

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

## Progress in Disaster Science

journal homepage: [www.elsevier.com/locate/pdisas](http://www.elsevier.com/locate/pdisas)

# Modeling the impact of traffic management strategies on households' stated evacuation decisions

Ruijie Bian<sup>a,\*</sup>, Pamela Murray-Tuite<sup>b</sup>, Praveen Edara<sup>c</sup>, Konstantinos Triantis<sup>d</sup>

<sup>a</sup> Louisiana Transportation Research Center, Louisiana State University, United States of America

<sup>b</sup> Glenn Department of Civil Engineering, Clemson University, United States of America

<sup>c</sup> Department of Civil and Environmental Engineering, University of Missouri, United States of America

<sup>d</sup> Grado Department of Industrial and Systems Engineering, Virginia Tech, United States of America

## ARTICLE INFO

### Keywords:

Hurricane evacuation  
Traffic management  
Stated evacuation decisions  
Contraflow

## ABSTRACT

Evacuation traffic management has been implemented in large-scale disaster evacuations (such as hurricanes) to facilitate traffic flow and reduce travel delay. The outcomes of these strategies were quantified via traffic simulation but were assumed to have no/limited impacts on households' evacuation-related decisions. This study analyzed and modeled the impact of these strategies on five evacuation related household choices (evacuate/stay, departure time, route, vehicle, and destination) separately based on 415 responses collected from a stated preference survey. The survey was conducted in 2017 in coastal areas near Hampton Roads. Traffic management is likely to motivate some (32%) households to evacuate instead of sheltering in place. In addition, not all households take the interstates with traffic management even though route choice is the most likely to be affected by traffic management. Households need more information for their departure time and destination choices in response to traffic management since they are more likely to feel uncertain of the impact of the strategies on these decisions. Such uncertainty in departure time and destination choice is especially true for those who evacuate late and for those who choose accommodations other than the home of friends/relatives. Emergency management agencies should also be aware that some households may intentionally depart before traffic management starts. Among the five choices, vehicle use is the choice that is least likely to be affected. All the above-mentioned findings potentially affect parameter specifications in evacuation traffic simulation studies. This study then used multinomial logit models to estimate the impacts of traffic management on each of the five evacuation related choices. The model estimation results can help improve evacuation demand predictions and guide evacuation information dissemination.

## 1. Introduction

During hurricane evacuations, transportation agencies implement traffic management strategies to facilitate the movement of the population away from coastal areas at risk. Contraflow (i.e., reversing the traffic direction of inbound lanes) and EvacuLanes (i.e., using shoulders in the outbound direction), typically implemented on limited access roadways, add extra outbound capacity to the highway system. Ramp closures can help smooth traffic flow, control access to contraflow facilities, and prevent evacuation traffic's access to dangerous areas [1]. On other roadway functional classes, evacuation traffic management strategies include: 1) implementing road closure to keep people out of hazardous areas and limit through traffic; 2) changing signal timing

plans at intersections to help increase outbound travel capacity; and 3) using manual (police) control at intersections to help regulate the traffic and reduce conflict points [1]. Crossing elimination, removing some intersection movements, also reduces conflict points. These operations have been publicized over two decades [2]. Households are expected to have different reactions to traffic management strategies implemented during hurricane evacuation, like they do to many other emergency management decisions (such as issuing an evacuation order). Some members of the public even have concerns about evacuation traffic management [3]. Major concerns include: traffic management strategies may attract more people to evacuate instead of sheltering in place and that route, as a consequence of traffic management strategy implementation, may attract more traffic [2,3]. If these concerns are realized,

\* Corresponding author.

E-mail addresses: [rbian1@lsu.edu](mailto:rbian1@lsu.edu) (R. Bian), [pmmurra@clemson.edu](mailto:pmmurra@clemson.edu) (P. Murray-Tuite), [edarap@missouri.edu](mailto:edarap@missouri.edu) (P. Edara), [triantis@vt.edu](mailto:triantis@vt.edu) (K. Triantis).

<https://doi.org/10.1016/j.pdisas.2022.100246>

Received 21 December 2021; Received in revised form 26 June 2022; Accepted 2 August 2022

Available online 8 August 2022

2590-0617/© 2022 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

evacuees may experience more congestion and longer travel times due to the increased demand and route selection.

So far, the evaluation of evacuation traffic management strategies has largely been based on total evacuation time or network clearance time, which assumed evacuation demands do not change and/or applied shortest path routing strategies in traffic simulation [4]. Traffic simulation study results showed that evacuation traffic management strategies increase road capacity and shorten total evacuation time [1,3,4]. However, evacuation behavioral studies have not fully addressed the question of whether/how traffic management strategies affect evacuees and their evacuation-related choices. To explore these effects, this paper studied and modeled (with a multinomial logit formulation) household responses to the implemented traffic management strategies in a hypothetical Category Four hurricane evacuation scenario. The data was collected from a mail-based behavioral intention survey receiving 415 eligible responses from households living in the Hampton Roads, VA area in 2017. More details about the survey are presented in Section 3.

The rest of the paper is organized as follows. Section 2 presents a review of studies that examine evacuation traffic management strategies and common factors considered in modeling household evacuation-related choices in general. Section 3 describes the household survey conducted in the Hampton Roads area and statistically analyzes household responses to traffic management strategies. Section 4 presents modeling results with parameter interpretations and discussions. The last section provides conclusions and future directions.

## 2. Literature review

### 2.1. Quantification of the impacts of traffic management via simulations

Traffic and transportation engineers became more involved in evacuation studies since Hurricane Floyd (1999) because of the heavy traffic jam that occurred during the evacuation [2,5]. Traffic management strategies were expected to alleviate the situation but few states in the U.S. had a traffic management plan for hurricane evacuation at that time [2]. Since then, researchers have been striving to propose, evaluate, and improve evacuation traffic management plans by quantifying their effectiveness for different storm scenarios and/or implementation configurations [6–10].

However, there are limitations to the previous simulations. First, the routing algorithms embedded in the simulation tools are typically based on a form of optimality that assumes drivers are fully aware of the traffic conditions on all available paths [11,12]. Traffic volume thus generally increases on routes with contraflow implementation [6]. Alternatively, evacuees have been assumed to follow prescribed evacuation routes. However, some drivers were found not to comply with evacuation route recommendations [13], while some others preferred taking an interstate route despite its congestion [5]. Fang and Edara illustrated the differences in evacuation performance estimates resulting from user equilibrium and system optimal route choice assumptions [14]. Some later simulation studies began to incorporate additional parameters, such as the percentage of drivers knowing the traffic condition and their compliance towards evacuation instructions [15]. Some behavioral studies investigated factors that could potentially affect route choice behavior. Lindell et al. found evacuees based their route choices on their familiarity and prior perceptions (about travel time, safety, and convenience) of routes [16]. Wu et al. suggested evacuees based their route choices on their past experiences, en-route traffic conditions, and route recommendations (from media and authorities) [17]. Assuming evacuees exclusively rely on any one of these factors will lead to inaccurate findings [17]. Based on this finding, traffic management strategies are highly likely to affect evacuees' route choices because the strategies would influence traffic conditions and route recommendations. With behavioral data, a step beyond setting up driver group percentages in traffic simulation is to have models predict route choice behavior at a disaggregate level. Chang et al. considered evacuation experience,

expected travel time to the destination, and willingness to use the recommended route in modeling household interstate choice behavior [18]. The three factors all increased the likelihood for households to take interstates. While enroute, length of delay and alternate route information (medium and content) in response to evacuation congestion could encourage route changes [19]. However, these considerations only account for the general travel time effects of congestion and do not explicitly account for the direct effects of traffic management strategies on route selection.

Second, evacuation traffic simulation studies seldom considered whether and how the implemented traffic management strategies could influence other choices in household evacuation plans. For example, past evacuation traffic simulation studies implicitly assumed that implementing traffic management strategies would not affect the total evacuation demand. Thus, with capacity added from contraflow lanes, implementing contraflow on certain routes generally improves travel speed and shortens travel time [8]. Besides route choice [18,20–22], household evacuation plans also involve the following choices. The evacuate/stay decision governs whether a household will leave the area [23–26]. Accommodation choice indicates the type of facility where the evacuees will stay [27,28], while destination indicates the location (e.g., city) of the accommodations [29,30]. The travel to these destinations is based on travel mode [31,32] and the number of vehicles for households who travel by personal vehicle [33,34]. When these trips begin is based on households' choices of departure time [35,36]. The most notable influence from authorities on household evacuation plans perhaps is whether a mandatory evacuation order is issued [37]. This factor was considered by most household evacuate/stay models. Households' responses to a given mandatory evacuation order are also consistent in both hypothetical and actual cases. Likewise, households may react to traffic management strategies implemented by authorities. Knowing that such strategies are being implemented could shape risk perceptions by providing cues that others are taking the hurricane threat seriously. Some households may update their evacuation plans accordingly. Household evacuation plan updates in turn affect traffic loadings onto the road network and thus affect evacuation traffic simulation results. However, this topic has not been explored yet by evacuation traffic simulation studies.

Lastly, the major metric used in evaluating the impacts of alternative evacuation traffic management strategies is the system-wide network clearance time. If travel time is not the only factor considered by households in making evacuation-related decisions, travel time should not be the only metric in evaluating the impacts of evacuation traffic management strategies. The percentage of households who are likely to be affected by traffic management strategies and the amount of time or expense households would lose from changing their evacuation plans are factors worth investigating.

### 2.2. Factors affecting household evacuation-related choices

As stated in the previous section, past studies have not looked into modeling the influence of traffic management strategies on household evacuation-related choices. This section provides a broader review – discussing common factors considered in modeling household evacuation-related choices in general (i.e., without taking traffic management influence into consideration). This section only provides relatively brief discussions in considering the numerous studies investigating each of the evacuation-related choices. Readers are encouraged to refer to past review studies for more thorough discussions [1,4,12,24,25,37].

#### 2.2.1. Risk, perception, and past experience

Risk factors (such as the storm category and the storm's distance from one's residence) objectively reflect the characteristics of an approaching storm. Risk factors are outstanding predictors in estimating household evacuation-related choices [5,16,23]. The stronger a storm

and the closer its proximity, the more likely that households will evacuate and depart earlier before the storm landfall.

Perceptions reflect households' subjective interpretations to an approaching threat and other information they received. Lindell and Perry's Protective Action Decision Model classified perceptions into three types – risk perceptions, protective action perceptions, and stakeholder perceptions [38,39]. Risk perceptions describe how households perceive the characteristics of an approaching threat. Protective action perceptions describe how households perceive the characteristics of a protective action: its effectiveness, cost, required knowledge, etc. Stakeholder perceptions refer to how households perceive the characteristics of stakeholders (such as authorities and news media): their expertise, trustworthiness, and protection responsibility. In Lindell and Perry's PADM [38], these three perceptions are not mathematically combined but rather are part of individuals' mental models and are considered the perceptions that form the foundation for a behavioral response when combined with situational impediments and facilitators.

Past experiences affect households' perceptions and/or attitudes towards a threat [40]. Factors reflecting past experiences take various forms. Measurement of experience may be as simple as whether a household experienced a storm or evacuated before. It may include experience details, such as unnecessary evacuation [41], travel delay [42], and experiencing injury/death [43]. Measurements may also involve the recency and frequency of the experience, such as the last time a household experienced a storm and the number of their storm/evacuation experiences [43]. However, some studies found that experience variables had a moderately consistent nonsignificant effect on evacuation related choices [25].

### 2.2.2. Social, economic, and demographic factors

Social, economic, and demographic factors are relatively weaker predictors compared to risk and risk perception factors [23,25]. Social, economic, and demographic factors were also reported as having inconsistent significance and parameter signs by past studies [37]. However, some past studies suggested that these factors seem to be more consistently related to the psychological variables that predict evacuation choices (i.e., indirect effects) [44,45]. This section presents variables that were typically considered and common explanations for these variables.

Social factors (such as household size and housing tenure) reflect how closely households may connect with local communities, which facilitates their abilities to understand an approaching hazard and acquiring additional information or resources [46,47].

Economic factors (such as income, education level, and home ownership) reflect the resources a household owns to facilitate their evacuation. For example, compared with lower income households, households who earn higher income were more likely to evacuate [48], more likely to evacuate earlier before a storm landfall [35], more likely to take a taxi instead of using other public modes [32], and more likely to evacuate to hotels/motels [31]. However, resource ownership could be impediments preventing households from evacuation due to resource protection concerns, such as protecting owned houses from storm impacts [49].

Demographic factors (such as age, gender, and ethnicity) were considered as proxies for hidden factors. For example, elderly individuals were considered less likely to evacuate because of physical impairments and medical conditions [50]; females were considered more likely to evacuate because of care-giving roles and greater risk perceptions [51]; minority groups were considered less likely to evacuate because of language barriers and limited social contacts [52].

There are some other factors reflecting household characteristics, such as the presence of children, disabled persons, or pets. These factors were tested and included in past modeling works because of households' safety concerns for children [50], longer mobilization times and transportation challenges [53], and accommodation challenges [16].

## 3. Survey and data descriptions

A survey was distributed to 2500 randomly selected households living in the Hampton Roads, VA area in 2017. The survey sample was purchased from Genesys, a branch of the Marketing Systems Group, which uses the U.S. Postal Service's address database system to select random addresses for research purposes. Respondents had to be at least 18 years old to participate in the survey. The survey was distributed by following the Dillman procedures to achieve a higher survey response rate: deploying respondent-friendly surveys, making four contacts through first-class mail, using stamped return envelopes, applying personalization of correspondence, and preparing prepaid financial incentives [54]. The research team conducted several rounds of focus group and pilot survey testing to ensure that the questions were easily understandable. Additionally, the survey involved five contacts via mail. An initial contact postcard was mailed out indicating that participation in a scientific research study was being requested. One week after the postcards were sent, the first wave of surveys was mailed out including a one-dollar bill incentive and a stamped return envelope. Two weeks later, a second wave of surveys was mailed out and a final, third wave was sent out two weeks after that. Two weeks after the third wave, a final reminder postcard was sent. To ensure personalization, the survey began with a note from the project's principal investigators. The total sample size (n) for the survey was 415 and corresponded to a 19% response rate; a cooperation rate of 96%; a refusal rate of 1%; and a contact rate of 20%.

Survey questions were presented in blocks in the following order: 1) risk perceptions and past experiences, 2) evacuation-related choices made in a hypothetical Category Four hurricane scenario with a mandatory evacuation order issued (called "initial decisions" in the following text), 3) responses to traffic management strategies to be implemented in the described scenario, and 4) household socio-demographic characteristics.

### 3.1. Household characteristics

Table 1 shows descriptions of variables included in the final models. Some major findings from the survey responses are summarized below. About 75% of the respondents thought they would be impacted by a storm in five years. If a hurricane were to impact them, 90% of the respondents thought they were likely to experience property damage and 8% thought they were likely to experience injury/death. Regarding their prior experience, 58% faced property damage while a few of them (3%) suffered injury to self and/or injury or death of a friend or relative. The percentage of respondents who chose to stay when evacuation was recommended in a previous storm was 27%. Some highlights in the demographic profiles of respondents showed that 1) the average age of all respondents was around 58 years old; 2) the average length of residence in the Hampton Roads area was 33 years; 3) the gender discrepancy of respondents was not large (54% of them were male); 4) only 10% of them were single; 5) 51% of them had a pet; and 6) the average household size and the average household vehicle ownership were both over two but the average number of drivers was less than two, which meant some households may have to leave some of their vehicles behind during evacuation. Other interesting findings included: 1) 91% of the respondents claimed they had an evacuation plan; 2) the average expected length of evacuation travel delay was about four hours; 3) 52% of respondents would choose to evacuate during daytime (6 am to 6 pm); and 4) only 9% of the respondents thought the government had more responsibility (than the household) to ensure people have the resources to evacuate.

Survey data were weighted to improve the representativeness of survey respondents in the population. According to the responses, 41% of the households had a household member over age 65, 1.3% of them did not own any vehicles, and 88.4% of them owned their homes. However, data from the 2017 American Community Survey (ACS)

**Table 1**  
Variable Descriptions.

| Variable  | No. of observations | Range         | Mean   | Std. Dev |
|---|---------------------|---------------|--------|----------|
| <b>Risk perceptions and past experiences</b>  |                     |               |        |          |
| Perception of injury/death (1 = likely to experience injury/death in a storm)                   | 313                 | [0,1]         | 0.08   | 0.27     |
| Expected travel delay (1 = yes)   | 336                 | [0, 1]        | 0.89   | 0.30     |
| Chose to stay when evacuation was recommended before (1 = yes)                                  | 369                 | [0, 1]        | 0.27   | 0.44     |
| <b>“Initial decisions” made before knowing about traffic management strategy implementation</b> |                     |               |        |          |
| Departure day (1 = 3+ days before)  | 338                 | [0, 1]        | 0.19   | 0.39     |
| The number of vehicles taken during evacuation  | 338                 | [0,3]         | 1.35   | 0.57     |
| Chose the home of a friend/relative as accommodation (1 = yes)                                  | 345                 | [0, 1]        | 0.53   | 0.50     |
| <b>Socio-demographics</b>   |                     |               |        |          |
| Annual household income (in \$1000)   | 357                 | [7.5, 250]    | 101.26 | 64.81    |
| Age (in years)  | 366                 | [25, 95]      | 58.68  | 14.93    |
| Pet presence (1 = yes)  | 368                 | [0, 1]        | 0.51   | 0.50     |
| Distance to the coast (in miles)  | 378                 | [0.03, 37.09] | 7.72   | 5.55     |
| Have a 4-year college degree or above (1 = yes)   | 378                 | [0, 1]        | 0.51   | 0.50     |
| White (1 = yes)   | 382                 | [0, 1]        | 0.77   | 0.41     |

showed that the corresponding percentages with margins of error were  $25.3 \pm 0.86\%$ ,  $6.9 \pm 1.12\%$ , and  $60.1 \pm 1.79\%$  for the study area [55]. Therefore, household observations were weighted by the three variables through a raking process to reduce bias [56]. Three variables were used because they are household demographics with low correlation and fewer missing values, which met the requirements of selecting weighting variables and helped retain as many observations as possible. The raking process adjusts cell counts so that marginal totals match control totals [57]. Then additional tests were conducted to find out whether the raking process successfully reduced bias in the samples. First, the average household income was \$101,261 before raking and \$88,213 after raking. According to the 2017 ACS, the average household income in the study area was \$82,248 [55]. Therefore, the raking process helped bring the sample mean closer to the population mean. Second, another two variables (i.e., marital status and ethnicity) were used to measure the percentage of bias reduction in categorical variables. The raking process reduced the sample bias by 10%. The process of weighting adjusts samples to match the population so that decisions made by people who are under-represented (because of low participation rates) in the sample can be better predicted by the estimated models [57].

### 3.2. Responses to traffic management

The survey requested that respondents “... imagine that the state transportation agency has announced that it will use various emergency measures to increase the number of cars that can travel on the interstate highways for the evacuation.” Here “emergency measures” technically refer to traffic management strategies. The survey continued with five questions intended to explore what, if any, effect knowing that transportation agencies were acting might have on behavioral intentions. The following subsections discuss responses to each of these questions. In each subsection, responses were first discussed without introducing other factors. Then, as shown in Table 2, responses were broken down by related decisions that respondents made before reading the set of traffic management impact questions (i.e., “initial decisions”).

#### 3.2.1. “How would this influence the likelihood that you will evacuate?”

According to the responses summarized in Table 2, traffic management strategies would encourage more than half (58%,  $N = 400$ ) of the households to evacuate. Only 5% ( $N = 400$ ) stated they would be less likely to evacuate.

When segmenting the data by respondents’ previously stated choice to evacuate/stay, the management strategies seemed to reinforce the choice to evacuate (see Table 2). Meanwhile, those who chose to stay were more likely to find traffic management strategies had no influence on their stay decisions. Implementing traffic management strategies was likely to motivate some people to evacuate instead of sheltering in place (32%,  $N = 32$ ).

#### 3.2.2. “How would this influence the time that you would begin your evacuation?”

It is somewhat surprising that 38% ( $N = 399$ ) of the respondents stated they would begin their evacuation before traffic management strategy implementation and only 11% ( $N = 399$ ) wanted to evacuate after traffic management strategy implementation. A possible explanation is that early-evacuating respondents thought that the traffic management strategy implementation would introduce uncertainty into their evacuation process; they would prefer to avoid that uncertainty and leave before its implementation. In addition, the percentage of respondents who felt uncertain about how the strategies would influence their departure times is the second largest when compared with their responses to the other evacuation plan adaptations in the presence of traffic management strategies (see the first column from the right-hand-side in Table 2).

Segmenting respondents by the departure day they chose prior to learning that traffic management strategies would be implemented (i.e., 3+ days, 2 days, or 1 day before the storm landfall), the percentage of respondents beginning their evacuation before traffic management strategies are implemented decreased as time passed (i.e., 55% vs. 38% or 33%). Those who expected to leave 3+ days before landfall are the most risk averse and thus the most inclined to leave still earlier as shown in the table. In contrast, the likelihood of beginning evacuation after the traffic management strategy is implemented increased in general (i.e., 9% or 8% vs. 18%). That is, those who chose to evacuate early tended to leave earlier and those who chose to evacuate late tended to leave later, with respect to the strategy.

#### 3.2.3. “How would this influence the likelihood that you will use the interstate highways to evacuate?”

More respondents (66%,  $N = 401$ ) stated they were more likely to use the interstate highways. Twenty-four percent of respondents stated that the implemented strategies would not affect their use of interstate highways.

Segmenting respondents by their previous route choices (i.e., interstates or other routes), traffic management strategies motivated some (58%,  $N = 129$ ) non-interstate users to take the interstates. However, 31% ( $N = 129$ ) of the non-interstate users stated traffic management strategies would have no influence on their route choices.

#### 3.2.4. “How would this influence the number of vehicles your household would use?”

As shown in Table 2, traffic management strategies were anticipated to have little effect on the number of vehicles evacuees would use.

Segmenting respondents by their previous vehicle choices (i.e., 1 or 2+ vehicles), respondents who chose two or more vehicles were more likely to use more vehicles (17%,  $N = 119$ ) when traffic management strategies are implemented than those who chose one vehicle (3%,  $N = 210$ ).

#### 3.2.5. “How would this influence your choice of evacuation destination?”

The majority of respondents (67%,  $N = 399$ ) stated that traffic management strategies would not affect their destination choices.

**Table 2**  
Responses to Traffic Management with Segmentation by “Initial decisions”.

| Choice            | “Initial decisions”                 | Count     | Response to traffic management        |                                       |                     |                  |
|-------------------|-------------------------------------|-----------|---------------------------------------|---------------------------------------|---------------------|------------------|
|                   |                                     |           | More likely to evacuate               | Less likely to evacuate               | No influence        | Uncertain        |
| (na)              | (na)                                | 400       | <b>58%</b>                            | 5%                                    | 34%                 | 3%               |
| Evacuate/ Stay    | Evacuate                            | 310 (91%) | <b>63%</b>                            | 3%                                    | 31%                 | 3%               |
|                   | Stay                                | 32 (9%)   | 32%                                   | 6%                                    | <b>59%</b>          | 3%               |
|                   |                                     |           | <b>Leave before</b>                   | <b>Leave after</b>                    | <b>No influence</b> | <b>Uncertain</b> |
| (na)              | (na)                                | 399       | 38%                                   | 11%                                   | 38%                 | <b>13%</b>       |
| Departure day     | 3+ days before                      | 66 (21%)  | 55%                                   | 9%                                    | 30%                 | 6%               |
|                   | 2 days before                       | 143 (46%) | 38%                                   | 8%                                    | 44%                 | 10%              |
|                   | 1 day before                        | 102 (33%) | 33%                                   | 18%                                   | 36%                 | 13%              |
|                   |                                     |           | <b>More likely to use interstates</b> | <b>Less likely to use interstates</b> | <b>No influence</b> | <b>Uncertain</b> |
| (na)              | (na)                                | 401       | 66%                                   | 6%                                    | 24%                 | 4%               |
| Route             | Interstates                         | 228 (64%) | 73%                                   | 5%                                    | 20%                 | 2%               |
|                   | Non-interstates                     | 129 (36%) | <b>58%</b>                            | 7%                                    | <b>31%</b>          | 4%               |
|                   |                                     |           | <b>Use more</b>                       | <b>Use fewer</b>                      | <b>No influence</b> | <b>Uncertain</b> |
| (na)              | (na)                                | 396       | 8%                                    | 8%                                    | <b>76%</b>          | 8%               |
| Vehicles to bring | 1 vehicle                           | 210 (64%) | 3%                                    | 9%                                    | 83%                 | 5%               |
|                   | 2+ vehicles                         | 119 (36%) | 17%                                   | 9%                                    | 66%                 | 8%               |
|                   |                                     |           | <b>Choose a different destination</b> |                                       | <b>No influence</b> | <b>Uncertain</b> |
| (na)              | (na)                                | 399       | 9%                                    |                                       | 67%                 | <b>24%</b>       |
| Accommodation     | Friends’/relatives’ home            | 182 (55%) | 5%                                    |                                       | <b>82%</b>          | 13%              |
|                   | Hotels/motels, shelters, and others | 150 (45%) | 11%                                   |                                       | 57%                 | <b>32%</b>       |

(Note: ‘na’ means not applicable. Percentages on each row add up to 100%. Values in bold are outstanding numbers explained in the texts. Shaded cells present responses without segmentation.)

However, a considerable percentage of respondents (24%, N = 399) felt uncertain about how the strategies would influence their destination choices in this situation. The percentage of respondents who felt uncertain about the influence on destination choice was the largest of the evacuation plan elements examined.

If their previous accommodation choices are considered, 82% (N = 182) of the respondents going to the homes of friends/relatives stated that they would not change their destination choices in the presence of traffic management strategies. The percentage is only 57% (N = 150) for those choosing other accommodations, suggesting hotel/motel and public shelter users are relatively less attached to a specific destination. In addition, they were less certain how the implemented strategies would influence their destination choices (i.e., 32%, N = 150). This suggests that hotel/motel and public shelter users’ travel would need more information to assist their decisions in this situation.

#### 4. Modeling results and discussions

Whether traffic management strategies influence household evacuation related decisions or not can be estimated by logit models. The number of alternatives in each choice is more than two so multinomial logit (MNL) models were used. The ordered logit models and random parameters multinomial logit (RPL) models (i.e., mixed logit models) were also tested during the estimation but were found inferior to models presented in this section.

Table 3 presents the model estimation results. A model may have a different number of alternatives than that shown in Table 2. This is because the alternative “Uncertain” sometimes does not have enough observations to produce reliable model estimation results. In such cases,

the alternative was left out of the model estimation process. In addition, the alternative “Uncertain” was considered in the modeling process because recent studies showed that information uncertainty could affect evacuation choice behavior [58,59]. Modeling “Uncertain” under the current study topic indicates who is likely to need additional information for their decisions.

Models were estimated using NLOGIT6 [60]. The number of observations used in each final model was different because each selected independent variable may have a different number of missing values. For all of the variables, the estimated parameters are significantly different from zero at a confidence level of 99% (i.e., p-value < .01). Marginal effects are presented in the last few columns on the right-hand-side. The goodness-of-fit statistics  $\rho^2$  are near or above 0.1, which means all the estimated models fit the data well. Correlations among all the independent and dependent variables are presented in Table 4.

As noted in Table 2, 310 out of the 342 (= 91%) respondents chose to evacuate before they read the set of traffic management strategy impact questions. Taking missing values into consideration, the modeling results reflect how evacuees change their previous decisions in the presence of evacuation traffic management. The following parameter interpretations and discussions are based on this point.

##### 4.1. Risk perceptions and past experiences

Evacuees with injury/death perceptions (i.e., who think they are likely to experience injury/death in a storm) are more likely to evacuate, to leave before traffic management strategy implementation, to take the interstates, and to choose a different destination in the presence of traffic management strategies. According to the Protective Action Decision

**Table 3**  
Modeling Results of Traffic Management Impacts on Different Choices.

| Evacuate/stay (N = 245; LL(0) = - 207.7; LL( $\hat{\beta}$ ) = - 187.5; pseudo $\rho^2$ = 0.10) |   |             |            |         |         |                         |                         |              |  |
|---|---|-------------|------------|---------|---------|-------------------------|-------------------------|--------------|--|
| Alternative   | Variable  | Coefficient | Std. error | z-value | p-value | Marginal effects        |                         |              |  |
|   |   |             |            |         |         | More likely to evacuate | Less likely to evacuate | No influence |  |
| More likely to evacuate (155; 63%)  | Constant  | -0.81       | 0.54       | -1.51   | 0.13    | (na)                    | (na)                    | (na)         |  |
|   | Perception of injury/death (1 = likely to experience injury/death in a storm) | 1.60***     | 0.38       | 4.13    | 0.00    | 0.32                    | -0.05                   | -0.26        |  |
| Less likely to evacuate (12; 5%)  | Annual household income (in \$1000)   | -0.02***    | 0.00       | -3.19   | 0.00    | 0.80E-3                 | -1.30E-3                | 0.50E-3      |  |
| No influence (78; 32%)  | Constant  | -0.53       | 0.44       | -1.19   | 0.23    | (na)                    | (na)                    | (na)         |  |
|   | Departure day (1 = 3+ days before)  | 0.93***     | 0.34       | 2.74    | 0.00    | -0.15                   | -0.01                   | 0.17         |  |

  

| Departure time (N = 251; LL(0) = - 298.0; LL( $\hat{\beta}$ ) = - 270.2; pseudo $\rho^2$ = 0.09) |   |             |            |         |         |                  |                |              |           |
|--|---|-------------|------------|---------|---------|------------------|----------------|--------------|-----------|
| Alternative  | Variable  | Coefficient | Std. error | z-value | p-value | Marginal effects |                |              |           |
|  |   |             |            |         |         | ...leave before  | ...leave after | No influence | Uncertain |
| More likely to leave before (96; 38%)  | Constant  | -2.24***    | 0.67       | -3.35   | 0.00    | (na)             | (na)           | (na)         | (na)      |
|  | Departure day (1 = 3+ days before)  | 1.34***     | 0.34       | 3.88    | 0.00    | 0.27             | -0.03          | -0.18        | -0.05     |
|  | Age (in years)  | 0.03***     | 0.00       | 3.87    | 0.00    | 7.80E-3          | -0.90E-3       | -5.40E-3     | -1.50E-3  |
| More likely to leave after (29; 12%)   | Constant  | -2.26***    | 0.58       | -3.86   | 0.00    | (na)             | (na)           | (na)         | (na)      |
|  | Pet presence (1 = yes)  | 1.36***     | 0.57       | 2.38    | 0.01    | -0.03            | 0.09           | -0.04        | -0.01     |
| No influence (97; 39%)   | Constant  | 0.51        | 0.33       | 1.55    | 0.12    | (na)             | (na)           | (na)         | (na)      |
|  | Perception of injury/death (1 = likely to experience injury/death in a storm) | -1.73***    | 0.60       | -2.85   | 0.00    | 0.24             | 0.06           | -0.38        | 0.08      |
| Uncertain (29; 11%)  | Distance to the coast (in miles)  | -0.13***    | 0.05       | -2.74   | 0.00    | 0.01             | 0.00           | 0.01         | -0.01     |

  

| Interstate use (N = 226; LL(0) = - 185.1; LL( $\hat{\beta}$ ) = - 162.3; pseudo $\rho^2$ = 0.12) |   |             |            |         |         |                   |                   |              |  |
|--|---|-------------|------------|---------|---------|-------------------|-------------------|--------------|--|
| Alternative  | Variable  | Coefficient | Std. error | z-value | p-value | Marginal effects  |                   |              |  |
|  |   |             |            |         |         | More likely to... | Less likely to... | No influence |  |
| More likely to use the interstate (159; 70%)   | Constant  | -0.27       | 0.55       | -0.50   | 0.61    | (na)              | (na)              | (na)         |  |
|  | Perception of injury/death (1 = likely to experience injury/death in a storm) | 1.23***     | 0.41       | 2.95    | 0.00    | 0.23              | -0.06             | -0.16        |  |
| Less likely to use the interstate (13; 6%)   | Expected travel delay (1 = yes)   | -1.61***    | 0.58       | -2.76   | 0.00    | 0.09              | -0.12             | 0.03         |  |
|  | Constant  | 3.51E-3     | 0.52       | 0.01    | 0.99    | (na)              | (na)              | (na)         |  |
| No influence (54; 24%)   | Departure day (1 = 3+ days before)  | 1.40***     | 0.38       | 3.67    | 0.00    | -0.19             | -0.02             | 0.22         |  |
|  | Have a 4-year college degree or above (1 = yes)                               | -1.25***    | 0.34       | -3.65   | 0.00    | 0.17              | 0.02              | -0.19        |  |

  

| Vehicle use (N = 266; LL(0) = - 188.2; LL( $\hat{\beta}$ ) = - 167.5; pseudo $\rho^2$ = 0.11) |   |             |            |         |         |                   |                    |              |           |
|---|---|-------------|------------|---------|---------|-------------------|--------------------|--------------|-----------|
| Alternative   | Variable  | Coefficient | Std. error | z-value | p-value | Marginal effects  |                    |              |           |
|   |   |             |            |         |         | Use more vehicles | Use fewer vehicles | No influence | Uncertain |
| Use more vehicles (19; 7%)  | Constant  | -1.27       | 0.82       | -1.54   | 0.12    | (na)              | (na)               | (na)         | (na)      |
|   | The number of vehicles taken during evacuation                                | 1.06***     | 0.39       | 2.67    | 0.00    | 4.99E-2           | -0.50E-2           | -4.16E-2     | -0.33E-2  |
| Use fewer vehicles (22; 8%)   | Constant  | 0.71*       | 0.40       | 1.75    | 0.08    | (na)              | (na)               | (na)         | (na)      |
| No influence (208; 78%)   | Constant  | 2.16***     | 0.41       | 5.28    | 0.00    | (na)              | (na)               | (na)         | (na)      |
|   | White (1 = yes)   | 1.36***     | 0.34       | 3.99    | 0.00    | -0.05             | -0.07              | 0.17         | -0.04     |
| Uncertain (17; 7%)  | Perception of injury/death (1 = likely to experience injury/death in a storm) | 1.72***     | 0.56       | 3.05    | 0.00    | -0.01             | -0.01              | -0.06        | 0.07      |

  

| Destination choice (N = 267; LL(0) = - 223.8; LL( $\hat{\beta}$ ) = - 198.8; pseudo $\rho^2$ = 0.11) |  |             |            |         |         |                   |              |           |  |
|--|--|-------------|------------|---------|---------|-------------------|--------------|-----------|--|
| Alternative  | Variable   | Coefficient | Std. error | z-value | p-value | Marginal effects  |              |           |  |
|  |  |             |            |         |         | More likely to... | No influence | Uncertain |  |
| More likely to choose a different destination (22; 8%)   | Constant   | -0.32       | 0.67       | -0.48   | 0.63    | (na)              | (na)         | (na)      |  |
|  | Chose to stay when evacuation was recommended before (1 = yes) | 1.69***     | 0.53       | 3.19    | 0.00    | 0.10              | -0.07        | -0.03     |  |

(continued on next page)

Table 3 (continued)

Destination choice ( $N = 267$ ;  $LL(0) = -223.8$ ;  $LL(\hat{\beta}) = -198.8$ ; pseudo  $\rho^2 = 0.11$ )

| Alternative             | Variable  | Coefficient | Std. error | z-value | p-value | Marginal effects  |              |           |
|-------------------------|---|-------------|------------|---------|---------|-------------------|--------------|-----------|
|                         |   |             |            |         |         | More likely to... | No influence | Uncertain |
| No influence (188; 70%) | Expected travel delay (1 = yes)   | -1.99***    | 0.70       | -2.83   | 0.00    | -0.12             | 0.08         | 0.03      |
|                         | Constant  | 0.78        | 0.22       | 3.51    | 0.00    | (na)              | (na)         | (na)      |
|                         | Perception of injury/death (1 = likely to experience injury/death in a storm) | -3.00***    | 0.66       | -4.54   | 0.00    | 0.12              | -0.57        | 0.44      |
|                         | Chose the home of a friend/relative as accommodation (1 = yes)                | 0.76***     | 0.29       | 2.65    | 0.00    | -0.03             | 0.14         | -0.11     |
| Uncertain (57; 22%)     | Perception of injury/death (1 = likely to experience injury/death in a storm) | -1.77***    | 0.64       | -2.75   | 0.00    | 0.03              | 0.26         | -0.29     |

(Note: '0 = otherwise' for binary variables. '(na)' means not applicable; \* $p < .1$ ; \*\* $p < .05$ ; \*\*\* $p < .01$ )

Model (PADM), households with greater risk perceptions are more likely to take actions to protect themselves [38]. First, traffic management strategies are implemented to facilitate more (and faster) evacuation trips out of the risk area. Hearing traffic management strategy implementation, evacuees who think they are likely to experience injury/death in a storm may become more likely to take actions and leave the risk area. Second, these evacuees might leave earlier (even before the traffic management strategy is implemented) because they are uncertain about the effect of the traffic management strategy. For example, contraflow plans may force some vehicles to travel much farther than the most direct route to their intended destination, so people might be concerned that it would be a potential evacuation impediment. In addition, evacuees who think they are likely to experience injury/death in a storm are also likely to feel uncertain about how the presence of traffic management strategies influences the number of vehicles to bring.

Evacuees who expected travel delay to occur during evacuation are more likely to take interstates when traffic management strategies are applied to the interstates or simply find that traffic management has no influence on their route choice. They are also less likely to choose a different destination in the presence of traffic management strategies.

Evacuees who chose to stay when evacuation was recommended in a previous storm are more likely to choose a different destination when traffic management strategies are implemented compared to their original decisions without knowing about the strategy implementation. As shown in the survey data, their risk perceptions (to property damage or injury/death) are lower than those who chose to evacuate in previous situations. With information on traffic management strategies and other social cues, they might perceive higher risk leading them to choose a farther inland destination (or other safer places).

4.2. "Initial decisions" made before knowing about traffic management strategy implementation

Evacuees who choose to leave three or more days before storm landfall are more likely to pay little heed to traffic management strategies when making their evacuate/stay and interstate use choices. Meanwhile, they are more likely to leave before the traffic management implementation. All the findings together suggest that this portion of evacuees tends to leave even earlier to avoid encountering the traffic management strategy. The average distance of these respondents' residences to water areas is 0.78 times that of those who evacuate later. The described scenario with traffic management may increase their risk perceptions. Environmental cues plus social cues could encourage them to take earlier protective actions in our hypothetical scenario.

Evacuees who choose to take more vehicles with them are more likely to use more vehicles when traffic management strategies are implemented. Taking more vehicles before knowing about the strategies indicates they own more vehicles. Traffic management strategies facilitate traffic flow on the road, which may encourage them to bring even

more vehicles out of the risk area.

Evacuees who choose a friend/relative's home as their accommodation are more likely to find traffic management has no influence on their destination choices. As shown in Table 2, they are more likely than hotel/motel users to feel no influence on their destination choices. The home of a friend/relative is located in a certain place, but hotel/motel resources are scattered in different places.

4.3. Socio-demographics

Evacuees with higher household income are less likely to stay in the presence of traffic management strategies. One potential explanation is that a respondent with higher household income has more monetary resources to facilitate their evacuation trips and lodging [61]. Evacuees with a higher education degree (i.e., 4-year college or above) are much more likely to use the interstate when a traffic management strategy is implemented on these types of roads (see marginal effects in Table 3). White respondents are more likely to find traffic management has no influence on their vehicle use choice. The average vehicle ownership rate of White respondents in our sample (i.e., 2.1) is slightly higher than that of the other race groups (i.e., 2.0). More research is needed to determine if the findings related to education level and ethnicity can be replicated and, if so, the explanations for them.

Older evacuees are more likely to leave before the traffic management implementation. Older evacuees may have shorter evacuation mobilization time [62], which enables them to leave early.

Evacuees who have pets are more likely to leave after the traffic management strategy implementation. The amount of mobilization time they need and their anticipation of better traffic conditions to facilitate their travel with pets could be potential explanations.

Evacuees who live further from the coast are less likely to feel uncertain about how their departure time choice would change in the presence of traffic management strategies. These evacuees are likely to evacuate to closer destinations than those who live closer to the coast [17]. Therefore, shorter trips and lower travel delays may make these evacuees more certain about what to do in the presence of traffic management.

5. Conclusions

Based on survey responses, implementing traffic management strategies on interstates to facilitate evacuation is less likely to influence households' destination choices (67%) and vehicle use (76%) when compared with their evacuate/stay, departure time, and route choices. The strategies are more likely to affect households' evacuate/stay choices (58% are more likely to evacuate and 5% are less likely to do so), departure time choices (38% are more likely to evacuate before the implementation and 11% are to evacuate afterwards), and route choices (66% are more likely to take interstate highways and 6% are less likely to do so). Some households are less certain on how strategies may

**Table 4**  
Correlation Matrix.

|      | [1]    | [2]    | [3]    | [4]    | [5]    | [6]    | [7]    | [8]    | [9]    | [10] | [11] | [12] | [13] | [14] | [15] | [16] | [17] |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|------|------|------|------|------|------|------|------|
| [1]  | 0      |        |        |        |        |        |        |        |        |      |      |      |      |      |      |      |      |
| [2]  | 0.2573 | 0      |        |        |        |        |        |        |        |      |      |      |      |      |      |      |      |
| [3]  | 0.2553 | 0.0047 | 0      |        |        |        |        |        |        |      |      |      |      |      |      |      |      |
| [4]  | 0      | 0.0168 | 0      | 0      |        |        |        |        |        |      |      |      |      |      |      |      |      |
| [5]  | 0.0000 | 0.0168 | 0.0001 | 0      | 0      |        |        |        |        |      |      |      |      |      |      |      |      |
| [6]  | 0.5276 | 0.0000 | 0.5370 | 0.0007 | 0.0001 | 0      |        |        |        |      |      |      |      |      |      |      |      |
| [7]  | 0.1082 | 0.2220 | 0.2647 | 0.9642 | 0.8232 | 0.0403 | 0      |        |        |      |      |      |      |      |      |      |      |
| [8]  | 0.0956 | 0.1248 | 0.9789 | 0.0543 | 0.5071 | 0.8403 | 0      |        |        |      |      |      |      |      |      |      |      |
| [9]  | 0.6067 | 0.0033 | 0.6230 | 0.5246 | 0.0223 | 0.4816 | 0.8770 | 0      |        |      |      |      |      |      |      |      |      |
| [10] | 0.6708 | 0.1225 | 0.8024 | 0.0086 | 0.4348 | 0.0985 | 0.4123 | 0      |        |      |      |      |      |      |      |      |      |
| [11] | 0.1628 | 0.6759 | 0.2078 | 0.2566 | 0.0066 | 0.3911 | 0.5079 | 0      |        |      |      |      |      |      |      |      |      |
| [12] | 0.0091 | 0.0838 | 0.0146 | 0.8297 | 0.7853 | 0.9900 | 0.0016 | 0.3027 | 0      |      |      |      |      |      |      |      |      |
| [13] | 0.2787 | 0.6654 | 0.4244 | 0.7864 | 0.6880 | 0.0044 | 0.5352 | 0      | 0      |      |      |      |      |      |      |      |      |
| [14] | 0.9983 | 0.0504 | 0.4784 | 0.6540 | 0.4994 | 0.9672 | 0.0021 | 0.0009 | 0.0021 | 0    |      |      |      |      |      |      |      |
| [15] | 0.0260 | 0.5320 | 0.7453 | 0.9426 | 0.7627 | 0.3143 | 0.8877 | 0.4416 | 0      | 0    |      |      |      |      |      |      |      |
| [16] | 0.0437 | 0.9026 | 0.0524 | 0.2540 | 0.1344 | 0.0339 | 0.7941 | 0      | 0      | 0    |      |      |      |      |      |      |      |
| [17] | 0.9869 | 0.0243 | 0.5146 | 0.4008 | 0.0560 | 0.0348 | 0.7983 | 0.0177 | 0      | 0    | 0    |      |      |      |      |      |      |

(Note: the table shows p-values from spearman correlation tests. Bonferroni correction was used to control experiment-wise error rate. Thus p-value < .0001 was selected to mark statistically significant correlations.) (Variable descriptions: [1] ~ [5] are dependent variables: evacuate/stay, departure time, interstate use, vehicle use, and destination choice; [6] Perception of injury/death (1 = likely to experience injury/death in a storm); [7] Expected travel delay (1 = yes); [8] Chose to stay when evacuation was recommended before (1 = yes); [9] Departure day (1 = 3+ days before); [10] The number of vehicles taken during evacuation; [11] Chose the home of a friend/relative as accommodation (1 = yes); [12] Annual household income (in \$1000); [13] Age (in years); [14] Pet presence (1 = yes); [15] Distance to the coast (in miles); [16] Have a 4-year college degree or above (1 = yes); [17] White (1 = yes))

influence their choices associated with possible destinations (24%) and departure times (13%).

With the survey data, five multinomial logit models were estimated to understand why households made such decisions in response to traffic management strategies. First, injury/death perception (i.e., perceiving the likelihood of experiencing injury/death in a storm) is the factor present in all the estimated models explaining evacuation plan adaptations. This finding is consistent with the Protective Action Decision Model (PADM) [38], which states risk perception is one of the most important factors in explaining protective actions. Second, a few factors reflecting socio-demographics (e.g., education and income) are significant in the estimated models. Emergency management agencies may want to review their evacuation traffic management plans to ensure there are no obstacles for all residents to understand their implementation.

With the survey responses and model estimation results, the influences of traffic management on household evacuation-related decisions lead to three considerations for emergency management agencies. The first is that traffic management strategies are likely to increase evacuation participation while they are less likely to change the number of household vehicles each household plans to use. Therefore, it is likely that more evacuation traffic will be generated due to an increased number of participating households after the implementation of supply management strategies is announced to the public.

The second consideration is based on households being less likely to change their destination choices while their route choices could be affected by the strategies. A destination can be accessed by different routes but individuals generally prefer the route with which they are familiar [20,21,63]. An individual may not be aware of all the alternatives and their travel times. Therefore, agencies should 1) clearly broadcast where and when the traffic management strategies will be implemented, 2) provide estimated travel times by route, and 3) ensure connections exist between interstates (with traffic management strategies) and local roads so that potential destinations can be reached.

The last consideration is that providing accommodation information by location is likely to divert a part of the traffic since users of hotels/motels and public shelters are less certain about the impact of the implemented traffic measures on their destination choices. These individuals are not as tied to specific destinations as those who choose the home of friends/relatives. One sub-consideration is that shelter opening hours should be optimized based on a good understanding of evacuee's responses to the implemented traffic management strategies.

Regarding future studies, the first avenue is to compare the influence of traffic management strategies (which are expected to improve traffic conditions) with that of other information (e.g., environmental and social cues) in households' evacuation-related choices. Do hazard exposures and risk perceptions outweigh traffic conditions in all evacuation-related choices and choice scenarios [64]? Do evacuees consider how much the traffic will be improved by the strategies (or the change of travel time) in making their decisions? These questions are worthwhile additional explorations based on recent findings about the impacts of estimated travel delay on household hurricane evacuation related choices [65]. Addressing these questions could also help emergency managers tailor their information provision based on whether warning-type information or action-type information (e.g., implementing a capacity enhancing strategy) is more effective in persuading people to take protective actions.

The second question to answer is why some people are more likely to evacuate before the implementation of traffic management strategies. Perhaps respondents interpret a transportation agency's implementation of traffic management strategies as an expectation of heavy traffic and delays since the strategies are intended to increase capacity and reduce delays. Heavy traffic volume is also likely to raise safety concerns [66]. An additional concern relates to households' familiarities about evacuation traffic management (e.g., access to interstate highways changes during contraflow operations). Households who are not familiar

with contraflow perhaps prefer to leave before the strategy's implementation so that they can avoid re-routing and uncertainty. Each potential reason requires further investigation to acquire a better understanding of such choice behaviors. However, emergency management agencies should be prepared for significant earlier departures to avoid the strategies.

Other studies could investigate how specific traffic management strategies affect households' evacuation-related decisions and how households assess the effectiveness of each operation in accomplishing a particular objective, such as increasing safety and/or decreasing travel time.

#### Credit author statement

The authors confirm their contributions to study conception and design, data collection, analysis and interpretation of results, and/or draft manuscript preparation. All the authors reviewed the results and approved the final version of the manuscript.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Acknowledgement

This work is supported by the NSF grant CMMI - 1536808, 1536477, and 1537762. The statements, findings, and conclusions are those of the authors.

#### References

- Lindell MK, Murray-Tuite P, Wolshon B, Baker EJ. Large-scale evacuation: The analysis, modeling, and management of emergency relocation from hazardous areas. Routledge/Taylor & Francis Group; 2019.
- Wolshon B. One-way-out: contraflow freeway operation for hurricane evacuation. *Nat Hazards Rev* 2001;2(3):105–12. [https://doi.org/10.1061/\(ASCE\)1527-6988\(2001\)2:3\(105\)](https://doi.org/10.1061/(ASCE)1527-6988(2001)2:3(105)).
- Wolshon B, Hamilton U, Levitan M, Wilmot CG. Review of policies and practices for hurricane evacuation. In: II: Traffic Operations, Management, and Control. *Natural Hazards Review*; 2005.
- Murray-Tuite P, Wolshon B. Evacuation transportation modeling: an overview of research, development, and practice. *Transp Res Part C: Emerg Technol* 2013;27: 25–45. <https://doi.org/10.1016/j.trc.2012.11.005>.
- Dow K, Cutter SL. Emerging hurricane evacuation issues: hurricane Floyd and South Carolina. *Nat Hazards Rev* 2002;3(1):12–8. [https://doi.org/10.1061/\(ASCE\)1527-6988\(2002\)3:1\(12\)](https://doi.org/10.1061/(ASCE)1527-6988(2002)3:1(12)).
- Theodoulou G, Wolshon B. Alternative methods to increase the effectiveness of freeway contraflow evacuation. In: *Transportation Research Record*, No. 1865; 2004. p. 48–56.
- Lim E, Wolshon B. Modeling and performance assessment of contraflow evacuation termination points. In: *Transportation Research Record*, No. 1922; 2005. p. 118–28.
- Collins J. Evaluation of contraflow lanes for hurricane evacuation. University of South Florida; 2008.
- Chiu Y-C, Zheng H, Villalobos JA, Peacock W, Henk R. Evaluating regional contraflow and phased evacuation strategies for Texas using a large-scale dynamic traffic simulation and assignment approach. *J Homeland Security Emerg Manag* 2008;5(1). <https://doi.org/10.2202/1547-7355.1409>.
- Stephen L. Evaluation of different contra-flow strategies for hurricane evacuation in Charleston. South Carolina: Clemson University; 2007.
- Lindell MK, Prater CS. Critical behavioral assumptions in evacuation time estimate analysis for private vehicles: examples from hurricane research and planning. *J Urban Plan Develop* 2007;133(1):18–29. [https://doi.org/10.1061/\(ASCE\)0733-9488\(2007\)133:1\(18\)](https://doi.org/10.1061/(ASCE)0733-9488(2007)133:1(18)).
- Pel AJ, Bliemer MCJ, Hoogendoorn SP. A review on travel behaviour modelling in dynamic traffic simulation models for evacuations. *Transportation* 2012;39(1): 97–123. <https://doi.org/10.1007/s11116-011-9320-6>.
- Lindell MK, Prater CS, Mohite A. Texas Gulf Coast Residents' expectations and intentions regarding hurricane. Texas: College Station; 2001.
- Fang L, Edara P. Sensitivity of evacuation performance estimates to evacuee route choice behavior. In: *Transportation Research Record*, No. 2376; 2013. p. 20–6. <https://doi.org/10.3141/2376-03>.
- Pel AJ, Hoogendoorn SP, Bliemer MCJ. Evacuation modeling including traveler information and compliance behavior. No. 3. 2010. p. 101–11.
- Lindell MK, Lu J-C, Prater CS. Household decision making and evacuation in response to hurricane Lili. *Nat Hazards Rev* 2005;6(4):171–9. [https://doi.org/10.1061/\(ASCE\)1527-6988\(2005\)6:4\(171\)](https://doi.org/10.1061/(ASCE)1527-6988(2005)6:4(171)).
- Wu H-C, Lindell MK, Prater CS. Logistics of hurricane evacuation in hurricanes Katrina and Rita. *Transp Res Part F: Traffic Psychol Behav* 2012;15(4):445–61. <https://doi.org/10.1016/j.trf.2012.03.005>.
- Chang D, Edara P, Murray-Tuite P, Trainor J, Triantis K. Taking the freeway: inferring evacuee route selection from survey data. *Transp Res Interdiscip Perspect* 2021;11:100421. <https://doi.org/10.1016/J.TRIP.2021.100421>.
- Robinson RM, Khattak A. Route change decision making by hurricane evacuees facing congestion. In: *Transportation Research Record*, No 2196; 2010. p. 168–75. <https://doi.org/10.3141/2196-18>.
- Akbarzadeh M. Dynamic route choice in hurricane evacuation. Louisiana State University; 2012.
- Sadri AM, Ukkusuri SV, Murray-Tuite P, Gladwin H. How to evacuate: model for understanding the routing strategies during hurricane evacuation. *J Transp Eng* 2014;140(1). [https://doi.org/10.1061/\(ASCE\)TE.1943-5436.0000613](https://doi.org/10.1061/(ASCE)TE.1943-5436.0000613).
- Sadri AM, Ukkusuri SV, Murray-Tuite P, Gladwin H. Hurricane evacuation route choice of major bridges in Miami Beach, Florida. *Transp Res Rec* 2015;2532: 164–73. <https://doi.org/10.3141/2532-18>.
- Baker EJ. Hurricane evacuation behavior. *Int J Mass Emerg Disasters* 1991;9(2): 287–310.
- Dash N, Gladwin H. Evacuation decision making and behavioral responses: individual and household. *Nat Hazards Rev* 2007;8(3):69–77. [https://doi.org/10.1061/\(ASCE\)1527-6988\(2007\)8:3\(69\)](https://doi.org/10.1061/(ASCE)1527-6988(2007)8:3(69)).
- Huang S-K, Lindell MK, Prater CS. Who leaves and who stays? A review and statistical Meta-analysis of hurricane evacuation studies. *Environ Behav* 2016;48(8):991–1029. <https://doi.org/10.1177/0013916515578485>.
- Wong SD, Pel AJ, Shaheen SA, Chorus CG. Fleeing from hurricane Irma: empirical analysis of evacuation behavior using discrete choice theory. *Transp Res Part D: Transp Environ* 2020;79:102227. <https://doi.org/10.1016/J.TRD.2020.102227>.
- Deka D, Carnegie JA. Forecasting shelter accessibility and vehicle availability for hurricane evacuation in Northern New Jersey using sample enumeration. *Int J Mass Emerg Disasters* 2012;30(3):275–300.
- Mesa-Arango R, Hasan S, Ukkusuri SV, Murray-Tuite P. Household-level model for hurricane evacuation destination type choice using hurricane Ivan data. *Nat Hazards Rev* 2013;14(1):11–20. [https://doi.org/10.1061/\(ASCE\)NH.1527-6996.0000083](https://doi.org/10.1061/(ASCE)NH.1527-6996.0000083).
- Cheng G, Wilmot CG, Baker EJ. Development of a time-dependent disaggregate hurricane evacuation destination choice model. *Nat Hazards Rev* 2013;14(3): 163–74. [https://doi.org/10.1061/\(ASCE\)NH.1527-6996.0000107](https://doi.org/10.1061/(ASCE)NH.1527-6996.0000107).
- Radwan E, Mollaghasemi M, Mitchell S, Yildirim G, Bd C, P. D. Candidate. Framework for modeling emergency evacuation. Orlando. 2005.
- Bian R, Wilmot CG, Gudishala R, Baker EJ. Modeling household-level hurricane evacuation mode and destination type joint choice using data from multiple post-storm behavioral surveys. *Transp Res Part C: Emerg Technol* 2019;99:130–43. <https://doi.org/10.1016/j.trc.2019.01.009>.
- Sadri AM, Ukkusuri SV, Murray-Tuite P, Gladwin H. Analysis of hurricane evacuee mode choice behavior. *Transp Res Part C: Emerg Technol* 2014;48(11):37–46. <https://doi.org/10.1016/j.trc.2014.08.008>.
- Alawadi, R., R. Bian, P. Murray-Tuite, S. V. Ukkusuri, and Y. Ge. Modeling the number of household vehicles used to evacuate from hurricane Matthew with a zero truncated poisson model. In *Modeling of household evacuation decision, departure timing, and number of evacuating vehicles from Hurricane Matthew*, Clemson University, Clemson.
- Yin W, Murray-Tuite P, Gladwin H. Statistical analysis of the number of household vehicles used for hurricane Ivan evacuation. *J Transp Eng* 2014;140(12): 04014060. [https://doi.org/10.1061/\(asce\)te.1943-5436.0000713](https://doi.org/10.1061/(asce)te.1943-5436.0000713).
- Gudishala R, Wilmot CG. Comparison of time-dependent sequential logit and nested logit for modeling hurricane evacuation demand. *Transp Res Rec* 2012; 2312:134–40. <https://doi.org/10.3141/2312-14>.
- Li J, Ozbay K, Bartin B, Iyer S, Carnegie JA. Empirical evacuation response curve during hurricane Irene in Cape May County, New Jersey. *Transp Res Rec* 2013; 2376(1):1–10. <https://doi.org/10.3141/2376-01>.
- Thompson RR, Garfin DR, Silver RC. Evacuation from natural disasters: a systematic review of the literature. *Risk Anal* 2017;37(4):812–39. <https://doi.org/10.1111/risa.12654>.
- Lindell MK, Perry RW. The protective action decision model: theoretical modifications and additional evidence. *Risk Anal* 2012;32(4):616–32. <https://doi.org/10.1111/j.1539-6924.2011.01647.x>.
- Lindell, M. K. Communicating imminent risk, pp. 449–477.
- Ajzen I. Martin fishbein's legacy: the reasoned action approach. *Ann Am Acad Political Soc Sci* 2012;640(1):11–27. <https://doi.org/10.1177/0002716211423363>.
- Dow K, Cutter SL. Crying wolf: repeat responses to hurricane evacuation orders. *Coastal Manag* 1998;26(4):237–52. <https://doi.org/10.1080/08920759809362356>.
- Dow K, Cutter SL. Public orders and personal opinions: household strategies for hurricane risk assessment. *Global Environ Change B Environ Hazard* 2000;2(4): 143–55. [https://doi.org/10.1016/S1464-2867\(01\)00014-6](https://doi.org/10.1016/S1464-2867(01)00014-6).
- Sharma U, Patt A. Disaster warning response: the effects of different types of personal experience. *Nat Hazards* 2012. <https://doi.org/10.1007/s11069-011-0023-2>.
- Huang S-K, Lindell MK, Prater CS, Wu H-C, Siebeneck LK. Household evacuation decision making in response to hurricane Ike. *Nat Hazards Rev* 2012;13(4):283–96. [https://doi.org/10.1061/\(asce\)nh.1527-6996.0000074](https://doi.org/10.1061/(asce)nh.1527-6996.0000074).

- [45] Huang S-K, Lindell MK, Prater CS. Multistage model of hurricane evacuation decision: empirical study of Hurricanes Katrina and Rita. *Nat Hazards Rev* 2017;18(3). [https://doi.org/10.1061/\(ASCE\)NH.1527-6996.0000237](https://doi.org/10.1061/(ASCE)NH.1527-6996.0000237).
- [46] Sadri AM, Ukkusuri SV, Gladwin H. The role of social networks and information sources on hurricane evacuation decision making. *Nat Hazards Rev* 2017;18(3): 04017005. [https://doi.org/10.1061/\(ASCE\)NH.1527-6996.0000244](https://doi.org/10.1061/(ASCE)NH.1527-6996.0000244).
- [47] Sadri AM, Ukkusuri SV, Gladwin H. Modeling joint evacuation decisions in social networks: the case of Hurricane Sandy. *J Choice Model* 2017;25(February):50–60. <https://doi.org/10.1016/j.jocm.2017.02.002>.
- [48] Hasan S, Ukkusuri SV, Gladwin H, Murray-Tuite P. Behavioral model to understand household-level hurricane evacuation decision making. *J Transp Eng* 2011;137(5): 341–8. [https://doi.org/10.1061/\(ASCE\)TE.1943-5436.0000223](https://doi.org/10.1061/(ASCE)TE.1943-5436.0000223).
- [49] Riad JK, Norris FH, Ruback RB. Predicting evacuation in two major disasters: risk perception, social influence, and access to resources. *J Appl Soc Psychol* 1999;25(5):918–34. <https://doi.org/10.1111/j.1559-1816.1999.tb00132.x>.
- [50] Smith SK, McCarty C. Fleeing the storm(s): an examination of evacuation behavior during Florida's 2004 hurricane season. *Demography* 2009;46(1):127–45. <https://doi.org/10.1353/dem.0.0048>.
- [51] Bateman JM, Edwards B. Gender and evacuation: a closer look at why women are more likely to evacuate for hurricanes. *Nat Hazards Rev* 2002;3(3):107–17. [https://doi.org/10.1061/\(asce\)1527-6988\(2002\)3:3\(107\)](https://doi.org/10.1061/(asce)1527-6988(2002)3:3(107)).
- [52] Gladwin H, Peacock WG. *Warning and evacuation: A night for hard houses*. New York, NY: Routledge; 1997.
- [53] Spence PR, Lachlan K, Burke JM, Seeger MW, Spence PR, Lachlan K, et al. *Media use and information needs of the disabled during a natural disaster*. *J Health Care Poor Underserved* 2007;18(2):394–404.
- [54] Dillman, D. A. *Survey implementation: In Mail and internet surveys: The tailored design method*, John Wiley & Sons, Inc., Hoboken, NJ, pp. 149–193.
- [55] U.S. Census Bureau. *American FactFinder*. US Census Bureau <http://factfinder.census.gov>. Accessed Jul. 16, 2021.
- [56] Pasek. J. *Package 'Anesrake'*. R. <https://cran.r-project.org/web/packages/anesrake/anesrake.pdf>. Accessed Apr. 15, 2019.
- [57] Mercer A, Lau A, Kennedy C. For weighting online opt-in samples. *What Matters Most?* 2018. <https://www.pewresearch.org/methods/2018/01/26/for-weighting-online-opt-in-samples-what-matters-most/>.
- [58] Shen J. *Exploring uncertainties in Households' hurricane evacuations*. Clemson University; 2020.
- [59] Ling L, Murray-Tuite P, Lee S, "Gurt" Ge Y, Ukkusuri SV. Role of uncertainty and social networks on shadow evacuation and non-compliance behavior in Hurricanes. *Transp Res Rec* 2020;2675(3):53–64. <https://doi.org/10.1177/0361198120962801>.
- [60] Greene WH. *NLOGIT Version 6 Reference Guide*. Plainview, NY: Econometric Software, Inc; 2012.
- [61] Wu, H.-C., M. K. Lindell, C. S. Prater, and S.-K. Huang. Logistics of hurricane evacuation in Hurricane Ike. In *Logistics: perspectives, approaches and challenges* (J. Cheung and H. Song, eds.), Nova Science Publishers.
- [62] Sadri AM, Ukkusuri SV, Murray-Tuite P. A random parameter ordered probit model to understand the mobilization time during hurricane evacuation. *Transp Res Part C: Emerg Technol* 2013;32:21–30. <https://doi.org/10.1016/j.trc.2013.03.009>.
- [63] Murray-Tuite P, Yin W, Ukkusuri SV, Gladwin H. Changes in evacuation decisions between hurricanes Ivan and Katrina. *Transp Res Rec* 2012;2312:98–107. <https://doi.org/10.3141/2312-10>.
- [64] Dash N, Morrow BH. Return delays and evacuation order compliance: the case of hurricane georges and the florida keys. *Environ Hazards* 2001;2(3):119–28. <https://doi.org/10.3763/ehaz.2000.0217>.
- [65] Bian R, Murray-Tuite P, Edara P, Triantis K. Household hurricane evacuation plan adaptation in response to estimated travel delay provided prior to departure. *Nat Hazards Rev* 2022;23(3). [https://doi.org/10.1061/\(ASCE\)NH.1527-6996.0000557](https://doi.org/10.1061/(ASCE)NH.1527-6996.0000557).
- [66] Abdel-Aty MA, Radwan AE. Modeling traffic accident occurrence and involvement. *Accid Anal Prev* 2000;32(5):633–42. [https://doi.org/10.1016/S0001-4575\(99\)00094-9](https://doi.org/10.1016/S0001-4575(99)00094-9).