ISSN: 2688-8653

Research Review on Emergency Logistics in Forest Fire Rescue

Wenhui Zhang, Zhi Liu*

School of Shenyang University of Technology, Shenyang, China

* Corresponding Author

Abstract

Forest fires are characterized by sudden outbreaks, rapid spread and complex rescue environments, which impose higher requirements on the rapid response and resource support capacity of emergency logistics systems. In recent years, with the advancement of intelligent optimization algorithms, unmanned aerial vehicle (UAV) technology and information technology, emergency logistics for forest fires has gradually become a vital research direction in the field of emergency management. Centering on the whole process of forest fire rescue, this paper systematically sorts out research progress in pre-disaster material reserve and layout, emergency material scheduling during fires, UAV material delivery, as well as information collaboration and intelligent decision-making. It summarizes deficiencies in existing research and prospects future research directions.

Keywords

Emergency logistics; forest fire; material scheduling; unmanned aerial vehicle; route optimization.

1. Introduction

Forests act as the "general regulator" of ecosystem balance, and human long-term high-quality survival is inseparable from forests. In recent years, global forest fires have occurred frequently. From 2009 to 2018, Greece suffered 986 fires, burning an average of 26,839 hectares of forests annually; Italy recorded 5,527 fires, with an average annual burned forest area of 67,639 hectares. In 2020 alone, 1,153 forest fires broke out in China, damaging 8,526 hectares of forests and causing economic losses exceeding 100 million yuan. Against the backdrop of global climate warming, forest fires present a frequent and high-incidence trend, creating an increasingly urgent demand for early rescue and rapid response.

For sudden disasters such as forest fires, emergency logistics plays a pivotal role, and its operational efficiency directly determines the response speed and guarantee effect of fire suppression and rescue. Compared with emergency logistics for other general natural disasters, forest fire rescue is restricted by more factors. Rational implementation of pre-disaster material reserve and resource pre-positioning, as well as rapid scheduling, route optimization and multi-transportation mode coordination during fires, has become a critical issue to improve forest fire emergency rescue capacity.

Scholars have carried out extensive research on forest fire emergency logistics in recent years. Nevertheless, relevant achievements are scattered across separate research fields including pre-disaster prevention, material scheduling, route optimization and UAV application. Systematic summaries and comprehensive analyses from the perspective of emergency logistics remain relatively scarce.

On this basis, this paper sorts out relevant research achievements of forest fire emergency logistics throughout the whole rescue process. First, it analyzes unique requirements imposed by forest fires on emergency logistics; second, it summarizes domestic and international research progress from four dimensions; finally, it concludes limitations of current studies and prospects the future development directions of forest fire emergency logistics, so as to provide references for relevant theoretical research and practical application.

2. Special Requirements of Forest Fire Rescue on Emergency Logistics

Forest fire rescue puts forward distinctive requirements for emergency logistics that differ from those of ordinary natural disasters.

First, the timeliness requirement is extremely high. Forest fires spread at an alarming rate, and the principle of "early detection and early disposal" is emphasized in fire suppression. Missing the golden response window will lead to out-of-control fire spread.

Second, material demand is highly uncertain. The spread direction and speed of fire are dynamically affected by wind, terrain, vegetation and other factors, making it difficult to accurately predict the type, quantity and location of material demands in advance.

Third, the "last-mile" bottleneck is prominent. Forest road networks are sparse, and vehicle access is completely unavailable in core fire zones. The last mile of material delivery from front command posts to frontline firefighters becomes a key factor restricting rescue efficiency.

Fourth, severe information asymmetry exists. There is an effective disconnection between fire situation information, material inventory information and frontline demand information, resulting in substantial blindness in material scheduling.

These special challenges make forest fire emergency logistics an extremely difficult research field.

3. Research on Pre-disaster Emergency Material Reserve and Layout

Pre-disaster material reserve and layout constitute a core component of the forest fire emergency logistics system. Its goal is to rationally allocate emergency resources prior to fire outbreaks and enhance rapid response capacity after disasters. Given the suddenness, seasonality and uneven spatial distribution of forest fires, scientific determination of reserve depot layout, optimization of material pre-positioning schemes and improvement of resource utilization efficiency have become key research focuses for domestic and foreign scholars. Existing studies mainly revolve around three aspects: reserve facility location, resource pre-positioning optimization and reserve system construction.

In terms of reserve depot location, Gan et al.[1] proposed a Monte Carlo simulation-based method for the Muli region of Sichuan Province, adopting a weighting method to obtain comprehensive evaluation indicators for determining the optimal number of material storage points. Ramalho et al. studied the strategic location of fire-fighting water reservoirs in Caparaó National Park, and found that aerial fire suppression only required 42 reservoirs to meet over 92% of demand, whereas ground fire suppression demanded 724 reservoirs with significantly higher costs.

Regarding resource pre-positioning optimization, Mendes and Alvelos[2] put forward a robust optimization method for pre-positioning forest fire suppression resources. A two-stage model was adopted: the first stage covers pre-disaster resource pre-positioning decisions, and the second stage involves resource movement decisions to fire sites after fire outbreaks. A row-and-column decomposition algorithm was designed for large-scale scenarios.

In terms of institutional development, China has continuously improved its forest and grassland fire prevention material reserve system in recent years. In 2022, the National Forestry and Grassland Administration issued the *Notice on Further Strengthening the Management of Forest and Grassland Fire Prevention Material Reserves*, proposing to improve the material reserve system following the principle of "serving daily operations and responding to wartime emergencies" and guide the participation of social forces. Meanwhile, standards such as the

ISSN: 2688-8653

Specification for Construction of Forest and Grassland Fire Fighting Material Reserve Depots further clarify depot classification, construction scale and material allocation requirements, providing institutional support for the development of China's forest fire emergency material reserve system.

Overall, most existing research focuses on static reserve layout. Studies on collaborative optimization combining pre-disaster reserve resources and in-disaster scheduling under dynamically evolving fire conditions remain insufficient. Future research should further integrate pre-disaster reserve and in-disaster scheduling to realize effective linkage between resource pre-positioning and dynamic scheduling.

4. In-disaster Emergency Material Scheduling

In-disaster material scheduling represents the core research content of forest fire emergency logistics. Current studies can be roughly divided into two categories.

The first category models material scheduling as a multi-supply-point and multi-demand-point material allocation problem, solved via linear programming, integer programming and other methods. For instance, Yang et al. [3] improved fire spread models considering the characteristics of Daxing'anling forest fires, and established a multi-objective fire emergency rescue scheduling model minimizing total transportation time and total transportation cost. Sun et al. [4] analyzed the temporal-spatial patterns of forest fire occurrence, and constructed an emergency material allocation model targeting minimum system operation time and cost. Matos et al. [5] studied fire suppression resource scheduling with the objective of minimizing burned forest area.

The second category transforms the problem into a Vehicle Routing Problem with Time Windows (VRPTW), optimizing vehicle travel routes subject to constraints including vehicle load capacity and time windows. Wu et al. [6] divided rescue priorities of affected sites based on disaster severity and fire spread speed, and built a fire vehicle rescue route model under resource constraints. Tian et al. [7] constructed a multi-objective vehicle emergency scheduling model under resource limits with consideration of rescue priorities for forest fires.

A unique feature of forest fire scenarios is that fire locations and material demands change dynamically over time, making multi-objective optimization a key research direction. The core contradiction lies in the trade-off between efficiency and equity: efficiency-oriented strategies may concentrate materials on key fire zones, while equity-oriented strategies need to guarantee basic material supply for all fire sites.

In general, research on vehicle route optimization has evolved from traditional single-objective and single-vehicle-type route planning to collaborative optimization with multiple vehicle types, multiple objectives and multiple constraints. Clustering decomposition, exact algorithms and intelligent optimization algorithms are continuously integrated to improve the solution efficiency and quality of rescue vehicle route optimization for complex forest fire scenarios.

5. Research on UAV Technology Applied in Forest Fire Emergency Logistics

Restricted by complex mountainous terrain, road barriers and rapid fire spread, forest fire rescue faces the prominent difficulty of "last-mile" transportation. Unmanned aerial vehicles (UAVs) feature strong mobility, flexible deployment and freedom from ground traffic restrictions, offering a new technical solution to tackle this bottleneck and becoming a major research hotspot in forest fire emergency logistics in recent years.

In single-UAV route planning, Pan et al. [8] constructed a multi-type general aviation rescue collaborative scheduling optimization model based on NSGA-II and weighted TOPSIS, and

ISSN: 2688-8653

verified its feasibility in improving efficiency and reducing costs for forest fire rescue via a multi-fire case in Liangshan Prefecture, Sichuan Province. Zhang and Yu[9] proposed an improved A* algorithm-based route planning method for forest fire rescue, introducing slope factors and Normalized Difference Vegetation Index (NDVI) as weights to optimize mountain route selection. Experiments prove that this method can effectively avoid steep slopes and dense vegetation to generate optimal routes. In flexible multi-base scheduling, Xie, Li and Zhao et al. proposed the Multi-Station Flexible Scheduling Problem for Drones (MSFSP-D), allowing UAVs to recharge and load/unload materials at multiple ground stations and breaking the traditional constraint of round-trip flights from a single base. UAV research has gradually shifted from single-unit optimization to collaborative scheduling across multiple stations and multiple tasks to boost overall system operational efficiency.

In coordinated transportation, Zhou et al. [10] targeted maximum satisfaction of emergency material distribution for mountain forest fires, constructed a location-routing optimization model for mountain forest fire emergency material delivery with truck-motorcycle-UAV coordination, and designed an improved tabu search algorithm with repair operators to solve the model via integer multi-vector encoding.

From a practical perspective, multiple pilot projects have been launched domestically and internationally. SF Express and JD.com have conducted UAV delivery tests for emergency rescue scenarios; globally, Zipline's UAV delivery model for medical supplies also provides references for fire rescue.

Overall, UAV technology has evolved from independent single-unit delivery to multi-UAV collaborative and air-ground coordinated delivery, showing great potential in improving the efficiency of emergency logistics for mountain forest fires. However, most existing relevant research remains limited to model construction and simulation verification. Future research should further promote deep integration of UAVs with ground vehicles, manned aircraft and intelligent scheduling platforms to build an integrated air-ground emergency logistics support system.

6. Information Collaboration and Intelligent Decision Support

Information acts as a link connecting all segments of emergency logistics, and the level of information collaboration directly determines the efficiency of material scheduling.

Current research mainly focuses on two aspects. First, the design of emergency logistics information platforms, which integrate modules including fire monitoring, road condition information, material inventory and demand declaration to break information silos and realize real-time information sharing and visualized management. Second, the development of intelligent Decision Support Systems (DSS), which combine scheduling models with Geographic Information System (GIS) technology to assist commanders in material allocation decisions. In terms of intelligent algorithm application, swarm intelligence algorithms such as Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) are widely adopted to solve complex scheduling optimization problems, while deep reinforcement learning has recently been explored for dynamic scheduling scenarios. Multi-agent systems provide a theoretical framework for collaborative multi-UAV scheduling.

Nevertheless, most existing studies on information collaboration focus on technical-level information transmission. Research on organizational information sharing mechanisms and emergency decision-making processes is relatively weak, and effective integration between technology and practical command systems remains to be further explored.

7. Research Deficiencies and Future Prospects

Remarkable progress has been achieved in research on forest fire emergency logistics in recent years, offering solid theoretical support for enhancing forest fire rescue efficiency. However, constrained by complex fire site environments and dynamic disaster evolution, existing research still has several deficiencies.

First, dynamic response capacity needs to be significantly improved. Most current scheduling models adopt static or quasi-static assumptions, failing to fully reflect dynamic factors including fire spread, road blockages and changing material demands, leading to insufficient adaptability to complex fire site environments.

Second, research on multi-transportation mode coordination is incomplete. Studies on coordinated delivery mechanisms such as "ground vehicles + UAVs" are relatively scarce, and a mature collaborative optimization framework has not yet been formed.

Third, a large number of studies only complete model construction and simulation verification, lacking application validation under real forest fire scenarios.

Fourth, the information chain is incomplete, and the full data link from fire perception to logistics decision-making has not been established.

8. Conclusion

Future research on forest fire emergency logistics can focus on the following directions:

1. Construct an integrated intelligent emergency logistics system integrating fire perception, risk prediction, resource scheduling and transportation execution, realizing closed-loop whole-process management of "perception – prediction – decision-making – execution".

2. Further deepen the application of intelligent optimization algorithms in dynamic scheduling, combining swarm intelligence algorithms, reinforcement learning and other methods to improve real-time optimization capacity under complex environments.

3. Promote deep integration of new-generation information technologies including digital twins, Internet of Things (IoT), remote sensing and artificial intelligence with emergency logistics, providing technical support for plan deduction and auxiliary decision-making.

4. Strengthen research on multi-mode transportation coordination, exploring organic connection modes of "ground trunk transportation + UAV terminal delivery".

References

[1] Gan, C. J., Diao, C., & Wang, M. Q. (2021). Optimal design of forest fire protection based on Monte Carlo simulation in Muli, Sichuan. Modern Information Technology, 5(4), 72–76. https://doi.org/10.19850/j.cnki.2096-4706.2021.04.018.

[2] Mendes, B. A., & Alvelo, E. P. F. (2024). A robust optimisation approach for the placement of forest fire suppression resources. International Transactions in Operational Research, 32(3), 1312–1342. https://doi.org/10.1111/itor.13524

[3] Yang, Z. Z., Guo, L. Q., & Dong, X. D. (2014). Research on optimal scheduling of emergency resources for forest fires in Daxing'anling. Journal of Dalian University of Technology, 54(6), 644–650.

[4] Sun, S. F., Wang, L. J., Wang, W., Li, H., & Zhang, T. (2020). Research on emergency resource reserve and scheduling of forest fires in the northern primeval forest area of Daxing'anling, Inner Mongolia. Journal of Central South University of Forestry and Technology, 40(2), 10–16.

[5] Matos, M. A., Rocha, A. M. A. C., & Costa, L. A. (2022). A genetic algorithm for forest firefighting optimization. In International Conference on Computational Science and Its Applications (pp. 55–67). Springer International Publishing. https://doi.org/10.1007/978-3-031-10484-2_5

ISSN: 2688-8653

[6] Wu, P., Wang, L. B., & Chu, C. B. (2021). Scheduling of emergency forest fire rescue resources considering rescue priority under resource constraints. Journal of Systems Science and Mathematical Sciences, 41(12), 3461–3477.

[7] Tian, G., Fathollahi-Fard, A. M., Ren, Y., & Wang, H. (2022). Multi-objective scheduling of priority-based rescue vehicles to extinguish forest fires using a multi-objective discrete gravitational search algorithm. Information Sciences, 608, 578–596. https://doi.org/10.1016/j.ins.2022.07.009

[8] Pan, W., Huang, Y., Yin, Z., & Li, S. (2023). Optimal collaborative scheduling of multi-aircraft types for forest fires general aviation rescue. Aerospace, 10(9), 741. https://doi.org/10.3390/aerospace10090741

[9] Zhang, C., & Yu, F. (2022). Research on forest fire rescue path planning based on improved A* algorithm. International Journal of Frontiers in Engineering Technology, 4(5), 1–5.

[10] Zhou, Y. F., Cheng, J. H., Liu, C. S., & Zhao, Q. (2026). Location-routing optimization of emergency material distribution for mountain forest fires. Journal of Systems Engineering, 41(3), 452–471. https://doi.org/10.13383/j.cnki.jse.2026.03.003

[11] Špulák, P. (2019). Aerial firefighting of forest fires–spatial data support. ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-3/W8, 409–413. https://doi.org/10.5194/isprs-archives-XLII-3-W8-409-2019