Coastal Bend Study Area Hurricane Evacuation Study Transportation Analysis Report

Prepared by

Texas A&M Transportation Institute
and
Texas A&M Hazard Reduction & Recovery Center

The Texas A&M University System

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The main purpose of the transportation analysis component of the Coastal Bend region Hurricane Evacuation Study (HES) was to produce estimates of the length of time needed to evacuate ahead of a hurricane. The length of time needed to evacuate is also referred to as "clearance time." Since there is no single type of storm or storm threat, the clearance time was estimated for many different types of storm threats and related evacuations, which were called "scenarios." A portion of the evacuation scenarios were defined by data from a survey of Coastal Bend residents regarding Hurricane Harvey evacuations as well as from information obtained for and resulting from the vulnerability analysis. The remaining scenarios were defined by variations in behavior and roadway operations inputs developed with input and review from state and local emergency management and resource agencies. **The clearance time analysis represents the estimated number of hours for residents and seasonal visitors in Aransas, Calhoun, Kenedy, Kleberg, Nueces, Refugio, San Patricio, and Victoria Counties to clear the area bounded by these counties**.

The scenarios represent different assumptions of factors that have the most influence on the evacuation clearance time. The scenarios reflect many different evacuation possibilities. For the Coastal Bend HES, the scenarios contained ranges of assumptions on:

- Proportion of population evacuating.
- How soon evacuees start to leave after an evacuation is called.
- Presence of evaculane (use of shoulder) and contraflow (lane reversal) on Interstate Highway 37 (IH 37).

Based on a set of 36 preliminary scenarios and clearance time estimates for these scenarios, regional and local emergency management representatives and the project team developed 27 scenarios that represented desired combinations of values of the above assumptions as well as other less influential, but important, data inputs. Table E-1 presents a generalized summary of these final scenarios and the estimated clearance times. The evaculane and contraflow clearance times reflect operation of those treatments on IH 37 only.

Table E-1. Summary of Evacuation Scenarios and Clearance Times

Percent of Population Evacuating From				Means This Many Persons Evacuating	Will Take This Long to Clear The 8-County Coastal Bend Study Area* (hours)		
"A" Zones	"B" Zones	"C" Zones	Outside Evacuation Zone		No Evaculane or Contraflow	Evaculane	Evaculane & Contraflow
75%	50%	40%	45%	377,000	45	42	40
90%	65%	55%	60%	479,000	58	50	45
100%	100%	100%	100%	681,500	80	70	60

*Reflects total time for all evacuees in private vehicles to depart the 8-county project study area. DOES NOT REFLECT TIME TO FINAL DESTINATION

The clearance time estimate for the 100% participation scenario shown in Table E-1 should be viewed as a worst-case scenario in terms of the number of hours of time needed to clear the coastal counties in the event of a coastal storm threat.

BACKGROUND

Purpose

The purpose of the transportation analysis portion of the Coastal Bend Hurricane Evacuation Study (HES) was to provide estimates of time needed to evacuate residents of the Coastal Bend study area (Aransas, Calhoun, Kleberg, Kenedy, Nueces, Refugio, San Patricio, and Victoria Counties) evacuation zones under a variety of evacuation scenarios. The clearance time estimates are inputs to the state and local storm planning efforts directed toward formalization of evacuation protocols. As such, the clearance times should make use of procedures that (a) reflect the state of the practice in evacuation scenario clearance time estimation; (b) are based on latest available local population, population characteristics, and evacuation behavior data; and (c) reflect storm impact/evacuation scenarios that state, regional, and local planners believe represent likely evacuation events.

Relationship to Other Study Components

The transportation analysis is one of the four major components of the Coastal Bend HES. The other components are the evacuation zone development, evacuation behavioral analysis, and vulnerability analysis portions of the study. The clearance time estimation aspect of the transportation analysis brings together results from the evacuation zone development, evacuation behavioral analysis, and vulnerability analysis. The evacuation zone development process defined the geographic areas that are subject to calls for evacuation and aided in the determination of the population that resides in those geographic areas that need to be evacuated. Thus, evacuation zones represent the area for which clearance time analysis was performed. The survey of Coastal Bend residents regarding Hurricane Harvey evacuation decisions and the associated behavioral analysis were informed many of the behavioral response assumptions of the evacuation scenarios. Data analysis conducted either as part of the vulnerability analysis or used directly in the vulnerability analysis including development of population estimates by census block and estimation of seasonal housing units was also used in part in the development of evacuation scenario inputs and/or assumptions.

Evacuation Zone Development

The updated evacuation zone boundaries defined as part of the HES comprised the areas for which clearance times were estimated. Each evacuation zone as shown in Figure 1 and the associated population of each evacuation zone was identified in FEMA's Real- Time Evacuation Planning Model (RtePM) clearance time estimation software to facilitate creation of multiple evacuation scenarios under which a range of evacuation response input assumptions were defined.

Behavioral Analysis

The behavioral analysis component of the HES included a survey of Coastal Bend residents regarding evacuation responses in advance of the landfall of Hurricane Harvey in August 2017.

Survey responses regarding the decision to evacuate or not (participation rate), the timing of evacuation (response rate), and the nature of departure in terms of number of people and vehicles were used to create baseline evacuation scenarios and to guide discussion with state, regional, and local stakeholders regarding variations in such inputs to form the scenario variations that were used in the clearance time estimation portion of the transportation analysis.

Vulnerability Analysis

The vulnerability analysis process provided estimates of household, seasonal, and at-risk populations that served as input population data for which clearance time estimates were modeled.

CLEARANCE TIME MODELING

Introduction and Background

Given the variety of circumstances under which evacuations may occur, the clearance time estimation portion of the transportation analysis involved the modeling of multiple evacuation scenarios. In this way, the results of the scenario modeling would offer a range of clearance times given different evacuation circumstances.

The clearance time estimation process brought together population and population-related characteristics as well as the roadway system of the defined evacuation zones and immediate surrounding areas with both localized and generalized behavioral characteristics to estimate a clearance time for different combinations of these inputs. Starting with information from the evacuation survey as an initial set of data and the vulnerability analysis component, the study team established input data for the following RtePM data items:

1. Evacuation zones.
2. Behavioral data that include:
    a. Evacuation participation rate.
    b. Percent of population using private vehicles.
    c. Percent of evacuating pedestrians.
    d. Persons per vehicle.
    e. Percent of vehicles towing another vehicle.
    f. Percent of evacuating population using shelters.
    g. Percent of population using transit.
    h. Expected response time for evacuation
    i. Evacuation start time.
    j. Destinations of evacuating population.
3. Roadway data including:
    a. Base evacuation roadway network.
    b. Selection of destination points and weight assigned to each destination point based on proportion of evacuating population destined for that location.

   c. Modification of selected roadway network to reflect evaculane as a stand-alone roadway operations enhancement and contraflow along with evaculane. This entailed modification to free-flow speed, number of lanes, and use of shoulder setting in the RtePM roadway network.
   d. Addition of new roads as may be needed to provide connecting ramps for representation of contraflow operations.
4. Seasonal population.
5. Global variables that included level of typical daily traffic occurring during the evacuation (background traffic) and prevalence of crashes and disabled vehicles impeding traffic flow (incident level).

Some of the data items used in the clearance time analysis were applied across all applications of RtePM (defined as global inputs in the next section), while others were varied to represent different evacuation scenarios. The variations of these values are listed under the Evacuation Scenario Development portion of this report section.

Even though most of the evacuation traffic uses freeway segments to evacuate the area, it is possible that heavy rains ahead of the need for evacuation might result in some of the base roadway network being inaccessible. The clearance time modeling assumed no impacts to the roadway system due to inland rainfall prior to initiation of evacuation.

The goal of the transportation analysis portion of the HES was to develop estimated clearance times to a point of safety, which was an area defined by the extent of the geographic area for which the HES was being performed. As such, the destination specifications used in the clearance time estimation were the locations where a roadway exited the multi-county region. No estimates of travel time by evacuees to final destination (e.g., San Antonio, Laredo, Austin, Houston, etc.) were developed by this study.

Global Inputs

Among the global inputs to the clearance time estimation process were the evacuation zones, evacuation zone populations, some behavioral data, the base evacuation network, and shelter information.

Evacuation Zones

Using RtePM's graphic interface, evacuation zones were defined based on the RtePM geographic units, which are census block groups, to match, as closely as block group boundaries allowed, the newly defined evacuation zones for the eight counties in the study area, as shown in Figure 1.

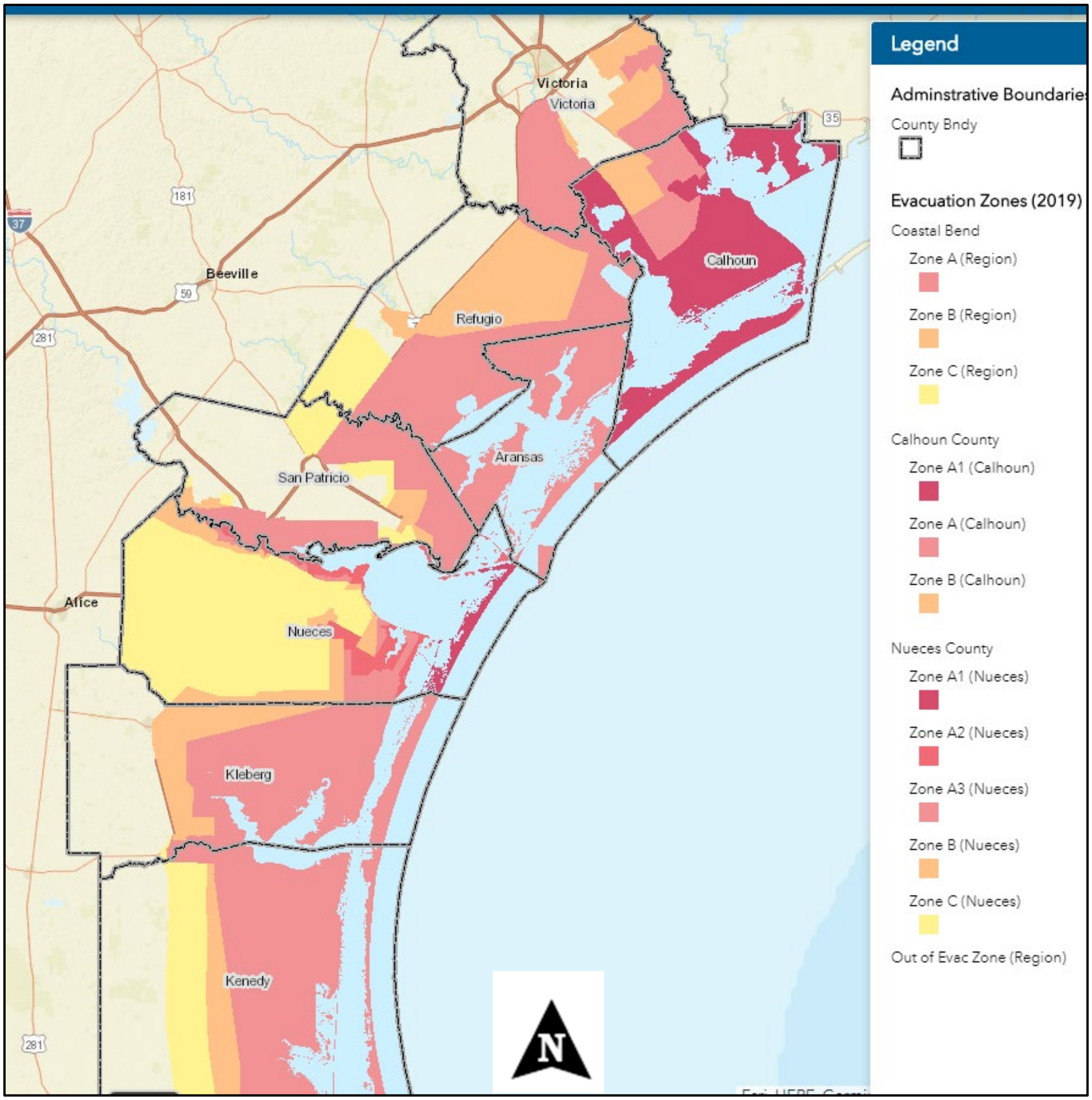

Figure 1. Coastal Bend Study Area Evacuation Zones

The areas within the study area counties but outside the evacuation zones proper were also included in clearance time estimation. These areas were included to represent populations that may evacuate along with populations within the designated evacuation zones—also referred to as the "shadow" evacuation population. For the Coastal Bend HES, shadow evacuation zones included all areas within the eight counties that were not part of the evacuation zones.

Using household population data developed for use in the HES vulnerability analysis, the RtePM estimate of population of each of the evacuation zones was adjusted within RtePM to match the population total developed for and used in the vulnerability analysis. Table 1 presents the resident populations of the evacuation zones based upon data collected for the vulnerability analysis.

Table 1. Evacuation Zone Resident Populations

Evacuation Zone	Calhoun County	Nueces County	Remaining HES Counties	HES Region
A1	15,640	12,942	--	28,582
A2	--	59,968	--	59,968
A3	--	40,821	--	40,821
A	5,989	--	55,330	61,319
B	115	70,074	18,655	88,844
C	--	177,412	13,991	191,403
Total	21,744	361,217	87,976	470,937

Behavioral Inputs

The occurrence of Hurricane Harvey presented an opportunity that benefited the Coastal Bend HES by offering the ability to bring data from actual evacuation behavior into an analysis of evacuation clearance times. Rather than rely on typical hypothetical responses to an evacuation, Harvey offered the chance to survey residents who dealt with the decision to evacuate and the experiences of evacuating among those who chose to evacuate. The survey component of the behavioral analysis involved a survey of residents regarding various aspects of the response to Hurricane Harvey. The reporting of the survey data included a compilation of data on evacuation characteristics that are key clearance time modeling inputs. The behavior data served to inform the scenario development process with values based on an event in the Coastal Bend in the recent past. Consistent with the regional-oriented approach to the transportation analysis, behavior survey results that varied across counties and within counties was averaged so that all zones within the region with the same surge risk were treated similarly.

Table 2 presents RtePM behavioral inputs that were derived from the survey of Coastal Bend residents and applied universally across all evacuation scenarios.

Table 2. Behavioral Data Input Derived from Behavioral Survey

Input Data Item[A]	Evacuation Zone			Outside Evacuation Zone
	A*	B	C	
Percent of population using private vehicles	95%	95%	95%	95%
Percent of population using other means	5%	5%	5%	5%
Persons per vehicle	2.0	2.0	2.0	2.0
Percent of vehicles towing another vehicle	15%	10%	7%	4%

* Includes A-1, A-2, and A-3 zones where they exist.

[A] From "Evacuation Modes" section of Behavior Report

Table 3 presents the RtePM behavior inputs regarding the distribution of evacuation departures of the study area among the major roadways leading out of the study area. Assumptions regarding the roadways themselves and the distribution of demand were varied among a set of preliminary scenarios and the final scenarios presented in subsequent sections of the report. The preliminary scenario endpoint roadway and shares of demand were automatically determined by RtePM. For the final set of scenarios, the endpoint roadways and demand shares were adjusted to reflect status as a designated evacuation route by the Texas Department of Transportation (TxDOT) and input from regional and local project stakeholders. This adjustment was performed so that the clearance time results would reflect observed and known choices on location and scope of traffic exiting the study area during an evacuation event

Table 3. Study Area Roadway Endpoint Distribution of Demand

Endpoint Roadway	Share of Evacuation Demand
SH 285	2%
SH 35	5%
US 59	8%
FM 665	5%
IH 37	35%
US 77	5%
US 183	3%
FM 624	2%
US 181	15%
E Highway 44	10%
SH 141	5%
US 87/Broadway	5%

Level of Background Traffic

In the context of clearance time analysis within RtePM, background traffic represents non-evacuation-related traffic that occurs on the roadway systems on a typical day. Although the level of background traffic does not substantially affect resulting clearance time, the level of background traffic was set to the "high" option within RtePM to provide the most conservative level of clearance time.

Level of Incidents

The level of traffic incidents, like background traffic, is used within RtePM to affect the clearance time estimates. As with background traffic, the level of traffic incidents does not substantially affect resulting clearance time. To produce clearance time estimates to support the most conservative approach to evacuation timing, the level of traffic incidents was set to the "high" option within RtePM.

Roadway Data

Roadway configuration and operational data from HERE are built into RtePM and were used to define the initial roadway network for use in the clearance time analysis. The portions of the roadway network used in the clearance time modeling are automatically selected following definition of the evacuation zones either by freehand drawing of a polygon or importing polygon geography. It is noteworthy that once a base evacuation roadway network has been automatically selected, it is possible to manually add or delete a roadway segment from the evacuation network. However, roadways that cross the evacuation area boundary cannot be added to the network. For the Coastal Bend HES, the study team reviewed the base evacuation roadway network selected by RtePM for content and consistency with known roadway coverage and found it to be acceptably accurate. The base roadway network for the Coastal Bend HES is shown in Figure 2.

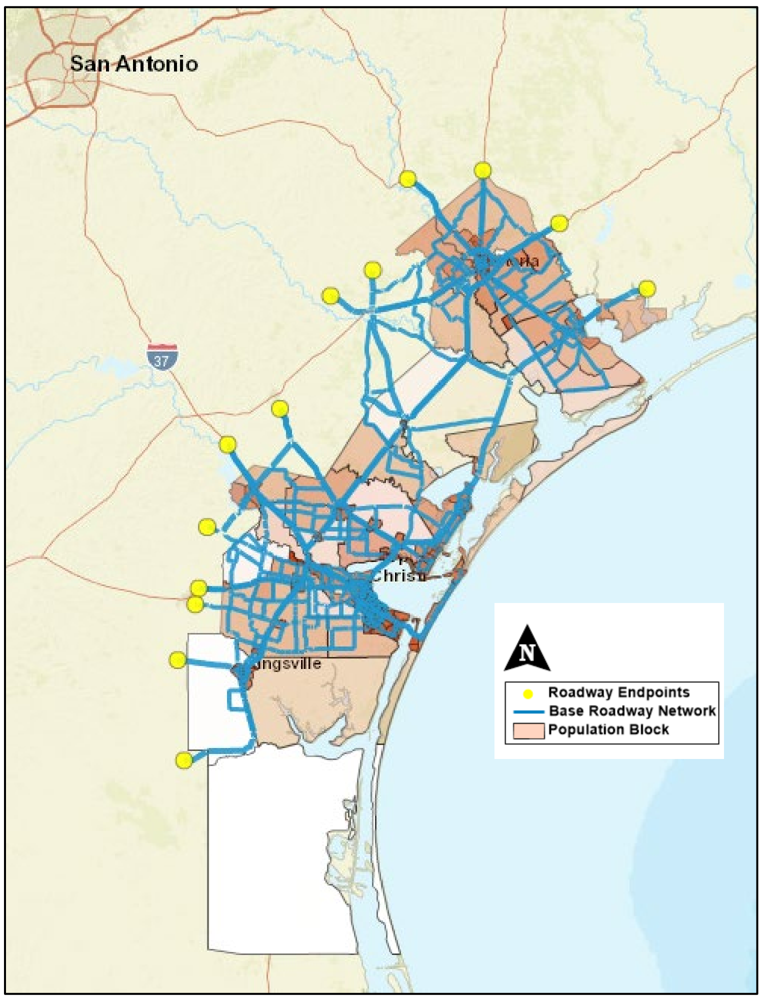

Figure 2. Base Roadway Network for Coastal Bend HES

Shelter Data

For the Coastal Bend HES, no shelters were added to the RtePM model as there are no public shelters in the study area.

Scenario-Specific Inputs

Among the scenario-specific inputs were a set of behavioral data, changes to roadway data to reflect evaculane and contraflow operations on IH 37, use of seasonal populations, and global variables such as level of background traffic and incidents during evacuation.

Behavioral Data

Behavioral data inputs that varied by scenario included:

1. Evacuation participation rate.
2. Evacuation response time.
3. Evacuation start time.

Evacuation Participation Rate

The evacuation participation rate represents the proportion of residents who participate in an evacuation. The participation rate is varied among evacuations zones to reflect changes in level of participation corresponding to level of exposure and perceived life-safety threat due to storm surge. Results from the behavior survey conducted as part of the HES behavioral analysis were used in defining the set of baseline scenarios which were then varied to reflect different levels of participation as desired by regional and local emergency management representatives.

Evacuation Response Time

Evacuation response time, in the context of the RtePM clearance time analysis, represents the time lapse between the advisement or ordering of an evacuation and the point at which all those participating in the evacuation have departed their evacuation trip origin point. The length of the response time affects that rate at which evacuation demand enters the roadway system and many times heavily influences the clearance time outcome. The response time is varied to create scenario variations. Results from the behavior survey conducted as part of the HES behavioral analysis were used in defining the baseline scenarios which were then varied to reflect different levels of response time as desired by regional and local emergency management representatives.

Evacuation Start Time

Evacuation start time defines the time of day at which evacuation travel begins. The start time is commonly defined with the assumption that hurricane-oriented evacuations are not immediate in nature and allow evacuees to engage in preparation for evacuation and then departure early in the daylight hours. The start time is also tied to evacuation response time in that response times of 24 hours or less assume most evacuees will travel during daylight hours.

Roadway Data

RtePM allows represented roadway networks to be modified to reflect evaculane (shoulder) or contraflow (lane-reversal) operations. For the Coastal Bend HES study, the study team used evaculane and contraflow plans from the Department of Public Safety and TxDOT to represent the evaculane and contraflow operations on IH 37 among the evacuation scenarios.

Seasonal Population

Seasonal population represents the population residing in seasonal housing units (i.e., hotels, motels, condos) and in mobile housing units (recreational vehicles, travel trailers, mobile homes) during an evacuation event. Estimates of the population among these two components of were developed as part of the Vulnerability Analysis component of the HES and are based upon counts of seasonal housing and mobile units developed with state and local data sources along with detailed review of aerial imagery. These estimates of seasonal units were reviewed by local project stakeholders who provided additional supplemental data that were included in the final estimates of seasonal units.

Seasonal population is included in the estimation of total population in the study area so that evacuation population includes resident and seasonal populations. Seasonal population for each evacuation zone was included among the scenario inputs. As with resident population, participation rates among seasonal population were varied as part of the evacuation scenario definition. Table 4 presents the estimate of total seasonal population both within the evacuation zones and outside the evacuation zones.

Table 4. Seasonal Population Estimate

Evacuation Zone/Area			Outside Evacuation Zone		Study Area Total
A	B	C	San Patricio and Victoria Counties	Refugio and Kleberg Counties	
58,900	7,100	13,300	8,300	500	88,100

EVACUATION SCENARIO DEVELOPMENT

Theoretically, the variety of scenarios analyzed was limited only to the variations of input data values available either in RtePM or via local data. Practically, there was a need to limit the scenarios so that (a) each reflected local- and state-level stakeholder interests, (b) they were focused on variables to which RtePM exhibited sensitivity, and (c) they were not so numerous as to result in an inability of the team to effectively communicate results or for the team and project stakeholders to draw meaningful conclusions.

Scenario Development Process

The scenario development process was performed in two steps. Informed by data from the behavioral survey for the RtePM inputs on participation rates, response timing, persons per vehicle, percent towing and percent evacuating, the study team constructed a preliminary set of scenarios. A total of 36 preliminary scenarios were constructed. The set of scenarios consisted of a baseline scenario and variations off that scenario with respect to participation rates, response timing, inclusion of seasonal population and availability of evaculane. The variations also involved alternating use of RtePM's roadway endpoint demand distribution which imparts optimal routing on the evacuating demand to minimize delay and clearance time and pre-set roadway endpoint traffic distribution assumptions. These preliminary scenarios were then modeled with RtePM and the results taken into a second stage of scenario development that reflected the desires of regional and local emergency managers and other project stakeholders on the behavioral and roadway operations assumptions.

The results of the clearance time analysis of the preliminary scenarios were presented to regional and local stakeholders for review and discussion. The assumptions regarding participation rates and response times that characterized the preliminary scenarios were discussed and decisions were made regarding the assumptions regional and local stakeholders wished to include in the final set of scenarios. In addition, scenario assumptions regarding treatment of seasonal populations and destination roadway endpoints, and agreement on the use of results from the behavioral survey with respect to inputs on the level of use of private vehicles, prevalence of towing, and evacuation of persons per vehicle, were established through discussion with regional and local stakeholders.

Based on these discussions, regional and local stakeholders communicated preference that the final set of scenarios all include seasonal population and that the roadway endpoint demand shares be based completely on local experience and knowledge rather than internally determined by RtePM. Regional and local project stakeholders concurred with the proposed participation rates and response time assumptions. What resulted were a set of 27 final scenarios for estimation of clearance times by RtePM.

Evacuation Scenarios

Based on discussion with regional and local project stakeholders and input on the construction and results of the preliminary scenarios, the process for development of the final scenarios yielded three groups of scenarios with respect to evacuation participation, as shown in Table 5. Much like the preliminary scenario group, this set of 'final' scenarios consisted of a baseline scenario in which the behavioral inputs were drawn from the results of the behavior survey and then variations developed off the baseline that reflect the desire on the part of the regional and local emergency management community to see scenarios that would support the most conservative levels of evacuation planning. The first group, named the "Recent Experience" group, was based upon the evacuation participation levels as reported in the evacuation behavior survey. The participation data reported in the behavior survey report at the county level was broken down to the evacuation zone level for development of the baseline scenario. While participation rates varied across the study area among zones of similar designation (i.e., among "A" zones in the study area and among "B" zones in the study area), the participation rates were averaged across all zones of similar designation for input into RtePM. For example, the average of participation rates across the "A" zones of all counties was 75% participation. Applying participation rates uniformly across the zones is done to support the philosophy of a region-wide approach to evacuation response.

The second group of scenarios reflected the regional and local emergency managers desire to see participation levels moderately higher than those observed for Hurricane Harvey. This group of scenarios was termed "Recent Experience Plus." The third set of scenarios was developed to gain a sense of clearance times in the extremely unlikely circumstance of 100% of the population from the entire region participating in an evacuation. This group of evacuation scenarios, termed "Maximum Evacuation" group and developed for application with the clearance time analysis tool RtePM, reflected the desires of regional and local emergency managers to view as 'worst case' scenario. The philosophy of different levels of participation was meant to provide clearance times for evacuations of varying degrees of magnitude.

Table 5. Scenario Groups—Evacuation Participation and Population

Scenario Group	Population	Evacuation Zone/Area				Persons Evacuating
		A	B	C	Outside Evacuation Zone	
Recent Experience	% Resident Pop	75%	51%	40%	44%	
	% Seasonal Pop	75%	51%	40%	44%	377,000
Recent Experience Plus	% Resident Pop	90%	66%	55%	59%	
	% Seasonal Pop	90%	66%	55%	59%	479,200
Maximum Evacuation	% Resident Pop	100%	100%	100%	100%	
	% Seasonal Pop	100%	100%	100%	100%	681,400

Table 6 shows the results of the application of the global variables (i.e., applying to all scenarios) dealing with the proportion of the population evacuating by private vehicle and the average number of persons per vehicle.

Table 6. Persons Evacuating in Private Vehicles and Vehicles Evacuating

Scenario Group	Persons Evacuating in Private Vehicles	Vehicles
Recent Experience	357,700	179,000
Recent Experience Plus	454,800	227,500
Maximum Evacuation	646,900	323,600

Among the three levels of participation, the following inputs were varied to create the final scenario set.

Response Time

Three different response times were selected for creating the scenario groups among each of the levels of participation. Five hours, 24-hours, and 2-days. The five-hour response time is meant to reflect the result of the behavior survey as close as can be accomplished within RtePM. In a similar philosophy to the participation rates, the five-hour response was treated as a baseline response time from which variations of 1-day (24 hours) and 2-days were chosen to reflect variations off the baseline.

As part of response time specification in RtePM, a 'start time' is also specified within RtePM. For the 5-hour and 24-hour response times options, the RtePM default start time of hour 8 was used. This means the pace of vehicles entering the roadway occurs over a 5-hour and 24-hour period, respectively starting at hour 8.

For the 2-day response time, the start time and end time for each day was specified as required. These specifications were set as hour 4 for the start time and hour 24 for the end time each day. Such specification means that evacuees entered the roadway system for 40 hours of the '2-day' period and that the response time is actually 44 hours – hour 4 on Day 1 to hour 24 on Day 2. The modeling of a 2-day response in RtePM requires specification of proportion of participation demand for each of the 2-days. All 2-day scenario variations assumed the division of evacuation response shown in Table 7.

Table 7. Evacuation Response Rate—2-Day Scenarios

	All Areas
Day 1	65%
Day 2	35%

Evaculane

Use of the shoulder of the outbound section of IH-37 outbound (away from coast) shoulder on IH-37 between A and B. Evaculane was assumed non-operational and operational as a scenario variation.

Contraflow

Reversal of inbound section of IH-37 to outbound direction was assumed non-operational and operational. Based on discussion with representatives of the Texas Division of Emergency Management and the Texas Department of Public Safety; the latter of which is charged with operating contraflow, contraflow was assumed to operate simultaneously with evaculane.

Scenario Group 1—Recent Experience

The study team, with input from regional and local project stakeholders, developed nine variations of scenarios in which the evacuation participation rate mirrors that seen in the Coastal Bend evacuation behavior survey. These scenarios are shown in Table 8.

Table 8. Recent Experience Scenario Group

Scenario Group	Evaculane	Contraflow	Response Time
Recent Experience	No	No	2 days 24 hours 5 hours
	Yes	No	2 days 24 hours 5 hours
	Yes	Yes	2 days 24 hours 5 hours

Scenario Group 2—Recent Experience Plus

The study team, with input from regional and local project stakeholders, identified nine variations of scenarios for the Recent Experience Plus group. These scenarios are shown in Table 9.

Table 9. Recent Experience Plus Scenario Group

Scenario Group	Evaculane	Contraflow	Response Time
Recent Experience Plus	No	No	2 days 24 hours 5 hours
	Yes	No	2 days 24 hours 5 hours
	Yes	Yes	2 days 24 hours 5 hours

Scenario Group 3—Maximum Evacuation

The study team, with input from regional and local project stakeholders, identified nine variations of scenarios for the Maximum Evacuation group. These scenarios are shown in Table 10.

Table 10. Maximum Evacuation Scenario Group

Scenario Group	Evaculane	Contraflow	Response Time
Maximum Evacuation	No	No	2 days 24 hours 5 hours
	Yes	No	2 days 24 hours 5 hours
	Yes	Yes	2 days 24 hours 5 hours

Clearance Time Results

The clearance times for the group of final scenarios are presented below. Results for the preliminary scenarios along with the final scenarios are presented in Appendix A.

Recent Experience

Using RtePM, the study team calculated clearance times for the nine scenarios that made up the Recent Experience scenario group. The clearance time results for the nine scenarios are shown in Figure 3.

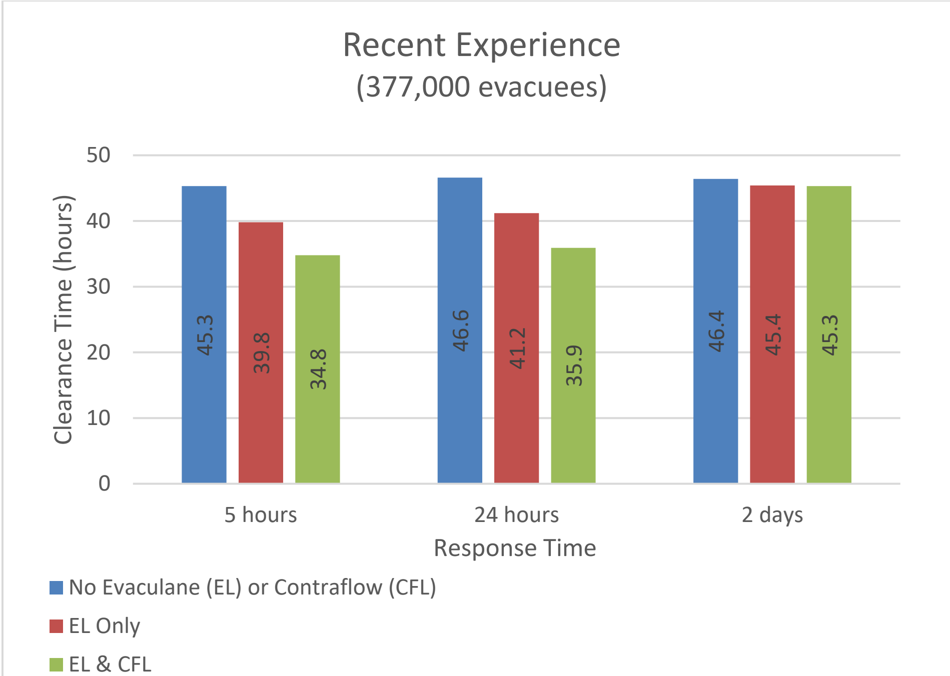

Figure 3. Clearance Time—Recent Experience Scenario Group

The relatively similar clearance time values among the 5 hours and 24 hours response times suggest that the level of congestion when the response time is 24-hours or less is substantial and will extend clearance time well beyond the response times. When the response time extends into a second day, the results suggested the response time will dictate clearance time more than congestion. With respect to operational treatments of evaculane and contraflow, the results show that operations of evaculane on IH 37 alone as well as both evaculane and contraflow on IH 37 reduce clearance time by up to 23% for all response times for the 5-hour and 24-hour response times. The relatively limited impact of evaculane and contraflow for the 2-day response time suggests that evaculane and contraflow have little effect on clearance time when not much more than 50% of the total population of the Coastal Bend region (375,000 of 681,000) enter the roadway system over a 2-day period.

Recent Experience Plus

Using RtePM, the study team produced clearance time estimates for the nine scenarios that represent evacuation participation rates that are higher than recent experience but less than full participation. Figure 4 presents the results from this scenario group.

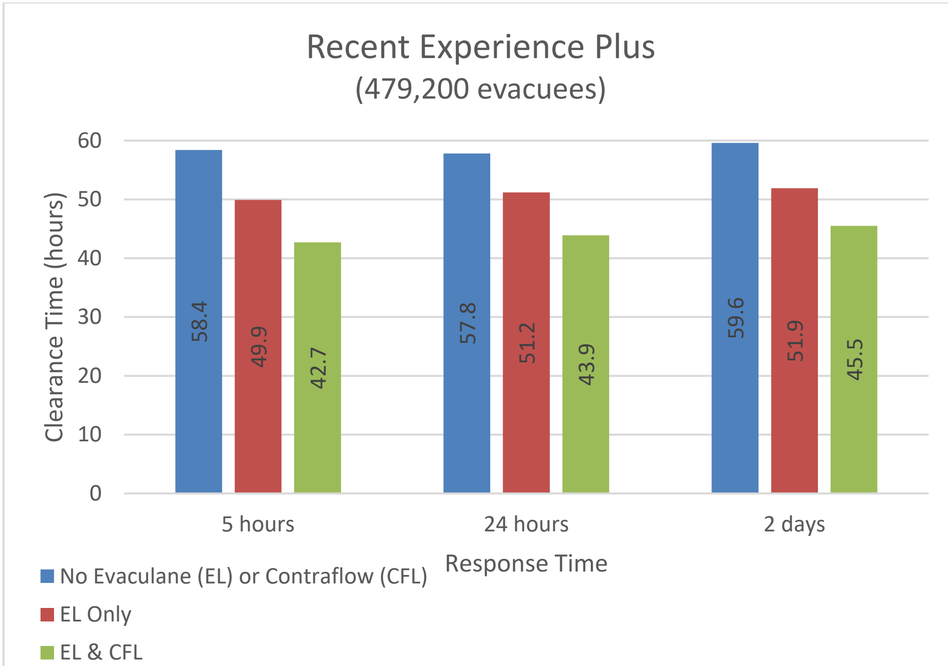

Figure 4. Clearance Time—Recent Experience Plus Scenario Group

The clearance time results among the 5-hour and 24-hour response show very little difference which may indicate that the level of participation is such that congestion is dictating the clearance time rather than the length of the response time. As compared to the Recent Experience participation level, the Recent Experience Plus participation does indicate some level of congestion even in the 2-day response time as evidenced by the fact that clearance times are many hours more than the minimum possible time of 44 hours for the 2-day scenario. Only in the case of the EL & CFL option is the clearance time essentially the number of hours of the 2-day response time (i.e., 44 hours). As with the Recent Experience scenario group and as would be expected, implementation of evaculane on IH 37 reduces clearance time, and implementation of both contraflow and evaculane on IH 37 reduces clearance time even further, for the 5-hour and 24-hour response time variations. These results also indicate that even for the multi-day response time variation, evaculane and contraflow on IH 37 do substantially reduce clearance time. This is likely due to the higher level of evacuation population in this scenario group compared to the Recent Experience scenario group.

Maximum Evacuation

Using RtePM, the study team produced clearance time estimates for the nine scenarios that represent 100% participation rates by residents and seasonal visitors to the Coastal Bend study area. Figure 5 presents the results from this scenario group.

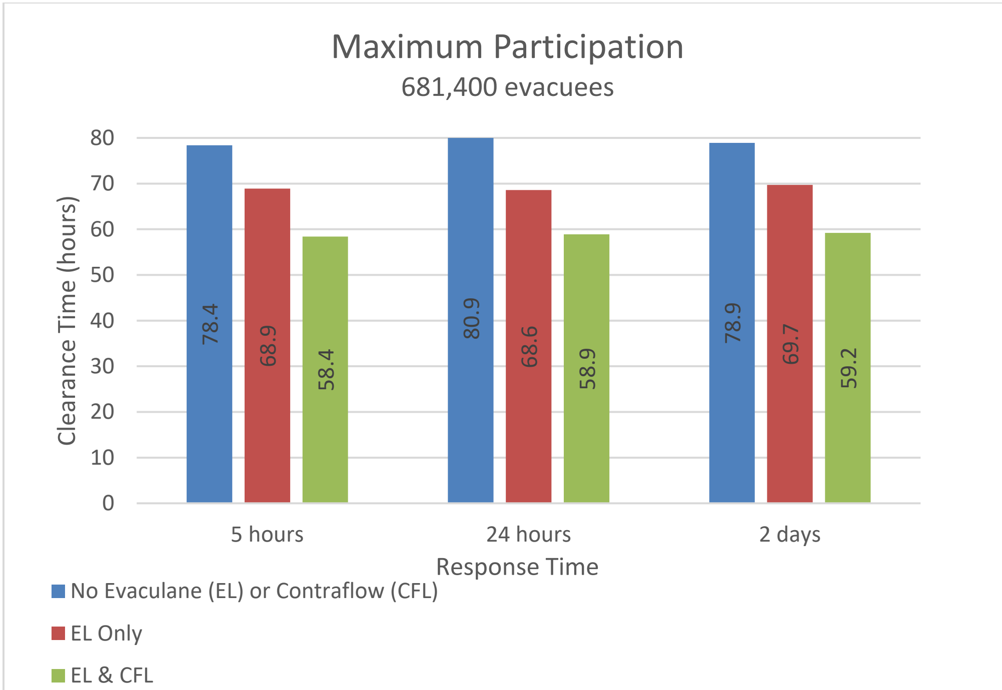

Figure 5. Clearance Time—Maximum Participation Scenario Group

The results for the 5-hour and 24-hour response times are essentially the same, which suggest that the level of congestion for such as high level of participation is such that even stretching the response time from 5-hours to 24-hour does not change the time needed to clear the area. In fact, the results suggest that even the 44 hours of response of the 2-day scenario still had no substantial effect on the resulting clearance time. As with the Recent Experience Plus scenario group, the implementation of evaculane and contraflow on IH 37 substantially reduce clearance time for all response time variations. This further illustrates the need and benefit of implementing evacuation/contraflow on IH 37 as the expected number of evacuating population increases.

Roadway-Related Results

A look at the clearance time results suggests that at all participation levels evaluated, response time seems to have little effect on the clearance time when no evaculane or contraflow is present. This suggests that, at least for evacuating populations of 375,000 or more, clearance time is not affected by the provision of additional lead time (i.e., response time—time between call and when last evacuees start their evacuation trip). This is not meant to imply that additional lead time is not important or that it does not result in reduction in congestion experienced by evacuees, but demonstrates that additional lead time does not shorten the time for all evacuees to reach a location of safety outside an area expected to be impacted by storm surge. Figure 6 presents the clearance times for the no evaculane and no evaculane/contraflow variations for all three scenario groups and shows the lack of variation of clearance time among a scenario group.

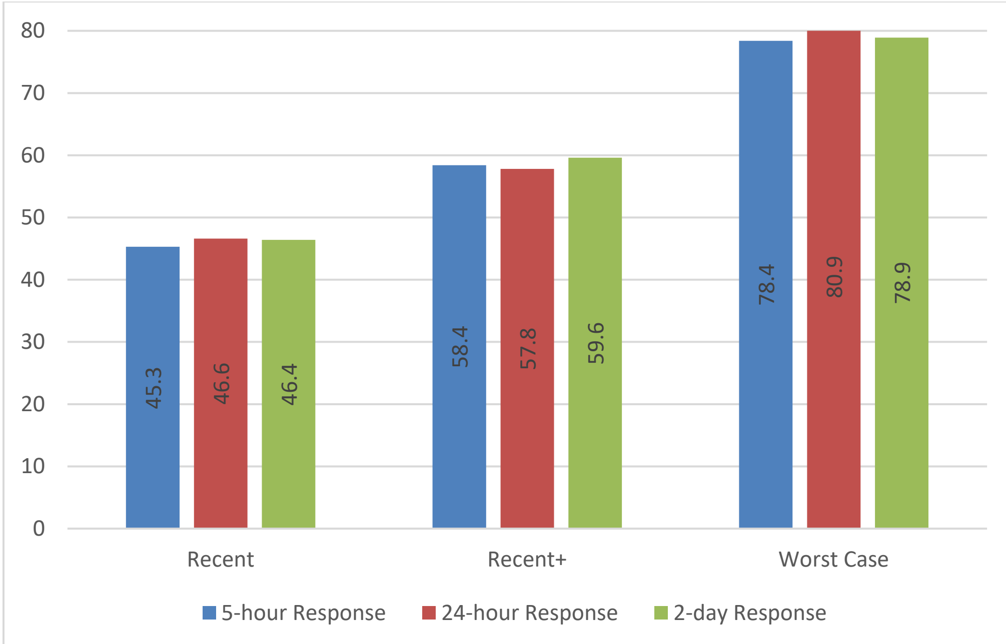

Figure 6. Clearance Time—No Evaculane and/or Contraflow

The other major takeaway from the results is that the clearance time modeling shows that the operation of evaculane alone on IH 37 as well as evaculane along with contraflow on IH 37 substantially reduces clearance time. Table 11 presents the reduction of clearance time relative to the no evaculane/contraflow scenario variations.

Table 11. Reduction in Clearance Time Relative to No Evaculane and No Evaculane and Contraflow

Participation Level	Response Time	IH 37 Evaculane Only		IH 37 Evaculane & Contraflow	
		Hours Reduced	Percent Reduced	Hours Reduced	Percent Reduced
Recent	5 hours	5.5	12.1%	10.5	23.2%
	24 hours	5.4	11.6%	10.7	23.0%
	2 days	1.0	2.2%	1.1	2.4%
Recent Experience Plus	5 hours	8.5	14.6%	15.7	26.9%
	24 hours	6.6	11.4%	13.9	24.0%
	2 days	7.7	12.9%	14.1	23.7%
Maximum Participation	5 hours	9.5	12.1%	20.0	25.5%
	24 hours	12.3	15.2%	22.0	27.2%
	2 days	9.2	11.7%	19.7	25.0%

As would be expected, the implementation of additional evacuation traffic capacity on a roadway increases the amount of traffic on that roadway. For the Coastal Bend study, the scenario variations that include evaculane alone on IH 37 and evaculane plus contraflow on IH 37 result in IH 37 becoming more highly used as a route out of the study area. Table 12 presents the change in expected traffic volume compared to the no evaculane and no contraflow scenario variation. The data confirm that the evacuation volume on IH 37 increases substantially in conjunction with the increased capacity provided by evaculane and contraflow. The provision of these operational enhancements results in IH 37 becoming a more optimal route for evacuating vehicles within the RtePM traffic assignment process. The increase in expected traffic volume on IH 37 results in a decrease in expected traffic volume on other departure routes. These values represent the total traffic at the point where the exiting roadway crosses the Coastal Bend study area boundary (i.e., the county line).

Table 12. Change in Traffic Volume on Exiting Roadways

Roadway	Percent Change in Traffic Volume*	
	IH 37 Evaculane	IH 37 Evaculane & Contraflow
IH 37	23%	44%
SH 285	−16%	−30%
SH 35	−10%	−23%
US 59	−15%	−28%
FM 665	−14%	−26%
US 77	−15%	−28%
US 183	−14%	−31%
FM 624	−18%	−25%
US 181	−15%	−29%
E Highway 44	−15%	−28%
TX 141	−12%	−25%
US 87/Broadway	−15%	−33%

*Compared to no evaculane and no contraflow on IH 37.

Note: Average of response times for max participation scenario.

Although RtePM is not meant for operational analysis of roadways, it does provide tabular and visual reporting of congestion (i.e., delay) by road section. Figure 7 and Figure 8 present images of roadway performance for 1-hour segments of time within a multi-hour evacuation clearance analysis. These figures come from the Recent Experience Plus scenario group.

Figure 7 shows the state of the roadways in the 6th hour of evacuation event from the Recent Experience Plus scenario group with a 5-hour response time and no evaculane or contraflow. Slow-downs on the roadway segments represented in RtePM are indicated by a change in color from green to yellow and then to red based on the level of congestion. Yellow diamonds represent intersections where significant delays occur. Population blocks with remaining evacuating population are showing in varying degrees of shading with darker shading indicating higher proportion of remaining evacuees.

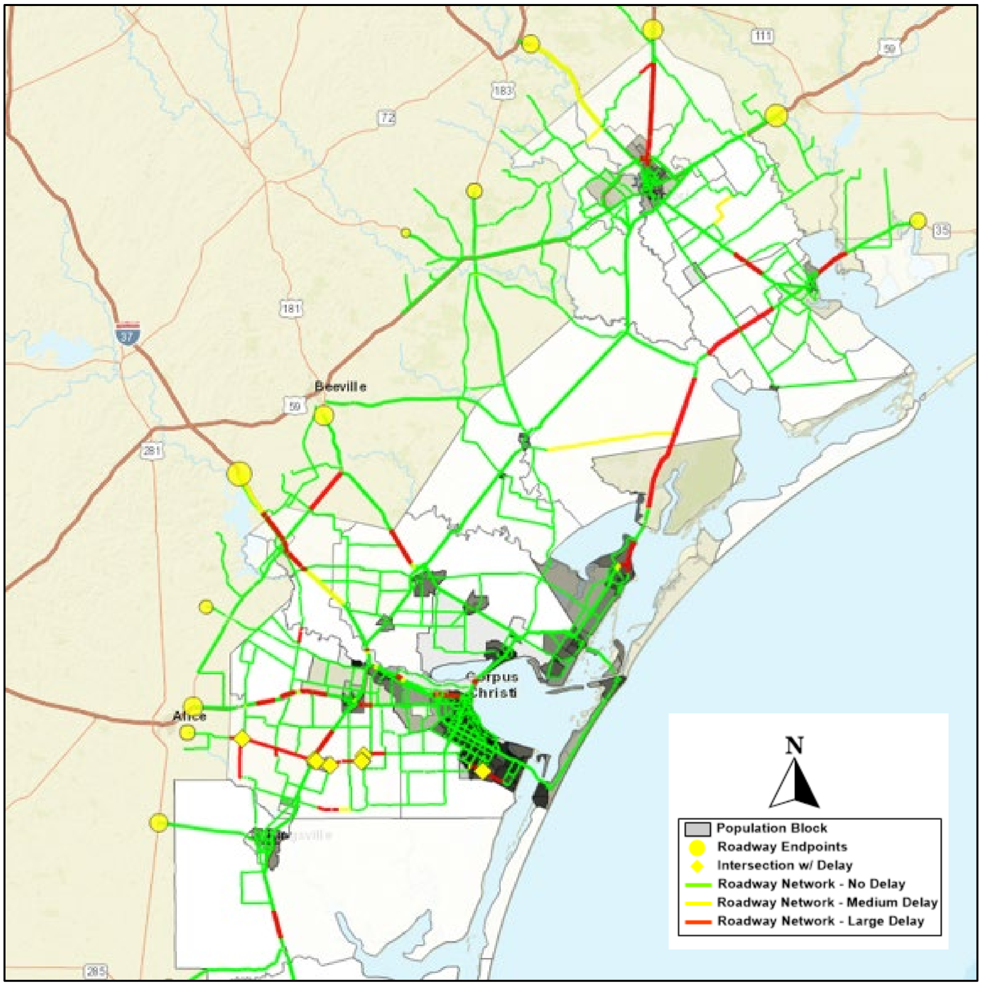

Figure 7. Roadway Status: Recent Experience Plus 5-Hour Response—Hour 6

Figure 8 presents the state of the roadways in the 12th hour of evacuation event from the Recent Experience Plus scenario group with a 5-hour response time and no evaculane or contraflow. As the figure indicates, the presence of larger amount of roadway segments in red indicates that roadway congestion has increased.

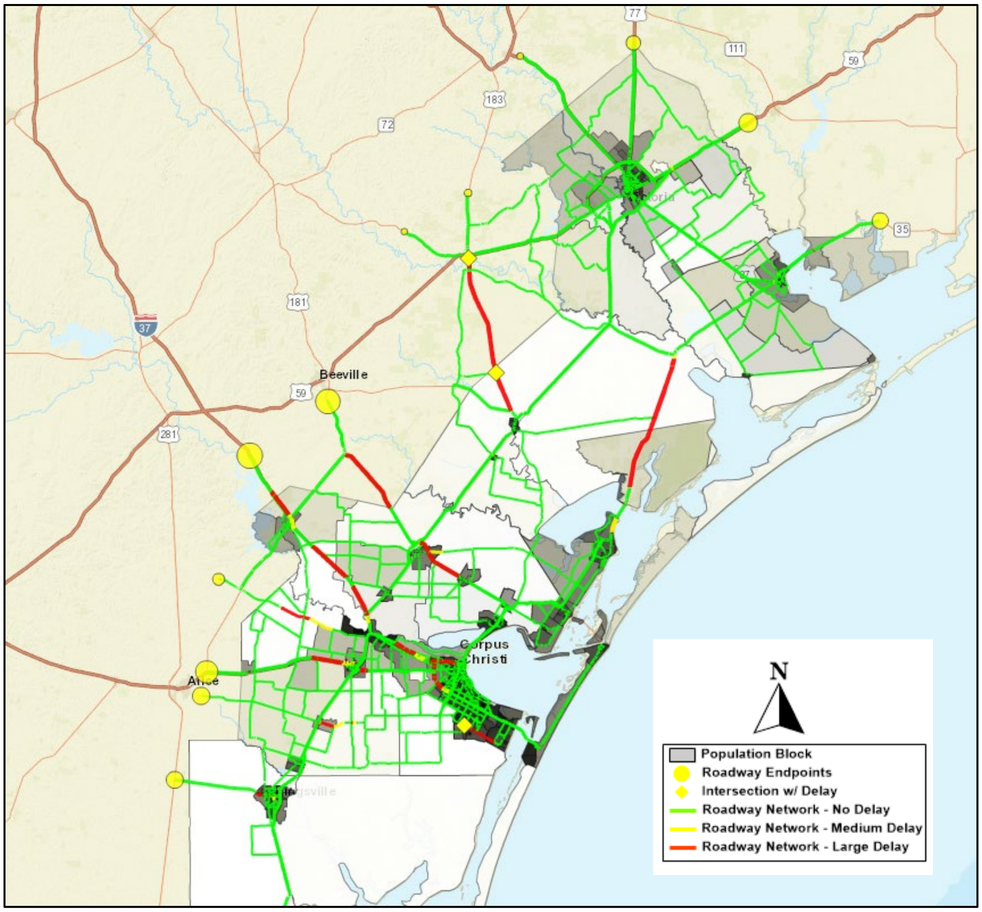

Figure 8. Roadway Status: Recent Experience Plus 5-Hour Response—Hour 12

Although congestion does appear (as indicated by segments colored red and yellow), none of the roadway segments were found to be continuously congested during the evacuation response time for any of the scenarios. The most prominent areas of congestion are along road segments outside the populated core of the study area near or connected to the roadway system endpoints of the study area.

SUMMARY

Among the final set of 27 scenarios analyzed in this report[1], the baseline scenario (i.e., Recent Experience, Figure 3) that assumes participation rates like that of Hurricane Harvey shows that clearance times are no less than 35 hours even with roadway operational enhancements are implemented.

[1] The clearance times for all 63 scenarios, including 36 preliminary scenarios and 27 final scenarios selected in coordination with stakeholders, is provided in Appendix A for reference.

Clearance time analysis of an evacuation event involving levels of evacuation in between Harvey levels but less than 100% evacuation (i.e., Recent Experience Plus, see Figure 4) would require slightly less than 60 hours for evacuees to clear the area under non-optimum routing assumptions. Implementation of evaculane alone on IH 37 would reduce that time by slightly less than 10 hours, while implementation of evaculane along with contraflow on IH 37 would reduce clearance time by roughly 15 hours.

A worst-case evacuation event that involved all resident and common seasonal populations departing the eight-county area (i.e., Maximum Participation, Figure 5) would require roughly 80 hours of clearance time. Implementation of evaculane on IH 37 could reduce that time to roughly 70 hours, and implementation of evaculane plus contraflow on IH 37 could reduce that time another 10 hours to roughly 60 hours.

Overall, the single most important controlling factor on clearance time was participation rate. The clearance time modeling for the three participation groupings selected shows that, as more evacuees are introduced into the roadway network, overall clearance time increases. Increase in response time was generally shown to have less substantial impact on overall clearance times. For all levels of participation, and when no operational roadway enhancements are implemented, the clearance times for the 2-day response time are like those of the 5-hour and 24-hour response times. This is not meant to imply that additional lead time is not important or that it does not result in reduction in congestion experienced by evacuees, but demonstrates that additional lead time does not shorten the time for all evacuees to reach a location of safety outside an area expected to be impacted by storm surge.

When operational roadway enhancements are implemented, clearances times are effectively reduced for short and long response times for greater levels of participation rate (i.e. Recent Experience Plus and Maximum Participation). However, operational roadway enhancements have less impact on clearances times when there is a long response time and lower participation rate (i.e. Recent Experience). It's should be noted that time needed to implement the operational roadway enhancements is not included in the overall clearance times. Detailed plans should be established by local emergency managers to determine adequate timelines for implementation prior to evacuation.

APPENDIX A: FULL SCENARIO LIST

As part of the process for preparation for the developing scenarios with regional and local project stakeholders, the project team modeled 36 preliminary scenarios and 27 final scenarios for a total of 63 scenarios. The behavioral variations of these scenarios involved evacuation participation rates, response timing and presence of seasonal population. The roadway operations variations used in defining the scenarios were presence (or not) of evaculane (use of shoulder) and contraflow (lane reversal in conjunction with evaculane (or not). Additionally, the use of RtePM's roadway endpoint demand distribution to optimize roadway performance and clearance time was varied. When not used, endpoint distributions were based on local knowledge and experience of the Coastal Bend emergency management and roadway operations representatives.

The parameters and results of the 36 preliminary scenarios were used in discussion with regional and local stakeholders to obtain preferences for the final set of scenarios. Table A-1 presents the values for the input parameters that constituted the scenario variations and clearance time results for the 63 scenarios (36 preliminary and 27 final) scenarios developed as part of the Coastal Bend HES.

Table A-1. Listing of Preliminary and Final Scenarios

Type	Participation	Response Time	Seasonal Population	Roadways	Endpoint Shares	Clearance Time (hours)
Preliminary	Recent	5	None	Reg	Determined by RtePM	32.2
Preliminary	Recent	24	None	Reg	Determined by RtePM	25.1
Preliminary	Recent	2-day*	None	Reg	Determined by RtePM	45.4
Preliminary	Recent Plus	5	None	Reg	Determined by RtePM	42.0
Preliminary	Recent Plus	24	None	Reg	Determined by RtePM	25.3
Preliminary	Recent Plus	2-day*	None	Reg	Determined by RtePM	45.2
Preliminary	Worst	5	None	Reg	Determined by RtePM	46.1
Preliminary	Worst	24	None	Reg	Determined by RtePM	38.9
Preliminary	Worst	2-day*	None	Reg	Determined by RtePM	45.2
Preliminary	Recent	5	With	Reg	Determined by RtePM	36.9
Preliminary	Recent	24	With	Reg	Determined by RtePM	25.3
Preliminary	Recent	2-day*	With	Reg	Determined by RtePM	45.5
Preliminary	Recent Plus	5	With	Reg	Determined by RtePM	46.6
Preliminary	Recent Plus	24	With	Reg	Determined by RtePM	32.3
Preliminary	Recent Plus	2-day*	With	Reg	Determined by RtePM	45.2
Preliminary	Worst	5	With	Reg	Determined by RtePM	56.4
Preliminary	Worst	24	With	Reg	Determined by RtePM	48.5
Preliminary	Worst	2-day*	With	Reg	Determined by RtePM	45.3
Preliminary	Recent	5	With	Evac	Determined by RtePM	35.4
Preliminary	Recent	24	With	Evac	Determined by RtePM	26.6
Preliminary	Recent	2-day*	With	Evac	Determined by RtePM	45.3
Preliminary	Recent Plus	5	With	Evac	Determined by RtePM	42.2
Preliminary	Recent Plus	24	With	Evac	Determined by RtePM	29.1
Preliminary	Recent Plus	2-day*	With	Evac	Determined by RtePM	45.4
Preliminary	Worst	5	With	Evac	Determined by RtePM	51.3
Preliminary	Worst	24	With	Evac	Determined by RtePM	44.6
Preliminary	Worst	2-day*	With	Evac	Determined by RtePM	45.6
Preliminary	Recent	5	None	Reg	Determined by local input	38.0
Preliminary	Recent	24	None	Reg	Determined by local input	39.5
Preliminary	Recent	2-day*	None	Reg	Determined by local input	45.1
Preliminary	Recent Plus	5	None	Reg	Determined by local input	47.7
Preliminary	Recent Plus	24	None	Reg	Determined by local input	48.8
Preliminary	Recent Plus	2-day*	None	Reg	Determined by local input	49.1
Preliminary	Worst	5	None	Reg	Determined by local input	69.5
Preliminary	Worst	24	None	Reg	Determined by local input	68.0
Preliminary	Worst	2-day*	None	Reg	Determined by local input	69.5

* - 48 hours less 8 hours when new evacuees not entering roadway system

Reg - Normal roadway configuration

Evac - Evaculane (shoulder lane) operational

Evac + Contra - Both Evaculane and Contraflow (reversed lanes) operational

Table A-1. Listing of Preliminary and Final Scenarios (continued)

Type	Participation	Response Time	Seasonal Population	Roadways	Endpoint Shares	Clearance Time (hours)
Final	Recent	5	With	Reg	Determined by local input	45.3
Final	Recent	24	With	Reg	Determined by local input	46.6
Final	Recent	2-day*	With	Reg	Determined by local input	46.4
Final	Recent Plus	5	With	Reg	Determined by local input	58.4
Final	Recent Plus	24	With	Reg	Determined by local input	57.8
Final	Recent Plus	2-day*	With	Reg	Determined by local input	59.6
Final	Worst	5	With	Reg	Determined by local input	78.4
Final	Worst	24	With	Reg	Determined by local input	80.9
Final	Worst	2-day*	With	Reg	Determined by local input	78.9
Final	Recent	5	With	Evac	Determined by local input	39.8
Final	Recent	24	With	Evac	Determined by local input	41.2
Final	Recent	2-day*	With	Evac	Determined by local input	45.4
Final	Recent Plus	5	With	Evac	Determined by local input	49.9
Final	Recent Plus	24	With	Evac	Determined by local input	51.2
Final	Recent Plus	2-day*	With	Evac	Determined by local input	51.9
Final	Worst	5	With	Evac	Determined by local input	68.9
Final	Worst	24	With	Evac	Determined by local input	68.6
Final	Worst	2-day*	With	Evac	Determined by local input	69.7
Final	Recent	5	With	Evac+Contra	Determined by local input	34.8
Final	Recent	24	With	Evac+Contra	Determined by local input	35.9
Final	Recent	2-day*	With	Evac+Contra	Determined by local input	45.3
Final	Recent Plus	5	With	Evac+Contra	Determined by local input	42.7
Final	Recent Plus	24	With	Evac+Contra	Determined by local input	43.9
Final	Recent Plus	2-day*	With	Evac+Contra	Determined by local input	45.5
Final	Worst	5	With	Evac+Contra	Determined by local input	58.4
Final	Worst	24	With	Evac+Contra	Determined by local input	58.9
Final	Worst	2-day*	With	Evac+Contra	Determined by local input	59.2

* - 48 hours less 8 hours when new evacuees not entering roadway system

Reg - Normal roadway configuration

Evac - Evaculane (shoulder lane) operational

Evac + Contra - Both Evaculane and Contraflow (reversed lanes) operational