Community Emergency Supplies Management: A Survey on Material Classification, Government-Enterprise Cooperation, and Supply Chain Optimization

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Abstract

The comprehensive survey on community emergency supplies management emphasizes the critical integration of systematic material classification, strategic government-enterprise cooperation, and advanced supply chain optimization to enhance disaster preparedness and response. Key findings highlight innovative frameworks like the RescueChain, which accelerates consensus processes and improves user outcomes, and the application of Bayesian Stackelberg game approaches, which significantly enhance security resource allocation. The survey underscores the importance of community engagement, suggesting substantial opportunities for improving disaster preparedness through enhanced engagement practices. Additionally, the necessity for adaptable models in Emergency Medical Services (EMS) is emphasized, advocating for the integration of advanced forecasting techniques and evolving data sources. The survey concludes by advocating for the development of comprehensive models that incorporate complex traffic scenarios and external factors, thereby enhancing the adaptability and resilience of emergency logistics systems. Future research should continue to explore these integrated approaches to ensure communities are better equipped to manage the complexities of disaster scenarios effectively.

1 Introduction

1.1 Importance of Community Emergency Supplies Management

Effective management of community emergency supplies is essential for disaster preparedness and response, serving as a cornerstone for organized emergency operations. The significance of this management is highlighted by its facilitation of collaboration among organizations, which is crucial for resource management during emergencies [1]. Reliable communication networks are vital in disaster-affected areas, as emphasized by Wang et al., who advocate for secure data-sharing frameworks to coordinate supply chain activities effectively during crises [2]. This is particularly important in situations requiring rapid adaptability to meet the needs of affected populations.

Community engagement is another critical dimension of emergency supplies management. Ryan et al. demonstrate how community involvement enhances preparedness for natural hazards [3]. Integrating local insights into supply chain decisions, as explored by Tian et al. through the P-median facility location problem, underscores the necessity of considering local dynamics in emergency logistics planning [4].

The application of advanced technologies and innovative strategies in logistics, as discussed by Hossain et al. in the context of hierarchical networks, shows the potential for improving emergency

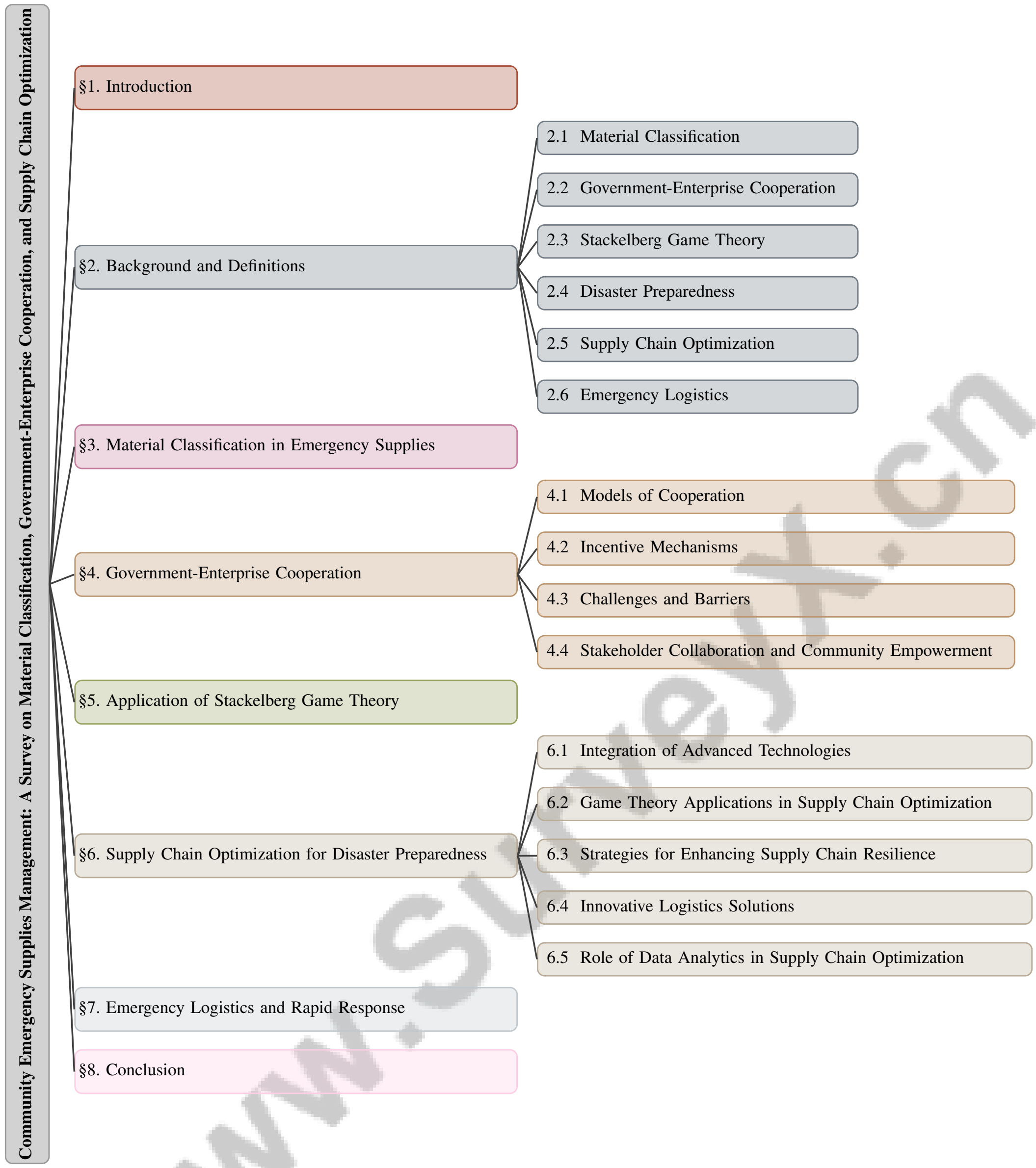


Figure 1: chapter structure

response capabilities through modern methods [5]. These advancements contribute to a more resilient and responsive emergency supply chain, addressing the complex challenges posed by disasters.

Effective management of community emergency supplies enhances resilience and ensures swift resource deployment during disasters. This encompasses strategic planning, multi-organizational collaboration, and the integration of advanced technologies. By leveraging community engagement techniques and optimizing resource distribution through intelligent supply chain principles, authorities can significantly improve response times and mitigate the impact of emergencies. Comprehensive preparedness strategies are vital for reducing the effects of natural disasters and enhancing social stability [3, 6, 7, 8, 1]. Ongoing research highlights the necessity for continuous improvement and adaptation of supply chain processes to meet evolving disaster preparedness challenges.

1.2 Challenges in Current Emergency Supplies Management

The management of emergency supplies faces numerous challenges that hinder effective disaster response operations. A primary issue is the inadequate integration of decision-making across supply

AI-generated, for reference only.

chain entities, exacerbated by privacy concerns and restricted access to critical information, which often results in suboptimal planning [9]. The reluctance of governmental bodies and enterprises to engage in open data sharing further complicates data integration efforts [10].

Coordination and planning deficiencies among organizations frequently lead to resource congestion and ineffective distribution during crises [1]. These challenges are compounded by limited resources, infrastructural inadequacies, regulatory hurdles, and adverse weather conditions that significantly impede efficient operations in disaster scenarios [11]. The COVID-19 pandemic has exposed critical shortages and inflated prices of essential supplies, such as personal protective equipment (PPE), highlighting the need for resilience-oriented supply chain designs [12]. Additionally, the lack of coordinated efforts between governmental and pharmaceutical enterprises reveals vulnerabilities in managing active pharmaceutical ingredient (API) shortages [13].

Supply chain disruptions during the COVID-19 pandemic have adversely affected operational efficiency, particularly in the retail sector [14]. Variability in service delivery across emergency medical services (EMS) systems and the challenge of establishing universal operational guidelines complicate effective EMS management [15]. Furthermore, UAV networks face security threats, and existing communication methods in disaster scenarios are often inadequate [2]. The inefficiency of current algorithms in processing large datasets presents additional challenges [16].

Community engagement efforts suffer from variability in the effectiveness of techniques, lack of systematic evaluation, and insufficient resource allocation, which impede preparedness and response initiatives [3]. The complexity of healthcare processes, concerns over data privacy, and the need for high-quality labeled data pose significant barriers to deploying advanced algorithms in emergency logistics [5]. Addressing these multifaceted challenges necessitates a comprehensive and integrated approach to enhance the resilience and effectiveness of emergency supplies management.

1.3 Role of Material Classification and Government-Enterprise Cooperation

The integration of material classification with government-enterprise cooperation is vital for enhancing the efficiency of emergency supplies management. Material classification involves systematically categorizing resources based on their characteristics, urgency, and utility, which optimizes supply allocation during emergencies. Employing advanced algorithms and predictive analytics, as proposed by Hoseininia, enables organizations to anticipate resource needs and enhance supply chain efficiency [16].

Government-enterprise cooperation is equally crucial, leveraging the strengths of both sectors to address the challenges of emergency logistics. Collaborative frameworks, such as those highlighted by Shen et al., emphasize agility, information sharing, and collaborative efforts in building resilient supply chains [14]. These partnerships facilitate resource pooling and expertise sharing, leading to more effective decision-making and resource distribution.

Digital transformation strategies, as discussed by Xie, further enhance cooperation between government and enterprises, improving supply chain responsiveness through better data integration and processing capabilities [17]. Government policies promoting open data sharing, as noted by Fan et al., create a cooperative environment that supports efficient emergency logistics [10].

Innovative technologies, such as the RescueChain framework proposed by Wang et al., which combines blockchain with vehicular fog computing, exemplify the potential for technological advancements to enhance data sharing and processing in disaster scenarios [2]. These technologies improve the overall coordination and efficiency of emergency response efforts.

Incorporating multi-objective optimization models with geographical information systems (GIS), as illustrated by Rodriguez et al., provides a robust approach to facility location and resource allocation in disaster management, ensuring that emergency supplies are strategically positioned for maximum impact during crises [1].

1.4 Structure of the Survey

This survey is meticulously designed to analyze critical dimensions of community emergency supplies management, emphasizing material classification, government-enterprise collaboration, and supply chain optimization strategies essential for enhancing emergency responses to public health crises and natural disasters. By integrating advanced technologies and fostering multi-sectoral cooperation, the survey aims to address research gaps and improve the effectiveness of emergency logistics systems [6, 15, 18, 7, 8]. The structure guides the reader through an in-depth analysis, beginning with foundational concepts and progressing to advanced applications and strategic implementations.

The survey opens with an that underscores the critical role of emergency supplies management in disaster preparedness and response, particularly given the increasing frequency and severity of natural disasters and public health crises. This section outlines how effective emergency logistics mitigates losses and injuries, improves response times, and supports social stability, emphasizing the necessity for comprehensive planning and collaboration among organizations to optimize resource allocation and ensure efficient disaster relief operations [8, 6, 1]. It highlights the pivotal roles of material classification and government-enterprise cooperation in optimizing supply chain processes, setting the stage for subsequent discussions.

Following the introduction, the **Background and Definitions** section provides a thorough overview of key terminologies and concepts essential for understanding the survey's thematic focus, including material classification, government-enterprise cooperation, Stackelberg game theory, disaster preparedness, supply chain optimization, and emergency logistics.

The next section, **Material Classification in Emergency Supplies**, delves into the systematic categorization of materials, examining its critical impact on emergency logistics. It explores various classification methods and their implications for logistics efficiency, as well as the influence of sociodemographic factors on preparedness levels.

Government-Enterprise Cooperation is then examined, focusing on the strategic collaboration between governmental entities and enterprises. This section analyzes different models of cooperation, incentive mechanisms, and the challenges and barriers to successful collaboration while exploring strategies for enhancing stakeholder collaboration and community empowerment.

The application of **Stackelberg Game Theory** is explored in the subsequent section, emphasizing its role in optimizing decision-making within emergency supply chain management. It discusses distributed equilibrium seeking, leader-follower dynamics, and innovative applications within supply chain contexts.

The survey transitions to **Supply Chain Optimization for Disaster Preparedness**, analyzing strategies to enhance supply chain processes. This section discusses the integration of advanced technologies, game theory applications, strategies for resilience, innovative logistics solutions, and the role of data analytics.

Finally, the **Emergency Logistics and Rapid Response** section addresses logistics strategies crucial for rapid response during emergencies, exploring efficiency, adaptability, coordination challenges, and the role of innovative technologies and aviation in emergency response.

The survey concludes with a comprehensive that synthesizes key findings, emphasizing the importance of an integrated approach to community emergency supplies management. It highlights how this approach enhances disaster preparedness and emergency logistics while identifying significant research gaps and future directions for investigation. The insights gained from this survey aim to inform practical applications in emergency response and academic inquiries, ultimately contributing to more effective strategies for managing emergencies and improving community resilience in the face of natural disasters and public health crises [3, 8, 6].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Material Classification

Material classification is pivotal in emergency supplies management, enhancing disaster response through systematic categorization based on urgency, utility, and context-specific attributes. This process improves resource allocation and distribution, bolstering emergency rescue strategies in complex scenarios [19]. By addressing system imperfections, such as those noted by Cao [6], classification frameworks mitigate delays in rescue efforts, enhancing supply chain agility and responsiveness.

Furthermore, material classification supports the integration of advanced technologies for data sharing during disasters. Categorizing UAVs and ground vehicles by data-sharing capabilities, as discussed by Wang et al. [2], is crucial for maintaining communication networks in disaster-affected areas, ensuring optimal resource deployment. In public health emergencies, classification addresses challenges like medical supply shortages and inefficient distribution, enhancing preparedness and response capabilities [18, 20].

Hossain et al. [5] illustrate the benefits of systematic classification in healthcare, demonstrating its role in enhancing operational efficiency across domains. By leveraging technologies such as AI and big data, material classification strengthens supply chain resilience and operational effectiveness during disaster preparedness and response, fostering multi-organizational collaboration and improved emergency outcomes [6, 19, 8, 14, 1].

2.2 Government-Enterprise Cooperation

Government-enterprise cooperation strategically combines public and private sector resources to enhance emergency supply management. This collaboration addresses logistics challenges, such as drug shortages, through innovative stockpiling strategies and active stakeholder participation [13, 21]. By aligning interests, this partnership fosters resilient supply chains, ensuring timely responses to emergencies.

Cooperative strategies aim to achieve Pareto optimality, particularly in digital ecosystems where enhanced data integration benefits both parties [17]. This cooperation is vital for overcoming challenges like unbalanced regional development, which can hinder digital transformation. In supply chain management, government-enterprise cooperation addresses CSR and sustainability issues, with Khademi et al. [22] emphasizing the need for collaboration among supply chain actors to maximize profits while considering CSR, particularly in carbon reduction efforts [23].

Challenges such as outdated data platforms and privacy concerns [10] necessitate robust incentive mechanisms to encourage enterprise cooperation, such as stockpiling APIs to prevent shortages [13]. Integrating educational cooperation among government, enterprises, and universities can enhance graduate employment and technological integration, underscoring the broader significance of government-enterprise cooperation in fostering innovation [21].

Game theory, particularly the Quasi-Perfect Stackelberg Equilibrium (QPSE) method, provides a strategic framework for understanding government-enterprise cooperation in emergency supplies management. Marchesi et al. [24] highlight the importance of leaders committing optimally while considering followers' responses, crucial for effective decision-making and resource allocation.

2.3 Stackelberg Game Theory

Stackelberg game theory analyzes hierarchical decision-making in supply chain management, characterized by a leader-follower dynamic anticipating reactions to strategic decisions. This framework is valuable for understanding competitive dynamics, investment strategies, and technology-sharing in contexts with asymmetric information and conflicting objectives [25, 26, 27, 28, 29].

In supply chain management, Stackelberg games facilitate coordination among actors like suppliers and retailers. Zhao et al. demonstrate the application of Stackelberg games in robot collaboration, enhancing performance in uncertain environments [30]. The versatility of Stackelberg game theory extends to multi-period multi-leader-follower scenarios, with Wang et al. addressing follower coordination challenges [31].

Stackelberg equilibrium (SE) offers a refined understanding of strategic interactions, essential in supply chain management, where leaders' actions inform market conditions [32]. Innovative applications include the Stackelberg POMDP framework by Brero et al., which models the leader's learning problem while incorporating followers' responses [33]. Additionally, Stackelberg games are employed in security contexts, optimizing policies to influence agent behavior in non-cooperative settings [34].

Stackelberg game theory provides a dynamic framework for strategic decision-making in supply chain management, optimizing CSR allocation among members while maximizing profits and sustainability outcomes [35, 22]. By enabling leaders to coordinate effectively with followers, Stackelberg games enhance supply chain resilience and adaptability, fostering efficient and sustainable operations.

2.4 Disaster Preparedness

Disaster preparedness is crucial for emergency logistics, equipping communities to respond effectively to catastrophic events and enhancing healthcare system resilience [36]. In operations and supply chain management, disaster preparedness integrates various response phases, emphasizing long-term resilience [37].

Organizing disaster preparedness into systems, policies, competencies, and supplies enhances community resilience, particularly in remote areas prone to natural hazards [38, 39]. Advanced technologies, including AI, are transforming disaster management strategies, enabling accurate predictions and efficient resource allocation [40].

Systematic analysis of potential disaster scenarios optimizes resource deployment and facility utilization [1]. Community engagement is vital for disaster preparedness, fostering a culture of resilience [3]. Engaging communities actively in planning and response enhances preparedness.

Disaster preparedness significantly bolsters emergency logistics by integrating diverse systems, utilizing advanced technologies, and fostering community engagement. This approach ensures robust and adaptable supply chains, informed by successful engagement strategies and collaborative resource management techniques that optimize logistical operations during emergencies. Incorporating data-driven decision-making and local knowledge further improves evacuation procedures and resource allocation, leading to effective disaster mitigation and response outcomes [3, 1, 14, 39].

2.5 Supply Chain Optimization

Optimizing supply chain processes is critical for enhancing emergency preparedness and response efficiency. The complexity of supply chain optimization arises from large-scale combinatorial problems requiring specialized knowledge for effective resolution [41]. Machine learning techniques, such as the Predictive Resource Allocation (PRA) model, forecast resource requirements in real-time, facilitating optimal distribution in network systems [42].

Reinforcement learning optimizes supply chains with complex demand structures, improving logistics efficiency [43]. Game-theoretic frameworks, especially the Stackelberg game model, offer a strategic perspective for optimizing supply chain interactions, capturing asymmetric interactions among actors [44].

Adaptive pricing and resource allocation strategies enhance supply chain responsiveness to real-time demands, minimizing idle time and maximizing throughput [45]. Multi-scale approaches refine supply chain optimization by enhancing predictive accuracy and accommodating stochastic fluctuations [46].

Proactive planning and advanced technology integration are essential for efficient emergency logistics under uncertainty. The multi-period multi-objective distributionally robust optimization framework optimizes procurement decisions while balancing cost and service levels, addressing demand fluctuations and logistical disruptions during emergencies [12, 14].

2.6 Emergency Logistics

Emergency logistics focuses on the rapid mobilization and distribution of resources in response to disasters, playing a pivotal role in delivering essential supplies to affected areas. Efficiency in emergency logistics is crucial for reducing response times and optimizing resource allocation, significantly impacting disaster management and humanitarian efforts. Integrating advanced technologies such as big data, AI, and IoT into emergency logistics enhances operational effectiveness and supports proactive planning and multi-sectoral cooperation in response to natural disasters and public health emergencies [8, 6].

UAVs are critical in emergency logistics, providing efficient aerial surveillance and delivery in disaster scenarios. Arshad et al. highlight UAVs' versatility in overcoming logistical challenges posed by damaged infrastructure and inaccessible terrain [11]. Coordinating various stakeholders—government agencies, NGOs, and private enterprises—is essential for an efficient response, maximizing resource utilization and minimizing inefficiencies [13, 1, 19, 8].

Advanced technologies, including real-time data analytics and machine learning, enhance decision-making and operational efficiency in emergency logistics systems. Leveraging these technologies improves response times and supports social stability during disasters. Future research should focus on proactive planning and multi-sectoral cooperation to optimize emergency logistics under uncertain conditions [7, 8, 6, 15]. Predictive analytics and risk assessment inform the strategic positioning of emergency supplies, enhancing aid delivery efficiency and ensuring that logistics frameworks adapt to various disaster scenarios. Proactive planning is essential for managing complex interactions between different types of disasters and maximizing the impact of humanitarian logistics initiatives [19, 15, 8, 1, 11].

3 Material Classification in Emergency Supplies

3.1 Systematic Material Classification and Emergency Logistics

Systematic material classification is essential for enhancing emergency logistics by aligning resource distribution with actual demand during disaster responses. By employing classification techniques, stakeholders can optimize coordination and resource allocation. The Dynamic Programming System (DPS), for instance, utilizes geographical data to evaluate flood risks, facilitating optimal resource distribution among organizations [1]. Similarly, classifying UAVs and ground vehicles based on their data-sharing capabilities, as discussed by Wang et al., enhances logistics by ensuring secure communication networks during emergencies [2].

Incorporating user preferences into facility location decisions, as demonstrated by Tian et al.'s branch-and-cut decomposition algorithm, further enhances logistical efficiency and user satisfaction [4]. Community engagement, emphasized by Ryan et al., integrates local insights into classification strategies, improving resource allocation relevance through workshops and coalitions [3]. Advances in predictive accuracy and personalized treatment plans, as noted by Hossain et al., underscore the potential for systematic classification to optimize logistics operations, ensuring precise resource deployment during emergencies [5].

As illustrated in Figure 2, the hierarchical structure of systematic material classification significantly impacts emergency logistics. This figure categorizes the main areas of focus, including resource optimization, data sharing, and predictive analytics, while highlighting key methods and applications derived from various studies.

Systematic material classification is thus vital for optimizing resource allocation, improving co-ordination, and leveraging advanced technologies, thereby enhancing supply chain resilience and responsiveness in disaster scenarios. This approach, evidenced by successful case studies like JD.com during the COVID-19 pandemic, leads to more effective disaster response efforts [14, 6].

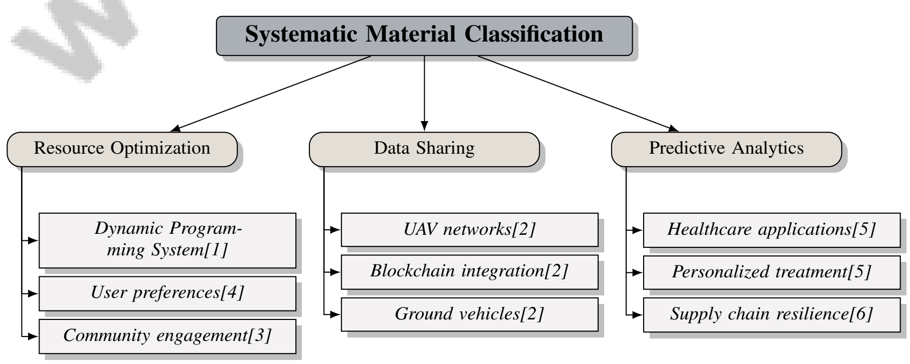


Figure 2: This figure illustrates the hierarchical structure of systematic material classification and its impact on emergency logistics. It categorizes the main areas of focus, including resource optimization, data sharing, and predictive analytics, highlighting key methods and applications from various studies.

3.2 Classification Methods and Their Impact

The methods used for classification in emergency logistics greatly affect resource management efficiency. Traditional methods often lack effectiveness, necessitating innovative approaches to address the complexities of emergency supplies management. Zhang et al. highlight the limitations of existing Multi-Agent Reinforcement Learning (MARL) methods, advocating for advanced techniques that enhance efficiency in emergency logistics [47].

Adapting classification methods to the dynamic nature of disaster scenarios is crucial, as resource needs can rapidly change. Advanced methodologies with machine learning algorithms enable real-time data analysis, enhancing precision and timeliness in resource allocation. This capability is critical in emergencies, minimizing delays and optimizing supply chain efficiency, thereby reducing losses during disasters and public health crises. Technologies such as big data, AI, and IoT support these enhanced strategies and improve collaboration among organizations involved in emergency logistics [7, 8, 6, 1].

Integrating predictive analytics into classification methods improves forecasting and resource allocation accuracy. By utilizing historical and real-time data, emergency logistics can gain insights into demand patterns, enabling strategic resource positioning to minimize shortages and enhance disaster response effectiveness. This proactive planning is essential for managing multi-organizational collaboration, optimizing resource allocation, and improving response times, contributing to a resilient emergency management system [7, 8, 6, 1].

User-centric approaches that consider community preferences and needs enhance logistics strategies' relevance and effectiveness. Effective emergency logistics is crucial for responding to natural disasters and public health crises, improving response times and reducing losses. By leveraging advanced technologies and promoting multi-sectoral cooperation, logistics strategies can be tailored to address the unique challenges of diverse emergency medical service systems, leading to improved outcomes in urgent situations [8, 15]. Aligning resource distribution with affected populations' specific requirements ensures more effective utilization of emergency supplies, thereby enhancing overall disaster response efforts.

3.3 Sociodemographic Factors and Preparedness Levels

Sociodemographic factors are critical in shaping community preparedness levels for potential disasters. Variables like age, gender, marital status, and the presence of children significantly influence how individuals and households prepare for emergencies. Bronfman et al. categorize preparedness levels according to these sociodemographic variables, revealing varying readiness degrees across demographic groups [48].

Research shows that age is a crucial determinant, with individuals aged 30 to 59, especially those living with partners and school-age children, exhibiting higher preparedness levels. This increased readiness is linked to accumulated life experiences and heightened vulnerability awareness, enhancing their response capabilities to natural hazards [48, 39]. Younger individuals may show lower preparedness due to inexperience or perceived invincibility. Gender differences also emerge, as women often assume primary responsibility for household preparedness activities, while men may be more engaged in physical aspects of disaster response.

Marital status and family composition significantly affect preparedness behaviors, with those living with partners and children demonstrating higher readiness than other demographic groups [3, 5, 39, 37, 48]. Married individuals or those with children are generally more likely to participate in preparedness activities, driven by a sense of responsibility towards family members. The presence of children often prompts parents to prioritize emergency planning, ensuring adequate provisions and safety measures are in place.

Analyzing sociodemographic factors highlights the necessity for disaster preparedness initiatives to be customized to meet the unique needs of various population segments, as different groups exhibit varying preparedness levels based on age, gender, family structure, and socio-economic status. For instance, individuals aged 30 to 59, particularly those with partners and school-age children, demonstrate higher preparedness for natural disasters such as earthquakes and floods. This underscores the need for disaster management agencies to adopt targeted community engagement strategies that address demographic differences, enhancing overall resilience in multi-hazard environments [48, 3].

By understanding the influence of sociodemographic factors on preparedness levels, policymakers and emergency management professionals can develop targeted interventions that bolster community resilience and ensure effective disaster response.

4 Government-Enterprise Cooperation

4.1 Models of Cooperation

Government-enterprise cooperation models are pivotal for optimizing emergency supplies management through strategic collaboration and resource sharing. The Stackelberg game-theoretic framework is a prominent approach that creates a hierarchical decision-making structure, effectively addressing the cooperative dynamics necessary for efficient emergency supplies management. This model enhances coordination among stakeholders, thereby improving supply chain resilience and efficiency [33]. The Stackelberg POMDP framework, in particular, captures complex leader-follower interactions, resulting in economic designs that consider strategic responses.

Digital transformation strategies further enhance operational efficiency in government-enterprise cooperation by developing digital ecosystems that tackle data integration and resource allocation challenges. This integration supports responsive emergency logistics operations, bolstered by subsidies and incentives [4].

Centralized and decentralized integration models offer distinct frameworks for resource management in emergency logistics. Centralized models are primarily managed by government entities, while decentralized models encourage active enterprise and community participation. These frameworks are part of the Government-Enterprise-University Synergy (GEUS) model, highlighting how collaboration among these entities can optimize resource efficiency. Educational cooperation data analysis suggests that partnerships among government, enterprises, and universities enhance educational outcomes and logistical challenges more effectively. Strategies such as increasing default payments and enhancing corporate participation expedite collaboration and improve performance in emergency logistics and other sectors [8, 21].

As illustrated in Figure 3, the primary models of government-enterprise cooperation in emergency logistics focus on the Stackelberg framework, digital transformation, and multi-agent systems. Each model contributes to optimizing resource management, enhancing coordination, and improving operational efficiency through strategic collaboration and technological integration.

Stackelberg games in security frameworks underscore the need for innovative algorithms to optimize resource allocation between defenders and attackers. These games model scenarios where attackers observe defenders' strategies, necessitating sophisticated security resource management. For example, in critical infrastructures like transportation and communication networks, the defender's strategy—whether pure or mixed—significantly influences the attacker's decisions. Understanding these dynamics and cost-sensitive parameters can lead to more effective security measures, as demonstrated by successful implementations like the ARMOR system at Los Angeles International Airport and the IRIS scheduler for the U.S. Federal Air Marshal Service [49, 50]. This strategic balance is crucial for efficient resource allocation during emergencies.

Integrating multi-agent systems (MAS) with intelligent agents enhances collaboration by optimizing routing and production plans while ensuring confidentiality of sensitive information. This hybrid MAS framework supports efficient communication and coordination among stakeholders, addressing real-world supply chain complexities and mitigating information-sharing challenges. Optimization algorithms within this framework aid in developing effective solutions for production routing problems, leading to improved decision-making and operational efficiency [5, 51, 9]. This approach ensures efficient management of emergency supplies.

Despite these models' advantages, achieving synchronized decision-making and cooperation remains challenging. Comprehensive frameworks that align stakeholders' interests and promote collaboration across sectors are essential for enhancing disaster preparedness and response capabilities. Such frameworks should integrate advanced technologies, encourage community engagement, and ensure efficient information sharing among organizations involved in disaster management [3, 8, 5]. By leveraging advanced game-theoretic models and strategic frameworks, governments and enterprises can enhance cooperation, leading to more resilient emergency response efforts.

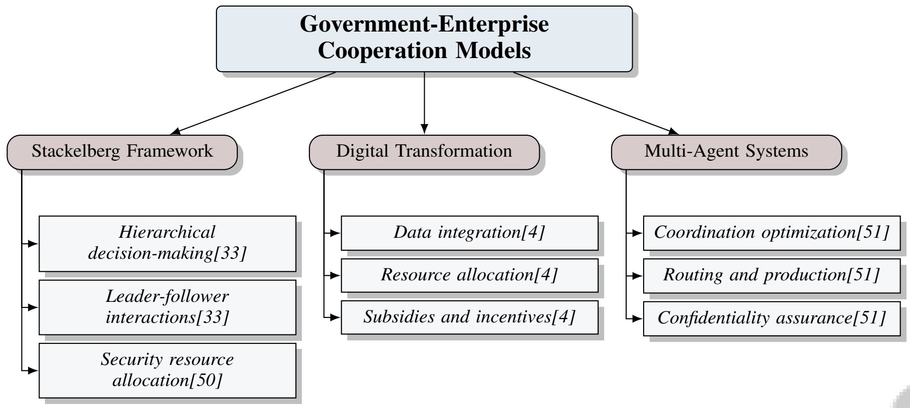


Figure 3: This figure illustrates the primary models of government-enterprise cooperation in emergency logistics, focusing on the Stackelberg framework, digital transformation, and multi-agent systems. Each model contributes to optimizing resource management, enhancing coordination, and improving operational efficiency through strategic collaboration and technological integration.

4.2 Incentive Mechanisms

Incentive mechanisms are crucial for fostering effective cooperation between government entities and enterprises in emergency supplies management. These mechanisms align the interests of stakeholders—including governments, enterprises, and universities—enhancing the efficiency and mutual benefits of their partnerships. Strategies like increasing default payments and boosting corporate participation create a cooperative environment that addresses issues such as graduate employment and educational technology integration [26, 21, 8, 9, 52]. Game-theoretic models, particularly Stackelberg games, provide a structured framework for understanding strategic interactions between leaders and followers, which is instrumental in designing effective incentive mechanisms.

The Stackelberg game framework allows for agents to take the lead in certain scenarios, promoting a balanced cooperative dynamic that can be advantageous for all parties involved [53]. This flexibility is especially relevant in emergency logistics, where optimizing resource allocation and distribution is crucial.

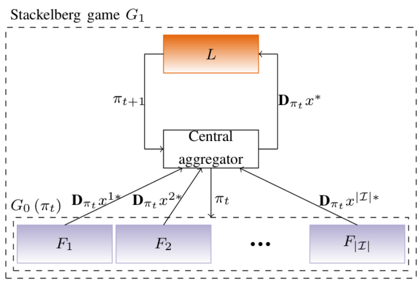
Credit-based incentive mechanisms, as proposed by Kang et al., reward peers for their contributions and adjust resource allocation based on their credits within a Stackelberg game framework [52]. This incentivization encourages enterprises to actively participate in cooperative efforts, ensuring efficient and equitable resource allocation. By incorporating such mechanisms, stakeholders can enhance their collaborative capabilities, leading to more resilient supply chains.

The integration of evolutionary game models further facilitates cooperation among stakeholders by allowing for dynamic strategy adjustments based on evolving interactions [21]. This adaptability fosters continuous improvement, contributing to the long-term success of cooperative initiatives.

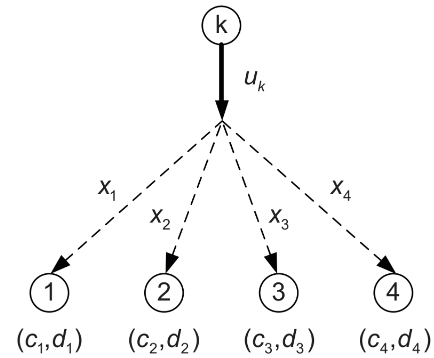
Cost-sharing mechanisms are crucial for promoting enterprise participation by distributing the financial burden of cooperative efforts. As emphasized by Fan et al., these mechanisms are essential for collaboration in emergency logistics, where resource constraints often impede effective cooperation [10]. Implementing cost-sharing arrangements mitigates financial risks and enhances collective capacity for emergency response.

Moreover, the use of incentive policies to influence agent behavior, as explored by Aurell et al., demonstrates the potential of Stackelberg games in encouraging compliance with health guidelines during epidemics [34]. This highlights the strategic importance of incentives in aligning stakeholder behavior with broader public health objectives.

As shown in Figure 4, the design and implementation of effective incentive mechanisms are crucial for aligning diverse stakeholders' objectives in government-enterprise cooperation. The Stackelberg game (G1) illustrates strategic interactions between two players, F1 and F2, with a central aggregator determining optimal decision vectors based on their inputs. This model emphasizes the hierarchical nature of decision-making, where one player's choices influence others' actions, facilitating a struc-



(a) Stackelberg game G1[54]



(b) A Directed Acyclic Graph (DAG) with a single root node labeled "k" and four nodes labeled 1, 2, 3, and 4, connected by directed edges labeled "x1", "x2", "x3", and "x4".[52]

Figure 4: Examples of Incentive Mechanisms

tured approach to cooperation. In contrast, the DAG example presents a network-based perspective, where a root node labeled "k" connects to four subordinate nodes through directed edges. This representation highlights the flow of influence and decision-making in a decentralized framework, illustrating how incentives can be structured to foster effective collaboration between government entities and enterprises [54, 52].

4.3 Challenges and Barriers

Government-enterprise cooperation in emergency supplies management faces numerous challenges and barriers that hinder effective collaboration and resource optimization. Balancing diverse product ranges at Forward Distribution Centers (FDCs) with limited inventory space and costs complicates maintaining optimal stock levels during emergencies [55].

The complexity of bi-level robust optimization problems, particularly in scenarios with multiple leaders, poses significant implementation challenges due to computational demands [56]. This complexity is exacerbated by the need to capture all relevant interactions within the system, often requiring extensive computational resources that may not adequately model real-world scenarios [46].

Misinformation and resulting strategic and cognitive instability further complicate cooperative efforts. Cheng et al. note that maintaining strategic stability in the face of misinformation can lead to disparate player observations and strategies, complicating coordination [57]. This issue is compounded by reliance on historical data for predictions, which may not reflect rapidly changing environments [42].

The theoretical foundations of cooperation, often rooted in evolutionary game theory, incorporate bounded rationality and information asymmetry among stakeholders [21]. These factors can obstruct objective alignment and the establishment of effective cooperative frameworks. Moreover, the complexity of modeling optimal supply chain designs requires substantial computational resources, limiting the applicability of such models across diverse scenarios [58].

The lack of generalizability of models due to biases in training data and insufficient regulatory guidance for clinical deployment poses significant limitations [5]. Inconsistent evaluation methods and underreporting of community engagement outcomes further undermine collaborative efforts [3].

Lastly, the oversimplification of attack and defense strategies in existing models may not adequately capture real-world complexities, limiting strategic planning and cooperation effectiveness [49].

To address these multifaceted challenges, it is essential to develop comprehensive frameworks that enhance model generalizability and facilitate robust cooperation among stakeholders. Leveraging advanced technologies, such as Large Language Models, can bridge the gap between complex automated systems and human understanding, improving decision-making in supply chain optimization.

Additionally, fostering optimal information-sharing environments through innovative information flow modeling can enhance coordinated disaster response efforts across multijurisdictional networks, ultimately promoting collective preparedness and resilience in crises [41, 5].

4.4 Stakeholder Collaboration and Community Empowerment

Enhancing stakeholder collaboration and empowering communities are vital for effective emergency supplies management. Community-based approaches, integrating local wisdom, have been shown to significantly improve disaster resilience compared to top-down strategies [39]. These methods foster ownership and responsibility among community members, leading to more adaptive disaster responses.

Active participation in educational cooperation benefits all parties, promoting a deeper understanding of disaster risk reduction strategies and enhancing preparedness levels [21]. Strategies such as increasing default payments and adjusting benefit distributions can incentivize stakeholders to engage more actively in cooperative efforts, strengthening the collaborative framework necessary for effective disaster management.

Future research should focus on enhancing stakeholder collaboration through effective training programs and integrating disaster preparedness into local governance and education systems [38]. This integration ensures that disaster preparedness becomes an integral part of community planning and decision-making processes, resulting in more robust and sustainable strategies.

The Moroccan Solidarity Hackathon exemplifies the importance of collaboration among stakeholders, including governments, NGOs, and tech companies, in developing robust AI systems for disaster management [40]. This interdisciplinary partnership underscores the potential of advanced technologies to enhance disaster response capabilities.

Furthermore, future research should explore establishing a comprehensive reserve medical supplies system, improving inter-agency coordination, and enhancing global procurement and distribution systems for emergency supplies [20]. These efforts are crucial for ensuring resources are readily available and efficiently distributed during emergencies, thereby mitigating disaster impacts on affected communities.

Sociodemographic characteristics linked to higher preparedness levels offer valuable insights for disaster risk reduction strategies [48]. Tailoring interventions to address the specific needs of diverse population segments can enhance community resilience and ensure a more effective disaster response.

5 Application of Stackelberg Game Theory

The multifaceted applications of Stackelberg game theory are especially relevant in distributed systems characterized by decentralized decision-making among multiple agents with diverse objectives. Table 3 presents a detailed comparison of methodologies employed in distributed Stackelberg equilibrium seeking, leader-follower dynamics, and modeling interactions with Stackelberg game frameworks, showcasing their diverse applications and innovative approaches. The following subsection examines distributed Stackelberg equilibrium seeking, emphasizing methodologies and frameworks that enhance agent coordination. This exploration highlights the significance of hierarchical decision-making in optimizing outcomes and showcases advancements in game-theoretic approaches that address the complexities of distributed environments.

5.1 Distributed Stackelberg Equilibrium Seeking

Achieving Stackelberg equilibrium in distributed settings is crucial for optimizing decision-making across decentralized networks, where agents operate under distinct objectives and constraints. Hierarchical decision-making frameworks are employed to facilitate agent interactions, thereby improving efficiency in supply chain management and other complex systems. Recent advancements, such as the formulation of Stackelberg games for analyzing security interactions between attackers and infrastructure administrators, demonstrate the potential of these frameworks to address security challenges in distributed environments [59].

Sampling techniques for computing Nash equilibria based on followers' responses, as proposed by Wang et al., play a vital role in coordinating followers for improved outcomes in distributed Stackelberg games [31]. This is further complemented by the CSE Learning method, which enables leaders and followers to iteratively adapt strategies based on observed outcomes, converging to a correlated Stackelberg equilibrium in multi-leader-single-follower (MLSF) games [32]. Such iterative learning processes are essential for achieving equilibrium in complex, dynamic strategic interactions.

Gradient-based algorithms, as discussed by Fiez et al., facilitate strategy updates for both leaders and followers, aligning with the hierarchical structure of Stackelberg models [60]. This enhances adaptability in distributed networks, leading to more efficient equilibrium-seeking processes.

Moreover, Hori et al. propose smoothing techniques to simplify the evaluation of Nash equilibria in multi-leader-multi-follower games, streamlining the optimization process by smoothing followers' response functions [61]. This approach is particularly advantageous in distributed settings, where complex interactions necessitate straightforward optimization methods.

Brero et al. describe a two-phase process where followers initially respond to the leader's policies, followed by the leader receiving rewards based on these interactions, exemplifying the iterative nature of equilibrium-seeking in distributed environments [33]. This method highlights the importance of feedback loops in refining strategies to achieve optimal outcomes.

5.2 Leader-Follower Dynamics and Equilibrium Computation

Method Name	Hierarchical Structure	Equilibrium Computation	Adaptability and Convergence
EGD-SG[31]	Leader-follower Dynamics	Gradient Descent Optimization	Stochastic Gradient Descent
SLD[60]	Leader-follower Relationship	Differential Stackelberg Equilibria	Iteratively Update Strategies
SMM[61]	Multiple Leaders Followers	Smoothing Response Functions	Convergence TO Equilibrium
SGM[49]	Defender Commits First	Strong Stackelberg Equilibrium	Dynamic Strategy Adjustments

Table 1: Comparison of Various Methods in Stackelberg Games: This table outlines different methodologies for modeling leader-follower dynamics within Stackelberg games, focusing on hierarchical structure, equilibrium computation, and adaptability. The methods include EGD-SG, SLD, SMM, and SGM, each offering unique approaches to optimizing strategic interactions in complex systems.

Leader-follower dynamics in Stackelberg games are critical for modeling hierarchical decision-making, where leaders set strategies anticipating followers' responses. This dynamic allows leaders to influence the strategic environment, optimizing outcomes in complex systems. In viral marketing contexts, as explored by De Silva and Wimalasena, the Stackelberg framework positions one firm as the leader and another as the follower, emphasizing the sequential nature of strategic interactions [27].

Equilibrium computation in Stackelberg games addresses the intricate interplay between leaders and followers, particularly in competitive environments. Wang et al.'s method, capable of handling arbitrary equilibrium selection procedures, provides unbiased gradient estimates that enhance utility for leaders [31]. This ensures effective strategy optimization for both leaders and followers, improving overall system performance.

In decentralized settings, ensuring well-defined Jacobians and computing local Stackelberg equilibria without compromising privacy is challenging. Iterative methods that update leaders' and followers' strategies based on their respective gradients are essential for convergence to differential Stackelberg equilibria (DSE) [60]. This iterative process is vital for achieving equilibrium in complex, dynamic strategic interactions.

The assumptions of linear demand, identical firms, and constant marginal costs are crucial for maintaining the Stackelberg independence property, as discussed by Hinnosaar [28]. These assumptions underpin the theoretical framework of Stackelberg games, ensuring accurate modeling of strategic interactions.

Hori et al.'s method of smoothing shared variables among leaders and followers addresses the challenges of interpreting solutions due to shared variables, facilitating the evaluation of Nash equilibria in multi-leader-multi-follower games [61]. This approach simplifies optimization processes, making them more accessible in distributed settings.

The adaptability of leader strategies is emphasized by the need for dynamic adjustments to align with follower responses, particularly in modeling sequential interactions between defenders and attackers in critical infrastructures [49]. This adaptability is crucial for ensuring robust decision-making where followers' best responses align with the leader's strategy. Table 1 provides a comprehensive comparison of methods used to model leader-follower dynamics and equilibrium computation in Stackelberg games, highlighting their hierarchical structures, computational techniques, and adaptability to strategic changes.

5.3 Modeling Interactions with Stackelberg Game Frameworks

Method Name	Hierarchical Interactions	Application Domains	Optimization Techniques
SGOF[62]	Leader-follower Game	Energy Management	Probabilistic Modeling
Bi-AC[51]	Asymmetric Treatment	Energy Management	Smoothing Techniques
IAGTF[59]	Stackelberg Game	Energy Management	Smoothing Techniques
DPGD[63]	Decentralized Optimization	Smart Mobility	Projected Gradient Descent
SMM[61]	Multi-leader–multi-follower	Energy Management, Security	Smoothing, Variational Inequality
FASO[64]	Structured Decision-making	Incentive Design	Gradient Descent
ATSG[65]	Distinct Roles	Energy Management	Probabilistic Modeling

Table 2: This table provides a comprehensive overview of various methods utilizing the Stackelberg game framework to model hierarchical interactions across multiple domains. It details the specific hierarchical interactions, application domains, and optimization techniques employed by each method, highlighting the versatility and adaptability of the Stackelberg approach in addressing complex strategic decision-making scenarios.

The Stackelberg game framework effectively models hierarchical interactions, particularly in systems where leaders and followers have distinct objectives and asymmetric information. It enhances decision-making across various domains, including energy management through strategic interactions between aggregators and utilities in wholesale market bidding, improving security strategies for interdependent assets via optimal randomized policies, and facilitating multi-agent coordination in demand response management within smart grids. These applications leverage game-theoretic models to address uncertainties and ensure robust outcomes [66, 67, 68, 44].

In energy management, the Stackelberg game framework models interactions among stakeholders, such as service facility centers and residential units. The integration of game theory with probabilistic modeling, as demonstrated by Li et al., achieves optimal scheduling solutions for integrated energy systems [62]. This approach allows leaders to anticipate follower responses, optimizing energy consumption and pricing strategies.

The framework's adaptability is further illustrated in multi-agent coordination, where the Bi-level Actor-Critic (Bi-AC) method achieves higher payoffs and stable convergence compared to Nash equilibrium-based methods [51]. This demonstrates the framework's ability to enhance coordination among agents through hierarchical decision-making structures.

In security contexts, the Stackelberg game framework captures interdependencies and optimizes resource allocation, such as backup power sources, to mitigate attack impacts [59]. Theoretical proofs by Korzhyk et al. establish conditions under which Stackelberg strategies can interchange with Nash equilibria, underscoring the framework's robustness in addressing security challenges [69].

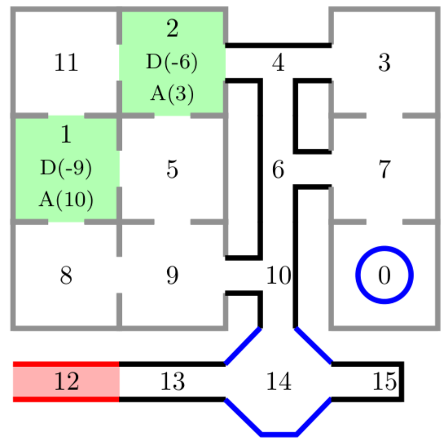
The framework also facilitates decentralized computation of leader strategies, where iterative updates based on followers' local best responses are enabled by the Implicit Function Theorem [63]. This iterative process is crucial for achieving equilibrium in distributed settings characterized by complex strategic interactions.

Smoothing methods transform followers' response functions into forms amenable to optimization, facilitating the solution of multi-leader-multi-follower games as single-level variational inequalities [61]. This approach simplifies optimization processes, making them more accessible in scenarios involving multiple stakeholders.

Additionally, evaluating linear quadratic differential game models under various scenarios, including noncooperative and Stackelberg games, provides insights into strategic interactions and decision-making processes in dynamic environments [17]. These models underscore the framework's versatility in capturing the complexities of hierarchical interactions.

$$
\begin{aligned}
\sum_{t\in[T]} \eta_t \mathbb{E}\left[\|\nabla \tilde{f}(x_t)\|^2\right] &\le \left(\tilde{f}(x_0) - \tilde{f}(x^*)\right) \\
&+ \frac{\tilde{\ell}^2 d^2}{4} \sum_{t\in[T]} \eta_t \delta_t^2 + 2e_0 d^2 L_2^2 \sum_{t\in[T]} \frac{\eta_t}{\delta_t^2} \alpha^t \\
&+ \underbrace{2Cd^4 L_2^2 \sum_{t\in[T]} \frac{\eta_t}{\delta_t^2} \sum_{k=0}^{t-1} \alpha^{t-k} \eta_k^2}_{\text{Term E}} \\
&+ \underbrace{CL_2^2 d^2 \sum_{t\in[T]} \frac{\eta_t}{\delta_t^2} \sum_{k=0}^{t-1} \alpha^{t-k} \delta_k^2}_{\text{Term F}} + 4d^2 \tilde{L}^2 \tilde{\ell} \sum_{t\in[T]} \eta_t^2
\end{aligned}
$$

(a) The image is a mathematical equation representing a sum of terms related to the gradient of a function and its derivatives.[64]



(b) The image depicts a floor plan of a building with various rooms and areas marked with numbers and labels.[65]

Figure 5: Examples of Modeling Interactions with Stackelberg Game Frameworks

As shown in Figure 5, the exploration of Stackelberg Game Theory applications reveals two compelling examples that illustrate the diverse modeling interactions achievable within the Stackelberg Game Frameworks. The first example, represented by a mathematical equation, emphasizes the intricate sum of terms related to the gradient of a function and its derivatives, structured into components that reflect the complexity of interactions in Stackelberg games. The second example offers a visual representation through a detailed floor plan of a building, where various rooms and areas are distinctly marked with numbers and labels, integrating strategic elements that reflect the dynamic interplay of decision-making processes within the Stackelberg framework. These examples collectively demonstrate the versatility and depth of Stackelberg Game Theory in modeling both mathematical and spatial interactions, providing a robust framework for analyzing hierarchical decision-making scenarios [64, 65]. Furthermore, Table 2 presents a detailed comparison of methods employing the Stackelberg game framework, illustrating their application across diverse domains and the optimization techniques they utilize.

5.4 Innovations in Stackelberg Game Applications

Innovations in Stackelberg game theory have significantly advanced its applications, particularly in supply chain management, enhancing decision-making capabilities and operational efficiencies. A notable development is the gradient-based approach by Wang et al., which outperforms existing methods in optimizing the leader's strategy in Stackelberg games with multiple followers [31]. This is crucial for optimizing supply chain processes, where dynamic interactions and precise strategic decisions are essential.

The CSE Learning method introduced by Yu et al. achieves convergence to a correlated Stackelberg equilibrium in multi-leader-single-follower (MLSF) games, even under noisy feedback conditions [32]. This method enhances strategic collaboration between supply chain stakeholders, ensuring robust and adaptive decision-making processes.

Fiez et al. emphasize the superiority of Stackelberg learning dynamics over simultaneous gradient descent, achieving stable learning and convergence to appropriate equilibria more effectively [60]. This innovation is particularly relevant in supply chain contexts, where stability and convergence are critical for maintaining efficient operations amidst complex interactions.

Hori et al.'s smoothing method for evaluating Nash equilibria in multi-leader-multi-follower games demonstrates the effectiveness of transforming response functions into forms amenable to optimization [61]. This approach simplifies the optimization process, enhancing scalability and efficiency in supply chain management scenarios involving multiple stakeholders.

Fabiani et al. introduce a two-layer algorithm that approximates a local Stackelberg equilibrium in a multi-agent hierarchical setting with nonconvex data, showcasing significant advantages in scalability and privacy [70]. This innovation is crucial for distributed supply chain systems, where effective coordination and resource allocation depend on privacy and scalability.

These innovations in Stackelberg game applications underscore the framework's versatility and effectiveness in optimizing supply chain processes and strategic interactions. By applying advanced algorithms and strategic frameworks, Stackelberg games enhance decision-making processes, optimize resource allocation, and improve operational efficiency in diverse fields, including mobile edge computing, where they facilitate resource allocation between Mobile Edge Clouds (MECs) and End Users (EUs) while maximizing revenue and utility under budget constraints. Additionally, these games are utilized in security applications, where their ability to compute equilibria in extensive-form games aids in real-time decision-making for scenarios like airport patrolling and wildlife protection [71, 72].

In recent years, the importance of effective supply chain management has become increasingly evident, particularly in the context of disaster preparedness. A comprehensive understanding of the various strategies available is essential for enhancing resilience and efficiency in critical situations. As illustrated in Figure 6, the hierarchical structure of supply chain optimization strategies encompasses several key areas, including advanced technology integration, game theory applications, resilience strategies, innovative logistics solutions, and data analytics. Each of these categories is meticulously divided into specific technologies, models, and applications, thereby elucidating their respective roles and interconnections in bolstering supply chain efficiency and adaptability during emergencies. This structured approach not only clarifies the multifaceted nature of supply chain optimization but also underscores the significance of a coordinated strategy in mitigating the impacts of disasters.

Feature	Distributed Stackelberg Equilibrium Seeking	Leader-Follower Dynamics and Equilibrium Computation	Modeling Interactions with Stackelberg Game Frameworks
Optimization Approach	Hierarchical Decision-making	Iterative Strategy Updates	Hierarchical Interactions
Application Domain	Security Interactions	Viral Marketing	Energy Management
Key Innovation	Sampling Techniques	Unbiased Gradient Estimates	Probabilistic Modeling

Table 3: This table provides a comparative analysis of three distinct methodologies within the realm of Stackelberg game theory, focusing on their optimization approaches, application domains, and key innovations. It highlights the hierarchical decision-making processes, iterative strategy updates, and probabilistic modeling techniques employed across various domains such as security interactions, viral marketing, and energy management. The table serves to elucidate the diverse applications and advancements in Stackelberg game frameworks, emphasizing their adaptability and effectiveness in optimizing distributed systems.

6 Supply Chain Optimization for Disaster Preparedness

6.1 Integration of Advanced Technologies

Advanced technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and digital twins are pivotal in optimizing supply chains and enhancing disaster preparedness. These technologies offer robust frameworks for data collection, analysis, and decision-making, essential for managing modern supply chain complexities during emergencies. Future research should integrate these technologies to analyze epidemic ripple effects and develop resilience strategies against disruptions [37].

AI and IoT enable intelligent emergency supply chains through real-time monitoring and predictive analytics, fostering informed decision-making and proactive resource management [6]. AI enhances supply chain adaptability and responsiveness, ensuring timely delivery of essential supplies during crises. Digital twins, as virtual replicas of physical networks, facilitate logistics operations by allowing scenario simulation and optimization, identifying potential bottlenecks to strengthen strategies [7]. Stackelberg game-based methods optimize pricing and resource allocation, balancing energy consumption and user rationality [73].

Additionally, these technologies contribute to resilient security strategies by incorporating network structure uncertainties, developing frameworks to guard against disruptions [68]. Investments in aviation infrastructure and disaster response training are critical for effective integration, ensuring logistics operations are supported by adequate resources and skilled personnel [11]. Aligning

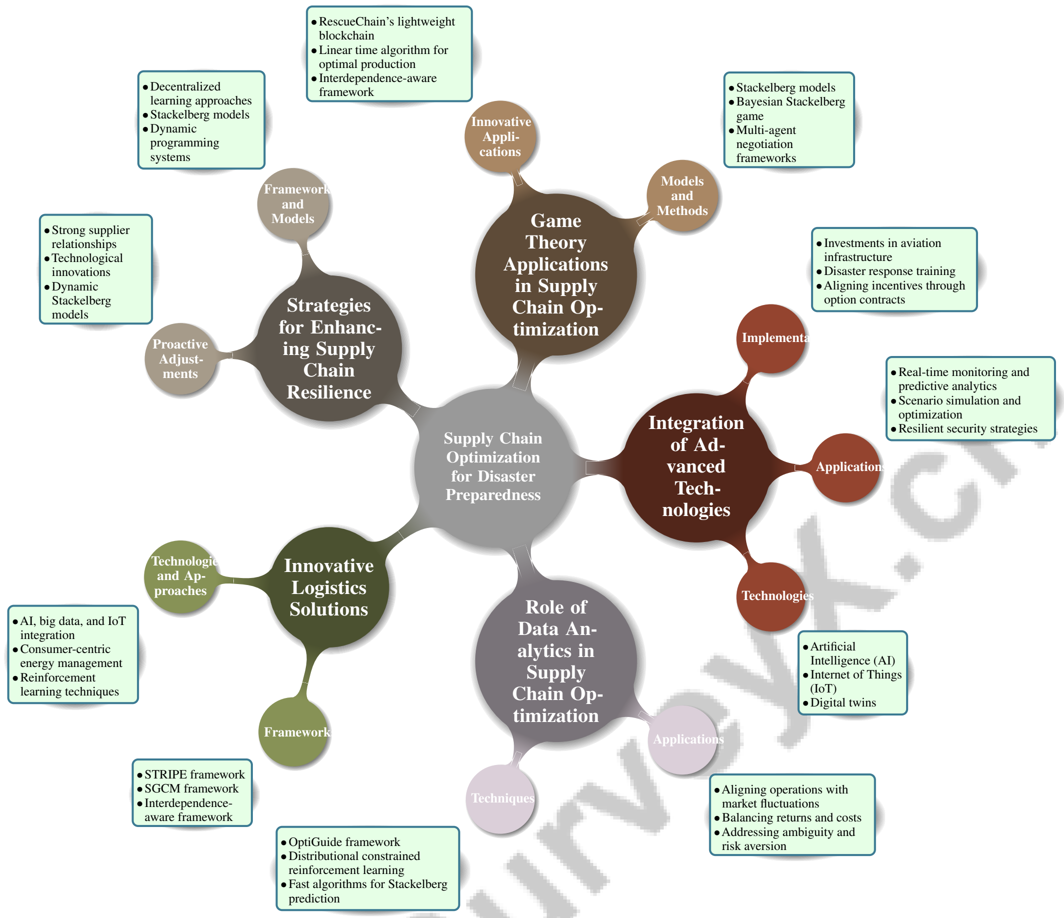


Figure 6: This figure illustrates the hierarchical structure of supply chain optimization strategies for disaster preparedness, categorizing key areas such as advanced technology integration, game theory applications, resilience strategies, innovative logistics solutions, and data analytics. Each category is further divided into specific technologies, models, and applications, highlighting their roles and interconnections in enhancing supply chain efficiency and adaptability during emergencies.

incentives through option contracts mitigates risks and fosters stakeholder cooperation, enhancing overall resilience [13].

6.2 Game Theory Applications in Supply Chain Optimization

Game theory is a powerful tool for optimizing supply chains by modeling strategic interactions among stakeholders, enhancing resource allocation and adaptability during emergencies. Stackelberg models facilitate strategic pricing and resource allocation among supply chain members, effectively balancing supply and demand in fluctuating markets [22, 74, 16, 35, 75].

The RescueChain's lightweight blockchain framework exemplifies game theory's innovative application, enhancing disaster preparedness through improved data sharing and coordination [2]. A linear time algorithm for optimal production strategies enhances operational efficiency [76]. The Bayesian Stackelberg game method optimizes security resource allocation, crucial for maintaining supply chain security against potential attacks [50].

Multi-agent negotiation frameworks optimize decisions while maintaining confidentiality, fostering trust and cooperation among stakeholders [9]. The STEP method enhances agent coordination, demonstrating game theory's role in supply chain optimization [77]. A strategic framework for budget allocation in viral marketing captures competitive dynamics, offering insights into resource

AI-generated, for reference only.

allocation strategies [27]. The interdependence-aware framework strategically allocates resources based on interdependencies, ensuring optimal traffic flow under attack scenarios [59].

6.3 Strategies for Enhancing Supply Chain Resilience

Enhancing supply chain resilience against disruptions requires strategic frameworks and advanced technologies for continuity in dynamic environments. Decentralized learning approaches optimize processes without centralized control, improving adaptability and responsiveness [32]. Stackelberg models offer robust frameworks for analyzing leader-follower interactions, facilitating effective resource allocation and strategic planning during disruptions [33].

Proactive adjustments and technology utilization are vital for resilience. Organizations like JD.com highlight the importance of strong supplier relationships and technological innovations in enhancing adaptability and efficiency [14]. Dynamic programming systems optimize resource use, preventing congestion and improving service delivery during disasters [1]. Dynamic Stackelberg models optimize profits and corporate social responsibility, contributing to resilience through strategic stakeholder interactions [35].

6.4 Innovative Logistics Solutions

Innovative logistics solutions are crucial for addressing emergency challenges, ensuring supply chains remain efficient and responsive. Integrating AI, big data, and IoT into logistics operations enhances resilience and adaptability during disasters, leading to better resource management and decision-making [8, 14, 6, 1].

A consumer-centric energy management scheme maximizes benefits while minimizing costs for central power stations, offering efficient energy management solutions in emergency logistics [78]. Novel algorithms applying the newsboy problem to inventory optimization demonstrate potential for enhancing business metrics [55]. Reinforcement learning techniques promise optimization in logistics operations, particularly in complex routing scenarios [43].

Incorporating stochastic elements into supply chain design enhances robustness and efficiency in unpredictable emergencies [58]. Developing integrated solutions for aviation logistics in disaster management emphasizes the need for innovative technologies and enhanced stakeholder training [11]. Conditional cooperation through strategic frameworks motivates sustainable practices, contributing to environmentally friendly emergency responses [23].

The STRIPE framework enhances logistics adaptability by jointly designing risk preferences and contracts [79]. The SGCM framework utilizes leader computational power to guide followers, improving task performance and resilience to uncertainties [30]. The interdependence-aware framework significantly enhances security in interdependent systems, reducing deviations and maintaining operational integrity during emergencies [59].

6.5 Role of Data Analytics in Supply Chain Optimization

Data analytics is vital for optimizing supply chains, enhancing decision-making and operational efficiency through advanced techniques. Frameworks like OptiGuide translate complex queries into optimization code, producing actionable insights that improve accessibility and applicability [41].

In supply chain management, data analytics aligns operations with market fluctuations, optimizing demand and supply dynamics. Huang's work exemplifies simultaneous optimization, leading to increased energy efficiency [74]. The integration of distributional constrained reinforcement learning highlights balancing returns and costs while managing risk, enhancing resilience amid uncertainty [80].

Data analytics addresses ambiguity and risk aversion challenges in supply chain interactions, significantly influencing equilibrium strategies and decision-making [81]. Fast algorithms for Stackelberg prediction offer opportunities for further optimizations, with preliminary results indicating a 30

7 Emergency Logistics and Rapid Response

7.1 Efficiency and Adaptability in Emergency Logistics

Efficiency and adaptability are crucial for emergency logistics, facilitating swift mobilization and resource distribution in dynamic disaster scenarios. Unmanned Aerial Vehicles (UAVs), integrated with frameworks like RescueChain, enhance these capabilities through secure data-sharing, enabling real-time information exchange and adaptive logistics operations [2]. Flexible supply chain strategies, utilizing predictive analytics and real-time monitoring, allow logistics managers to preemptively address potential disruptions, optimizing resource allocation and minimizing delays during emergencies. This strategic foresight is essential for timely delivery of goods and services during natural disasters and public health crises, ultimately improving response times and social stability [7, 8].

Strategic resource deployment, informed by data-driven insights and advanced modeling, optimizes routing, inventory management, and resource utilization, ensuring prompt delivery of essential supplies to affected areas. Integrating big data, artificial intelligence, and IoT enhances response times and social stability during disasters, facilitating proactive planning and multi-sectoral collaboration, thus creating a resilient emergency logistics framework [6, 15, 41, 7, 8]. Incorporating these strategies significantly boosts operational effectiveness, leading to more rapid and efficient disaster response efforts.

7.2 Coordination Challenges and Solutions

Coordination in emergency logistics faces challenges that can hinder disaster response. A key issue is fragmented communication networks, leading to inefficient information exchange among stakeholders, exacerbated by a lack of standardized protocols and interoperable systems [2]. Secure and intelligent data-sharing frameworks like RescueChain enhance real-time coordination and information flow among entities involved.

Misalignment of objectives among stakeholders, including government agencies, NGOs, and private enterprises, results in conflicting strategies and resource allocation decisions, undermining emergency logistics efficiency. Game-theoretic models, such as the Stackelberg framework, align stakeholder objectives by optimizing resource distribution and modeling hierarchical decision-making processes [31]. Anticipating strategic responses of different actors, these models facilitate coherent and coordinated disaster response efforts.

The complexity of multi-agent interactions in emergency logistics further complicates coordination. Multi-agent systems (MAS), equipped with intelligent agents, optimize logistics operations by enhancing routing and production plans while maintaining privacy [9]. These systems enable dynamic adaptation to evolving conditions, ensuring efficient and responsive logistics in disaster scenarios. Equitable resource distribution is challenged by sociodemographic factors affecting preparedness levels among impacted populations [48]. Tailoring logistics strategies to diverse community needs enhances resource allocation relevance and effectiveness, ensuring critical supplies reach the most vulnerable.

7.3 Innovative Technologies and Aviation in Emergency Response

Innovative technologies and aviation play a pivotal role in enhancing emergency response efficiency and effectiveness. Integrating Unmanned Aerial Vehicles (UAVs) into emergency logistics offers significant advantages in rapid deployment and real-time data collection, addressing logistical challenges associated with damaged infrastructure and inaccessible terrain [11]. This capability is crucial for minimizing response times and optimizing resource allocation during disasters.

Blockchain technology, exemplified by the RescueChain framework, enhances data sharing security and reliability in emergencies [2], reducing information fragmentation and improving overall responsiveness. Aviation infrastructure, including strategic use of aircraft and air transport services, is vital for effective emergency response. Investments in aviation infrastructure and disaster response training are essential for supporting logistics operations and equipping personnel to navigate complex emergency scenarios [11]. Rapid resource mobilization via air transport significantly enhances disaster response capacity, especially when ground transportation is hindered.

Advanced data analytics and machine learning integration into aviation logistics optimizes routing, scheduling, and resource allocation, providing critical insights into disaster impacts and facilitating precise decision-making processes. This enhancement improves emergency response coordination and effectiveness, reducing losses and injuries, and promoting social stability in affected areas. Leveraging big data, artificial intelligence, and IoT, these technologies significantly optimize resource allocation and operational strategies in disaster management [8, 39, 1].

8 Conclusion

This survey underscores the critical importance of adopting a holistic approach to community emergency supplies management, emphasizing the integration of systematic material classification, strategic government-enterprise collaboration, and advanced supply chain optimization. These elements are pivotal for bolstering disaster preparedness and enhancing emergency response capabilities. The exploration of innovative frameworks, such as those that leverage consensus-building technologies, offers promising avenues for future advancements in emergency logistics. Moreover, the application of game theory, particularly Bayesian Stackelberg models, is highlighted for its efficacy in optimizing security resource allocation, demonstrating significant potential in diverse operational contexts.

The strategic application of seried-balanced algorithms is noted for its ability to enhance production efficiency and mitigate losses from adversarial actions, further illustrating the depth of game-theoretic approaches in supply chain management. Additionally, the survey identifies community engagement as a crucial area for development, suggesting that enhancing these practices could significantly improve disaster preparedness efforts.

The necessity of creating adaptable models tailored to various Emergency Medical Services (EMS) scenarios is also highlighted. Incorporating advanced forecasting techniques and leveraging evolving data sources are essential for effective EMS planning. These insights collectively emphasize the need for resilient frameworks that can address the complex challenges of emergency logistics, ultimately contributing to improved community resilience and more effective management of emergencies.

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