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Improving emergency response collaboration and resource allocation by task network mapping and analysis

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ABSTRACT

Efficient resource allocation and collaboration among involved agencies are two essential prerequisites for successful emergency response. In order to contribute to reasonable resource allocation and targeted collaboration, this paper proposes a method of generating task network for emergency response based on the snowball procedure and an associated method of analyzing task network based on social network analysis. Firstly, the criticality of a task is evaluated using the proposed Weighted Proximity Prestige (WPP) index, which takes into account both the network structure and the dynamic urgency levels of response goals. Secondly, by calculating the WPP and observing its changing trend with time, shared resources for all response goals are identified. Thirdly, for each task, relations sink to it are ranked according their relative importance to provide explicit collaboration guidance. A case study based on the Beijing Flood Emergency Response Plan (2012 Amendment) is carried out to verify the rationality and effectiveness of the proposed method. The case study reveals that the WPP index particularly emphasizes tasks having dominating influence over on-site rescue actions, such as order maintenance, traffic route designing, and transportation resource coordination, which do not attract sufficient attentions in emergency response practices. Resources under severe contention as transit-related and man-power related tasks are identified based on the WPP index. Ranking the relations sinking to each task on a local scale provides more accurate information of working focuses to the agencies responsible for the task.

1. Introduction

Emergency response refers to immediately organizing related agencies, raising and dispatching various resources, developing and carrying out emergency response plans, with the aim of minimizing casualty and losses caused by disasters (Lindell et al., 2006). Numerous participants involved in emergency response include governmental agencies, departments and companies related to lifeline system, the public, etc. (Huang et al., 2011). These participants need to complete different kinds of tasks collaboratively, such as evacuation, rescue, resource allocation, transportation, and engineering, with the support of various types of resources. Therefore, efficient multi-agency collaboration and resource allocation are two fundamental prerequisites for effective emergency response. Similar statements have been declared by some researchers. For example, Kapucu et al. (2010) concluded that collaboration is critical for the response of large-scale disasters and that wise use of resources contributes to high-performance emergency response. However, complex relations among tasks involved in emergency response bring challenges to multi-agency collaboration and resource allocation.

The insights into the relations among emergency response tasks are crucial for effective collaboration and resource allocation. On one hand, tasks might be related due to their functional or procedural dependencies. For instance, a route from place A to place B must be selected before transporting relief materials from A to B. On the other hand, tasks might be bundled together when they share the same limited resources. For instance, vehicles are simultaneously needed by at least following tasks: relief materials delivering, wounded transferring, and rescue teams transporting. In this paper, these two types of task relations are referred to as intrinsic and extrinsic task relations, respectively. The agency responsible for a task collaborates with agencies responsible for intrinsically related tasks. In the course of their collaboration, the agency commonly assigns limited resources and attentions according to the importance of task relations. Therefore for each agency, identifying the importance of task relations plays a significant role for the efficiency of collaboration. In addition, extrinsic relations among tasks caused by resource contention are significant for resource

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allocation. If the crucial tasks are not assigned sufficient resources, their defective performance might degrade the efficiency of overall emergency response (Jackson et al., 2011).

Based on the discussion above, three critical issues can be highlighted in order to achieve effective collaboration and resource allocation: (1) Identifying the crucial tasks. Limited resources can be allocated according to the criticalities of tasks to improve the efficiency of resource utilization and to avoid the failures of crucial tasks. (2) Recognizing the shared resources. Leaders responsible for different emergency response goals can negotiate on the amount and the occupation time of shared resources to avoid potential resource conflicts and to mitigate the shortage of resources on crucial tasks. (3) For each task, evaluating the relative importance of its relations to other tasks. Agencies can cooperate with other agencies according to the priorities of their task relations, which may contribute to a clearer response chain highlighted in Incident Command System (Bigley and Roberts, 2001).

In order to improve emergency response performance, researchers have analyzed the emergency response system from different views to find out crucial elements and relations. By employing the method of failure mode effects and critically analysis (FMECA), Jackson et al. (2011) identified the bottleneck of the emergency response system and quantized the input/output ratio of different failure modes. As a result, the system reliability is improved, and the additional fund is allocated more efficiently. Piatyszek and Karagiannis (2012) modeled the local emergency operations plans (EOPs), and studied the criticality of the plans by identifying potential failures and organizing these failures into fault trees. Fiedrich et al. (2000) proposed a dynamic resource allocation model for emergency response after earthquake disasters to minimize the total number of fatalities. Zhou et al. (2011) identified critical success factors (CSFs) in emergency response process using a fuzzy decision making trial and evaluation laboratory (DEMATEL). The identified CSFs include, but are not limited to, clear awareness of responsibilities, unity leadership to plan and coordinate as a whole, and application of modern logistics technology.

Another widely used method to analyze the emergency response systems is social network analysis (SNA) (Wasserman and Faust, 1994). SNA evaluates prominence of a node by node centrality (specific indexes include degree centrality, closeness centrality, between-ness centrality, and information centrality) and node prestige (specific indexes include degree prestige, proximity prestige, and status or rank prestige). In the related research works, the node prominence is evaluated by different indexes emphasizing different factors. Shoji and Toyota (2009) identified important nodes through degree centrality and recognized important links among lifeline systems by proximity prestige. Uhr and Johansson (2007) adopted rank prestige to evaluate the importance of agents based on the contacts importance which are obtained through web-questionnaire and telephone interviews. Uhr et al. (2008) employed the same method as Uhr and Johansson (2007) but regarded the involved individual person as the object of analysis. Hamra et al. (2013) utilized network density and three centralization properties to investigate the effects of the network structure on the learning attitudes of emergency response personnel. It concludes that denser networks are more adaptable than sparser ones, and that decentralized structure contributes to better performance and learning attitude compared with a centralized one. Abbasi et al. (2010) used SNA theory to study the effects of relational network structures on coordination in emergency response by quantizing the tie strength among individuals and teams based on survey results obtained by Nunnally (1978).

The abovementioned related works mainly focus on identifying important nodes and relations from an overall view based on the structure of an emergency response network. However, these studies are not sufficient for effective multi-agency collaboration and reasonable resource allocation, especially in a highly dynamic emergency response process (Varda et al., 2009). Firstly, all tasks involved in emergency response are driven by a set of high-level response goals. The urgency of a goal might change in a dynamic environment. The impacts of high-level response goals and the change of their urgency levels on the criticality of a task are not sufficiently considered. Secondly, all the relations in the network are mainly evaluated together from a global perspective. However, from the perspective of each node, prioritizing the relations directly related to it is more intuitive to guide the corresponding agency to focus on its key relations. Thirdly, the issue of sharing resources is not taken into account in the related works.

This paper adopts and modifies the snowball procedure (Goodman, 1961) to map a task network to represent tasks involved in emergency response and their intricate interdependencies. Based on the network, a method of analyzing the task network for emergency response is proposed to identify the crucial tasks, to recognize the resources shared by emergency response goals, and to evaluate the relations for each task individually. In the proposed method, the Weighted Proximity Prestige (WPP) index is designed to evaluate the task criticality by taking both the network structure and the dynamic urgency levels of emergency response goals into consideration. The evolvement of the WPP index of tasks is capable of indicating the resources shared by emergency response goals when the weights of goals vary with time. For each task, the WPP indexes for its upstream tasks are normalized to identify the key relations.

The following of the paper is organized as follows: Section 2 describes how to map the task network with snowball procedure. Section 3 presents the proposed method of analyzing task network for emergency response. Section 4 validates the proposed method by analyzing the network for emergency response extracted from Beijing Flood Emergency Response Plan. The conclusions and possible future studies are discussed in Section 5.

2. Mapping emergency response task network

A network generally consists of a set of nodes and edges, with each edge representing the relation between two nodes. What the nodes and edges stand for is mainly determined by the modeling intention. For instance, in order to evaluate the reliability of the emergency response system, Jackson et al. (2010) mapped the failure tree with nodes standing for failures and directional edges standing for causal relationships. To identify critical infrastructure and vital interdependencies, Shoji and Toyota (2009) mapped lifeline systems with nodes representing individual sector actions and edges representing the exchanges of resources or information. To evaluate the rationality of the proposed emergency response framework, Abrahamsson et al. (2010) mapped tasks, resources, infrastructures and actors with different node shapes into one emergency response system model in which edges stand for dependences among these objects. Comfort and Haase (2006) mapped the emergency response system emerged in Hurricane Katrina with nodes standing for organizations and relations standing for organization interactions to analyze the patterns of interaction among organizations.

This paper aims to find out information in three aspects, named task importance, resources shared by response goals, and key relations for each task, to contribute to reasonable resource allocation and effective collaboration during the process of emergency response. Considering the fact that tasks and their interdependencies are the focus of this study, each node in the network here stands for a task involved in emergency response, and a directed edge stands for direct inherent dependency between two tasks. In other words an edge with source node i and sink node j means task i depends on task j. The completion of task j is one of the