Valley 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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Prepared by: Texas A&M Transportation Institute
The Texas A&M University System
3135 TAMU
College Station, TX 77843-3135
(713) 686-2971

Hazard Reduction & Recovery Center
College of Architecture
Texas A&M University
College Station, TX 77843-3137
(979) 845-7813

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Authors: James A. (Andy) Mullins III
Research Scientist
Texas A&M Transportation Institute

Roma G. Stevens, P.E.
Associate Research Engineer
Texas A&M Transportation Institute

Darrell W. Borchardt, P.E.
Senior Research Engineer
Texas A&M Transportation Institute

Dr. Walter G. Peacock
Director
Hazard Reduction & Recovery Center

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The main purpose of the transportation analysis portion of Valley 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'. As 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'. These scenarios, constructed with a high degree of input and review from state and local emergency management and resource agencies, estimated clearance times for many different evacuation possibilities.
The scenarios represent different assumptions about those things that have the most influence on the evacuation clearance time. What this meant for the Valley HES is that scenarios contained ranges of assumptions on

- percent of people evacuating,
- how soon evacuees start to leave after an evacuation is called,
- how much seasonal population is present, and
- presence of contraflow.

A total of 85 different scenarios were developed with assistance from state and local representatives that contained different combinations of values of the above assumptions as well as other less influential, but important, data inputs. Table 1 presents a generalized summary of these scenarios and the estimated clearance time.

TABLE E-1
SUMMARY OF EVACUATION SCENARIOS & CLEARANCE TIMES

Percent of Population Evacuating From				Means This Many	Will Take This Long to Clear 3-County Area (hours)	
Evacuation Zones	Rest of Cameron & Willacy Counties	Hidalgo County	Seasonal Area	Persons Evacuating	No Contraflow	Contraflow
40%	0%	0%	65%	183,000	20 - 25	--
55%	20%	15%	65%	314,000	32 - 35	--
80%	40%	20%	100%	453,000	44 - 50	34 - 40
100%	50%	25%	100%	564,500	app. 60	app. 50

It is suggested that local emergency planners and managers take advantage of the ease of access offered by FEMA's/CORPS clearance time estimation tool to evaluate the effect of changes to assumptions of the scenarios as well as develop variations of the study scenarios and create new scenarios. In this way, the study products and the clearance time estimation tool can continue to serve its main purpose; which is to provide evacuation planning information and tools, that continue to be used beyond the conclusion of the study.

BACKGROUND

Purpose

The primary purpose of the transportation analysis portion of the Valley Hurricane Evacuation Study (HES) is to provide estimates of time needed to evacuate residents of the Valley study area (Cameron, Hidalgo and Willacy 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 1) reflect the state of the practice in evacuation scenario clearance time estimation 2) be based on latest available *local* population, population characteristics and evacuation behavior data 3) reflect storm impact/evacuation scenarios that state, regional and local planners believe bound and reflect what would constitute likely evacuation events.

A secondary purpose of the transportation analysis was to provide an assessment of the evacuation clearance time estimation tool developed for FEMA referred to as RtePM (Real Time Evacuation Planning Model). Prior to the Valley HES, RtePM had been used in limited fashion in hurricane evacuation studies. There was a desire to assess RtePM in terms of ease of use, sensitivity and consistency in outputs under a variety of evacuation scenarios.

Relationship to Other Study Components

The transportation analysis is one of the three major components of the Valley HES along with the evacuation zone development and vulnerability analysis portions of the study. The clearance time estimation aspect of the transportation analysis merges the outcome of the evacuation zone development and aspects of the vulnerability analysis. The evacuation zone development process defines the geographic areas which are subject to calls for evacuation and hence were largely the focus of the clearance time analysis scenarios as well as the outputs of the clearance time analysis. Data analysis conducted either as part of the vulnerability analysis or used in the vulnerability analysis directly also was used in part in the construction of evacuation scenario inputs and/or assumptions.

Evacuation Zone Development

The updated evacuation zone boundaries defined as part of the HES were used in the selection of RtePM population blocks that comprised the areas for which clearance times were estimated. Each of the three evacuation zones were separately identified in RtePM to facilitate creation of multiple evacuation scenarios under which a range of evacuation response assumptions were input to RtePM.

Vulnerability Analysis

Although the clearance time modeling tool RtePM contains population information that can be used directly in analysis, the Vulnerability analysis process provided independent estimates of household, seasonal and at-risk population. The clearance time estimation used these population data as input to all scenarios modeled with RtePM.

Steps of the Transportation Analysis

The first step of the transportation analysis process was to develop familiarity and understanding in development of inputs and in the application of RtePM as part of the assessment of RtePM. Following this, the sensitivity tests were structured and conducted in order to evaluate the clearance time effect of changes to a subset of inputs for which the study would have no definitive local data. The sensitivity tests were then performed and the results of these tests were presented to federal, state and local project stakeholders for discussion in order to develop evacuation scenarios for the primary aspect of the transportation analysis; clearance time modeling.

RtePM Assessment

In preparation for the use of the RtePM clearance time modeling software, the team engaged in an assessment of RtePM that included a review of a prior validation of RtePM (1) against other evacuation modeling techniques and tools as well as direct testing of RtePM itself by the project team. The direct testing of RtePM involved repeated use of the scenario definition/creation process, application of the tool for running scenarios and interpretation of results. Additionally, the team engaged in sensitivity testing of the model for purposes of understanding which variables would be important to vary as part of the definition of scenarios. Through these combined activities, the team provides an overall assessment as to the ease of use along with the sensibility and the ability to understand, summarize and communicate clearance time results.

Validation

The project team reviewed the documentation of a prior validation of RtePM (1) dealing with the comparison of model generated evacuation times and independent measurements/estimates of the actual evacuation times. This effort focused on two levels of validation.

The first-level validation was referred to as a "conceptual" validation. This form of validation dealt with the structure and characteristics of RtePM and the degree to which these matched what those performing the assessment felt should be present in an effective evacuation tool The second-level validation, referred to as operation validation involved the assessment of RtePM's inputs, stability, sensitivity and ability to match observed data.

With regard to the conceptual validation, it was determined that RtePM met six of the eight critical factors. This assessment noted that weather and emergency services factors were not able to be accounted for by RtePM directly. However, it was pointed out that work-arounds do exist within RtePM to provide some measure of accounting for these factors.

In terms of the operation validation, the assessment concluded that RtePM's inputs are accurate and useful and recommends review and update as needed of these inputs as part of RtePM application. This recommendation was incorporated into the efforts of the Valley HES through the adjustment of RtePM population data to reflect estimates developed by the team as part of the evacuation zone development process. The operation validation assessment also determined that RtePM produces stable results, is appropriately sensitive to input data changes and was able to match independent estimates of clearance time as well as real-world event clearance times to a high degree.

Sensitivity Analysis

The second aspect of the RtePM assessment was the performance of sensitivity testing through variation of options and global parameters that have an impact upon the results of the model itself. The primary purpose of the sensitivity analysis was to develop an understanding how variations in the global and scenario specific inputs affected RtePM's prediction of clearance time. In this way, the results of the sensitivity analysis allowed for informed construction of scenario options to present to project stakeholders for consideration. Secondarily, the sensitivity analysis provided an opportunity to evaluate RtePM ease of use and performance as part of the overall assessment of RtePM.

The sensitivity analysis was completed by applying RtePM to the counties of Cameron and Willacy located within the Valley HES limits. As the evacuation zones for the HES were under development at the time of the sensitivity analysis testing, the analysis used evacuation zones based on those in existence at the outset of the study. The testing focused on four input variables along with two separate methods of RtePM application. The four input variables tested were:

- % population evacuating (hereafter referred to as evacuation response rate)
- length of time between decision/call for evacuation and evacuees beginning travel (hereafter referred to as evacuation response time);
- background traffic level; and
- incident level.

All scenarios used constant values for average number of persons per vehicle (3.0), percent of vehicles towing a trailer (3%) and percent of population using private vehicle (85%). Keeping each of these values as constant throughout the analysis provides for a valid comparison amongst the other variables. The sensitivity analysis was completed by developing a matrix of changing variables, executing the changes within the RtePM tool, and then recording the resulting estimated clearance time as well as the amount of clock time from when the job was submitted until the answers were provided. The base matrix varied the evacuation response rate [30%, 70%, and 100%], levels of traffic incident modelling [none, low, medium, high], presence of background traffic [none, low, medium, high], and evacuation response time [slow, medium, fast]. In addition, each of the matrix values was evaluated using both the deterministic model as well as the probabilistic model with twelve simulations.

This resulted in a total of 288 simulation runs of the RtePM tool. When comparing the resulting estimated clearance times for the deterministic versus the probabilistic runs for the evacuation network used for the sensitivity analysis, the values were generally with 10% of each other. Table 1 summarizes the sensitivity testing scenario input variations

Table 1. Sensitivity Analysis Input Data Variation

		EVACUATION RESPONSE RATE											
RESPONSE RATE	BACKROUND TRAFFIC	30%				70%				100%			
		INCIDENTS				INCIDENTS				INCIDENTS			
		None	Low	Medium	High	None	Low	Medium	High	None	Low	Medium	High
5-hour	None	X	X	X	X	X	X	X	X	X	X	X	X
	Low	X	X	X	X	X	X	X	X	X	X	X	X
	Medium	X	X	X	X	X	X	X	X	X	X	X	X
	High	X	X	X	X	X	X	X	X	X	X	X	X
8-hour	None	X	X	X	X	X	X	X	X	X	X	X	X
	Low	X	X	X	X	X	X	X	X	X	X	X	X
	Medium	X	X	X	X	X	X	X	X	X	X	X	X
	High	X	X	X	X	X	X	X	X	X	X	X	X
11-hour	None	X	X	X	X	X	X	X	X	X	X	X	X
	Low	X	X	X	X	X	X	X	X	X	X	X	X
	Medium	X	X	X	X	X	X	X	X	X	X	X	X
	High	X	X	X	X	X	X	X	X	X	X	X	X

An additional 96 simulations were completed to determine if there was any major impact on the start time of the evacuation with respect to the level of background traffic. It is understood that the volume of background traffic is based upon evacuation response rate demand loaded onto the network based on a peak period departure curve. The tool also assumes that the background traffic peaks around 8am and decreases around 8pm. RtePM was executed at all of the levels of background traffic with the start time of the evacuation varied from 12am through 11pm on an hourly basis. For the base simulations of no background traffic, as expected the estimated clearance time did not change with different evacuation start times. The impact of the background traffic by time of day evacuation start times is presented in the graphical representation below. The impact peaks with a nearly 20% impact in the 4 am hour and drops to around 5% starting at 7pm. It is noteworthy that the base evacuation clearance time for the sensitivity analysis network was 14.8 hours, the percentage impact by hour for a different set of evacuation zones with a larger quantity of traffic may differ. Figure 1 presents a summary.

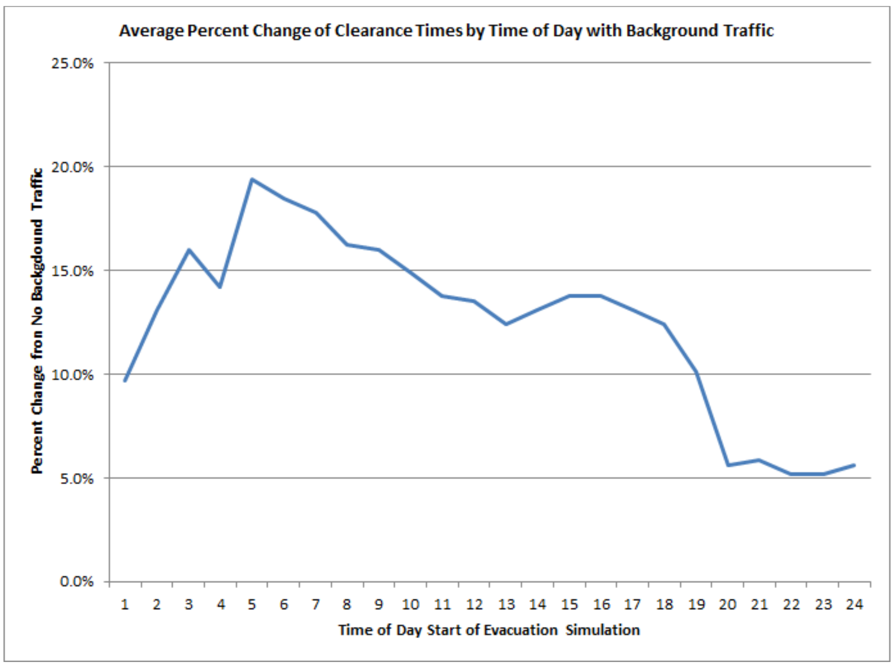

Figure 1. Change in Clearance Time

Conclusions

In reviewing and comparing each of the model run results and the variation of clearance times varied based on input data changes, the following were of most note:

- For Evacuation of Small or Lower Level of Populations
    - Background traffic
        - Little difference among low, medium, and high levels if response rate and incidents are held constant

- Incident Level
    - Results similar among low and medium incidents for same response rates and same background traffic
    - For high levels of background traffic – then none and low incidents are about the same results
    - Traffic incident setting has greater effect with shorter response rates
- For Evacuation of Increased Level of Populations
  - Background traffic
    - Little difference among low and medium if response rate and incidents are held constant
  - Incident Level
    - Results similar among low and medium incidents for same response rates and same background traffic
    - For high levels of background traffic – then none and low incidents are about the same results
    - Traffic incident setting has greater effect with shorter response rates

The findings were translated into use in scenario development in the following manner:

- The incident levels should be set at both the low and high levels regardless of the amount of populated to be evacuated from a region.
- For lower proportions of population evacuations, only the low and high levels of background traffic should be evaluated. However when looking at large areas with large populations, it is recommended that all three levels of background traffic [low, medium, and high] should be studied.

These findings were incorporated in the clearance time modeling process as part of the information used in the evacuation scenario development with the project stakeholders.

Clearance Time Modeling

Introduction & 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 brings 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. Based on the RtePM assessment, the team established input data for the following RtePM data items:

1. Evacuation zones
2. Behavioral data that includes
    a. Evacuation response 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 and evacuation start time,
    i. 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 to that location,
    c. Modification of selected roadway network to reflect contraflow, changes in free-flow speed, change in number of lanes, and use of shoulder as may be needed for evacuation operations,
    d. Addition of new roads as may be needed for evacuation operations.
4. Shelter data
5. Seasonal population
6. Global variables that included level of background traffic, incident level, use of modified roads, and use of seasonal population,

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 is using 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.

Global Inputs

Among the global inputs data were the evacuation zones, evacuation zone population, some of the behavioral data, the base evacuation network and shelter information.

Evacuation Zones

Using RtePM's graphic interface, evacuation zones were defined based on the RtePM's geographic unit, which are census block groups, to match, as closely as block group boundaries allow, the three new evacuation zones (zones A, B and C) developed as part of this HES. The areas outside the evacuation zones proper were selected as 'shadow' evacuation zones to be used for particular scenarios to represent areas of 'shadow' evacuation. For the Valley HES, shadow evacuation zones included all areas within Cameron, Hidalgo and Willacy counties that were not part of evacuation zones A, B, and C.

Using household population data developed for use in the HES vulnerability analysis, the RtePM estimate of population of the each of the three evacuation zones was adjusted within RtePM to match the population total developed for and used in the Vulnerability Analysis.

Behavioral Data

The Valley HES benefitted from a 2013 Valley area behavioral study (2) which involved a survey of residents regarding various aspects of anticipated responses to storms and/or evacuations. The reporting of this survey data included compilation of data on evacuation characteristics that are key clearance time modeling inputs. These data were used to supplant default values available in RtePM as it was felt the clearance time analysis would benefit from locally-based inputs.

Table 2 below summarizes the behavioral inputs that are universal to all evacuation scenarios modeled.

Table 2. Behavioral Data Inputs

Input Data Item	Value
Percent of evacuating pedestrians	0%
Percent of population using private vehicles	90%
Percent of population using transit	10%
Persons/vehicle -	2.5
Percent of vehicles towing another vehicle	3%
Percent of evacuating population using shelters	0%
Destinations of evacuating population	Table A-1

Roadway Data

The RtePM graphic interface provides HERE's roadway data as a default choice for selecting a roadway network for evacuation. Drawing a freehand polygon around the area to be evacuated automatically selects the roadway network that may be used for evacuation. It is of note that once a base evacuation roadway network has been automatically selected, it is possible to manually delete a roadway segment from the evacuation network, however the interface does not let a user manually add an existing roadway (visible on the graphic interface) to the evacuation network if it is not automatically selected by RtePM. For the valley 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 valley HES is shown in Figure 2

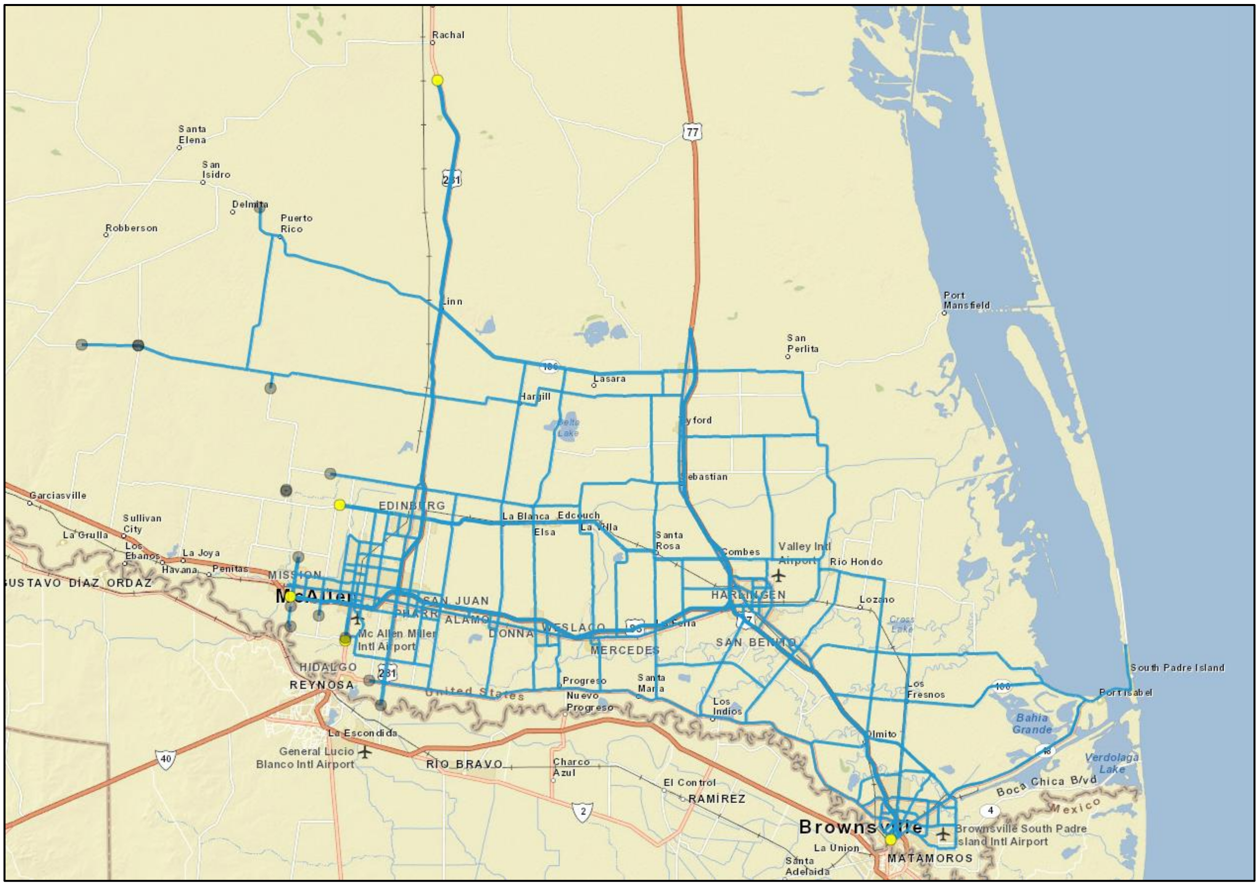

Figure 2. Base Roadway Network for Valley HES

Destination points were selected just outside the boundary of the evacuation area (including shadow evacuation zones) along major roadways that lead to destinations (San Antonio, Laredo, Houston, Austin, Dallas, Edinburg, Brownsville, McAllen etc.) defined in the 2013 Behavioral Study (2). The study team also assigned weights to these destination points based on the proportions of evacuating population headed to that destination as defined in the 2013 Behavioral Study (2). The destination points and weighting are presented in Appendix A.

Shelter Data

For the Valley HES, no shelters were added to the RtePM model. The available shelter capacity in the Valley area was not considered large enough to make significant difference in clearance time calculations. Discussions with the local study stakeholders suggested that majority of available shelters in the evacuation area will be used as temporary places to gather special needs evacuees and might be used by non-evacuating population as shelters of last resort.

Scenario specific inputs

Among the scenario specific inputs were a set of behavioral data, changes to roadway data to reflect contraflow operations, 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 include:

1. Evacuation response rate,
2. Evacuation response time, and
3. Evacuation start time.

Roadway Data

The RtePM allows the user to modify existing roadway network to reflect contraflow operations if so needed, change number of lanes, close lanes, and use of shoulder lanes. For the Valley HES study, study team obtained contraflow plans from TxDOT Pharr District and used the Modified Roads and Additional Roads tab to code these as accurately as possible and developed a roadway network for contraflow operations to be used as a scenario specific input for a set of scenarios.

Seasonal Population

Making use of data collected for use in the Vulnerability Analysis, estimated total seasonal population information was obtained and finalized with input from local study stakeholders. This seasonal population was included as evacuating population for certain scenarios. For the valley HES, maximum seasonal population was estimated to be 50k and was placed in evacuation zone A.

Global Variables

Global variables that were varied for developing different evacuation scenarios include

1. Level of background traffic
2. Level of roadway incidents

Evacuation Scenario Development

The construction of the evacuation scenarios relied on the results of the sensitivity analysis along with input from local project stakeholders. The results from the sensitivity analysis were used to identify the RtePM input variables that resulted in the most sensitivity in terms of estimated clearance times for the Valley study area. Subsequently, the project team worked with project stakeholder and study area local representatives to select combinations of input variable values to represent increments of evacuation demand and timing as well as specific storm impacts in terms of RtePM input assumptions.

Scenario Development Process

Theoretically speaking, the variety of scenarios analyzed was limited only to the variations of input data values either available in RtePM and/or via local data. Practically speaking, there was a need to limit the scenarios so that 1) they reflected local and state-level stakeholder interests 2) were focused on variables to which RtePM exhibited sensitivity and 3) were not so numerous as to result in an inability of the team to effectively communicate results or the team and project stakeholders to draw meaningful conclusions.

The RtePM assessment and, in particular, the sensitivity analysis results were used to identify the RtePM input variables for consideration in the development of scenarios. For this reason, the scenario development process relied upon the RtePM assessment as well as stakeholder outreach meetings and discussions to develop all scenarios for which clearance time modeling was performed. Subsequently, the project team worked with project stakeholders and study area local representatives to select combinations of input variable values that would constitute different evacuation scenarios.

Evacuation Scenarios

The factors that heavily influenced that nature of the evacuation scenarios for which clearance times were estimated with RtePM are influenced by the fact that the Valley region has not undergone a formal hurricane evacuation. Secondly, other than the 2013 Behavioral Study (2), which essentially represented stated evacuation response, there was lack of data on actual hurricane evacuation response by residents of the Valley HES area. The project team in consultation with project stakeholders did use available post-storm behavioral response data from the Hurricane Rita evacuees that was compiled by the project team as the basis for some of the evacuation scenario response characteristics. This was done with the understanding that Rita evacuation behavior was likely heavily affected by the circumstances of Hurricane Katrina just three weeks prior to Hurricane Rita. The project team took this circumstance into account as much as possible in the use of the Katrina data in constructing evacuation scenarios.

These realities led the team and the project stakeholders to conclude during scenario development discussions that clearance time estimates from a set of scenarios representing different increments of evacuating population would offer project stakeholders insight into how clearance times for the Valley HES area might change given different types of evacuation calls. While these 'incremental' scenarios represented a wide range of evacuation scenario possibilities, the scenario development discussion among the project team and stakeholders led to the development of a second set of scenarios which represented the effects of different storms/storm intensities and timings.

At an early stage of scenario development, the study team developed scenarios to represent phased evacuations from different zones. However discussions with the local emergency managers suggested that a mandatory evacuation order for an evacuation zone or zones could result in substantial self-initiated evacuations from the zones or zones not under mandatory evacuation. To reflect this perceived probability in the scenarios, it was decided to have the same evacuation start time for each evacuation zone.

As a result, the project team and stakeholders agreed to develop two scenario groups. The first group designed to provide clearance times coincident with incremental change in evacuating population (hereafter is referred to as 'Scenario Group 1') the second designed to provide clearance times for differing levels of storm 'impact' (hereafter referred to as 'Scenario Group 2'). The 'impact' was translated by the team and stakeholders into RtePM inputs. Using this approach the study team created 5 base scenarios in 'Scenario Group 1' and 4 base scenarios in 'Scenario Group 2'. Each base scenario represented a specific resident population response rate and a specific seasonal population response rate. The study team then developed variations of each of the base scenarios by varying the scenario specific inputs described previously.

Scenario Group 1

Table 3 below presents the evacuation response rate from each zone for the 5 base scenarios in Scenario Group 1.

Table 3. Scenario Group 1 Base Scenarios - Evacuating Population

Base Scenario	Population	Evacuation Zone/Area					Persons evacuating
		A	B	C	Remainder of Cameron and Willacy County	Hidalgo County	
A	% Resident Pop.	50	50	50	20	20	304,127
	% Seasonal Pop.	50	-				
B	% Resident Pop.	60	60	60	25	20	352,023
	% Seasonal Pop.	60	-				
C	% Resident Pop.	70	70	70	30	20	399,921
	% Seasonal Pop.	70	-				
D	% Resident Pop.	80	80	80	35	20	447,817
	% Seasonal Pop.	80	-				
E	% Resident Pop.	85	85	85	40	20	473,571
	% Seasonal Pop.	85	-				

The variation sets of the Group 1 Base scenarios were created using the, following inputs.

1. Response time - 2 days and 5 hours
2. Level of background traffic - low and high
3. Level of Incidents - low
4. Modeling approach - deterministic and probabilistic
5. Seasonal population – used for all scenarios

Initially 20 scenarios were developed in this scenario group to reflect variations in the evacuation response rate, background traffic and modeling approach (deterministic versus probabilistic). However based on stakeholder feedback to the clearance time results and the expressed desire to see the effects of a fast response time, a response time variation was introduced; resulting in 5 additional scenarios Thus, the final set of Group 1 scenarios, presented in Table 4 totaled 25 scenarios

Table 4. Scenario Group 1 Full Scenario Set

Base Scenario	Scenario	Modeling Approach	Background Traffic	Response Time
A	A1	D	Low	2 Days
	A2	P		
	A3	D	High	
	A4	P		
	A5	D	High	5 Hours
B	B1	D	Low	2 Days
	B2	P		
	B3	D	High	
	B4	P		
	B5	D	High	5 Hours
C	C1	D	Low	2 Days
	C2	P		
	C3	D	High	
	C4	P		
	C5	D	High	5 Hours
D	D1	D	Low	2 Days
	D2	P		
	D3	D	High	
	D4	P		
	D5	D	High	5 Hours
E	E1	D	Low	2 Days
	E2	P		
	E3	D	High	
	E4	P		
	E5	D	High	5 Hours

For the Group 1 scenarios that involve 2-day response time, the proportion of the evacuating population for each day must be provided. Table 5 below presents the proportions used as the 2-day response time input. The evacuation population proportions were kept the same for all scenarios with the two-day response time.in this group.

In addition to evacuating population proportions, evacuation start and end times were also part of the inputs for two day evacuation scenarios. All 2-day response time scenarios used 4:00 am as the start time and midnight as the evacuation end time on each day resulting in total response time of 44 hours over the two day time period. For the 5-hour response time, an evacuation start time of 7:00am was used.

Table 5. Proportion of Evacuating Population by Day for Two-Day Response Time

Input Variable	Proportion Evacuating	Evacuation Zone/Area				
		A	B	C	Remainder of Cameron and Willacy County	Hidalgo County
Response Time - 2 Days	On day 1	85	50	40	40	40
	On day 2	15	50	60	60	60

Scenario Group 2

Table 6 below presents the evacuation response rate from each zone for the four base scenarios in Scenario Group 2.

Table 6. Scenario Group 2 Base Scenarios – Evacuating Population

Scenario	Population	Evacuation Zone/Area					Persons Evacuating
		A	B	C	Remainder of Cameron and Willacy County	Hidalgo County	
1 – Low Impact	% Resident Pop.	65	40	30	-	-	183,162
	% Seasonal Pop.	65	-				
2 - Medium Impact	% Resident Pop.	65	60	50	20	15	314,176
	% Seasonal Pop.	65	-				
3 - High Impact	% Resident Pop.	85	80	75	40	20	453,241
	% Seasonal Pop.	100	-				
4 – Worst-Case Impact	% Resident Pop.	100	100	100	50	25	564,275
	% Seasonal Pop.	100	-				

The variation sets of the Group 2 Base scenarios were created using the following inputs.

- Response time (2 days, 24 hours, and 5 hours)
- Level of background traffic (low and high)
- Level of Incidents (low and high)
- Modeling approach (deterministic)
- Seasonal Population (used and not used)
- Contraflow (used/not used) only for scenarios 3 and 4.

Base Scenario 1 – Low Impact

The study team developed 10 variations of this base scenario as shown in Table 7. As this scenario set was not expected to generate substantial congestion on the evacuation network no contraflow was modeled for this set of scenarios.

Table 7. Scenario Group 2 Base Scenario 1
Low Impact Set

Base Scenario	Scenario Id	Contraflow	Seasonal Population	Response Time	Background Traffic	Incident Level
1- Low Impact	1-A1	No	Yes	2 Days	Low	Low
	1-A2					High
	1-A3				High	Low
	1-A4					High
	1-A5			5 Hours	High	High
	1-B1		No	2 Days	Low	Low
	1-B2					High
	1-B3				High	Low
	1-B4					High
	1-B4			5 Hours	High	High

<u>Base Scenario 2 – Medium Impact</u>

The study team developed 10 variations for this base scenario as shown in Table 8. As this scenario set was not expected to generate substantial congestion on the evacuation network, no contraflow was modeled for this set of scenarios.

Table 8. Scenario Group 2 Base Scenario 2
Medium Impact Set

Base Scenario	Scenario Id	Contraflow	Seasonal Population	Response Time	Background Traffic	Incident Level
2-Medium Impact	2-A1	No	Yes	2 Days	Low	Low
	2-A2					High
	2-A3				High	Low
	2-A4					High
	2-A5			5 Hours	High	High
	2-B1		No	2 Days	Low	Low
	2-B2					High
	2-B3				High	Low
	2-B4					High
	2-B5			5 Hours	High	High

<u>Base Scenario 3 – High Impact</u>

The study team developed 20 variations, as shown in Table 9, for this base scenario. As this scenario set was expected to generate congestion on the evacuation network, contraflow was modeled for this set of scenarios.

Table 9. Scenario Group 3 Base Scenario 3
High Impact Set

Base Scenario	Scenario Id	Contraflow	Seasonal Population	Response Time	Background Traffic	Incident Level
3-High Impact	3-A1	No	Yes	2 Days	Low	Low
	3-A2					High
	3-A3				High	Low
	3-A4					High
	3-A5			5 Hours	High	High
	3-B1		No	2 Days	Low	Low
	3-B2					High
	3-B3				High	Low
	3-B4					High
	3-B5			5 Hours	High	High
	3-C1	Yes	Yes	2 Days	Low	Low
	3-C2					High
	3-C3				High	Low
	3-C4					High
	3-C5			5 Hours	High	High
	3-D1		No	2 Days	Low	Low
	3-D2					High
	3-D3				High	Low
	3-D4					High
	3-D5			5 Hours	High	High

Base Scenario 4 – Worst-Case Impact

This scenario was developed to gain a sense of clearance timed in the extremely remote circumstance of 100% of the population from the three evacuation zones actually evacuating. The study team developed 20 variations of this base scenario as shown in Table 10. As this scenario set was expected to generate substantial congestion on the evacuation network, contraflow was modeled for this set of scenarios.

Table 10. Scenario Group 2 Base Scenario 4 Worst-Case Impact Set

Base Scenario	Scenario Id	Contraflow	Seasonal Population	Response Time	Background Traffic	Incident Level
4-Worst Impact	4-A1	No	Yes	24 Hours	Low	Low
	4-A2					High
	4-A3				High	Low
	4-A4					High
	4-A5			5 Hours	High	High
	4-B1		No	24 Hours	Low	Low
	4-B2					High
	4-B3				High	Low
	4-B4					High
	4-B5			5 Hours	High	High
	4-C1	Yes	Yes	24 Hours	Low	Low
	4-C2					High
	4-C3				High	Low
	4-C4					High
	4-C5			5 Hours	High	High
	4-D1		No	24 Hours	Low	Low
	4-D2					High
	4-D3				High	Low
	4-D4					High
	4-D5			5 Hours	High	High

Table 11 below presents the evacuation response rate for each day for those Group 2 scenario variations involving a 2-day response time. All scenarios used 4:00 am as the evacuation start time and midnight as the evacuation end time on each day resulting in total response time of 44 hours over the two day time period. For the 5-hour response time, an evacuation start time of 7:00am was used.

Table 11. Scenario Group 2 – Evacuation Response Rate

Scenario	Response Time	Proportion of Population Evacuating	Evacuation Zone/Area				
			A	B	C	Remainder of Cameron and Willacy County	Hidalgo County
1 – Low Impact	2 Days	On day 1	85	50	40	-	-
		On day 2	15	50	60	-	-
2 – Medium Impact	2 Days	On day 1	85	50	40	50	50
		On day 2	15	50	60	50	50
3 – High Impact	2 Days	On day 1	70	50	40	40	50
		On day 2	30	50	60	60	50
4 – Worst Impact	24 Hour	On day 1	100	100	100	100	100
		On day 2	-	-	-	-	-

Clearance Time Results

What follows are the resulting clearance times from the application of RtePM, for each of the scenarios described above. The set of results presented below represent the product of several iterations of RtePM application. These iterations of RtePM application revealed characteristics of RtePM not included in user documentation and apparently observable only through application of the tool. Some of these characteristics results in modification of the application process by the team that were then carried forward through all final scenario applications.

A summary of the characteristics of RtePM that were discovered during initial scenario modeling are presented in the Summary and Conclusions section.

Scenario Group 1

Using RtePM, the study team calculated clearance times for 25 scenarios in this scenario group. The clearance time results for the 20 scenarios with 2-day response time are shown in Figure 3. For those scenarios involving use of RtePM's probabilistic option, the average of the clearance times is presented. The data in Figure 3 reveal that both background traffic and modeling approach (i.e., deterministic or probabilistic) did not have a significant effect on clearance time results when the number of persons evacuating stays the same. However, as one would expect, clearance time increases with increasing number of people evacuating.

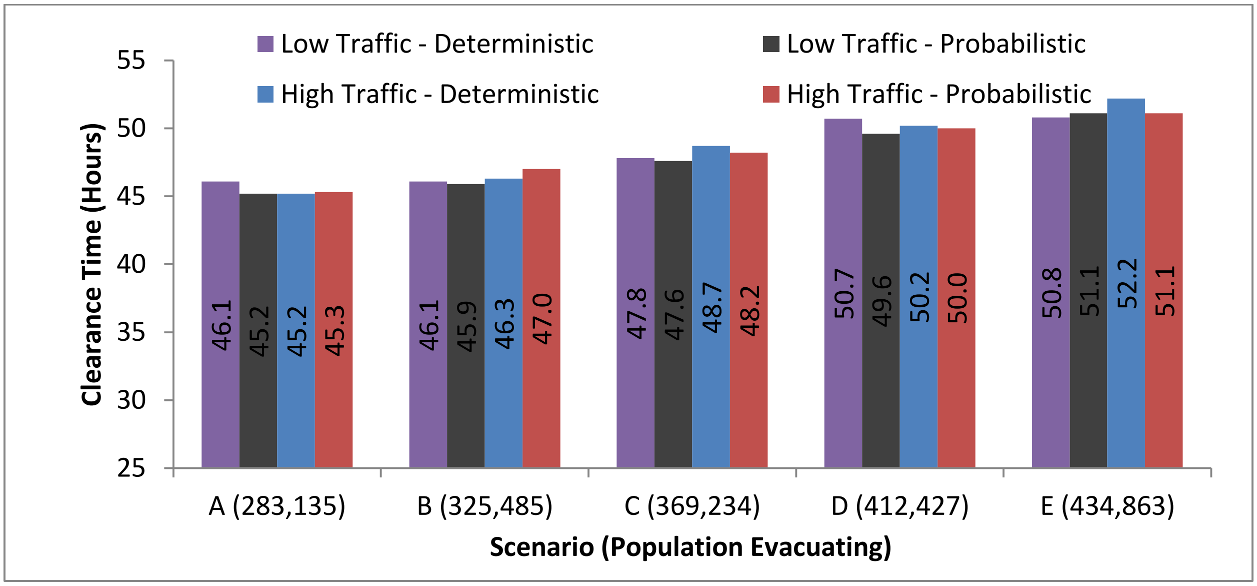

Figure 3. Clearance Times for Scenario Group 1 with 2-Day Response Time

Figure 4 and Figure 5 below show variability among the clearance times for each probabilistic RtePM application for each of the Group 1 scenarios. It can be seen that difference between maximum and minimum clearance times for any given scenario and under both low and high background traffic conditions is less than 10%. This is consistent with the findings of the sensitivity testing.

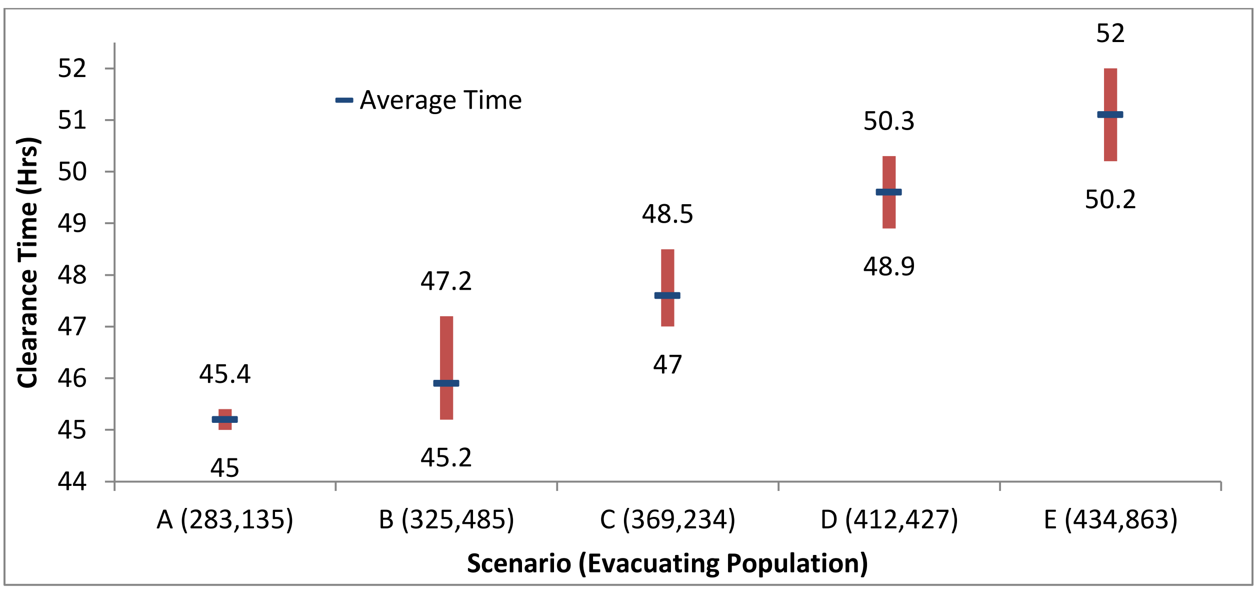

Figure 4. Clearance Time Variability for Probabilistic Modeling
Scenario Group 1 - Low Background Traffic

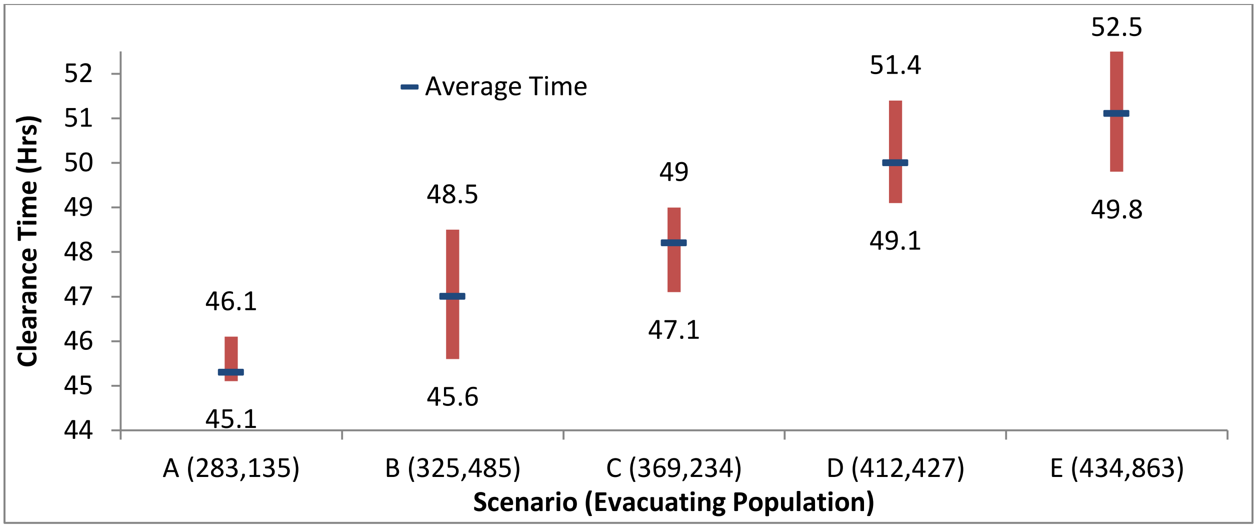

Figure 5. Clearance Time Variability for Probabilistic Modeling Scenario Group 1 - High Background Traffic

Upon completion of RtePM applications to a first set of 20 scenarios that comprised Scenario Group 1 to reflect variations in evacuation response rate, background traffic and modeling approach (deterministic versus probabilistic) and a review of results, the study stakeholders desired modeled clearance times for a set of scenarios for a very short response time. Thus, clearance times were calculated for five additional Scenario Group 1 scenarios, each for sets A thru E with a 5-hour response time. These additional five scenarios used the deterministic modeling approach, high background traffic, low incidents, and presence of seasonal population at the time of evacuation.

Figure 6 presents the clearance time results from the modeling of the 5-hour response time for each of the base scenario groups (i.e., scenario groups A through E). For comparison purposes, the clearance times presented in Figure 3 are included in Figure 6 to emphasize the effect of the shorter response time. The results suggest that estimated clearance times are significantly impacted by the response time selected in RtePM, especially for scenarios with low levels of evacuation.

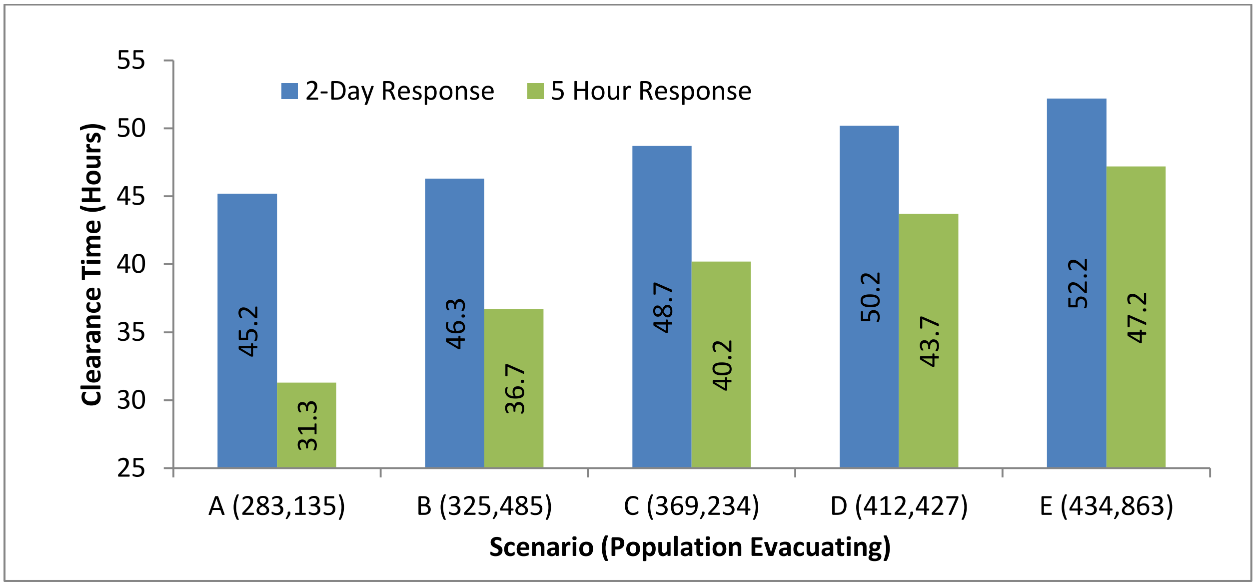

Figure 6. Clearance Time versus Response Time for Scenario Group 1

Scenario Group 2

Using RtePM, the study team produced clearance time estimates for a total of 60 scenarios in this scenario group. There were 4 base scenarios (i.e., Scenario Groups 1-4) in this group developed to reflect the effects of 4 different levels storm 'impact'. The clearance time results are presented for set of scenarios associated with each base scenario.

<u>Results for Scenario Group 1 – Low 'Impact' Storm</u>

This scenario group consisted of 10 variations (shown in Table 7) of the low 'impact' scenario. Figure 7 shows the clearance time results for the eight scenarios of this group which included the 2-day response time. As can been seen, there is no difference in clearance time among the variations of this group as the clearance time is almost exclusively a function of the response time for scenarios with small amounts of evacuating population. The other two scenarios use the shorter 5-hour response time and only high background traffic and high incident level.as background traffic and incident level did not affect the clearance times of the low 'impact' group. Figure 8 shows the clearance times for the two scenarios as well as the clearance times for two scenarios presented in Figure 7 for comparison purposes to emphasize the effect of the shorter response time.

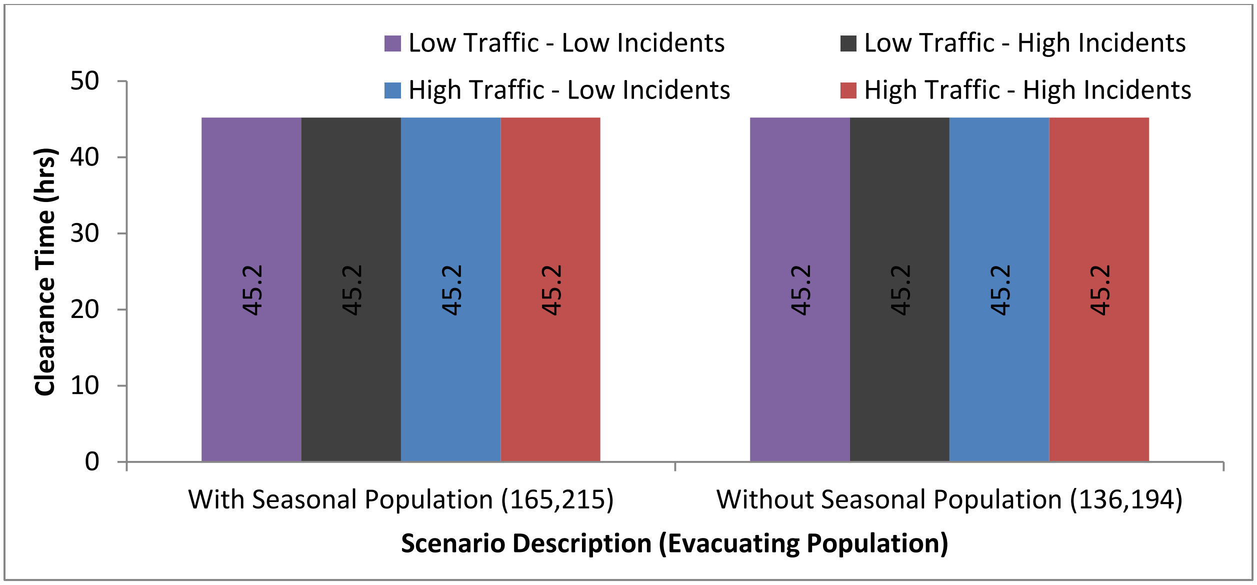

Figure 7. Clearance Times for Low Impact Scenario 1 with 2-Day Response Time

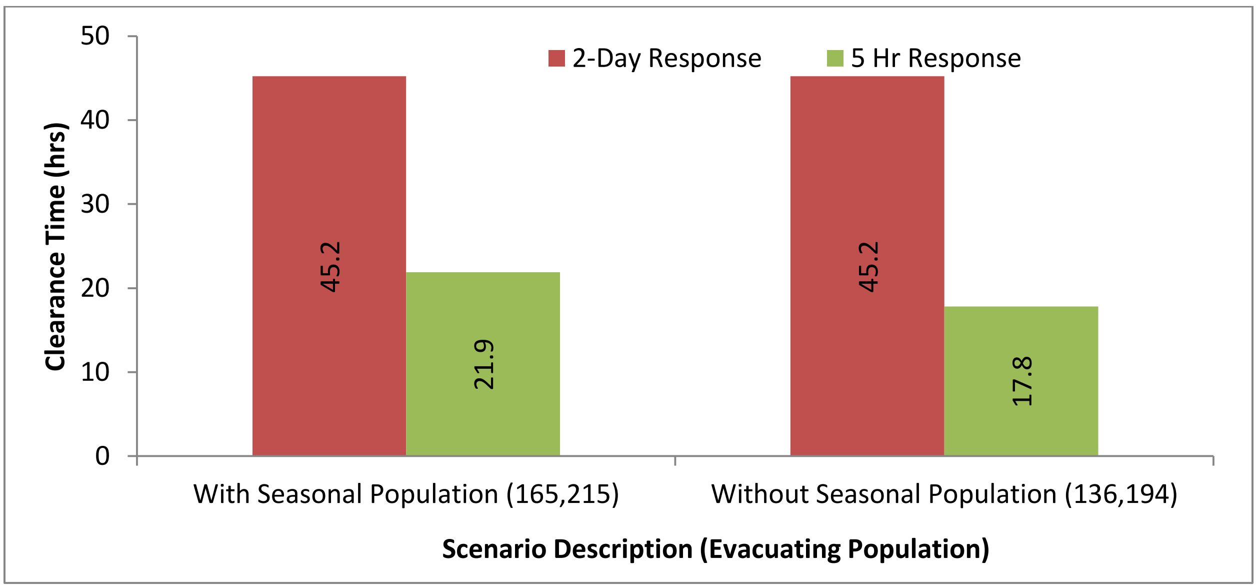

Figure 8. Clearance Times for Low Impact Scenario 1 with Different Response Times

<u>Results for Scenario Group 2 – Medium 'Impact' Storm</u>

This scenario group consisted of 10 variations (shown in Table 8) of the medium 'impact' scenario. Figure 9 shows the clearance time results for the eight scenarios of this group which included the 2-day response time while Figure 10 presents the clearance times for the two scenarios of the group with the shorter 5-hour response time. Figure 10 includes results for two scenarios presented in Figure 9. Comparison of the results of the shorter response time scenarios of Scenario Group 1 and Scenario Group 2; in Figures 8 and 10, respectively, reveals that when clearance time is not dictating response time, the clearance time does increase, as expected, with an increase in evacuating population.

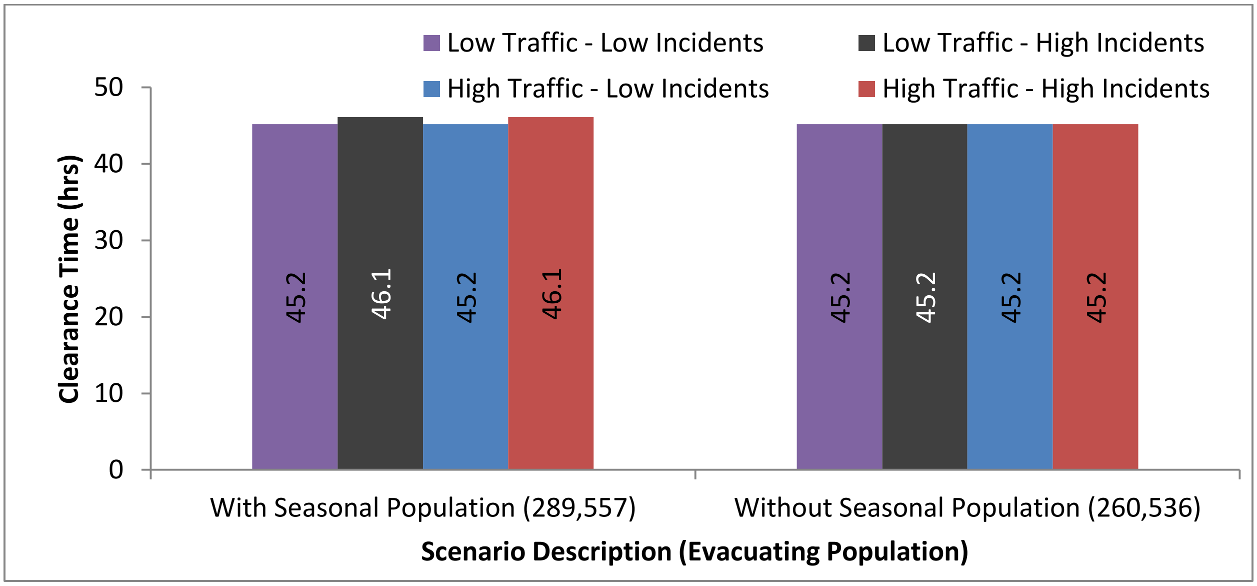

Figure 9. Clearance Times for Medium Impact Scenario 2 with 2-Day Response Time

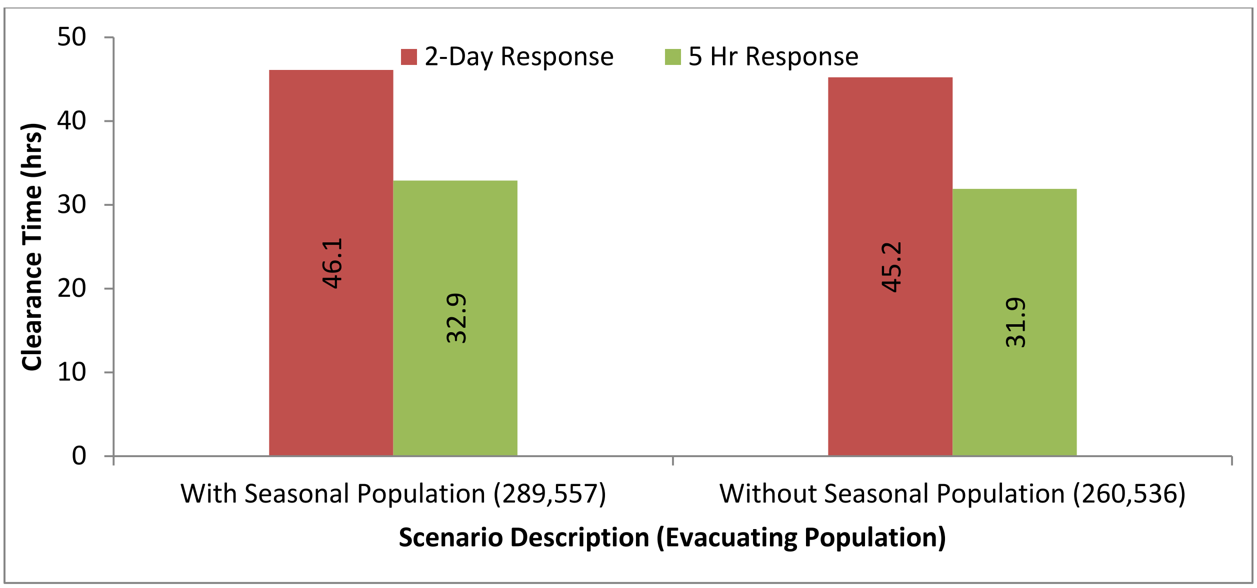

Figure 10. Clearance Times for Medium Impact Scenario 2 with Different Response Times

<u>Results for Scenario Group 3 – High 'Impact' Storm</u>

The study team produced clearance time estimate for 20 scenario variations for this group as detailed in Table 9. This scenario group is the first to include use of contraflow operations as the size of the evacuating population is large and the effect of incidents and background traffic increases. Figure 11 shows the clearance time results for the 16of these scenarios that used a 2-day response time and Figure 12 shows the clearance times for the four scenarios with a 5hour response time. For comparison purposes, Figure 12 also includes results for four scenarios presented in

Figure 11 that used 2-day response time. The results suggest use of contraflow operations is an effective tool, particularly in scenarios where the response time is short. These results show that even under a 2 –day response time assumption, there was some benefit to implementing contraflow operations.

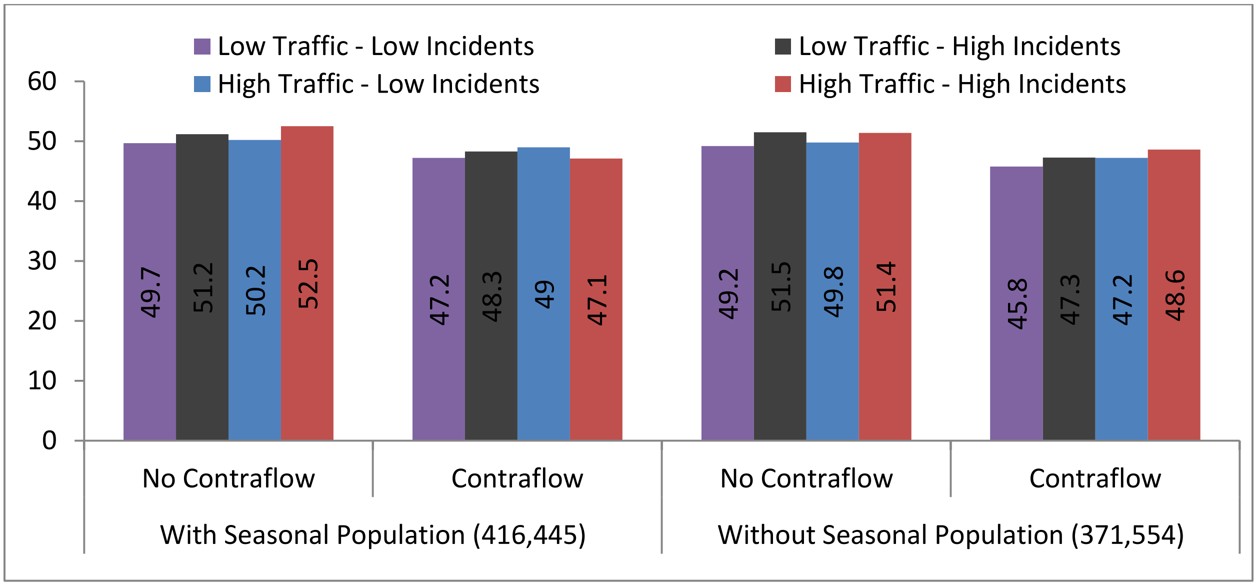

Figure 11. Clearance Times for High Impact Scenario 3 with 2-Day Response Time

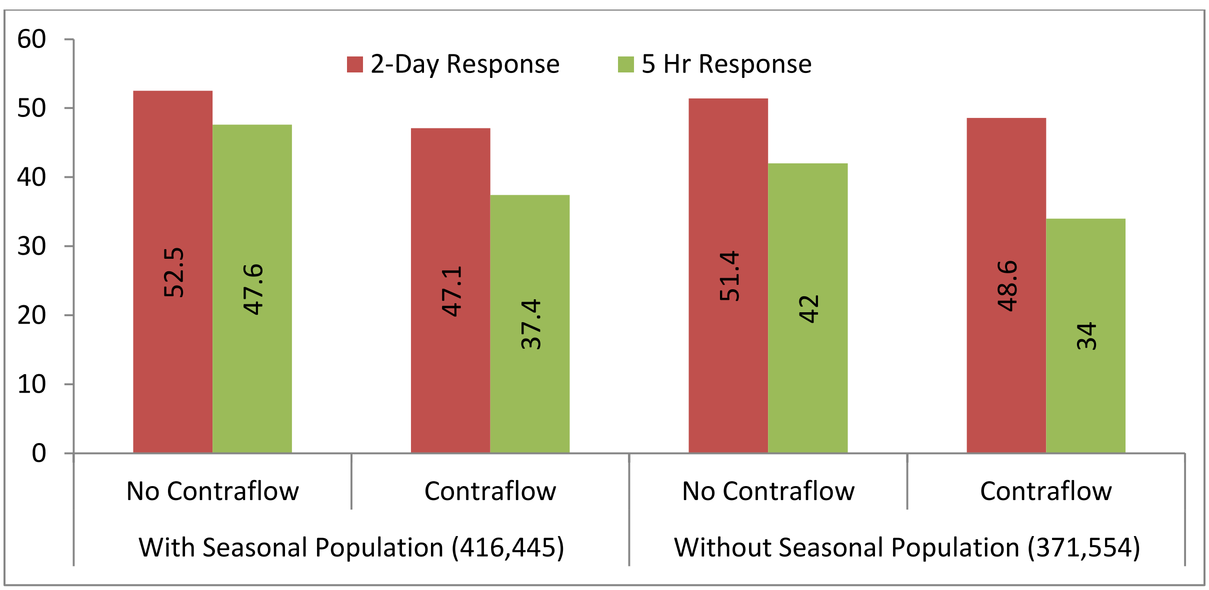

Figure 12. Clearance Times for High Impact Scenario 3 with Different Response Times

<u>Results for Scenario Group 4 – Worst-Case 'Impact' Storm</u>

Although, based on input for regional stakeholders, the likelihood of a 100% evacuation of the Valley study area was deemed to be extremely low, there was interest among the project and regional stakeholders to have clearance time estimates for such a scenario as a way to establish an upper limit on clearance times for the Valley study area. Therefore, the study team estimated clearance times for 20 variations, as shown in Table 10 of a 100% evacuation. This scenario grouped was termed a worst-case 'impact' storm group. Figure 13 shows the clearance time results for the 16 scenarios of this group with 2-day response time while Figure 14 presents the clearance time results for the four scenarios of the group with 5-hour response time. Figure 14 includes, for comparison purpose, results from the comparable four scenarios of the 2-day response set presented in Figure 13.

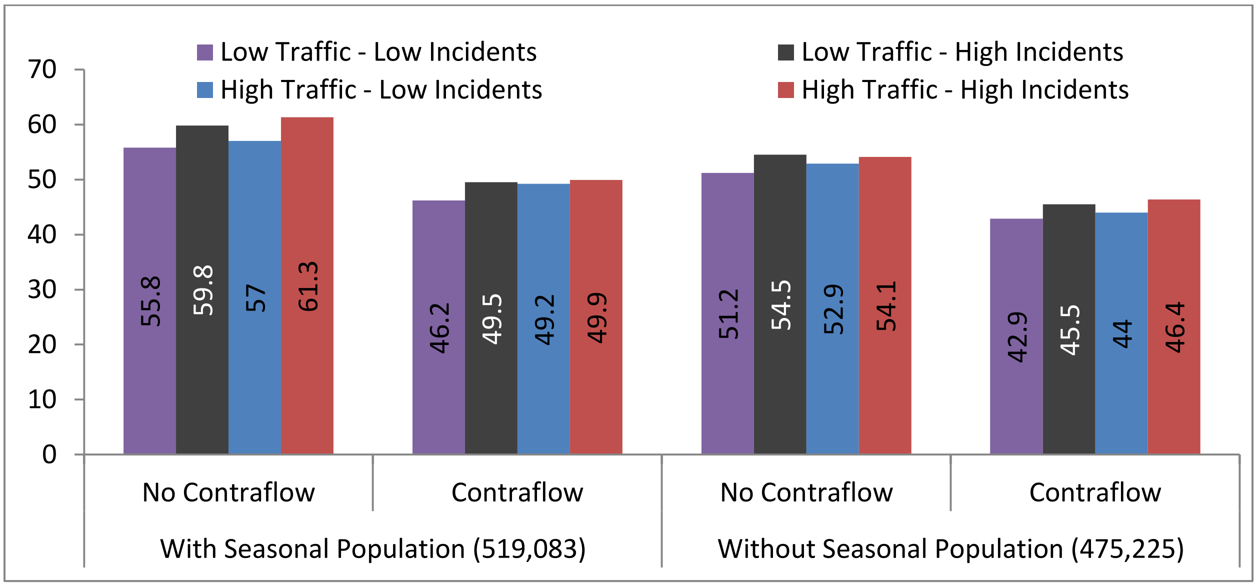

Figure 13. Clearance Times for Worst Impact Scenario 4 with 24 Hour Response Time

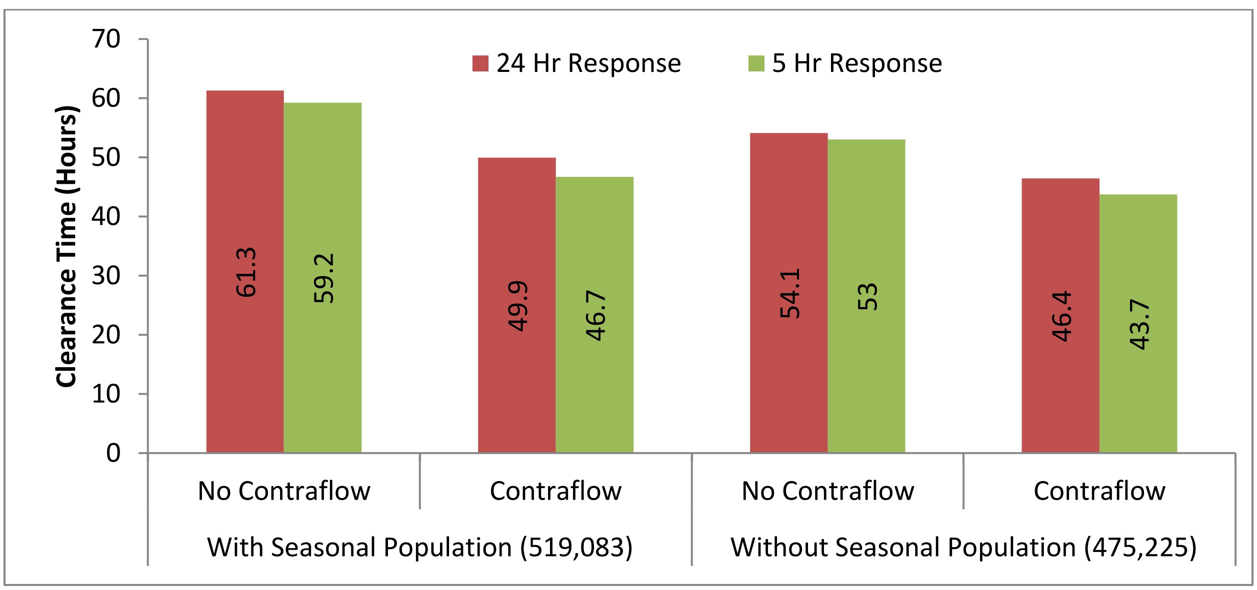

Figure 14. Clearance Times for Worst Impact Scenario 4 with Different Response Times

A look at the clearance time results suggest that as number of evacuating population reaches over 450,000, the effect of response time on clearance time reduces and the need for contraflow operations increases.

Figure 15 is an example of the typical roadway congestion/bottleneck information that RtePM is capable of producing when simulating a scenario. This particular result is taken represents hour 12 of Scenario Group 1, evacuation scenario B.

Although congestion does appear (indicated by segments colored red and yellow), none of the roadway segments were found to be continuously congested for any of the scenarios. The segment locations near freeway-to-freeway interchanges showed intermittent congestion for certain periods for all scenarios whereas congestion in other roadway segments was also seen based on the presence of an incident.

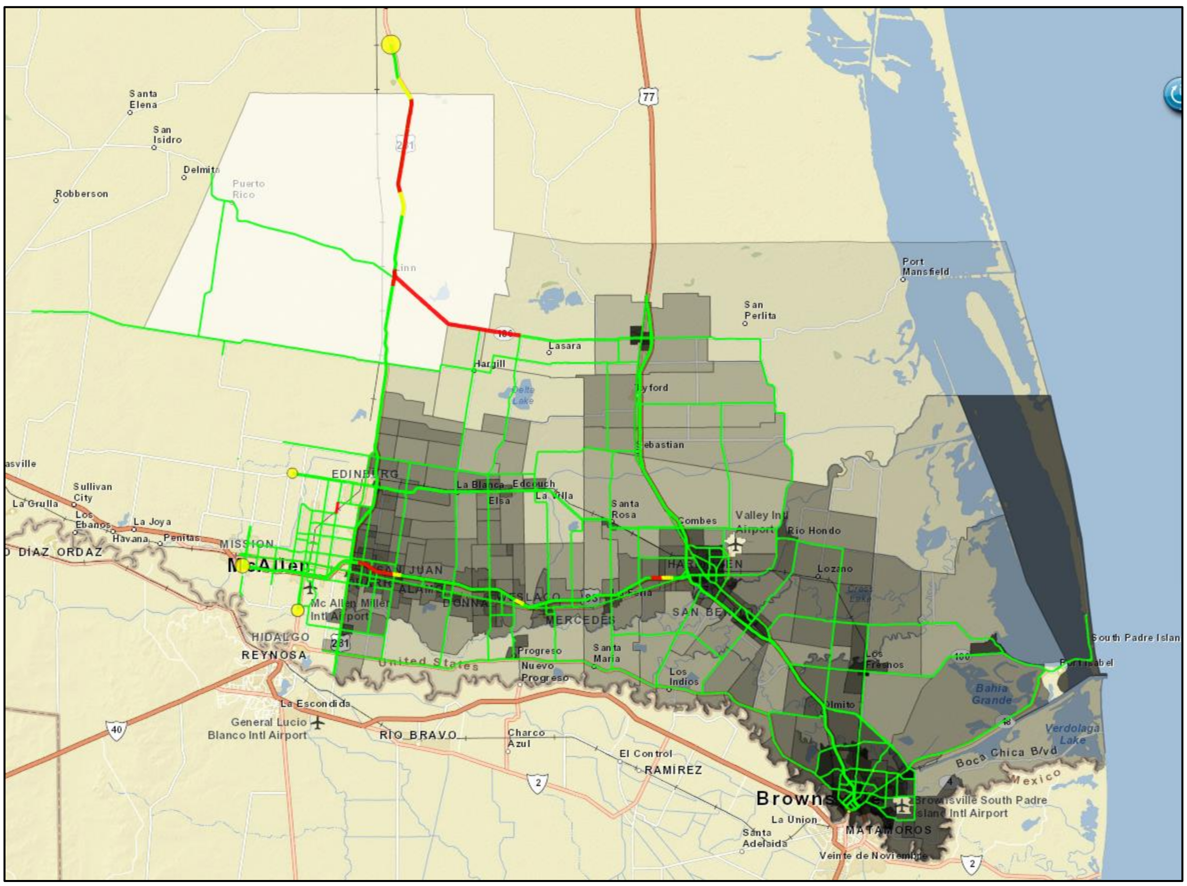

Figure 15. Example of Roadway Congestion Shown in RtePM

SUMMARY AND CONCLUSIONS

Clearance Time Results

For the Valley study Area, when using a 2-day response time a minimum clearance time was 45 hours and a maximum clearance time was 61 hours. When using a 5 hour fast response time, maximum clearance time was 59 hours and minimum clearance time was dependent upon the evacuation response rate. For a storm of low impact when only 50% or less of the population is expected to evacuate, the minimum clearance time was calculated to be 18 hours. These clearance times will change if US 77 is available as an evacuation route and destination proportions of evacuating population are different than what was used for this study.

In almost in all scenarios, RtePM resulted in zone A took the longest time to clear even when faster response times were selected. This is likely due to limited roadway capacity to evacuate the South Padre Island and use of simultaneous evacuations from all zones. If seasonal population is expected to be part of the evacuation traffic from South Padre Island, every effort should be made to evacuate South Padre Island ahead of the other evacuating zones.

In general, RtePM showed intermittent congestion near freeway-to-freeway interchanges and along TX 186 just south of US 281. RtePM did not show a continuous congestion at any of the roadway segments.

The Tool

Settings/Inputs

While the RtePM tool does provide the evacuation clearance time estimates for those involved in emergency management in a relatively simple and concise manner, there are some items that should be considered for future upgrades of the tool. These will result in RtePM having increased flexibility of its usefulness while at the same time not increasing the input requirements of users.

- At initial log in, RtePM should display an information screen that indicates some information on the data resources used, especially the census year data of the population information. Users can then use this information to better determine what, if any, growth rates need be applied. Furthermore, it might be helpful to allow for the selection of available versions of population and roadway networks so that the user may specify the base years to be evaluated.

- The persons-per-vehicle value is currently only adjustable in increments of 0.5 – this should be changed to 0.1 for increased accuracy in loading the appropriate number of vehicles to the roadway network.

- Population values can only be increased and cannot be decreased – the ability to decrease populations should be available in the model to better reflect real-world conditions.

- RtePM provides the ability to add new roadways, however new roadways get added as a two point single roadway segment with each end point connecting to an existing roadway segment. For example the study team was not able to understand the process for adding a new roadway segment that splits into two roadways – an entry ramp to the freeway system and an access road that connects to cross streets. This limits the user's ability to account for roadways in the base network that haven't been automatically selected by RtePM interface or new roadways that may have been constructed in recent past and are not part of the default roadway network available in RtePM. Improvements to the additional roadway interface should incorporate a user's ability to add multi-point roadway segments.

- There is need to better document the process for coding and simulating contraflow operations. The study team was able to simulate contraflow operations only after receiving guidance from RtePM developer team. The study team's experience with use of contraflow operations suggests that emergency managers might find it difficult to develop clearance times for scenarios that require the use of contraflow network for evacuation.

Capabilities

From the traffic engineering standpoint, one of the most difficult issues to predict in any evacuation scenario are the instances of traffic bottlenecks and excessive congestion. The presence of bottlenecks can turn a smooth flowing evacuation operation into one of start, stops, and significant travel time delays and frustration for evacuating traffic. Roadway operational information coming out of RtePM would be a benefit to those trying to identify and communicate roadway performance.

- A major need in terms of output from the RtePM tool would be detailed information on traffic operations within each roadway segment. This is important from being able to identify problematic traffic areas to determining the potential impact of different strategies to relieve the congestion as well as to help prioritize roadway improvements.

- There is a significant need to be able to have output tables on a roadway segment basis that presents measures such as throughput traffic volumes, speeds, and volume-to-capacity ratios. This would increase the effectiveness of RtePM by allowing emergency management personnel to better refine hurricane evacuation plans through improvements in capacity and traffic control at critical locations.

During initial scenario modeling, as a result of locations more than 100 miles from the HES boundary being selected as RtePM destination endpoints, clearance time results appeared to not be able to be reported beyond 72 hours with reporting including substantial portions of the evacuating population still in the study area. Based on these it appears RtePM may be have a 'cap' of 72 hours of clearance analysis after which it reports this result and the population still in the evacuation area after 72 hours. Although destination endpoints were moved closer to the study area to resolve this situation, there could potentially be scenarios in which clearance time would legitimately be more than 72 hours for which RtePM may not be able to report.

Destination weights when set for individual evacuation zones, revert back to default values after one simulation run and thus need to be entered again if the scenario is saved as and rerun by making a few global changes such as background traffic or incident level. To ensure that destination weights input is properly accounted for in calculating the clearance times, study team used the destination weights tab under the roadway tab which uses global destination weights for the entire evacuation area rather than for each zone.

While the model does allow for the starting time of a road closure to be specified, contraflow conditions are either activated or deactivated. In some evacuation scenarios, it may be necessary to either start or stop any contraflow operations at pre-determined times during the evacuation which will impact the overall evacuation clearance time.

The Process

The overall process for performing the transportation analysis is straight-forward, particularly given the high degree of prescriptiveness associated with the use of RtePM. RtePM provides certainty for those constructing scenarios in terms of the variables that are available for use and the possible values that can be adopted in the scenario construction. The two biggest challenges with regard to the clearance time modeling involved 1) translating between storm/evacuation terminology used by emergency managers and weather professionals and RtePM terminology and 2) fitting desired scenario assumptions into RtePM input parameter boundaries.

With regard to translation of terminology, the challenge involved translating the input for local emergency managers into terms that are the inputs to RtePM and conversely the RtePM inputs to terminology familiar to local emergency managers. Local stakeholders could also easily express desired scenarios in terms of prior storms. Not being able to express these storms in RtePM-oriented inputs resulted in not being able to purely model a scenario that was locally familiar. The difficulty is not with RtePM itself, but with availability of data about the nature of these storms in RtePM terminology.

The development of scenarios for the clearance time modeling aspect of the transportation analysis was somewhat affected by limitations of possible input values. Of most impact to the Valley HES, the limitation of a two-day maximum evacuation limited the ability to model some of the locally desired scenarios as did the limitation a single response rate per evacuation zone. While the limitations offer benefits to the ease-of-use of RtePM, they did affect the scenario development process of this study by limiting the types of scenarios for which clearance times could be modeled.

The evacuation zones created as part of the Valley HES are meant to be easily communicable and interpretable by the public. The zones were defined to make use of easily identifiable streets so that those potentially impacted by an evacuation call understand their location relative to the three evacuation zones. However, these boundaries do not coincide with the census block group geography that is the basis for the population data and, hence, the identification of evacuation zones in RtePM. For this reason, the study team, after selecting block groups that most closely resembled each evacuation zone, had to use RtePM's evacuation zone population change option to globally add population to the evacuation zone. This was done so that the clearance time analysis would be based on an evacuation zone population that matched the study team's population estimate that was developed based on detailed data and was the basis for the vulnerability analysis portion of the Valley HES. Given the geographic detail of the RtePM population data, the evacuation zone population change option applies the population change uniformly across the evacuation zone, perhaps resulting in imprecise estimates of loadings out of the evacuation zone and affecting in a minor way the resulting clearance time.

The RtePM modeling performed for the Valley HES included use of destination weights derived from the 2013 behavioral study (2). Through the iterative process of scenario development and testing, it was revealed that use of RtePM's default destination weights resulted in substantially shorter clearance times as compared to use of those from the 2013 behavioral study (2). This appears to be due to RtePM designating less distant destinations. The Destination end points and weighting should be developed based on local information, either through behavioral data and/or local knowledge rather than rely on RtePM default destination weighting.

The sensitivity testing and initial scenario modeling revealed that the estimated clearance time is highly dependent on the input response time in scenarios in which less than half of the study area population was evacuating. In other words, the length of time to evacuate the study area is a function of how soon people respond to an evacuation order or advisory and has very little to do with travel time when less than half of the Valley study area is evacuating. This underscores the importance of having a good understanding of expected response time when using RtePM to calculate clearance times that will be used to develop evacuation plans and make an evacuation decision.

When seasonal population was added using RtePM's seasonal population tab, the clearance times calculated by RtePM were much higher as compared to clearance times calculated when the seasonal population was accounted for through an increase in the evacuation zone population. The amount of difference between the resulting clearance time was such that the team felt that the using the seasonal population tab to add seasonal population resulted in unrealistic delays in clearance times for the seasonal population and the study area as a whole. As such for the Valley HES, the study team increased the evacuation zone to reflect the amount of seasonal population for a given scenario.

APPENDIX A: EVACUATION DESTINATIONS

Table A-1. Expected Evacuation Destinations, by County (%) (2)

Destination \ County	Cameron	Willacy	Hidalgo	Overall
San Antonio	45.5	43.0	47.8	47.0
Houston	8.9	17.7	10.1	9.8
Austin	8.2	16.4	10.9	10.1
Laredo	11.1	6.4	9.3	9.9
Dallas	7.7	4.5	2.4	4.2
McAllen	10.8	7.1	1.7	4.8
City in Mexico	3.8	0.0	7.3	6.0
Brownsville	1.9	0.0	0.0	0.7
Edinburg	0.2	0.0	3.7	2.5
Harlingen	1.7	3.0	0.0	0.6
Other Cities (<1%)	14.4	13.9	16.7	15.9

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2. Michael K. Lindell, Yue Ge, Shih-Kai Huang, Carla S. Pratar, Hao-Che Wu, HunLung Wei. *Behavioral Study, Valley Hurricane Evacuation Study, Willacy, Cameron, and Hidalgo Counties, Texas.* Texas A&M University Hazard Reduction & Recovery Center, September 2013.