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Decision Support

Timeliness evaluation of emergency resource scheduling☆

Hong Chi, Jialian Li*, Xueyan Shao, Mingang Gao

Research Center of Overall Planning, Safety and Security Management, Institute of Policy and Management, Chinese Academy of Sciences, China

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ABSTRACT

Most current research describes emergency resource scheduling as a multi-objective optimization problem. Each objective contributes to scheduling comprehensive effects. In many cases, goals are correlated. For example, reducing the scheduling time requires more resources and costs. Thus, an effect that approaches reality should be observed under conditions of mutual matching and combined roles of objectives. This study constructs a non-linear timeliness evaluation function for emergency resource scheduling that incorporates a single affected point, multiple supply centers and one type of resource, which combines two scheduling objectives, i.e., time and resource satisfaction, into a timeliness function. The evaluation function is a monotonically increasing function and a monotonically decreasing function with respect to the quantity and time of two batches of resource arrivals, respectively. Function values change within the range of demands for quantity and time of resources arrivals, but function values change little beyond the range of the demands, which is highly consistent with qualitative cognition. This study considers real mine water leak accidents and calculates the time for the water level in the mine to drop to the safety line using a simulation method according to the mechanism of water level change caused by the mine structure, water leakage flow and pumping, and then implements contrastive analyses of the results of the timeliness evaluation function and simulation method, and then concludes that timeliness evaluation functions are reasonable and require less information and less detail. This research provides new insight into the design of objective functions utilized in emergency resource scheduling.

1. Introduction

After emergencies, it is essential to conduct rescue immediately. Rescue actions require resources; therefore, emergency resource scheduling can significantly impact the effectiveness of rescue actions. Evaluations of emergency resource scheduling aid the selection of reasonable scheduling plans and improve the timeliness and effectiveness of rescue. Previous studies have evaluated emergency resource scheduling mainly in terms of time, expenses, quantity of resources, etc. Evaluation indexes addressing several of these aspects and non-inferior solution sets are obtained using a multi-objective optimization algorithm incorporating different concerns. Most existing studies indirectly evaluate the effectiveness of a scheduling scheme utilizing several indexes; however, few studies consider direct and comprehensive scheduling schemes. Actually, some of these indexes are not independent in some cases; for instance, the larger the quantity of delivered resources is, the more the time or expense will be required. Utilizing emergency resource scheduling mechanism analysis, this paper constructs a timeliness evaluation function so that scheduling schemes can be evaluated more systematically and directly. The paper also verifies the rationality of the function utilizing empirical examples.

Emergency logistics planning has been studied utilizing statistical and probabilistic models (Coles & Pericchi, 2003; Xu, Qi, & Hua, 2010), queuing theory (Artalejo, 2000), simulation (Hu, Qing, Ming-Hui, & Qi, 2008; Reshetin & Regens, 2003), decision theory (Cret, Yamazaki, Nagata, & Katayama, 1993; Tamura, Yamamoto, Tomiyama, & Hatono, 2000), fuzzy methods (Esogbue, Theologidu, & Guo, 1992; Jiang, Deng, Chen, Wu, & Li, 2009) and, most commonly, optimization methods. Recent studies of optimization concentrate on aspects including the establishment of optimization objective functions and the design of solution algorithms. Many optimization algorithms currently exist to identify solutions, including linear programming, nonlinear programming, heuristic algorithms, improved and mixed algorithms and new algorithms

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* Corresponding author.
E-mail addresses: lijialian@casipm.ac.cn, jialianli1982@126.com (J.L. Li).

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that are constantly being proposed. This paper focuses on the design of the optimization objective function. Therefore, the previous research on this aspect of the literature is presented as follows.

Optimization objective functions for emergency resource scheduling progress from simpler to deeper designs that gradually approach reality. The optimization objective functions in the existing body of literature includes several types, such as expenses (Oh & Haghani, 1997), time (Ozdamar, 2011; Ozdamar & Demir, 2012; Zhang, Li, & Liu, 2012), resource satisfaction quantity (rate) or dissatisfaction quantity (rate) (Afshar & Haghani, 2012; Chang, Wu, Lee, & Shen, 2013; Ji & Zhu, 2012; Lin, Batta, Rogerson, Blatt, & Flanigan, 2011; Ozdamar, 2004; Sheu, 2007; Tzeng, Cheng, & Huang, 2007; Yi & Kumar, 2007; Yi & Ozdamar, 2007), differences in resource satisfaction rates at various locations (Lin et al., 2011), and casualties (Fiedrich, Gehbauer, & Rickers, 2000; Huang, Carmeli, & Mandelbaum, 2015; Sung & Lee, 2016; Wilson, Hawe, Coates, & Crouch, 2013). People possess limited cognition of the initial features and laws of emergencies and design objective functions of emergency resource scheduling by applying the methods of general resource scheduling, such as minimizing expenses and satisfying resource demands under time constraints (Oh & Haghani, 1997). Next, these researchers gradually recognized that time was important for emergency resource scheduling and that expenses were relatively less significant. Thus, minimizing time became an objective of emergency resource scheduling, but meeting resource demands continued to serve as a constraint (Ozdamar, 2011; Ozdamar & Demir, 2012; Zhang et al., 2012; Zheng, Ling, Shi, Chen, & Chen, 2014). Later research on emergency resource scheduling problems deepened, and it was observed that large amounts of resources were usually required over a short period during an emergency such that it was difficult for resources to satisfy demands. Additionally, such studies also observe that demands are dynamic and the arrival of resources requires time. For example, in cases of fire, better outcomes will be obtained if firefighters and fire trucks arrive soon after the fire occurs. On the contrary, if help arrives after the fire has become serious, the outcomes will be less desirable. There will be no effect on the outcome even if many fire trucks and firefighters arrive after the fire has been naturally extinguished. Consequently, many studies consider resource satisfaction quantity (rate) or dissatisfaction quantity (rate) as an objective function and have begun to consider grading changes in resource demands (Afshar & Haghani, 2012; Ozdamar, 2004; Yi & Kumar, 2007). Some studies develop mathematical models to compute the quantity of resources demanded at each stage (Sheu, 2007). Gradually, time and expenses have been included, which forms the bi-objective optimization problem of resource satisfaction rate and expenses (Sheu, 2007), the bi-objective optimization problem of resource satisfaction rate and time (Ji & Zhu, 2012), the tri-objective optimization problem of resource satisfaction (or dissatisfaction) rate, time and expenses (Chang et al., 2013; Tzeng et al., 2007), and the tri-objective optimization problem of resource dissatisfaction costs (expenses are established to punish lateness and absence) and expense and satisfaction rate difference (Lin et al., 2011). Some studies consider minimizing casualties to be of the utmost importance; these studies develop models to calculate casualties and present a single object optimization problem that treats casualties as the objective function (Fiedrich et al., 2000; Huang et al., 2015; Sung & Lee, 2016; Wilson et al., 2013).

Objective functions for emergency resource scheduling take different forms in different studies. Some studies sum the arrival times of all scheduled resources (Zhang et al., 2012), whereas other studies consider factors such as transportation facilities (e.g., vehicles and airplanes) or total delivery time of the transportation facilities (Ozdamar, 2011; Ozdamar & Demir, 2012). Additionally, vehicles are sometimes assigned weights; for instance, when many important resources are delivered by a vehicle, a large weight will be assigned (Zheng et al., 2014). The expense objective function sums all expenses incurred in emergency scheduling (Oh & Haghani, 1997). The main methods of computing resource objectives include the following aspects: (a) The total dissatisfaction quantity of resources. The total dissatisfaction quantity of all types of resources at all stages is utilized as an objective function (Ozdamar, 2004). The dissatisfaction quantity of resources refers to the difference between the quantity of resources demanded and the quantity of resources that arrive. For instance, 10 units of resources are required, but only eight units actually arrive. Thus, the value of resource dissatisfaction is 2. (b) The sum of the weighted resource dissatisfaction. When the total quantity of resource dissatisfaction is calculated, different types of resources are assigned various weights (Afshar & Haghani, 2012; Chang et al., 2013; Yi & Kumar, 2007) because different types of resources have various degrees of importance. For example, in a fire, firefighters and fire trucks are important. If the dissatisfaction quantity is large, serious consequences may result. Thus, these resources will be endowed with a larger weight. (c) The resource satisfaction rate. For example, some studies seek to maximize the resource satisfaction rate at each stage (Ji & Zhu, 2012). The resource satisfaction rate is obtained by dividing the total quantity of resources demanded by the total quantity of resources that arrived. (d) For each stage and each type of resource, take the minimum quantity of resource satisfaction at the affected points and sum these minimum values for all stages and all resources (Tzeng et al., 2007). (e) When the resource dissatisfaction is calculated, expenses are established to punish lateness and missing resources; the final objective is to minimize these punishing expenses (Lin et al., 2011).

Existing studies have considered many features of emergency resource scheduling in the design and specific forms of the objective functions. However, additional problems need to be considered. For example, most of these studies consider the objectives of emergency resource scheduling to be independent and describe this as a multi-objective optimization problem. In other words, each objective is computed separately, and non-inferior solution sets are solved by a multi-objective optimization algorithm to reflect the fact that emergency resource scheduling is characterized by multiple principles and objectives. In fact, each objective affects the comprehensive effect of emergency resource scheduling, and some objectives are correlated. Thus, to approximate reality more closely, there should be a comprehensive effect under the conditions of mutual matching and a combination of objectives. The emergency resource schedule with the best comprehensive effect is optimum. The best comprehensive effect refers to the tradeoff between emergency response effect and development trend control. Therefore, in addition to the resources quantity and quality meeting requirements, their arrival time also need to be fast, which is timeliness. However, summing time, expenses and resource dissatisfaction produces problems such as (a) the varying effects of rescue according to whether resources are delivered simultaneously, which assumes that the emergency resource schedule is certain, and (b) the need to coordinate resources among tasks to produce an optimum matching relation for tasks an resources. This situation cannot be reflected by simply summing resources. For instance, when a coal mine suffers a water leak, that water must be pumped out, a task that requires pumps, pipelines, and people to carry the pipelines and install the pumps. If any of these resources, such as the pumps, is lacking, accomplishing the task will be impossible even if many other resources are available. Moreover, the outcome of the rescue effort will likely be suboptimal even when the total amount of resources utilized is large. Finally, (c) summing resources assumes linear behavior. In fact, the effects of the quantity of resources and their arrival time on the emergency response may not be linear. For example, the moment of receiving a