Household-Level Model for Hurricane Evacuation Destination Type Choice Using Hurricane Ivan Data

Rodrigo Mesa-Arango; Samiul Hasan; Satish V. Ukkusuri, A.M.ASCE; and Pamela Murray-Tuite, A.M.ASCE

Abstract: Hurricanes are costly natural disasters periodically faced by households in coastal and, to some extent, inland areas. Public agencies must understand household behavior to develop evacuation plans that align with evacuee choices and behavior. This paper presents a previously unknown household-level hurricane evacuation destination type choice model. The discrete choice of destination type is modeled using a nested logit model. Although previous literature considers only houses of friends and relatives and hotels for modeling purposes, this paper incorporates public shelters, churches, and an aggregated destination type denoted other. This research found that the variables influencing this choice include hurricane position at evacuation time, household geographic location, race, income, preparation time, changes in evacuation plans, previous experiences with major hurricanes, household members working during the evacuation, and evacuation notices. The findings of this paper are useful to understand the competition among destination types and how the characteristics of the demand can be used to develop evacuation strategies, such as increasing and/or decreasing use of public shelters, and measuring the effect of evacuation notices in areas with high accessibility to hotels. DOI: 10.1061/(ASCE)NH.1527-6996.0000083. © 2013 American Society of Civil Engineers.

CE Database subject headings: Hurricanes; Evacuation; Models.

Author keywords: Hurricane evacuation destination type choice; Nested logit model; Hurricane evacuation behavior; Hurricane Ivan.

Introduction

Hurricanes are one of the most dangerous and costly weather-related natural hazards in the United States. From 1981 to 2010, hurricanes were responsible on average for about 47 fatalities per year. This is one of the highest fatality rates compared with floods, lightning-related events, and tornados. However, between 2001 and 2010, the average fatalities per year related to hurricanes increased to 116, which ranks hurricanes and heat as the most deadly natural hazards (NOAA 2011).

In 2005–2008, hurricanes, and in a smaller proportion tropical and subtropical storms, were responsible for approximately 2,835 fatalities in the Atlantic basin (1,551 fatalities and monetary damage over $125.5 billion in the United States) (Brown et al. 2010; Brennan et al. 2009; Franklin and Brown 2008; Beven et al. 2008). The most catastrophic hurricane in this time period was Hurricane Katrina (1,500 deaths and around $81 billion in property damage in the United States) (Beven et al. 2008).

Considering these devastating impacts and the role of evacuation on their mitigation, it is the responsibility of public agencies to understand all the dimensions of an evacuation process. Comprehensive evacuation plans must integrate transportation theory with evacuation behavior. Lindell and Prater (2007) list the principal behavioral variables for the development of transportation models in hurricane evacuations. They also describe empirical data relevant to estimating models that link social science research with transportation engineering. In their work, models are classified into three major groups: trip generation, departure timing, and destination and/or route choice.

Trip generation is related to the question of whether to evacuate. Several researchers (Hasan et al. 2011c; Dash and Gladwin 2007; Lindell et al. 2005; Whitehead et al. 2000; Gladwin and Peacock 1997) use statistical and econometric models to understand this decision, which is a function of variables related to households’ socioeconomic characteristics, household location, and hazard characteristics. Likewise, understanding departure timing allows the prediction of dynamic evacuee demand and the development of effective evacuation strategies. This phenomenon has been studied by some researchers (Hasan et al. 2011a; Fu and Wilmot 2006 and 2004; Sorensen 1990) using statistical and econometric models related to environmental, social, and demographic factors.

However, hurricane evacuation destination choice has only been studied by a small number of researchers who provide assumptions and definitions useful to understand and model this choice (Cheng et al. 2008; Barrett et al. 2000; Southworth 1991; Wilmot et al. 2006). Three types of zonal-level models have been used to represent destination choice; these are the gravity model (Wilmot et al. 2006), intervening opportunity model (Wilmot et al. 2006), and multinomial logit (MNL) model (Cheng et al. 2008). These models only consider houses of friends and relatives and hotels as possible destinations. Likewise, they focus on zonal trip distribution without incorporating the choice among destination types and considering the percentage of evacuees traveling to each destination type as a given input.

A better understanding of the household-level characteristics driving destination type choice is important for public agencies and researchers to recognize the factors that encourage households to select their more desired destinations. Some examples that show the advantages of having this information include recognizing public...
shelter demand and improving their locations and settings; developing better evacuation notices per population segment, giving advice on what destination types to choose; developing cooperative programs with hotels guaranteeing some levels of demand; and recognizing potential regions that are attractive for evacuees to anticipate traffic congestion. Likewise, comprehensive hurricane evacuation models must consider all dimensions involved in this process, and destination type choice is not an exception.

This research develops a household-level nested logit (NL) model to understand hurricane evacuation destination type choice. The model contributes to hurricane evacuation research by identifying the variables influencing destination type choice among four common alternatives: houses of friends and relatives; hotels; public shelters and churches; and other. Data from Hurricane Ivan 2004 is used to calibrate the model. This is the first model of its type found in hurricane evacuation modeling literature.

The remainder of this paper is organized as follows. Literature Review presents a literature review on hurricane evacuation destination choice. The Data section discusses the dataset used to develop the model, which is followed by a review of the modeling in Methodology. Estimation Results and Discussion presents and discusses the estimation results. Finally, Conclusions and Future Directions summarizes the major findings and presents future research extensions.

**Literature Review**

This section reviews previous works related to hurricane evacuation destination choice and highlights the need for household-level destination type choice models. Barrett et al. (2000), define evacuation destination as the location to which the evacuee is traveling to seek safety. Barrett et al. (2000) and Southworth (1991) provide assumptions for modeling primarily what Lindell and Prater (2007) refer to as the proximate destination, which is the point in the transportation network where the evacuee exits the risk area. The ultimate destination refers to both the town and/or city and the type of accommodation where the evacuees will stay until they can return to their homes (Lindell and Prater 2007). The second part of this ultimate destination (accommodation type) is the focus of this paper. Two of the assumptions of Barrett et al. (2000) allude to the ultimate destination: the location where the evacuee is predicted to seek safety or the evacuation location recommended in the evacuation plan. Similarly, Southworth (1991) mentions following an evacuation plan, but also recognizes that evacuees will display some degree of dispersion in their destination selection, depending upon such factors as the location of friends and relatives and the speed of the hazard onset. This last observation suggests that observed, behavioral studies would be useful in modeling evacuees’ ultimate destinations.

The town, or traffic analysis zone, portion of the ultimate destination is related to the trip distribution step of a transportation planning model, where origins and destinations are matched at the aggregate, rather than household or individual, level. Mei (2002) and Modali (2005) indicate that before their study, no model of trip distribution for evacuations appears to have been developed, with the exception of the Oak Ridge Emergency Management System (OREMS) package. Wilmot et al. (2006) tested both a gravity model and an intervening opportunity model for trip distribution under hurricane evacuation conditions, concluding that the gravity model offers better results. These models are only applicable to aggregated zones and must be calibrated for each accommodation type independently, which ignores the process related to how evacuees choose among destination types.

Cheng et al. (2008) use a MNL model for hurricane evacuation destination choice at the zonal level. They present two separate MNL models for friends and relatives and hotel and/or motel choice, where each evacuation zone is an alternative (28 alternatives). They found that destination (zone) choice is affected by the trip distance and the following variables related to the destination zone: risk, White population, total population (for friends and relatives), presence of a major metropolitan area (for friends and relatives), number of hotels (for hotel and/or motel), and presence of an interstate highway (for hotel and/or motel). These models require strong aggregation assumptions to have a manageable number of alternatives in the choice set and do not consider the destination type choice.

The homes of friends and relatives are widely acknowledged to be the most preferred accommodation type, followed by hotels and/or motels (Smith and McCarty 2009). Mei (2002), Modali (2005), and Chen (2005) listed the ranges of evacuee percentages choosing each type as 69–55% for friends’ and/or relatives’ homes, 13–26% for hotels and/or motels, and 3–12% for public shelters. The preference for relatives’ homes over public shelters is consistent with earlier social findings (Drabek and Boggs 1968; Moore et al. 1963; Quandrelli 1982).

Despite their relative lack of use (Mileti et al. 1992), public shelters are required for some types of emergencies, such as nuclear power plant emergencies, and are critical resources for some evacuees. Lower income evacuees are more likely to use public shelters (USACE 2001; Mileti et al. 1992; Moore et al. 1963). Lindell and Prater (2003) suggest that lower income households are in temporary housing longer than other income groups because of a lack of resources and their homes having higher preimpact vulnerability because of location or construction. Other factors associated with public shelter use include the evacuation of a city (vs. a town), type of emergency (hurricanes showed the highest use), night time evacuation, publication of shelter availability, age, ethnicity, and proportion of the population evacuated (Mileti et al. 1992). The United States Army Corps of Engineers (USACE 2001) found that the greater the hazard at the evacuees’ locations, the less frequently they reported selecting public shelters.

The variables race and age, indicated as significant by Mileti et al. (1992), were not statistically significant in the logistic regression models of Smith and McCarty (2009) for the accommodation types friends’ and/or relatives’ homes, hotels and/or motels, and public shelters. Their models for Florida hurricane evacuations are separate for each accommodation type. Among the investigated variables, Smith and McCarty found household size and number of years living in Florida to be highly significant in selecting friends’ and/or relatives’ homes, and gender was significant to a lower degree. The statistical significance of the years in Florida decreased in the hotel and/or motel model and further decreased in the public shelter model. In addition to this variable, the hotel and/or motel model had home ownership and living in a mobile home as moderately significant. The public shelter model showed living in a mobile home and income as marginally significant, as well as the years living in Florida. In addition to race and age, education was insignificant in all three models.

The previous review indicates that few household-level hurricane evacuation models for destination type choice have been developed so far, especially models that account for the utility differences among the options. This paper addresses this gap in the literature by developing a model using the Hurricane Ivan 2004 survey (Morrow and Gladwin 2005). The consistent finding of socioeconomic status being at least marginally significant to the accommodation type selection leads to the inclusion of this consideration in this study. Although the significance of race/ethnicity is mixed in the previously reviewed literature, it is considered in the
models here. This study also includes variables indicating the hazard at the evacuees’ homes, which are significant in the USACE (2001) study; here, the hazard is reflected by the distance from the hurricane, elapsed time between the decision to evacuate and the action of evacuating, and whether an evacuation notice is received. The evacuees’ home states are also considered, which could reflect state-specific evacuation guidance or experiences. Previous experience with hurricanes is included, because of its relationship with the number of years living in a particular area, which was significant in the study of Smith and McCarty (2009). An indicator of being required to work during the evacuation is included. Work obligations have been shown to reduce the likelihood of evacuation (Baker 1991), but if damage or conditions are hazardous enough, workers may evacuate at the last minute to closer destinations. Other variables specific to the Ivan dataset, such as whether the final accommodation type is the same as the one originally selected, are also investigated in this study. Because data availability determines some modeling constraints, an overview of the dataset is presented in the following section.

Data

Data from a Hurricane Ivan 2004 survey (Morrow and Gladwin 2005) is used to calibrate the model. (Access to this data set was provided by Dr. Gladwin as part of ongoing collaborations). This survey includes a random sample from the area adjacent to the hurricane path in Alabama, Florida, Louisiana, and Mississippi. Households were asked 116 questions about evacuation decisions and behavior, home mitigation and/or preparation, household circumstances and economic impacts, as well as household information needs. For those surveyed households that evacuated (1,443 of 3,200; 45.09%), there is a specific question related to the type of destination they used. From those that evacuated, 1,419 identified their destination type.

Fig. 1 presents the percentage of evacuees per destination type. Consistent with the findings in previous evacuations, homes of friends and relatives (FR) and hotels (H) are the most preferred destination types. Because there are few households evacuating to public shelters, churches, and working places, the first and second types are aggregated in a destination type called public shelters and churches (PSC). This is considered to be a reasonable aggregation given the similar characteristics of these destination types. Likewise, the destination type workplace is aggregated with the destination type that aggregates other unspecified destinations or so-called other (O). Fig. 2 presents a tag cloud that gives an idea of the heterogeneous mixture of destinations encapsulated in the destination type O (without workplace), where the highest frequency for a word is four.

Table 1 presents summary statistics for those variables in the survey that were significant in the modeling process and other complementary variables. Table 1 shows that the percentages of evacuees per state related to each destination type follow similar trends compared with the total reported values (i.e., FR is the more desired destination type, followed by H, O, and finally PSC). It is interesting to observe that the percentage of evacuees going to H in Louisiana is very close to the percentage going to FR. This trend allows the recognition of a potential indicator variable for Louisiana that affects the selection of H.

The number of evacuees that changed their destinations after leaving home is higher for those who finally selected hotels. This insight is useful to define an indicator variable that captures this change and improves the explanatory power of other variables.

In general, a high number of households where a member had to work during the evacuation process evacuated to FR.

Another variable tested in the model is the average distance between the hurricane and household’s zip code centroid at evacuation time. This variable is computed using online data from Historical Hurricane Tracks, which is available on the National Oceanic and Atmospheric Administration website (NOAA 2010). The centroids of the zip codes reported in the survey data and the measurements to the hurricane track are estimated with the software TransCAD (2007). On average, this distance is smaller for households that evacuate to PSC.

From the variables related to household race, it is possible to appreciate that White households present the highest proportions for all destination types. A high number of households with this characteristic evacuated to FR and H. A similar trend is observed with households that present as African American. The number of households related to other races is considerably low; thus, they are not considered in the model.

A high percentage of households that received an evacuation notice choose FR and H. In general, for few households, the time between the decision for evacuating and the actual evacuation is ≤6 hours. The data show a higher proportion of households with this characteristic evacuating to FR.

Finally, many of the households with 2004 income less than $25,000 evacuate to FR.

As a consequence of data cleaning, the final models were estimated with slightly less observations than those present in the entire data set. The total number of observations used in the model is 1,029.

The following section presents the methodology followed to develop the household-level NL model for hurricane evacuation destination type choice.

Methodology

An important task in developing a household-level hurricane evacuation destination type choice model is selecting a modeling framework that accurately represents this decision and fits the available data set. The destination type choice can be approached using discrete choice models such as MNL, NL, and MNL with random parameters. This section reviews these models and presents...
the process followed to select the NL approach. Some of the mathematical derivations used in this section are based on the discrete choice theory presented by Train (2009) and Washington et al. (2011).

As presented in the Literature Review, one of several decisions that a household faces in a hurricane evacuation is what evacuation destination type $j$ to choose among a set of alternatives $J$. Discrete choice theory assumes that each household knows and assigns a utility $U_{hj}$ to each destination type $j \in J$. Finally, the selected alternative $j^*$ is the one that represents the maximum utility to $h$, that is, $j^* = \max(U_{hj}) \forall j \in J$. Although $U_{hj}$, $\forall j \in J$ is unknown to the researcher; it can be estimated as $U_{hj} = V_{hj} + e_{hj}$. The representative utility $V_{hj}$ can be computed as $V_{hj} = \beta x_{hj}$, where $x_{hj}$ is a vector of variables or attributes of $h$ obtained from the Hurricane Ivan 2004 survey, and $\beta$ is a set of estimated coefficients associated with each attribute. Furthermore, $e_{hj}$ captures unobserved factors that affect $U_{hj}$.

In the MNL model (McFadden 1981; McFadden 1978), the probability $P_{hj}$ that household $h$ chooses the destination type $j \in J$ can be computed as

$$P_{hj} = \frac{e^{V_{hj}}}{\sum_{j' \in J} e^{V_{hj'}}}$$

The $\beta$ parameters can be estimated using maximum likelihood methods. In the MNL case, the following log-likelihood function is used to estimate them:

$$LL(\beta) = \sum_{h=1}^{H} \left[ \sum_{j=1}^{J} \delta_{hj} \left( \beta_j x_{hj} - LN \sum_{j'=1}^{J} e^{\beta_{j'} x_{hj'}} \right) \right]$$

where $\delta_{hj} = (1,0) = 1$ if the observed destination type chosen by household $h \in H$ is $j \in J$ and 0 otherwise.

A critical assumption in the MNL model is the disturbance terms $e_{hj}$ are assumed to be independently and identically independent from irrelevant alternatives (IIA) distributed. The IIA property indicates that the relative probability of choosing an alternative remains the same if another option is removed from the choice set.

This assumption does not hold when a subset of the alternatives share the same unobserved effects. In this case, the model has major specification errors.

The NL model (McFadden 1981) overcomes the IIA assumption problem by nesting alternatives and cancelling out their shared unobserved effects. The unconditional probability of household $h \in H$ choosing destination type $j \in J$ is given by $P_h(j) = P_h(i)P_h(j|i)$. In this expression, $P_h(i)$ is the unconditional probability of household $h$ selecting the group of alternatives in nest $i \in I$, and $P_h(j|i)$ is the conditional probability of selecting alternative $j$ in nest $i$, given that $j$ is part of $i$. The following expressions present the formal mathematical formulation for these probabilities:

$$P_h(i) = \frac{e^{\beta_i x_{h}}}{\sum_{i' \in I} e^{\beta_{i'} x_{h}}} + \phi_i LS_{hi}$$

$$P_h(j|i) = \frac{e^{\beta_j x_{h}}}{\sum_{j' \in J} e^{\beta_{j'} x_{h}}}$$

$$LS_{hi} = LN(\sum_{j' \in J} e^{\beta_{j'} x_{h}})$$

where $LS_{hi}$ = inclusive value, also known as log sum value; and $\phi_i$ = estimable parameter with the following characteristics: (1) the inequality $0 \leq \phi_i \leq 1$ must hold to be consistent with the formal NL derivation; (2) if $\phi_i = 1$, the nested model reduces to a MNL; (3) if $\phi_i \leq 0$, the factors that increase the likelihood of choosing destination type $j$ in nest $i$ decrease the likelihood of choosing nest $i$; and (4) if $\phi_i = 0$, the correct model is recursive (separated).

Both MNL and NL models assume that the estimated parameters are fixed across all the observations. If this assumption does not hold, the parameters and the corresponding probabilities are inconsistently estimated. This limitation is overcome by using MNL with random parameters or mixed logit models (Train 2009; McFadden and Train 2000). In these models, the probability of household $h$ choosing destination type $j$, $P_h^m(j)$, is given by the following expression:

---

Fig. 2. Percentage tag cloud: destinations aggregated in the type O
### Table 1. Summary Statistics for Households That Evacuated: Hurricane Ivan 2004 Data Set

<table>
<thead>
<tr>
<th>Variable</th>
<th>Public Shelter and Church</th>
<th>Friend/Relative</th>
<th>Hotel</th>
<th>Other</th>
<th>Cases*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination type</td>
<td>0.042 ± 0.200</td>
<td>0.595 ± 0.491</td>
<td>0.257 ± 0.437</td>
<td>0.107 ± 0.309</td>
<td>1,419</td>
</tr>
<tr>
<td>Indicator variable for AL (1 if the household is located in AL, 0 o.w.)</td>
<td>0.007 ± 0.084</td>
<td>0.088 ± 0.284</td>
<td>0.027 ± 0.161</td>
<td>0.017 ± 0.129</td>
<td>1,419</td>
</tr>
<tr>
<td>Indicator variable for FL (1 if the household is located in FL, 0 o.w.)</td>
<td>0.018 ± 0.132</td>
<td>0.173 ± 0.379</td>
<td>0.056 ± 0.229</td>
<td>0.033 ± 0.179</td>
<td>1,419</td>
</tr>
<tr>
<td>Indicator variable for LA (1 if the household is located in LA, 0 o.w.)</td>
<td>0.006 ± 0.079</td>
<td>0.190 ± 0.393</td>
<td>0.125 ± 0.331</td>
<td>0.032 ± 0.177</td>
<td>1,419</td>
</tr>
<tr>
<td>Indicator variable for MS (1 if the household is located in MS, 0 o.w.)</td>
<td>0.011 ± 0.102</td>
<td>0.143 ± 0.350</td>
<td>0.049 ± 0.217</td>
<td>0.025 ± 0.155</td>
<td>1,419</td>
</tr>
<tr>
<td>Indicator variable for not original destination (1 if household changes its mind about where to go after leaving home, 0 o.w.)</td>
<td>0.005 ± 0.070</td>
<td>0.047 ± 0.212</td>
<td>0.053 ± 0.224</td>
<td>0.019 ± 0.137</td>
<td>1,419</td>
</tr>
<tr>
<td>Indicator variable for work during the evacuation (1 if anyone in the household has to work during Ivan evacuation, 0 o.w.)</td>
<td>0.009 ± 0.095</td>
<td>0.154 ± 0.361</td>
<td>0.095 ± 0.293</td>
<td>0.041 ± 0.198</td>
<td>1,415</td>
</tr>
<tr>
<td>Indicator variable for previous experience (1 if household experienced a major hurricane before 2004, 0 o.w.)</td>
<td>0.029 ± 0.168</td>
<td>0.483 ± 0.500</td>
<td>0.190 ± 0.392</td>
<td>0.084 ± 0.277</td>
<td>1,411</td>
</tr>
<tr>
<td>Average distance between the hurricane and the centroid of the zip code where the household is located measured at evacuation time</td>
<td>371.318 ± 273.103</td>
<td>419.092 ± 240.855</td>
<td>441.929 ± 217.811</td>
<td>425.528 ± 257.6</td>
<td>1,409</td>
</tr>
<tr>
<td>Indicator variable for White race (1 if the race that best describes the household is White, 0 o.w.)</td>
<td>0.032 ± 0.176</td>
<td>0.513 ± 0.500</td>
<td>0.220 ± 0.414</td>
<td>0.097 ± 0.296</td>
<td>1,381</td>
</tr>
<tr>
<td>Indicator variable for African American race (1 if the race that best describes the household is African American, 0 o.w.)</td>
<td>0.007 ± 0.080</td>
<td>0.054 ± 0.225</td>
<td>0.020 ± 0.139</td>
<td>0.007 ± 0.080</td>
<td>1,381</td>
</tr>
<tr>
<td>Indicator variable for Hispanic race (1 if the race that best describes the household is Hispanic, 0 o.w.)</td>
<td>0.001 ± 0.027</td>
<td>0.009 ± 0.093</td>
<td>0.008 ± 0.089</td>
<td>0.000 ± 0.000</td>
<td>1,381</td>
</tr>
<tr>
<td>Indicator variable for Asian race (1 if the race that best describes the household is Asian, 0 o.w.)</td>
<td>0.001 ± 0.038</td>
<td>0.001 ± 0.038</td>
<td>0.002 ± 0.047</td>
<td>0.000 ± 0.000</td>
<td>1,381</td>
</tr>
<tr>
<td>Indicator variable for Native American race (1 if the race that best describes the household is Native American, 0 o.w.)</td>
<td>0.001 ± 0.027</td>
<td>0.006 ± 0.076</td>
<td>0.004 ± 0.060</td>
<td>0.003 ± 0.054</td>
<td>1,381</td>
</tr>
<tr>
<td>Indicator variable for other race (1 if the race that best describes the household is other, 0 o.w.)</td>
<td>0.001 ± 0.027</td>
<td>0.012 ± 0.107</td>
<td>0.003 ± 0.054</td>
<td>0.001 ± 0.038</td>
<td>1,381</td>
</tr>
<tr>
<td>Indicator variable for evacuation notice (1 if the household receives any kind of evacuation notice from anyone in an official position, 0 o.w.)</td>
<td>0.020 ± 0.139</td>
<td>0.371 ± 0.483</td>
<td>0.182 0.386</td>
<td>0.064 ± 0.245</td>
<td>1,379</td>
</tr>
<tr>
<td>Indicator variable for time passed between decision and actual evacuation (1 if this time is ≤6 h, 0 o.w.)</td>
<td>0.008 ± 0.087</td>
<td>0.136 ± 0.343</td>
<td>0.056 ± 0.230</td>
<td>0.022 ± 0.146</td>
<td>1,327</td>
</tr>
<tr>
<td>Indicator variable for low income (1 if 2004 household income is less than $25,000, 0 o.w.)</td>
<td>0.021 ± 0.142</td>
<td>0.147 ± 0.354</td>
<td>0.045 ± 0.207</td>
<td>0.015 ± 0.122</td>
<td>1,119</td>
</tr>
</tbody>
</table>

Note: Data are mean ± standard deviation; o.w. = otherwise.

*Total number of cases with no missing data; for indicator variables include both cases: 1 and 0.

\[
P^*_B(j) = \int x e^{V_w} \sum_j e^{V_\beta} \int f(\beta | \phi) d\beta
\]

where \( f(\beta | \phi) \) = density function of \( \beta \) with parameters \( \phi \) (mean and variance). The model allows some elements of \( \beta \) to be fixed parameters, whereas others are random parameters. As shown by Train (2009), the ratio of any two destination type choice probabilities is not independent of any other probability, solving the commonly faced IIA problem of the MNL model. The estimation of this model involves maximum likelihood with simulation approaches.
In addition to the modeling framework selection, estimating a destination type choice model requires the selection of appropriate variables that can be used to explain this process. Although the available data set presents 116 questions that could be potential explanatory variables, many of them are endogenous to the dependent modeled variable, that is, there is some causality between a large number of questions in the survey and the question of which destination type was chosen. This is illustrated by the following example. Although introducing information related to how much money a household spent per day on the evacuation could naively increase the goodness of fit of the model, it is evident that this variable is a direct implication of the destination type chosen, and hence, is endogenous to the choice itself, that is, the selection of an hotel increases the daily expenses compared with other destinations, but this increment was already considered and assumed by the household when choosing a hotel. After a comprehensive analysis of the data set, a reduced set of variables is considered for testing in the model.

The overall process of selection and estimation of the final model is presented next. The software used to estimate these models is Limdep 7 (1995). After data cleaning and the identification of potential endogenous variables, a MNL model is initially developed. Because the Hurricane Ivan 2004 survey does not provide information about the complete set of alternatives available to each household when they evacuate, it is assumed that the four destination types are available to each household in the development of the models. After having a MNL model with acceptable goodness of fit, a MNL model with random parameters is formulated and tested. After several trials, it is found that the standard deviations of the random parameters are not significantly different from zero. Hence, it is concluded that a model with fixed parameters is reasonable to depict this phenomenon. To check whether the model presents problems with the IIA assumption, a NL model is formulated. The formulation of such a model is not an easy task because there is no evident nesting structure to group alternatives sharing unobserved effects. As a starting point, the heterogeneous composition of the destination type O provides a basis for handling it as a separate nest. Then, it is observed that the accommodation type FR presents some specific characteristics that differentiate it from other public facilities such as PSC and H. These characteristics are related to the familiarity that evacuees have with the people in the destination place that is not present in PSC and H, which involve sharing space with unknown people, following some behavioral rules set by figures of authority, such as public shelter managers, priests, or hotel staff, that could be relaxed or found at a different level by choosing FR. Likewise, there are some personal emotions attached to the destination type FR that might not exist with public facilities such as PSC and H. After this analysis, the nesting structure in Fig. 3 is proposed. The significant estimation results shown in the following section indicate that this is an appropriate structure to capture the unobserved shared effects among alternatives and overcome the IIA assumption violation.

**Estimation Results and Discussion**

In this section, the estimation of a NL model for hurricane evacuation destination type choice is presented. The model is estimated to determine this choice among four destination types: PSC, FR, H, and O. PSC and H are grouped in a nest denominated public facilities (PF) (Fig. 3).

After following the methodology presented in the previous section and a large number of estimation trials, the results of the best model specification are presented in Table 2. Model statistics are presented in Table 3.

All variables presented in Table 2 are statistically different from zero with a level of confidence greater than 95%, which is expected for any meaningful statistical and/or econometric model. Likewise, the inclusive value (Logsum) parameter $\rho_{PF}$ for the PF nest is in the range (0,1) and statistically different from one and zero with a level of confidence greater than 95%.

Table 4 presents the elasticity for the continuous variables and pseudoelasticity for the binary indicator variables of each alternative. Values in Table 4 correspond to the average percentage change in output with respect to a 1% change in the value of the variable.

The indicator variable for households located in Louisiana that previously experienced an evacuation related to a major hurricane captures specific evacuation conditions and memories affecting the choice process. Table 4 shows that a marginal increment of this variable on average decreases the probability of selecting PSC and

---

**Fig. 3.** Nested logit structure for hurricane evacuation destination type choice

---

16 / NATURAL HAZARDS REVIEW © ASCE / FEBRUARY 2013
has some marginal increment in the probability of selecting H, FR, and O. This increment is higher for the alternative H.

After estimating the average distance between the hurricane and the centroid of the zip code where the household is located measured at evacuation time, the natural logarithm of this distance is used in the model rather than the distance itself. This decision is taken because using the linear value indicates that an undefined increment of this distance has the same linear effect in the choice probabilities, which is not realistic. Thus, using the natural logarithm of the distance allows considering the notion that, after some threshold, the changes in this distance might be imperceptible for the households. The elasticity in Table 4 shows that a 1% change in the
natural logarithm of this distance, on average, decreases the probability of choosing PSC by 2.57%, and increases the probability of choosing FR and O by 0.05%, and H by 0.33%, indicating a marginal preference to select H when the hurricane is far away from the household location. The decrement in the probability of choosing PSC is expected because of the lower levels of comfort that evacuees experience when they stay in PSC for long periods. It is expected that households evacuating when the hurricane is far away from their location can reach places that are at a safe distance and most likely will be different from PSC. This dynamic feature of the model is important for public agencies to determine the expected demand of destinations by households that did not plan to evacuate early enough. These households increase their probabilities of choosing FR, O, and PSC. On average, the probability of selecting PSC has a higher increment. This could be related to households needing to quickly find shelter and finding PSC to be the more convenient destination at the last minute.

On average, being White increases the household’s probability of selecting O by 6.41% and decreases the probability of choosing other destinations by 0.75%. The White race indicator variable encapsulates idiosyncratic and socioeconomical characteristics that make this population segment more attracted to O.

The pseudoelasticity related to the low-income indicator variable (households with 2004 income less than $25,000) suggests that, on average, low-income households have a higher probability of selecting PSC. Likewise, they increase their probabilities of choosing FR and O but in a smaller proportion. This intuitive result shows that low-income households reduce their probabilities of choosing H, which could be a more expensive alternative compared with the other three destination types. PSC are usually located close to residential areas that might involve lower transportation expenses than other destination types. Likewise, they do not require a fee as destination types such as H do.

On average, households that evacuated to a destination different from the one selected before leaving their homes have higher probability of selecting H. In contrast, on average, it decreases the probability of selecting PSC. Similar to the location variable, this variable is used to capture unobserved effects that are not appreciable from the survey questions and increase the number of observations available in the data set. Although there are different aspects that can influence this decision (e.g., congestion effects, hurricane damage to the original destination, and no vacancy, among others), this information is not available in the current data set. Some underlying insights behind this suggest future studies to understand the factors influencing this change and what the initially selected destinations were.

Continuing with the analysis of the variables, households that experienced short time periods between their decisions to evacuate and their actual evacuations, on average, are less likely to choose H. This result is related to the amount of time required to find and book a hotel. Likewise, in an evacuation context, hotels could be saturated by evacuees looking for safe places, which could hinder their proper selection by households that did not plan to evacuate early enough. These households increase their probabilities of choosing FR, O, and PSC. On average, the probability of selecting PSC has a higher increment. This could be related to households needing to quickly find shelter and finding PSC to be the more convenient destination at the last minute.

### Table 4. Average Destination Type Choice Elasticity (continuous variable) and Pseudoelasticity (indicator binary variables)

<table>
<thead>
<tr>
<th>Variable</th>
<th>PF (%)</th>
<th>PSC (%)</th>
<th>H (%)</th>
<th>FR (%)</th>
<th>O (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator variable for LA and previous experience (1 if the household is located in LA and experienced a major hurricane before 2004, 0 o.w.)</td>
<td>−0.06</td>
<td>−3.11</td>
<td>0.14</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Natural logarithm of the average distance between the hurricane and the centroid of the zip code where the household is located measured at evacuation time</td>
<td>−0.14</td>
<td>−2.57</td>
<td>0.33</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Indicator variable for White race (1 if the race that best describes the household is White, 0 o.w.)</td>
<td>−0.75</td>
<td>−0.75</td>
<td>−0.75</td>
<td>−0.75</td>
<td>6.41</td>
</tr>
<tr>
<td>Indicator variable for low income (1 if 2004 household income is less than $25,000, 0 o.w.)</td>
<td>−0.40</td>
<td>0.94</td>
<td>−1.01</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Indicator variable for not original destination (1 if household changes its mind about where to go after leaving home, 0 o.w.)</td>
<td>0.45</td>
<td>−1.49</td>
<td>0.55</td>
<td>−0.34</td>
<td>−0.34</td>
</tr>
<tr>
<td>Indicator variable for time passed between decision and actual evacuation (1 if this time is ≈6 hours, 0 o.w.)</td>
<td>−0.77</td>
<td>1.89</td>
<td>−1.56</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>Indicator variable for evacuation notice (1 if the household receives any kind of evacuation notice from anyone in an official position, 0 o.w.)</td>
<td>1.09</td>
<td>−2.88</td>
<td>1.67</td>
<td>−0.54</td>
<td>−0.54</td>
</tr>
<tr>
<td>Indicator variable for work during the evacuation (1 if anyone in the household has to work during Ivan evacuation, 0 o.w.)*</td>
<td>0.49</td>
<td>−1.33</td>
<td>0.71</td>
<td>−0.25</td>
<td>−0.25</td>
</tr>
<tr>
<td>Indicator variable for FL and previous experience (1 if the household is located in FL and experienced a major hurricane before 2004, 0 o.w.)</td>
<td>−0.27</td>
<td>−0.27</td>
<td>−0.27</td>
<td>−0.27</td>
<td>1.76</td>
</tr>
<tr>
<td>Indicator variable for AL and previous experience (1 if the household is located in AL and experienced a major hurricane before 2004, 0 o.w.)</td>
<td>−0.80</td>
<td>−0.80</td>
<td>−0.80</td>
<td>0.38</td>
<td>−0.80</td>
</tr>
<tr>
<td>Indicator variable for MS and previous experience (1 if the household is located in MS and experienced a major hurricane before 2004, 0 o.w.)</td>
<td>−0.34</td>
<td>−0.34</td>
<td>−0.34</td>
<td>0.19</td>
<td>−0.34</td>
</tr>
<tr>
<td>Indicator variable for high income (1 if 2004 household income is equal to or greater than $25,000, 0 o.w.)</td>
<td>−0.69</td>
<td>−0.69</td>
<td>−0.69</td>
<td>0.34</td>
<td>−0.69</td>
</tr>
</tbody>
</table>

Note: FR = friends or relatives; H = hotel; O = other; o.w. = otherwise; PF = public facilities; PSC = public shelters and churches.

*First line: variable in the utility function for H; second line: variable in the utility function for O.
Households receiving an evacuation notice, either mandatory or nonmandatory, on average, increase their probability of choosing H. On average, they slightly reduce their probabilities of choosing FR and O (by 0.54%), but strongly reduce their probability of choosing PSC (by 1.09%). This result reflects the impact of preparedness on evacuation decisions. Evacuation notice is a tool that can improve the welfare of evacuees by letting them select destinations that are more comfortable than PSC. This finding is important for agencies in charge of developing hurricane evacuation plans, in the sense that issuing evacuation notices early enough can decrease the amount of demand going to PSC and reduce the necessity of large numbers of PSC facilities. Additionally, accessibility and availability of H in the surrounding areas can complement PSC demand reduction strategies.

Households with members that have to work during the evacuation process, on average, increase their probabilities of choosing H and O. Because work place is a destination choice aggregated in type O, households with working members might evacuate to their work places. Likewise, working under these hazardous conditions could involve some additional income that eases the selection of H.

Finally, households that have previously experienced an evacuation related to a major hurricane may have realized the importance of having an emergency plan, which is likely to make them more independent in their emergency logistics. This is confirmed in other hazards such as earthquakes. It was observed that people were better prepared when a 7.3 magnitude earthquake hit Indonesia on January 10, 2012 because of their previous experience (Schonhardt 2012). Likewise, experiences are perceived differently in different geographic locations. The marginal effects show that previous hurricane experience, on average, represents a significant increment in the probability of selecting FR (0.38% for households in Florida, 0.19% for households in Alabama, 0.34% for households in Mississippi). Likewise, this feature is related to an average decrease in the probabilities of choosing PSC, H, and O. This result suggests that previous experience may encourage households to plan for the next event, including accommodations. FR is well known to be the most attractive type of accommodation (Modali 2005; Chen 2005; Mei 2002; Mili et al. 1992; Drabek and Boggs 1968; Moore et al. 1963), and preplanning the logistics to arrive there may make their execution easier.

Conclusions and Future Directions

This paper presents a NL model for hurricane evacuation destination (accommodation) type choice using Hurricane Ivan 2004 data. A nest denoted PF aggregates the destination types PSC and H. FR and O are also considered as alternatives in the choice set. Variables influencing this decision include household location, socioeconomic characteristic, evacuation attributes, previous hurricane experience, and hurricane position.

Literature related to hurricane evacuation destination type choice is limited. Previous researchers developed approaches to distribute the flow of evacuees among predefined evacuation regions. Because it has been observed that destination town and/or city choice is influenced by the accommodation type chosen, these models require segregating the demand by accommodation type before assigning it to an evacuation region. However, there is no evidence of a rigorous statistical model used to define these shares. Instead, they are based on general proportions obtained in posterior analysis or individual logistic regression models. This paper presents a novel choice model that can be used to determine the probability that each household in a hazardous region chooses an accommodation type among the four previously mentioned alternatives. This is another improvement to previous research, which only considered two alternatives (FR and H).

From a practitioner perspective, given a population threatened by a hurricane and known data (either by collection or estimation) related to socioeconomic, hurricane specific, and evacuation specific features (i.e., the variables that are significant in this research), the presented model can be applied to determine the number of households that will head to each of the four modeled destination types. This information is important to determine the potential supply of evacuation facilities (e.g., PSC and H), and estimate whether the available capacity is sufficient. Likewise, public agencies and researchers can benefit from the model by recognizing the factors that influence the use of public shelters, its competition with other destination types, the possibilities of cooperation with hotels, and the tradeoffs between increasing capacity of public shelters or issuing evacuation notices early enough to speed up the evacuation process. Furthermore, using household-level behavioral models increases the modeling realism by increasing the level of detail that can be achieved with these models. Ideally, this model could be integrated with a larger set of behavioral models into an agent-based simulation framework to comprehensively model the hurricane evacuation process and detect emergent behavior that is not easily observable from the individual analysis of separated decisions.

Future extensions to this work include relaxing some of its limitations. The first idea to improve the model is collecting more data pertaining to socioeconomic information and variables that are independent from the evacuation destination choice, reducing the number of endogenous variables. Given that future surveys might not ask about the set of destination types available for the surveyed household, an extension to this research would be to include modeling techniques like Choice Set Generation (Swait 2001) to build more accurate models. Likewise, it is expected that the availability of more data with more variation between observations propitiates the development of MNL models with random parameters, relaxing the assumption of fixed parameters found in this paper. Likewise, testing transferability of the model to other hurricane contexts is an interesting future research direction. Regarding this extension, Hasan et al. (2011b) found that the decision of whether to evacuate can be transferable among hurricane evacuation contexts, which opens the possibility of finding affirmative results for other hurricane evacuation behavioral models. Additionally, this work can be used to develop more sophisticated hurricane evacuation models for the joint decisions of whether to evacuate, when to evacuate, and/or where to evacuate, or the joint choice of hurricane evacuation destination type and evacuation distance that can be approached by discrete-continuous models, including selectivity-bias correction (Manning 1986).

Acknowledgments

This research presented in this paper was supported by National Science Foundation Award SES-0826874 and SES-0826873 “Incorporating Household Decision Making and Dynamic Transportation Modeling in Hurricane Evacuation: An Integrated Social Science-Engineering Approach,” for which the writers are grateful. However, the writers are solely responsible for the findings of the research work. The writers would also like to thank Dr. Hugh Gladwin for providing access to the survey data. Support of USACE for the Ivan survey and Dr. Betty Morrow are also acknowledged.

References


