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Wildfire Evacuation Insights from GPS Data: Contrasting Tantallon and Jasper, Canada

Apratim Sen [a]*, Max Kinateder [b], Noureddine Bénichou [c], Jeong Woo Kim [d], Xin Wang [e]

[a] *University of Calgary, apratim.sen@ucalgary.ca*
[b] *National Research Council Canada, Max.Kinateder@nrc-cnrc.gc.ca*
[c] *National Research Council Canada, noureddine.benichou@nrc-cnrc.gc.ca*
[d] *University of Calgary, jw.kim@ucalgary.ca*
[e] *University of Calgary, xcwang@ucalgary.ca*
* Corresponding author

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Abstract: Wildfires pose significant threats to communities, and understanding evacuation dynamics is critical for improving emergency preparedness. GPS data offer a reliable and scalable tool for analyzing evacuation, with insights into spatial patterns, route preferences, and regional differences. This study examines GPS records during the wildfires in Upper Tantallon, Nova Scotia (2023), and Jasper, Alberta (2024) and explores evacuation patterns and road usage. The analysis focuses on key highways and towns impacted by the wildfires, highlighting evacuation timelines and the distance traveled. In Upper Tantallon, a significant decline in GPS device activity was observed, reflecting a reduction in population. In contrast, Jasper showed a highly erratic GPS device activity and the evacuees also traveled longer distances on average. The research underscores the differences in wildfire evacuation behavior between the two regions.

1. Introduction and motivation

Wildfires are becoming more frequent and intense (Christianson et al. (2024)) due to climate change and pose serious threats (Jain et al. (2024)) to human safety, infrastructure, and ecosystems (Erni et al. (2024)). Wildfire evacuation travel patterns remain a focus of interest, given that evacuees can face challenges such as unclear evacuation routes, traffic congestion, and limited time to react to the fire (Kuligowski (2021)).

GPS technology has become a vital tool for analyzing evacuation dynamics, enabling real-time routing and traffic optimization. GPS data is scalable and allows for in-depth analysis for various scenarios; for example, by mapping movements and identifying bottlenecks, GPS data can support faster evacuations by identifying traffic congestion in the route (D'Andrea and Marcelloni (2017)). In addition, carbon emissions associated with prolonged traffic delays, can be minimized as well. By leveraging GPS data, this study aims to provide insights into evacuee movements and evacuation decision-making in Canada.

In recent years, GPS-based evacuation research has advanced significantly, offering new insights into evacuee behavior, route selection, and traffic dynamics during wildfire events. For example, Zhao et al. (2022) used large-scale GPS datasets to categorize evacuees into groups such as self-evacuees, shadow evacuees, and ordered evacuees. These studies found that self-evacuees and shadow evacuees often account for the majority of movements, underlining the need for flexible evacuation planning. Cova et al. (2024) focused on the destination of the evacuees during the same evacuation and found an unexpected diversity of destination with different travel distances. Traffic modeling studies of the 2020 Glass Fire demonstrated the role of background traffic and the importance of real-time traffic data in understanding evacuation scenarios (Rohaert et al. (2023)). Melendez et al. (2021) used location data produced by cellphone users to study and predict vehicular densities on evacuation routes, using data from Lilac (California, USA) wildfire in 2017.

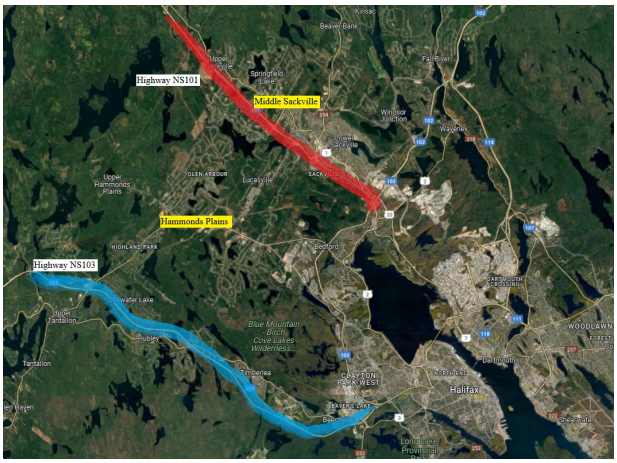

Figure 1. Satellite image of Halifax region with the highways and towns.

Much of prior research has focused on the western United States, with fewer studies addressing incidents in Canada. Population density, and therefore, urban region density in Canada is significantly lower compared to the United States, requiring new analysis to understand wildfire evacuation in the Canadian context. One study conducted by Raei et al. (2025) utilized GPS data for spatial and temporal modeling of evacuation behavior and traffic prediction during the evacuation from Lytton, British Columbia in 2021. However, limitations in data coverage, particularly in rural ar-

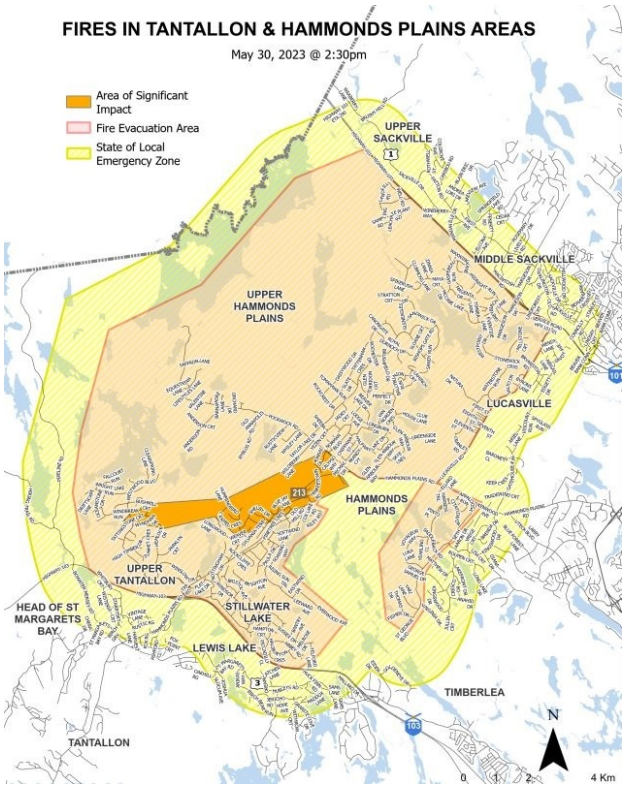

Figure 2. Map of the fire spread in Upper Tantallon, Nova Scotia, recorded on 30th May 2023. (Source: Halifax Regional Municipality)

eas, remain a challenge.

The present contribution focuses on the evacuation pattern caused by the wildfires in two Canadian areas using GPS data; Upper Tantallon, a suburban community outside Halifax, Nova Scotia, and the town of Jasper, Alberta, a major tourist region. Specifically, the main objectives were to understand spatial evacuation patterns in each region, examine differences in distance traveled, highway usage and evacuation routes between suburban and tourist settings, and identify factors influencing evacuation behavior, such as proximity to highways and communities, and wildfire spread. While Western Canada has experienced frequent large scale evacuations due to wildfires, this is still a relatively rare in Eastern Canada. The two sites were chosen to compare an East Canadian community with a stable suburban population to an isolated West Canadian community characterized by a more transient population.

2. Study Areas

2.1 Tantallon: Geography and 2023 Wildfires

Tantallon community lies in the Halifax Regional Municipality in Nova Scotia, about 32 kilometers from Halifax. It is located on the outskirts of the Halifax suburbs, with Upper Tantallon on the north and Glen Haven on the south of the community. This region, comprising Tantallon and neighborhoods, has a combined population of around 12 thousand people. The region is well-connected to Halifax (the capital of Nova Scotia) through several major highways, including Highway 101, 102, and 103.

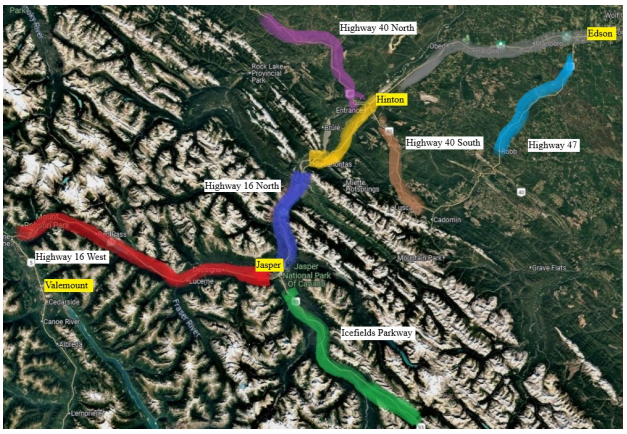

Figure 3. Satellite image of Jasper with the roads and towns.

On May 28, 2023, a wildfire ignited in the Upper Tantallon and Hammonds Plains communities. Spanning more than 900 hectares, this wildfire became the municipality's most extensive wildland urban interface (WUI) fire, displacing over 16,000 residents and destroying approximately 200 structures, including 151 homes. The spread of this fire is shown in Figure 2. (Source: Moving forward from the 2023 wildfires in the Halifax Regional Municipality - Halifax Emergency Management (2023))

2.2 Jasper: Geography and 2024 Wildfires

Jasper is a specialized municipality in western Alberta, Canada, situated within Jasper National Park in the Canadian Rockies, on the border of Alberta and British Columbia. Located around 320 kilometers west of Edmonton, 360 kilometers North-West of Calgary and 290 kilometers north of Banff, the town is geographically isolated and positioned at the intersection of two major highways; Highway 16 (Yellowhead Highway); running east-west, it connects Jasper to Edmonton in the east and continues westward toward British Columbia, and Highway 93 (Icefields Parkway); extending southward, it links Jasper to Banff, travelling further eastwards to Calgary. Despite being a popular tourist destination, it serves as home to almost five thousand people.

On 22 July 2024, a wildfire swept through the Jasper region, forcing the evacuation of approximately 25,000 residents and visitors from the town and surrounding areas. The fire caused extensive damage to forested areas, infrastructure, and parts of the town, which is a major tourism hub in the Canadian Rockies. (Source: Wildfire Timeline - Municipality of Jasper (2024), Jasper Wildfire 2024 - Jasper National Park (2024)). Figure 4 shows the spread of the fire on 4th August 2024.

3. Methodology

3.1 Obtaining geospatial information

Geospatial information on regional boundaries and road network were sourced from publicly available resources (e.g., Nova Scotia's Geographic Data Directory website). Shapefiles covering the urban regions, communities and

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32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-5-29-2025 | © Author(s) 2025. CC BY 4.0 License

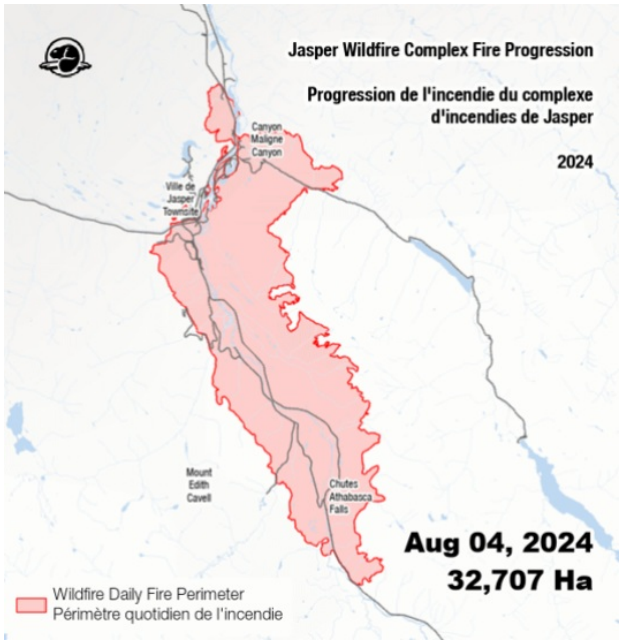

Figure 4. Map of the fire spread in Jasper, Alberta. (Source: Parks Canada)

highways were generated using GIS tools like ArcGIS. Since GPS coordinates do not always reflect the accurate position due to various positioning errors, we drew a one kilometer buffer along the highways for processing, as can be seen in figure 5. Using spatial join operations, we were able to extract the GPS information in these highways and communities.

Community shapefiles for the Upper Tantallon region were obtained for the communities of Hammonds Plains, Lucasville, Upper, Middle and Lower Sackville. Figure 1 shows a satellite overview of the region, with the communities and highways marked in different colors. For the road network, we primarily focused on Nova Scotia highways 101 and 103 which connected the wildfire region to Halifax and fell inside the wildfire evacuation zone.

For Jasper, the wildfire mostly covered the town of Jasper, and parts of Hinton. Valemount in British Columbia was also in the zone but since it is a very sparsely populated town outside of Alberta, it did not have a significant impact on the traffic.

Being an isolated tourist spot, the town of Jasper has a significant road network around the region and majority of the GPS entries has been observed on the highways, rather than the town itself. This prompted the need to divide the road into segments for easier processing.

Figure 3 shows the satellite view of Jasper and the adjacent highways. Yellowhead Highway (Highway 16) that leads west into British Columbia is highlighted in red. There are no major towns in vicinity except the village of Valemount, but it being in British Columbia, and having very few GPS entries, was excluded from the analysis. The major highways leading towards interior Alberta were Highway 93 or Icefields Parkway, which leads to the city of Calgary, and

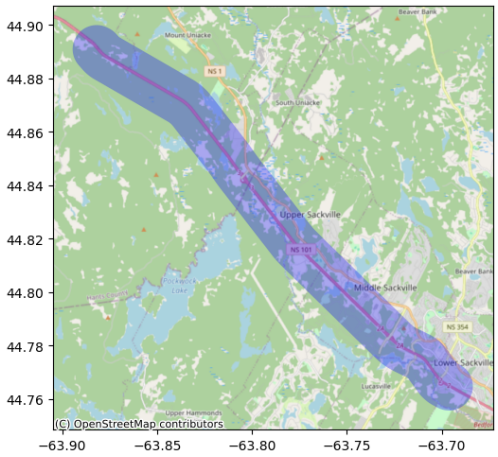

Figure 5. An example of a 1km buffer along NS101 highway

Yellowhead Highway (Highway 16) towards the east, leading towards Edmonton. Due to the length of this section, it was further divided into three parts, the blue area denoting the north-bound segment of the highway, the yellow segment leading towards the town of Hinton, and the grey segment leading towards the town of Edson, AB. Edmonton is approximately 181 km east of Edson. At Hinton, the highway branches out into northern and southern highway 40, denoted in purple and brown. Before reaching Edson, it further branches out to highway 47 (marked in sky blue), connecting to highway 40.

3.2 GPS data preprocessing

In order to contrast the patterns before, during and after the wildfire, GPS data were obtained for both study areas, covering a few days from before the fire ignited until weeks after the traffic restrictions were lifted.

The raw data were then preprocessed by dropping duplicate entries and removing the entries for any GPS ID which had fewer than four entries in the set. In addition, while calculating distances, devices with distances traveled less than 500 meters were eliminated, to ensure that GPS positioning errors are not considered.

For the Upper Tantallon wildfires, GPS data were obtained from 24 May 2023, 00:00:00 to 28 July 2023, 23:59:59; i.e. from two days before the wildfire. The raw data comprised 30,066,101 GPS entries, covering 206,087 unique devices. After cleaning, 71,860 devices were dropped and 29,945,187 GPS observations remained.

The Jasper GPS data ranged from 14 July 2024, 00:00:00 to 2nd November 2024 23:59:59. Since the dataset contained entries from months after the wildfire ended, we deleted the entries occurring after 15th September 2024, as the traffic patterns during those months are not particularly relevant for our study.

There were a total of 45,182,729 GPS entries, covering 188,605 unique GPS devices from this region and the above time frame. Similar to Halifax, dropping duplicate data and removing less frequent GPS IDs resulted in the removal of 30,000 devices. The total number of GPS entries therefore became 45,130,012.

Tables 1 and 2 show the percentage distribution of the frequency of the GPS IDs for Upper Tantallon and Jasper wildfires respectively.

No. of Entries	Distribution	
	No. of Devices	Percentage
0-99	105,123	78.3
100-499	19,507	14.5
500-999	4,230	3.2
1000-1999	2,573	1.9
2000-3999	1,461	1.1
4000+	1,333	1.0

Table 1. Distribution of number of unique GPS devices for Halifax

No. of Entries	Distribution	
	No. of Devices	Percentage
0-99	102,635	64.7
100-499	39,508	24.9
500-999	7,697	4.9
1000-1999	4,291	2.7
2000-3999	2,558	1.6
4000+	1,916	1.2

Table 2. Distribution of number of unique GPS devices for Jasper

4. Results and discussion

4.1 Halifax

4.1.1 Regions affected

On plotting the GPS data obtained from the regions (figure 7), we observed a significant decline in the number of unique GPS devices in the Hammonds Plains region, starting from 29th May 2023, which is a day after the wildfire started. Interestingly, in the subsequent days, the number of GPS entries did not rise to the pre-wildfire levels.

For Middle Sackville however, the decline is much more gradual, unlike that of Hammonds Plains. Hammonds Plains has a higher population compared to Middle Sackville, however, higher levels of GPS activity were recorded in Middle Sackville compared to Hammonds Plains during the wildfire, suggesting that a lot of people there chose to stay.

Lower Sackville being outside of the fire evacuation zone, did not see a significant change in GPS entries; while the number of unique GPS entries from Lucasville and Upper Sackville were too few to observe any meaningful decline.

4.1.2 Road network analysis

Analysing the GPS points within a one kilometer buffer along the road networks showed that the highways NS101 and NS103 did not see any significant decline of traffic volume during the wildfires as per figure 7. This could be because the wildfire did not affect the highways as such. It is also interesting to note that during the start of wildfire, when people were evacuating into other regions, there is no noticeable spike in highway activity either; suggesting

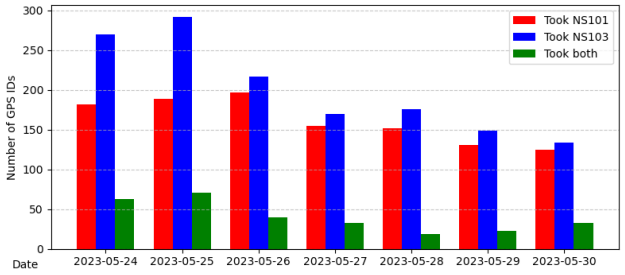

Figure 6. Choice of highways among people living in Hammonds Plains prior to the wildfire

either that the spike has been offset by a lower-than-usual traffic during the evacuation period, or that the people used the same highways and routes before the wildfire so there is no noticeable increase in the total number of unique GPS devices during the same.

Further analysis of the GPS points along the highways gives us figures 6 and 8, which shows that the devices which were previously located inside Hammonds Plains, i.e. people living in Hammonds Plains, did not have any specific preference in choosing the highway for evacuation, but those living in Middle Sackville, overwhelmingly chose to evacuate via NS101 over NS103, as highway 101 lies in close proximity to the region.

Upon examining the total distance traveled for every device in figure 12, we noticed a predictable trend in case of the Halifax wildfires where the mean total distance traveled dropped significantly during the evacuation period. The closure of various work-places and schools could be the reason behind this drop, but it was slightly offset by the people evacuating from the region of fire.

However, the median distance traveled did not show any significant drop. As we saw before, while a lot of people from Hammonds Plains had evacuated, other regions (e.g. Sackville, Lucasville) did not face an evacuation to this degree. The mean could be lowered due to the overall drop in travel (fewer trips and smaller road networks being used), however the median is less affected because for the people who stayed back, they did not exhibit any change in travel distances.

4.2 Jasper

4.2.1 Regions affected

Studying the GPS patterns (figure 9), we observe that from 22nd July (the day when the wildfire evacuation started), the number of unique GPS entries observed in Jasper went down by about a thousand, and that of the neighbouring town of Hinton did not see any significant change. This gap in the number of unique GPS entries remained consistent throughout the entire time period. However, despite Jasper town being located directly in the wildfire zone, we still obtained a significant number of GPS devices, approximately a few thousand, in the Jasper town.

Somewhat unexpected, we did not observe a reduction in GPS activity, indicating that the number of people in the affected area did not change. We speculate that Jasper being

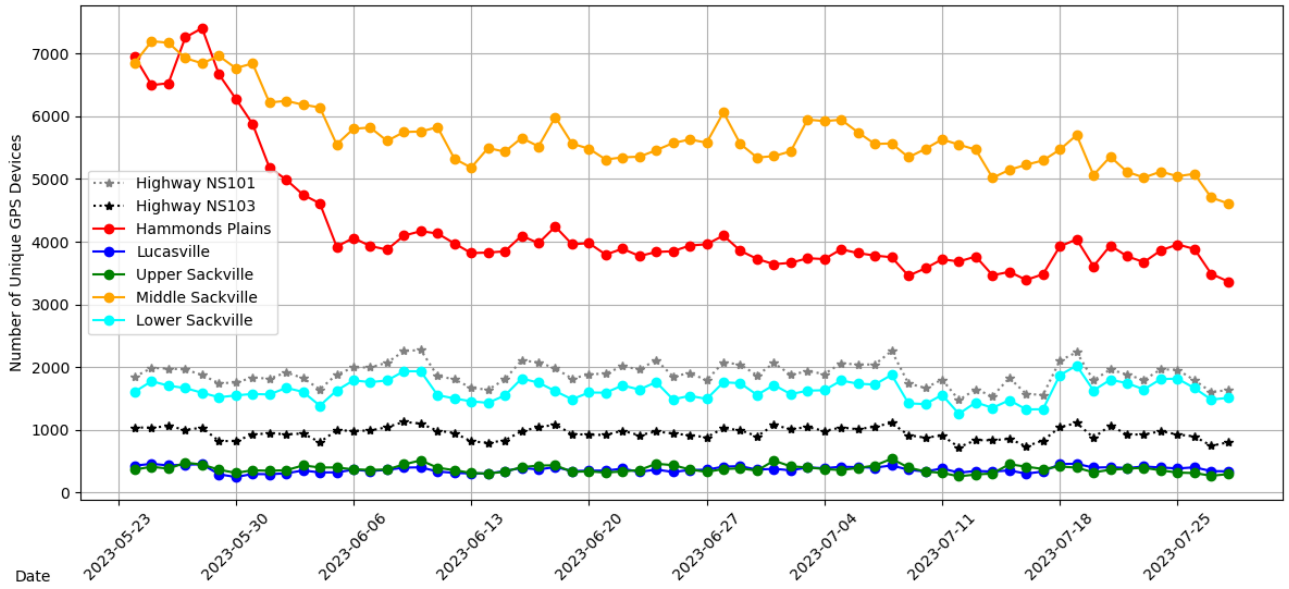

Figure 7. Daily Unique GPS Devices Observed on the highways and various communities around Halifax during wildfire

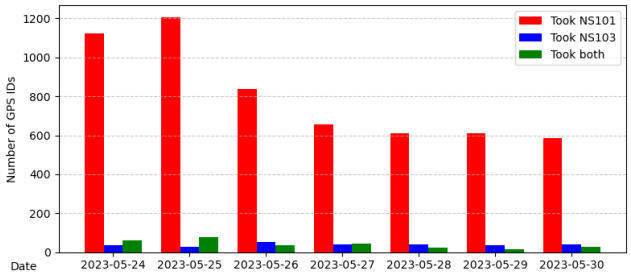

Figure 8. Choice of highways among people living in Middle Sackville prior to the wildfire

a tourist hub, the presence of tourists, emergency responders, and other transient populations contributed to continued traffic movement, which could mask the decline in local population. To further explore this hypothesis, we filtered the GPS entries to track only those entries that were seen in the Jasper region before the wildfire. After doing so, the number unique GPS IDs decrease over time in Jasper and to a slower degree in Hinton after 22nd July (figure 10).

4.2.2 Road network analysis

Figure 9 illustrates that the number of unique devices per day was highly random, and no meaningful pattern could be inferred. However, it was seen that most people chose Yellowhead highway over Highway 93/Icefields Parkway, suggesting that most people opted for Edmonton over Calgary, either due to Edmonton being slightly closer to Jasper than Calgary, or because, as can be seen in figure 4, a large section of Icefields Parkway was inside the fire perimeter, compared to that of Yellowhead highway.

Upon filtering the GPS entries to only include the devices present in Jasper before the wildfire, we were able to see a clear and predictable pattern of GPS activity slowly decreasing as the wildfire begins; starting from 21st July; and the difference in traffic between Yellowhead Highway North and Icefields Parkway reduces significantly.

The Sankey diagram presented in figure 11 suggests that most of the people who chose the northbound Yellowhead Highway 16 either stopped at Hinton or went towards Edson. A minority of people chose the route via Highway 40, which provides an alternate route to Calgary. An even lesser percentage of people chose Highway 47 (bound south) before reaching Edson.

Figure 12 details the mean and median distances traveled during the entire time period by each device present in the GPS dataset, and there is no noticeable trend observed. This highly haphazard pattern, as seen previously as well, indicates that for a tourist hotspot like Jasper, it can be difficult to properly analyze the evacuation.

4.3 Comparison and Discussions

4.3.1 Number of unique GPS devices

While Tantallon and Halifax suburban region showed a clear decline in the number of unique GPS devices as the wildfire progressed, Jasper did not show any decline until the entries were filtered to only include the GPS devices present in Jasper before the wildfire. Even then, the decline is not as significant as that of Halifax suburbs.

This difference could be attributed to the fact that Jasper is predominantly a tourist region, so even during wildfires, it continued to see traffic movement; while the suburban areas of Halifax are mostly residential or commercial areas, so the evacuation was prompt. This can be further supported by the fact that even during the wildfires, the weekends saw more traffic movement on average than the weekdays, while no such pattern was observed for Upper Tantallon wildfires.

4.3.2 Traffic distribution on the highways

Road network analyses of both cases revealed that while for Upper Tantallon, the highways shared more of an even load (NS101 saw approximately two times the traffic NS103 did), for Jasper, Yellowhead Highway North saw

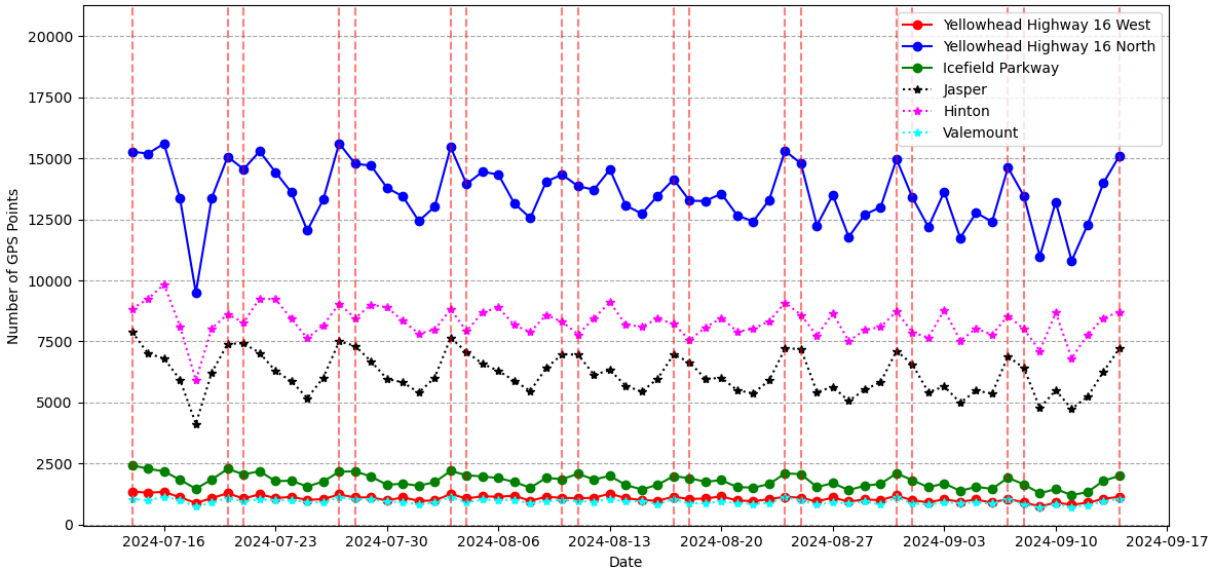

Figure 9. Daily Unique GPS Devices Observed on the highways and various communities around Jasper during wildfire. Weekends have been marked with dotted red lines.

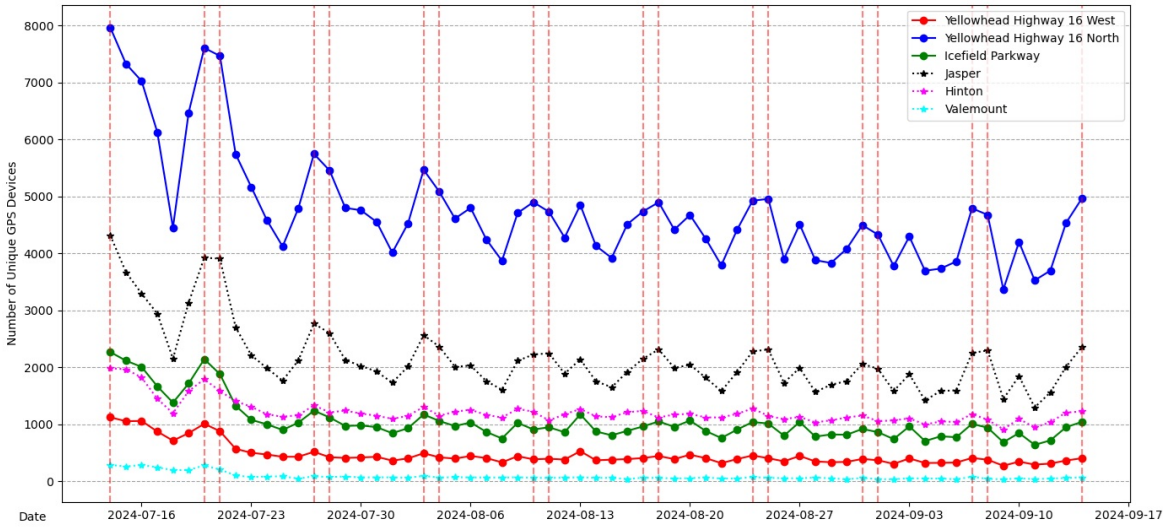

Figure 10. Daily Unique GPS devices observed on the highways and various communities around Halifax during wildfire; for those IDs present in Jasper before the wildfire.

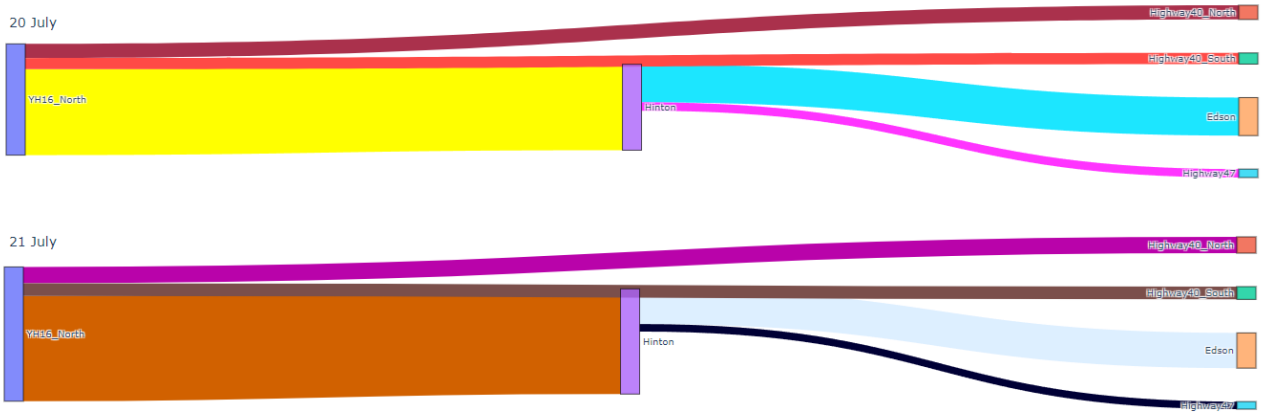

Figure 11. Choice of road for the people in northbound Yellowhead Highway 16

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32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-5-29-2025 | © Author(s) 2025. CC BY 4.0 License

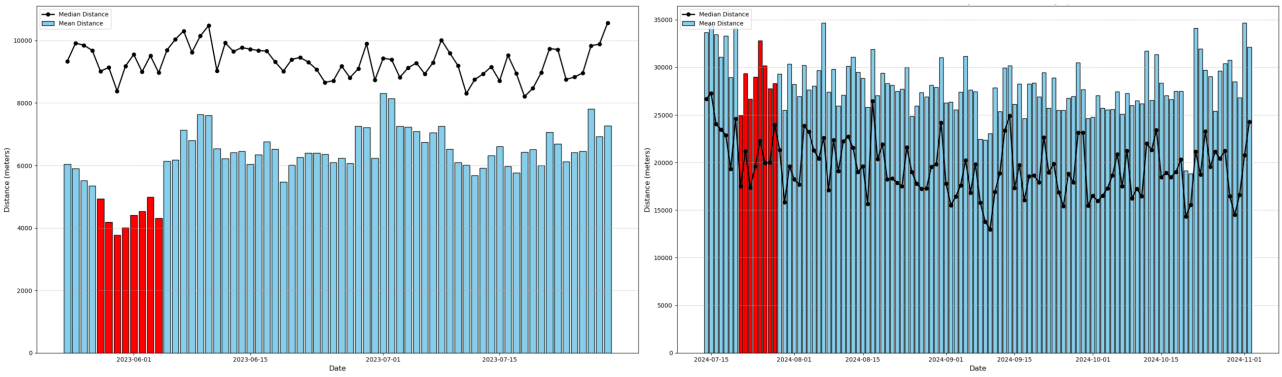

Figure 12. Mean and Median distance traveled for Halifax (left) and Jasper (right). Red bars indicate the first week of evacuation

almost four times the traffic compared to the other routes. This could be caused by three reasons:

1. For the Upper Tantallon wildfire, the evacuees moved to Halifax for shelter as it is the closest metropolis around the region, which was also outside of the fire zone. However, for Jasper, the people almost overwhelmingly moved inside Alberta (instead of crossing the border into British Columbia), so the highways leading out from Alberta to British Columbia did not see a significant traffic change.
2. Halifax is connected to the evacuation zone via both NS101 and NS103 highways. But for Jasper, the isolation of the place and lack of connectivity made people overwhelmingly choose Edmonton over Calgary, which resulted in the lopsided traffic distribution in the Yellowhead Highway North leading to Edmonton from Jasper. Moreover, northbound highway 16 also passes through other small towns like Hinton and Edson, making it a popular choice over highway 93 or westbound highway 16.
3. Even if we do not consider the evacuation scenario, highway 16 North seemed to have a higher traffic flow in general compared to the other highways, as is evident from the data before the wildfire. This resulted in a familiarity and therefore a popularity with the route which a lot of evacuees might have taken prior to the incident.

4.3.3 Frequency of GPS data

Contrary to what one would expect, the distribution of devices and their frequencies in Tables 1 and 2 shows that for Upper Tantallon, a 78.3 percentage of devices had fewer than hundred entries, compared to Jasper's 64.7.

Given that Jasper is a tourist spot; it is more likely to have less-frequent or one-time visitors. However, one explanation of this might be the extent of the GPS area; while Upper Tantallon wildfire only covers the suburbs and a small portion of the highways, the Jasper GPS area covers a lot more area; most of it being highways and road networks, and it likely covered a lot more residential areas than the Halifax GPS data did. Therefore, repetition of GPS entries became much more common.

4.3.4 Distance traveled

From Figure 12, we can see that the median distance traveled by people during Upper Tantallon wildfires is higher than the mean, whereas for Jasper, it is lower. During the evacuation period, the mean distance traveled for Halifax was around 3 km, with the median being almost 9 km, whereas for Jasper, the mean distance traveled during evacuation period is around 27 km with the median being 20 km. Typically, if the median is greater than the mean, it indicates left-skewing, with many people traveling relatively longer distances and a smaller number traveling short distances. There could be multiple interpretations behind this:

1. Jasper being more isolated, it is very obvious that almost everyone traveled for longer distances, which is why both the mean and median for Jasper is much higher than Tantallon.
2. The lack of towns near the Jasper region meant that the evacuation saw fewer people traveling very long distances relative to others. Whereas for Tantallon, more people traveled relatively longer compared to others, as they could roam around much more freely and explore areas in the dense connection of towns and communities.
3. The spread of wildfire could also be a potential contributing factor. In Tantallon, the fire spread rapidly, averaging 33 meters per minute, with peaks between 44 to 50 meters per minute, driven by sustained wind gusts (Source: May 2023 Wildland-Urban Interface (WUI) Wildfire Post Incident Analysis by Cathie O'Toole, Chief Administrative Officer). This might have forced larger-scale evacuations requiring longer distances. However, for Jasper, the spread was much slower, advancing at about 15 meters per minute (Source: Canadian Rockies town Jasper badly damaged by fast-moving wildfire - The Guardian), allowing for shorter, phased evacuations.

5. Limitations

The analysis had several limitations.

1. Although the GPS data collected encompass the wildfire region, it does not cover the nearest cities (e.g.

Halifax city, Edmonton or Calgary). This results in a lack in understanding of the place where the people chose to evacuate.

2. The GPS data obtained does not have a metric to determine the accuracy or degree of error, so every entry is assumed to be reasonably accurate, which may not be the case.

3. This study did not consider the dynamic spread of fire, smoke and other weather based events, which might have also impacted the choice of highways.

6. Conclusion and future work

The comparison between the evacuations during Tantallon and Jasper wildfires provide insight into the dynamics of wildfire evacuations in two distinct settings: a suburban fringe of a major city and a renowned tourist destination.

While the Tantallon wildfires demonstrated a clear and predictable evacuation pattern, with GPS data showing a significant decline in the number of unique devices in affected suburban areas, a relatively even traffic distribution across the highways for evacuation, and reduced mean distance traveled by people during the first week of evacuation, Jasper wildfires exhibited a more complex evacuation pattern, with no observable pattern for the GPS entries, relatively uneven distribution of traffic over the highways and no change in the mean distance traveled during the evacuation period.

This stark difference in the evacuation pattern visualizations could be attributed to the difference in the types of the areas (one being a primarily residential/professional area with mostly permanent residents, versus one tourist hotspot, situated in the middle of a highly active highway system with no big city around, having passengers either coming in only for work or just passing by) and the type of wildfires (Tantallon fires being more rapid and short-lived whereas Jasper wildfires were slower and longer). This shows that the evacuation dynamics is dependent on the type of city and that geographic and economic differences of areas need to be studied for better understanding of the evacuation scenario.

Future work could explore incorporating real-time data to detect congestion and provide dynamic routing capabilities. It would also explore trajectory mining to analyze common patterns in evacuation, and if possible, explore the behavioral tendencies like which applications the evacuees used. Expanding the study to include additional wildfire events, integrating environmental factors like smoke dispersion and economic and geographical characteristics of the city could further enhance preparedness and response strategies for diverse communities. A Large language model based chatbot can also be developed to guide the evacuees into safety and provide updated information regarding the wildfire spread, traffic and weather conditions.

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