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RECONSTRUCTING AN EMERGENCY EVACUATION BY GROUND AND AIR: THE FORT MCMURRAY WILDFIRE

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ABSTRACT

The May 2016 wildfire of Northern Alberta – the costliest wildfire disaster in Canadian history to date – led to an area-wide evacuation by road and air. Traffic count and flight data were used to assess the characteristics of the evacuation, including estimating people movements by vehicle and aircraft. The vehicle counts were first compared to historic values to examine traffic patterns, and were then used to create an evacuation response curve, revealing an expected “S-curve” shape and highlighting how quickly the evacuation occurred. Finally, aircraft data was combined with the vehicle data to construct a cumulative curve 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 quickly removing everyone from immediate danger using all possible exits. While unplanned contraflow added roadway capacity out of Fort McMurray, the secondary route was underutilized, suggesting that traffic routing management may reduce congestion. The evacuation response curve emphasized the volatility of wildfires, with resulting evacuations occurring under greater immediacy than hurricane evacuations. Finally, air transportation played a significant role in this evacuation, indicating that multimodal emergency evacuation plans may be critical for remote communities and sparse networks. These findings may be applied to evacuation planning and policy, to improve their efficiency and efficacy. This study contributes to the evacuation literature by providing a comprehensive empirical analysis of a wildfire evacuation by ground and air, which to our knowledge has not been conducted before.

Keywords: Wildfire Evacuation, Fort McMurray Wildfire, Air and ground evacuation, Evacuation Response Curve

INTRODUCTION

A wildfire discovered on May 1, 2016 in Northern Alberta, Canada, quickly spread and resulted in the evacuation of over 88,000 people from the urban service area of Fort McMurray (*1*). This evacuation lasted five days and resulted in the largest and costliest fire evacuation in Canada to date (*2*). With only one major highway running north-south through Fort McMurray, its remote location only allowed for ground evacuation via the highway; air evacuations were made through the airport, as well as airstrips at oil sands work camps to the north. This paper uses traffic count and flight radar data to assess the characteristics of the evacuation. We have estimated total person movements out of Fort McMurray and created an evacuation response curve, in order to extract useful lessons and insights for future evacuation planning.

Weather-induced wildfires have been part of an increasing trend in weather-related disasters in Canada since the 1960s (*3*). This affirms the importance of preparedness in evacuation and emergency transportation planning as the risk of disasters increase. Transportation engineers, planners, and managers have the responsibility to learn from these incidents for municipal and provincial-level network planning, such that transportation networks are able to transport people away from danger effectively, efficiently, and safely in times of emergencies.

Both air and ground transport modes played important roles in this recent wildfire evacuation, as Fort McMurray was first locally evacuated mainly by highway, while the surrounding region was later evacuated primarily by air as well as highway convoys. We aim to illuminate the characteristics of the evacuation by first assessing the traffic volume data from vehicle counters near Fort McMurray, then creating an evacuation response curve, and finally, estimating total person movements in the evacuation of Fort McMurray and the region by combining air and ground data. This study contributes to the evacuation literature by providing a comprehensive empirical analysis of a wildfire evacuation by ground and air, which to our knowledge has not been conducted before.

LITERATURE REVIEW

Evacuation research in transportation focuses on understanding the mass movements of people in emergency situations, how transportation networks are impacted, and how transportation systems can be better utilized to improve evacuation efficiency (*4*). Data has become more readily available due to technological advances and is used along traditional post-evacuation and stated preference surveys to study evacuation responses (*5*). In recent years, researchers have been able to effectively quantify the temporal and spatial distribution of evacuees leaving during hurricanes with the use of count data from vehicle counters (*5*) (*6*). Wolshon utilized traffic count data to evaluate the impact of the Hurricane Katrina evacuation on the surrounding roadway network, and to evaluate established evacuation plans (*6*). In 2013, Li et al. utilized traffic volume data to quantify the evacuees leaving Cape May County, New Jersey, due to Hurricane Irene, and identify bottlenecks in the transportation network (*7*).

Li et al. also created an evacuation response curve using traffic volume data, and assessed the fit of several common models to the curve shape (*5*). These S-shaped curves are commonly used to model the evacuation demand or response by looking at the cumulative percent of evacuees over time (*5*) (*7*). The S-shape is due to a smaller initial number of evacuees that leave before the evacuation order, followed by a surge of evacuees departing once an official evacuation order is given; this results in a steep rise to the curve that is followed by the slope tapering off as remaining evacuees leave (*8*). Researchers have developed different methods of developing them from statistical distributions or using empirical models (*5*). Researchers have fit curves using the logit function (*9*), Rayleigh distribution (*10*) and Poisson distribution (*11*). Fu et al. also developed an S-curve using a sequential logit model based on household characteristics, the evacuation status from authorities, and storm characteristics, to model when a household will choose to evacuate (*8*).

Current wildfire evacuation research has focused on evacuation of neighborhoods through microsimulation. Cova & Johnson conducted microsimulation of neighborhood evacuation from wildfires by modeling the street network and treating each household as an origin zone that evacuated based on the Poisson distribution (*11*). Cova et al. also conducted an extensive study identifying at-risk neighborhoods in the United States (*12*). However, to our knowledge, there have not been studies documenting the use of data to understand and evaluate evacuation response and behavior. The data used in this study enables us to create an evacuation response curve for a wildfire evacuation.

This study also builds upon the existing literature by using multiple sources of data to quantify total multimodal movement of people out of an evacuation zone. The aforementioned studies on Hurricane Irene and Hurricane Katrina focus on one data source and evacuation by one mode. Additionally, previous evacuation analyses have focused on hurricane evacuations, which have longer prediction times and estimates of time to landfall due to weather forecasting (*6*) (*7*). There was little to no forewarning of the evacuation in this wildfire situation. The evacuation response curve in this wildfire can be compared with S-curve models generally developed for hurricane evacuations, to identify how applicable these models are for evacuations caused by other types of disasters.

BACKGROUND

Geographic context

Fort McMurray, officially an urban service area in the Regional Municipality of Wood Buffalo, is located over 400 km northeast of Edmonton, the capital city of the province of Alberta, Canada. Fort McMurray has a permanent population of 78,382, and a shadow population of 42,606 (within Fort McMurray as well as oil sands project accommodations) in the region, consisting of oil sands camp workers. It is located within a heavily treed boreal forest (*13*) (*14*). Figure 1 shows the region and transportation network providing access to Fort McMurray and surrounding rural communities. The traffic counters are shown by number, and will be discussed in a later section. The oil sands industry serves as the major employer in the region with worksites located to the north of Fort McMurray. The roadways accessing the regional municipality consist of Highway 63 (Hwy 63), a major provincial highway that was in the process of being twinned during the evacuation (*15*) and Highway 881 (Hwy 881), an undivided 2-lane highway. Fort McMurray International Airport (CYMM) provides air services to the region. Several of the oil sands work camps have private airstrips from which air evacuations were conducted, including Shell at Albian (CAL4), Suncor at Firebag (CFG6), and Syncrude at Mildred Lake (CER4). The region is also accessible by winter roads (constructed on ice for use in the winter season), river, and heavy rail; however, these modes did not play a significant role in the evacuation.

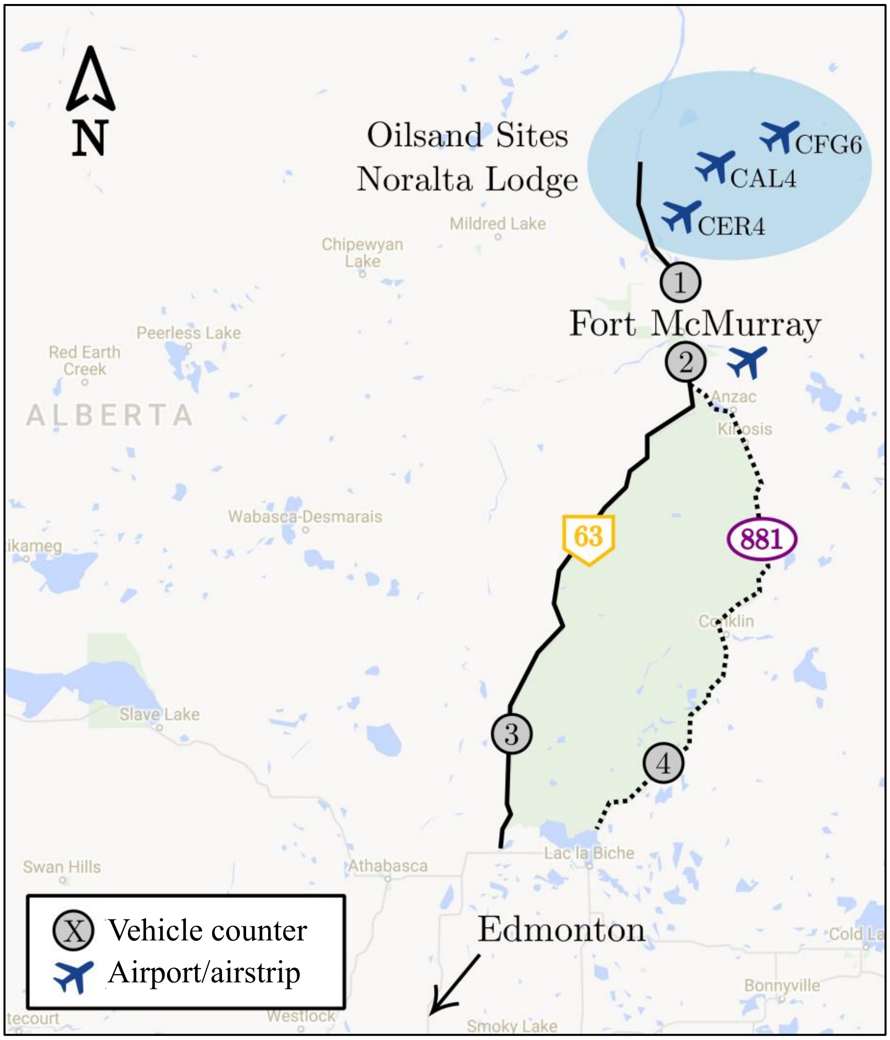


FIGURE 1 Fort McMurray area map.

Wildfire and Evacuation Timeline

The timeline of the wildfire and resulting evacuation was reconstructed using official announcements, news releases, and social media. On May 1, 2016, a wildfire two hectares in size was discovered southwest of Fort McMurray (*16*). This prompted the evacuation of three subdivisions; however our analysis begins on May 3 as these orders included only about 5% of the population (4,500 people) (*17*). Due to the fire's proximity to Fort McMurray, evacuation orders for the southern communities closest to the fire were given on May 3 at 2 pm MDT, while the mandatory evacuation order for all remaining residents was issued at 6:20 pm. This order advised some residents to evacuate north to the temporary Noralta Lodge shelters and oil sands work camps, and others to evacuate south via Hwy 63 (*18*). Social media sources, including the Twitter feeds of 511 Alberta (a government service providing road condition reports) as well as evacuees, indicated that congestion was heavy on Hwy 63 from the afternoon of May 3 until past midnight heading south, and heavy congestion until 8 pm May 3 heading north, with some drivers using inbound lanes to exit Fort McMurray. This is called contraflow operation, where lanes of travel are used in the opposing direction than intended (*19*). Although contraflow has historically been used in hurricane evacuations (*19*), government officials did not plan for contraflow in this evacuation

(Wing Choy, Alberta Transportation, personal communications). Twitter images and correspondence with Alberta Transportation verified that contraflow occurred unofficially from approximately 5 pm May 3 to 1 am May 4, southbound on Hwy 63 south of Fort McMurray, and from 4 to 8 pm north of Fort McMurray heading northbound. Figure 2 shows the fire's proximity to Hwy 63, where visibility was greatly reduced due to smoke and embers. On May 4, residents continued to evacuate, while at 4 pm Fort McMurray International Airport suspended all commercial flights due to the encroachment of the fire towards the airport. By the end of the day, the majority of residents had been evacuated from Fort McMurray.

FIGURE 2 Highway 63 at King Street (used with permission from Global News) (*20*)**.**

As the fire expanded on May 5, Hwy 63 was declared impassible south of Fort McMurray in both directions due to the smoke and fire, leaving people trapped in the northern camps (*21*). During this time, Shell and Suncor began evacuating their employees and Fort McMurray residents that had originally evacuated to their camps by air (from CAL4 and CFG6) to Edmonton International Airport (CYEG) and Calgary International Airport (CYYC) (*16*) (*22*). Syncrude began evacuating all their employees out of their worksite at Mildred Lake from CER4 (*16*) on May 7. Meanwhile, on May 6, the Royal Canadian Mounted Police (RCMP) began escorting platoons of 50 vehicles southbound on Hwy 63, through burning Fort McMurray, to the Hwy 881 junction (*23*). This evacuation continued through May 7 until the morning of May 8, when government statements declared there were no evacuees left north of Fort McMurray (*24*).

DATA

The two main sources of data used in this evacuation were flight data and traffic count data. The two data sources were first cleaned and the counts were roughly compared against those from social media and official government releases.

The flight data for the relevant airports and airstrips, during the timeframe of interest, was obtained for the Canadian airspace system. This flight data utilizes radar transponders in aircraft picked up by signals on the ground to provide a trajectory of each flight. In addition to the trajectory, the data contains an entry for each flight with the airport arrival and departure times, origin and destination airports, and aircraft type used. Entries of flights missing one or more of the aforementioned elements were filtered out, as they rendered the entries unusable. This enabled us to identify flights originating from and destined to the Fort McMurray area, the majority of which were traveling to/from to Edmonton and Calgary.

The passenger capacities of each aircraft type observed in the data were determined, by looking up the respective airlines' fleet listings for each aircraft model's attributes for each flight. Under the circumstances of severe and immediate danger, all passenger flights post-evacuation order are assumed to have been filled to capacity; however, since social media and releases indicated that pets were allowed to take up seats (*22*), a passenger load factor of 0.90 was assumed. The data was then filtered to only include flights to and from airports and airstrips in the region (CYMM, and private airstrips CAL4, CFG6, CER4) during the relevant timeframe. Further grouping of this data by departure times allows for hourly volumes of evacuees by air. Throughout the several days of the evacuation, 388 flights departed from Fort McMurray International Airport and the three private airstrips.

Alberta Transportation provided traffic count data collected from conventional automatic traffic recorders on Hwy 63 and Hwy 881. The recorders at each count station (locations shown in Figure 1) provided hourly totals of vehicles in each direction. There are count stations immediately north (labeled 1) and south (labeled 2) of Fort McMurray, as well as counters further south on Hwy 63 (215 km) and Hwy 881 (250 km). Since Hwy 63 provides the only highway access in and out of Fort McMurray, the vehicle counts recorded by counters 1 and 2 represent all persons leaving Fort McMurray by ground. Due to the remoteness of the region, as well as official notice by 511 Alberta that Hwy 63 was closed except for evacuation use, background traffic is assumed to be negligible and to only consist of emergency vehicles during the evacuation. An average vehicle passenger occupancy of 2 persons per vehicle was used to estimate the number of persons evacuating by passenger car. The 2015 Municipal Census of the Regional Municipality of Wood Buffalo reports an average of 2.99 people per dwelling in Fort McMurray (*14*), while Albertans averaged 1.87 vehicles per household in 2009 – this results in an average of 1.6 persons per vehicle (*25*). Although our occupancy of 2 persons per vehicle is somewhat higher than this figure, we assumed that urgency and uncertainty caused by the impending danger may have encouraged residents to leave together.

Contraflow vehicle counts were included in the directional count data. Vehicle counts recorded by counter 1 for the southbound lanes north of Fort McMurray were included as evacuee counts from 4 – 8 pm. Similarly, vehicle counts recorded by counter 2 for the northbound lanes were included from 5 pm – 1 am.

Estimated passenger load factors and occupancies applied to hourly aircraft and vehicle counts were used to estimate the total flow of evacuees, which is discussed below.

ANALYSIS AND DISCUSSION

We first examine the evacuation count data by both ground and air, and then create an evacuation response curve to assess the immediate evacuation of Fort McMurray and lastly construct a cumulative curve that estimates total evacuees.

Hourly Vehicle Volumes

Figures 3 and 4 show two days (May 3 and 4) of vehicle volumes from counter 2, just south of Fort McMurray, and counter 4, located on Hwy 881, respectively. The plots also display vehicle volumes averaged over the three months on Tuesdays and Wednesdays (the weekdays on which May 3 and 4 fell in 2016) prior to evacuation; these are assumed to represent typical daily traffic on these facilities. It can be observed that the historic and evacuation count curves follow closely until about 2 pm on May 3, when the evacuation volumes increase significantly due to the start of evacuations of neighborhoods closest to the fire (*16*).

In Figure 3, the orange curve represents total vehicle volumes for both the regular and contraflow lanes from 5 pm May 3 to 1 am May 4. The volumes peak at about 2,600 vehicles per hour on May 3 between 7 and 8 pm, with approximately one-third in the NB lanes contraflow and two-thirds in the southbound lanes. By 6 pm on May 4, total volumes approach zero, reflecting that vehicles were no longer exiting Fort McMurray southbound.

From Figure 3 we can observe that contraflow in this circumstance was effective in providing additional capacity, at a time when traffic congestion was significant and adding to the panic. However, even greater capacity (and safer operations) may have been provided if a northbound lane had been officially designated and controlled for planned contraflow operations.

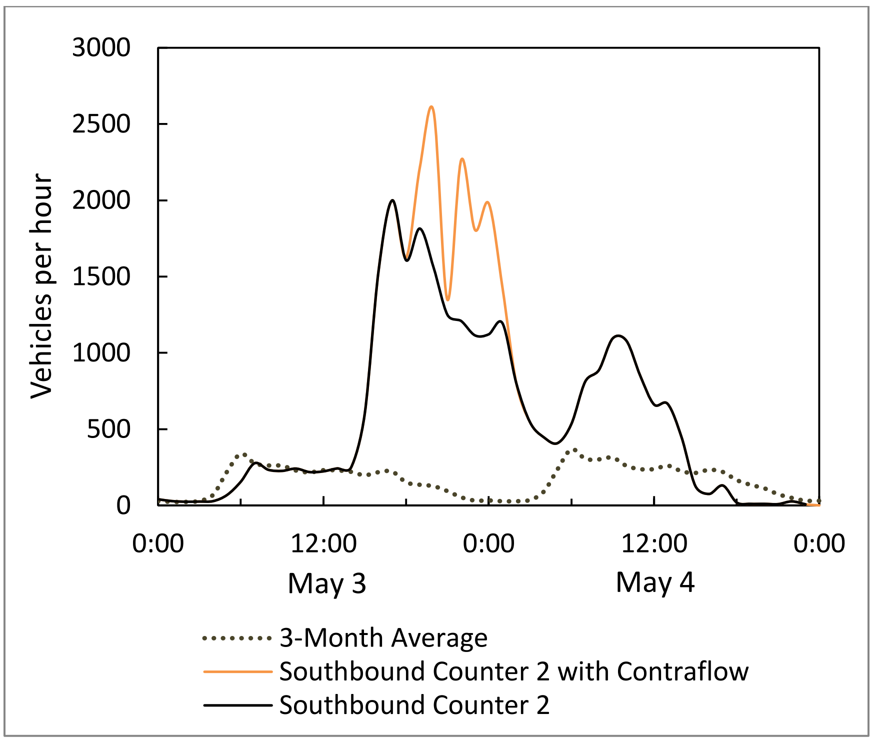


FIGURE 3 Hourly vehicle volumes, southbound on Hwy 63, May 3-4 (counter 2).

Figure 4 displayed southbound vehicle volumes on Hwy 881, at counter 4, on May 3 and 4. Hwy 881 branches off from Hwy 63 south of Fort McMurray; it experiences significantly lower daily vehicle counts compared to Hwy 63, as a more remote undivided 2-lane highway. In an analysis examining the use of secondary highways during hurricane evacuations, Wolshon and McArdle revealed that although historically underused, secondary highways played a significant role during Hurricane Katrina (*26*).

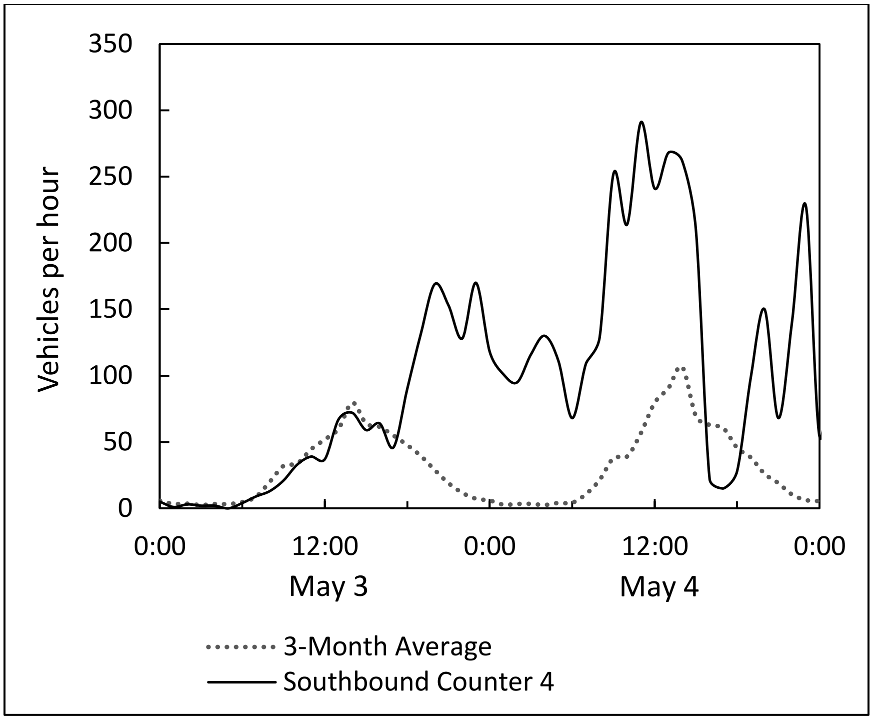


FIGURE 4 Hourly vehicle volumes, southbound on Hwy 881, May 3-4 (counter 4).

In Figure 4, several observations can be made: evacuation volumes peaked at almost 300 vehicles per hour compared to historic peaks of about 100 vehicles per hour; this took place with no evidence of contraflow. The sharp decrease in volumes at 4 pm on May 4 occurred as a result of a fatal collision on the highway (*27*). Finally, since the volumes in Figure 3 drop to zero after 6 pm due to the end of the evacuation by private vehicle, we would expect to see the same on Hwy 881 as well (with a travel time delay due to the counter's location 250 km south of Fort McMurray). However, they increase again after 6 pm due to an additional evacuation order for communities south of Fort McMurray including Anzac, Gregoire Lake Estates, and others along Hwy 881 (*16*).

Evacuation Response Curve

Evacuation response curves are commonly used in evacuation research to represent the response and rate of evacuees leaving a region (*5*). An evacuation response curve developed from hourly volumes is shown in Figure 5. This figure represents vehicles leaving Fort McMurray as part of the first stage of evacuation (i.e. before Hwy 63 was shut down). The x-axis is in hours while the y-axis represents the percentage of total evacuated vehicles exiting Fort McMurray after the evacuation order for the southern communities was declared. We create a cumulative vehicle count curve for May 3-4 (as Hwy 63 was closed by May 5) using data from Hwy 63 counters (1 and 2 in Figure 1). Recall that contraflow occurred from 4-8 pm on May 4 at count station 1, and 5 pm May 3 to 1 am May 4 at count station 2. We constructed the curve assuming that all vehicles that traveled north out of Fort McMurray did not travel back south through the city later.

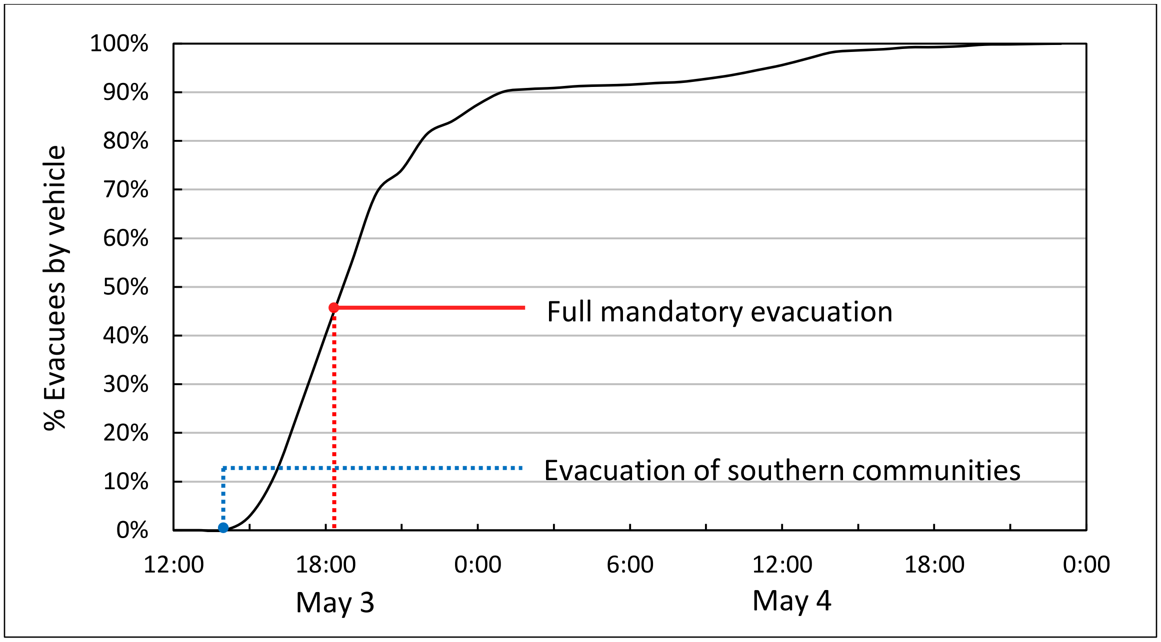


FIGURE 5 Cumulative curve of vehicles leaving Fort McMurray, May 3-4 (counters 1 & 2).

Based on the quick initiation of the evacuation and the slope of the curve, it is observed that the immediate evacuation from Fort McMurray occurred extremely quickly. Figure 5 reveals that about 45% of total departing vehicles did so by the time the full mandatory evacuation order was called, while 80% had done so by 9-10 pm. This indicates that a significant portion of Fort McMurray evacuees departed after the order for the southern communities. By midnight on May 3, almost 90% of vehicles had departed. The slope of the curve begins to decrease (i.e. flatten) after midnight on May 3. However, it increases again for a short time mid-morning on May 4, indicating that some residents waited until the morning of May 4 to depart. This figure suggests that during the contraflow periods (4-8 pm to the north, and 5 pm May 3 to 1 am May 4 to the south), a significant portion of the vehicles were able to leave.

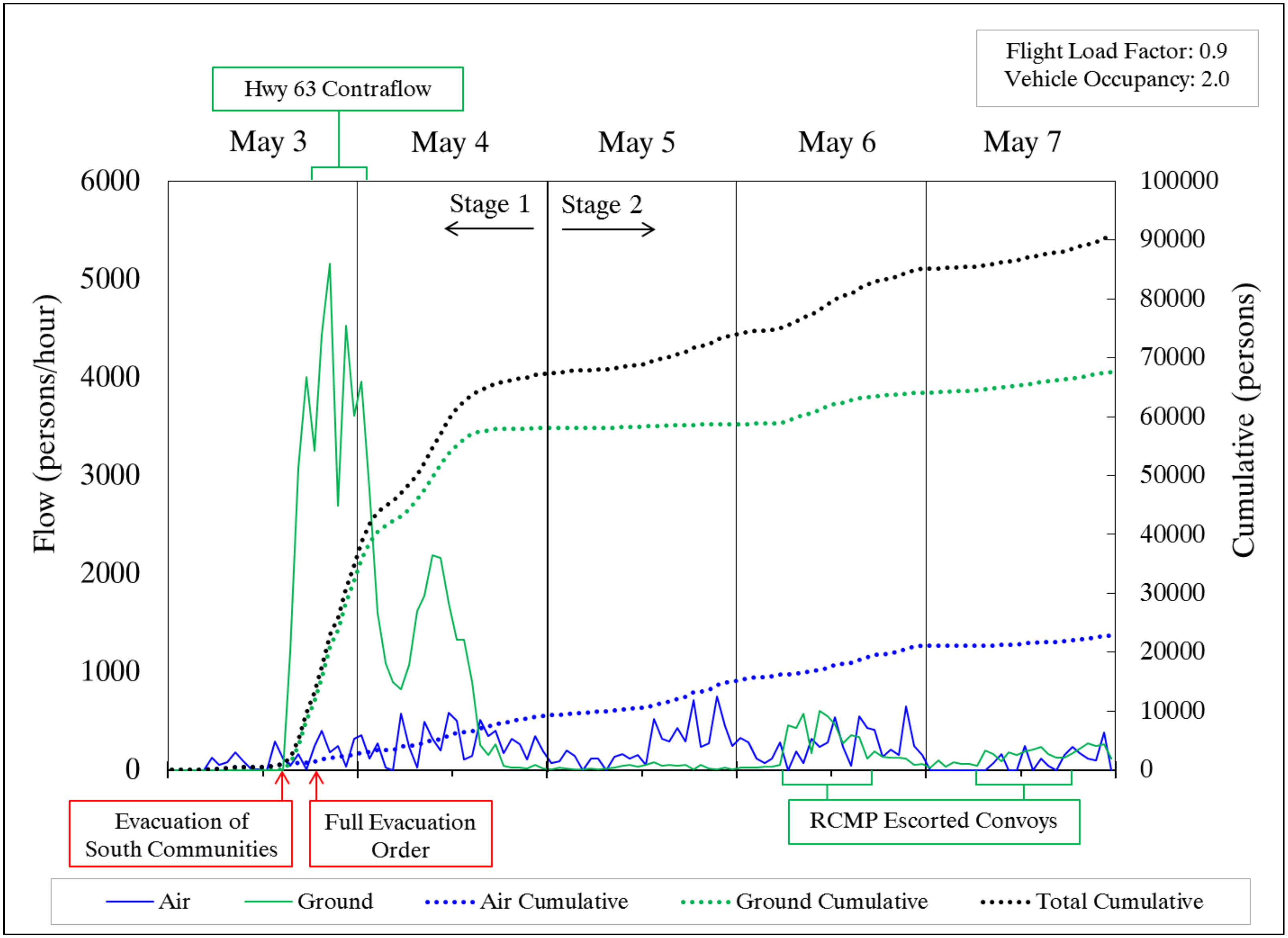
The resulting evacuation response curve has an "S" shape similar to those of U.S. hurricane evacuation curves seen in previous literature (*5*) (*7*). However, there are fundamental differences between those curves and this wildfire response curve. Hurricane evacuations occur with a much longer lead time; therefore, warnings and evacuation orders can be given out several days (if not weeks) in advance of landfall. In hurricane evacuations, 15-20% of evacuees leave before the mandatory evacuation order (*8*). In contrast, wildfires spread extremely quickly and their paths can be highly unpredictable. This was certainly the case in this wildfire event, where residents had time in the order of hours to evacuate. As a result, we observe that the left tail of the curve is very short; then, the slope becomes very steep very quickly after the official evacuation orders are made. Combined with a sparse transportation network to carry evacuees, the short warning time for wildfire evacuation in this remote northern region presents many complex policy and operational challenges for responsible agencies.

Estimated Cumulative Evacuees from the Region

The following analysis combines the vehicle counts and aviation data to provide a comprehensive overview of the evacuation from the larger impacted region, including the camps to the north. This analysis focuses on a larger timeframe and land area, illustrating the two stages of evacuation. The previous analysis was of Stage 1, which focused solely on the immediate evacuation of Fort McMurray while Stage 2, which is introduced below, focuses on evacuating residents from temporary shelters in the northern work camps via vehicle convoys and aircraft.

During the initial evacuation, officials instructed some residents to evacuate north to Noralta Lodge, while others were instructed to evacuate to the south (*18*). Hence, the evacuation took place in two stages: first, the immediate evacuation of Fort McMurray occurring from May 3-4, and second, the regional evacuation occurring from May 5-7. Everyone that drove south from Fort McMurray on Hwy 63 after the evacuation order on May 3 was considered to have evacuated the region. Those who drove north were presumably only able to evacuate the region via airlifts from the private airstrips, or the RCMP-led convoys due to restricted passage through Fort McMurray – no other modes of transportation were available in the area at the time.

Figure 6 shows the estimated counts of evacuees out of the region by the two modes (ground and air), over the entire five-day evacuation (from May 3-7), both as hourly (left y-axis) and cumulative (right y-axis) volumes. The cumulative count curve by ground only includes the vehicle count data from counter 2 south of Fort McMurray. This was done in order to prevent double counting evacuees who initially evacuated north from Fort McMurray and subsequently left the region by convoy or air. As Hwy 63 is the main route through Fort McMurray, on May 6 and 7 evacuees exiting south via RCMP-led convoys would also have been counted at counter 2. The cumulative count curve by air includes all hourly counts of evacuees (as estimated from load factors applied to aircraft passenger capacities) leaving CYMM, CAL4, CFG6 and CER4 from May 3-7.



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2 **FIGURE 6 Estimated evacuee counts (by ground and air) from Fort McMurray and surrounding communities, May 3-7.**

Figure 6 indicates that the predominant mode of evacuation was by vehicle immediately after the mandatory evacuation order was called. The rate of departures by vehicle then drops through the early hours of May 4, to increase again later that morning, suggesting that people waited until typical waking hours to leave Fort McMurray (Figure 6). This is consistent with Figure 5.

After conclusion of the Fort McMurray urban area evacuation on May 4, the rest of the (regional) evacuation was conducted as a "controlled" departure where remaining evacuees either left by aircraft or vehicle convoys. It is observed that the "ground cumulative" is nearly flat as Stage 2 begins (the small vehicle numbers counted consist of a handful of very late evacuees and emergency vehicles). It is notable that the "air cumulative" curve does not exhibit the same sharp S-shape of vehicle evacuations ("ground cumulative"), due to two reasons. Air was not a primary mode of evacuation during Stage 1. More importantly, aviation is a heavily controlled and regulated system, and passengers do not control aircraft movements. The vehicle volumes observed on May 6 and 7 represent 50-car convoys escorted by RCMP emergency personnel and helicopters (*24*). The Government of Alberta stated that over 2,400 vehicles were escorted on May 6 in convoys starting at 4:30 am (*24*); the traffic count data puts this number at about 2,600 from 4 pm–12 am May 6, as this includes the escort (and other emergency) vehicles.

The private airstrips located at the work camps allowed for evacuations by aircraft, which was a critical part of Stage 2. Flights evacuated both area residents and oil companies' employees (*22*) (*16*). The traffic counters recorded 12,000 vehicles travelling north from Fort McMurray in the first stage of the evacuation (May 3-4); 2,600 vehicles were eventually evacuated back south via convoy. This is comparable to official statements indicating that 17,000 people evacuated northbound (*28*). These numbers also indicate that people originally evacuated north in 9,400 vehicles were later evacuated via air. Without air evacuations, an additional 190 50-vehicle convoys would have been required. This would have significantly lengthened the regional evacuation, and possibly have been infeasible due to safety concerns.

Overall, we estimate that 90,000 evacuees were displaced from Fort McMurray and the northern oil sands work camps. Of these, 58,000 immediately evacuating south in Stage 1, while in Stage 2, 23,000 and 9,000 evacuated by air and ground convoys, respectively. A notice from the Regional Municipality of Wood Buffalo reported the number of evacuees to be 88,000 from the Fort McMurray alone (*1*). Our estimate is higher as it includes evacuees in the northern oil sands work camps and is based on an assumed vehicle occupancy and flight load factor. However, we believe our evacuee estimates to be reasonable given their similarity to numbers reported through social media and the news media. Also, this analysis has illuminated the strategy used for this wildfire evacuation; there was an initial ground evacuation (by personal vehicle) out of Fort McMurray that occurred quickly (about 1.5 days), and a secondary evacuation out of the surrounding region that occurred at a much slower, supervised, and controlled rate over the following three days.

CONCLUSIONS

Our empirical analysis of the May 2016 Fort McMurray wildfire evacuation investigated the movements of people by both ground and air, in order to explore the characteristics and timeline of this recent evacuation. This paper first assesses count data from vehicle counters around Fort McMurray to create an evacuation response curve, and then estimates the total person movements out of Fort McMurray and the region by combining air and ground data.

The vehicle count data revealed that directing people out of the city in both directions, combined with driver-initiated contraflow, contributed to the safe removal of citizens from immediate danger. The Stage 1 cumulative count curve captured the immediacy of this evacuation response; the curve's S-shape had a much shorter left tail and was far steeper than those seen in the previous hurricane evacuation literature. This was attributed to the proximity and speed of the wildfire prompting quick response. The analysis of cumulative evacuees leaving the region showed that the evacuation occurred in two stages. In addition, as expected, the cumulative curve of air evacuees did not exhibit the S-curve shape due to the controlled nature of the aviation system.

Our analysis of Canada's largest wildfire evacuation to date has highlighted five key implications that can help shape future evacuation plans and policies. Firstly, this evacuation occurred in a two-stage response, due to the rapid spread of the wildfire. Each stage played its own role in the emergency response. Stage 1 removed Fort McMurray residents from immediate danger by utilizing as much of the transportation network as possible, while Stage 2 served to move evacuees at the work camps to safety via vehicle convoys and aircraft. Future evacuation strategies may formally incorporate such plans as part of a first stage evacuation, as a means of removing people from immediate danger to intermediate locations as quickly as possible.

Secondly, we observed that Hwy 881 was underutilized during the initial 12 hours of the evacuation. Future evacuation policies might include procedures for traffic routing in order to more effectively utilize capacity and reduce congestion and panic.

Thirdly, the spontaneous contraflow operations were helpful in moving people away from immediate danger; however, its uncontrolled nature may have created unsafe traffic situations and blocked access for emergency service vehicles. Future plans could include strategies to quickly set up and manage controlled contraflow operations in coordination with traffic routing plans.

Fourthly, wildfires allow only very short warning times that result in highly urgent evacuation responses. Combined with the remoteness of many communities in Alberta (and throughout Canada), and the increasing frequency of climate change-induced weather events, this highlights the need for high-quality provincial and municipal evacuation plans, as well as a better understanding of our existing transportation network. More specifically, we must better understand the characteristics of our existing infrastructure (in terms of capacities and redundancies) to handle emergency evacuations, and identify infrastructure investment needs.

Lastly, we found that air transportation played a significant role in this evacuation. In a province with many remote communities with only sparse connections to the provincial highway network, there may be a heavy reliance on air transport in emergency situations. Multimodal emergency evacuation plans that utilize intermodal capabilities may provide great benefits in such situations.

Our study contributes to the evacuation literature by offering an empirical analysis of a multimodal evacuation due to wildfire which, to our knowledge, has not been conducted before. Based on our findings from this study, there is much work left to be done. Topics include fitting models or functions proposed for hurricane evacuations to this wildfire evacuation response curve, and a further review of wildfire evacuation strategies, and surveys to analyze residents' responses and reentry. Further research might also investigate comprehensive planning strategies to maximize person-throughput using all transportation facilities and modes during evacuations. In addition, there is the question of whether this type of analysis can be applied to less remote regions with more complex roadway networks than Fort McMurray. For this analysis, drawing cordons (or, evacuation boundaries to count vehicles and/or persons that have departed) to facilitate cumulative evacuation curves was done easily; this task would be more involved for regions with more complex transportation networks. However, with good data quality and sources (possibly even including "tracking" data such as Bluetooth, GPS, and cell phone signals), and reasonable assumptions, we believe this method can be adapted to more complex networks, including those of Edmonton and Calgary, Alberta.

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