PI-0334 Determine Major Gaps in Research on Wildfires and Transportation

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Problem Statement

Problem statement provided by the Division of Research, Innovation and System Information.

Wildfires have become an annual threat to California communities, including their transportation assets. To preserve human life during evacuations, these routes and services need to be kept safe and traversable. In addition, automobiles are not a viable option for many people during evacuations and cannot transport large numbers of people, such as the entire population of a town, to safety expediently.

Therefore, work is needed to better incorporate all travel modes, including public transit, rail, and other options, in both urban and rural environments into evacuation planning and coordination. Flexibility and diverse options in emergencies will be critical. There may also be other issues regarding wildfire evacuations as well as opportunities for coordination and operational improvements, but these are unknown.

What is needed is a literature review of current wildfire evacuation research to see where gaps in research on wildfires and transportation exist.

Background

Background provided by the Division of Research, Innovation and System Information.

Caltrans is the owner/operator of the State Highway System (SHS). Caltrans also plans, funds, and develops projects to promote walking, bicycling, and other forms of active transportation. Finally, Caltrans plans and funds the intercity passenger rail system in California as well as the public transportation system. Caltrans is therefore responsible for all modes of transportation statewide.

California experiences multiple major wildfire events annually, which have become more frequent and destructive in recent years, due to more persistent droughts and extreme heat driven by climate change. Climate projections estimate that these wildfire events will become more severe in the future.

To this point, the California Legislature has passed legislation to assess evacuation routes under several emergency scenarios, including wildfires. These are AB 747 (2019) and AB 1409). These bills require local governments to update the safety element of their general plan to take those scenarios into account. Additionally, Caltrans is proactively integrating climate change considerations through the inclusion of climate action in the 2020-24 Strategic Management Plan and the California Transportation Plan 2050. Further, Caltrans continues to work with partner agencies such as CAL FIRE and Cal OES to manage the SHS and other transportation systems and assets to ensure the safety of Californians.

Caltrans Division of Transportation Planning has been spearheading planning for climate change, which has wildfire as a focus. As we can see, wildfire safety and evacuation issues are prominent in several facets of transportation, and more research is necessary to ensure that decision-makers have the best possible wildfire research knowledge.

Keywords

Active Transportation, Australia, Bicycling, Buses, Disaster Planning, Evacuation, Evacuation Routes, Fires, Forrest Fires, Greece, Mass Transit, Planning, Portugal, Rail, Simulation, Spain, Transportation Planning, Transportation System Management.

Resources

The resources consulted: ASCE Library, Dogpile, eScholarship, Google Scholar, RiP (Research in Progress), RosaP, Research Needs Database, Science Direct and TRID.

After the search was completed, results related to wildfires and evacuation plans were narrowed to most relevant specific to evacuation planning, wildfires, and diverse populations. The results are organized under three subcategories and listed chronologically. The search was limited to the most recent five years with several older results relevant to the subcategory included.

Summary of Findings

Most of the literature is concerned with recent large wildfires, evacuation plans, and various models used to model the movement of evacuees. Several studies discuss the factors that evacuees use in deciding to leave based on awareness, preparation, and departure leave time. Lack of awareness or transportation limitations can lead to delays along with complications of evacuating families with children.

Gaps in Findings

Very little research has been done on rail or mass transit options for wildfire evacuation and transportation planning. TCRP Synthesis J-07/Topic SA-61 *State of Practice for Transit Recovery in the Aftermath of Severe Weather events* is a proposed literature search which will review federal and state guidelines, regulations, or requirements for the existence of a recovery plan. It will review industry standards, industry practices, and analysis of recovery plans. The proposed literature search will focus on large and small transit agencies.

There is also very little research done on vulnerable populations. Vulnerable populations are children, elderly adults, lower-socioeconomic persons, and those with disabilities or medical conditions that would make evacuations difficult. One study identified that many vulnerable populations are not in the wildfire urban interface, however, the populations that are in the wildfire urban interface in California need better

identification as recent wildfire deaths have occurred in the 60+ age group, and this age group is growing in California (Rad 2023). Also, none of the studies looked at pet or other domestic animal ownership and how that may factor in evacuation plans by evacuees. Only one of the studies indicated that they have conducted surveys in languages other than English, California is a state with many non-English speakers, so understanding how they evacuate wildfires would be useful to compare with native English speakers.

More study needs to be done on the pre-evacuation factors such as risk assessment, awareness of risk, and the decision-making process to evacuate. Related to this are more studies focusing on the actual behaviors of evacuees on why they chose a specific destination, and mode of travel used (Siam 2022, Wong 2020) and their experience with evacuation traffic along the route they chose. This behavioral data could be combined with the current models to better reflect realistic wildfire evacuation behavior.

Another consideration is the socioeconomics of the area being evacuated. Populations of low economic status may have fewer resources to evacuate and/or recover from wildfires and other natural disasters (Lambrou 2023). Most of the research focuses on modeling an evacuation plan for a specific area without consideration of the socioeconomics of the population being evacuated.

Thus, there are many avenues that could be areas for potential research. DIRSI will have to decide where to invest resources for further investigation.

Next Steps

The literature review will be used to identify gaps in the current research. These gaps are going to be areas of further investigation.

A suggestion is to develop a repeating search such as the National Transportation Library Clearinghouse on [Transportation and Climate Change.](#) The clearinghouse literature search is updated every month and is a way to keep up with the current literature. The Caltrans transportation library can develop a search like this one if there is interest.

Detailed Findings

In 2018 every district office created a climate change assessment report to align with part of the Caltrans mission," to provide a safe and reliable transportation network that serves all the people and respects the environment." These reports are available from Caltrans' 2019 Climate Change Vulnerability Assessments page and the reports feature detailed information on wildfire risk for each district. The *Caltrans Climate Change Statewide Summary Report* updated the information in 2021. These documents are not

included in the current literature listings as the directive was to locate sources outside of Caltrans.

Wildfires and Evacuation Routes

Most of the current evacuation literature from wildfire events is the development of a simulation model and then using a recent fire event of a specific location as a case study to see how well the model performed. The authors of the studies acknowledge that climate change is an issue in our current wildfire environment. The western United States is a focus for wildland urban interface research.

One area of research is traffic congestion during evacuation. One method is to collect data from connected vehicles which provided the geolocation and timestamp and revealed congestion points (Ahmad 2023). GIS is used along with trip simulation models to improve evacuation plans (Grajdura 2021, Louis 2022, Wu 2022, Zhao 2022).

The most common model used in the studies is an agent-based simulation model to incorporate interview subjects to determine the decision-making process to evacuate.

Six studies used a literature review format. Each focused on wildfire urban interface events and identified gaps in research (Beyki 2023, Ciriaco 2022, Grajdura 2021, Katzilieris 2022, Kuligowski 2022, Lambrou 2023). Some of the gaps listed were lack of behavioral data, understanding evacuee behavior, and the challenges of decision-based modeling. One review was on the use of resilience hubs in evacuation plans and the transportation needs of those facilities (Ciriaco 2022). Resilience hubs are located in communities to provide resources. Their locations are often non-profit organizations, schools or libraries. These hubs provide services in emergencies. The study mentioned placing hubs at walkable locations or near major roads or evacuation routes.

Wildfires and Vulnerable Populations

Of particular interest in current research is the decision-making behavior in response to wildfire evacuation. There are many factors that influence evacuation timing, such as presence or absence of children, residents defending their property, and a staged evacuation area.

Stephen D. Wong's dissertation (which he has used for other papers in this literature search) was the only paper on the sharing economy and included interviews with low-income, Spanish-speaking, older and disabled adults. Wang wanted to explore the role of the sharing economy in disasters; the benefits and limitations of public-private partnerships in the sharing economy and the willingness of private parties to participate in vehicle and home sharing. Data was drawn from 24 expert interviews and a survey that was sent to Hurricane Irma survivors. The survey yielded 1,266 responses, 938 completed surveys (74% completion rate) and 645 final responses after intensive data cleaning for analysis (Wong 2020 p. 46). The results demonstrated that each of the three

sharing economy companies Wong studied, Airbnb, Lyft, and Uber, have been involved in natural disasters, and over time each company has developed a more formal procedure and policy for dealing with them. The interviewed experts noted that sharing economy services could be used in wildfires, or small-scale events where it could be beneficial (Wong 2020 p.52)

The Hurricane Irma Survivors had concerns for safety and security about sharing resources in an evacuation. Survey Respondents did not use sharing economy services often and were more willing to share rides than homes although capacity exists in spare beds and vehicles. From this, sharing economy is a part of wildfire evacuations, and it would need to be addressed in current evacuation plans, however most private rideshare vehicles cannot transport large numbers of people at once.

Among the first nations in Canada, three studies were conducted (McGee 2021, Asfaw 2019, Christenson 2019). Each of the studies concluded that a lack of evacuation plans hindered evacuation efforts. Outreach should be done by local communities and the State to assist with developing plans and to follow-up on updates.

For different cultural attitudes toward evacuation, two studies by Vaiciulyte compare the behavior of French and Australians attitudes and priories in evacuating from a wildfire. The results from the surveys demonstrated that the French had more of a preference for a wait and see approach to evacuation compared to the Australians. This study gives additional information in what to consider in evacuation planning.

Research in Progress
The research in progress studies is on various topics, one is on the evacuation of tourist areas in Tennessee, Evacuation behavior and mobility impacts for coastal regions (Florida and California) and studying low economic communities and businesses to rank the importance of resilient transportation infrastructure for Portland, Oregon.

Wildfires and Rail Transportation
There is very little literature on rail transportation and wildfire evacuation. The literature found is on climate change effects and resilience in natural disasters. A search on other modes of transportation did not retrieve any results.

Current Literature
Wildfires and Evacuation Routes
Improving societal resilience through a GIS-based approach to manage road transport networks under wildfire hazards. Erica Arango, Maria Nogal, Hélder S. Sousa, José C. Matos, Mark G. Stewart, *Transportation Engineering,* (2024).
https://doi.org/10.1016/j.treng.2023.100219

This study presents the extension of a GIS-based methodology for fire analysis, providing decision-making support for the implementation of new fire-related policies for road transportation infrastructure. It represents a novel contribution that facilitates the transition towards proactive wildfire policies. To test the framework, the municipality of Pedróg?o Grande located in the Leiria District, Central Region of Portugal, is used as a case study. The use of a GIS framework can be used for reactive and proactive wildfire management. (Modified author abstract)

Evaluating driving behavior patterns during wildfire evacuations in wildland-urban interface zones using connected vehicle data. Salman Ahmed, Hafiz Usman Ahmed, Asad Ali, Xinyi Yang, Ying Huang, Mingwei Guo, et. al. *Fire Safety Journal*, (2024). https://doi.org/10.1016/j.firesaf.2023.104015

The western United States communities in the wildland-urban interface (wui) are at risk for wildfires. This study investigates the driving behavior patterns of individuals using past wildfire events with mandatory evacuation orders in rural and urban areas. The data used was a connected vehicle dataset which provided geolocation and timestamp of hard breaking (HB) and hard acceleration events. From the analysis traffic congestion points and hurried response on evacuation routes were revealed. Four case studies are used in the study Saratoga Springs, UT (Knolls Fire), Grand Lake and Granby, CO (East Troublesome Fire) and Estes Park, CO (Cameron Peak and East Troublesome Fires)

The analysis of traffic data of wildfire evacuation: the case study of the 2020 Glass Fire. Arthur Rohaert, Nima Janfeshanaraghi, Erica Kuligowski, Enrico Ronchi, *Fire Safety Journal*, (2023). https://www.sciencedirect.com/science/article/pii/S0379711223001777?via%3Dihub

This study developed a methodology to extract historical traffic data and used this methodology with a case study

of the 2020 Glass Fire in California. The Traffic Data Analyzer (TDA)tool results showed a reduction in speeds and traffic flows in US 101 during the evacuation scenario compared with the routine scenario. Background traffic had a role in the Glass Fire evacuation compared with other wildfire evacuations, for example, the 2019 Kincade fire.

Evacuation behavior and its mobility impacts in coastal communities from across the nation (Research in Progress) Brian Wolshon, Maritime Transportation Research and Education Center, University of Arkansas. (2023). https://rip.trb.org/view/1740687

Hurricanes in Florida and impending dam failure in California have led to emergency evacuations, this study is to examine the travel flow principles that govern the evacuation process and the impact of mobility on a community for different types of

hazards. This information can be used to better plan for and respond to evacuation events. Florida and California will be contacted for this study. This research will also be useful in developing best practices.

Evacuation simulation under threat of wildfire—an overview of research, development, and knowledge gaps. Shahab Mohammad Beyki, Aldina Santiago, Luis La?n, Hélder David da Silva Craveiro, *Applied Sciences,* (2023*).*
https://doi.org/10.3390/app13179587

This paper is a literature review of past and existing research on wildfires in wildland-urban interfaces (wui) and wildfire evacuation modeling. From analyzing the literature, the authors identified four specific sub-models: pedestrian evacuation modeling (trip generation), pedestrian sheltering(destination), evacuation transportation (mode choice), and traffic modeling (evacuation routes selection). Gaps in the current literature are discussed as potential solutions.

A data-driven approach to improving evacuation time estimates during wildfires for communities with part-time residents in the wildland-urban interface. Dapeng Li, *International Journal of Disaster Risk Reduction* (2022).
https://www.sciencedirect.com/science/article/abs/pii/S2212420922005829?via%3Dihub

This study aims to leverage different types of data, traffic simulation models, and geographic information systems to develop a data-driven wildfire evacuation model to improve evacuation time estimates in resort areas. Specifically, we consider household vehicle ownership data and the occupancy rate of second homes based on a variety of data in model construction. We used the Tahoe Donner neighborhood in Truckee, California in the case study and derived a series of evacuation time estimates. The results indicate that the evacuation time estimates vary significantly with the mean number of vehicles per home and second homes' occupancy rate in resort areas**.**

Agent-based modeling framework for wildfire evacuation in damaged transportation settings. Ji Yun Lee, Fangjiao Ma, Pacific Northwest Transportation, Consortium, & Office of the Assistant Secretary for Research and Technology, (2022).
http://hdl.handle.net/1773/49800

The City of Santa Clarita was affected by the Rye fire, which was used to create an agent-based model framework for wildfire evacuation in damaged transportation settings. The framework includes advanced wildfire hazard modeling and vulnerability to increase the accuracy of wildfire evacuation in damaged transportation settings. An online survey was conducted to collect information on human behaviors on wildfire evacuation which was used to determine the evacuee's decision process in the model.

An interdisciplinary agent-based multimodal wildfire evacuation model: critical decisions and life safety. M. R. K. Siam, Haizhong Wang, Michael K. Lindell, Chen Chen, Eleni I. Vlahogianni, Kay Axhausen, *Transportation Research Part D: Transport and Environment*, (2022).
https://www.sciencedirect.com/science/article/pii/S1361920921004429?via%3Dihub

This study applied an agent-based model to wildfire evacuation in 2018 in Mati, Greece. This model integrated wildlife propagation, population response transportation network, and shelter response. The research objective was to study the effects of wildfire casualties from decisions made about departure time, transportation mode (walking vs. driving), and how fast to travel. Results showed the lack of children, multi-modal transportation, staged evacuation, and increased shelter capacity led to more successful evacuation.

Estimating wildfire evacuation decision and departure timing using large-scale GPS data. X. Zhao, Y., Xu., R., Lovreglio, E. Kuligowski, D. Nilsson, T. J. Cova, *Transportation Research Part D: Transport and Environment,* (2022).
https://www.sciencedirect.com/science/article/pii/S136192092200102X

This study proposes a new methodology to analyze wildfire evacuation by leveraging a large-scale GPS dataset. This methodology includes a proxy-home-location inference algorithm and an evacuation-behavior inference algorithm, to systematically identify different groups of wildfire evacuees (i.e., self-evacuee, shadow evacuee, evacuee under warning, and ordered evacuee). We applied the methodology to the 2019 Kincade Fire in Sonoma County, CA. We found that among all groups of evacuees, self-evacuees and shadow evacuees accounted for more than half of the evacuees during the Kincade Fire. (Author abstract)

Evacuation behavior of affected individuals and households in response to the 2018 Attica wildfires: From empirical data to models. Konstantinos Katzilieris, Eleni I. Vlahogianni, Haizhong Wang, *Safety Science*, (2022).
https://www.sciencedirect.com/science/article/abs/pii/S0925753522001382

This paper surveys the current literature and data collected on evacuation decision-making and behavior during wildland-urban interface fires, identifies research gaps, and develops a plan for future wildland-urban interface fires.
(Contact Library for a copy)

Evacuation route planning for alternative fuel vehicles. D. S. D., Purba, E., Kontou, C., Vogiatzis, *Transportation Research Part C: Emerging Technologies*, (2022).
https://www.sciencedirect.com/science/article/pii/S0968090X22002571?via%3Dihub

This study examines the importance of evacuation plans to incorporate alternative fuel vehicles. The authors formulated and solved a seamless evacuation route plan and

applied the proposed framework to the Sioux Falls transportation network. They discuss in the findings how individual fuel types impact evacuation route plans.

Exploring 'wait and see' responses in French and Australian WUI wildfire emergencies. Sandra Vaiciulyte, Lynn M. Hulse, Edwin R. Galea, Anand Veeraswamy, *Safety Science*, (2022).
 https://www.sciencedirect.com/science/article/abs/pii/S0925753522002053

This study surveyed and systematically compared the responses of residents in French and Australian at-risk regions (N = 450). Those with recent wildfire experience described their actual responses; those lacking experience responded to a hypothetical fire. The results showed regional differences, with participants in France tending to choose to 'wait and see' more often than participants in Australia. (Author abstract) (Contact Library for a copy)

Fast-moving dire wildfire evacuation simulation. Sarah Grajdura, Sachraa Borjigin, Deb Niemeier, *Transportation Research Part D: Transport and Environment*, (2022). https://www.sciencedirect.com/science/article/pii/S1361920922000219

This paper created an agent-based simulation model (ABM) for the 2018 Camp Fire evacuation. They used post-evacuation interviews and decision trees to model movement. The results show that longer evacuation travel times are associated with reduced smartphone use, increased delays in awareness, and reduced vehicle access.

Improving our understanding of fire displacement effects. Sarah Grajdura, Deb Niemeier, National Center for Sustainable Transportation Research Report, (2022). Improving Our Understanding of Fire Evacuation and Displacement Effects (escholarship.org)

This report studies aspects of no-notice evacuation due to the 2018 Camp Fire. The report has three sections. The first section analyses the timing of leaving in a no-notice evacuation event and the messaging that was used in the 2018 Camp Fire to notify people. The second section explains how to simulate a no-notice wildfire evacuation model by creating an agent-based simulation. The final section has 26 interviews that were conducted post-fire in a shelter setting. Some of the findings were longer evacuation travel times, and that the limited vehicles and awareness delays lead to more trapped agents.

Operationalizing resilience practices in transportation infrastructure planning and project development. Amir Esmalian, Faxi Yuan, Akhil Anil Rajput, Hamed Farahmand, Shangjia Dong, Qingchun Li, et. al. *Transportation Research Part D: Transport and Environment*, (2022*)*.
https://www.sciencedirect.com/science/article/pii/S136192092200044X

This paper examines the incorporation of resilience in transportation agencies in Texas. Interviews were used as the method of data collection. The analysis found a gap between resilience research and engineering practice.

Predicting wildfire impacts on mobility using GIS and fire simulation. Joe Louis, Yelda Turkan, Saifaldawlah Al-Hamadani, U.S. Department of Transportation, (2022). http://hdl.handle.net/1773/49488

Oregon is a large timber-producing region that has suffered from major wildfires east of I-5. This project provided a framework to quantify the damage sustained by roadways in terms of the lengths and sections of roadways affected and to identify routes around impacted sections of roadways. A simulation-based methodology was used to model wildfire spread, and geospatial analysis was used to identify roadway sections that would be affected by the fire. This methodology was implemented for a case study of the Archie Creek Fire that occurred in Oregon in 2020. It is expected that this project will help improve the decision-making process by enabling the analysis and estimation of roadway sections and their lengths impacted by wildfires.

Rapid emergency evacuation planning, assessment for tourist attractions, and isolated communities. Lee, Han, Tennessee Department of Transportation, (2022). https://rip.trb.org/View/1743834

This research project is to develop an easy-to-use evacuation tool for tourist locations and isolated communities in Tennessee.

Review of resilience hubs and associated transportation needs. Thayanne G.M. Ciriaco, Stephen D. Wong, *Transportation Research Interdisciplinary Perspectives*, (2022). https://www.sciencedirect.com/science/article/pii/S2590198222001579

This paper discusses resilience hubs and transportation needs by using a literature review. The literature review identified that resilience hubs can be very useful to communities. The gaps in the literature are how people and relief supplies will travel to/from hubs, or potential transportation services that could be offered by hubs.

Wildfire evacuation decision modeling using GPS data. A. Wu, X., Yan, E. Kuligowski, R. Lovreglio, D. Nilsson, T. J. Cova, International *Journal of Disaster Risk Reduction*, (2022). https://www.sciencedirect.com/science/article/abs/pii/S2212420922005921

This study used GPS data generated by mobile devices to model evacuation rates. We are first an overlay of socio-demographic and built environment attributes—aggregated at the census-block-group-level—to the inferred home locations of the mobile device users. We then develop a linear regression model to examine how the socio-demographic and built environment variables affect evacuation rates across census block groups. We apply the GPS data (44.2 million signal records from over 5000

devices) collected during the 2019 Kincade Fire in Sonoma County, California to evaluate the proposed methodology. The results demonstrated the use of GPS data is a complement to existing methods in wildfire evacuation research and new insights to improve evacuation planning. (Modified author abstract)

Understanding California wildfire evacuee behavior and joint choice-making. Stephen D. Wong, Jacquelyn Broader, Joan L. Walker, Susan A. Shaheen, *ITS UC Berkeley*, (2022).
https://escholarship.org/uc/item/4fm7d34j

This study surveyed individuals impacted by the 2017 December Southern California Wildfires (n = 226) and the 2018 Carr Wildfire (n = 284). First, the study developed two latent class choice models (LCCMs) to evaluate the factors that influence the decision to evacuate or stay/defend. The study found an evacuation keen class and an evacuation reluctant class that are influenced differently by mandatory evacuation orders. This nuance is further supported by different membership of people to the classes based on demographics and risk perceptions. Second, the study developed two portfolio choice models (PCMs), which jointly model choice dimensions to assess multi-dimensional evacuation choice. We find several similarities between wildfires including a joint preference for within-county and nighttime evacuations and a joint dislike for within-county and highway evacuations. (Modified author abstract)

2020 Critical Update to Caltrans wildfire vulnerability analysis. James H. Thorne, Ryan M. Boynton, Allan D. Hollander, Jason P. Whitney, Kirsten D. Shapiro, *ITS UC Davis*, (2021),
https://escholarship.org/uc/item/4723h7j8

UC Davis conducted a wildfire vulnerability risk assessment for fuel reduction in Caltrans right-of-way to protect infrastructure and travelers. The project included a peer review of the 2019 GIS study conducted by Caltrans, collecting and assessing available climate change models for California, including future projections, developing a framework for the use of a prioritized segmented model to identify priority areas for fuels and risk reduction and interviews with Caltrans staff on opportunities and obstacles in fuel reduction. This model can be used to prioritize areas and to work with local governments to assist with fuel reduction

Awareness, departure, and preparation time in no-notice wildfire evacuations. Sarah Grajdura, Xiaodong Qian, Deb Niemeier, *Safety Science*, (2021).
https://www.sciencedirect.com/science/article/abs/pii/S092575352100103X

The authors used interview information from Red Cross shelters for evacuees of the 2018 Camp Fire. The paper has a review of the current literature, and how the authors created a model of the awareness time, preparation time, and departure time of evacuees. A discussion of the results explains the implications for wildfire evacuation

planning.
(Contact Library for a copy)

Cross-cultural comparison of behavioral itinerary actions and times in wildfire evacuations. Sandra Vaiciulyte, Lynn M. Hulse, Anand Veeraswamy, Edwin R. Galea. *Safety Science*, (2021).
https://www.sciencedirect.com/science/article/abs/pii/S0925753520305191?dgcid=rss_sd_all

This study presents the first cross-cultural investigation of its kind: survey data (N = 293) from the South of France and Australia were compared. Participants with experience of wildfires and those inexperienced yet residing in at-risk areas answered questions about what they did or would hypothetically do, respectively, and for how long, before commencing evacuation. Results revealed that, across the two regions, the discrete actions comprising behavioral itineraries were similar overall, albeit their priority sometimes differed. (Author abstract) (Contact Library for a copy)

Evacuation decision-making and behavior in wildfires: past research, current challenges, and a future research agenda. Erica Kuligowski, Fire *Safety Journal*, (2021).
https://www.sciencedirect.com/science/article/abs/pii/S0379711220302204

This article is to present the current research in wildfire urban interface fires and to identify current gaps in research.
(Contact Library for a copy)

Evacuating First Nations during wildfires in Canada. Tara K. McGee, *Fire Safety Journal*, (2021).
https://www.sciencedirect.com/science/article/abs/pii/S037971122030182X

Members of the First Nations in Canada are at high risk for wildfires. The First Nations Wildfire Evacuation Partnership has researched to explore the evacuation experiences of seven First Nations in three Canadian provinces. This paper presents findings from research across the seven First Nations. Results show that few participating First Nations had an up-to-date emergency plan tailored to their community, which contributed to challenges during the evacuation. (Author abstract).
(Contact Library for a copy)

Identifying critical corridors during an area-wide disruption by evaluating network bottleneck capacity". Sabrena Jahan Ohi, Amy M.Kim, *International Journal of Disaster Risk Reduction* (2021).
https://www.sciencedirect.com/science/article/abs/pii/S2212420921004489?via%3Dihub.

This paper broadly identifies facilities in Alberta, Canada that are critical to a community's evacuation capability. These are facilities that, if inaccessible or non-operational, could hinder evacuation efficiency. The authors identify the maximum flow or bottleneck capacity between an origin (evacuating community) and destination (host community) using the min-cut max-flow (MCMF) theorem [1] and a grid-based scanning system. Application of this method can help governments determine which facilities require more investment and emergency evacuation studies.
(Contact Library for a copy)

Integrating traffic network analysis and communication network analysis at a regional scale to support more efficient evacuation in response to a wildfire event. Kenichi Soga, Louise Comfort, Bingyu Zhao, Paola Lorusso, Sena Soysal, *ITS UC Berkeley,* (2021). https://escholarship.org/uc/item/1z913878

This study constructed a framework of dynamic models which included fire dynamics, communication processes, and traffic activity. Two communities, Paradise, CA, and Bolinas, CA were chosen to be case studies to demonstrate the application of the framework. The case study simulations identified potential communication and traffic bottlenecks. The framework supports the integration of fire dynamics, communication processes, and traffic simulation into evaluating evacuation performance assessments.

Modelling traffic during Lilac Wildfire evacuation using cellular data. Benjamin Melendez, Sahar Ghanipoor Machiani, Atushi Nara, *Transportation Research Interdisciplinary Perspectives*, (2021).
https://www.sciencedirect.com/science/article/pii/S2590198221000427#:~:text=This%20study%20examines%20how%20cellular,on%20roadways%20by%20cellular%20networks.

This study examines how cellular data can be used to predict vehicular densities on evacuation routes. A mathematical model was developed to aid in the prediction of vehicular densities on evacuation networks. Correction factors were produced to adjust for the overestimation of users on roadways by cellular networks. Extrapolation factors were also developed for the estimation of the number of cellular users based on a single cellphone counts data point. The Lilac Wildfire data in Dec 2017, was used to test and validate the developed model. This methodology may prove useful to transportation planners and emergency managers in planning evacuations in areas not served by a network of traffic sensors. (Author abstract)

Preparing for wildfire evacuation and alternatives: exploring influences on residents' intended evacuation behaviors and mitigations. Amanda M. Stasiewicz, Travis B. Paveglio, International *Journal of Disaster Risk Reduction*, (2021).
https://www.sciencedirect.com/science/article/pii/S2212420921001436?via%3Dihub

This study explored the evacuation intentions among wildland-urban interface residents in Pend Oreille County, Washington. The study explored how fuel reduction efforts,

structure improvements, and active firefighting preparation are different among three categories of evacuation intentions, and the study evaluated if this range of factors correlated with participants' evacuation intentions. Results suggested that a high proportion of residents in the study area intend to stay and defend their property from wildfire, with smaller populations intending to evacuate or shelter in place.

Influence of demand and capacity in transportation simulations of short-notice, distant-tsunami evacuations. N. Wood, K. Henry, J. Peters, *Transportation Research Interdisciplinary Perspectives*, (2020).
https://www.sciencedirect.com/science/article/pii/S2590198220301226#:~:text=Vehicle%20simulation%20can%20describe%20road,on%20resident%20and%20employee%20assumptions.

The authors use the coastal community of Bay Farm Island (City of Alameda, California) and the distant-tsunami threat posed by Aleutian-Alaskan earthquakes as a case study to explore the use of agent-based, transportation simulation to support short-notice, tsunami-evacuation planning. Results demonstrate how vehicle simulation can characterize network performance during a tsunami evacuation in the absence of real-world measurements of vehicle demand and flow. (Modified author abstract)

Measuring transportation network performance during emergency evacuations: a case study of Hurricane Irma and Woolsey Fire. Nikhil Menon, Brian Staes, Robert L. Bertini, Center for Transportation, Equity, Decisions & Dollars, & Office of the Assistant Secretary for Research and, Transportation. (2020)
https://rosap.ntl.bts.gov/view/dot/54690

This project will utilize Big Data to investigate in detail the evacuation operations undertaken during Hurricane Irma in FL (2017) and the Woolsey Fire in CA (2018) to analyze temporal and spatial traffic patterns and assess the performance of the transportation network. An examination of the evacuation traffic patterns, and travel time during said events will serve as an important baseline to benefit emergency planning and management in areas with similar circumstances. This study is timely due to the nature of these natural disasters and their widespread impacts in the states of Florida, and California. (Author Abstract)

A revealed preference methodology to evaluate regret minimization with challenging choice sets: a wildfire evacuation case study. Stephen D. Wong, Caspar G. Chorus, Susan A. Shaheen, Joan L. Walker, *ITS UC Berkeley,* (2020).
https://escholarship.org/uc/item/2k12q9ph

Regret is often experienced for difficult, important, and accountable choices. Consequently, we hypothesize that random regret minimization (RRM) may better describe evacuation behavior than traditional random utility maximization (RUM). However, in many travel-related contexts, such as evacuation departure timing,

specifying choice sets can be challenging due to unknown attribute levels and near-endless alternatives, for example. This has implications, especially for estimating RRM models, which calculate attribute-level regret via pairwise comparison of attributes across all alternatives in the set. While stated preference (SP) surveys solve such choice set problems, revealed preference (RP) surveys collect actual behavior and incorporate situational and personal constraints, which impact rare choice contexts (e.g., evacuations). Consequently, we designed an RP survey for RRM (and RUM) in an evacuation context, which we distributed from March to July 2018 to individuals impacted by the 2017 December Southern California Wildfires (n=226). While we hypothesized that RRM would outperform RUM for evacuation choices, this hypothesis was not supported by our data. We explain how this is partly the result of insufficient attribute-level variation across alternatives, which leads to difficulties in distinguishing non-linear regret from linear utility. (Author abstract)

Review of California wildfire evacuations from 2017 to 2019. Stephen D. Wong, Jacquelyn Broader, Susan A. Shaheen, *ITS UC Berkeley,* (2020).
https://trid.trb.org/view/1707564

To holistically address these challenges and bolster current disaster and evacuation planning, preparedness, and response in California, the authors summarize the evacuations of eleven major wildfires in California between 2017 and 2019 and offer a cross-comparison to highlight key similarities and differences. The authors present results of new empirical data they collected via an online survey of individuals impacted by 1) the 2017 October Northern California Wildfires (n=79), 2) the 2017 December Southern California Wildfires (n=226), and 3) the 2018 Carr Wildfire (n=284). These data reveal the decision-making of individuals in these wildfires including choices related to evacuating or staying, departure timing, route, sheltering, destination, transportation mode, and reentry timing. The authors also present results related to communication and messaging, non-evacuee behavior, and opinion of government response. Using the summarized case studies and empirical evidence, they present a series of recommendations for agencies to prepare for, respond to, and recover from wildfires. (Author abstract)

Vulnerability assessment of Alberta's provincial highway network. Katsuri Mahajan, Amy M. Kim, *Transportation Research Interdisciplinary Perspectives,* (2020).
https://doi.org/10.1016/j.trip.2020.100171.

This article is a case study of Alberta, Canada's transportation network. Alberta, Canada was chosen to study due to remote population centers in areas that are susceptible to wildfires. This paper applied network analysis measures to study the vulnerability to disruption due to wildfires of emergency evacuation and facilities. Findings include evacuation plans that should include existing multimodal infrastructure.

An open multi-physics framework for modeling wildland-urban interface fire evacuations. Enrico Ronchi, Steven M.V. Gwynne, Guillermo Rein, Paolo Intini, Rahul Wadhwani, *Safety Science*, (2019).
https://www.sciencedirect.com/science/article/abs/pii/S0925753518312281?via%3Dihub

This study presents a multi-physics framework for the stimulation of evacuation of wildfire urban interface incidents that includes three main modeling layers: wildfires, pedestrians, and traffic. The framework integrates the three main modeling layers affecting wildfire urban interface fire evacuations and increasing the safety of such evacuations.

Evacuation preparedness and the challenges of emergency evacuation in Indigenous communities in Canada: The case of Sandy Lake First Nation, Northern Ontario. Henok Workeye Asfaw, Sandy Lake First Nation., Tara K. McGee, Amy Cardinal Christianson, International *Journal of Disaster Risk Reduction*, (2019).
https://www.sciencedirect.com/science/article/abs/pii/S2212420918310860

In 2011, the community of Sandy Lake was evacuated due to wildfire. Residents were airlifted to eleven cities and towns in Ontario and Manitoba. This study examined the pre-event preparedness and communication during the event that influenced the evacuation of Sandy Lake First Nation residents. Fifty-six interviews and a focus group were completed with evacuated Sandy Lake residents. The finding was the lack of community preparedness for wildfire was a major problem.
(Contact Library for a copy)

Traffic dynamics during the 2019 Kincade wildfire evacuation. Arthur Rohaert, Erica D. Kuligowski, Adam Ardinge, Jonathan Wahlqvist, Steven M.V. Gwynne, Amanda Kimball, et. al., *Transportation Research Part D: Transport and Environment*. (2019).
https://www.sciencedirect.com/science/article/pii/S136192092300007X

This paper presents key traffic flow data collected during the 2019 Kincade Fire. The data (69 116 data points from 24 locations) have been sourced from the Performance Measurement System of the California Department of Transportation. A set of commonly used models that describe the relationships between speed, flow, and density has been fit to the data and compared to the model from the Highway Capacity Manual. In evacuation scenarios, the vehicle speed is about 3.5 km/h lower in comparison with the speed in routine scenarios, both for low and high traffic density.
(Author Abstract)

Reconstructing an emergency evacuation by round and air: the wildfire in Fort McMurray, Alberta, Canada. M. Woo, K. T. Y. Hui, K. Ren, K. E. Gan, A. Kim,

Transportation Research Record: Journal of the Transportation Research Board, (2017). https://journals.sagepub.com/doi/10.3141/2604-08

Traffic count and flight data were used to assess the characteristics of the evacuation, including estimates of people's movements by vehicle and aircraft. The vehicle counts were compared first with historic values to examine traffic patterns and were then used to create an evacuation response curve, which revealed an expected S-shaped curve and highlighted how quickly the evacuation occurred. Finally, data for people evacuated by aircraft were combined with data for people evacuated by ground vehicle to construct a curve of the cumulative number of evacuees leaving the region. This study identified several key implications for evacuation planning and operations. The decision to evacuate residents to temporary shelters in the north was instrumental in the quick removal of everyone from immediate danger via all possible exits. (Author abstract)

Wildfire evacuation scenario in Colorado: comparison of adapted four-step metropolitan planning organization modeling results and planning process findings with actual experience. Maureen Paz de Araujo, Mary L. Lupa, Craig T. Casper, Bret Waters, *Transportation Research Record: Journal of the Transportation Research Board,* (2014). https://journals.sagepub.com/doi/10.3141/2430-14

This study examines the wildfire evacuation plan developed by the City of Colorado Springs and Pikes Peak Area Council with what happened with the real wildfire evacuation even two years later.

Evacuation transportation modeling: an overview of research, development, and practice. Pamela Murray-Tuite, Brian Wolshon, *Transportation Research Part C: Emerging Technologies,* (2013). https://www.sciencedirect.com/science/article/pii/S0968090X12001386?via%3Dihub

This paper is a review of the current literature on modeling highway-evacuation routes. The review includes the major components of roadway transportation planning and operations, including the current state of modeling in the forecasting of evacuation travel demand, distribution, and assignment of evacuation demand to regional road networks to reach destinations, assignment of evacuees to various modes of transportation, and evaluation and testing of alternative management strategies to increase capacity of evacuation networks or manage demand. (Author Abstract)

Wildfires and Rail

Modeling urban rail transit system resilience under natural disasters: a two-layer network framework based on link flow. Ying Wang, Ou Zhao, Limao Zhang, *Reliability Engineering & System Safety,* (2024).

https://www.sciencedirect.com/science/article/abs/pii/S0951832023005331?dgcid=rss_sd_all

To better understand the system response under service disruption and followed recovery processes, a purely data-driven approach is proposed to model the system's absorptive and adaptive resilience. To do so, the urban rail transit system is modeled as a customized two-layer network to distinguish its infrastructure layer and service layer. A new localized measure, i.e., link flow, is suggested to construct the system functionality in attack-repair scenarios. It is estimated based on recorded smart card data. Applied to the Hangzhou Metro system, service restoration relying on the new metric is 2~3 times faster and more robust (i.e., smaller normalized standard deviation) than that relying on the common metric (i.e., recovery cost) under a portfolio of attacks tested with varying severity. Stably high correlations (i.e., 0.65 to 0.8) are observed between the two sets of rank indices, i.e., of infrastructure topology-based importance and flow-based importance. Furthermore, the system response to attacks with the estimated link flow is consistent with simulated ones with known and exact link flow. (Author abstract) (Contact Library for a copy)

Chapter 5 resilience of rapid transit systems: a practical outlook. Stephen, L., Hughes *Objective Resilience,* (2022).
https://ascelibrary.org/doi/10.1061/9780784415917.ch5

Rapid transit systems (RTS) play a significant role in well-being and overall quality of life, wherever they are located. This chapter discusses the issues that can reduce or enhance RTS resilience objectively, as well as some of the important policies of RTS that can impact their resilience. The different resilience components are presented in the context of the definition of resilience. Case studies of actual hazards are included, along with RTS responses and subsequent recoveries from losses. Some publicly available resilience assessment methods are presented that are specifically focused on RTS. Two objective resilience assessment approaches are detailed for two main components of RTS: mass transit stations and tunnels. A summary of recommended practices that can help enhance RTS resilience is included. (Author abstract)

Assessment of ENSO risks to support transportation resilience. Karl, Kim Rashed Chowdhury, Pradip Pant, Eric Yamashita, Jinwath Ghimire, *Progress in Disaster Science,* (2021).
 https://www.sciencedirect.com/science/article/pii/S2590061721000569

Following a description of ENSO (El Niʔo/La Niʔa Southern Oscillation) climate patterns and hazards (hurricane, rainfall, flooding, drought, wildfires, high winds, and storm surge), the implications for transportation systems (road, rail, transit, auto, pedestrian, and bicycle) are summarized. Based on data from strong El Niʔo years, the impacts on California, Hawaii, and the Pacific Islands are quite different, as are the requirements for

emergency managers, transportation system operators, and planners concerned with mitigation and adaptation. (Author abstract)

Impacts of climate change on operation of the U.S. rail network. Paul, Chinowsky, Jacob Helman, Sahil Gulati, James Neumann, Jeremy Martinich, *Transport Policy*, (2019).
https://www.sciencedirect.com/science/article/pii/S0967070X16308198

In this study, the issue of potential impacts on the rail network is analyzed in terms of the cost of potential increases in delays that will occur due to responses of train network operators to temperature increases. Impacts analyzed using a range of climate models indicate that the rail network may incur an increase in delay-minute costs over typical historic costs of between $25 and $45 billion cumulatively through 2100 under a low greenhouse gas emissions future, and between $35 and $60 billion under a high emission scenario. However, these costs could be reduced by up to an order of magnitude if current sensor technologies are incorporated into tracks, coupled with refinements to current speed reduction policies that better leverage temperature monitoring capabilities. (Author abstract)

Wildfires and Vulnerable Populations

Rapid emergency evacuation planning/assessment for tourist attractions and isolated communities. Ruqing Huang, Lee D., Han, Hairuilong Zhang, Yangsong, Gu, University of Tennessee, (2023).
RES2021-10: Rapid Emergency Evacuation Planning Assessment for Tourist Attractions and Isolated Communities (trb.org)

This study proposed, implemented, tested, and demonstrated an emergency evacuation modeling framework called T-REX, or Tennessee Rapid Evacuation MicroSimulation. Five case studies were conducted for Gatlinburg, Manchester, Downtown Nashville, Lynchburg, and the Wears Valley area of Tennessee.

Social drivers of vulnerability to wildfire disasters: a review of the literature. Nicole Lambrou, Crystal Kolden, Anastasia Loukaitou-Sideris, Erica Anjum, Charisma Acey, *Landscape and Urban Planning,* (2023).
https://www.sciencedirect.com/science/article/pii/S0169204623001160

This study is a literature review on social vulnerability to wildfire by synthesizing factors related to exposure, sensitivity, and adaptive capacity that contribute to a population's or communities' overall vulnerability to wildfires

Social vulnerability of the people exposed to wildfires in U.S. west coast states. Arash Moderesi Rad, John T. Abatzoglou, Erica Fleishman, Miranda H. Mockrin, Radeloff, Volker

C. Radeloff, et. *Science Advances*, (2023).
https://www.science.org/doi/10.1126/sciadv.adh4615

This study used an index from the U.S. Centers for Disease Control and Prevention to assess the social vulnerability of populations exposed to wildfire from 2000–2021 in California, Oregon, and Washington, which accounted for 90% of exposures in the western United States. The number of people exposed to fire from 2000–2010 to 2011–2021 increased substantially, with the largest increase, nearly 250%, for people with high social vulnerability. In Oregon and Washington, a higher percentage of exposed people were highly vulnerable (>40%) than in California (~8%). Increased social vulnerability of populations in burned areas was the primary contributor to increased exposure of the highly vulnerable in California, whereas encroachment of wildfires on vulnerable populations was the primary contributor in Oregon and Washington. (Modified author abstract)

Improving our understanding of fire displacement effects. Sarah Grajdura, Deb Niemeier, ITS UC Davis, (2022).
 https://escholarship.org/uc/item/6h99c6j0

This research report features a literature review on large-scale no-notice and short-notice wildfires, a statistical analysis of the timing of when evacuees become aware of a short-notice wildfire, an agent-based simulation model of the 2018 Camp Fire, and a qualitative analysis of first-person interviews of the evacuee experience.

Integrate socioeconomic vulnerability for resilient transportation infrastructure planning, research in progress. Liming Wang, TREC, Portland State University, (2022).
https://trec.pdx.edu/research/project/1433/Integrate_Socioeconomic_Vulnerability_for_Resilient_Transportation_Infrastructure_Planning

In this research, we will integrate socioeconomic vulnerability indicators into the vulnerability assessment of transportation systems. We will consider both the vulnerabilities of individuals/households (for equality consideration) and community businesses (for economic impact). The research will first review relevant literature, and, based on the literature review, design and test social vulnerability indicators to rank the importance of transportation infrastructure in serving vulnerable populations and businesses. Finally, utilizing data from the Census, Quarterly Census of Employment and Wages (QCEW), we will apply our methodology to evaluate the vulnerabilities of transportation infrastructure in the Portland metropolitan area and combine them with the assessment of the physical vulnerability of the transportation infrastructure. The final products of the research include a project report, data, and working papers on the methodology, as well as a software tool for the integration of socioeconomic vulnerability in resilient transportation infrastructure planning. (Author abstract)

An interdisciplinary agent-based multimodal wildfire evacuation model: critical decisions and life safety. M. R. K., Siam, Haizhong, Wang, Michael K. Lindell, Chen, Chen, Eleni I. Vlahogianni, Kay Axhausen, *Transportation Research Part D: Transport and Environment,* (2022).
https://www.sciencedirect.com/science/article/pii/S1361920921004429

This study created an agent-based model of wildfire evacuation in 2018 in Mati, Greece. The model integrated wildfire prorogation, population response, transportation network, and shelters. The research objective is to investigate the decision-making behavior of evacuees of wildfires, such as departure time, transportation mode, and speed.

Trust and compassion in willingness to share mobility and sheltering resources in evacuations: a case study of the 2017 and 2018 California wildfires. Stephen D. Wong., Joan L. Walker, Susan A. Shaheen, *International Journal of Disaster Risk Reduction*, (2021).
 https://www.sciencedirect.com/science/article/abs/pii/S2212420920314023

This study sent a survey to test the hypothesis that trust and compassion could trigger willingness to share transportation and shelter during an evacuation. A survey was distributed to 2017 Southern California Wildfires and 2018 Carr Wildfire. Results found variables to departure and routing increase transportation sharing willingness.

Can sharing economy platforms increase social equity for vulnerable populations in disaster response and relief? A case study of the 2017 and 2018 California wildfires. Stephen D. Wong, Jacquelyn C. Broader., Susan A., Shaheen, *Transportation Research Interdisciplinary Perspectives, (*2020).
https://www.sciencedirect.com/science/article/pii/S2590198220300427

To explore the social equity implications of the sharing economy in disasters, we conducted four focus groups (n = 37) of vulnerable populations impacted by California wildfires in 2017 or 2018. To structure these data, we employed the **S**patial-**T**emporal **E**conomic **P**hysiological **S**ocial (STEPS) equity framework in an evacuation context. We contribute to the literature by 1) summarizing the focus groups and their opinions on the sharing economy in evacuations; 2) capturing wildfire evacuation obstacles through the STEPS transportation equity framework, and 3) linking STEPS and focus group results to exploring the future potential of shared resources. Using STEPS, we also expand our shared resource exploration to 18 vulnerable groups.

We found that all focus groups were highly concerned with driver availability and reliability and the ability of vehicles to reach evacuation zones, not necessarily safety and security. Each group also expressed specific limitations related to their vulnerability. (Author abstract)

Compliance, congestion, and social equity: tackling critical evacuation challenges through the sharing economy, joint choice modeling, and regret minimization. Stephen D. Wong, Dissertation, UC Berkeley. (2020).
https://escholarship.org/uc/item/9b51w7h6

This dissertation discusses three research areas: the role of the sharing economy in disasters, and its use by vulnerable groups, the use of choice modeling in wildfire evacuations, and contributing to the empirical data by sending surveys to the following disaster survivors: Hurricane Irma, 2017 December Southern California Wildfires, and the Carr fire. Four focus groups were held with low-income, Spanish-speaking, older, and disabled adults impacted by wildfires in 2017-2018.

Current state of the sharing economy and evacuations: lessons from California. Stephen D. Wong, Susan A. Shaheen, ITS UC Berkeley, (2020).
https://escholarship.org/uc/item/16s8d37x

In many evacuations including wildfire evacuations, public agencies often do not have enough resources to evacuate and shelter all citizens. Consequently, we propose that the sharing economy, through private companies and/or private citizens, could be leveraged in disasters for transportation and shelter resources. To assess this feasibility, we distributed surveys to individuals impacted by three major wildfires in California: 1) the 2017 October Northern California Wildfires (n=79), 2) the 2017 December Southern California Wildfires (n=226), and 3) the 2018 Carr Wildfire (n=284). Using these data, we find that private citizens are moderate to highly likely to share transportation and sheltering resources in future disasters, but numerous reservations persist about sharing. We also find significant spare capacity in evacuating vehicles and potential homes. To supplement this work, we also conducted four focus groups (n=37) of vulnerable populations to determine the benefits and limitations of a sharing economy strategy in terms of equity. Groups included low-income (2017 December Southern California Wildfires), older adults (2017 October Northern California Wildfires), individuals with disabilities (2017 October Northern California Wildfires), and Spanish-speaking (2018 Mendocino Complex Wildfire). We find that while severe equity limitations exist, groups were able to develop several recommendations for successfully leveraging sharing economy resources for the general population and their specific vulnerable group. We conclude with several local agency and statewide recommendations for building a sharing economy framework for California to prepare for future evacuations. (Author abstract)

Vulnerability assessment of Alberta's provincial highway network. Kasturi Mahajan, Amy M., Kim, *Transportation Research Interdisciplinary Perspectives*, (2020).
https://www.sciencedirect.com/science/article/pii/S2590198220300828

This paper is a case study of the application of several underlined network analysis measures (related to network topology, community accessibility, and transportation facility characteristics) to this wildfire-prone region, to better understand the region's vulnerability in the face of emergency evacuation and facility disruption. Our results show communities in the Regional Municipality of Wood Buffalo are highly vulnerable to facility disruptions while accessibility to major centers during evacuation is relatively low. Our results also determine critical communities concerning network vulnerability and locations for interim emergency supplies. Despite the concentrated populations supporting oil and gas extraction, historical indigenous communities, and the growing prevalence of wildfires and evacuations, justification of transportation infrastructure investments is difficult in this remote area. (Author abstract)

After the fire: vulnerable communities respond and rebuild. Ryan Richards, Center for American Progress, (2019). https://www.americanprogress.org/article/fire-vulnerable-communities-respond-rebuild/

This report discusses the aftermath and recovery of the Camp Fire. The author proposes a targeted universal framework, by establishing a universal goal, then assessing the performance against the goal, determining who will need transportation assistance, assessing the structural issues that cause the gaps, and then using a targeted solution to close the gap. Policy suggestions are given and discussed at the end of the report.

Implications of the California wildfires for health, communities, and preparedness: proceedings of a workshop. Steve Olson, National Academies Press, (2019). https://www.nationalacademies.org/our-work/implications-of-the-california-wildfires-for-health-communities-and-preparedness-a-workshop

Chapter 3 discusses populations impacted by wildfires, including vulnerable populations.

Wildfire evacuation experiences of band members of Whitefish Lake First Nation 459, Alberta, Canada. Amy Cardinal Christianson, Tara K. McGee, Whitefish Lake First, Nation, *Natural Hazards.* (2019). https://doi.org/10.1007/s11069-018-3556-9 (Contact Library for a copy)

This paper presents the results of a study that examined how a mandatory wildfire evacuation affected members of Whitefish Lake First Nation 459, in Alberta, Canada. A qualitative case study approach was used, and semi-structured interviews were completed with 45 band members to learn about their evacuation experiences during the wildfire evacuation in May 2011 and explore the factors that complicated the evacuation process and put further strain on the evacuees and First Nation. (Author abstract)

An emergency evacuation planning model for special needs populations using public transit systems. Evangelous I Kaiser, Linda Hess, Alicia Benazir Portal Palomo, *Journal of Public Transportation*, (2012).
https://www.sciencedirect.com/science/article/pii/S1077291X22007457

For this study, special needs populations will include, but are not limited to, people with physical disabilities, older adults, non-English-speaking populations, residents and employees without vehicles, and tourists. The main objective of this study was to evaluate different evacuation procedures for special needs populations from large urban areas using current public transit systems. A microscopic simulation model was constructed to analyze real-life scenarios for evaluation methodologies. A linear programming optimization model was developed to find the optimum locations for evacuation bus stops for the case study area. The results from this study are very interesting and can aid evacuation planners in the future. (Author abstract)