DATA COLLECTION RELATED TO EMERGENCY EVENTS

by

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1. INTRODUCTION

Travel surveys have concentrated primarily on urban person movement in the past. Interest is currently growing in freight travel demand, and long distance travel received a resurgence of interest in the United States with the introduction of the American Travel Survey in 1996, after the last large-scale long distance survey, the National Travel Survey, was conducted in 1977. Interest in continuing to provide data on long distance travel has been demonstrated by the collection of long distance travel in the 2001 National Household Travel Survey. However, while it is apparent that there is a diversification in the type of data being collected, there is a growing need to collect data on emergency-related events and yet this seems to have received little attention in the past. For example, has data been collected on the travel related to the eruption of Mount St. Helens in 1980, the wildfires of California in 2003, or even the destruction of the Twin Towers in New York on September 11, 2001? We need to know how people behave in terms of travel during an emergency in order to be able to model that behavior and develop contingency plans for the future.

Security has become a much more important issue in the United States and elsewhere since 9/11. One way of improving security is understanding, and being able to predict, how people behave under different emergency conditions. This capability permits investigation of different scenarios and the strategies and policies that can lead to the optimum handling of people movement during emergency events. However, if we are to model human travel behavior effectively, the first requirement is good data on human response to emergencies and the factors that influence their response. In the past, most data collected on emergency events has been collected to observe the behaviour and attitudes of people exposed to these conditions, and relatively little attention has been given to identify the factors that influence these decisions so that a modeling capability can be developed. Since developing a modeling capability of travel during emergencies is so important to achieve the maximum safety of the population, this paper is aimed at encouraging the travel survey community to enter the realm of data collection of travel during emergency events because of the great contribution they can make in this area from their experience in data collection for urban transportation planning.

2. TYPES OF EMERGENCY EVENTS

There are a wide variety of events that could be classified as “emergencies”. The Webster dictionary defines an emergency as “a serious situation or occurrence that happens unexpectedly and demands immediate action” or “a condition of urgent need for action or
assistance”. There is thus the concept of “unexpectedness”, “urgency”, “risk”, and the need for “undelayed action”. This can apply to events that provide limited warning as well as those that occur without warning, man-made versus natural events, localized versus extensive, and those that present limited danger and those that provide catastrophic danger. With such a wide variety of possible emergency events, it is useful to establish a typology that helps identify appropriate treatment for each event. For example, emergencies that provide little or no warning of their pending occurrence, do not permit pre-event evacuation as a means of mitigating their effect. Similarly, events that produce a lasting danger require post-event evacuation whether pre-event evacuation occurred or not (e.g. a radiation release from a nuclear power plant). One typology that distinguishes among events in terms of the warning time they provide, and therefore their suitability to pre-event evacuation, is shown in figure 1.

Events that provide the least warning time, such as acts of terrorism or earthquakes, generate a need for travel if a lasting danger exists for the public, and emergency response vehicles need to access the area. Examples of this are the 9/11 attack and the impact this had on the movement of people in Manhattan, or the earthquake in San Francisco in 1989 when several freeway bridges collapsed. In general, little study has been conducted on the travel implications of disasters such as these. The problem is that this class of disaster can take on so many forms that observing past disasters does not necessarily equip one for the next. However, this does not mean that the travel
implications of disasters of this type should be ignored; development of contingency plans that can serve a wide variety of disasters could be extremely beneficial.

Emergencies that may provide a limited amount of warning time, such as chemical releases, nuclear power plant accidents, volcanic eruptions, and tsunamis, present the possibility of rapid evacuation prior to the event, and, if necessary, further evacuation after the event. This occurred with the Three Mile Island nuclear accident in Pennsylvania in 1979 where pre-event evacuation did take place but, due to being able to avert meltdown of the core, post-event evacuation was not necessary. At the Chernobyl nuclear power plant accident in the Ukraine in 1986, overheating of the core and the subsequent explosion of the reactor provided a warning of literally only a few seconds and only post-event evacuation was conducted to remove people from areas with high levels of high radiation fallout. Volcanic eruptions sometimes allow both pre-event and post-event evacuation but in others there is no warning (as in the case of Mount St. Helens) and it becomes an issue of whether the aftermath of the eruption in terms of lava flow or fallout of ash warrants, or is alleviated by, evacuation. Interestingly, tsunamis almost always provide pre-warning now with the seismic monitoring that exists virtually worldwide, although the warning is usually only in terms of hours, making effective pre-event evacuation difficult. One possible example of this is what some scientists believe is a pending disastrous tsunami that would be generated if a massive landslide would occur along a fault on the island of La Palma in the Canary Islands. It is estimated that the tsunami that would be generated would take eight hours to cross the Atlantic and devastate the East Coast of the U.S for at least 12 miles inland.

However, it is emergencies that provide the longest warning time that are most significantly affected by travel – specifically because the negative impact of the event is mitigated by evacuation, and emergency personnel must often be able to move into, and within, affected areas. Prime examples of the type of emergency that is alleviated by pre-event evacuation are wildfires and hurricanes. Data collection for these types of emergencies is needed to understand human behaviour, to estimate models that can test alternative evacuation policies and strategies, and to monitor evacuation behavior once a policy or strategy is introduced to test its effectiveness.

Of the data collected on emergency events in the past, much has been on human behaviour in the face of emergencies that provide relatively long warning times such as hurricanes. With long warning times, more discretion is afforded to those affected than in immediate crises. Since more discretion means greater opportunity to influence the
decisions of the public and emergency managers to strategies and policies that will provide the greatest opportunity for safety of the population, it is in this area this paper suggests data collection should be directed. Data of this type will allow modelers to test strategies and policies that will allow people to avoid as much of the danger of the event as possible.

3. **Surveys Conducted In The Past**

Almost all of the surveys conducted on evacuation from emergencies in the past have been post-event behavioral studies. That is, they have been conducted following the emergency event and have recorded the reported behaviour of individuals or households during the event. Some surveys have included questions asking respondents how they would behave under different hypothetical conditions, but full-fledged stated preference surveys of behavior under emergency conditions are rare. One survey, designed with the help of David Hensher and Peter Stopher of the University of Sydney, was conducted in New Orleans in 2003 and involved 600 respondents reporting how they would react in terms of evacuation when faced with eight different hurricane scenarios. Methods of gaining information regarding evacuation behavior in the face of bushfires in Australia are currently also being investigated at the Institute of Transport Studies at the University of Sydney.

A large number of post-event surveys have been conducted with respect to hurricane evacuation. Baker (1991) lists 15 such surveys conducted between 1963 and 1990 in the United States. Since 1990 evacuation surveys have been conducted on all major hurricanes and, in some cases, multiple surveys have been conducted on the same hurricane. However, very few of these surveys have been conducted by transportation professionals and, as a result, transportation information in them tends to be sparse. For example, most do not record the time of departure of those evacuating, they do not record the occupancy of vehicles used in the evacuation, do not identify intermediate stops (if any), nor the time of arrival at the place of shelter. Most importantly, the information they do collect tends to be unrelated to time, making relating evacuation behaviour to conditions (which are constantly changing as the hurricane approaches) very difficult. If models of evacuation behavior are going to be constructed, the data collection process must be adapted to provide the necessary data.

The preferred method of data collection for hurricane evacuation has been telephone interviews without contact being made prior to the interview and without a printed questionnaire being issued to the respondent. These surveys have usually been conducted
months, and sometimes years, after the event. The approach is similar to the initial telephone surveys conducted in the early days of urban transportation planning where respondents were asked to report on travel made, in most cases, on the most recent complete day. One of the developments that have occurred in urban travel surveys since those days, is to move from retrospective to prospective reporting where respondents are asked to record travel performed on a prescribed day in the future, and to rely on a printed questionnaire or diary to record travel or activities during the survey day (Stopher and Metcalf, 1996). While the prospective data collection approach is clearly inapplicable to evacuation data collection, the idea of having a diary to record individual activities during the evacuation process may be useful. Particularly, the day-timer type of activity diaries may be very useful in capturing the temporal nature of the data important in evacuation modeling.

4. MODELING EVACUATION TRAFFIC

The threat of a nuclear accident at the Three Mile Island nuclear plant in 1979 sparked interest in the development of evacuation packages that could be used to model evacuation traffic. Among the first models to be developed was NETVAC which was specifically developed to model evacuation radially away from a point of danger, as would be the case with a nuclear accident (Sheffi, Mahamassani, and Powell, 1982). NETVAC assumes that all households within the risk area will evacuate and, therefore, travel demand estimation is incidental in the model. Most of the model’s accomplishment was in modeling the movement of traffic through the transportation network.

Several other evacuation models followed NETVAC, including DYNEV, MASSVAC, and later HURREVAC, TEDSS, OREMS, and ETIS (KLD Associates, 1984, Hobeika and Jamei, 1985, COE, 1994, Hobeika and Changykun, 1998, ORNL, 1999, PBS&J, 2000a, Lewis, 2001). However, all these models either assumed that evacuation demand was given, or they estimated it by means of a subjectively-based system of participation rates. Participation rates were based on past evacuation behavior and assigned to evacuation zones in which evacuation behavior was assumed to be reasonably uniform. If time-dependent travel demand was required, subjectively-defined response curves were used to distribute the total demand over time. The response curves have typically been described as three alternative ogives (S-shaped curves) of different slope to represent “slow”, “medium”, and “fast” evacuation. Choice of the appropriate curve has also been subjective.
The identification of evacuation zones has typically been conducted on the basis of areas of similar flooding potential, areas for which population data is identifiable, areas which are identifiable by verbal description (so that inhabitants can respond to calls for evacuation from their area), and areas contained within jurisdictional boundaries (Meduri, 2004). Within individual zones, participation rates are different for those living in mobile homes versus other structures, and among residents versus transients (tourists, visitors). Those living in mobile homes have higher participation rates than those living in other types of homes, and transients have higher participation rates than residents.

Existing evacuation modeling procedures have modest data demands. They require information on the local topography, jurisdictional boundaries, areal descriptors (such as ZIP-code or telephone exchange areas, subdivision names, etc.), housing type, population composition, and population totals at evacuation zone level. Generally, these data can be obtained from existing data sources such as QUAD maps, standard GIS files, land use records, tourist and business statistics, and census data. Thus, there has not been a need in the past to collect data for evacuation modeling other than to observe past behavior in order to make good subjective estimates of participation rates and response times. However, if models are to be developed that are capable of estimating the consequences of alternative policies and strategies, then data will be required that allows the impact of policies and strategies on evacuation behavior to be estimated. These data needs are discussed later in the paper.

5. NEW MODELING PROCEDURES

The 4-step travel demand estimation process used in urban transportation planning is an approach to travel demand estimation that has worked successfully for almost 50 years. It is tempting to expect that evacuation travel demand estimation can be conducted in the same way. However, evacuation from dangers such as hurricanes presents conditions that are very different from the conditions encountered in urban transportation planning. For example, in urban transportation planning many trips are discretionary, while in evacuation trips are virtually mandatory. In urban transportation planning trips are relatively short, while in evacuation planning they are long, and often involve high levels of congestion. In urban transportation planning route choice is entirely discretionary while in evacuation it may be necessary to direct traffic along certain routes, and in some cases, even in certain directions. Thus, while models have been identified that work well in urban transportation planning, they may not work as well in evacuation planning because of the differences in the two situations. One area where this is particularly relevant is in traffic assignment. Static traffic assignment requires that trip travel times
be shorter than the analysis period so that the assumption in the assignment process that trips traverse all links between origin and destination is fulfilled (Sheffi, 1986). It is also assumed that travel remains stable (uniform) during that period. While these assumptions are generally honored in urban transportation planning, evacuation involves trips that may extend from 10-20 hours and flow conditions may vary considerably over this period. Having to assume uniform flow over such an extended period and forego knowledge of how speed, volume, density, delay, and travel time vary within the network over this period, is a major compromise. Dynamic traffic assignment is required to provide this information.

Travel demand is usually estimated for an entire day in urban transportation planning and when travel demand is needed for shorter periods, time-of-day factors are typically used. The same approach has been used in evacuation planning, but the temporal behavior in evacuation planning is likely to be more variable than the relatively stable day-to-day variation observed in urban transportation planning. This is because factors such as the proximity of the storm, its path, its forward speed, and its intensity may change from hour to hour. This suggests that variables describing these aspects of the danger should be included in a model so that it can respond to changes in these values. However, it is even more important that policy and strategy variables be included in the model in order to assess how policies and strategies can alleviate an evacuation situation. For example, a policy variable such as the timing and type of evacuation order issued can have a considerable influence on the loading of the transportation network. Similarly, if the strategy of reverse-laning, and its timing, were included in the model, this would allow estimation of the consequences of various reverse-laning strategies in terms of the impact on evacuation time, the volume of people evacuated, levels of congestion, flow patterns, and so on.

Requiring variables in new models of evacuation demand that not only describe travel and the traveler (as in urban transportation planning), but also reflect changing conditions related to the storm, and allow the impact of policy directives and operational strategies to be incorporated into the model, places a considerable new burden on data collection. The collection of dynamic data in travel surveys in the past has only been accomplished by supplementing static data with dynamic information obtained from other sources. For example, Mei (2002) supplemented static data on evacuation from hurricane Andrew in Southwest Louisiana with dynamic information on storm characteristics from the National Hurricane Center and evacuation order information from emergency managers in individual parishes in the region.
6. **NEW DATA NEEDS**

The challenge facing those collecting data on travel related to emergency events is primarily to move from a time-insensitive approach to a time-sensitive one. In urban transportation planning the major determinants of travel are static features of the traveler such as household size, vehicle ownership, and household income. Travel is collected with the time of travel reported, but little emphasis is placed on this temporal information and little use is usually made of it in the modeling process. Characteristics of the network, while changing during the analysis period, are assumed to remain stable in the trip assignment process. While such assumptions may work adequately for planning aimed at identifying infrastructure needs, they compromise the ability of the models to plan for more recent urban transportation concerns such as mobile emissions and congestion. However, as unsuitable as the omission of temporal considerations is becoming in urban transportation planning, its omission in evacuation planning is untenable. Conditions that influence the evacuation decision change rapidly in emergency situations, and conditions on the transportation network change rapidly in response to the evacuation, making the assumption of stable flow quite inappropriate. Thus, it becomes imperative in evacuation planning that dynamic data be collected, with attention being given to recording changing conditions and behavior over time. This may necessitate the collection of data over more than one day, with specific attention being given to determine a time line of behavior. Activity and time use surveys may be well suited to capture dynamic travel behavior needed in evacuation planning. However, on the other side, the collection of dynamic data of changing conditions introduces a totally new need in data collection.

The data that describes the development of the conditions that prompt evacuation is multifaceted. It is likely to be different for each type of emergency although expressions of risk, urgency, and opportunities for evasion will be present in each case. Taking evacuation from an approaching hurricane as an example, the conditions that prompt evacuation have been researched quite extensively and, therefore, are fairly well known. Baker (1991) suggests that, after studying evacuations over three decades, five factors stand out as the main determinants of hurricane evacuation:

- risk level of the area in which the household resides (e.g. vulnerability to flooding)
- action taken by public authorities including the issuing of evacuation orders
- type of housing in which the household resides (e.g. mobile homes versus other more permanent structures)
- perception of personal risk
- storm-specific threat factors (e.g. storm intensity, size, and path)

Information on these factors, and specifically dynamic information on them, is likely to come from a variety of factors. First, time-dependent reports of current storm characteristics, and predictions of expected flooding and path of the storm are likely to be available from agencies such as the National Hurricane Center and FEMA. Flooding potential is dependent on the storm intensity, forward speed and path of a hurricane. Storm surge is caused by the wind pushing the sea toward land and having the swell accentuated by the bathymetry of the coastline. In addition, the low barometric pressure at the eye of the storm causes the water to rise even further. In the U.S., the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is the official flood model used by FEMA and administered by the National Hurricane Center. Second, land use or housing inventories can be used to establish type of housing in an area. However, land use inventories are notoriously out of date, and housing records maintained by local authorities may be difficult to access and may not distinguish the type of structure in sufficient detail for the purposes of emergency planning. Third, the actions taken by local authorities in terms of issuing evacuation orders and opening and closing reverse-lane operations, can be obtained from emergency managers provided the information has been recorded and they are prepared to divulge the information. Thus, dynamic information on the storm is likely to be available but it would require obtaining it from a variety of agencies and merging it with the information gathered in the dynamic travel survey on evacuation behavior.

One of the issues surrounding the use of official records to supplement evacuation travel survey data, is that the factual data from these sources may not match what the households receive, or perception of the information may vary from household to household. For example, some households may not hear all the information that is disseminated, the wording in the message issued may be different from what was officially issued, or some people may receive information second- or third-hand and this may change in the telling (like the message sent down the trench in World War I that said “Send reinforcements, we are going to advance”, and ended up at the other end of the trench as “Send three-and-fourpence, we are going to a dance”). Some researchers have studied the impact of the form of the message to the public in emergency conditions, and have found that considerable difference exists in response depending on what is said, how it is said, and how it is conveyed. For example, ordering an evacuation by having state troopers go from house to house is much more effective than issuing an order by means
of radio. What is said can also have a major impact. For example, when hurricane Floyd was moving up the East Coast of the U.S. in 1999, it was likened to hurricane Andrew that, seven years earlier, had caused the greatest damage of any hurricane in U.S. history. Hurricane Floyd ended up generating the largest evacuation in U.S. history.

One of the interesting possibilities that can be investigated in evacuation planning is the implementation of staged evacuation. This is the sequencing of evacuation from portions of a region in such a manner that the transportation network is optimally used. The idea is that policy variables, such as the type and timing of evacuation orders or the opening or closing of reverse-lane operations, are used to influence people’s evacuation behaviour so as to achieve the sequenced loading of the network. Data is needed to estimate people’s response to these variables.

7. **POSSIBLE NEW DATA COLLECTION PROCEDURES**

The main form of data collection on evacuation has been post-event collection of revealed behavior. While it certainly is a valid approach, it has several disadvantages that new data collection procedures could help reduce. In particular, an event must occur before a survey can be conducted. When such events are rare, this can be a severely limiting factor. Another disadvantage of the current approach is that the characteristics of the event are essentially the same for all persons affected, making it impossible to determine the influence of the characteristics on the behavior of the individuals. For example, if the event is a hurricane, the characteristics of the storm (e.g. its intensity, size, and forward speed), are the same for all respondents making it impossible to determine their affect on evacuation behavior. Either data must be combined from multiple storms, or a stated preference approach must be adopted to present alternative storm scenarios to a respondent.

It is interesting to draw a parallel between data collection for emergency events and data collection for urban transportation. As noted earlier, just as most of the early travel surveys for urban transportation were based on the recall approach of people reporting on their travel behavior “yesterday”, so most of the surveys conducted on emergency events have been surveys of past behavior. If, in the context of technological forecasting, travel surveys of urban transportation are considered a “leading indicator” to surveys of evacuation behavior, then the move from the recall approach to the prospective approach (where a respondent is asked to record their travel on a specified day in the future) in urban travel surveys, could be considered as a parallel move from post-event surveys to “during-event” emergency evacuation surveys. Similarly, stated choice surveys in urban
transportation could be considered the precursor to pre-event stated choice surveys in evacuation planning.

If this notion of urban travel surveys playing a leading indicator role to emergency evacuation surveys is true, then “during-event” data collection may be the next type of survey to emerge in evacuation planning. Three possible forms of “during-event” data collection are suggested below.

First, there is the possibility of using cell phone activity as a measure and locator of travel intensity. New cell phones using FCC-mandated G3 technology, produce a record of the location and incidence of a call each time a call is made. Merging this information to a GIS would permit identification of calls made from vehicles. Research would be needed to match cell phone activity to traffic volumes. In addition, emergency conditions are likely to generate greater call activity than normal conditions, and this would need to be accounted for. However, it is a vast resource of continuous, free data.

Linked to the above method of obtaining estimates of traffic flow from cell phone activity, is the possibility of voluntary reporting of traffic conditions via cell phone from those in the process of evacuating. People could be invited via radio or printed evacuation material to call in and report traffic conditions they are currently experiencing. Supplemental information such as where they evacuated from, when they left, how many vehicles they are using, household composition, and so on, could also be gathered during the phone call. Considering that up to 90% of traffic incidents are reported voluntarily by cell phone in some cities (FHWA, 2000), this could be a useful form of data collection. One limiting factor is that cell phone activity can become so intense during an evacuation that it fails to be an effective means of communication during the crisis (Jenkins et al, 2000).

Second, there is the possibility of using unmanned aircraft (drones) with on-board video cameras to capture traffic conditions (volume, speed, traffic composition, breakdowns, etc.) during an emergency event. These aircraft are used extensively in military applications and the technology developed there could be applied to civilian applications. Real-time data collection with image processing can lead to considerable information over widespread areas. However, this technology may not be suitable for hurricanes due to high winds and low visibility although they may be useful in other emergency conditions. The information provided by this technology is limited to traffic conditions at individual locations at the time of observation and, therefore, does not provide the
information typically required for evacuation planning. However, it can provide information for verification of demand estimates in the same way that traffic counts and screenlines are used to verify demand estimates in urban transportation planning. Also, the observations are useful for operational management of the system, as evidenced by the use of light aircraft to monitor evacuation in some states in the past (Stubblefield, 2000). There is a great demand for real-time traffic information to assist in operational management during an evacuation (Decker, 2000).

Third, there is the possibility of adapting the mail-out, mail-back self-administered questionnaire approach to emergency survey applications in those situations where an emergency event provides sufficient warning that the survey can be issued to the respondent in advance of the event. The procedure would be initiated by recruiting potential participants over a wide area in advance, getting their agreement to participate in a survey if and when an emergency occurs. The arrangement would be that as soon as an emergency arose, they would be contacted to verify their continued willingness to participate in the survey. If they were willing to participate, a diary would be sent out to them plus a GPS instrument that they would switch on in the vehicle they evacuated in. If multiple vehicles were used, multiple GPS instruments would be issued to them. The diary and the GPS instruments would be sent by UPS or Fedex by overnight service to get to them as rapidly as possible. The household would be asked to complete the diary during the evacuation recording information such as the type of vehicle used, any trailers or boats hauled, occupants of each vehicle, nature of the destination at any location where they stopped, etc. At the end of the emergency, the household would be asked to mail back the questionnaire and the GPS instrument(s) in a provided UPS or Fedex box.

The list of latent survey participants described in the previous paragraph does present some daunting challenges for emergencies that occur over a wide area and are rare events. For example, for hurricane evacuation in the US, all inhabitants along the Atlantic and Gulf coasts would be involved although individual communities may be impacted by a hurricane perhaps only every ten years. However, at least two major hurricanes are projected to make landfall on the US coastline each year, making the potential for data collection large. In addition, while maintenance of the list of latent participants will require continuous effort and will need to involve a large number of households to obtain adequate sample sizes of completed diaries, the effort is in recruitment for a possible future event only. It is also related to an activity that people generally regard as important and which they are generally willing to relate their personal experiences on.
Pre-event surveys in the form of stated choice surveys are particularly relevant to emergency event planning because of the rarity of emergency events and the limited warning time of some emergency events. However, one of the problems associated with the use of this approach in emergency planning is to be able to make storm conditions realistic enough that the respondent can make meaningful decisions. One possibility is to establish audio-visual scenarios on a DVD that portray a situation as a short movie on the television. Each scenario would present the emergency as it would be reported on TV including news reporters on the scene, graphic footage of the impending danger, reports from experts, and so on. The video would be compiled in a TV studio using archive video material, and actors acting out fictional scenes. After viewing each scenario, respondents would be asked to indicate how they would respond.

One issue that seems to stand out when considering data collection related to emergency events, is the need for greater passive data collection. Passive data collection reduces respondent burden in a situation where the need to collect dynamic information in emergency events increases the amount of data to be collected. Passive data collection also assists in getting accurate temporal information and in gathering information that is difficult to report such as the route taken, the speed traveled, the amount of delay experienced, and accurate total travel time. Therefore, passive data collection devices such as GPS, traffic counters, satellite imagery, and cell phone information need to be considered with renewed interest to supply the data needed in emergency planning.

8. CONCLUSIONS

It has been suggested in this paper that collection of data associated with travel generated during an emergency event is an area that provides interesting possibilities for travel survey practitioners. Expertise gained in conducting urban travel surveys will be useful but the unique conditions that exist in emergency situations, will require the development of new approaches. Of particular concern are the need to provide dynamic information, limit the respondent burden to manageable amounts, and develop new techniques whereby supplemental data can be gathered. Data that has been collected in the past does not fulfill the needs of an effective emergency modeling capability.
REFERENCES


