

Climate migration using highway infrastructure: A Review of Literature for Texas

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Natural hazards across the globe are becoming more frequent, intense, and resulting in economic loss and fatalities. Macro and micro level resilient technologies and strategies can enhance the deterrence against natural disasters, but at times such deterrence is not enough, given the scale of natural disasters. Migration due to the exposure to natural hazard can be another alternative adopted by the populace. Multiple instances exist in Texas history, where mandatory evacuations were issued where populace of the impacted areas are expected to relocate during the natural disaster event. Roadways and highway infrastructure are expected to be used by the evacuees. Given the critical role of the evacuation routes and transportation infrastructure plays in the evacuation of the people, the study conducted a review of existing literature for the evacuation requirements based on federal highway and TXDOT standards. Further, this paper focused on the factors that determine the evacuation of the populace. Items of concern include factors that may cause citizens to evacuate later causing highways to be over capacity.

Keywords: Hurricane, Highway Infrastructure, Evacuation, Temporary migration, Evacuation Capacity

Introduction & Background

The impact of humans on the environment can no longer be ignored. There are indications that the consequences of human impacts and changing climate would result in a future climatic paradigm that will be altering the existing climatic norm across the globe (McLeman and Smit, 2006; Williams et al., 2007; Mora et al., 2013). Instances also exist where environmental deterioration caused by human developmental paradigm exacerbated the impacts of the disasters (McLeman and Hunter, 2010), thus further complicating the problems and impacts of climate change. Across the globe, 15,000 extreme weather events recorded between the periods of 1995-2014 resulted in casualties exceeding 500,000 people, and losses estimated to exceed 3.0 Trillion USD (Kreft et al., 2016). About 24 million people were impacted by natural events such as floods, hurricanes, and others, in 2016 across the globe (Stapleton et al., 2017). Within the US, in the last 38 years (1980-2018), top five years with the most frequent and most expensive Billion-Dollar disaster events occurred in the last decade (2008-2018) (NOAA, 2018). As per NOAA (2018), 2017 was recorded as the year with a maximum number of natural disasters for the last three decades (16 natural events) with costs exceeded 300 Billion USD. Thus, indicating the increasing frequency and intensity in natural disasters. There is a growing concern for the changing weather patterns, not only within the research community but also among the general population. Leisertowitz et al. (2012) surveying the adult American population found that majority of the respondents (52%) believe that the weather in the US has become worse. The impact of the disasters is not merely economic but also has social and political impacts. Further, changing climate is resulting in the migration (temporary and permanent) of the populace (McLeman and Hunter, 2010; Warner et al., 2012).

Mitigation strategies and migration

Lindell and Prater (2003) define a natural disaster as an extreme event (hydrological, meteorological, geological, and other) where the impacts of the event exceed the community's capacity to cope with the particular event. One of the ways to mitigate or minimize the impacts associated with the natural disasters is to adopt mitigation strategies with the intention of reducing damages and causalities associate with the natural disaster (Lindell and Prater, 2003). These mitigation strategies can exist at multiple scales. Macro-level mitigation technologies/strategies mitigate the impacts of natural disasters at an urban/societal/community level. The technologies/strategies aim towards enhancing the resilience of entire communities towards natural disasters and are mostly adopted by the states or counties or communities. Such technologies/strategies can be in the form of codes, seawalls, and others that aim to alleviate the impacts of natural disasters and benefit communities on an overall basis. On the other end of the spectrum are the micro-level resilient technologies and strategies. Micro-level technologies and strategies are implemented or adopted by individuals that aim towards enhancing the resilience of individual units/household from natural hazards. The micro-level resilient technologies can be in response to macro- level resilient technologies such as municipal codes or at the will of the individual owner. Some of the examples of micro-level resilient technologies and strategies are detention pond for temporarily retaining flood water, installing hurricane clips on the rafters to provide resistance against strong winds, building the homes on stilts, and others. Even post-adoption and implementation of micro and macro resilient technologies/strategies within the built environment, a certain household can choose to migrate in response to an impending natural disaster.

The decision to migrate can be in response to multiple reasons such as the scale of the expected natural event, mandatory evacuation, or others. Multiple researchers (McLeman and Smit, 2008; McLeman and Hunter, 2010; Sabine et al., 2008; Tacoli, 2009) identify climate migration of the population as a form of "*adaptive response.*" The "*adaptive response*" can impact certain socio-economic groups more than others and can be in response to an onset of the natural event and can be categorized as *sudden-onset* or *slow-onset* events (McLeman and Hunter, 2010). *Sudden-onset* natural events occur at short durations, and examples include hurricane, floods, or others, and the population can potentially evacuate before the beginning of the event (McLeman and Hunter, 2010). For example, in response to the impacts of Hurricane Katrina about 150,000 people sought refuge in Houston, TX for a limited time (McLeman and Hunter, 2010). The migration of people, in response a "*sudden-onset event,*" utilize existing highway infrastructure to relocate from New Orleans to Texas in response to Hurricane Katrina or moving from Galveston, Port Aransas, and other gulf coast counties to inland in response to Hurricane Harvey. Thus, indicating the importance of the role the highway infrastructure plays in the evacuation of the populace, in response to natural disasters.

The movement of people with ease, convenience, and efficiency is of critical importance during the evacuation, in response to the impending natural disaster. Stapleton et al. (2017) state that the impact of climate change on human mobility needs to be investigated. McLeman and Hunter (2010) identify the need for empirical relationship studies that need to be conducted between environment and migration relationship to better predict the future movement of the population in response to a climatic event. Building on the identified need, the research aimed to identify the literature gap regarding the migration of the people in response to the climatic event using existing highway infrastructure in the state of Texas.

The literature review aimed to focus from the perspective of the following three areas, for the state of Texas:

1. Migration in response to a sudden-onset event
2. Highway capacity and its role in the movement of population
3. Highway evacuation efficiency functions

These three areas were selected as it allows identification of reasons that dictate the movement of people in response to a natural disaster. For this study, "*sudden-onset event*" such as a hurricane, flood, tornadoes, and others were considered. Along with the identification of the issues dictating the movement of the populace, the study also analyzed the state of literature about highway capacity and efficiency functions. The selection of highways was deemed as critical as highways tend to facilitate the movement of people to avoid the impacts of natural disasters and evacuate using the existing infrastructure.

The state of Texas was selected as the unit of analysis for this study because of its unique geographical location. The state has been impacted by seventy-three incidents resulting in losses over a Billion-Dollar in Weather and Climate Disasters in the last two decades (FEMA 2018a). Thereby, making it the state within the nation with the highest disaster incident rate in the nation followed by Illinois and Georgia (NOAA, 2018). From 2008-2018, Federal Emergency Management Agency (FEMA) issued thirteen Major Natural Disaster Declarations for a natural disaster such as Flooding, Hurricanes, Severe Storms, Straight-line Winds, Wildfires, and Tornadoes. In 2017, Hurricane Harvey resulted in the generation of 670,000 personal and commercial property claims to private insurers which includes 354,000 residential property claims (Insurance Journal, 2018). The Texas Department of Insurance expects the final figure related to claims issued for Harvey in the range of 15-16 Billion USD (Insurance Journal, 2018). The identified costs are merely direct costs and do not account for indirect losses.

Method

This research was conducted to identify the existing literature on the migration of the people in response to sudden-onset of the event along with the literature that identified the design requirements for highways that helped in the evacuation of the people. The literature associated with the resilience of the identified infrastructure (highways), social issues of migration, and communication methods used to efficiently facilitate the movement of the people along the highways during a sudden-onset event (such as a hurricane, floods, others) was identified. The three areas were selected purposely, as societal migration in response to an impending natural disaster is expected to utilize infrastructure such as highways. The highways would only be effective mediums of evacuation if all information is conveyed to the people appropriately and are functioning efficiently to allow movement of the population. Thus, the reason for the selection of the three topics.

To determine the gap, a review of existing literature in the last twenty years was performed for a) migration of people in response to natural disaster b) highway capacity (temporary migration of people using the interstates), and c) evacuation efficiency functions which include drainage capacity of highway and signage and their impact on efficiency. While reviewing literature, lessons learned from previous hurricanes, transportation needs, and challenges and environmental review were analyzed. Utilizing the literature review, the research sought answers to the following questions:

1. What social factors are associated with the Migration of People due to extreme climate?
2. What is the capacity of the highway when utilizing one-direction for evacuation?
3. What evacuation efficiency functions dictate successful migration of population in response to natural disasters?

The listed questions affect the decision-making of the populace for migration, in response to an impending natural disaster.

Results

As the state and the coastal areas of the state continue to see an increase in population, response to severe weather events becomes more important. Texas is also projected to receive the most number of climate migrants from other states in the US, in response to the sea-level rise. (Hauer, 2017). Given the increase in expected population and the number of natural disasters impacting the state, the research reviewed the literature identifying the factors that impact on people's decision to migrate, followed by the literature on the highway design standard and highway evacuation efficiency functions within the state.

Migration of People due to extreme climate

The mobility of the people from one location to another can be tied to migration (Aksakal and Schmidt-Verkerk, 2015) and at times as an adaptation to an impending natural disaster (Stapleton et al., 2017). In response to a catastrophic event that places the substantial risk on a geographical region, migration of the people from potentially impacted geographical zone to a safer location might be a natural corollary. At times, in response to the magnitude of the natural event, state agencies might issue a mandatory evacuation of a region, in response to the on-coming event impacting the region. The term "*Climate Refugees*" is associated with "*.... people who undergo forced migration related to environmental change*" (Farbitko and Lazrus, 2012). At the same time, there is a greater discussion for the terminology associated that ought to be used for the people that are forced to move from one geographic area to another due to the sudden onset of the climatic event (Farbitko and Lazrus, 2012). For the study, the debate and congruence on the terminology that ought to be associated with the movement of people due to natural disasters are beyond the scope of the study. In addition, the authors realize that various migration types (social, economic, political, others) occur and are beyond the scope of the study. The study purely focussed on the migration of the people due to natural hazards such as hurricanes or floodings. For this study, people who choose to leave/migrate in response to a specific climatic event have been defined as "*....persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country..*" (Werner et al., 2009). Social migration in response to climate change can be associated as an adaptation technique (McLeman and Smit, 2006; McLeman and Hunter, 2010). At the same time, societal migration in response to a climatic event should not be oversimplified (Hauer, 2017) and state that migration has multiple social factors contribute towards the behavior to evacuate (McLeman and Smit, 2006). Factors deemed as important towards deciding for evacuation are- "*threat definition as real, perceived level of personal risk, and the existence of a plan*" (Perry et al., 1980). Elliott and Paris (2006) studying the evacuation patterns for the city of New Orleans found that household income played an important and decisive roled for predicting in the evacuation. In addition, age, marital status, education, household ownership, and income, social capital were some of the factors that impacted on the decision to migrate (Elliott and Patts, 2006; McLeman and Hunter, 2010) and whether the climate migration would be temporary or permanent. Hauer (2017) found that about *56%* of the nation's counties (*1,735 out of 3,113*) could be impacted by net migration by 2100 due to climatic conditions and income and economic opportunities could be important factors in determining the movement of the people and the distances that are moved. Elliott and Patts (2006) also found that in the case of evacuation from New Orleans, poorer people were less likely to evacuate than economically stable because of multiple reasons such as lack of accommodation, transportation, social networks and ability to collect financial assistance if they stayed back. As per research (Landry et al., 2007; 2016; Smith and McCarty, 2009; Thiede and Brown, 2013; Thomas et al., 2013; Whitehead, 2003), some of the most common factors determining the migration of people in response to an impending natural disaster are *Household income, gender, age, race, marital status, education, home ownership, pet ownership*, and others.

Along with social factors that impact the evacuation of the population, previous experience with evacuation, information about the sudden-onset event can impact the decision of the individuals or certain sections of the society. For example, during Hurricane Harvey, one of the main evacuation routes, I-10, directed traffic towards San Antonio. Interstate 10 has two lanes each direction and a frontage road with one lane each direction on both sides for a total with contra-flow of 8 possible lanes toward Austin (Travis County) and San Antonio (Bexar County). Rain totals and wind damage in these counties were small in comparison to the local Houston area (TXGLO, 2018). However, two years earlier Austin and San Antonio both had torrential rains and flooding on Memorial Day weekend. The event could have affected travel choices. Further, as Harvey moved inland, the hurricane changed direction just outside of San Antonio, which could have deterred traffic from heading in that direction. As the hurricane continued east towards Louisiana, people who had evacuated and relocated post-Hurricane Katrina might have been discouraged. After evaluating the southern cities, a northerly path toward Dallas remains, with options for College Station or Waco on the way.

Currently, Texas does not have a Transportation Analysis available through FHWA. To this end, the Texas Department of Transportation (TxDOT) had research conducted on "*Recommended Practices For Hurricane Evacuation Traffic Operations*" (Ballard and Borchardt, 2006). Although a thorough investigation of options presented by other states was performed, the report does not establish timelines for decision making, announcements or contra-flow. Ten years after the recommendations were published, the Mayor of Houston did not order evacuations (Andone et al. 2017). It is still up to local government to determine if evacuations are required (Texas Government Code, 2009). This can be a factor that can play a critical role among the potentially impacted population as they try to decide about evacuating or migrating temporarily. If the local authorities do not require evacuation or provide enough notification for evacuation, citizens may opt instead to shelter-in-place. Just as individuals use the recent, experience to decide whether to evacuate, local officials may do the same. Previous experience by the local officials or shared by the peers can impact the decision issuing an evacuation. For example, deaths associated with Hurricane Rita, also in the Houston area, were mostly due to traffic jams. The traffic itself is considered to be a response to Hurricane Katrina (Levin, 2017). Transportation infrastructure is one motivator in the evacuation decision-making process, from both the individual and local government level.

Thus, establishing the need to identify the literature and determine the efficiency of the established system. The subsequent section discusses the literature about highway design and highway evacuation efficiency functions.

Highway Design

Typical highway design is based on needs and standards (AASHTO, 2018), so minimum requirements are not always identified. However, there are some commonly identified normal flow rates for vehicular traffic. Design capacity ranges from 1,500-1,650 vehicles per hour per lane (PBS&J, 2000). An assumption is also made that traffic flows both directions and shoulders are not included. When traffic demands exceed the capacity, traffic jams happen with slower moving traffic and complete stoppages occurring.

However, when identifying flow rates for evacuation routes, the assumption changes and all lanes should be open to evacuation. Shoulders should remain open for emergency or stopped vehicles. However, High Occupancy Vehicle (HOV) lanes can be fully opened for the use and increase in the overall capacity. The Federal Highway Administration (FHWA) provides some direction on this topic. Opposite direction traffic lanes should be reversed known as contra-flow, which will double the capacity of the roadway. Interstate 45 leading north from Houston has four lanes each direction, shoulders on both sides and a frontage road with one lane each direction on both sides for a total with contra-flow of 16 possible lanes. After Hurricane Rita in 2005, I-45 was opened for contra-flow allowing up to 16 lanes of evacuation traffic. Considering each lane of traffic can move 3,000 vehicles per hour (PBS&J, 2000), if 16 lanes were open as were during Hurricane Rita on I-45 (Vásconez and Kehrli, 2010), it would take 136 hours. However, evacuation inland directed routes also include I-10 and State Highway 290. Assuming at least additional 16 lanes, it would take 67 hours to evacuate. In general, using a value of 1,500-1,650 vehicles per hour per lane (PBS&J, 2000) should be used to determine the hurricane highway evacuation rate.

Contra-flow has some drawbacks as emergency vehicles may still need access to the disaster location. There is a strong need for adequate communication before activating contra-flow. The lanes must be emptied before letting traffic move to the opposite direction flow. Typically announcements are made as to when the full capacity of the evacuation routes will be opened for use. There is some generalized knowledge as to how long to plan for contra-flow and evacuations. FHWA (2003) has provided general parameters for decision-making but recommends that each state perform its' own Transportation Analysis to determine the time required for evacuation.

Evacuation routes should be marked clearly with signage, and many states, such as North Carolina, South Carolina, and Texas, also have websites for identifying the evacuation routes in advance of leaving (PBS&J, 2000). However, the highways may not be perpendicular to the storm and may lead through areas of flooding. Coastal highways frequently run parallel to the coast, where that perpendicular to the coastal highways is the focus for evacuation. Weather predictions do give a cone of influence for the hurricane path, which inevitably leads to the jet stream. The predictions can indicate which highways are best suited to escape the initial landfall for hurricanes. However, hurricanes are known to double back on themselves and eventually head east via the jet stream which may be the identified evacuation path.

Although Harvey made landfall much closer to Victoria, it was the flooding in Houston that caused problems. Weather predictions did not indicate the need for the evacuation of Houston. The Mayor stated that putting 6.5 million people on the road would be "*creating a nightmare*" (Andone et al., 2017). Evacuations must take into consideration not only the initial disaster, in this case, a hurricane, but the secondary disaster as well, which was torrential rain and flooding. Another concern is previous disasters, such as Hurricane Rita, in which the evacuation itself left more than 20 people dead (Levin, 2017). The deaths occurred ten years before, but like those who evacuated from Katrina, it may not have been long ago enough to consider evacuation.

Having enough roadway, specifically the number of available lanes on the interstate, it an important focus for evacuation. In the 2018 hurricane season, much of the devastation seen from Hurricane Florence was flooding due to rain and storm surge. Convincing the public that rainfall and flooding affect the ability to shelter in place versus traditional high-wind events associated with hurricane may be one of the next steps in education for evacuation. The ability to move the water off the road and move traffic is equally important for potential evacuees.

Highway evacuation efficiency functions

As per the literature, (Ballard et al., 2006; Cashdollar, 2005; TXDOT, 2017) certain functions determine the successful migration of populace from geographic locations facing natural disasters to safe locations, utilizing highway infrastructure. Some of those functions include- drainage capacity along the highways, evacuation route signage, a constant supply of food, water, and gas at regular intervals along the highways, and others. Of the identified functions, the study purposively selected the first two (drainage capacity for rains and signage for evacuation) for the literature review and the gap analysis.

Drainage capacity

Basic drainage guideline of Texas is found in hydraulic design manual uses the probability model to design runoff pattern from rainfall or watershed properties (Garcia 2016). This method is useful where records more than 20 years of stream gauge data available. Peak discharges and runoff hydrographs are estimated for TxDOT design and evaluation by following methods: a) Statistical Analysis of Stream Gauge Data, b) Omega EM Regression Equations, c) Rational Method and d) Hydrograph Method. TxDOT's approach to selecting the design standard for a drainage facility is to use a reference table that specifies a range of design Annual Exceedance Probability (AEP) for different types of facilities. According to hydraulic design manual (Garcia 2016), culvert and bridges are designed based on a) 50 years flood design (runoff) at freeways; b) 10 years flood design (runoff) at principal arterials; c) 5 years flood design (runoff) at minor arterials and collectors (including frontage roads); and d) 2 years flood design (runoff) at local roads and streets.

Hurricanes contribute to flooding. Greatest flood threats are hurricanes, seasonal storms and heavy rainfall occurring in a short period. Problems typically occur along with low lying areas, along with major drainage canals, areas flooded by the overflow from lakes, and coastal areas that can be impacted by tidal surges. Low lying areas are identified as Special Flood Hazard Areas on the NFIP Rate Map published by FEMA (National Research Council, 2009 and FEMA map- FEMA 2018). Flood warning should be broadcast on TV and all radio stations. During prolonged rainfall, areas should be patrolled by Police Officers, Stormwater, Public Works, Water, and other staff. Transportation officials are increasingly challenged faced about how to design, plan, and manage infrastructure to confront changes in climate and extreme weather events (Rowan et al. 2013). Figure 1 shows US 69 Before and After Flooding Resulting from the Impact of Hurricane Harvey. Figure 2 shows Flooded Section of US 69 from Hurricane Harvey Impacts. What was not found during the literature review was any reference to how flooding effects evacuation, either through loss of lane-use or evacuee decision-making processes.

Evacuation route signage

Traffic flow is very important before and after a hurricane. Before hurricanes, traffic must flow as efficient as possible. As mentioned earlier, the normal flow rate of traffic ranges from 1,500-1,650 vehicles per hour per lane from PBS&J 2000. After the hurricane, flooding and power outage damage may result in long-term road closures and, there would be significant detours. The DOT should be prepared to develop signal timing plans based on extraordinary traffic patterns (FDOT, 2005). These are following recommendations concerning traffic signals from Hurricane Response Evaluation and Recommendations from FDOT- 2005 manual. 1) Check regularly design standards for freeway signing, traffic signal and designs, vehicle detection systems, intelligent transportation systems cameras, and lane control signals in coastal communities. 2) Prioritize key intersections for repair after the storm (Cashdollar, 2004). 3) Develop a plan for refueling generators and develop options for occasions when fuel is unavailable for extended periods and/or sufficient numbers of refueling personnel are unavailable. 4) Real-time signals in aftermath where damage closes a major road, thereby significantly altering traffic patterns. 5) Ensure signals on evacuation routes have switches that allow operators to give priority to the evacuation traffic approach with flashing yellow displays while all conflicting movements receive flashing red. 6) Train staff in signal damage assessment and documentation procedures required by the Federal Highway Administration (FHWA) and the Federal Emergency Management Administration (FEMA).

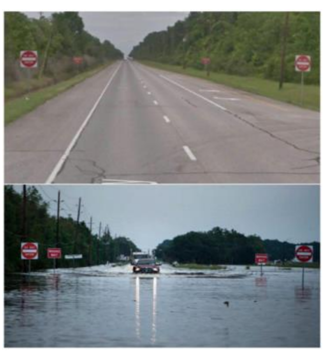

Figure 1: US 69 Before and After Flooding Resulting from the Impact of Hurricane Harvey

Figure 2: Flooded Section of US 69 from Hurricane Harvey Impacts

(Source: TxDOT, 2017)

Conclusion and Future Research

The study found that as per literature the concept of migration in response to climatic change is not new (McLeman and Smit 2006) and has been identified as an adaptive technique. The changing climate will exasperate migration, in the near future. The research also found multiple social factors that impact the decision to evacuate, as per the literature. Age, marital status, education, household ownership and income, and social capital factors impact the decision to migrate. Also, the ability to possess a vehicle was also identified as a reason to determine the ability to migrate.

Regarding the highway infrastructure that is in place to allow the movement of the people from one geographic location to the another, the study found that as per the national data, values of 1,500 vehicles per hour per lane have been used to determine flowing traffic. When the rate goes to 3,000 vehicles per hour per lane, traffic stops moving which becomes a separate hazard. This can be an issue when reviewing in the context of mass migration/ evacuation of an area due to a natural disaster. The study found no reference to how flooding effects evacuation, either through loss of lane use or evacuee decision-making processes, for the state of TX. Future studies need to be conducted to prioritize the social factors that determine the ability of people when asked to evacuate. Also, the impact of flooding highways on evacuation needs to be determined, in detail.

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