Article

Applications of Operations Research in Wildfire Management: A Systematic Review

Kibele Sebnem Yildirim, Amin Ahmadi Digehsara, and Amir Ardestani-Jaafari*

Faculty of Management, University of British Columbia, 1137 Alumni Avenue, Kelowna, BC V1V 1V7, Canada; sebnemkibeleyildirim@gmail.com, armitat@mail.ubc.ca, aahmadid@mail.ubc.ca, amir.ardestani@ubc.ca
* Correspondence: amir.ardestani@ubc.ca

Abstract: This review examines the importance of Operations Research in enhancing wildfire management strategies. The comprehensive analysis of 90 articles between 2000-2023 reveals a growing global awareness and a sense of urgency. Our study emphasizes the need for international cooperation and practical strategies for effective wildfire management.

Keywords: wildfire management; operations research; optimization; disaster response; systematic review

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1. Introduction

Wildfire management is becoming an urgent global concern, as indicated by the magnitude of harm caused by wildfires in spite of increased expenditures on firefighting. Wildfires are natural disasters affecting various landscapes around the world, often resulting in significant economic losses for communities. In response, it becomes imperative to develop pre-disaster preparedness plans, humanitarian and monetary resource allocation, and post-disaster emergency response plans to safeguard communities. Furthermore, it is crucial to meticulously analyze the benefits and limitations of current practices, as well as suggesting future directions for research in this context [1].

Risk analysis, a methodical approach for assessing numerous risk factors, has gained considerable attention in wildfire management literature over the past decade [2]. A wildfire risk analysis can be categorized into three main groups: (i) occurrence likelihood, which assesses the probability of wildfires; (ii) level of severity, which evaluates the potential intensity and destructiveness of these events; and (iii) disaster impacts, which assess the environmental and community consequences.

Operation Research (OR) applies advanced analytical methods to enhance decision-making and efficiency through mathematical modeling, statistical analysis, and optimization. In wildfire management, OR aids significantly in risk analysis, offering effective strategies for managing and mitigating wildfire risks. One crucial role of OR is resolving decision-making issues before wildfire occurrence, reducing challenges through predictive analytics for early-stage detection system placement. Additionally, OR methods, including Integer Linear Programming, optimize resource allocation for post-disaster emergency response, maximizing effectiveness in recovery efforts. Thus, OR plays a crucial role in addressing global wildfire management challenges.

Existing research on wildfire management and its associated challenges has identified four primary subject areas: prevention, recovery, risk management, and methodology. Only three studies in Table 1 offer literature reviews within wildfire management research, highlighting the need for further investigation into wildfire management operations. Examining articles published between 1961 and 2015, [1] summarized the evolution of modeling approaches in operational wildfire suppression, aiming to enhance decision support systems. Similarly, [2] conducted a comprehensive literature review, emphasizing risk analysis's suitability for assessing wildfire timing, location, and potential effects. In another study, [3] explored the increasing complexity of wildfire management, considering factors like the wildland–urban interface expansion and inter-agency resource sharing.

Table 1. Review papers related to wildfire management.

Reference (sorted chronologically)	Article type	Year	Subject area				Survey period
			Prevention	Response	Risk management	Methodology	
Minas et al. [3]	literature review	2012		✓		✓	1974–2012
Miller and Ager [2]	literature review	2013			✓		1972–2013
Duff and Tolhurst [1]	literature review	2015	✓			✓	1961–2015
Our study	systematic review	2023	✓	✓	✓	✓	2000–2023

Despite a significant need for utilizing OR methods in wildfire management, there's a notable gap in academic literature regarding their application, as revealed by our broad literature review. Therefore, our systematic review paper will focus on OR techniques to propose their implementation in wildfire management, enhancing overall effectiveness worldwide. Furthermore, our review aims to encourage wildfire control experts to integrate OR methods into their decision-making processes to address emerging issues exacerbated by climate change and overpopulation.

Thus, it's crucial to underscore the objective of this work: to conduct a systematic review and evaluation of existing research on the database of OR techniques in wildfire control, addressing a significant gap in scientific literature. With wildfires becoming more frequent and intense globally, we believe this approach will offer a thorough overview of current research and suggest key methods for future advancements in wildfire risk assessments and management strategies. Specifically, we aim to address the following critical research question: How does existing literature tackle issues concerning wildfire management through OR methodologies?

Our systematic review will explore the contributions of countries and articles to wildfire control emergencies and the insights gained. We aim to identify global wildfire management trends through literature assessment, shedding light on collaboration and potential OR solutions. This study, guided by research objectives, reviews OR methods in wildfire control, aiming to inspire further research and contribute to wildfire control knowledge.

The remained parts of this article are structured as follows. Section 2 describes the review methodology of this systematic review. Section 3 explicates the descriptive analysis of the review database.

2. Review Methodology

To conduct a comprehensive assessment and collect relevant papers, we adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach [4]. The PRISMA methodology comprises four stages: 'Identification,' 'Screening,' 'Eligibility,' and 'Inclusion.' The searches were conducted in November 2023 using the Web of Science (WoS) database, specifically evaluating literature published from 2000 to 2023.

Figure 1 illustrates the process of choosing and screening literature through the PRISMA method to arrive at a final selection of 90 articles for a comprehensive study. Additionally, Figure 2 visually represents our search process and the number of articles identified at each stage.

We employed two search methods to identify relevant articles. In the first search (Search I), we sought articles in the Web of Science's ORMS category that covered wildfire-related topics, resulting in 108 articles. In the second search (Search II), we used keywords such as 'game theory,' 'optimiz*,' 'linear program*,' 'stochastic program*,' and 'integer program*' to identify articles related to our research topic, including a title search for 'wildfire.' Our initial search yielded 234 articles.

According to Figure 2, following the removal of duplicates and screening for relevance (which involved excluding non-English and irrelevant articles), we included 90 articles in our comprehensive study. The papers in our final selection underwent a thorough examination procedure to ensure their relevance to our research issue and alignment with the urgency of tackling wildfires. This rigorous review aims to guarantee that the selected

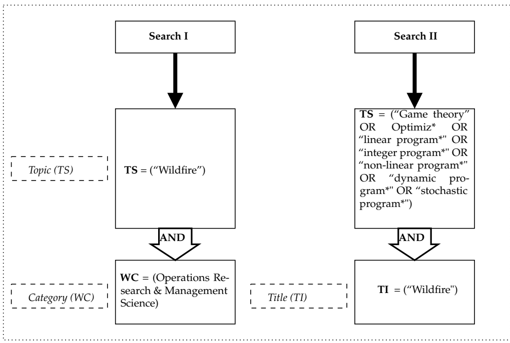

Figure 1. Searching strategy.

publications significantly contribute to our inquiry into the use of OR methodologies in wildfire management.

We aim to gather ideas from real-world issues caused by wildfires through selecting publications addressing wildfire urgency. Global relevance ensures insights from chosen papers extend regional limits, aiding a holistic understanding of wildfire management. We've evaluated articles to match wildfire urgency and preserve global relevance.

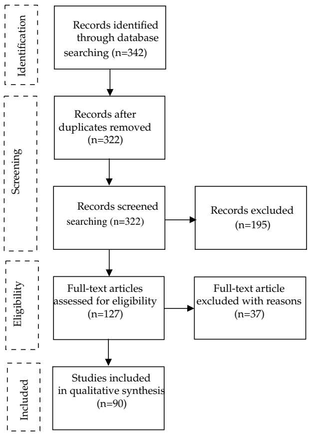

Figure 2. PRISMA flowchart.

The selected 90 articles were then examined to understand the distribution of countries engaged in wildfire management and suppression, indicating the global urgency of this issue. Figures 3 and 4 summarize the contributing journals and the distribution of publication years for articles related to wildfire management, revealing a significant increase in the urgency of wildfires over the past five years, particularly between 2018 and 2023. Figure 5 depicts the distribution of countries actively involved in wildfire management, reinforcing our hypothesis that wildfire management is a global concern. This visualization supports our study in discerning the widespread international involvement and emphasizes the interconnected nature of the challenges associated with wildfire management.

3. Descriptive analysis of the review database

To conduct a comprehensive descriptive analysis of the review database, we thoroughly examined all 90 publications, considering various characteristics such as contributing journals, geographical diversity, and methodologies used.

The dataset, comprising contributions from 43 publications, showcases a wide range of scientific sources, indicating a diversified and extensive breadth of study in the wildfire control sector. This variety of journal sources reflects a diverse approach to the investigation of wildfire-related subjects, gathering ideas from various scientific fields and viewpoints.

Table 2. Contributing journals information based on JCR

Article(s)	Source Title	Publisher	ISSN	Impact Factor	JCI Quartile
[5–13]	European Journal Of Operational Research	ELSEVIER	0377–2217	6.4	Q1
[14–18]	Annals Of Operations Research	SPRINGER	0254–5330	4.8	Q1
[19–21]	Omega	ELSEVIER	0305–0483	6.9	Q1
[22]	International Journal Of Production Research	TAYLOR & FRANCIS	0020–7543	9.2	Q1
[23]	International Journal Of Production Economics	ELSEVIER	0925–5273	12	Q1
[24,25]	Computers Environment And Urban Systems	ELSEVIER	0198–9715	6.8	Q1
[26]	Transportation Research Part E	ELSEVIER	1366–5545	10.6	Q1
[1–3,27,28]	International Journal Of Wildland Fire	CSIRO PUBLISHING	1049–8001	3.1	Q1
[29]	Journal Of Construction Engineering And Management	ASCE	0733–9364	5.1	Q1
[30]	IEEE Transactions on Power Systems	IEEE	0885–8950	6.6	Q1
[31]	Computers & Industrial Engineering	ELSEVIER	0360–8352	7.9	Q1
[32]	Forests	MDPI	1999–4907	2.9	Q1
[33]	IEEE Transactions on Smart Grid	IEEE	1949–3053	9.6	Q1
[34]	International Journal Of Electrical Power & Energy Systems	ELSEVIER	0142–0615	5.2	Q1
[35]	Applied Energy	ELSEVIER	0306–2619	11.2	Q1
[36]	Operational Research	SPRINGER	1109–2858	2.7	Q2
[37–42]	Safety Science	ELSEVIER	0925–7535	6.1	Q2
[43]	Operations Research Perspectives	ELSEVIER	2214–7160	2.5	Q2
[44–47]	Computers & Operations Research	ELSEVIER	0305–0548	4.6	Q2
[48–50]	Production And Operations Management	WILEY	1059–1478	5	Q2
[51]	Mathematical Programming	SPRINGER	0025–5610	2.7	Q2
[52–55]	Canadian Journal Of Forest Research	CANADIAN SCI. PUB.	0045–5067	2.2	Q2
[56,57]	Frontiers In Forests And Global Change	FRONTIERS	2624–893X	3.2	Q2
[58]	Canadian Journal Of Forest Research	CANADIAN SCI. PUB.	0045–5067	1.66	Q2
[59]	Fire Technology	SPRINGER	0015–2684	3.4	Q2
[60,61]	IEEE Transactions on Industry Applications	IEEE	0093–9994	4.4	Q2
[62]	European Journal Of Forest Research	SPRINGER	1612–4669	2.8	Q2
[63–65]	Natural Hazards	SPRINGER	0921–030X	3.7	Q2
[66]	Naval Research Logistics	WILEY	0894–069X	2.3	Q3
[67–69]	International Transactions in Operational Research	WILEY	0969–6016	3.1	Q3
[70]	Euro Journal on Computational Optimization	ELSEVIER	2192–4406	2.4	Q3
[71]	IISE Transactions	TAYLOR & FRANCIS	2472–5854	2.6	Q3
[72]	Optimization and Engineering	SPRINGER	1389–4420	2.1	Q3
[73–81]	Forest Science	OXFORD PRESS	0015–749X	1.4	Q3
[82]	Electronics	MDPI	2079–9292	2.9	Q3
[83]	Journal of Computational Science	ELSEVIER	1877–7503	3.3	Q3
[84]	International Transactions on Electrical Energy Systems	WILEY	2050–7038	2.3	Q3
[85]	TOP	SPRINGER	1134–5764	1.7	Q4
[86]	Optimal Control Applications & Methods	WILEY	0143–2087	1.8	Q4
[87,88]	INFOR	TAYLOR & FRANCIS	0315–5986	1.3	Q4
[89]	Acm Transactions on Modeling And Computer Simulation	ASSOC. COMPUT. MACH.	1049–3301	0.9	Q4
[90]	Combustion Science And Technology	TAYLOR & FRANCIS	0010–2202	1.9	Q4
[91]	Decision Analysis	INFORMS	1545–8490	1.9	Q4

The inclusion of contributions from a diverse range of publications enhances the overall diversity and depth of the research environment (15 Q1, 13 Q2, 9 Q3, and 6 Q4 papers according to Scimago Journal Country Rank (SJR) as shown in Table 2). However, Figure 3 displays journals with multiple articles, accounting for 70 percent (63 articles) of the 90 papers published in the 15 contributing journals. Seven out of the fifteen journals in Figure 3 are classified as ORMS category, namely *European Journal of Operational Research*, *Annals of Operations Research*, *IIE Transactions on Industry Applications*, *Computers and Operations Research*, *Production and Operations Management*, *OMEGA-international Journal of Management Science*, and *International Transactions in Operations Research*. The *European Journal of Operational Research* contributed the most articles, with nine aligning with *Forest Science*, which is not an ORMS journal, followed by *Annals of Operations Research* with five articles, and the other ORMS journals with four, three, and two articles, respectively.

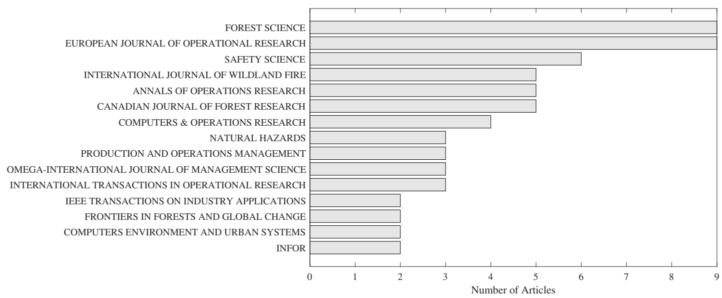

Figure 3. Distribution of articles by contributing journals.

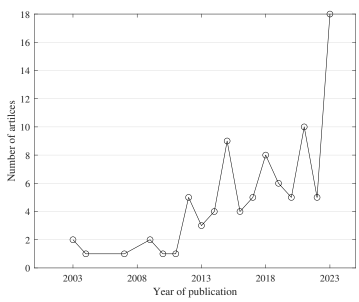

Figure 4. Distribution of articles by years.

The objective of wildfire management is to prevent, manage, and mitigate the impacts of wildfires on both human and natural settings. The goals and methods of wildfire management can vary depending on the setting, environment, and unique challenges posed by wildfires. Our next step is to review OR methods to explore which OR techniques might be useful in order to propose optimal strategies for prevention, recovery, risk management, or methodology.

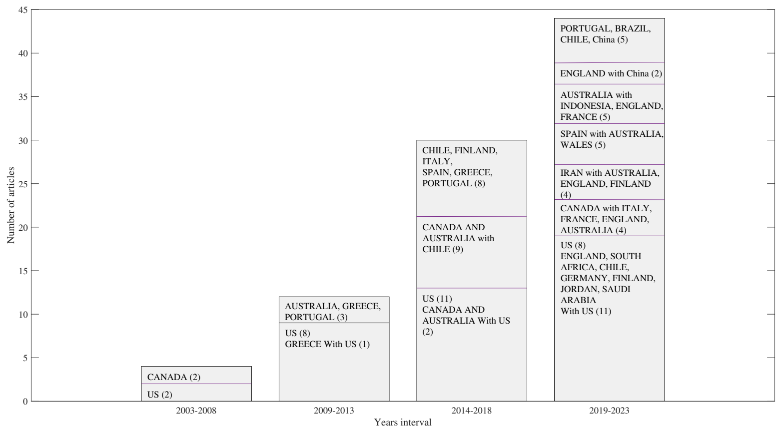

Figure 5. Distribution of articles by contributing countries in 10 years period.

Assessing wildfire control systems and operational research (OR) traditionally focused on the United States and Australia. However, collaboration with Canada, England, and Chile is increasing, indicating a global perspective shift over the last five years (2019-2023), as shown in Figure 5. This data demonstrates a growing recognition of wildfires as a worldwide problem, with participation from all continents. International collaboration is crucial in addressing these challenges comprehensively.

4. Conclusion

In conclusion, our systematic review highlights the crucial role of Operations Research (OR) in wildfire management, emphasizing the urgent need for effective strategies to combat wildfires globally. Analyzing 90 articles published between 2000 and 2023, we've identified key trends, methodologies, and challenges in the field.

OR offers valuable insights and solutions for decision-making, resource allocation, and risk analysis in wildfire management through advanced analytical methods such as mathematical modeling and optimization. The increasing global awareness of wildfire challenges and collaboration among countries underscore the importance of developing comprehensive, internationally applicable solutions.

Moving forward, continued exploration of innovative OR techniques and interdisciplinary approaches is essential to improve wildfire prevention, response, and recovery strategies. In summary, our review contributes valuable insights for future research, policy development, and practical interventions in addressing the pressing global challenge of wildfires.

References

1. Duff, T.J.; Tolhurst, K.G. Operational wildfire suppression modelling: a review evaluating development, state of the art and future directions. *International Journal of Wildland Fire* **2015**, *24*, 735–748.
2. Miller, C.; Ager, A.A. A review of recent advances in risk analysis for wildfire management. *International journal of wildland fire* **2012**, *22*, 1–14.
3. Minas, J.P.; Hearne, J.W.; Handmer, J.W. A review of operations research methods applicable to wildfire management. *International Journal of Wildland Fire* **2012**, *21*, 189–196.

4. Moher, D. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *Annals of Internal Medicine* **2009**, *151*, 264.
5. Tapia, T.; Lorca, A.; Olivares, D.; Negrete-Pincetic, M.; et al. A robust decision-support method based on optimization and simulation for wildfire resilience in highly renewable power systems. *European Journal of Operational Research* **2021**, *294*, 723–733.
6. Kim, Y.H.; Bettinger, P.; Finney, M. Spatial optimization of the pattern of fuel management activities and subsequent effects on simulated wildfires. *European Journal of Operational Research* **2009**, *197*, 253–265.
7. Stepanov, A.; Smith, J.M. Modeling wildfire propagation with Delaunay triangulation and shortest path algorithms. *European Journal of Operational Research* **2012**, *218*, 775–788.
8. Minas, J.P.; Hearne, J.W.; Martell, D.L. A spatial optimisation model for multi-period landscape level fuel management to mitigate wildfire impacts. *European Journal of Operational Research* **2014**, *232*, 412–422.
9. Bhuiyan, T.H.; Moseley, M.C.; Medal, H.R.; Rashidi, E.; Grala, R.K. A stochastic programming model with endogenous uncertainty for incentivizing fuel reduction treatment under uncertain landowner behavior. *European Journal of Operational Research* **2019**, *277*, 699–718.
10. Krasko, V.; Rebennack, S. Two-stage stochastic mixed-integer nonlinear programming model for post-wildfire debris flow hazard management: Mitigation and emergency evacuation. *European Journal of Operational Research* **2017**, *263*, 265–282.
11. Bertsimas, D.; Griffith, J.D.; Gupta, V.; Kochenderfer, M.J.; Mišić, V.V. A comparison of Monte Carlo tree search and rolling horizon optimization for large-scale dynamic resource allocation problems. *European Journal of Operational Research* **2017**, *263*, 664–678.
12. Mendes, A.B.; e Alvelos, F.P. Iterated local search for the placement of wildland fire suppression resources. *European Journal of Operational Research* **2023**, *304*, 887–900.
13. Rashidi, E.; Medal, H.; Gordon, J.; Grala, R.; Varner, M. A maximal covering location-based model for analyzing the vulnerability of landscapes to wildfires: Assessing the worst-case scenario. *European journal of operational research* **2017**, *258*, 1095–1105.
14. van der Merwe, M.; Ozlen, M.; Hearne, J.W.; Minas, J.P. Dynamic rerouting of vehicles during cooperative wildfire response operations. *Annals of Operations Research* **2017**, *254*, 467–480.
15. Yang, Z.; Guo, L.; Yang, Z. Emergency logistics for wildfire suppression based on forecasted disaster evolution. *Annals of Operations Research* **2019**, *283*, 917–937.
16. Ferreira, L.; Constantino, M.; Borges, J.G. A stochastic approach to optimize Maritime pine (Pinus pinaster Ait.) stand management scheduling under fire risk. An application in Portugal. *Annals of Operations Research* **2014**, *219*, 359–377.
17. Minas, J.; Hearne, J.; Martell, D. An integrated optimization model for fuel management and fire suppression preparedness planning. *Annals of operations Research* **2015**, *232*, 201–215.
18. Garcia-Gonzalo, J.; Pukkala, T.; Borges, J.G. Integrating fire risk in stand management scheduling. An application to Maritime pine stands in Portugal. *Annals of Operations Research* **2014**, *219*, 379–395.
19. Bashiri, M.; Nikzad, E.; Eberhard, A.; Hearne, J.; Oliveira, F. A two stage stochastic programming for asset protection routing and a solution algorithm based on the Progressive Hedging algorithm. *Omega* **2021**, *104*, 102480.
20. Baselli, G.; Contreras, F.; Lillo, M.; Marín, M.; Carrasco, R.A. Optimal decisions for salvage logging after wildfires. *Omega* **2020**, *96*, 102076.
21. Shahparvari, S.; Abbasi, B.; Chhetri, P. Possibilistic scheduling routing for short-notice bushfire emergency evacuation under uncertainties: An Australian case study. *Omega* **2017**, *72*, 96–117.
22. Nikzad, E.; Bashiri, M. A two-stage stochastic programming model for collaborative asset protection routing problem enhanced with machine learning: a learning-based matheuristic algorithm. *International Journal of Production Research* **2023**, *61*, 81–113.
23. Araya-Córdova, P.; Vásquez, Ó.C. The disaster emergency unit scheduling problem to control wildfires. *International Journal of Production Economics* **2018**, *200*, 311–317.
24. Murray, A.T.; Church, R.L.; Pludow, B.A. Enhanced solution capabilities for multiple patch land allocation. *Computers, Environment and Urban Systems* **2022**, *97*, 101871.
25. Bodaghi, B.; Palaneeswaran, E.; Shahparvari, S.; Mohammadi, M. Probabilistic allocation and scheduling of multiple resources for emergency operations; a Victorian bushfire case study. *Computers, Environment and Urban Systems* **2020**, *81*, 101479.
26. Roozbeh, I.; Hearne, J.; Abbasi, B.; Ozlen, M. Decision support for wildfire asset protection: A two-stage stochastic programming approach. *Transportation research part E: logistics and transportation review* **2021**, *155*, 102520.
27. Arrubla, J.A.G.; Ntaimo, L.; Stripling, C. Wildfire initial response planning using probabilistically constrained stochastic integer programming. *International Journal of Wildland Fire* **2014**, *23*, 825–838.
28. Heyns, A.; Du Plessis, W.; Kosch, M.; Hough, G. Optimisation of tower site locations for camera-based wildfire detection systems. *International journal of wildland fire* **2019**, *28*, 651–665.
29. Kalhor, E.; Valentin, V. Cost estimation framework for optimal retrofit planning to mitigate residential building vulnerability to wildfires. *Journal of Construction Engineering and Management* **2018**, *144*, 05018003.
30. Trakas, D.N.; Hatziargyriou, N.D. Optimal distribution system operation for enhancing resilience against wildfires. *IEEE Transactions on Power Systems* **2017**, *33*, 2260–2271.
31. Zhou, S.; Erdogan, A. A spatial optimization model for resource allocation for wildfire suppression and resident evacuation. *Computers & Industrial Engineering* **2019**, *138*, 106101.
32. Zhou, K.; Zhang, F. An Event-Response Tree-Based Resource Scheduling Method for Wildfire Fighting. *Forests* **2023**, *14*, 102.

33. Bayani, R.; Manshadi, S.D. Resilient Expansion Planning of Electricity Grid under Prolonged Wildfire Risk. *IEEE Transactions on Smart Grid* **2023**.
34. Mohagheghi, S.; Rebennack, S. Optimal resilient power grid operation during the course of a progressing wildfire. *International Journal of Electrical Power & Energy Systems* **2015**, *73*, 843–852.
35. Izadi, M.; Hosseinian, S.H.; Dehghan, S.; Fakharian, A.; Amjady, N. Resiliency-Oriented operation of distribution networks under unexpected wildfires using Multi-Horizon Information-Gap decision theory. *Applied Energy* **2023**, *334*, 120536.
36. Rachaniotis, N.P.; Pappis, C.P. Minimizing the total weighted tardiness in wildfire suppression. *Operational Research* **2011**, *11*, 113–120.
37. Ronchi, E.; Gwynne, S.M.; Rein, G.; Intini, P.; Wadhwani, R. An open multi-physics framework for modelling wildland-urban interface fire evacuations. *Safety science* **2019**, *118*, 868–880.
38. Liberatore, F.; León, J.; Hearne, J.; Vitoriano, B. Fuel management operations planning in fire management: A bilevel optimisation approach. *Safety science* **2021**, *137*, 105181.
39. León, J.; Vitoriano, B.; Hearne, J. A risk-averse solution for the prescribed burning problem. *Safety science* **2023**, *158*, 105951.
40. Flores, I.; Ortuño, M.T.; Tirado, G. A goal programming model for early evacuation of vulnerable people and relief distribution during a wildfire. *Safety science* **2023**, *164*, 106117.
41. Lessan, J.; Kim, A.M. Planning evacuation orders under evacuee compliance uncertainty. *Safety science* **2022**, *156*, 105894.
42. Yazdani, M.; Haghani, M. Hospital evacuation in large-scale disasters using limited aerial transport resources. *Safety science* **2023**, *164*, 106171.
43. Nuraiman, D.; Ozlen, M.; Hearne, J. A spatial decomposition based math-heuristic approach to the asset protection problem. *Operations Research Perspectives* **2020**, *7*, 100141.
44. Pais, C.; Carrasco, J.; Moudio, P.E.; Shen, Z.J.M. Downstream protection value: Detecting critical zones for effective fuel-treatment under wildfire risk. *Computers & Operations Research* **2021**, *131*, 105252.
45. Nuraiman, D.; Ozlen, M.; Hearne, J. A decomposition approach for the stochastic asset protection problem. *Computers & Operations Research* **2022**, *138*, 105591.
46. Murray, A.T.; Church, R.L. Spatial optimization of multiple area land acquisition. *Computers & Operations Research* **2023**, *153*, 106160.
47. Roozbeh, I.; Ozlen, M.; Hearne, J.W. An adaptive large neighbourhood search for asset protection during escaped wildfires. *Computers & Operations Research* **2018**, *97*, 125–134.
48. Stauffer, J.M.; Kumar, S. Impact of incorporating returns into pre-disaster deployments for rapid-onset predictable disasters. *Production and Operations Management* **2021**, *30*, 451–474.
49. Arnette, A.N.; Zobel, C.W. A risk-based approach to improving disaster relief asset pre-positioning. *Production and Operations Management* **2019**, *28*, 457–478.
50. Gupta, S.; Starr, M.K.; Farahani, R.Z.; Matinrad, N. Disaster management from a POM perspective: Mapping a new domain. *Production and Operations Management* **2016**, *25*, 1611–1637.
51. Gnegel, F.; Fügenschuh, A.; Hagel, M.; Leyffer, S.; Stiemer, M. A solution framework for linear PDE-constrained mixed-integer problems. *Mathematical Programming* **2021**, *188*, 695–728.
52. Belval, E.J.; Wei, Y.; Bevers, M. A stochastic mixed integer program to model spatial wildfire behavior and suppression placement decisions with uncertain weather. *Canadian Journal of Forest Research* **2016**, *46*, 234–248.
53. Van Der Merwe, M.; Minas, J.P.; Ozlen, M.; Hearne, J.W. A mixed integer programming approach for asset protection during escaped wildfires. *Canadian Journal of forest research* **2015**, *45*, 444–451.
54. Belval, E.J.; Wei, Y.; Bevers, M. A mixed integer program to model spatial wildfire behavior and suppression placement decisions. *Canadian Journal of Forest Research* **2015**, *45*, 384–393.
55. Lee, Y.; Fried, J.S.; Albers, H.J.; Haight, R.G. Deploying initial attack resources for wildfire suppression: spatial coordination, budget constraints, and capacity constraints. *Canadian Journal of Forest Research* **2013**, *43*, 56–65.
56. Ferreira, L.; Baptista, A.N.; Borges, J.G.; Martins, I.; Marques, S.; Constantino, M. Integrating Wildfire Resistance And Environmental Concerns Into A More Sustainable Forest Ecosystem Management Approach. *Frontiers in Forests and Global Change*, *6*, 1177698.
57. Yemshanov, D.; Dawe, D.A.; Bakalarzcyk, A.; Liu, N.; Boulanger, Y.; Boucher, J.; Beauchemin, A.; Arseneault, D.; Leblond, M.; Parisien, M.A. Balancing Wildlife Protection and Wildfire Threat Mitigation Using A Network Optimization Approach. *Frontiers in Forests and Global Change*, *6*, 1186616.
58. Ntaimo, L.; Arrubla, J.A.G.; Stripling, C.; Young, J.; Spencer, T. A stochastic programming standard response model for wildfire initial attack planning. *Canadian Journal of Forest Research* **2012**, *42*, 987–1001.
59. Heyns, A.M.; du Plessis, W.; Curtin, K.M.; Kosch, M.; Hough, G. Analysis and exploitation of landforms for improved optimisation of camera-based wildfire detection systems. *Fire Technology* **2021**, *57*, 2269–2303.
60. Abdelmalak, M.; Benidris, M. Enhancing power system operational resilience against wildfires. *IEEE Transactions on Industry Applications* **2022**, *58*, 1611–1621.
61. Nazemi, M.; Dehghanian, P.; Alhazmi, M.; Darestani, Y. Resilient operation of electric power distribution grids under progressive wildfires. *IEEE Transactions on Industry Applications* **2022**, *58*, 1632–1643.

62. Hyytiäinen, K.; Haight, R.G. Evaluation of forest management systems under risk of wildfire. *European Journal of Forest Research* **2010**, *129*, 909–919.
63. Elimbi Moudio, P.; Pais, C.; Shen, Z.J.M. Quantifying the impact of ecosystem services for landscape management under wildfire hazard. *Natural Hazards* **2021**, *106*, 531–560.
64. Zeferino, J.A. Optimizing the location of aerial resources to combat wildfires: a case study of Portugal. *Natural Hazards* **2020**, *100*, 1195–1213.
65. Jose, E.; Agarwal, P.; Zhuang, J. A data-driven analysis and optimization of the impact of prescribed fire programs on wildfire risk in different regions of the USA. *Natural Hazards* **2023**, pp. 1–27.
66. Rashidi, E.; Medal, H.; Hoskins, A. An attacker-defender model for analyzing the vulnerability of initial attack in wildfire suppression. *Naval Research Logistics (NRL)* **2018**, *65*, 120–134.
67. Heyns, A.M.; du Plessis, W.; Curtin, K.M.; Kosch, M.; Hough, G. Decision support for the selection of optimal tower site locations for early-warning wildfire detection systems in South Africa. *International Transactions in Operational Research* **2021**, *28*, 2299–2333.
68. Yahiaoui, A.E.; Moukrim, A.; Serairi, M. GRASP-ILS and set cover hybrid heuristic for the synchronized team orienteering problem with time windows. *International Transactions in Operational Research* **2023**, *30*, 946–969.
69. Panadero, J.; Juan, A.A.; Ghorbani, E.; Faulin, J.; Pagès-Bernaus, A. Solving the stochastic team orienteering problem: comparing simheuristics with the sample average approximation method. *International Transactions in Operational Research* **2023**.
70. Demange, M.; Gabrel, V.; Haddad, M.; Murat, C. A robust p-Center problem under pressure to locate shelters in wildfire context. *EURO Journal on Computational Optimization* **2020**, *8*, 103–139.
71. Rashidi, E.; Medal, H.R.; Hoskins, A. Mitigating a pyro-terror attack using fuel treatment. *IISE Transactions* **2018**, *50*, 499–511.
72. Rodríguez-Veiga, J.; Penas, D.R.; González-Rueda, Á.M.; Ginzo-Villamayor, M.J. Application of decomposition techniques in a wildfire suppression optimization model. *Optimization and Engineering* **2023**, pp. 1–36.
73. Donovan, G.H.; Rideout, D.B. An integer programming model to optimize resource allocation for wildfire containment. *Forest Science* **2003**, *49*, 331–335.
74. Ntaimo, L.; Gallego-Arrubla, J.A.; Gan, J.; Stripling, C.; Young, J.; Spencer, T. A simulation and stochastic integer programming approach to wildfire initial attack planning. *Forest Science* **2013**, *59*, 105–117.
75. Rodríguez-Veiga, J.; Gómez-Costa, I.; Ginzo-Villamayor, M.J.; Casas-Méndez, B.; Sáiz-Díaz, J.L. Assignment problems in wildfire suppression: Models for optimization of aerial resource logistics. *Forest Science* **2018**, *64*, 504–514.
76. Armstrong, G.W.; Cumming, S.G. Estimating the cost of land base changes due to wildfire using shadow prices. *Forest Science* **2003**, *49*, 719–730.
77. Wei, Y.; Bevers, M.; Belval, E.; Bird, B. A chance-constrained programming model to allocate wildfire initial attack resources for a fire season. *Forest Science* **2015**, *61*, 278–288.
78. Armstrong, G.W. Sustainability of timber supply considering the risk of wildfire. *Forest Science* **2004**, *50*, 626–639.
79. Ferreira, L.; Constantino, M.F.; Borges, J.G.; Garcia-Gonzalo, J. Addressing wildfire risk in a landscape-level scheduling model: An application in Portugal. *Forest Science* **2015**, *61*, 266–277.
80. Ferreira, L.; Constantino, M.F.; Borges, J.G.; Garcia-Gonzalo, J. A stochastic dynamic programming approach to optimize short-rotation coppice systems management scheduling: an application to eucalypt plantations under wildfire risk in Portugal. *Forest Science* **2012**, *58*, 353–365.
81. Snyder, S.A.; Stockmann, K.D.; Morris, G.E. An optimization modeling approach to awarding large fire support wildfire helicopter contracts from the US Forest Service. *Forest Science* **2012**, *58*, 130–138.
82. Rjoub, D.; Alsharoa, A.; Masadeh, A. Unmanned-Aircraft-System-Assisted Early Wildfire Detection with Air Quality Sensors. *Electronics* **2023**, *12*, 1239.
83. Arca, B.; Ghisu, T.; Trunfio, G.A. GPU-accelerated multi-objective optimization of fuel treatments for mitigating wildfire hazard. *Journal of Computational Science* **2015**, *11*, 258–268.
84. Ansari, B.; Mohagheghi, S. Optimal energy dispatch of the power distribution network during the course of a progressing wildfire. *International Transactions on Electrical Energy Systems* **2015**, *25*, 3422–3438.
85. Minas, J.P.; Hearne, J.W. An optimization model for aggregation of prescribed burn units. *Top* **2016**, *24*, 180–195.
86. Lin, Z.; Liu, H.H. Topology-based distributed optimization for multi-UAV cooperative wildfire monitoring. *Optimal Control Applications and Methods* **2018**, *39*, 1530–1548.
87. Haight, R.G.; Fried, J.S. Deploying wildland fire suppression resources with a scenario-based standard response model. *INFOR: Information Systems and Operational Research* **2007**, *45*, 31–39.
88. Troncoso, J.J.; Weintraub, A.; Martell, D.L. Development of a threat index to manage timber production on flammable forest landscapes subject to spatial harvest constraints. In *Forestry Applications*; Routledge, 2018; pp. 94–113.
89. Hu, X.; Ntaimo, L. Integrated simulation and optimization for wildfire containment. *ACM Transactions on Modeling and Computer Simulation (TOMACS)* **2009**, *19*, 1–29.
90. Petersen, J.E.; Kapur, S.; Gkantonas, S.; Mastorakos, E.; Giusti, A. Modelling and optimisation of extinction actions for wildfire suppression. *Combustion Science and Technology* **2023**, *195*, 3584–3595.
91. Belval, E.J.; Thompson, M.P. A Decision Framework for Evaluating the Rocky Mountain Area Wildfire Dispatching System in Colorado. *Decision Analysis* **2023**.