MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

19th Annual International Symposium
October 25-27, 2016 • College Station, Texas

Developing Early Risk Detection and Preparedness System with Risk Analysis and Contingency Plan

Joon-Yeoul Oh, Young Lee and Amir Hossein Gharehgozli

Department of Mechanical and Industrial Engineering
Texas A&M University-Kingsville
Kingsville, TX 78363
Email: joon-yeoul.oh@tamuk.edu

Abstract

When the natural or human-made disasters, such as hurricanes, floods, tornadoes, wildfires and gas leaks, threaten a populated area, mass casualties and property losses may be followed. To avoid, minimize or eliminate the risks for public safety, a well-organized early risk detection and preparedness system is needed in order to save lives and minimize losses. To make this early detection system efficient yet effective, a mobile app, risk preparedness aid, was developed. This aid system can communicate with sensors, location information, and disaster management server. The aid was designed using the concepts of location based service and risk management and it includes gas leak detection, warning and emergency evacuation procedure with routing. Based on the identified risks and preparing procedure, various contingency plans were developed. The contingency plans should be very clear so that it is easy for public and employee to follow. Because each system has unique infrastructure its contingency plan must be unique. This paper also shows an evacuation process in the form of a flowchart for ease of use in the event of an emergency.

Keywords

System Safety, Risk Management, Risk Assessment, Emergency Responses, Preparedness, Contingency Plan, Early Risk Detection

1. Introduction

During the years from 1960 to 1970, evacuation studies mostly concentrated on the coastal areas because of the development of weather satellites and weather forecasting equipment. Hurricanes have had big impact on coastal areas around the world leading to billions of dollars in damage and a large number of losses in lives. One of examples is the Great Galveston hurricane which hit the coast of Texas with a wind speed of 145 mph deemed as a Category 4 hurricane and caused $30 million US in damages and 12000 deaths (Trumbla, 2012). From the past experience of man-made and natural disasters that have occurred, it is found that most of these disasters would not be able to provide a prior warning before the impact of those disasters. Disasters, such as tornadoes and hurricanes are preceded by warnings; however, these evacuations require long durations to be successful, since these disasters have constantly changing attributes like wind speed, temperature and weather patterns (Lahmar et al., 2006).

Most of disasters, such as earthquakes, hurricanes, tornadoes, wildfires and floods are disruptive in nature; since they not only affect more and more populations as they travel over large distances but also have an impact on the economy of the particular area being traversed. The other types of disasters, such as gas leaks, hazardous fluid spills have an adverse impact on a specified radius which can be controlled from spreading to larger distances.

Evacuations are considered one of the best solutions to help save more number of people and minimize the losses incurred. Evacuations can be initiated with or without prior warning. The evacuations undertaken with prior warning give the populations being evacuated and the emergency evacuation personnel a time window to decide on how and where to evacuate. This allows some time to analyze the situation and take into consideration all factors related to the evacuation process. The evacuations without prior warning have disastrous effects not only on the populations but also on the environment leading to losses on the economic as well as human lives.

In the evacuation process, there always exists a factor of uncertainty. This uncertainty occurs because of the changing situations during the evacuation process. One of these situations is the disaster affected area. The affected areas go on expanding which means that more and more populations get affected and larger distances must be travelled in order to avoid the effects of the disasters. There are many other factors involved in the evacuation process which can hamper the process and lead to huge number of consequences. Evacuations are thus an important aspect in the real world today since it involves a large number of people moving over large distances to safe areas.

In 2005, hurricanes Katrina, Rita and Wilma had significant impact along the Gulf and Atlantic Coasts, caused more than $ 100 billion damages and thousands of fatalities (Mayer et al., 2008). Due to the disastrous strength and relatively short notice, evacuation process should be operated efficiently following the proper evacuation plan in limited time. During hurricane Rita, Houston's hurricane evacuation plan experienced a lot of unexpected difficulties. Because of the extremely high traffic volume on the designated evacuation routes, evacuees had to drive more than 24 hours to reach safe areas such as College Station, San Antonio, Huntsville, Dallas and Lufkin, During the long evacuation delay, most of evacuees were stranded and some of them died on the road while trying to save the gasoline by not operating the air conditioners in the 98°F temperature (Mayer et al., 2008).

As the case of Houston shows, any evacuation plan could experience some unexpected problems. The residents around the threatened area need to be evacuated to at least 20 to 50 miles to locate a safe place within 24 hour period depending on the situation. With mass evacuation, 24-hour timeline is not enough since necessities such as lodging, restaurants and gas stations are limited; since the actual evacuation distance can easily be more than 100 miles (Chiu et al., 2007). Development of mass evacuation plan is challenging since it requires transfer of mass population through the limited route spaces within the limited time frame. The plan must be proactive and stay up-to-date with population growth, city expansion and more. If not, escaping one disastrous situation can easily lead to another disaster such as hurricane Rita's evacuation case. To avoid such a situation, an effective and efficient evacuation plan must be developed and validated (Song et al., 2009).

However, even a well-developed city's current evacuation routing information provides only paths to evacuate. In a real situation, the routing information did not provide enough information, such as a sudden road washed out, other paths' status. Radio or Television broadcasting and weather websites give accurate but delayed information to people in emergency situation. Also current GPS system provides one-directional information, from satellite to device, and only shows estimated time to reach the destination using the current vehicle speed [7]. So, the development of the bi-directional real-time evacuation routing aid is critical and the aid should provide critical information for current location in real-time so that people in the area will share information together (Zhou and Liu, 2011).

An Android application would be developed which would provide important emergency evacuation information in order to save lives (Wu et al., 2011). This Android application would be downloaded by the users on their smartphones. Whenever the emergency evacuation would be necessary, the app would provide alerts to the users to safely evacuate from the danger zone or would re-route the users to the shelters away from the disaster affected areas (Sinuany-Stern and Stern, 1993).

To assist the Android application, an emergency evacuation plan would be designed as a guideline to evacuation procedures for all types of natural disasters. To help the emergency personnel detect and avoid any risks that might hinder the evacuation process, a risk matrix would be created to show all the types of risks that could cause hindrance and the corresponding contingency plans in order to tackle those obstacles. An evacuation process would help to showcase this study in a picturesque form (Daganzo and So, 2011).

2. Bi-directional Emergency Evacuation Routing Aid

When a natural gas leak occurs, there is widespread chaos in the locality of the leak. The natural gas leak may be residential or industrial (Chen and Geng, 2010). However, whichever type it may be, it always has consequences on the surrounding areas. In the event of a natural gas leak, the emergency management response team has the uphill task of evacuating life from the affected areas. During an evacuation, there are many risks that are involved which may hinder the smooth functioning of the evacuation process (Song et al., 2009).

When the emergency occurs, the sensors or gas level detectors sense the abnormal levels of the leak which may have the potential to cause a hazard. In some cases these sensors or detectors may not respond properly to the grade of leak, causing the disaster to not be detected. To mitigate this risk, preventive maintenance, regular quality checks and auditing should be done in order to ensure the sensors are up to the desired safety standards else replacement or repairs are needed (Ni et al., 2010).

After the sensors detect the leak, they transfer the information to the main server which is located at the emergency response center or nearby. Here too, there are possible risks that might hinder the evacuation process, which include power failure, viruses, system failure, wrong interpretation of the information sent and clerical errors (Ni et al., 2010). To control the effects of these risks, quality audits, preventive maintenance need to be conducted on a regular basis to monitor the systems involved.

The database should be regularly updated to ensure that every individual can be evacuated in the event of an emergency (Aven, 2008). For this the database should be updated by collecting the census every six months from the expected affected areas. A backup server at a remote location would also be beneficial in the event of the main server being affected (Farrells, 2010).

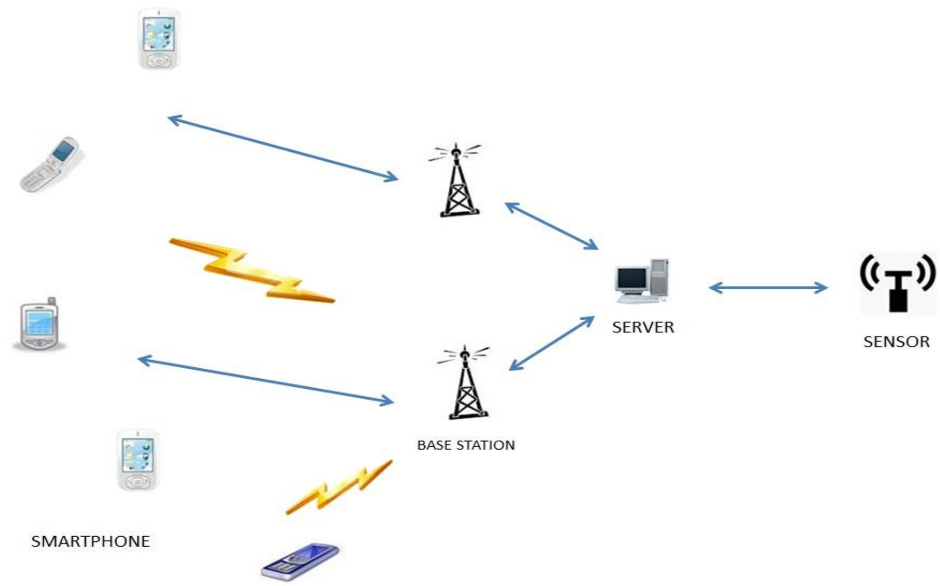

Fig. 1. Emergency Evacuation Routing Aid System

The server must translate the information from the sensors through the evacuation process to the users through the apps installed in the user's smartphones or tablets or portable electronic devices. This should also be sent to the local police departments, fire departments and hospitals. These devices at the receivers end must be up to date with the latest software to ensure the users receive the correct emergency information (Yuan and Wang, 2009). There may be misinterpreted information sent to the user's which may cause panic causing an unnecessary evacuation. To ensure this process is carried out in a well-defined manner, the experts at the emergency management response center must be accurate in making evacuation decisions. Thus the skilled personnel are very essential to ensure the smooth functioning of this particular process. Regular training sessions must be conducted along with knowledge enhancement programs to keep these individuals aware of the necessary precautions to ensure the safe functioning of the evacuation process (Chiu et al., 2007).

The information sent to the user must be understood properly by the users for the evacuation process. The users may not decipher the information properly leading to loss of lives. The user's psychological factors come into place here (Campos et al., 2012). The users need to understand the meaning of when to evacuate, how to evacuate and where to evacuate. Community awareness programs and mock evacuation drills can be carried out in order to minimize this problem. Through this, the user's would be able to completely understand about why, when and how to follow the evacuation guidelines (Campos et al., 2012).

3. Risk Analysis with risk matrix

The objective of risk analysis is to describe the risk involved, identify those risks and develop contingency plans or plans of action to mitigate the effects of those risks. The reasons behind analyzing the risks involved are to establish the big risk picture, compare the alternatives and solutions to the risks involved and identify and demonstrate the effects of those risks (Aven, 2008).

Once the evacuation process has commenced, there are still a number of risks that may follow. In the event of a mass evacuation, the transportation network comes under immense pressure to evacuate all the individuals to the shelters. Since there are a lot of types of vehicles like cars, buses, trucks, trailers to be evacuated the roadways get blocked causing traffic jams and other traffic snarls like accidents which cause congestion (Duran and Goodman, 2009). The transportation department comes into picture which must ensure that the road network is up to date through repairs or maintenance.

Even if the evacuation lanes are congested, heavy vehicles must be moved as soon as possible without much delay due to the heavy loads they would carry during evacuation. The GPS (Global Positioning System) plays an important role in such a situation. These devices must be regularly updated with the latest information and must provide important evacuating information. The radio stations must also provide regular updates to the users on which routes are affected and any other possible routing options which can be collected from the emergency response center (Bretschneider and Kimms, 2012). Regular audits and checks must be done of the road network from time to time. Mock evacuation scenarios may be carried out in advance in order to simulate the evacuation process to better understand the traffic congestions that may occur and also to carve out alternate routing options.

The emergency response team needs to carve out shelters at a safe distance from the affected areas in order to provide food and shelter to the affected individuals. These shelters are an important part of the evacuation process (So and Daganzo, 2010). In the event of a designated shelter being affected, alternate shelters must be planned out for temporary action like schools, community centers and industrial zones. These shelters must be strategically located near hospitals to provide medicine for the injured, and also must be able to accommodate medical air supply in the event of remote areas (Cova and Johnson, 2003).

Common meeting areas have to be carved in instances where the evacuees are transient dependent. These common meeting areas would provide common mass transportation to evacuate the evacuees to the shelters which would be located by the local emergency relief authorities at strategic locations in order to gather more number of evacuees with ease (Li et al., 2011).

Table 1 shows the risk matrix explained above in detail in a tabular form. In this risk matrix the risk items are the risks that could hinder the smooth functioning of the evacuation process. The next column would describe the risk in detail. The impacts considered in the risk matrix are Economical (where there may be property damage leading to losses of millions of dollar); Physical (losses to life and livestock resulting in casualties or fatalities); Psychological (this impact is because of human behaviors and tendencies and how they understand and execute the emergency procedure) and Technical (where the technology aspect of the process is considered for the risks described such as system failure or power shutdown).

The severity has been classified as High, Medium and Low based on the impact or the after effects of the risks if they are not taken care of in due time. The contingency plan is an action plan that has to be undertaken to reduce the effect of the risk. The Ranking considered on a scale from 1-4 (1-low risk; 2-moderate risk; 3-high risk; 4-extremely high risk).

Table 1. Risk Matrix Showing the Risks involved and the corresponding Contingency Plans

RISK ITEMS	RISK DESCRIPTION	IMPACT(Economical, Physical, Psychological, Technical)	Severity (High, Medium, Low)	Contingency Plan	Ranking (1-4)
Sensors or Gas Leak Detectors	Improper functioning causing the wrong information to be sent to the main server	Physical, Technical	High	Routine and Preventive Maintenance. Quality checks. Repair or Replacement	4
No Power on Main System	(i)Power Failure (ii)System Failure (iii)Viruses	Technical	High	(i)Power Backup Systems (ii)Routine Maintenance and Quality Health Check (iii)Complete Antivirus software	3
Wrong Decision Making	Misinterpreted information; wrong evacuation decisions; inexperienced mistakes	Technical	Medium	Skilled Personnel; Continuous audits, training and knowledge enhancement programs	3
User	Not able to understand the information sent by the emergency response center	Psychological; Physical; Economical	High	Community Awareness Programs; Mock evacuation drills	3
Condition	Bad road condition; Improper levelling; not enough paths	Physical; Economical	High	Regular quality audits; Repair or Maintenance work	4
Transportation System	Congestion; accidents	Physical; Economical	High	Regular quality checks; Evacuation lanes; Alternate routing; Emergency	3

				personnel constantly updating the evacuation information	
Electronic devices	Outdated technology or software	Technical	Mediu m	Regular information update; software updates; constant interaction	2
Shelters	Inappropriate location; not enough food, supplies, gas etc.	Physical; Economical; Technical	Mediu m	Assign strategic shelters; Helicopter access; Alternate temporary shelters	3
Common Meeting Area	Insufficient essential supplies; location inappropriate; overcrowding of evacuees	Technical; Physical	Mediu m	Allocate sufficient amount of resources; Easily accessible; Large openings for entry and exit	2

4. Evacuation Process

This evacuation plan would help the emergency personnel and panel of evacuation experts to devise a proper flow of the evacuation process in order to save more number of live and minimize the evacuation time. The process follows step by step emergency evacuation with conditions down the flowchart which then relate to final decisions or outputs.

4.1Evacuation Process Flowchart

The evacuation process flowchart has been explained step by step in detail as follows:

i) Risk Detection: In this part, the disaster is diagnosed and detected through sensors and other sensing devices in the area which is sent to the main server. This main server is based at the main emergency base station where a panel of expert emergency personnel reviews this information and collectively makes decisions on whether to carry out the evacuation process depending on the potential intensity of the disaster. There may be two types of warnings that may be issued depending on how much the disaster would affect the area (Campos et al., 2012). The recommended warnings indicate that the disaster is present; however, it may not be necessary to evacuate the area and to wait for further emergency instructions. The mandatory warnings indicate that the area would be affected and that evacuation is of utmost importance (Danganzo and So, 2011).

ii) Broadcasting Evacuation Messages: In this part, the warning messages are sent out to the affected or would be affected areas through the user's smartphones, radio and other broadcasting services. These messages contain vital information regarding the evacuation process.

iii) Mandatory Evacuation: This step is a decision where the emergency personnel would decide based on continuous weather updates and other critical information whether to declare the evacuation as mandatory or not. If mandatory then proceed else check for updates being broadcasted from time to time until the condition improves.

iv) Collect Essential Belongings: This step requires that the evacuees should collect all essential supplies and belongings that are kept in an easily accessible area known to them so as to create less confusion and loss of evacuation time.

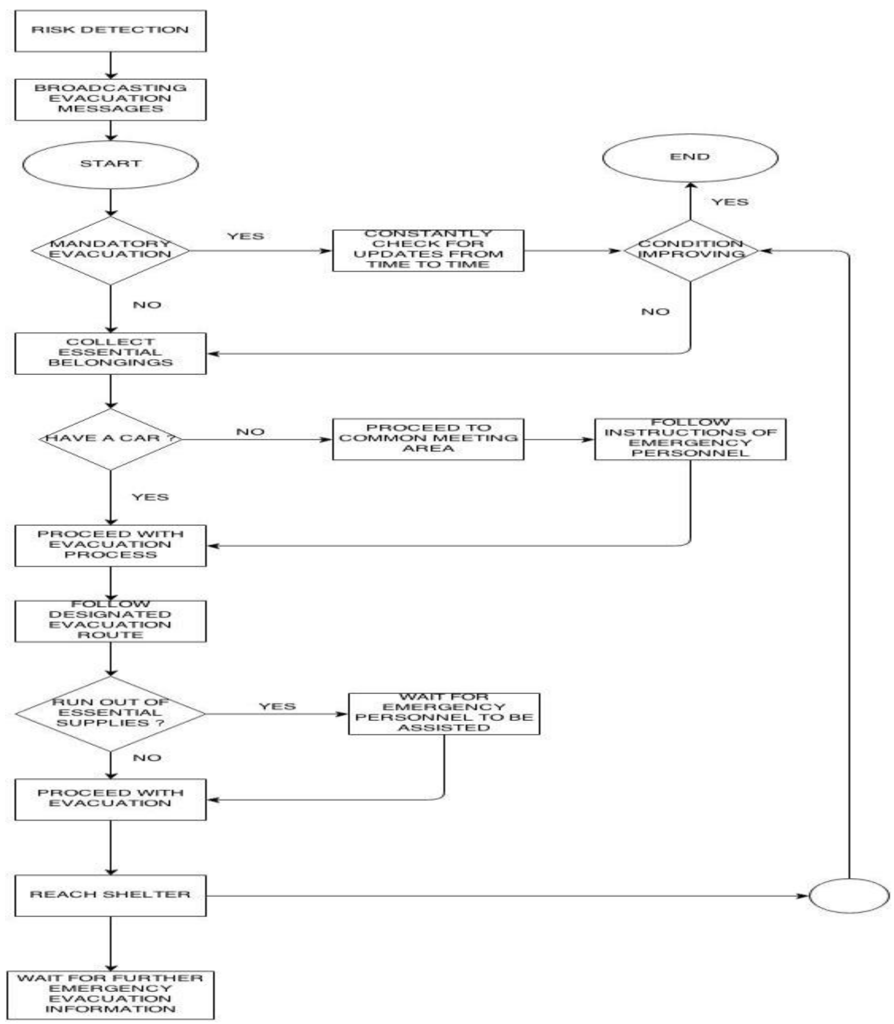

Fig. 2. Evacuation Process Flowchart

v) Have a car: This step checks whether the evacuees possess a mode of transportation or not. If not then the evacuees must move on foot to the designated common meeting areas from where there would be mass evacuation transport like buses to evacuate them to the shelters. These common meeting areas are locations decided by the disaster relief authorities in order to gather maximum number of evacuees at a common location like a school, football field, community center or any large open areas that could serve as the common meeting area.

vi) Follow the designated evacuation route: In this step the evacuees must follow the evacuation route displayed on the smart phone application based on their current location.

vii) Run out of essential supplies: At this step if the evacuees run out of essential supplies like food and gas then they should wait until they have been assisted by emergency personnel so as to proceed with the evacuation process. In such situations the evacuees, would either be assisted on the routes by emergency personnel through gas tankers or other trailers containing food etc. Otherwise, the evacuees must move to the side of the route and wait to be assisted (Song et al., 2009).

viii) Reach Shelter: This step depicts that the evacuees have reached the shelter and that they are out of danger for the time being. At the shelter the evacuees would wait for further evacuation instructions in the event of the disaster affecting larger distances threatening the location of the shelter. In such a case the loop goes back again to check whether the condition is improving or not. If the condition has improved then the evacuation has ended. This does not mean that the disaster has been completed averted, however, the disaster effects have been reduced. This condition would be closely monitored from time to time and would restart the evacuation process in cases where the intensity of the disaster may increase.

4.2 Evacuation Process with Risk Items and Contingency Plans

The following would explain the evacuation plan in detail for the evacuees for what they need to do during an evacuation. This plan would consist of vital evacuation information which would include step by step points. This particular plan would help the emergency evacuation teams to identify the risks involved in each of the steps and also the contingency plans for the corresponding risks.

1) Emergency Warning: The users receive the evacuation warning messages through their electronic devices such as cellphones, tablets, GPS etc. through which they must follow certain evacuation procedures. These evacuations may be recommended or mandatory. In case of recommended evacuation, these types of warnings are just sent out to the users for preventive action and do not mean that the users need to evacuate with immediate effect. However, the mandatory warnings require urgent action in terms of emergency evacuation.

2) Evacuate the Area: The users should evacuate the areas keeping in mind the emergency procedures that need to be followed during the evacuation process.

2.1) Essential belongings: The users sometimes, waste their time collecting unnecessary articles which can lead to wasting time and causing losses.

Contingency Plan: the user must keep aside all essential items in a safe place if living in an evacuation prone zone. These belongings must be kept in a safe and well designated area where the owner is aware of their location of their dwelling in order to minimize their evacuation time.

2.2) All gas valves and pipes and other electrical equipment: The users may forget to switch off electric appliances like microwaves, refrigerators, ovens etc. and also gas inlets in a hurry to vacate the area. These mistakes could cause explosions in the event of the gas leak entering the area.

Contingency Plan: The users must be aware of the main power lines, circuit breakers of the area, and other main power and energy sources. These should be well marked in the area so as to minimize the hazards that might be causes in the event that these appliances or valves come in contact with the leaked gas (Farrells, 2010).

2.3) Be sure mode of transport is filled with gas at all times: The users may forget to fill their vehicles with fuel which could lead to empty gas tanks and reduce their evacuation speed. This could cause losses.

Contingency Plan: If the user owns a car then make sure the vehicle is checked upon from time to time for fuel. If possible, the vehicle should contain a fuel reserve in the form of containers or other reserve equipment.

2.4) If no car then move to common meeting point: This common meeting point may be a place near to the evacuees location like a school, or hospital, or park, or bus station etc. from where the emergency personnel would provide common mass transport through buses or trailers (Sayyady and Eksioglu, 2010). The users who do not own a personal vehicle and have no modes of transport should move to the common meeting points or areas marked by the emergency personnel for further evacuation procedures.

3) Move on the designated evacuation route: The user must take up the desired evacuation route decided upon by the emergency personnel in order to reach the shelters on time. The evacuation routes would be decided as per the locations of the individuals. Sometimes the evacuees may opt to choose different routes apart from those chosen by the emergency personnel which may lead to hazards.

Contingency Plan (i): The evacuees must be aware of all the possible routing options provided to them by the emergency teams. They must strictly follow them in order to minimize the potential losses.

Contingency Plan (ii): If the shelters are located far away, then create “shelters” on the evacuation path towards the final destination. These shelters should be located on the evacuation route or nearby which have easy access and provide temporary accommodation (Hsueh et al., 2008).

4) Be Alert: The evacuees must be aware at all times of what is happening around them. They should be in constant contact with the emergency messages broadcasted from time to time through GPS, cellphones and radio etc.

5) Sometimes the vehicles on the emergency routes may run out of fuel. This could cause traffic jams. The evacuees may also run out of essential supplies like food and water in cases where the evacuation time and distance is long.

Contingency Plan (i): The emergency personnel may provide regular tankers filled with drinking water and gas moving along side by the evacuation route in order to suppress these abnormalities in order to speed up the evacuation process until the evacuees reach the designated shelters.

Contingency Plan (ii): The government officials make regular intervals of temporary relief shelters (e.g. schools, parks, community centers, training academies, parking lots, etc.) on the emergency route that would provide food, gas and other essential supplies.

6) If alternate routing is provided then proceed with care: Sometimes the freeways may get clogged up with traffic slowing down the evacuation time which could cause problems.

Contingency Plan: For this the emergency personnel could provide alternate routing options through major and minor arterial roads on the evacuation path. These paths may be temporary for a short distance and also for a short time. They may be closed after a period of time as soon as the traffic congestion is reduced.

4.3 Current versus Proposed Procedure

As mentioned on the Corpus Christi, TX website, in the event of a hurricane affecting the city, there is no concrete, well defined plan for the city. The evacuations plans and procedures are redirected to government websites such as The Texas Department of State Health Services and the Federal Emergency Management Agency websites. There are zones that have been created and shown on the map along with the evacuation routes; however, congestion has not been accounted for. The shelter has been located at San Antonio, TX which may not be feasible in high intensity natural disasters.

4.3.1. Evacuation Routes

Current Procedure - The shelter that has been located based on the evacuation during the hurricane Rita had been defined as San Antonio, TX. The major highway to be used was I-37. The emergency response teams showed that I-37 would not be able to accommodate the large traffic numbers. Thus, alternate routing options were provided as between SH 358 and N US 77 and between N US 77 interchange and Loop 410. These routes may get congested and the possible risk of these routes flooding, inaccessibility for emergency response teams were not taken into consideration.

Proposed Procedure - The proposed research fulfils these requirements by providing the amount traffic flowing on the highways thus allowing the emergency personnel to accommodate traffic on other possible routing options.

4.3.2. Shelters

Current Procedure - The location of the shelter used in the evacuation plans by the emergency response teams was San Antonio, TX. However, this shelter may not be feasible if a higher intensity hurricane strikes the area. This shelter did not have enough lodging and boarding options to accommodate all the evacuees which led to high prices. Also, the city did not have enough supplies like food and gas in order to provide these facilities to the rising numbers of evacuees.

Proposed Procedure - The proposed research would help to solve those problems by providing shelters in strategic locations in order to reduce the congestion and determine the optimal number of shelters in the event of a natural disaster using factors like the number of vehicles moving on the highways.

4.3.3. Evacuation Messages

Current Procedure - The current plan advises the evacuees to send a text message to the disaster relief centers in order to receive critical updates on the current situation of the evacuation process.

Proposed Procedure - The proposed study would help to solve that problem by providing the critical updates directly on the evacuee’s smartphones.

4.3.4. Risks Involved

Current Procedure - The current plan contains a well-defined plan about what should be done in the event of a natural disaster. However, it does not explain what risks can occur and how those risks would affect the smooth functioning of simple steps of the evacuation process.

Proposed Procedure - The proposed research would help to solve this problem by providing a risk matrix which would help the emergency response teams and the evacuees to understand, what types of risks are involved and what contingency plans should be undertaken to mitigate or reduce the effects of those risks.

4.3.5. Common Meeting Area

Current Procedure - The other factor that current evacuation plans do not consider is of the common meeting area. It is just briefly explained for transit dependent evacuees who would not be able to evacuate on their own and would need assistance.

Proposed Procedure - The proposed plan would account for this as well. There would be a common meeting area where not only evacuees who need assistance but also evacuees who do not own a vehicle to evacuate would also be considered.

4.3.6. Evacuation Process Steps

Current Procedure - There is no concrete evacuation process about the evacuation in the event of a natural disaster affecting an area. The plan is described in detail in theoretical form with no visualizations about the evacuation process.

Proposed Procedure - The proposed research would show the evacuation process as a flowchart in picturesque form in order to understand the steps involved in the evacuation process which would not only help the emergency response teams to understand the evacuation process in detail but also help the evacuees to understand what exactly is happening.. The evacuees can estimate which steps have been completed and which steps need to be completed in order to reach the shelters.

5. What-If Analysis with Linear Programming

The linear programming application used in this research would include combining the counties of La Salle, Webb, Duval, McMullen, Dimmit, Frio and Atascosa in Texas. All the populations were considered as approximate values shown in Table 2 (Williams, 2013). These values were summed up to get an approximate total of 400,000 persons living in those counties. It is assumed that every 4 persons from the above mentioned value would consist in one vehicle. So that would give an approximate value of 100,000 vehicles in this area considered (Williams, 2013).

Table 2. List of Counties by Population

Name of County	**Population (approximate values)**
La Salle	7000
Webb	263000
Duval	12000
McMullen	700
Dimmit	20000
Frio	18000
Atascosa	47000
Total	400000

The number of vehicles is calculated as 120,000 vehicles per day per freeway / 24 hours in a day = 5,000 vehicles per hour. This is the condition of a normal day being assumed by considering the each vehicular speed at 60 miles/ hour (Park et al., 2012).

Table 3. Assumptions: Number Approximations

Total Number of Evacuating Population	280,000 (70% of 400,000)
Total Number of Evacuating Vehicles	70,000 (70% of 100,000)
Single Lane Traffic per Hour	2500
Number of vehicles per hour on I-35 N	5000

(2 lanes)	
Number of Vehicles handled per Shelter	10,000
Time Savings per Shelter	1.3 hours

It is assumed that 70 percent of the population would evacuate the affected areas to reach the shelters located near San Antonio, TX. Thus 70 percent of the population would give 280,000. Similarly, the amount of vehicular traffic on the highway would also be reduced to a quarter of the original amount which would be 70,000 vehicles (Park et al., 2012). The routes are simplified with network diagram as in Fig. 3.

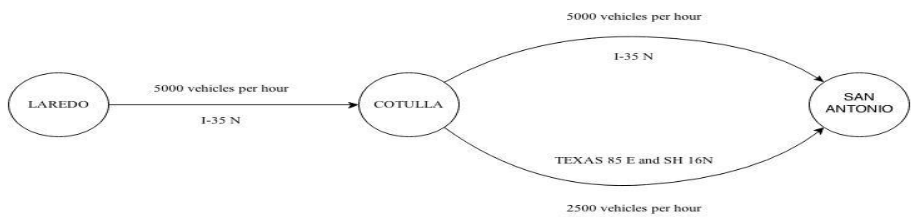

Fig. 3. Network Diagram Showing Mass Evacuation Route

Fig. 3 shows the locations of Laredo, TX, Cotulla, TX and San Antonio, TX. In the event of a mass evacuation as explained above, the amount of vehicles moving from Laredo, TX to Cotulla, TX would be 5,000 per hour on I-35 N. Similarly, from Cotulla, TX to San Antonio, TX there would now be two routing options, firstly using I-35 N with 5000 vehicles per hour and secondly using TEXAS 85 E and SH 16 N with 2500 vehicles per hour since these roads have only a single lane.

Table 4. Evacuation Time taken by evacuees considering no shelters

Time taken to reach San Antonio, TX from Laredo, TX and Cotulla, TX	
Total Expected Evacuees	280,000
Number of vehicles	70,000
From Laredo	14 hours
From Cotulla	9.3 hours

The time required to reach a safe place in San Antonio from Laredo, TX is dividing the total number of vehicles to the number of vehicles per hour, 70,000 / 5,000 = 14 hours in the event of a mass evacuation. The amount of time it takes on a normal day to reach San Antonio would be around 2 hours, and the difference is around 12 hours. This value is what we are trying to minimize in the event of a mass evacuation being declared. The other assumption that is made in this study is that Cotulla, TX previously considered in the test scenario is at an approximate two-thirds of a distance away from Laredo, TX. Then, we can assume that the time taken to reach San Antonio from Laredo being 14 hours is now considered as 9.3 hours from Cotulla, TX to San Antonio, TX. This value is what we are trying to minimize in the event of a natural disaster affecting Cotulla, TX and the other surrounding counties since they would also be passing through Cotulla, TX by the interstate 35 N. The above mentioned assumptions have been briefly shown in Table 3.

The evacuation time takes more than three times than normal travel time, so reducing the evacuation time is critical. One of ways to reducing the time is to build shelters. The location of shelter should be safe, easy to access. In this scenario, two locations are selected in terms of latitude & longitude; 28.972209, -98.548115, 29.172653, -98.899678. The first one is located at four freeways are crossing and the second one is located at two major freeways are crossing so that they are easy to access and absorb many traffics. The shelter would take some traffics and it is assumed that it holds about 5000 traffics and the difference in the evacuation times is approximately 1.3 hours which the time is saved during a mass evacuation. Let's define the decision variables as following.

Decision Variables:

SHELTER – The number of shelters
TIMETOSA – The time taken to reach San Antonio
TIME – The evacuation time

Case 1 - Evacuation Time considering One Shelter

LINDO Input:

```
MIN   TIME
s.t.
      TIMETOSA = 9.3
      TIME - TIMETOSA + 1.3 SHELTER = 0
      SHELTER = 1
End
```

Case 2 - Evacuation Time considering Two Shelters

LINDO Input:

```
MIN   TIME
s.t.
      TIMETOSA = 9.3
      TIME - TIMETOSA + 1.3 SHELTER = 0
      SHELTER = 2
End
```

Table 5 shows the approximate evacuation time from Cotulla, TX to San Antonio, TX by considering three assumptions of having no shelters, having one shelter and two shelters. The values obtained in this table would be shown using LINDO.

Table 5. LINDO output - Evacuation Time from Cotulla, TX to San Antonio, TX

No Shelter	1 Shelter	2 Shelter
9.3 Hours	8 Hours	6.7 Hours

From table 5 it is seen that there is a reduction in the evacuation time when no shelters are considered. This shows that having shelters on the evacuation path would reduce the evacuation time since these shelters would provide temporary accommodation and essential supplies like food, gas and medical facilities to the evacuees on the evacuation route. Then, how many shelters required reducing the evacuation time to normal travel time, which is less than 3 hours?

Case 3 - To find the optimal number of shelters when the evacuation time is approximately less than three hours

LINDO Input:

```
MIN    SHELTER
s.t.
       TIMETOSA = 9.3
       TIME - TIMETOSA + 1.3 SHELTER = 0
       TIME <= 3
End
GIN SHELTER
```

The output of the case 3 indicates that it requires 5 shelters and then it takes 2.8 hours. This particular case would help emergency personnel to determine how many shelters are required based on the evacuation times as calculated in the previous sections thus helping to reduce the overall evacuation time and save more number of lives.

6. Conclusions and Future Study

To reduce the chaos during a mass evacuation, effective yet efficient evacuation plan is required. To help the plan, a real time bidirectional emergency evacuation system was developed. The risks during the evacuation procedure were identified and possible contingency plans also discussed. This research would help the concerned authorities to proactively plan towards any unexpected disasters and would help in creating effective and efficient responses in managing the crisis at hand.

This research would help to solve the traffic congestion problems during mass evacuation by providing the evacuees with alternate routing options to reach the designated shelters which would be achieved by developing a smart phone application. The developed scenarios could also be applied to larger cities, such as Houston or Dallas for further research purposes by dividing small zones and providing alternate routing options for each of those zones. These zones would help the emergency personnel in broadcasting emergency information to the zones depending on the extent of the disaster affecting the particular zone.

Further research can also include developing new applications and routing options by considering other factors like atmospheric conditions, psychological aspects and so on. This research can be modified to suit the particular needs of specific situations by referring to this manual and making necessary changes for further action. The future work could also include a simulation of the evacuation process showing how the evacuation would progress with the inclusion and exclusion of shelters locations.

References

Aven, T., 2008. *Risk analysis: assessing uncertainties beyond expected values and probabilities*. John Wiley & Sons.

Bretschneider, S., Kimms, A., 2012. Pattern-based evacuation planning for urban areas. *European Journal of Operational Research*, 216(1), 57-69.

Campos, V., Bandeira, R., Bandeira, A., 2012. A method for evacuation route planning in disaster situations. *Procedia-Social and Behavioral Sciences, 54,* 503- 512.

Chen, Y. M., & Geng, H., 2010. Research of real-time traffic emergency evacuation management. *New Trends in Information Science and Service Science (NISS), 2010 4th International Conference on IEEE*, 666-670.

Chiu, Y. C., Zheng, H., Villalobos, J., Gautam, B., 2007. Modeling no-notice mass evacuation using a dynamic traffic flow optimization model. *IIE Transactions,* 39(1), 83-94.

Cova, T. J., Johnson, J. P., 2003. A network flow model for lane-based evacuation routing. *Transportation Research Part A: Policy and Practice*, 37(7), 579-604.

Daganzo, C. F., So, S. K., 2011. Managing evacuation networks. *Procedia-Social and Behavioral Sciences*, 17, 405-415.

Durak, M., & Goodman, E., 2009. Optimizing Traffic Signal Control for Emergency Evacuation. http://www.redcedartech.com/pdfs/AB2031_Traffic%20Signal.pdf (Nov. 24, 2014).

Farrells, J., 2010. Recommended minimum evacuation distances for natural gas pipeline leaks and ruptures. http://www.pipelineawareness.org/wp-content/uploads/2010/06/Evacuation- Distances-for-Natural-Gas.pdf. (Nov. 24, 20014)

Hillier, F., Lieberman, G., 2001. *Introduction to operations research* (7th ed.). Boston: McGraw-Hill.

Hsueh, C. F., Chen, H. K., Chou, H. W., 2008. Dynamic vehicle routing for relief logistics in natural disasters. *Vehicle Routing Problem*, 1, 71-84.

Kaufman, D. E., Nonis, J., Smith, R. L., 1998. A mixed integer linear programming model for dynamic route guidance. *Transportation Research Part B: Methodological,* 32(6), 431-440.

Kim, S., Shekhar, S., Min, M., 2008. Contraflow transportation network reconfiguration for evacuation route planning. *Knowledge and Data Engineering, IEEE Transactions*, 20(8), 1115-1129.

Lahmar, M., Assavapokee, T., Ardekani, S. A., 2006. A dynamic transportation planning support system for hurricane evacuation. *Intelligent Transportation Systems Conference, 2006. ITSC'06. IEEE,* 612-617.

Li, J., Zhang, B., Liu, W., Tan, Z., 2011. Research on OREMS-based large-scale emergency evacuation using vehicles. *Process Safety and Environmental Protection,* 89(5), 300-309.

Lim, G. J., Baharnemati, M. R., Zangeneh, S., Parsaei, H. R., 2009. A network flow based optimization approach for hurricane evacuation planning. *Proc. ICOVACS*.

Liu, H. X., He, X., Ban, X., 2007. A cell-based many-to-one dynamic system optimal model and its heuristic solution method for emergency evacuation. *The 86th Annual Meeting Transportation Research Board, Washington, DC*.

Mayer, B. W., Moss, J., Dale, K., 2008. Disaster and preparedness: lessons from Hurricane Rita. *Journal of Contingencies and Crisis Management,* 16(1), 14-23.

Ni, H., Chen, A., Chen, N., 2010. Some extensions on risk matrix approach. *Safety Science,* 48(10), 1269-1278.

Park, B. J., Fitzpatrick, K., Brewer, M., 2012. Safety Effectiveness of Super 2 Highways in Texas. *Transportation Research Record: Journal of the Transportation Research Board,* 2280(1), 38-50.

Ron Trumbla, NOAA's National Weather Service, 2012. The Great Galveston Hurricane of 1900. http://celebrating200years.noaa.gov/magazine/galv_hurricane/welcome.html (Nov. 24, 2014)

Saadatseresht, M., Mansourian, A., Taleai, M., 2009. Evacuation planning using multiobjective evolutionary optimization approach. *European Journal of Operational Research,* 198(1), 305-314.

Sayyady, F., Eksioglu, S. D., 2010. Optimizing the use of public transit system during no-notice evacuation of urban areas. *Computers & Industrial Engineering*, 59(4), 488-495.

Sinuany-Stern, Z., Stern, E., 1993. Simulating the evacuation of a small city: the effects of traffic factors. *Socio-Economic Planning Sciences,* 27(2), 97-108.

So, S. K., Daganzo, C. F., 2010. Managing evacuation routes. *Transportation research part B: methodological*, 44(4), 514-520.

Song, R., He, S., Zhang, L., 2009. Optimum transit operations during the emergency evacuations. *Journal of Transportation Systems Engineering and Information Technology*, 9(6), 154-160.

Song, W., Liu, Y., Dong, Y. C., Zhu, L., Li, Q. 2009. Evacuation model and application for emergency events. *Computer Sciences and Convergence Information Technology, 2009. ICCIT'09. Fourth International Conference on IEEE*, 1325-1329.

Stepanov, A., Smith, J. M., 2009. Multi-objective evacuation routing in transportation networks. *European Journal of Operational Research*, 198(2), 435-446.

Williams, C., 2013. Texas Population, 2013 (Projections). *Population Data (Projections) for Texas Counties, 2013*. http://www.dshs.state.tx.us/chs/popdat/ST2013.shtm. (Nov. 24, 2014)

Wu, X., Mazurowski, M., Chen, Z., Meratnia, N., 2011. Emergency message dissemination system for smartphones during natural disasters. *ITS Telecommunications (ITST), 2011 11th International Conference on IEEE*, 258- 263.

Yang, S., Li, C., 2010. An enhanced routing method with Dijkstra algorithm and AHP analysis in GIS-based emergency plan. *Geoinformatics, 2010 18th International Conference on IEEE,* 1-6.

Yuan, Y., Wang, D., 2009. Path selection model and algorithm for emergency logistics management. *Computers & Industrial Engineering*, 56(3), 1081-1094.

Zhang, H., Liu, H., Wang, J., 2010. Modeling of evacuations to no-notice event by public transit system. *Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference*, 480-484.

Zhou, Y., Liu, M., 2011. An Intelligent System for Emergency Traffic Routing. *Applied Informatics and Communication*, 429-436.