Incorporating Wildfire Evacuees’ Behavioural Inputs to Agent-Based Evacuation Simulation in Small Canadian Communities

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1. Context and Motivation

Wildfires can rapidly escalate into emergencies, necessitating evacuation in cases where they breach the wildland-urban interface and spread into communities. Understanding potential evacuation behaviours and traffic operations is essential to developing good community wildfire evacuation strategies. Wildfire evacuation movements differ entirely from “regular” daily traffic patterns in major urban areas, which are modeled using long-established travel demand forecasting models. We typically focus on one key trip for wildfire evacuations: departing from an origin, usually the home, to reach an evacuation destination of safety. This movement is motivated and influenced by largely different factors compared to daily travel. It also differs from other types of long-notice evacuations cause by, for example, hurricanes, as wildfire evacuations typically occur with short- or even no-notice. The unpredictability and urgency of such events make wildfire evacuation outcomes highly dependent on individual decisions, further emphasizing the need to incorporate behavioral factors into wildfire evacuation models (Grajdura et al., 2022; Lovreglio et al., 2019, 2020; Nguyen et al., 2019; Zhao & Wong, 2021). However, it can be argued that the decisions to depart, when, and to where are the most fundamental outcomes to know for such short-notice evacuations.

Agent-based models (ABM) have emerged as a valuable tool in modelling evacuations because of the importance of representing individual behavior. Microsimulation models use predetermined rules to load vehicles to the network, while ABM allows for the user to model individual decisions. Each agent in an ABM can adjust their plan dynamically based on their unique attributes, unique planning scheme, and real-time traffic conditions. They enable the representation of diverse decision-making processes, capturing the complex interplay of individual and collective behaviors that drive large-scale human movements during wildfire evacuations. (Durst et al., 2014; Kim et al., 2017; Yuan et al., 2017). Despite this interest, research has yet to systematically and transparently integrate behavioural data (intended or stated) into agent-based models for wildfire evacuations. Current modelling approaches tend to be assumption-heavy when assigning behaviours and actions to agents, not relying on empirical evidence. Consequently, this study focuses on answering the following research question: *How can wildfire evacuation simulation modeling be enhanced by incorporating behavioral inputs derived from survey data on evacuees’ intentions?*

To answer this question, we investigate how behavioral inputs derived from stated preference survey data can be integrated into an evacuation simulation model. Specifically, we use agent-based simulation models of evacuation, which capture each evacuee’s individual decision-making attributes, such as departure time. We use large-sample survey data collected from five communities across British Columbia and Alberta, with Census 2021 population data, to simulate wildfire evacuation movements in two small Canadian communities: Canmore in Alberta, and Salmon Arm in British Columbia, each modeled under its prominent wildfire scenario using the open-source MATSim (Multi-Agent Transport Simulation) platform.

By analyzing the simulation results, we can then assess traffic conditions and examine how transportation network performance is influenced by both evacuees' choices and control measures implemented during wildfire-induced evacuations. The findings from this study will assist communities understand where infrastructure needs more attention in case of evacuation, how it would inform traffic operations and management strategies to optimize the evacuation movements which can be helpful in developing emergency management plans, ensuring communities are better prepared in case of an evacuation.

Data and Methods

A large-sample stated preference survey was conducted with residents of fire-prone communities in Alberta and British Columbia. These surveys, distributed through Qualtrics, gathered information on respondents' past experiences with wildfires, their evacuation intentions in the event of an evacuation—including destination choice, estimated departure time, number of vehicles used, and navigation preferences—as well as demographic details and other related factors (Zehra, S.N. (in press)).

The survey data was collected from two main sources: (1) a panel dataset obtained through the Qualtrics platform, which includes responses from 1,371 residents of Alberta and British Columbia, and (2) a convenience dataset (n=1456) specifically gathered from the five communities studied in this research. Since both datasets contained similar questions, a third combined dataset was created by merging them while excluding any questions missing from either source. Table 1 summarizes the key statistics of these datasets. The details of the survey and results are documented in (Zehra, S.N. (in press)).

Table 1: Survey datasets statistics

Dataset name	Number of samples	Description
Panel dataset (1)	1371	Collected from respondents across Alberta and British Columbia. All respondents self-reported that there was high or very high potential of a wildfire reaching their residence
Convenience sample (2)	Canmore: 563, Salmon Arm: 322, Quesnel: 187, Nelson: 235, Whitecourt: 149	Collected specifically from the 5 communities of this study through community-based outreach mechanisms
Combined (1)+(2)	2827	Combination of the two above datasets, excluding questions missing from either dataset

Previous wildfire evacuation behavior research identifies evacuee departure time as a key factor to consider for evacuation modelling and evacuation time estimates (Grajdura et al., 2022; Zhao & Wong, 2021). Thus, we focus on departure time, which we define as the respondents' expected time of departing their home after deciding and preparing to evacuate. Based on this definition, the starting point of evacuees' departure times in our simulation is marked by the first individual's decision to evacuate, which may occur either before or after an official evacuation notice. We examined a wide range of survey variables – including demographic variables, risk perceptions, and hazard experience – to identify those that were most influential on evacuee departure time. We applied both Ordinary Least Squares (OLS) and Generalized Linear Model (GLM) regression analyses, since OLS assumes that the residuals are normally distributed with a mean of zero and constant variance while GLM does not require this condition.

After extracting departure times defined by statistically significant parameters, we fitted several statistical distributions—namely, Weibull, Gaussian, Rayleigh, Log-Normal, and Log-Logistic—to our departure times. These distributions have been previously used to model evacuation departure curves (Borody and Wong, 2025; Helbing et al., 2000; Pel et al., 2012). This approach enables us to identify the underlying statistical distribution of our departure curves. Next, we extracted the distribution of the number of vehicles that each household would use during an evacuation from the convenience survey dataset specific to each community. This allowed us to convert Census population data into vehicles (agents) for our simulation.

2. Results

Out of all potential impacting factors on departure times, only prior direct experience with wildfires and the presence of at least one child in the household emerged as statistically significant determinants of departure time. Factors including car ownership, type of residence, income, household size, and the presence of older adults did not appear to have a statistically significant impact. The OLS and GLM regression results showed that although neither model demonstrated an ideal overall fit, they proved useful in identifying statistically significant parameters. These findings were consistent across all survey datasets listed in Table 1. As a result, evacuees were categorized into four groups based on two factors: previous direct experience with wildfires—defined here as selecting at least one of the following survey options: "My job is related to wildfires," "Had personal property destroyed or damaged due to a wildfire," "Been evacuated from my house due to a wildfire," or "Been injured as a result of a wildfire"—and the presence of at least one child in the household. Our analysis showed that the departure curves extracted for each community using the convenience dataset were very similar to one another.

Next, we fitted statistical distributions, with the Log-Normal distribution yielding the best fit with the highest log-likelihood values and lowest Residual Sum of Squares (RSS) error. The results of the four fitted curves (Table 2) indicate that evacuees with *no previous experience* and *no children in their household* had the highest mean and thus overall slowest departure times. Respondents *with children in their household* and *previous direct experience with wildfires* had the fastest departure times (smallest mean); evacuees with either a child or previous wildfire experience had expected departure times between these two.

Table 2: Parameters of fitted Log-Normal curves for each binned population's departure times

Departure curve	Log-normal Mean (μ, minutes)	Log-Normal Standard Deviation (σ)	Residual Sum of Squares (RSS)
No Experience, No Child	62.27	0.77	19,225
Has Experience, No Child	55.94	0.76	5,164
No Experience, Has Child	57.05	0.76	8,686
Has Experience and Child	39.22	0.66	103,17

Table 3 shows the distribution of vehicles per household used for evacuation, calculated from the convenience survey dataset's evacuees with prior direct wildfire experience in each community.

Table 3: Percentage of respondents with prior direct experience with wildfire events and the distribution of the number of vehicles taken in evacuation for each household across the communities

Town	Previous direct wildfire experience	1 vehicle	2 vehicles	3+ vehicles	Sample Size
Canmore	15.45%	66.26%	30.49%	3.25%	563
Salmon Arm	36.64%	51.15%	47.33%	1.52%	322
Quesnel	29.11%	51.90%	39.24%	8.86%	187
Nelson	29.36%	64.22%	28.44%	7.34%	235
Whitecourt	39.44%	47.89%	39.44%	12.67%	149

Using the extracted behavioral information, we conducted simulations for Canmore and Salmon Arm. We used 2021 Census population data to represent evacuation demand and added background traffic to represent internal trips prior to community egress. The behavior-informed simulations produced some insights for evacuation planning, infrastructure development, and emergency management. Key outcomes include the following. In the Canmore simulations, favoring major movements at signalized intersections led to reduced congestion on major movements, creating more localized congestion but leading to improved network-wide performance. In the Salmon Arm simulations, residents could evacuate both eastbound and westbound on Highway 1; improved outcomes were achieved when evacuees would leave by splitting evenly in both directions, which have similar capacities. When 80% are assigned westbound towards Kamloops while the remaining 20% eastbound towards Revelstoke, we observe significantly more delays, exacerbated by the fact that Salmon Arm lies south of Highway 1 and thus westbound evacuees must turn left. When MATSim is allowed to determine an optimal vehicle split, it splits evacuees approximately 50/50 westbound and eastbound, indicating the following. First, flexibility in destination and therefore, routing, may have benefits, while second, direction should be considered when locating evacuee reception centres.

3. Conclusion and Discussion

In this study, we integrated behavioral inputs from surveys into the MATSim agent-based framework to simulate short-notice wildfire evacuation. Our approach followed these key steps:

- We used stated preference surveys administered across fire-prone communities in British Columbia and Alberta, capturing evacuees' intended behaviors such as departure times, destination choices, vehicle usage, and demographics. The combined sample had 2,827 respondents.
- We applied regression analyses to identify significant determinants of departure times, particularly focusing on prior wildfire experience and the presence of children in households.
- The log-normal distribution was found to be the best fit to the departure curves from the survey data.
- Census population figures were converted into vehicle counts for simulation using survey-derived data on the number of vehicles per household.
- We conducted simulations for Canmore and Salmon Arm using multiple scenarios (including sensitivity testing) to assess traffic conditions and performance.

Of many assumptions and limitations due to limited data, they included the following: 1) our simulations only included evacuees that were residents counted in the 2021 Census (and not tourists and visitors, which can number significantly in both communities simulated), 2) the proportion of households with prior wildfire experience was the same as the proportion of evacuees with this attribute, 3) while the proportions of households with previous wildfire experience and children were derived from the survey and Census, these attributes were randomly assigned to households, 4) although many households tow recreational boats, animal transport equipment, etc. these larger vehicle lengths were not captured, and 5) the simulation was limited to a 15 km Euclidean distance from each community's centre. However, our work suggests that incorporating behavioural data into evacuation simulation models can be a step towards improving these models, and guide improvements to infrastructure, operations, and emergency management.

4. References

Borody, I. & Wong, S.D. (2025). Evacuation and Reentry Curves for Wildfire Evacuations Using Network Mobility Data. Transportation Research Record. Accepted February 20, 2025

Durst, D., Lämmel, G., & Klüpfel, H. (2014). Large-Scale Multi-modal Evacuation Analysis with an Application to Hamburg. In U. Weidmann, U. Kirsch, & M. Schreckenberg (Eds.), *Pedestrian and Evacuation Dynamics 2012* (pp. 361–369). Springer International Publishing. https://doi.org/10.1007/978-3-319-02447-9_30

Grajdura, S., Borjigin, S., & Niemeier, D. (2022). Fast-moving dire wildfire evacuation simulation. *Transportation Research Part D: Transport and Environment*, *104*, 103190. https://doi.org/10.1016/j.trd.2022.103190

Helbing, D., Farkas, I., & Vicsek, T. (2000). Simulating dynamical features of escape panic. *Nature*, *407*(6803), 487–490. https://doi.org/10.1038/35035023

Kim, J., Lee, S., & Lee, S. (2017). An evacuation route choice model based on multi-agent simulation in order to prepare Tsunami disasters. *Transportmetrica B: Transport Dynamics*, *5*(4), 385–401. https://doi.org/10.1080/21680566.2016.1147002

Lovreglio, R., Kuligowski, E., Gwynne, S., & Strahan, K. (2019). A modelling framework for householder decision-making for wildfire emergencies. *International Journal of Disaster Risk Reduction*, *41*, 101274. https://doi.org/10.1016/j.ijdrr.2019.101274

Lovreglio, R., Kuligowski, E., Walpole, E., Link, E., & Gwynne, S. (2020). Calibrating the Wildfire Decision Model using hybrid choice modelling. *International Journal of Disaster Risk Reduction*, *50*, 101770. https://doi.org/10.1016/j.ijdrr.2020.101770

Nguyen, C., Schlesinger, K. J., Han, F., Gür, I., & Carlson, J. M. (2019). Modeling Individual and Group Evacuation Decisions During Wildfires. *Fire Technology*, *55*(2), 517–545. https://doi.org/10.1007/s10694-018-0770-7

Pel, A. J., Bliemer, M. C. J., & Hoogendoorn, S. P. (2012). A review on travel behaviour modelling in dynamic traffic simulation models for evacuations. *Transportation*, *39*(1), 97–123. Scopus. https://doi.org/10.1007/s11116-011-9320-6

Yuan, S., Chun, S. A., Spinelli, B., Liu, Y., Zhang, H., & Adam, N. R. (2017). Traffic evacuation simulation based on multi-level driving decision model. *Transportation Research Part C: Emerging Technologies*, *78*, 129–149. https://doi.org/10.1016/j.trc.2017.03.001

Zehra, S. N. (in press). *Exploring heterogeneity in wildfire evacuation choices for holistic evacuation planning [Unpublished master's thesis]. University of Alberta*.

Zhao, B., & Wong, S. D. (2021). *Developing Transportation Response Strategies for Wildfire Evacuations via an Empirically Supported Traffic Simulation of Berkeley, California*. https://doi.org/10.1177/03611981211030271