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Disaster spread simulation and rescue time optimization in a resource network

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ABSTRACT

To design and verify disaster rescue programs in cases of disaster spread, this study presents a base application tool for the simulation, assessment and analysis of disaster spread in a complex resource network based on a multi-agent system (MAS). Various yards, warehouses, distribution centers and other storage nodes are typical resource-intensive sites at which catastrophes and disasters, such as fires and chemical leakage, are prone to occur and spread. Resources are stored in block units called resource nodes. Each resource node is represented by an agent in an MAS. A resource network (network of resource storage nodes) is formed from the disaster spread relationships among resource nodes. Disaster spread simulation and rescue time analysis in resource networks are key problems in disaster prevention and relief. Based on the principles of disaster spread in resource networks, a property model of resource nodes is proposed that incorporates the values of the resources, the disastrous energy of each node, the disaster spread path, and the disaster spread characteristics. To study the dynamics of disaster spread, a state diagram is used to construct a microscopic behavior model for the resource nodes by regarding the resource nodes as agents. Then, decision models are gradually constructed to determine the optimal times for disaster rescue and emergency resource preparation. The proposed models are demonstrated using a multi-layer simulation system.

1. Introduction

Fire, chemical leakage and explosion are typical disasters faced by resource-intensive sites, such as bulk yards, warehouses, distribution centers, and transit stations. These sites are known as "resource centers". Resources are commonly stored individually in isolated blocks called "resource nodes". A resource network describes the disaster spread relationships among resource nodes. Because of the existence of flammable, explosive, easily leaked materials, it is difficult to entirely avoid the occurrence of disasters such as fires and chemical leakage. Once such disasters occur, the consequences are serious. The methods based on the concept of a multi-agent system (MAS) that are proposed in this work were developed with port bulk yards as the primary considered application background. Moreover, fire disasters were the key type of disaster considered for their effects on the resource network. However, the proposed approaches can be extended to other types of resource networks and disasters by modifying the layout of the resource network and the disaster spread behavior in the network. The

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unique features of various types of resource networks and disasters can lend considerable complexity to disaster spread problems. Therefore, this work focuses on the general features of disaster spread in a resource network.

Resource-intensive sites and disaster spread behavior have been studied in various scenarios. Dashti et al. [10] have identified various external factors of resource performance. Önüt et al. [34] have addressed a multi-level warehouse layout design problem. Accorsi et al. [1] have presented an original decision-support system (DSS) for the design, management, and control of warehousing systems. Specifically, the proposed DSS implements a top-down methodology that considers both strategic warehouse design and operative operations management. The DSS can simulate the logistics and material-handling performance of a warehousing system. Robenek et al. [41] have highlighted the differences in operations between bulk ports and container terminals. Vo et al. [53] have applied radio-frequency identification (RFID) in asset monitoring. These studies primarily focused on complex models or algorithms for resource operations and management. With regard to disaster spread, Overholt et al. [35] and Morvan et al. [30] have studied a model of fire spread on grassland. Cheng et al. [8] and Kim et al. [26] have addressed fire spread among buildings. Many modeling and simulation approaches, e.g., random walk theory [15,50], Markov processes [21,25], probabilistic networks [28], multi-agent system-based simulations [11,22,23,48,49] and GIS-based simulations [5,14,31], have been focused on specific applications. General models have not been developed, and the theoretical aspects of interactions among disastrous nodes have not been investigated. Moreover, instructions for disaster relief have seldom been formulated in the literature. This work establishes general models and simulation approaches for disaster spread in resource networks.

Resources are stored in separated blocks (resource nodes) according to their types and volumes. A resource network consists of resource nodes and is formed based on the types of resources associated with these nodes and the distances between them. This work addresses general spread principles and disaster relief strategies. Resource nodes are considered to form a resource network based on their spatial relationships. A disaster spreads on this resource network. The spread of the disaster evolves and becomes complex for the following reasons: each entity has certain tolerance, destruction, and spreading times depending on the specific degree of the disaster, and the probability and time of spreading among resource nodes are determined by the relationships among these nodes.

This study contributes to the literature on fire disaster spread [26,55], disaster relief and resource management by examining an extremely complex application of an agent-based simulation method to a disaster spread problem. First, this study provides a general disaster spread framework based on fire disasters and fire spread behaviors. Second, the framework and the simulation system are basic tools for the modeling of disasters at resource-intensive sites. The evolutions of the disaster spread and rescue times reveal that an understanding of the disaster spread dynamics is important for disaster reduction. Third, based on an MAS, a property model and a state diagram are established to model the static structure and dynamic behaviors of a resource network. Moreover, the approaches to the optimization of rescue times and the preparation of emergency resources are investigated based on the evolution of losses and rescue costs.

The paper is organized as follows. Section 2 reviews the concepts of resource management, disaster spread and multi-agent systems. Section 3 defines and analyzes the problem. The resource network, property model and dynamic behavior model used to develop the disaster spread assessment models and disaster reduction strategies are studied in Section 4. The proposed models and approaches are demonstrated in Section 5. In Section 6, the contributions of this study and intentions for future work are discussed.

2. Related studies

Resource (or asset) management plays an important role in supply chain and logistics systems. As a result of the rapid development of industries and globalization, problems of resource management in yards, warehouses, distribution centers and transport channels are growing in complexity, especially in the context of disruptions, contingent events and disasters. The complexity of resource management manifests in three aspects: procurement, usage, and storage. Sun et al. [52] have developed a model of the relationship between purchasing demand and real-time purchasing decisions and have demonstrated the influence of purchasing demand on real-time purchasing decisions. Resource usage management includes the managerial processes implemented when a resource is in use, such as monitoring, maintenance, and collection. Dashti et al. [10] have discussed the external factors that influence the performance of resources in electrical systems and have offered relevant advice. Vo et al. [53] have demonstrated an asset-monitoring method based on RFID technology to achieve automatic management, whereas Kök and Shang [24] have evaluated cycle-count policies for supply chains with inventory inaccuracy and their implications with respect to RFID investments. Andersen et al. [2] have designed an air cargo service network by considering equipment intensity to improve controllability and manageability. Rahim et al. [40] have proposed a model to solve problems of asset management. The storage management of resources consists of inventory control, warehouse layout, and other related factors. However, the current concept of an asset management (AM) system focuses on the lifecycle of engineered assets, and little attention has been paid in the literature to the relationship between AM and organizational strategy [13].

Gue et al. [16] have analyzed customer demands to formulate storage strategies. Olhager et al. [33] have discussed the differences between make-to-order and make-to-stock approaches. Sadjady et al. [46] have analyzed models, lead times, and inventory costs related to the design of supply chain networks. In the context of storage layout and warehousing design, Önüt et al. [34] have devised a particle swarm optimization algorithm for the problem of multiple-level warehouse layout