Bilevel Programming in Post-Disaster Emergency Material Scheduling: A Review (Postprint)

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Abstract

The key to emergency rescue in sudden disaster events is the rational dispatch of emergency supplies. To reduce property damage and casualties while improving victim satisfaction, this study provides a comprehensive review of emergency material dispatch problems under sudden disaster events from the perspective of emergency rescue, based on bilevel programming theory. Centering on emergency material dispatch, we systematically organize and discuss various aspects including the current status of post-disaster emergency response, emergency material location-allocation, emergency material dispatch under different constraints, and the applications of bilevel programming and swarm intelligence optimization algorithms in emergency material dispatch. The findings indicate that current research on post-disaster emergency material dispatch primarily focuses on single-level emergency network structures, with discrepancies existing between model objective functions and constraints and actual situations. By incorporating the practical characteristics of emergency material dispatch, this paper proposes improvement suggestions that consider a two-level emergency network structure, thereby constructing a bilevel programming model to achieve joint optimization of upper-level and lower-level objectives.

Full Text

Preamble

Review on Application of Bi-level Programming in Post-Disaster Emergency Supplies Scheduling

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Abstract: The reasonable emergency supplies scheduling plays a critical role in emergency rescue. In order to reduce property loss and human casualties, improve the satisfaction of the victims, this paper summarized the supplies scheduling problem under sudden disasters based on bi-level theory and from the perspective of emergency rescue. Focused on the emergency supplies scheduling, it carried out the review and discussion from the perspectives of post-disaster emergency status, emergency material location-allocation, emergency supplies scheduling under different constraints, and the application of bi-level programming and swarm intelligence optimization algorithms in emergency supplies scheduling. The results shows that the research on the post-disaster emergency supplies scheduling currently focuses on the single-level emergency network structure, and the objective function and constraint condition of the model are different from the actual situation. Combining the actual characteristics of the emergency supplies scheduling, this paper proposes some improvement suggestions. It considers the two-level emergency network structure, and then builds a bi-level programming model to achieve joint optimization of the lower and upper level goals.

Keywords: sudden disaster; bi-level programming; emergency supplies scheduling; emergency rescue

0 Introduction

Despite advanced modern science and technology, natural disasters, military conflicts, and terrorist attacks remain frequent occurrences. These sudden events cause massive property damage, casualties, and environmental destruction, severely impacting people’ s lives. China is one of the countries most severely affected by natural disasters worldwide, with vast territory, complex geography, diverse disaster types, high intensity, and long duration, requiring substantial resources to address these threats to economic development and social stability. For instance, the major snowstorm that struck southern China in early 2008 affected 21 provinces, with crop damage covering 177 million acres, 354,000 collapsed houses, and direct economic losses reaching 111.1 billion yuan. Similarly, the Wenchuan earthquake on May 12, 2008—the most destructive and widespread earthquake since the founding of the People’ s Republic—resulted in 69,227 deaths, 17,923 missing persons, 374,176 injuries, and direct economic losses of 845.1 billion yuan [1]. The frequent occurrence of such sudden disasters, characterized by unpredictability, uncertainty, and high social harm, underscores the urgent need for emergency rescue research.

Post-disaster emergency supplies scheduling constitutes a primary task in emergency rescue operations. When disasters strike, it is essential to select appropriate transportation modes and routes under limited time, space, and resource constraints to deliver relief supplies to disaster sites promptly and efficiently, rapidly meeting demand in affected areas and preventing further loss escalation.

Moreover, emergency supplies scheduling involves a two-level network structure influenced by the characteristics of sudden disaster emergency response, with different hierarchical participants requiring bi-level programming analysis. Therefore, constructing reasonable post-disaster emergency supplies scheduling models integrated with bi-level programming is particularly crucial. Based on existing literature, this paper provides a comprehensive review of emergency supplies scheduling research, examining both domestic and international studies while considering applications of bi-level programming and swarm intelligence optimization algorithms, and concludes with future development prospects.

1 Research Status

1.1 Post-Disaster Emergency Research Status

Sudden disasters often cause enormous casualties and property losses, making effective post-disaster emergency response critical for loss reduction. Yasui [2] studied post-earthquake reconstruction in the Mano and Mikura communities, analyzing the relationship between community vulnerability and resilience. Zhou Lu et al. [3] analyzed relief food transported from Chengdu to disaster areas using cumulative and regression analysis, identifying three characteristics of Wenchuan earthquake supplies: phasing, correlation, and demand hierarchy. Zuo Jing et al. [4] applied an improved entropy-weight clustering SVD method to railway emergency rescue processes featuring high-dimensional, large-scale data.

Since disasters are inevitable and emergency logistics forms the core of post-disaster rescue operations, scholars worldwide have conducted extensive research on emergency logistics. Many have analyzed emergency logistics from macro or holistic perspectives. Ardekani et al. [5] discussed transportation systems' role in post-earthquake emergency response following the 1985 Mexico earthquake, identifying emergency supplies transportation and management as key challenges. Thomas [6] noted various constraints in post-earthquake emergency logistics, including capacity limitations, transportation network damage, and insufficient supplies, and analyzed optimization problems in material allocation and vehicle scheduling. Ding Yu [7] examined organizational issues in earthquake emergency logistics systems, constructing a two-level organizational structure comprising material collection centers, transfer centers, and distribution points. Wang Xuping et al. [8] analyzed emergency logistics characteristics, types, and their impact on system design from a systems engineering perspective, proposing emergency logistics system structures and rapid response mechanisms.

1.2 Emergency Supplies Location-Allocation Research Status

Optimal emergency facility layout and supplies allocation are critical to post-disaster scheduling systems, with interdependent and mutually constraining relationships necessitating integrated optimization research. This section reviews research on post-disaster emergency location, allocation, and location-allocation problems.

1) Post-Disaster Emergency Location Research Status. Emergency facility location holds significant economic, social, and military importance, attracting substantial scholarly attention. Rawls et al. [9] established a two-stage stochastic mixed-integer programming model for emergency facility location considering demand uncertainty and transportation network availability after disasters. Aksen et al. [10] developed a shelter location model addressing site selection randomness. Li et al. [11] used scenario-based approaches to construct a bi-level programming model for shelter selection and evacuation routing during hurricanes. Li Zhouqing et al. [12] established a nonlinear multi-objective mixed-integer programming model minimizing time and cost for transfer node location in large-scale relief operations. Yu Dongmei et al. [13] constructed an emergency supplies repository location optimization model based on time satisfaction under non-overlapping demand regions. Yu Wuyang et al. [14] utilized travel time risk to characterize uncertainty between candidate emergency service facilities and demand points, incorporating demand point tolerance for emergency service arrival times to minimize total risk. Zhao Rong et al. [15] studied shelter location problems for sudden disasters using dynamic programming methods while considering varying road capacities.

2) Post-Disaster Emergency Supplies Allocation Research Status. After sudden disasters, demand for emergency supplies at affected points increases dramatically while reserves are limited, creating supply shortages. Scientific and rational allocation of limited emergency supplies thus becomes crucial. Özdamar et al. [16] argued for rapid deployment to disaster areas, establishing an emergency supplies scheduling model minimizing transportation delays based on dynamic and multi-stage characteristics. Sheu [17] proposed a hybrid fuzzy clustering optimization method to improve emergency logistics collaborative distribution efficiency during critical rescue periods through affected area classification and coordinated rescue. Najafi et al. [18] developed a multi-objective, multi-mode, multi-commodity, multi-period stochastic model for managing emergency supplies and injured personnel allocation given post-earthquake shortages. Ge Honglei et al. [19] established an emergency supplies allocation model minimizing victim losses by comprehensively analyzing disaster severity and attributes of affected points and supplies. Wang Xuping et al. [20] constructed an emergency supplies allocation model considering victims' irrational comparison psychology to ensure effective initial allocation in large-scale earthquakes. Yang Jijun et al. [21] addressed fairness issues in multi-affected-point scenarios using game theory to construct an emergency supplies scheduling game model, designing an improved ant colony algorithm for solution. Chen Gang et al. [22] established an emergency supplies allocation model minimizing total weighted envy and logistics costs to address initial supply shortages in large-scale disasters.

3) Post-Disaster Location-Allocation Research Status. In integrated location-allocation research, Li et al. [23] noted that emergency supplies allocation involves distribution center location and transportation mode selection, establishing a location-allocation model minimizing total transportation time and system losses from integrated emergency logistics optimization. Yu Wuyang [24] introduced time satisfaction functions based on trapped personnel survival probability, establishing an emergency supplies transfer transportation model using traditional point-to-point and transfer modes. Rath et al. [25] argued for establishing emergency supplies transfer stations in post-disaster distribution, dividing the system into two levels and constructing a multi-objective optimization model for two-level distribution systems with an adaptive metaheuristic algorithm. Ruan Junhu et al. [26] developed a joint transportation model for emergency medical supplies with changing transfer points during helicopter and vehicle coordinated operations.

1.3 Post-Disaster Emergency Supplies Scheduling Research Status

Scholars worldwide have conducted extensive research on emergency supplies scheduling, continuously summarizing rescue characteristics and improving scheduling models based on actual disasters. Hindi et al. [27] established a mixed-integer programming model minimizing total system cost for two-stage multi-commodity scheduling. Widener et al. [28] developed an emergency supplies scheduling model minimizing total cost, response time, and maximizing victim satisfaction. Lin et al. [29] proposed a comprehensive evaluation function incorporating urgency, arrival time, and demand satisfaction from the demand point perspective, establishing a scheduling model minimizing this function while considering diverse supply-demand conditions and transportation modes. Hu et al. [30] constructed a time- and cost-minimization model for emergency supplies scheduling, proposing genetic algorithms and identifying network crossing points as critical components. Chi et al. [31] combined time and material satisfaction into a timeliness function objective, constructing a nonlinear time evaluation model for emergency resource scheduling with single impact points, multiple supply centers, and single resources.

Domestic research primarily focuses on emergency supplies distribution, routing, and vehicle scheduling, evolving from static to dynamic scheduling, single to hybrid algorithms, single to multi-objective optimization, and single-level to bilevel theory. Liu Chunlin et al. [32] studied continuous consumption problems in multi-rescue-point scheduling, establishing a model minimizing rescue points under time constraints. Guo Zixue et al. [33] proposed fuzzy chance-constrained programming for emergency supplies scheduling, constructing a triangular fuzzy information-based model for rapid response. Zhao Ming et al. [34] studied one-time and continuous consumption materials in emergency rescue, establishing multi-objective models minimizing time and losses. Tang Weiqin et al. [35] explored victim satisfaction in initial large-scale incident scheduling using whitening functions to define satisfaction, establishing a multi-objective grey decision model. Chen Yehua et al. [36] examined two-layer distribution networks for series demand systems, constructing models minimizing system recovery time and cost for vertical and combined distribution patterns, solved with genetic algorithms.

1.4 Emergency Supplies Scheduling Under Different Constraints

Research on emergency supplies scheduling varies by focus and constraints, which can be categorized into transportation capacity, multimodal transport, time windows, and dynamic constraints.

1) Transportation Capacity Constraints. Post-disaster infrastructure damage reduces transportation capacity, making vehicle arrangement and route planning critical yet understudied. Ma et al. [37] proposed a tabu search algorithm with adaptive penalty mechanisms for vehicle routing problems with time windows and link capacity constraints. Wang Xuping et al. [38] constructed a mixed-integer programming model minimizing victim losses and vehicle scheduling costs under capacity limitations. Wang Jun et al. [39] developed a maritime emergency supplies scheduling model considering marine environments, time, capacity, and resource constraints. Zheng Bin et al. [40] established a bi-level programming model for post-earthquake emergency logistics optimization incorporating time window and capacity constraints.

2) Multimodal Transport Constraints. Damaged transportation networks post-disaster necessitate multiple transport modes (road, rail, water, air) to accelerate supply and improve efficiency. Barbarosoğlu et al. [41] constructed a two-stage stochastic programming framework for emergency response transportation planning considering multi-commodity and multi-mode transport. Lin Yong et al. [42] established a decision model for multi-supply, multi-demand emergency supplies scheduling under multiple transport tools. Chen Gangtie et al. [43] studied joint transport of emergency vehicles and helicopters, integrating road disruption, repair, and demand uncertainty. Li Mengliang et al. [44] developed a multimodal emergency supplies allocation model combining road, rail, and air transport characteristics with robust optimization. Song Xiaoyu et al. [45] established a multi-level, multi-rationing, multi-mode, transferable emergency supplies scheduling model for nonlinear continuous consumption scenarios.

3) Time Window Constraints. During initial disaster phases, affected points urgently need supplies, requiring rapid delivery to minimize casualties and economic losses. Lin et al. [46] constructed a multi-objective integer programming model for multi-commodity, multi-vehicle, multi-stage, soft time-window, batch-distribution scenarios. Wang Shaoren et al. [47] built a fuzzy dynamic location-routing problem (LRP) optimization model with time windows considering post-earthquake demand timeliness, system dynamics, and uncertainty. Wu Kaijun et al. [48] designed a chaotic particle swarm algorithm for multi-depot emergency supplies scheduling with time limits, integrating Gaussian distribution and chaotic ergodicity to improve precision and convergence. Xia Hongyun et al. [49] established a bi-level programming model maximizing demand point benefits and minimizing delay costs using time windows and network flow theory, solved with a two-stage heuristic algorithm.

4) Dynamic Constraints. Post-disaster communication damage prevents timely information on supplies demand and road conditions, which continuously change, making scheduling a dynamic decision process. Fiedrich et al. [50] constructed a dynamic optimization model minimizing fatalities in early post-earthquake response, solved with tabu search and simulated annealing. Dan et al. [51] designed an improved ant colony optimization algorithm for dynamic vehicle routing in emergency supplies scheduling. Tian Jun et al. [52] used triangular fuzzy numbers to establish a multi-objective dynamic scheduling model addressing uncertain demand information and dynamic transportation network complexity. Wang Haijun et al. [53] studied dynamic scheduling with fuzzy supply and demand quantities in a three-level network structure comprising supply points, distribution centers, and demand points.

1.5 Application of Bi-level Programming in Emergency Supplies Scheduling

As society progresses, real-world problems grow in scale, complexity, and hierarchical structure, increasing attention to multi-level theory. Bi-level theory represents the most fundamental and common hierarchical theory, with substantial research achievements. Internationally, scholars have applied bi-level programming to urban power supply and road lighting. Carli et al. [54] proposed bi-level models for strategic urban road lighting energy management to maximize energy allocation fairness. Liu et al. [55] developed multi-objective bi-level planning models for active distribution networks considering network transfer capability and dispersed energy storage systems. Other applications include transportation, enterprise services, and agriculture. Du et al. [56] established fuzzy bi-level programming for hazardous materials multi-vehicle routing, with upper-level customer-to-warehouse assignment and lower-level optimal routing. Yang et al. [57] controlled traffic signals to influence driver behavior under congestion, constructing corresponding bi-level models. Abdelaziz et al. [58] developed multi-objective bi-level programming for shared inventory with emergency and backorders.

Domestically, Xu Xiangdong et al. [59] established bi-level programming models for one-way street layout optimization to reduce network congestion, designing heuristic algorithms. Lyu Yibing et al. [60] constructed bi-level water resources allocation models maximizing social and individual benefits from water market behavior perspectives. Jiang Min [61] addressed multi-loss bi-level risk decision problems in two-level supply chains. Pang Mingbao et al. [62] analyzed game theory among government, bus companies, and travelers for bus stop location bi-level programming. Zheng Yue et al. [63] eliminated information asymmetry in principal-agent problems using bi-level programming with fuzzy interactive coordination algorithms.

However, bi-level programming applications in post-disaster emergency supplies scheduling remain limited. Wang Susheng et al. [64] established a bi-level programming model minimizing rescue costs while ensuring earliest global emergency response start time, balancing timeliness and efficiency. Zheng Bin et al. [65] developed a bi-level programming model for post-earthquake location-transportation problems, with upper-level time minimization and lower-level fairness maximization, solved by a novel hybrid genetic algorithm. Song Xiaoyu et al. [66] constructed a bi-level emergency supplies scheduling model minimizing total cost and system response time based on distribution center inventory-critical inventory relationships. Liu Bo et al. [67] established a robust bi-level optimization model for emergency vehicle routing under uncertain demand and road conditions, with upper-level time minimization and lower-level cost minimization.

1.6 Application of Swarm Intelligence Optimization Algorithms in Emergency Supplies Scheduling

Intelligent optimization algorithms—including simulated annealing, particle swarm optimization, artificial fish swarm algorithms, genetic algorithms, ant colony algorithms, and tabu search—address the NP-hard nature of emergency supplies scheduling. Internationally, Azi et al. [68] proposed an exact two-stage algorithm for multi-route vehicle routing with time windows. Yi et al. [69] decomposed emergency supplies scheduling into vehicle routing and multi-commodity scheduling problems, solved by metaheuristic ant colony algorithms. Zhang et al. [70] designed an adaptive mutation genetic algorithm for emergency supplies scheduling, demonstrating superiority over standard genetic algorithms. Wex et al. [71] developed an improved heuristic algorithm for post-disaster resource allocation and scheduling to enhance response rates. Chang et al. [72] designed a greedy-search-based multi-objective genetic algorithm for emergency logistics scheduling, validated using Taiwan earthquake data.

Domestic scholars focus on algorithmic improvements and innovations. Pan Yu et al. [74] designed particle swarm algorithms for continuous consumption emergency resource scheduling. Lyu Yongbo et al. [75] developed dynamic genetic algorithms with oscillating fitness functions and dynamic crossover/mutation probabilities for disaster relief distribution. Li Jin et al. [76] designed improved heuristic algorithms combining network optimization and linear programming for multi-affected-point, multi-resource scheduling considering secondary disasters. Chen Sen et al. [77] applied genetic algorithms and dynamic programming to road network repair and vehicle distribution. Sun Huali et al. [78] used robust optimization for uncertain demand, constructing multi-objective models minimized for time and cost, solved by improved genetic algorithms. Hu Feihu et al. [79] established hierarchical scheduling models for multi-commodity, multi-vehicle problems, solved by improved genetic algorithms with paired first- and second-level chromosomes. Song Xiaoyu et al. [80] designed hybrid multi-objective particle swarm algorithms combining particle swarm and non-gradient side-step hill-climbing algorithms.

2 Summary of Research Status

Analysis of the aforementioned literature reveals several characteristics of emergency supplies scheduling research:

a) **Network Structure.** Research primarily focuses on single-level emergency networks delivering supplies directly from supply to demand points, with limited attention to two-level networks requiring transfer centers for temporary storage, redistribution, and transshipment.

b) **Constraints.** Most models consider single commodity types with sufficient supply assumptions, single transport modes, limited capacity considerations, single supply/demand points, and deterministic demand information. These assumptions contradict actual emergency features: multi-commodity, large-scale, dynamic demand, multiple supply/demand points, potential unsatisfied demand, transfer center necessity, multimodal transport with varying capacity limits, and time window requirements.

c) **Objective Functions.** Previous studies often optimize time or cost separately, whereas real emergency decisions require integrated multi-objective optimization with weak economic considerations requiring proper weighting. Limited research addresses victim satisfaction, and multi-stakeholder decision-making processes necessitate bi-level programming analysis.

d) **Intelligent Optimization Algorithms.** Due to problem complexity and numerous constraints, obtaining global optimal solutions is difficult, leading scholars to use intelligent optimization algorithms for approximate solutions. Algorithm development has evolved from parameter-controlled single algorithms to hybrid algorithms combining multiple approaches, with improved algorithms demonstrating significantly enhanced computational efficiency and accuracy.

3 Research Prospects

Based on the literature review, several improvements and future directions emerge for emergency supplies scheduling:

a) **Emergency Supplies Scheduling Research.** Emergency response involves numerous interacting uncertain factors affecting demand, supply, and scheduling impacts, while victim psychology post-disaster remains understudied. Integrating victim psychological satisfaction into scheduling research represents a valuable direction.

b) **Bi-level Programming Application.** Sudden disaster management exhibits complex hierarchical structures, making bi-level programming—fundamental to multi-level management—highly suitable. Based on actual rescue conditions, establishing emergency transfer centers creates a two-level structure: upper-level distribution from supply points to transfer centers, and lower-level distribution to affected points. Different decision-makers, content, and objectives at each level require bi-level programming analysis combined with actual emergency characteristics and appropriate assumptions. Current applications remain superficial, particularly regarding integration with game theory, despite pervasive game behaviors among decision-makers, supplies, vehicles, affected points, and victims. Combining bi-level programming with game theory in emergency supplies scheduling warrants extensive exploration.

c) **Intelligent Optimization Algorithm Research.** Real-time processing of emergent information is critical in emergency response, necessitating fast, efficient, and practical algorithms. Designing such algorithms represents a key research focus.

d) **Improving Emergency Management Systems.** While China has established a characteristic emergency rescue mechanism with central and local relief material reserves, gaps remain compared to developed countries: imperfect comprehensive coordination mechanisms, inadequate laws and policies, and insufficient public disaster awareness. National and local governments must improve existing systems based on regional characteristics.

In summary, introducing bi-level programming into emergency supplies scheduling represents a future research focus and hotspot. This study' s framework is illustrated in Figure 1 [Figure 1: see original paper].

4 Conclusion

This paper systematically reviewed literature on emergency supplies scheduling, summarizing research status on post-disaster emergency response, location-allocation, scheduling under different constraints, and applications of bi-level programming and swarm intelligence optimization algorithms. It analyzed existing problems and proposed improvement suggestions and research frameworks.

This review combines bi-level programming theory with post-disaster emergency supplies scheduling, offering novel content and a unique perspective that aligns with practical needs, facilitating new methods for post-disaster emergency supplies scheduling and improving emergency rescue theoretical systems. Future research can build upon this work by integrating bi-level programming, game theory, swarm intelligence optimization algorithms, and emergency supplies scheduling to construct game models, using simulation for hierarchical, leader-follower, and game-theoretic analysis. This comprehensive topic requires further development. As disaster frequency increases, establishing practically valuable models, improving constraints, and designing efficient intelligent optimization algorithms represent key future research directions.

References

[1] Liu Nan, Ge Honglei. *Theory, Method and Application of Emergency Resource Allocation Decision* [M]. Beijing: The Science Publishing Company, 2014: 3-8.

[2] Yasui E. Community vulnerability and capacity in post-disaster recovery: the cases of Mano and Mikura neighborhoods in the wake of the 1995 Kobe earthquake [D]. Vancouver: University of British Columbia, 2007.

[3] Zhou Lu, Chen Xi, Chen Hong, et al. Study on the features of supply about relief material under the emergency circumstance: a case study of the food supply in Wenchuan earthquake [J]. *Management Review*, 2008, 20(12): 25-29.

[4] Zuo Jing, Shuai Bin, He Kaini, et al. Assistant decision-making method railway emergency rescue based on modified entropy weight clustering SVD model [J]. *Journal of the China Railway Society*, 2017, 39(8): 18-26.

[5] Ardekani S A, Hobeika A G. Logistics problems in the aftermath of the 1985 Mexico City earthquake [J]. *Transportation Quarterly*, 1988, 42(1): 107-124.

[6] Thomas A. *Humanitarian logistics: enabling disaster response* [M]. Fritz Institute, 2008.

[7] Ding Yu. Research on the organization of emergency logistics system in earthquake disaster based on grid [D]. Beijing: Beijing Jiaotong University, 2009.

[8] Wang Xuping, Fu Kejun, Hu Xiangpei. Research on emergency logistics system and its emergent response mechanism [J]. *China Soft Science*, 2005(6): 127-131.

[9] Rawls C G, Turnquist M A. Pre-positioning of emergency supplies for disaster response [J]. *Transportation Research Part B: Methodological*, 2010, 44(4): 521-534.

[10] Aksen D, Aras N. A bilevel fixed charge location model for facilities under imminent attack [J]. *Computers & Operations Research*, 2012, 39(7): 1364-1381.

[11] Li A C Y, Nozick L, Xu Ningxiong, et al. Shelter location and transportation planning under hurricane conditions [J]. *Transportation Research Part E*, 2012, 48(4): 715-729.

[12] Li Zhouqing, Ma Zujun. Transshipment nodes location of relief materials based on improved GA [J]. *Computer Engineering*, 2011, 37(5): 4-6.

[13] Yu Dongmei, Gao Leifu, Zhao Shijie. A location model with demand regions and algorithm for emergency supplies repository [J]. *China Safety Science Journal*, 2015, 25(11): 170-176.

[14] Yu Wuyang, Lyu Jing. Emergency facility location model based on risk of travel time [J]. *Journal of Natural Disasters*, 2016, 25(4): 1-8.

[15] Zhao Rong, Liu Keyan, Ren Peiyu. Min-max multiple sink location problem in dynamic path networks with different traffic capacity constraint [J]. *Chinese Journal of Management Science*, 2017, 25(9): 133-140.

[16] Özdamar L, Ekinci E, Kucukyazici B. Emergency logistics planning in natural disasters [J]. *Annals of Operations Research*, 2004, 129(1): 217-245.

[17] Sheu J B. An emergency logistics distribution approach for quick response to urgent relief demand in disasters [J]. *Transportation Research Part E*, 2007, 43(6): 687-709.

[18] Najafi M, Eshghi K, Dullaert W. A multi-objective robust optimization model for logistics planning in the earthquake response phase [J]. *Transportation Research Part E: Logistics & Transportation Review*, 2013, 49(1): 217-249.

[19] Ge Honglei, Liu Nan, Zhang Guochuang, et al. A model for distribution of multiple emergency commodities to multiple affected areas based on loss of victims of calamity [J]. *Journal of Systems & Management*, 2010, 19(5): 541-545.

[20] Wang Xuping, Zhang Nana, Zhan Hongxin. Emergency material allocation model considering the non-rational psychological comparison of the victims [J]. *Chinese Journal of Management*, 2016, 13(7): 1075-1080.

[21] Yang Jijun, She Lian. Game model and optimization based on resource requirements of multiple crisis locations [J]. *Chinese Journal of Management Science*, 2016, 24(8): 154-163.

[22] Chen Gang, Fu Jiangyue. Multi-objective emergency resources allocation with fairness and efficiency considerations [J]. *Chinese Journal of Management*, 2018, 15(3): 459-466.

[23] Li Shuanglin, Ma Zujun, Zheng Bin, et al. Multiobjective location-transportation problem in post-earthquake delivery of relief materials [C]// *Proc of IEEE International Conference on Industrial Engineering and Engineering Management*. IEEE Press, 2011: 1468-1472.

[24] Yu Wuyang. Transshipment model for emergency materials based on time satisfaction criterion [J]. *Journal of Systems & Management*, 2013, 22(6): 882-887.

[25] Rath S, Gutjahr W J. A math-heuristic for the warehouse location-routing problem in disaster relief [J]. *Computers & Operations Research*, 2014, 42(2): 25-39.

[26] Ruan Junhu, Wang Xuping. Disruption management of emergency medical supplies intermodal transportation with updated transit centers [J]. *Operations Research and Management Science*, 2016, 25(4): 114-124.

[27] Hindi K S, Basta T, Pieńkosz K. Efficient solution of a multi-commodity, two-stage distribution problem with constraints on assignment of customers to distribution centers [J]. *International Transactions in Operational Research*, 1998, 5(6): 519-527.

[28] Widener M J, Horner M W. A Hierarchical approach to modeling hurricane disaster relief goods distribution [J]. *Journal of Transport Geography*, 2011, 19(4): 821-828.

[29] Lin Yong, Jiang Dali, Zhang Li, et al. Emergency supplies scheduling model and algorithm for multi-supply point and multi-demand point [J]. *Application Research of Computers*, 2016, 33(5): 1293-1297.

[30] Hu Feihu, Wang Yulong, Ma Beilong, et al. Emergency supplies research on crossing points of transport network based on genetic algorithm [C]// *Proc of IEEE International Conference on Intelligent Transportation, Big Data and Smart City*. IEEE Press, 2016: 370-375.

[31] Chi Hong, Li Jialian, Shao Xueyan, et al. Timeliness evaluation of emergency resource scheduling [J]. *European Journal of Operational Research*, 2016, 258(3): 1022-1032.

[32] Liu Chunlin, He Jianmin, Shi Jianjun. The study on optimal model for a kind of emergency material dispatch problem [J]. *Chinese Journal of Management Science*, 2001, V(3): 30-37.

[33] Guo Zixue, Guo Liang, Zhang Pei, et al. Time minimization model for emergency material dispatching based on triangle fuzzy information [J]. *China Safety Science Journal*, 2015, 25(10): 172-176.

[34] Zhao Ming, Chang Chunguang. Improved artificial bee colony algorithm and its application on optimization of emergency scheduling [J]. *Application Research of Computers*, 2016, 33(12): 3596-3601.

[35] Tang Weiqin, Zou Li, Guo Qiyun, et al. Grey multi-objective programming model for emergency material dispatching in initial stage of emergency [J]. *China Safety Science Journal*, 2016, 26(4): 155-160.

[36] Chen Yehua, Ma Xiaoyu. Research on the cooperative scheduling of emergency material in series demand system under the situation of emergency [J]. *Operations Research and Management Science*, 2017, 26(4): 89-95.

[37] Ma Hong, Cheang B, Lim A, et al. An investigation into the vehicle routing problem with time windows and link capacity constraints [J]. *Omega*, 2012, 40(3): 336-347.

[38] Wang Xuping, Ma Chao, Ruan Junhu. Model and algorithm of relief materials dynamic scheduling without sufficient vehicle quantity [J]. *Systems Engineering-Theory & Practice*, 2013, 33(6): 1492-1500.

[39] Wang Jun, Wang Meirong. Study on optimizing of emergency resources scheduling for maritime perils [J]. *China Safety Science Journal*, 2013, 23(1): 166-170.

[40] Zheng Bin, Ma Zujun, Zhou Yufeng. Bi-level model for dynamic location-transportation problem for post-earthquake relief distribution [J]. *Journal of Systems & Management*, 2017, 26(2): 326-337.

[41] Barbarosoğlu G, Arda Y. A two-stage stochastic programming framework for transportation planning in disaster response [J]. *Journal of the Operational Research Society*, 2004, 55(1): 43-53.

[42] Lin Yong, Jiang Dali, Zhang Li, et al. Emergency supplies scheduling model and algorithm for multi-supply point and multi-demand point [J]. *Application Research of Computers*, 2016, 33(5): 1293-1297.

[43] Chen Gangtie, Li Qingsong, Gan Junwei. Emergency relief supplies multi-modal scheduling optimization study after the earthquake [J]. *Journal of Xihua University: Natural Science Edition*, 2016, 35(1): 53-57.

[44] Li Mengliang, Wang Xifu, Sun Quanxin, et al. Research on allocation strategies of multimodal transportation for emergency resources based on robust optimization [J]. *Journal of the China Railway Society*, 2017, 39(7): 1-9.

[45] Song Xiaoyu, Zhang Yulong, Chang Chunguang. Multiple rationing multi-level emergency material dispatching model and its algorithm [J]. *Information and Control*, 2017, 46(5): 543-550.

[46] Lin Y H, Batta R, Rogerson P A, et al. A logistics model for emergency supply of critical items in the aftermath of a disaster [J]. *Socio-Economic Planning Sciences*, 2011, 45(4): 132-145.

[47] Wang Shaoren, Ma Zujun. Fuzzy dynamic LRP with time windows in post-earthquake emergency logistics systems [J]. *Operations Research and Management Science*, 2011, 20(5): 63-72.

[48] Wu Kaijun, Wang Tiejun. Model and optimization algorithm of multi-depot emergency materials dispatching with time limits [J]. *Computer Engineering and Applications*, 2012, 48(30): 19-23.

[49] Xia Hongyun, Jiang Yiping, Zhao Lindu. Emergency rescue vehicle scheduling model based on bi-level programming [J]. *Journal of Southeast University: Natural Science Edition*, 2014, 44(2): 425-429.

[50] Fiedrich F, Gehbauer F, Rickers U. Optimized resource allocation for emergency response after earthquake disasters [J]. *Safety Science*, 2000, 35(1): 41-57.

[51] Dan Bingbing, Zhu Wanhong, Li Huabing, et al. Dynamic optimization model and algorithm design for emergency materials dispatch [J]. *Mathematical Problems in Engineering*, 2013, 2013(2): 1-6.

[52] Tian Jun, Ma Wenzheng, Wang Yingluo, et al. Emergency supplies distribution and vehicle routes programming based on particle swarm optimization [J]. *Systems Engineering-Theory & Practice*, 2011, 31(5): 898-906.

[53] Wang Haijun, Wang Jing, Ma Shihua, et al. Decision-making for emergency materials dynamic dispatching based on fuzzy demand and supply [J]. *Chinese Journal of Management Science*, 2014, 22(1): 55-64.

[54] Carli R, Dotoli M. Bi-level programming for the energy retrofit planning of street lighting systems [C]// *Proc of IEEE International Conference on Networking, Sensing and Control*. IEEE Press, 2017: 543-548.

[55] Liu Jia, Cheng Haozhong, Tian Yuan, et al. Multi-objective bi-level planning of active distribution networks considering network transfer capability and dispersed energy storage systems [J]. *Journal of Renewable & Sustainable Energy*, 2018, 10(1): 015501.

[56] Du Jiaoman, Li Xiang, Yu L, et al. Multi-depot vehicle routing problem for hazardous materials transportation: a fuzzy bilevel programming [J]. *Information Sciences*, 2017, 399(C): 201-218.

[57] Yang Hai, Yagar S. Traffic assignment and signal control in saturated road networks [J]. *Transportation Research Part A: Policy & Practice*, 1995, 29(2): 125-139.

[58] Abdelaziz F B, Mejri S. Multiobjective bi-level programming for shared inventory with emergency and backorders [J]. *Annals of Operations Research*, 2018, 267(1): 47-63.

[59] Xu Xiangdong, Cheng Lin. Bi-level programming model and hybrid solution algorithm for the configuration of one-way streets [J]. *Systems Engineering-Theory & Practice*, 2009, 29(10): 180-187.

[60] Lyu Yibing, Wan Zhongping, Hu Tiesong, et al. Bi-level model of water resources optimal allocation [J]. *Systems Engineering-Theory & Practice*, 2009, 29(6): 115-120.

[61] Jiang Min. A bi-level programming of multi-loss conditional value-at-risk model and its applications [J]. *Systems Engineering-Theory & Practice*, 2013, 33(4): 926-933.

[62] Pang Mingbao, Zhang Silin, Li Chunxia. Bi-level programming of urban bus stop locating [J]. *Journal of Highway and Transportation Research and Development*, 2013, 30(3): 118-124.

[63] Zheng Yue, Wan Zhongping, Yuan Liuyang. Coordination problem of the principal-agent based on bi-level programming [J]. *Systems Engineering-Theory & Practice*, 2014, 34(1): 77-83.

[64] Wang Susheng, Wang Yan, Sun Jian, et al. Continuity constrained emergency resource allocation algorithm for multiple disaster places [J]. *Journal of Systems & Management*, 2011, 20(2): 143-150.

[65] Zheng Bin, Ma Zujun, Li Shuanglin. Integrated optimization of emergency logistics systems for post-earthquake initial stage based on bi-level programming [J]. *Journal of Systems Engineering*, 2014, 24(1): 114-125.

[66] Song Xiaoyu, Zhang Qing, Chang Chunguang. Improved bee colony algorithm for solving double layer emergency resource scheduling [J]. *Information and Control*, 2015, 44(6): 729-738.

[67] Liu Bo, Li Yan. Robust bi-level optimization model for vehicle routing of emergency commodities [J]. *Systems Engineering*, 2016, 34(5): 77-81.

[68] Azi N, Gendreau M, Potvin J Y. An exact algorithm for a single-vehicle routing problem with time windows and multiple routes [J]. *European Journal of Operational Research*, 2007, 178(3): 755-766.

[69] Yi W, Kumar A. Ant colony optimization for disaster relief operations [J]. *Transportation Research Part E*, 2007, 43(6): 660-672.

[70] Zhang Liming, Lin Yuhua, Yang Guofeng, et al. Emergency resources scheduling based on adaptively mutate genetic algorithm [J]. *Computers in Human Behavior*, 2011, 27(5): 1493-1498.

[71] Wex F, Schryen G, Feuerriegel S, et al. Emergency response in natural disaster management: allocation and scheduling of rescue units [J]. *European Journal of Operational Research*, 2014, 235(3): 697-708.

[72] Chang Fusheng, Wu J S, Lee C N, et al. Greedy-search-based multi-objective genetic algorithm for emergency logistics scheduling [J]. *Expert Systems with Applications*, 2014, 41(6): 2947-2956.

[73] Wang Yin, Hu Dawei, Automobile S O, et al. Study on emergency material supply model based on multiple supply subjects under uncertain factors [J]. *Journal of Safety Science & Technology*, 2017.

[74] Pan Yu, Yu Jia, Da Qingli. Emergency resources scheduling on continuous consumption system based on particle swarm optimization [J]. *Journal of Systems Engineering*, 2007, 22(5): 556-560.

[75] Lyu Yongbo, Jia Nan, Ren Jinluan, et al. Dynamic genetic algorithm for problems of distributing goods to disaster areas [J]. *Journal of Management Sciences in China*, 2008, 11(3): 29-34.

[76] Li Jin, Zhang Jianghua, Zhu Daoli. Multi-resource emergency scheduling model and algorithm in disaster chain [J]. *Systems Engineering-Theory & Practice*, 2011, 31(3): 488-495.

[77] Chen Sen, Jiang Jiang, Chen Yingwu, et al. Emergency logistics distribution problem model under uncertain roadway network structure and its application [J]. *Systems Engineering-Theory & Practice*, 2011, 31(5): 907-913.

[78] Sun Huali, Wang Xunqing, Xue Yaofeng. Robust optimization for multi-stage location-routing problem with stochastic demand under emergency logistics [J]. *Operations Research and Management Science*, 2013, 22(6): 45-51.

[79] Hu Feihu, Tian Chaohui, Zhao Muhua, et al. Research on hierarchical linkage scheduling emergency supplies based on genetic algorithm [J]. *Application Research of Computers*, 2016, 33(2): 439-443.

[80] Song Xiaoyu, Wang Jianguo, Chang Chunguang. Nonlinear continuous consumption emergency material dispatching problem [J]. *Journal of Systems*

Engineering, 2017, 32(2): 163-176.

Figure 1. Emergency supplies scheduling research framework

Framework showing: Sudden disaster event → Emergency rescue supplies scheduling research → Event judgment, classification, and emergency plan determination → Emergency supplies allocation problem → Emergency supplies scheduling/distribution optimization problem → Emergency facility location problem → Integration of bi-level theory, game theory, operations research, combinatorial mathematics, fuzzy mathematics, and learning effects → Multi-factor learning effects embedded in initial scheduling, time-window scheduling, disruption management scheduling, and rescheduling → Multimodal transport

Note: Figure translations are in progress. See original paper for figures.

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