Video Analysis of Human Behaviour during Wildfire Evacuations

As published the Canadian Journal of Civil Engineering, 2024

https://doi.org/10.1139/cjce-2023-0450

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Abstract

Wildfire impacts are increasing due to the multiplicative effect of several factors, including climate change, increased vulnerability in the wildland-urban interface, and impacts of management decisions. This has also led to an increase in evacuations due to the number of wildfires and people affected. This study collected information on behaviour during wildfire evacuation to fill critical research gaps in human behaviour and evacuation knowledge. Seven videos of residents' evacuations from the 2016 Fort McMurray fire were collected from public platforms. Their routes were analyzed, and notable behavioural events were recorded. The evacuees mainly used major roads before getting onto the highway (the only route available for vehicular egress). The notable behaviours observed included using opposite lanes and driving outside of marked roads to avoid congestion. Much of the observed behaviours appeared to be motivated by the surrounding traffic or fire behaviour, further supporting the need for further studies of evacuation.

Key words: wildfires, human behaviour, evacuation, video analysis, traffic behaviour, Fort McMurray Fire

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1. Introduction

Globally, wildfires are increasing in number and severity. The increase is associated with climate-change associated factors; increased interactions between people and the wildland through population growth, urbanization and seasonal recreation; and changes in fuels and ecosystems, among others [1], [2]. It is forecasted that by 2100, the number of severe wildfire events will increase by a factor of 1.31 to 1.57, depending on climate mitigation efforts, though the change in number and severity of wildfires is expected to vary geographically [3]. Human's impact on the weather through climate change is considered one of the largest reasons driving the increase in number and severity of wildfires [3]. Global warming is expected to lead to increased wildfire events through direct effects such as more extreme weather including stronger winds, higher temperatures, and increased lightning, as well as through indirect effects such as changing fuel types and availability [3]. Between 1998-2017, it is estimated that wildfires caused $68 billion USD in economic damages globally, though only 41% of economic losses from wildfires is reported [4].

Since 2012, Canada has experienced an average of 5,700 wildfires per year, resulting in over 2.8 million hectares burned [5]. Due to climate change, it's predicted that the likelihood of extreme wildfires in Western Canada will increase between 1.5 and 6 times in the next ten years [6]. An analysis of the fire seasons from 1959-2015 found that the average fire season length in Canada increased by approximately two weeks during that period [7]. In British Columbia, a study found climate change may be attributed to 86-91% of the area burned during the 2017 fire season [8].

This changing geophysical climate is particularly impactful given the exposure of communities. It is estimated that 4.1 million people in Canada live in areas defined as a wildland-urban interface (WUI), where "built structures, such as homes, are meet or are dispersed within wildland vegetation," a demographic which is only expected to increase with population growth and urbanization [1], [2]. However, it should be noted, that this area does not include additional interface areas between industrial infrastructure or infrastructure used for transport and utilities, such as roads and powerlines, which are excluded from the WUI definition [1]. Wildfires are increasingly threatening all forms of the intermix, with fires occurring in forested, suburban and urban areas, for example, the 2018 Camp Fire, the 2021 Marshall Fire and the 2023 Maui wildfires [9]. The economic cost of wildfires is also expected to increase. Prior to 2003, no wildfire event had cost more than $10 million, but there have been a number of costly wildfires in the last decade [10]. In Canada, the 2023 wildfire season was the worst wildfire season on record. As of the final National Fire Situation Report of 2023, over 17 million hectares has been burned and over 230,000 people have been evacuated [11], [12]. In mid-August 2023, 27,000 people in the Northwest Territories, over half its population, were under evacuation orders, including the entire capital city of Yellowknife [13]. The wildfires have caused record-setting air quality alerts across Canada and the United States, including the record for the worst daily total wildfire carbon emissions since they began tracking the statistic, 20 years ago [14]–

[16]. It was estimated that Canada's 2023 wildfire season was responsible for 23% of the total global wildfire emissions for 2023 [17].

The increase in wildland and WUI fires has also resulted in an increasing trend in the number of evacuations and amount of people evacuated, where between 2013-2018 there was an average of almost 50 evacuations per year affecting almost 38,000 people [18]. In light of the increasing impact of wildfires on people, data on human behaviour in wildfires has been identified as a critical research need [19]–[22], with a call specifically for more research on wildfire evacuation decision-making and behaviour [23], [24].

2. Background

2.1 Wildfires and Human Behaviour

Data on human behaviour in wildfires is used to inform wildfire mitigation and evacuation plans as well as verify and validate wildfire models in order to better prepare for and mitigate the impacts of wildfires on people. The data can also be used to inform behavioural theories, such as the Protective Action Decision Model (PADM) and cognitive biases, or used to develop new theories and frameworks to describe behaviours. A review of research on human behaviour in large outdoor fires, which includes wildland and WUI fires, found that much of the research is on evacuation decision-making, with a focus on the decision to evacuate and evacuation preparation decisions [25]. There have also been studies looking at the behaviours during evacuation such as wayfinding [26], and transportation mode and intermediate actions [27], [28]. Kuligowski has also identified three main areas of research needs within the field of evacuation research: 1) more information on evacuation decision-making, 2) more evacuation movement data and 3) more behavioural research [23].

It should be noted that not all data on behaviour during evacuations may be transferrable between jurisdictions due to differences in environment, infrastructure, and culture. A study investigating wildfire evacuations in Canada between 1980-2019 noted differences in the wildfire characteristics that prompted the evacuation and the evacuation mode, where remote communities are less likely to be able to self-evacuate due to a lack of road access [29]. Wildfire community response policies and legislation vary in different jurisdictions internationally [30]. There have been limited studies comparing cross-cultural differences, though some studies have observed differences in hypothetical and actual evacuation behaviours between French and Australian participants [31], [32].

Data collection of human behaviour during emergencies is difficult to collect due to ethical, financial, and logistical barriers. A review of human behaviour research for large outdoor building fires, which includes wildfires, found that the majority of studies used empirical data collected from participants through methods such as surveys and interviews [23], [25]. While surveys and interviews can collect important behavioural information, self-report of historical behaviour – especially during emergencies – has significant methodological limitations [33].

Additionally, within the field of human behaviour in fires, there is an effort to make survey and interview questions more consistent to allow for better comparisons across studies [25]. While a review of empirical methods for evacuation behaviour as a whole found that the use of virtual reality (VR) has risen in the past few years [34], there is limited use in wildfire contexts [35]. Using GPS data is also an emerging technology and while its use for wildfire evacuations currently limited, there are studies evaluating its potential as a research tool [36]. Evacuation drills are commonly used for training and research purposes and are seen by some as one of the better and more credible tools to evaluate occupant behaviour [37]. However, behaviour during an evacuation drill may not match what happens during an actual emergency event [38]. Additionally, they also have a number of financial, logistical, and ethical issues and difficulties associated with conducting them [39]. As such, few communities conduct wildfire evacuation drills [40], though in light of recent wildfire disasters, some communities have started in order to better prepare its residents [41], [42].

Data on human behaviour during evacuations, as mentioned previously, is difficult to collect and of the existing studies, many focus on the evacuation decision and evacuation preparation [25]. How wildfire evacuees behave during a vehicular evacuation is an identified research gap, though work is ongoing [23], [25]. Studies of wildfires in California used surveys and interviews to investigate departure times, route decisions, evacuation mode and destination choices [28], [43], [44]. A study by Brachman et al. investigated wayfinding and route choices by evacuees using post-event surveys [26]. Studies have also used traffic and GPS data to analyze overall traffic density and flow during evacuations [45], [46]. The WUI-Nity coupled model used data from a community evacuation drill and post-event surveys to investigate evacuation times and route choices [47]. However, these studies largely investigate the evacuation behaviour from wider perspective, examining the overall route decision and evacuation times, or larger traffic patterns. There is less focus on examining decisions made during the evacuation journey on a smaller scale.

2.2 Human Behaviour in Emergencies Frameworks and Theories

There are a number of behavioural frameworks and models that have been applied to emergency contexts. ASET/RSET analysis uses a linear, chronological approach to describe behavioural actions, where each action is assigned a duration of time. Newer frameworks have expanded to incorporate the decision-making process itself and not just the resulting action. The Protective Action Decision Model (PADM) is a behavioural model that has been applied to wildland fires and WUI fires and other disasters such as hurricanes as a framework for decision-making [48]. The conceptual model divides decision-making behaviour into three main stages of decision-making: 1) pre-decision making where perceived threats and cues are observed and understood, 2) credible threat and risk assessment, where the cues are evaluated to determine if they pose a credible threat and its associated level of risk and 3) protective action, decision options are created, evaluated, and implemented. Throughout all three stages, additional information is sought after and evaluated.

Cognitive biases is another behavioural theory that has been applied to human behaviour in fires, though not wildland fires specifically [49]. Cognitive biases provide short behavioural statements that can be used to describe people's behaviours and provide context. However, they also create the risk of oversimplifying behaviours resulting in potentially critical information being overlooked. A recent framework has also emerged regarding the role of social identity in decision-making during mass gatherings [50]. This framework suggests that during emergency events, a shared identity can emerge among those impacted and lead to more collective decision-making. There are also many other behavioural frameworks currently being examined and those presented herein are only a select few.

These behavioural models can provide useful frameworks to contextualize people's behaviours, however, many of them lack validation due to insufficient data, which has previously been identified as a critical research need [51]. Additionally, the theories were largely created without considering specific wildfire contexts, though the PADM has been applied to wildfire contexts [48], [52]. However, the PADM has largely been applied to pre-evacuation decisions and not decision-making during the evacuation itself. As every wildfire event and community is different, the factors affecting decision-making and what actions are taken may also be different [31].

As the number and severity of wildfires impacting people increase, there is a need to collect data on human behaviour during evacuations in order to inform evacuation management and strategies. The objective of this research was to analyze videos of Fort McMurray evacuations for notable human behaviour and traffic behaviour and with an overarching vision to compare the behaviours observed to existing behavioural frameworks. Additionally, the study aimed to collect quantifiable data about the evacuation process and determine the appropriateness and applicability of the video analysis methodology. This research contributes to the critical research need for more data on human behaviour in wildland and WUI fires during the evacuation itself, using an exploratory methodology that, at the time of writing, had not yet been applied to wildfire evacuations. This manuscript is based on data and analysis from the author's thesis project [53].

3. 2016 Fort McMurray Wildfire

The 2016 Fort McMurray Fire (also known as the Horse River Fire or Wood Buffalo Fire) is one of the largest WUI fires in Canadian history and the largest evacuation in Alberta's history with 88,000 residents evacuated and almost $8.9 billion in damages [54]. Its evacuation was largely regarded as successful, however, only 24% of residents surveyed considered the evacuation well-organized. The fire began in the afternoon of May 1, 2016 and reached the Athabasca River the next day. Overnight between May 2 and May 3, the fire had "jumped" over the Athabasca River, a distance of almost one kilometre, however, the sky remained relatively clear in the morning, so the approaching fire was not visible to the residents. At 11:00 a.m. local time on May 3, a press conference offered mixed messages to the residents, saying to go along with their day as normal, but also advising to on high alert as fire conditions were extreme. However, by early afternoon, the fire had grown larger and closer to the community due to high winds and mandatory evacuation orders were issued to the communities surrounding Fort McMurray [54]. Evacuation orders in Canada may be encouraged and promoted by the Royal Canadian Mounted Police or local police authorities, however, there is no legislative requirement to leave [55].

At 6:49 p.m. local time on May 3, a full evacuation of Fort McMurray was ordered, though many of the surrounding communities had already evacuated. As a rural WUI community, Fort McMurray only has two egress routes, north or south via Highway 63. Approximately 20,000 people evacuated north towards work camps while 60,000 evacuated south towards Edmonton. Because of the remote location, there are very few amenities available along the highway in either direction and many vehicles ran out of fuel before arriving to intended evacuation destinations. The evacuation orders issued in quick succession as well as residents self-evacuating before an official evacuation order caused high congestion on the single vehicular egress route Highway 63 [54]. However, due to the limited resources available at the northern work camps, many evacuees went south towards Edmonton when Highway 63 re-opened the morning of May 4, which forced them to drive back through the wildfire areas [54]. On May 5, the wildfire temporarily closed Highway 63 south of Fort McMurray, preventing evacuation and leaving people stranded in the northern work camps. On May 6, the Royal Canadian Mountain Police (RCMP) escorted convoys of 50 vehicles south until the work camps were empty. Additionally, some employees and residents were also evacuated from the work camps by air [56].

4. Methods

The methodology used was the video analysis of footage of evacuations from Fort McMurray. Video analysis of emergency events such as wildfires, as a method of data collection has been used in the past to collect empirical data on human behaviour from a variety of emergency scenarios, such as earthquakes and evacuations of buildings and stadiums [34], [57]–[59]. The advantage of this methodology of analysis is that the videos are taken from real-world events and therefore are considered highly representative and credible. However, as a real-world event and not an experiment, there is very little control over variables and responses. Additionally, real-world events inherently have very low replicability capabilities where it is difficult to recreate the circumstances, and as such, the sample sizes available may not be representative of the event [60]. The methodology also does not allow for explanations on behaviours observed or the underlying decision-making processes as only the final actions are shown.

A study has been done analyzing YouTube videos of the Fort McMurray Wildfire which included videos of the evacuation, however, the purpose of the study was not to examine the behaviours present, but to investigate the types of experiences and narratives that are present in the videos [61]. At the time of writing, it is believed that this is the first study examining videos of people evacuating from the Fort McMurray Fire for the purpose of collecting data on human behaviour.

4.1 Video Sourcing and Analysis

Videos were collected from YouTube, and Facebook, with the majority originating from YouTube (see Table 1). Search terms for videos included “Fort McMurray evacuation”, “Fort McMurray wildfire”, “Fort McMurray” etc. in order to source videos of the evacuation. YouTube’s recommended video function was also used to collect videos. For videos which were included in news media, the original video, if possible, was found for inclusion and to determine if the video had been altered, such as shortened, by the news media. The video inclusion criteria were that the video had to be from the 2016 Fort McMurray evacuation and depict a vehicular journey leaving Fort McMurray. The videos should be one continuous recording with no jump cuts or skipping ahead chronologically. While other public online platforms such as Twitter and Instagram were also searched, only videos from YouTube and Facebook were included based on the above criteria. A total of seven videos were included in the analysis. Three of the videos (Video 2-4) originated from the same user and depicted the same journey, split into separate videos. The videos were all under 10 min.

Table 1: Summary of videos analyzed

Video	Video Description	Platform	Type of Video	Audio
1	Time-lapsed video of a portion of an evacuation	YouTube	Video recording	No
2	Dash cam footage of part of an evacuation (Part 1)	YouTube	Dash cam	Yes
3	Dash cam footage of part of an evacuation (Part 2)	YouTube	Dash cam	Yes
4	Dash cam footage of part of an evacuation (Part 3)	YouTube	Dash cam	Yes
5	Video footage of an evacuation	YouTube	Video recording	Yes

Video	Video Description	Platform	Type of Video	Audio
6	Time-lapsed dash cam footage of an evacuation	Facebook	Dash cam	No
7	Time-lapsed dash cam footage of an evacuation	YouTube	Dash cam	No[1]

Timestamps and descriptions of notable behaviours were recorded from each video. Observations were not limited to the occupants of the vehicle but extended to the surroundings including other evacuees recorded. The observations made were not intended to cast judgement on the actions and decisions of the evacuees, only to record their actions. Once the analysis was complete, the observations were analyzed for common themes or observations. Using visual clues such as landmarks and road signs from the videos, the evacuation route taken by each evacuee was retraced in Google Earth using the *Draw Shape* project tool.

4.2 Ethics Considerations

All videos were collected from YouTube, and Facebook which are public platforms. As those platforms do allow for different levels of privacy settings for videos, all videos analyzed were, at the time of searching, publicly available to everyone with no restrictions. By nature, the videos do contain some identifying information about the evacuees. Analysis of videos from public platforms was treated as secondary data analysis of identifiable data due to the nature of the videos. As the videos were sourced from public platforms, identifiable data of the evacuees was not treated as confidential. However, no personal information about the evacuees has been included in this publication. This research study was approved by York University's Ethics Review Board (Certificate #STU 2022-058).

However, it must be noted that the use of social media for research purposes has numerous debates around if the act of posting on a public platform qualifies as informed consent or if a researcher has an obligation to seek explicit consent for use of the data [62], [63]. Anonymity of has also been expressed as a concern of using public information from social media, with arguments on whether to protect the identity of the source or on if proper credit should be given [62]. In order to preserve the anonymity of the evacuees featured in the videos, the names of the videos and their source links have not been provided.

[1] As a compressed, time-lapsed video, there was no audio. However, there was audio of a conversation, however it is unclear whether it was synced properly.

5. Results

A summary table (Table 2) below describes notable results and observations.

Table 2: Summary of notable themes and associated behaviours observed

Category	Observed Behaviours
Evacuation Route	• Largely used main roads • All went south on Highway 63 • Few detours
Lane Uses	• Used opposite lanes to avoid congestion and/or flames • When possible, drove as close to the middle of the road • Vehicles drove outside the marked lanes offroad to avoid congestion
Smoke Impact	• Vehicles appeared to slow down when visibility decreased • Vehicle occupants were concerned about smoke exposure and inhalation

5.1 Evacuation Routes

The evacuation routes from the videos were retraced in Google Earth and presented below (Figure 1). While seven videos were analyzed, only five routes are shown. This is because three of the videos (Videos 2 – 4) are of the same evacuation journey by the same individual and their route has been combined into one. All five evacuations were of residents who went south towards Edmonton, Alberta. The majority of videos ended once they were on Highway 63 and leaving Fort McMurray. All of the routes used main roads to get to the highway. Three of the evacuation routes started when they were leaving residential areas, while two of them started while they were nearing or on the highway. Where the evacuation routes originated is due to when the individuals chose to begin their filming and not necessarily indicative of where they actually started their evacuation. A conversation captured in Video 5 indicated that they had stopped at a Walmart prior to evacuating.

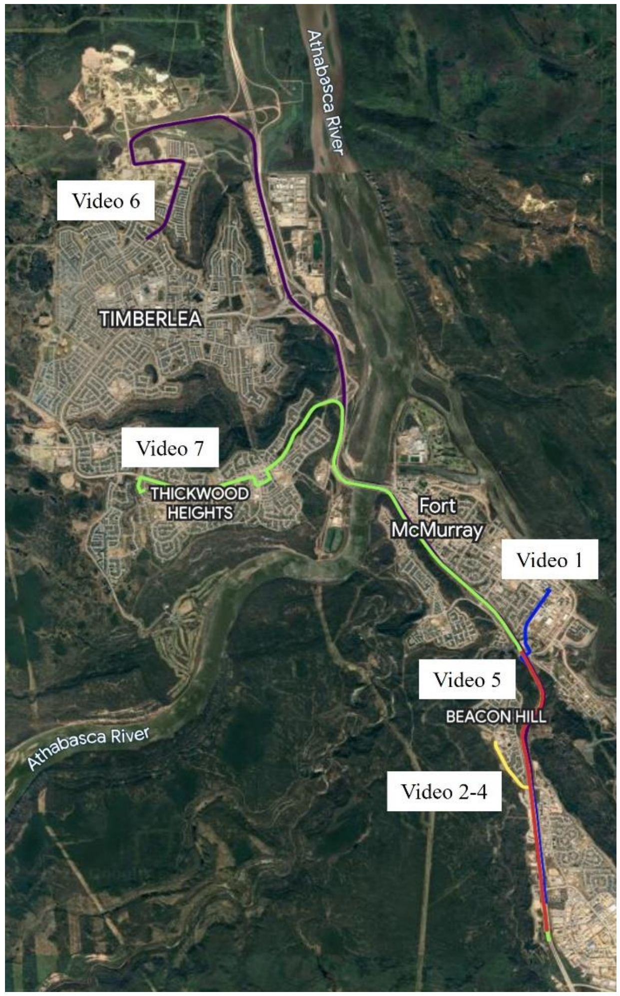

Figure 1: Evacuation routes from videos mapped in Google Earth (Figure was created using Google Earth v.10.45.0.3 and the "add path" function. Base maps are courtesy of Google, Airbus and Maxar Technologies).

In the majority of videos, evacuees were observed to drive towards the highway with no detours. However, in Video 7, they briefly took a short detour. They entered a plaza ahead of an intersection and remained there for a few minutes. As there is no audio, it is unclear why they entered the plaza. Once they left the plaza, they took a side residential street and then cut through the parking lot of a different plaza to return to the main road and by-pass the congested intersection.

5.2 Lane Reversals and Lane Use

Notable traffic behaviours were observed across all the evacuation videos. One notable theme through all the videos was the different lane uses. It was observed that lane changes were primarily driven by the direction of authorities or by the wildfire conditions. In Video 1, authorities, assumed to be police, directed vehicles to use the northbound lanes to evacuate south, assumedly to increase the traffic capacity going southbound. In Video 6, there was also a lane reversal directed by authorities, however, this one appeared to be motivated by fire behaviour and not for traffic-related reasons. In fact, earlier in Video 6, officials had directed some vehicles who were using the northbound lane going south back into the southbound lane. However, when approaching a stretch of highway where there were flames close to the roadside, officials had closed the southbound lane and directed people in the northbound lane to be farther from the flames. Later in the video, once past the area where flames were close to the roadside, some cars returned to the southbound lane, while others continued south in the northbound lane. While the lane reversals observed were directed by authorities, they were not part of official government evacuation plans [56].

In Video 2 and 3, there was also use of the opposite lane, however, these were not authority-driven. In a residential two-way street, the right lane was heavily congested, while the left lane was largely empty with only emergency vehicles using it. However, in Video 2, vehicles began changing into the opposing lane, presumedly to get ahead of the congestion. There appeared to be a bandwagon effect, as once the first car began to change lanes, another four cars did the same. However, it also caused an issue where an emergency vehicle was attempting to use the left lane in the designated direction and was forced to wait for the other evacuating cars to pass and merge back into the right lane before moving past.

In Video 3, cars also began using the left lane, however, this was motivated by fire behaviour as large flames approached the side of the road. As flames approached cars changed into the left lane to avoid the curb. The evacuee was heard stating they could “feel the heat through the car” while on a phone call in Video 4. They continued to use the left lane once past the large flames as the right lane was still heavily congested until they reached an intersection and were directed by authorities into the proper lanes. Again, there appeared to be a bandwagon effect as some cars also began changing into the left lane seeing other cars doing the same. However, in Video 4, more cars began changing into the left lane as the right lane was heavily congested when approaching a intersection.

In addition to using opposite lanes, use of lanes going in one direction was also observed. In Video 1, on the highway, there were three lanes going south. It appeared as though the majority of vehicles were using the left and middle lanes as there were flames close to the right lane. However, as the left and middle lanes were also the slowest due to the high traffic load, some cars can be seen using the right lane, closest to the flames in order to presumedly move faster and avoid the congestion of the middle and left lanes. This behaviour was notable as it occurred within three lanes that did not involve any lane reversals.

5.3 Other Traffic Behaviours

The smoke visibility also was observed to affect the traffic behaviour. In Video 4, cars noticeably slowed down when the visibility decreased due to the smoke. In Video 7, it was also observed cars slowing down as visibility darkened, however, it is more unclear due to the video time lapse.

While there have been limited studies on the effects of smoke on driving behaviour in wildfires, it is consistent with results observed in virtual reality experiments on the topic as well as walking speeds in smoke and driving speeds in fog [35]. Additionally, cars turned on their blinkers in response to the decreased visibility in Video 4. There also appeared to be a bandwagon effect as once one car turned their blinkers on in response to smoke, other cars began to do the same.

There were also a number of unusual traffic behaviours observed during the videos. These behaviours further demonstrate how traffic, fire and human behaviour are all linked as such behaviours are typically not accounted for in traffic models. In Video 3, traffic was forced to stop as there was an animal running across the road, presumedly to escape the flames. In the same video, cars were observed driving outside the marked road and down a hill in order to avoid congestion and enter an intersection. It was also observed during Video 7, where a car was seen driving in the grass divider, separating the northbound and southbound lanes of Highway 63. Also in Video 7, while remaining within the marked road, cars had to maneuver around a police officer and their car, who were parked a few metres past the intersection near the grass divider.

5.4 Audio Observations

A disadvantage to video-only analysis is that underlying motivations and decision-making processes are solely speculative based on observed actions. While not all the videos included audio, there were audio conversations that provided more insight into the thoughts of the evacuees as well as some background on their evacuation journey. In Video 4 and Video 5, both evacuees had phone calls with someone else. The content of the phone calls was similar with the evacuees recounting their journey and the fire damage they saw. Both phone calls also included reassurances that they were leaving the area.

Video 5 was the only video where it was confirmed that there was more than one evacuee in the vehicle through the video's title. As such, the couple had conversations with each other. Their conversations were mainly related to the wildfire damage they see while evacuating, such as exclaiming that a Denny's and a hotel by the highway that was a common landmark was on fire or passing a burning forest area next to the highway. They also expressed worry during the evacuation, with the woman specifically concerned about smoke inhalation and wishing she had a mask. The audio also provided some insight to their evacuation journey that was not featured in video itself, where the occupants of the car saying said they had stopped at a store prior to evacuating and the man contemplating contemplated whether to stop at an open gas station near the highway was open and while the woman saying said not to bother and to just keep going.

6. Discussion

6.1 Alignment with Existing Behavioural Theories

Some behaviours observed were consistent with different existing behavioural theories such as cognitive biases where there did appear to be a bandwagon effect. However, not all behaviours observed have been categorized under contemporary behavioural frameworks, due to a lack of validation of those theories during wildland fire evacuations and are simply stated such as driving outside of marked lanes. Additionally, some frameworks lack applicability to the context of the videos analyzed. Many of the theories which have been applied to wildfire contexts, such as PADM, have largely been applied to pre-decision phases and not actions during the evacuation itself [64]. As the footage analyzed is of the residents' evacuation itself and not the pre-evacuation stages, there is not enough evidence to categorize behaviours under PADM which relies on pre-decision information and behaviours. Additionally, behavioural frameworks describing group behaviour were also not used as each video showed an individual evacuation journey and as a video, the underlying motivations are not available, the impact of a collective identity is not evident.

Cognitive biases, defined as "systematic deviations from normal or rational judgment using inferences" can effect how the information is perceived [49]. During the video analysis, the bandwagon cognitive bias, defined as doing an action because others are doing the same [49], appeared to occur. This bandwagon effect has also been observed in studies of indoor building evacuations and exit choice [65]. In Video 2 and Video 3, when one car changed into the opposite lane to avoid congestion or flames, other cars did the same. Additionally, in Video 4, when the visibility got worse due to smoke, cars began to turn on their blinkers. While some may have chosen to do so independently, there appeared to be a bandwagon effect as it was staggered across the cars.

The presence of authority figures, such as those directing traffic, may have indicated that there was an "authority bias" where actions are done because an authority figure does or requests it [49] as there were authority figures directing traffic. The presence of authority was mainly seen at intersections and lane merges where they directed traffic. Additionally, during the evacuation, authorities had changed the lane directions of the highway to one-way, in order to allow for more evacuees to head south. These lane reversals were unofficial decisions on the part of the local authorities and not part of the government's official plans [56]. In addition to directing lane reversals, at intersections they were observed to manage the traffic flow as well as direct traffic towards the egress routes. While some intersection traffic lights still functioned, traffic was largely directed by police which played a role in the evacuation route.

Authorities were also present at highway entrances, directing vehicles. Due to Fort McMurray's remote location, there were only two vehicular egress routes, either north or south on Highway 63. Thus, evaluating authorities' impact on egress route choice is difficult as evacuees did not have many options. Some hurricane studies have found that when evacuating from a community, residents preferred familiar routes [23] which is consistent with indoor evacuation studies [59], however, it has been found that some wildfire evacuees will use other non-highway roads if available [43], [66]. It is difficult to make conclusions on evacuation route strategies due to the already limited egress routes that were available to residents of Fort McMurray, as all vehicular routes observed in the videos used major roads which led to the highway.

There may have been other cognitive biases that could have been identified, however, the purpose of the video analysis was not to identify cognitive biases present and thus they may have been missed. It must be noted that the cognitive bias framework has not been validated using wildland and WUI fire contexts. Identifying cognitive biases specific to wildfire evacuations using video analysis is recommended as future work.

6.2 Common Observations across Videos

As mentioned previously, the use of lane reversals was evident across many of the videos, driven by the direction of authority, or by the driver's own risk perception based on traffic congestion or fire behaviour. While the use of lane reversals is not an uncommon traffic control method used during large-scale evacuations, Fort McMurray's lane reversals were all "unofficial" on the part of the local authorities and the residents [56]. There is limited empirical data on individual driving behaviour during evacuations and as such, it is difficult to compare the lane reversal behaviour observed in the videos to other evacuation events. As the videos were all of individual evacuations and not the evacuation as a whole, it is difficult to determine the impact of these lane reversals on the evacuation, though a previous study did find that it reduced the congestion [56].

There were also driving behaviours observed where evacuees appeared to engage in their own risk assessment before making a driving choice. For example, in Video 1 some residents chose to use the right-most lane which was close to the wildfire instead of using the more congested middle lanes. In other videos, when faced with high levels of traffic congestion, drivers chose to use the opposite lane or drive outside of marked roads. These unique driving behaviours have not been researched in detail. The majority of studies done on traffic during evacuations focus on the traffic flow itself and not on individual driving behaviours enroute. While a study has found that some evacuees may choose to use backroads to avoid congestion [66], more local measures such as lane changes and driving outside unmarked lanes has not been studied.

Not all the driving behaviours were motivated by traffic behaviour and congestion, as fire behaviour also played a role in actions. In Video 6, authorities closed one of the highway lanes due to the fire's proximity to the side of the highway. In Video 3, cars swerved into the opposite lane to avoid flames approaching the right curb. These actions further support the need for coupled modelling as these are actions which may not be represented in current modelling due to a lack of coupling and data. Smoke from the fire was also observed to slow cars down and motivate others to turn on their blinkers. While there have been limited studies on the effects of smoke on driving behaviour in wildfires, it is consistent with results observed in virtual reality experiments on the topic as well as walking speeds in smoke and driving speeds in fog [35].

7. Limitations

This study also contains limitations. It is a limited sample size with seven videos total and five separate evacuations. As such, it is unclear whether the observations made from the videos are representative of evacuations from Fort McMurray of which there were 88,000 people evacuated. While only five evacuation routes were analyzed, behavioural observations were not limited to the occupants of the vehicle but extended to all vehicles featured in the video. Videos were also only of those who evacuated south out of the town and none who evacuated north. While some behaviours were seen in multiple videos, more analysis is needed before they can be determined if they are representative. However, the observations it has found demonstrates that this methodology can produce useful data on behaviours during wildfire evacuations. It is outside the scope of this project to analyze videos from wildfires other than Fort McMurray, however, preliminary observations have found behaviours such as driving outside of marked lanes and lane reversals in videos of other wildfire evacuations such as the 2018 Camp Fire. This suggests that some behaviours may not be unique to a specific wildfire. Additionally, this demonstrates that this methodology can be used for different wildfire evacuations and could be expanded to other types of evacuations.

Another limitation is that as these are videos posted by the evacuee(s) themselves, there may be some bias by the evacuee as to which videos are posted publicly. However, because only their actions are portrayed in the video, the underlying motivations behind the decision-making process are solely speculative by the authors and are without input from the individuals. Another limitation is that the video analyses were all conducted by one person, the author, with no specific methodology for categorizing behaviours under existing frameworks, as one of the goals of this study was to determine if the behaviours observed could be categorized under existing frameworks.

8. Conclusions

In conclusion, the increase in the number and severity of wildfires has also increased the amount of people impacted by wildfires through evacuation. This exacerbates the critical research need for data on human behaviour during wildfire evacuations. Using video analysis of public videos from social media sites, this study observed unusual traffic behaviours across multiple videos of the 2016 Fort McMurray Fire, which included using lanes in the opposite direction and driving outside of marked roads, in response to traffic and wildfire conditions.

This study supports the need for coupled evacuation modelling as unusual traffic behaviours not usually present under normal traffic conditions were observed. These behaviours can also be used to inform evacuation management and planning.

Competing Interests Statement

The authors declare there are no competing interests. John Gales served as an Associate Editor at the time of manuscript review and acceptance; peer review and editorial decisions regarding this manuscript were handled by another Editorial Board Member.

Funding Statement

This work was supported by the Natural Sciences and Engineering Research Council of Canada's (NSERC) Discovery Grant (2022-05335), the NSERC CGS-M graduate scholarship and the Social Sciences and Humanities Research Council of Canada's (SSHRC) Insight Development Grant (430-2020-01070).

Data Availability Statement

Some or all the data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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