,100 persons/km^2). To introduce the application of the $REMP_{SERT}$ map in decision support on the establishment of additional ERAs, a case study of Seoul was conducted. Table 4 shows a summary of the data (Seoul) of the $REMP_{SERT}$ map that were used in the analysis. Through the $REMP_{SERT}$ map, the ERA's non-service areas and their population (i.e., potential beneficiaries) could be analyzed. This results promise to support decision maker in selecting the site for the establishment of new ERA. The details of this case study were illustrated as below.

- Non-service areas of the ERAs: The non-service areas of the ERAs can be derived by overlapping the region where the $REMP_{SERT}$ of each rescue equipment is 0. In addition, the exposed population in the non-service areas can be estimated by utilizing the census data. According to the $REMP_{SERT}$ map of Seoul, about 3.27% (11.537 km^2) of the target region of Seoul (352.8 km^2) was a non-service area. In addition, 2.3% (209,116 persons) of the total population of Seoul (9,076,299 persons) were found to be exposed to the non-service area. As shown in Fig. 9, it can be confirmed that the non-service areas are located around region A (the Gangseo-Gu neighborhood), region B (the Geumcheon-Gu neighborhood), and region C (the Gangdong-Gu neighborhood).
- Supplement priority of an ERA among the non-service areas: The new service area can be created by establishing a new ERA in the centroid of the non-service areas in Seoul. In this

study, the supplement priority of an ERA among the non-service areas was established based on the number of beneficiaries in the new service area. As shown in Fig. 9, the supplement priority of an ERA among the non-service areas in Seoul was analyzed as follows: 1st rank, Region B (service area: 15,364,600 m^2; expected beneficiaries: 74,250 people); 2nd rank, Region C (service area: 17,564,200 m^2; expected beneficiaries: 61,612 people); and 3rd rank, Region A (service area: 19,205,600 m^2; expected beneficiaries: 32,373 people).

Decision support for optimal dispatching of rescue equipment: Case study of 'Mauna Ocean Resort' collapse, South Korea

'The Mauna Ocean Resort', located in South Korea, collapsed without any portent at 21:15 on February 17, 2014 (refer to Fig. 10). This event raised the public's attentions and griefs with the losses of unmeasurable values (i.e., 115 casualties including 10 fatalities). From this event, the problems in emergency management have been exposed to come out. It was reported that the impetuous decision on equipment request and haphazard equipment dispatching were the main reasons for the chaos in the rescue operation.

In this section, it was assumed that 'The Mauna Ocean Resort' incident was re-enacted in Seoul. An overview of this hypothetical case is shown in Fig. 10. This case is a v-shaped collapse of the panel roof and accordingly the mobilization of heavy equipment was essential. Therefore, five kinds of private rescue equipment (i.e., excavator, loader, dump truck, crane, dozer, and forklift) of 48 private companies which made a contract with 26 ERAs of Seoul were additionally analyzed. Lastly, based on the report provided by the district ERA (i.e., Gyeongju ERA), the main problems were found as belows:

- Which ERA should be the first responder: The first responder unit plays the most critical role in a rescue operation in that they are the one who establishes and initiates the first rescue plan. At the time of the event, although the district ERA (i.e., Gyeongju ERA) was not the most adjacent ERA, they led response teams while arriving too late (i.e., 21:43 PM, after 37 minutes from the event).

- Which equipment should be mobilized from which ERA: At the time of the emergency, although, the eight ERAs located in the adjacent areas performed rescue operations, essentially required rescue equipment did not arrive in a timely manner and arrived too late with excessive amount, leading to lag time and congestion in rescue operations. It was pointed out that the haphazard and unclear request for additional equipment made confusions among eight ERAs. As a result, the equipment located in the nearest distance from the scene did not get the request call, and the one located far from the scene was mobilized instead.

With the $REMP_{SERT}$ map, the two agendas can be handled in a very intuitive way. The map will provide which ERA should be the first responder unit in terms of their response speed with the simple input of a destination location (i.e., event location). And also, with the use of the $REMP_{SERT}$ map, an on-scene manager's sense of situational understanding and insight to classify useful (i.e., available in time) or useless (i.e., not available in time) equipment could be increased which leads more reasonable request and well-coordinated equipment mobilization among the ERAs. Once a request made from on-scene manger, again the map will find the optimal dispatching plan based on OD-Time of each ERA.

- Which ERA should be the first responder: Through the $OD\text{-}Time_{ik}$ (i.e., the minimum travel time from $ERA_{(k)}$ to $destination_{(i)}$) results of the $REMP_{SERT}$ map, it is possible to derive the response priority of ERAs on the mobilization of additional rescue equipment. As shown in Fig. 11, the district ERA was $ERA_{(Eunpyeong)}$ (distance: 5.895 km; OD-Time: 16.05 minutes), but based on the OD-Time, it was reasonable for $ERA_{(Seodaemun)}$ (distance: 2.451 km; OD-Time: 6.84 minutes) to provide the initial response. If rescue equipment other than those of $ERA_{(Seodaemun)}$ is required, the support should be provided in the order of $ERA_{(Mapo)}$ (distance:

5.805 km; OD-Time: 15.2 minutes), $ERA_{(Eunpyeong)}$ (distance: 5.895 km; OD-Time: 16.05 minutes), $ERA_{(Gangseo)}$ (distance: 9.652 km; OD-Time: 16.7 minutes), and $ERA_{(Jongno)}$ (distance: 7.383 km; OD-Time: 19.03 minutes) (refer to Fig. 11).

- Which equipment should be mobilized from which ERA: An on-scene manager can take advantage of the $REMP_{SERT}$ of each rescue equipment as the criterion for deciding which rescue equipment he/she should request for. As shown in Fig. 11, it was determined from the analysis that 16 kinds of rescue equipment can be mobilized within the SERT. Since a lighting control car and a smoking control car were not available within the SERT, they should be replaced with smoking-lighting control car, if required. Similarly, the crane and dozer were also impossible to be mobilized within the SERT, however, this rescue equipment could not be replaced with other equipment, and therefore, they need alternative rescue strategies. The interview with the on-scene manager of $ERA_{(Seodaemun)}$ was conducted for identifying the additional rescue equipment using the $REMP_{SERT}$ of each rescue equipment (refer to Fig. 11). With the use of the established response priority of ERAs, the list of additional rescue equipment that the adjacent ERAs should mobilize could be derived (refer to Table 5). Table 6 shows a list of the private rescue equipment to be mobilized by each private company. Through this, it is possible to mobilize requested rescue equipment in a well-coordinated way within the time desired by on-scene manager, and to take precautions against possible congestion due to the excessive mobilization of rescue equipment.

Conclusion

This paper proposed a novel approach for decision support on emergency management under a limited time space: the SERT. The $REMP_{SERT,}$ which quantifies the potential for mobilizing rescue equipment within the SERT, was estimated and mapped based on the GIS, using actual-measurement data. Through the proposed $REMP_{SERT}$ map, the following specific solutions for emergency management (i.e., the pre-diagnosis of response potential and decision support for optimal equipment dispatching) could be achieved: (i) the non-service areas of the ERA and the supplement priority of an ERA among the non-service areas; and (ii) the response priority of the adjacent ERAs in an emergency, and the list of additional rescue equipment that each ERA should mobilize.

Along with the accuracy evaluation, the two case studies were investigated to demonstrate how the proposed map support decision makers in emergency preparedness and response phases.

The main contribution of this research is that it is the first effort in emergency management domain to design and measure the extent of potential for equipment mobilization. The proposed $REMP_{SERT}$ map promises to support on-scene managers in making reasonable rescue strategy in a novel way, as well as decision makers in analyzing candidate regions for the establishment of new ERA.

However, for on-site application, the following limitations should be addressed in future researches: (i) establishment of integrated database for private and public rescue equipment, (ii) reflection of dynamic condition for road network, and (iii) development of a method for validating the effectiveness of the $REMP_{SERT}$ map considering human aspect.

First, in some cases, mobilization of private rescue equipment is indispensable due to the uncertainty of the events. However, the private rescue equipment data that were used in this study were restricted to those of private companies in Seoul. Therefore, an integrated database including the private rescue equipment data and that of the ERAs should be established on a national level. Second, the road network condition (i.e., the traffic speed of each link) always fluctuates over time, but the time-varying road network condition could not be reflected in this study. If devices and programs that can immediately receive and process real-time traffic data become available in the future, the accuracy and reliability of the $REMP_{SERT}$ map must be greatly improved, which will enable dynamic decision-making support in emergency response. Lastly, to validate the effectiveness of the proposed $REMP_{SERT}$ map, the scientific method for investigating how an on-scene manager effectively uses and applies the $REMP_{SERT}$ map in making a decision within his/her cognitive capability should be carefully addressed. As a part of this effort, systemization of the proposed $REMP_{SERT}$ map with an effective and efficient graphical user interface should be also included in the future research. The use of dynamic time frame for various situations will be a starting point of systemization of the proposed $REMP_{SERT}$ map, which enables dynamic decision support. These improvements will enhance the applicability and accuracy of the proposed $REMP_{SERT}$ map, which ultimately improve the management capability of ERA in emergency situations.

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Supplemental Data

Tables S1–S2 and Figs. S1–S8 are available online in the ASCE Library (ascelibrary.org).

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Table 1 Summary of related works

Classification	Author	Level of emergency	Topic
Emergency response time	Lam et al. (2015)	-	Impact factors of emergency response time
	Clark et al. (2013)	-	Impacts of emergency care and response time on survivability
Relocation of emergency facilities	Shi et al (2015)	Large-scale (i.e., disaster)	Location of local distribution centers and logistics of relief goods
	Sigrid et al. (2014)	Large-scale	Location and routing problems of local distribution centers
	Nogueira Jr et al. (2014)	Small-scale	Location of ambulance bases
	Daskin & Dean (2004)	Large-scale	Location of emergency medical services
	Marianov & ReVelle (1996)	Large-scale	Location of emergency medical services
Prediction of resource demand	Yuxuan & Nan (2015)	Large-scale	Prediction of time-varying medical relief demand
	Jiuh-Biing (2010)	Large-scale	Relief goods logistics

Table 2 Source of the actual measurement GIS data

Classification	Spatial data type	Data source
Administrative division data	Polygon	Ministry of Public Administration and Security
Land use data	Polygon [30m x 30m]	Landsat image of Water Resource Management Information System [processed by Biz-GIS corporation, Ltd.]
National standard node-link data	Point and line	National Transportation Information Center
[a]UTIS's traffic data	[attribute data]	Urban Traffic Information System of Urban Traffic Information Center
Emergency response agency, and it's rescue equipment data	Point	Rescue equipment statistics of Ministry of Public Safety and Security
Census data	Point [100m x 100x]	New address system database of Ministry of Public Administration and Security, and census output area database of National Statistical Office [processed by Biz-GIS corporation, Ltd.]

Note: [a]*UTIS* stands for the Urban Traffic Information System of South Korea

Table 3 The summary of validation result (Unit: minutes)

ERA	[a] OD-Time	[b] Calibrated travel time from the *Naver map navigation*									[e] Time gap	[d] MAPE
		12AM	3AM	6AM	9AM	12PM	3PM	6PM	9PM	Avg.		
Seodaemun	5.5	5.8	5.1	5.8	6.4	6.4	6.4	7.1	6.4	6.2	0.71	11.5%
Mapo	12.2	10.3	11.6	10.9	14.1	12.2	13.5	14.8	15.4	12.9	0.66	5.2%
Eunpyeong	12.8	10.9	10.9	10.9	14.1	14.1	16.7	15.4	13.5	13.3	0.49	3.6%
Kangseo	13.4	12.2	12.2	11.6	15.4	13.5	14.8	14.8	13.5	13.5	0.13	0.9%
Yangcheon	14.9	11.6	10.9	11.6	16.7	14.1	13.5	16.7	13.5	13.6	1.32	9.7%
Jongno	15.2	14.1	12.9	13.5	15.4	16.1	18.0	19.3	17.3	15.8	0.59	3.7%
Yeongdeungpo	17	14.1	12.9	13.5	18.0	16.7	16.1	17.3	16.7	15.7	1.38	8.8%
Seongbuk	18.5	14.1	12.9	13.5	23.1	15.4	16.1	21.8	16.1	16.6	1.92	11.6%
Headquarter	19.1	19.9	18.0	18.0	22.5	23.8	24.4	25.1	24.4	22	2.94	13.4%
Emerg. center	19.5	19.9	18.6	19.3	23.1	24.4	25.1	26.3	24.4	22.6	3.19	14.1%
Yongsan	19.6	14.8	14.1	14.1	16.7	20.6	18.0	23.1	19.3	17.6	2.04	11.6%
Guro	19.8	14.1	18.6	14.8	25.1	19.9	19.9	25.1	17.3	19.4	0.47	2.4%
Dongjak	20.6	17.3	16.7	17.3	22.5	21.2	21.2	23.8	21.8	20.2	1.32	1.9%
Avg.											1.32	7.6%

Note: [a] *OD-Time* stands for the travel time of the proposed $REMP_{SERT}$ map, [b] *Calibrated travel time from the Naver map navigation* is calculated by multiplying the emergency factor (i.e., 25.7/40) to the travel time from the *Naver map navigation*. [c] *Time gap* is the difference between *OD-Time* and *Calibrated travel time from the Naver map navigation*. [d] *MAPE* stands for mean absolute percentage error between *OD-Time* and *Calibrated travel time from the Naver map navigation*.

Table 4 GIS data of Seoul, South Korea

GIS-based data	Detailed contents
Administrative district shape	A total of 25 Gu and 442 Dong
Ground condition	Populated area: 61.2 % and non- populated area: 38.8%
National standard node-link	A total of 10570 links
Emergency response agency and rescue equipment	A total of 26 emergency response agency in Seoul and 15 types of rescue equipment
Population information	A total of 29658 point [100m x 100m], 9076299 people

Table 5 The list of additional rescue equipment based on the response priority of ERAs

ERA	OD-Time (Unit: Min.)	Rank	Additional rescue equipment list				
			Pump car	Rescue-100	Rescue-200	Ambulance	Command car
Seodaemun	6.84	1	4	1	1	5	1
Mapo	15.2	2	0	1	1	7	0
Eunpyeong	16.05	3	0	1	1	5	0
Gangseo	16.7	4	0	1	1	6	0
Jongno	19.03	5	0	1	1	6	0
Yangcheon	20.6	6	0	1	1	6	0
Yeongdeungpo	21.3	7	0	1	1	7	0
Seongbuk	23.1	8	0	0	0	5	0
Total			4	7	7	47	1

Table 6 The list of additional rescue equipment list based on the response priority of private companies

Private company (name)	OD-Time (Unit: Min.)	Rank	Additional rescue equipment list	
			Excavator	Crane
Heagwang.	7.51	1	1	0
Hongik	11.68	2	0	1
Dega	18.86	3	0	1
Total			1	2