Analysis of the Collaboration System of Multi-Departmental Governmental Agents for Earthquake Emergency Rescue

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Abstract. Considering the distinctive features of emergency response in crisis situations, this study delves into the mechanism of governmental multi-agency collaboration in the aftermath of an earthquake. Adopting a management science perspective, the paper scrutinizes the post-earthquake emergency response and rescue process, culminating in the proposal of a collaborative work model termed as "objective-task-agent-resource," rooted in the regional seismic emergency response plan. This model strives to actualize the mapping relationship denoted as "Objective-Task-Agent-Resource-Objective" (OTARO) within the emergency response and rescue domain.The OTARO mapping relationship establishes a comprehensive linkage between emergency rescue tasks and the pertinent agents, furnishing a conceptual framework for the assessment and analysis of multi-agent collaboration under the auspices of emergency management.

Keywords: Emergency collaboration; emergency response; emergency rescue;

1 Introduction

In the contemporary era of rapid global economic development and heightened urbanization, cities are presented with unprecedented opportunities for advancement. However, this progress is accompanied by an array of destabilizing factors. The acceleration of urbanization has given rise to various unforeseen disasters in recent years, inflicting severe harm upon the lives and property of individuals.

The domain of earthquake disasters is extensive, necessitating a comprehensive and coordinated emergency response involving multiple departments. The complexity of this task precludes the possibility of any singular department or agency independently executing effective earthquake rescue efforts [1]. However, existing agencies and organizations engaged in emergency response grapple with challenges such as information asymmetry, irrational decision-making, and inadequate resources. These dilemmas are exacerbated by the inherent time constraints and formidable tasks associated with emergency response and coordination. Consequently, inefficient bottlenecks persist in the emergency response and coordination processes [2]. The fundamental reason underlying these challenges is the lack of seamless

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interconnection between diverse institutions and organizations involved in the emergency coordinated rescue process. Thus, a critical focus of research should be on understanding the landscape of governmental multisectoral participation in emergency rescue. This involves elucidating the specific roles of different departments in the rescue process, leveraging their unique functions, enhancing emergency rescue capacities, and investigating the impact of multisectoral collaborations in addressing the core issues of the main body of the problem.

In the examination of collaborative endeavors among multiple agents, She Zhenyu undertaked an intricate analysis of complex interrelationships inherent in multi-agent systems. This scholarly inquiry served to encapsulate the intrinsic nature and evolutionary attributes of complex systems[3].In a parallel scholarly effort, Li Lu et al. focued their research on the domain of emergency management, particularly in the context of public health crises. Their work advanced the analysis of policies pertaining to the prevention and control of infectious diseases[4].Concurrently, Du Jian contributed to the scholarly discourse on multi-agent collaboration within the realm of emergency management. The specific focus of this research lied in addressing the intricacies surrounding the execution of decision-making tasks within a collaborative multi-agent system. Du Jian systematically tackled key aspects, encompassing the generation, decomposition, distribution, and implementation of decision-making tasks[5].

The existing body of literature reflects a discernible accumulation of theoretical insights into emergency response collaboration. But there are fewer researches on the collaborative analysis of emergency rescue under the earthquake scenario.This paper endeavors to address this gap by adopting a perspective rooted in management science to scrutinize the intricacies of the emergency response and rescue process following an earthquake.From a managerial standpoint, this study introduces a novel collaborative work model founded on the "objective-task-agent-resource" (OTAR) paradigm inherent in preplanned strategies. This model articulates a structured mapping relationship encapsulated within the "Objective-Task-Agent-Resource-Objective" (OTARO) framework during the course of emergency response and rescue operations. By delineating the interplay among objectives, tasks, agents, resources, and subsequent objectives, this model offers a systematic and comprehensive representation of the collaborative dynamics inherent in the emergency response and rescue process.In light of the proposed collaborative work model, this paper advances a cogent approach to multi-agent collaborative analysis within the realm of emergency response management.

2 Theory of multi-agentive collaboration

2.1 Multi-agent

The term "Agent" denotes an individual or unit endowed with a specific initiative within the context of a complex system[6]. Coined by Carl Hewitt in 1977, the concept is defined as an object possessing interactivity, adaptability, and a concurrent processing mechanism. Within a multi-agent system, each agent assumes a distinct role, precluding a solitary agent from independently executing system tasks. Instead, the entirety of system operations must be accomplished through the collaborative interactions among agents[7]. Presently, a standardized definition of the agent remains elusive within the academic domain, as diverse researchers have ascribed varying contents, structures, and capabilities to the concept in their respective investigations[8].-In the context of mass casualty events and the extensive array of departments

involved in emergency response, this paper delineates the emergency response agent as a collective entity comprising diverse emergency response departments sharing similar responsibilities and functions. These agents possess the capability to interact both amongst themselves and with the environment. Furthermore, each individual agent autonomously engages in activities, with its behavior emanating from its own perceptual inputs and interactions with other agents within the system.

2.2 Multi-agentive relationship

In the realm of research pertaining to the coordination of multi-agent earthquake emergency responses, a discernment has been made regarding three distinct relationships—parallel, sequential, and selective—that manifest among the agents engaged in the emergency response process during seismic events.

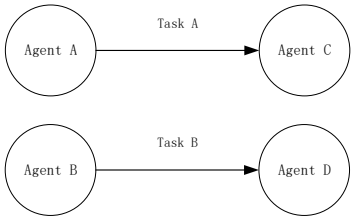

Fig. 1. Parallel relationship

The extent of competition and interdependence among entities engaged in a parallel relationship is characterized by a low degree, wherein each entity exhibits relatively independent behavior. In this scenario, subject A may execute task A concurrently with subject B undertaking task B, signifying that the behaviors of the involved subjects can occur simultaneously with minimal mutual influence. The parallel relationship is shown in the figure 1.

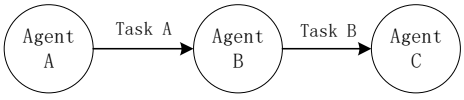

Fig. 2. Sequential relationship

Conversely, in a sequential relationship, subject A and subject B's tasks demonstrate a dependency in their successive execution. Notably, subject B can only initiate the execution of task B subsequent to the completion of task A by subject A. This sequential arrangement underscores a heightened level of interdependence between the involved subjects. The sequential relationship is shown in the figure 2.

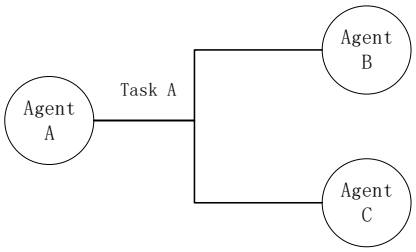

Fig. 3. Selective relationship

Within a selective relationship, subject B and subject C present alternative options for task execution. Post the completion of task A by subject A, a decision is made to either delegate task B to subject B or task C to subject C. Importantly, tasks assigned to subject B and subject C do not transpire concurrently, further illustrating the nuanced nature of the selection relationship. The selective relationship is shown in the figure 3.

In summation, the diverse dispositional relationships observed among multiple subjects serve to optimize overall benefits realization. Furthermore, these relationships can be strategically transformed into collaborative arrangements, thereby augmenting the efficacy of collaboration among multiple subjects. This strategic alignment ultimately contributes to the maximization of target benefits.

2.3 Multi-agentive collaboration

The term "collaboration" was initially introduced by Herman Hacken in the early 1970s, delineating a concept that involves the coordination, synchronization, and cooperation of various subsystems within a complex system. This collaborative effort aims to facilitate the systematic progression of behavioral processes among the subsystems[9]. A comprehensive review of extant literature reveals that scholars commonly define "collaboration" as the synchronized and cooperative engagement of two or more agents. This collaboration seeks to fortify inter-agent information exchange and resource sharing, thereby enhancing the efficiency of specific rescue tasks[10]. The overarching objective is to orchestrate an orderly course of action by the involved entities, ultimately achieving the shared goal of mitigating casualties and losses—an endeavor commonly characterized as the reduction of casualty losses.Multi-agent collaboration, in its essence, can be construed as a system where numerous agents collaborate to accomplish a task or goal through concerted and cooperative efforts. Fundamentally, this entails multiple agents engaging in consultative processes, providing mutual assistance, and collectively acting to fulfill a series of tasks, culminating in the attainment of a unified objective.

Emergency scenarios unfold within intricate environments characterized by heightened complexity and urgency, prompting an imperative focus on efficiency and cost-effectiveness in their mitigation. Invariably, the management of emergencies requires a collaborative approach, as reliance solely on a single agent proves insufficient. Thus, there arises a critical need for synergistic interactions among multiple agents. The spectrum of multi-agent collaboration is delineated into three distinct categories based on the nature of collaborative engagements: resource-based multi-agent synergy, knowledge-based multi-agent synergy, and task-based multi-agent collaboration [11].

(i) The resource-based multi-agent collaboration. Concerning resource-based multi-agent collaboration, the predominant paradigm involves the cooperative engagement of multiple agents facilitated through the utilization of specific resources. Collaborating entities establish synergistic relationships by leveraging these resources to interconnect, subsequently formulating collaborative programs and ultimately executing concerted actions[12].

(ii) The knowledge-based multi-agent collaboration. Emergencies, characterized by their multifaceted and interdisciplinary nature, necessitate the integration of knowledge spanning multiple disciplines and specialties. Agents engaged in emergency response must not only apprehend and comprehend the developmental patterns of emergencies through a comprehensive knowledge base but also formulate effective response strategies grounded in pertinent knowledge.

(iii) The task-based multi-agent collaboration.Collective completion of emergency rescue tasks in crises is achievable through the collaborative efforts of multiple agents. This collaboration manifests primarily in two forms: firstly, multiple agents collaborate to jointly accomplish identical emergency rescue tasks, and secondly, multi-agents collaborate to fulfill emergency rescue tasks while exhibiting a partial order relationship.

3 The collaborative working model

Through an extensive review of literature and the preceding synthesis, it is evident that multi-agent collaboration takes various forms, including resource-based, knowledge-based, and task-based collaborations. Building upon prior research, this paper posits a collaborative work model termed "objective-task-agent-resource" based on the emergency plan. It is shown in the figure 4. The sequential process of this model is as follows:

a. Establishment of Objectives: In response to the uncertainties inherent in emergencies and the pressing nature of time constraints, the expeditious determination of the coordinated disposal goal becomes paramount. Key nodes of synergistic sub-targets are subsequently identified in accordance with the prioritized order of disposal.

b. Task Decomposition: Guided by the emergency plan, the intricate emergency rescue task undergoes meticulous decomposition. This involves refining and breaking down the vast and complex emergency task into sub-tasks that are discernible and effectively executable by the emergency rescue entities.

c. Task Allocation: Task allocation is executed based on the specific attributes of emergency rescue sub-tasks, the responsibilities of the emergency departments, and the inherent rescue capabilities of these departments. Factors such as the nature of the emergency and departmental resources are considered in arranging the allocation of sub-tasks to the corresponding responsible entities.

d. Task Execution: In the execution phase of emergency rescue tasks, a meticulous determination of the sequential relationships and urgency among sub-tasks is imperative. This ensures the systematic and seamless execution of emergency rescue tasks. Additionally, adhering to the requisites of tasks undertaken by the primary entities,

resources are effectively configured to optimize the efficiency of emergency rescue activities.

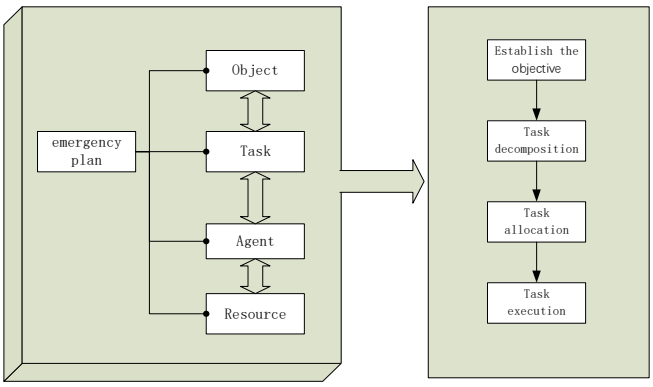

Fig. 4. The model of "objective-task-agent-resource" based on the emergency plan

3.1 Objectives of emergency rescue collaboration

The primary objective of emergency rescue endeavors is to mitigate the consequences of the incident, encompassing casualties, property losses, and environmental damage. Central to this objective is the effective execution of emergency rescue operations, with a specific emphasis on rescuing the injured and minimizing casualty losses. In the current landscape of research on emergency rescue for mass casualty events, a definitive and universally accepted definition of emergency rescue collaboration is yet to be established. This paper delineates governmental multisectoral subject collaboration in emergency rescue as follows: following the occurrence of a public emergency, the various governmental entities involved in rescue collaboratively engage and coordinate efforts to protect lives and ensure safety, with the overarching goal of minimizing human casualties.

3.2 Critical Operational Segments and Phases in Emergency Response"

Based on an analysis of regional earthquake response plans and a retrospective study of earthquake response reports from previous years, this study focuses on illustrating the complexity of the emergency response process, emphasizing the multisectoral governmental procedures involved from the onset of the casualty event to the subsequent transport of the casualty to a medical facility. Through the lens of emergency management, the entire emergency response process is categorized into three distinct phases and ranked in chronological order of disposition.

The Emergency Response Stage transpires approximately two hours post-earthquake, necessitating an early assessment and discernment of the disaster event's characteristics. This stage is critical for acquiring a preliminary understanding of the unfolding circumstances, thereby facilitating preparations for comprehensive emergency rescue initiatives.

The Injured Search and Rescue Stage, integral to the Emergency Response Stage, assumes a central role in the overarching emergency rescue endeavor. Search and rescue personnel

operate with utmost urgency to locate and retrieve injured individuals within the shortest possible timeframe.

Subsequently, the Injured Transportation Stage follows the Injured Search and Rescue Stage. During this phase, the medical sector orchestrates the deployment of ambulance vehicles and other requisite resources to the disaster area. Upon successful retrieval by search and rescue personnel, the injured are promptly transported to hospitals via designated rescue vehicles, thus culminating in the completion of medical assistance.

3.3 The mapping correlation of the "Objective-Task-Agent-Resource-Objective" (OTARO)

Through an in-depth analysis of the emergency rescue process, we delineate the tasks undertaken by agents in various departments to fulfill functional requirements, with a focus on specifying the corresponding tasks for each agent involved in earthquake emergency rescue. An examination of agent-centric emergency rescue tasks, resource allocation, and goal attainment informs the establishment of a comprehensive mapping relationship within the framework of "Objective-Task-Agent-Resource-Objective." Our proposition posits that, during the execution of emergency rescue operations by each agent, the regional earthquake emergency plan should serve as a guiding operational framework. Commencing from the emergency rescue goal, tasks are systematically organized, corresponding to the designated agents responsible for task completion. Each agent, in turn, mobilizes rescue resources to accomplish the specified tasks, thereby achieving the overarching operational objective. This mapping relationship is advocated as a cognitive framework for analyzing the collaborative participation of each agent in emergency rescue operations, as illustrated in the figure 5.

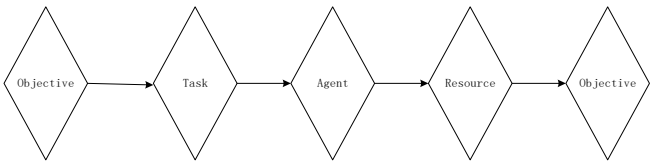

Fig. 5. The "Objective-Task-Agent-Resource-Objective"mapping correlation

4 Summary

Through an extensive review of the literature, it is evident that there exists a certain level of theoretical foundation in the domain of emergency response collaboration. However, a discernible research gap is observed concerning the mechanism analysis of emergency response coordination systems within the specific context of earthquake scenarios. In response to this, the present paper conducts a comprehensive analysis and synthesis of multi-agent coordination theories, elucidating their intricate interrelationships.

Building upon insights derived from the regional seismic emergency response plan, the study meticulously organizes the post-earthquake emergency response and rescue processes, discerning key operational junctures. To address this research gap, the paper proposes a cooperative work model, denominated as "objective-task-agent-resource," anchored in the regional seismic emergency response plan. This model delineates a nuanced mapping of the

"goal-task-agent-resource" relationship within the realm of emergency rescue. Extending this mapping relationship to encompass "Objective-Task-Agent-Resource-Objective" (OTARO), the paper establishes a direct correlation between emergency rescue tasks and the respective agents entrusted with their execution. This conceptual framework offers a structured approach for contemplating the analysis of multi-agent synergistic evaluation within the overarching domain of emergency management.

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