

Resilience Assessment of Transportation Infrastructure in the Northwest Atlantic Corridor

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This study conducts a resilience assessment of the northwest Atlantic corridor, with a particular focus on the road routes between Porto and Vigo ports. The transportation infrastructure in this region is frequently challenged by natural disruptions, including forest fires which can lead to significant traffic disruptions. The impacts of these disruptions on road networks will be modeled using mesoscopic simulation techniques. This simulation framework evaluates the robustness and adaptive capacity of the transportation routes under the worst disruption scenario. The results highlight key vulnerabilities and potential mitigation strategies, providing insights for enhancing the resilience of the transport infrastructure. This research advances the understanding of disaster management and infrastructure resilience in transnational transportation networks, emphasizing the importance of robust infrastructure planning and resilience assessment in mitigating the impacts of natural disruptions.

Keywords: Resilience, Northwest Atlantic Corridor Transportation, Traffic Disruption, Forest Fire Disasters.

1. Introduction

Wildfires have become an increasingly severe global issue, exacerbated by climate change and global warming. In the European Union alone, wildfires have caused damages exceeding \$60.5 billion over the past two decades and claimed the lives of more than 600 people, including firefighters and civilians (Gonzalez F. 2021). Recent fire events highlight the urgency of addressing this threat, with Europe's 2021 wildfire season being the second worst on record, burning over 0.5 million hectares of land (San-Miguel-Ayaz et al. 2018). Other regions, such as Australia and the United States, have similarly suffered devastating losses, with millions of hectares burned, billions of dollars in damage, and significant human displacement (Wibbenmeyer M et al. 2021). The increasing frequency and severity of these events demand a shift from fire suppression to proactive prevention and preparedness strategies (IPCC. 2022).

Road networks are critical infrastructure within transport systems, vital for economic activity, disaster response, and social stability. However, their spatial distribution makes them particularly vulnerable to climate change-related hazards, including wildfires (Der Sarkissian et al.

2020). Disruptions to major road networks, whether from closures or degraded capacity, can cause cascading effects, such as increased travel times, reduced accessibility, and challenges for emergency response. Therefore, it is essential to integrate wildfire risk considerations into road network planning and management.

This study leverages fire risk maps to identify road segments at the highest risk of wildfire. These maps, overlaid with the major road network, identify critical road sections where disruptions could have the most significant impacts. Roads in the highest risk zones are modeled as fully closed, and traffic simulations are conducted to evaluate the consequences of these closures. This approach focuses on understanding how wildfire risks affect road network performance and identifying strategies to enhance resilience.

While traditional risk-based approaches to infrastructure protection assess the likelihood and potential consequences of specific hazards, resilience-based approaches focus on the system's capacity to adapt and recover from disruptions (Park et al. 2013, Hughes et al. 2014). Both concepts are complementary and crucial for understanding how road networks can prepare for and withstand wildfire-related challenges. In this context, resilience analysis is particularly useful for

addressing the uncertainties associated with fire risk, as it focuses on the broader system capabilities rather than solely on probabilistic hazard assessments.

This paper contributes to the growing body of research on wildfire preparedness by integrating fire risk assessments with road network resilience evaluation. The study provides a novel framework for analyzing the impacts of wildfire, considering its risk of happening on road traffic networks. By focusing on major road networks and simulating their responses to the highest risk scenario, this research supports decision-making processes for wildfire preparedness and long-term infrastructure resilience.

The remainder of this paper is structured as follows: Section 2 provides a review of relevant literature on road network vulnerability and resilience to natural hazards. Section 3 details the methodology, including the study area, data collection, and simulation framework. In Section 4, we present the simulation results, highlighting vulnerabilities and adaptive capacity under disrupted scenario. Section 5 discusses the implications of our findings and proposes potential mitigation strategies. Finally, Section 6 concludes the paper with a summary of findings and suggestions for future research.

2. Literature Review

Risk management has been the traditional approach to protecting infrastructure, but it falls short in addressing modern, unpredictable hazards. Resilience, which complements risk management, focuses on preparing systems to handle unforeseen events effectively. While risk assessment evaluates the likelihood and consequences of identifiable hazards, resilience adopts a broader perspective, emphasizing adaptability across various domains. This shift from risk to resilience leads to better preparedness for unexpected disruptions. In the case of wildfires, particularly extreme ones, resilience-based strategies are more suitable for optimizing road network preparedness (Hughes et al. 2014, Nogal et al. 2018, Park et al. 2013).

Resilience in transportation networks is defined as the system's ability to withstand, adapt, and quickly recover from disruptions (Jardim Gonçalves et al. 2024). Recent frameworks assess resilience by examining both robustness, how much strain a system can endure, and adaptive

capacity, how effectively it adjusts in real time to maintain service. Various methodologies, including mesoscopic and macroscopic traffic models, have been used to analyze resilience in road networks. These models simulate different disruption scenarios and assess how traffic reroutes and redistributes, providing valuable insights into network behavior during crises (Bil et al. 2015). However, there is limited research specifically targeting the resilience of transportation networks to forest fires, particularly in terms of adaptive capacity, which is crucial for handling real-time evacuations and detours.

Mesoscopic simulations, which provide a balance between detail and computational efficiency, could be applied to analyze the potential road closures caused by natural hazards like fire (Shahdani et al. 2022, Shahdani et al. 2021). These models allow for scenario-based assessments to evaluate the resulting impact on traffic flow across alternative routes. For instance, recent studies have used mesoscopic models to assess disruptions, identifying critical bottlenecks and analyzing traffic redistribution patterns when key routes face risks of closure. This approach yields valuable data on which areas of the network are most susceptible to congestion and highlights potential mitigation strategies, such as rerouting plans and capacity adjustments on alternative roads (Shahdani et al. 2021).

In summary, while significant advancements have been made in understanding the resilience of road networks to natural disruptions, research specifically focused on assessing disruption associated with forest fires remains limited. Recent studies underscore the importance of developing resilience strategies that account for the impact of forest fires, which can necessitate proactive measures to maintain safety and minimize disruption for road users (Arango et al. 2023; Li et al. 2020).

3. Methodology

This study uses a simulation-based methodology to evaluate the resilience of transportation infrastructure in the Northwest Atlantic Corridor during forest fire disruptions. Figure 1 illustrates this corridor between the ports of Porto (Portugal) and Vigo (Spain), as well as the fire risk level for each major road in the transportation network within this region.

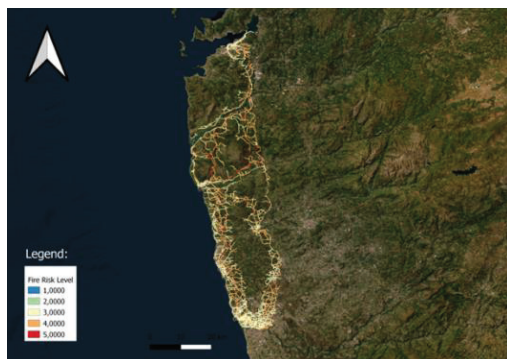


Fig. 1. Fire **risk** level in the major roads of the Northwest Atlantic Corridor

Building on the approach used in previous research on flood impacts in road networks (Shahdani et al. 2022), this methodology is adapted to focus on the resilience of main roads facing potential disruptions due to forest fires.

The mesoscopic simulation approach was selected to model the road networks with sufficient detail to capture traffic flow dynamics while maintaining computational efficiency. The simulation was conducted using SUMO (Simulation of Urban Mobility) which allows for scenario-based assessments of road closures and rerouting. SUMO is an open-source, microscopic, and multimodal traffic simulation tool widely used for transportation research. It supports different levels of simulation granularity, including microscopic (individual vehicle behavior), mesoscopic (aggregated vehicle groups), and macroscopic (flow-based modeling). SUMO implements traffic behavior models such as the Krauss car-following model, lane-changing models, and dynamic route choice algorithms. It requires network topology data, demand data (e.g., OD matrices or route-based assignments), and additional configuration files for traffic control and vehicle characteristics. Due to its flexibility, SUMO is suitable for evaluating traffic flow, transport resilience, and the impact of network disruptions.

3.1. Network Modelling and Data Preparation

The road network for the study area was obtained from Infraestruturas de Portugal (IP), focusing specifically on major roads critical for regional connectivity. Attributes such as road geometry, capacity, and speed limits were incorporated into

the model. As shown in Figure 2, road segments at the highest risk of disruption were identified by overlaying fire risk maps produced by external collaborators with the road network.

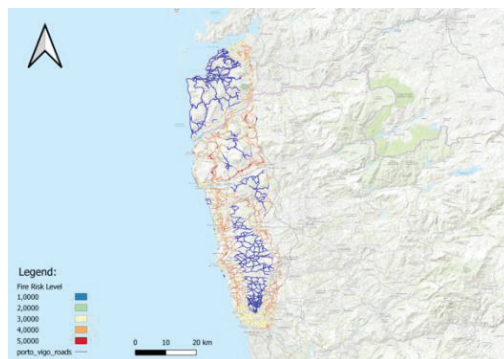


Fig. 2. Overlaying the roadway network and fire risk map

From this overlapping procedure, 21 major roads were assumed to be impassable due to the high fire risk (level 5 of fire risk), as shown in Figure 3. These potentially affected segments were modeled as fully closed during a fire disruption scenario, allowing the simulation to focus on the network's response to potential road closures.



Fig. 3. Closed assets (in red) by fire disruption

The required traffic demand data was obtained from IP to simulate traffic flow. This origin-destination data reflects typical travel patterns in the region. The route assignment process used SUMO's Dynamic User Assignment (DUA) module, which iteratively assigns trips based on the fastest available paths while adjusting to road closures and real-time congestion on alternative routes. This approach more accurately models

realistic rerouting decisions in response to fire risk scenarios, providing a dynamic adjustment to changing conditions.

3.2. Disruption scenario

This study evaluates the resilience of the road network under a single disruption scenario, where segments with the highest fire risk are closed. This approach focuses on understanding the network’s behavior under critical conditions, ensuring targeted analysis of its most vulnerable areas. While multiple scenarios provide a broader perspective, this focused method allows for practical and detailed insights into key vulnerabilities and mitigation strategies. In this single disruption scenario:

- Road Closures: Based on fire risk maps, road segments identified as having the highest fire risk (level 5) are modeled as fully closed.
- Traffic Redistribution: Traffic is dynamically rerouted to alternative paths, allowing the simulation to evaluate the network’s capacity to manage displaced traffic and maintain functionality.
- Key Assumptions: It is assumed that all closed roads are impassable for the entire duration of the simulation and that the remaining network operates under normal conditions.

The resilience of the road network under fire-induced disruptions was evaluated through metrics focused on traffic redistribution, travel time deviation, and connectivity loss. These metrics quantify how traffic is rerouted, highlight key vulnerabilities, and assess impacts on travel efficiency and network accessibility.

Simulation outputs compared baseline and disrupted conditions. Key findings include increased congestion on alternative routes and significant impacts on travel times and connectivity. These results emphasize the importance of interventions to mitigate disruption impacts, such as reinforcing critical links and enhancing alternative routes.

4.Results and Analysis

The results of the simulation provide valuable insights into the network’s behavior under the disruption scenario. Key findings are summarized as follows:

- Traffic Volume Redistribution: Significant traffic was rerouted to alternative roads, leading to speed reduction and congestion in specific areas. These congestion hotspots indicate where the network struggles to handle displaced traffic. Figure 4 illustrates the changes in traffic speed across the network, highlighting congestion hotspots.

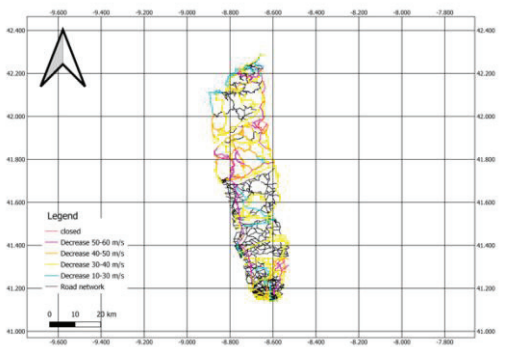


Fig. 4. Speed differences between normal and disrupted networks during a day

- Travel Time Impacts: Average travel times across the network increased notably compared to normal conditions. In some roads, travel times exceeded acceptable limits, highlighting areas requiring intervention. Table 1 compares average travel times in normal and disrupted scenarios.

Table 1. Fire induced changes in travel time.

Travel Time	Normal Network	Disrupted Network
Sum (hours)	6170220	11843120
Absolut difference (hours)	-	5672900
Relative increase (%)	-	66

- Connectivity Loss: The analysis revealed that a portion of origin-destination pairs lost direct connectivity due to road closures. To assess this loss, Dijkstra’s algorithm was used to determine whether alternative routes

Table 2. Fire-induced changes in trips between OD pairs

Affect on OD pairs	Number of affected OD pairs	Percentage of the whole trips
Cancel all trips	9978740	2
With 10 % cancellation	156333583	53
With 20 % cancellation	56546190	37
With 50 % cancellation	26609971	18

existed between OD pairs or if they became completely disconnected. This loss underscores the need for improving redundancy in the network. Table 2 provides visualizations of traffic flow patterns, and congestion hotspots in Figure 4 illustrate the spatial distribution of impacts. These results highlight areas of vulnerability and provide a foundation for resilience strategies. Recommendations based on these findings include optimizing traffic management during disruptions and planning alternative routes to enhance overall network resilience.

5. Discussion

The findings of this study emphasize the importance of resilience planning in transportation networks to mitigate the impacts of fire-induced disruptions. The analysis highlights critical vulnerabilities, including congestion hotspots and connectivity loss, which underline the need for mitigation interventions.

Key recommendations derived from this study include strengthening critical links, enhancing the capacity of alternative routes, and implementing preemptive traffic management strategies. These measures can significantly improve the network's ability to adapt to and recover from disruptions.

The study's reliance on a single disruption scenario provides a focused and practical framework for assessing network resilience. However, it is acknowledged that this approach does not capture the full range of potential impacts under varying fire intensities or scenarios. Future studies may incorporate different mitigation actions to analyze the recovery process and network resilience. Also, multiple disruption

scenarios to provide a more comprehensive assessment would enhance the reliability of results.

Additionally, the results highlight the importance of redundancy and connectivity in ensuring the robustness of road networks. Investing in alternative routes and diversifying traffic flow paths can enhance the overall resilience of transportation infrastructure.

This discussion provides a foundation for policymakers and infrastructure planners to prioritize investments and develop strategies that reduce the vulnerability of road networks to fire-induced disruptions.

6. Conclusion

This study presents a resilience assessment of the transportation network in the Northwest Atlantic Corridor under a forest fire disruption scenario. By focusing on road segments with the highest fire risk, the study offers insights into network vulnerabilities and potential mitigation strategies.

The analysis revealed significant impacts on traffic flow, travel times, and connectivity, emphasizing the need for proactive resilience planning. Strengthening critical links, enhancing alternative routes, and implementing effective traffic management strategies emerged as key recommendations to mitigate disruption impacts.

While this study adopts a single disruption scenario for practical analysis, future research could explore multiple disruption scenarios, including cascading failures and multi-hazard impacts, to provide a more comprehensive assessment of transportation network resilience. Additionally, integrating real-world traffic data for model validation and incorporating adaptive traffic management strategies, such as rerouting algorithms or emergency response plans, could enhance the practical applicability of the findings. Further research could also investigate the influence of long-term mitigation strategies, such as infrastructure reinforcements or alternative route planning, to improve overall network resilience.

In conclusion, this research contributes valuable insights for improving the robustness and adaptability of road networks, supporting efforts to mitigate the impacts of natural disruptions on transportation infrastructure.

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