

# Applications of Operations Research in Wildfire Management: A Systematic Review

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**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

## 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.

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

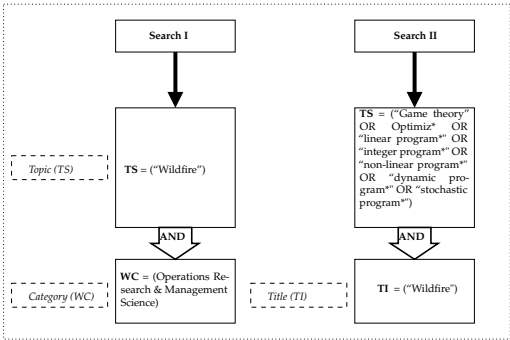


Figure 1. Searching strategy.

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.

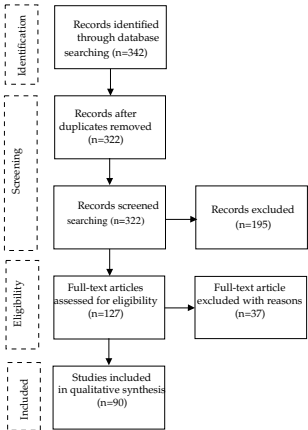


Figure 2. PRISMA flowchart.

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. 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

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	0733-9564	5.1	Q1
[30]	IEEE Transactions on Power Systems	IEEE	0885-8050	6.6	Q1
[31]	Computers & Industrial Engineering	ELSEVIER	0360-8352	7.9	Q1
[32]	Forests	MDPI	1999-4807	2.9	Q1
[33]	IEEE Transactions on Smart Grid	IEEE	1949-8053	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	1109-2658	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 SCL PUB.	0045-5067	2.2	Q2
[56,57]	Frontiers In Forests And Global Change	FRONTIERS	2624-891X	3.2	Q2
[58]	Canadian Journal Of Forest Research	CANADIAN SCL 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	0894-669X	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]	ISE Transactions	TAYLOR & FRANCIS	2472-5854	2.6	Q3
[72]	Optimization and Engineering	SPRINGER	1380-4420	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	1545-8890	1.9	Q4

according to Scimago Journal Country Rank (SJCR) 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.

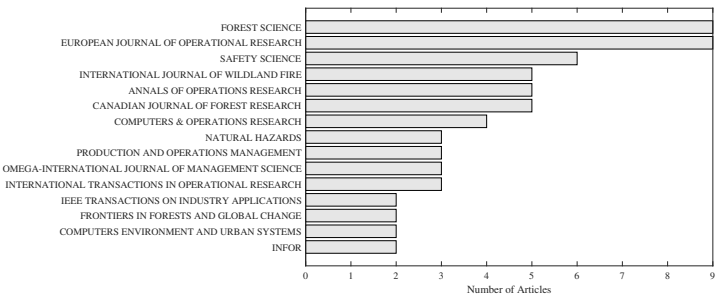


Figure 3. Distribution of articles by contributing journals.

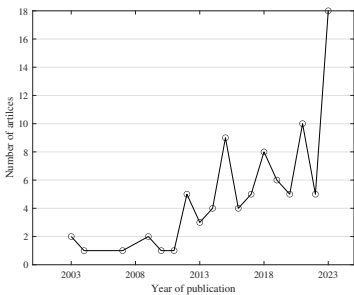
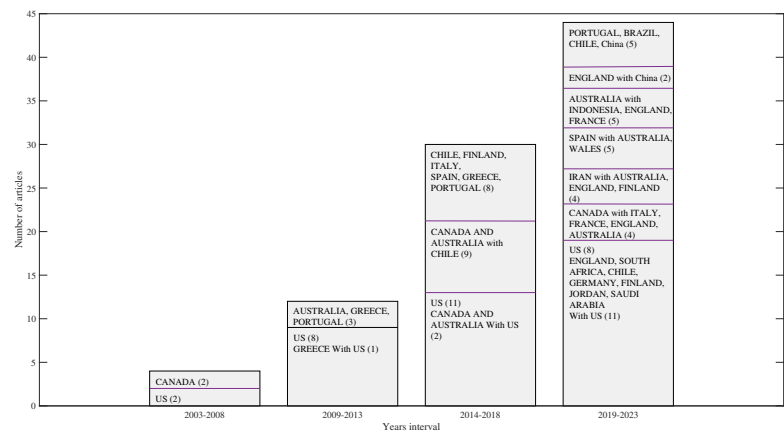


Figure 4. Distribution of articles by years.

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.

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