

# *A Customized Modeling and Simulation Tool for Port and Airport Evacuation and Recovery*

## *An Integrated Tool for Enhancing Preparedness and Response*

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**Abstract**— Effective planning for the evacuation of port and airport facilities during or in advance of an event, and for the recovery of normal operations after an event, requires a comprehensive understanding of the potential effects of response decisions, both on the facilities themselves and on the surrounding areas. Only through a coordinated, integrated planning and analysis effort can emergency managers accumulate the appropriate knowledge to make confident decisions.

Response strategies that determine when, where and how passengers and employees evacuate must be objectively evaluated to assess whether sufficient resources have been allocated and appropriate practices put in place to minimize the risk of death and injury. Such evaluations must include consideration of the effects of and to existing conditions on roadways within and surrounding facilities. Further, because any evacuation consists of a combination of pedestrian and vehicle movement, the interactions between these factors must be considered.

In a similar manner, planning for recovery requires a comprehensive analysis of end-to-end movements. In a seaport environment, this includes thorough examination of vessel capacities, tug and pilot resources, berth availability, and terminal throughput, all within the constraints imposed by geography, landside accessibility, and transportation network capacity.

Until recently, this sort of comprehensive analytical effort has not been successfully undertaken. Through its project entitled “Development, Implementation and Maintenance of a Customized Evacuation and Recovery Model and Simulation Tool (CMST),” the Port Authority of New York & New Jersey is developing and implementing such a solution. Working in concert with a contractor team led by Delcan Corporation, PANYNJ deployed this solution in July, 2012.

The CMST offers a systematic approach to planning for, and responding to, current and future threats. It involves the application of a suite of modeling and simulation tools to analyze the evacuation of the Port Newark/Elizabeth Marine Terminals (PNEMT) and Newark Liberty International Airport (EWR) in the event of a disaster, and the recovery of normal operations at PNEMT after the threat clears. The tool consists of the following three components:

- A road traffic model, overlaying evacuation and recovery vehicles onto existing traffic conditions
- A Pedestrian Evacuation Model (PEM), which establishes the rate at which pedestrians are evacuated from EWR facilities to points where they board vehicles or reach other pre-defined destinations on EWR property
- A harbor model, evaluating the rate at which PNEMT facilities and the Captain of the Port Zone can resume normal operations after an evacuation

The tool consists of a graphical user interface (GUI) through which emergency managers and operations planners can input values for a variety of parameters and execute simulations that provide comparative results. Based on these results, which are presented in terms of measures of effectiveness (MOEs) such as time to evacuate, evacuation rate, and time to recover, the user can assess the effectiveness of various response strategies.

Key to the system’s success is that it does not require modeling or simulation expertise to operate. Users need only have an understanding of response capacity, such as the number of each of various types of vehicles available for evacuation, the number of individuals to evacuate, and the likely distribution of pedestrians between multiple pick-up points.

The CMST represents a first-of-its-kind, integrated planning and operations support tool that has the ability to be customized to model and simulate evacuation and recovery operations at any type of facility. Its successful deployment in the Newark Airport/Port Newark & Elizabeth Marine Terminal complex offers evidence of its value as a decision-support tool.

*Keywords*—evacuation, simulation, port, airport, recovery, on-line, near real-time

### I. INTRODUCTION

The CMST is primarily intended as a decision-support tool for use by operations and planning staff within PANYNJ. The key design imperatives for the tool were:

- User friendliness – The principal intended users are not modelers, so CMST needed to be configured to be used

by staff without modeling and simulation expertise, and the interface needed to provide straightforward means to enter important operational information.

- End-to-end analysis – Evacuation analysis requires the examination of the movement of people from a point within a threat area to a point outside the threat area. This must include the transition among different modes of transportation and the externalities of traffic and other roadway conditions. Recovery analysis similarly requires end-to-end analysis, including the movement of vessels and trucks that transport goods to and from the terminals. The CMST needed to encompass pedestrian, vehicle and vessel movement, all within the operational context in which they move, and produce unified, comprehensive output.
- Clear, quantitative results – CMST is intended to be a decision support tool. Hence, the results it produces must provide actionable intelligence. If users are to make planning and operations decisions—some of which involve investment and others which require actions by external entities—then the results must be easily understood and numerically-grounded.

## II. KEY CHARACTERISTICS OF CMST

### A. Why Would I Use It?

CMST offers users key capabilities along three major dimensions: 1) Improved emergency planning; 2) More effective response; and 3) Justification for investment. A closer examination reveals how the tool provides these capabilities to the users.

Emergency planning can be improved through the delivery of numerical assessments of response plans. When comparing alternate actions, CMST provides numerical and graphical output that allows for direct comparison between the results of each response plan. The CMST also serves as a support tool for inter-agency cooperation. If one entity seeks the cooperation of another, CMST allows the combined results to be demonstrated in a manner that clearly identifies the collective benefit of the cooperative action versus an uncoordinated or singular response. Planning is also improved by the tool because it allows for an extensive array of input and condition combinations, which allows the user to examine a very large number of response plans in a very short period of time.

The CMST was designed primarily as a planning tool, but it also has been developed to support near-real-time operations decisions, thereby offering the capability to better manage response. Given a predefined set of evacuee data, the tool can execute an evacuation simulation typically in less than 1 minute. This is especially useful in instances where an unexpected event occurs (e.g., an accident closes a roadway) because a user can quickly conduct a comparative assessment of alternative actions to adjust a predetermined strategy. In these circumstances the tool provides fast results with the detail necessary for decision-making.

In addition to the ability to support planning and operations decisions, the CMST also offers users the capability to conduct

assessments of the relative value of resource expenditures. Though costs are not factored into the tool, it can provide clear, demonstrable assessment of resource implications. For instance, if the user needs to better understand the relative effect of adding evacuation vehicles, the tool allows for the comparison of any number of alternatives to the baseline number. Just as importantly, the CMST produces results in a format that is user-friendly and well-suited for executive demonstration.

### B. What Does It Produce?

The CMST is intended to provide decision support for two different activity types—evacuation and recovery. As such, the results it produces need to offer decision makers with information that supports planning and operations along these two dimensions, all in forms that are easy to understand and communicate quickly. This capability was incorporated into the tool through the use of measures of effectiveness (MoEs) presented using graphical representations accompanied by numerical output. The basic MoEs are:

*MOE #1: Time to Evacuate PANYNJ Property.* This MOE describes the time required to fully evacuate the EWR and/or PNEMT facilities given response plan inputs.

*MOE #2: Number of Evacuees Remaining on Site.* This MOE can be used to forecast how many evacuees will remain within the facility after set time intervals.

*MOE #3: Time to Evacuate Pedestrians.* This pedestrian evacuation MOE quantifies how long the pedestrians will take to reach one of the vehicles (car, bus, train) used to evacuate them from EWR.

*MOE #4: Time to Recover Harbor Operations.* This MOE reflects the time it will take for the vessel queue within the NY Harbor Captain of the Port Zone (COTPB) to return to “normal” conditions. Normal is defined as when the ships in the model are at or en route to their assigned destination (includes anchorages).

*MOE #5: Traffic Congestion During Recovery.* This MOE is intended to measure the congestion produced by the extra trucks brought in and out of PNEMT during recovery. It is the difference between the average delay measured during recovery and the one measured during ordinary conditions.

### C. Why Should I Trust It?

Simulation tools such as CMST rely on the ability of the underlying modeling tools to reliably predict the outcomes associated with the defined set of inputs. This reliability is typically tested through calibration and validation. For this project, it was determined that the traffic simulation tool needed to be calibrated and validated in order to ensure that the traffic movements built into the model reflected realistic values.

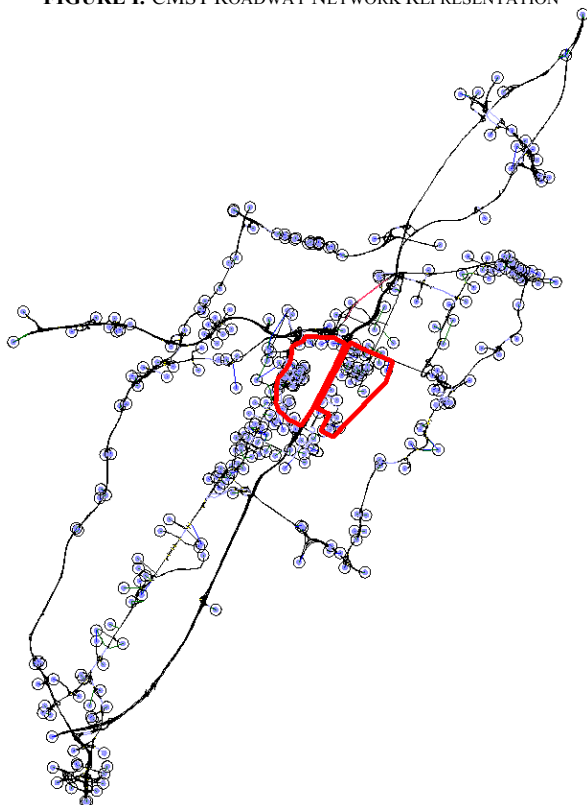
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Identify applicable sponsor/s here. (*sponsors*)

Calibration is a Process where the analyst selects the model parameters that cause the model to best reproduce field-measured local traffic operations conditions. Validation is Process where the analyst checks the overall model-predicted traffic performance for a street/road system against field measurements of traffic performance, such as traffic volumes, travel times, average speeds, and average delays.

Because evacuation of the PANYNJ facilities (see the red outlines in Figure 1) requires the movement of vehicles onto the surrounding road network in the Newark and Elizabeth, NJ region (depicted in Figure 1 as the series of lines), it was necessary to calibrate and validate the model using actual traffic data from the region.

**FIGURE I. CMST ROADWAY NETWORK REPRESENTATION**



As part of the process, validation targets were established for link counts, total counts, travel speeds, and bottlenecks across the roadway network. The calibration and validation results indicated that available counts were matched to within acceptable reasonable targets, and total counts matched well (correct magnitude of traffic). Travel speeds matched well for some segments, but weren't able to capture some reduced speeds from toll plaza delays (limited data samples limited usefully of comparison). Bottlenecks and general areas of congestion qualitatively matched against the local modeler's knowledge of typical conditions.

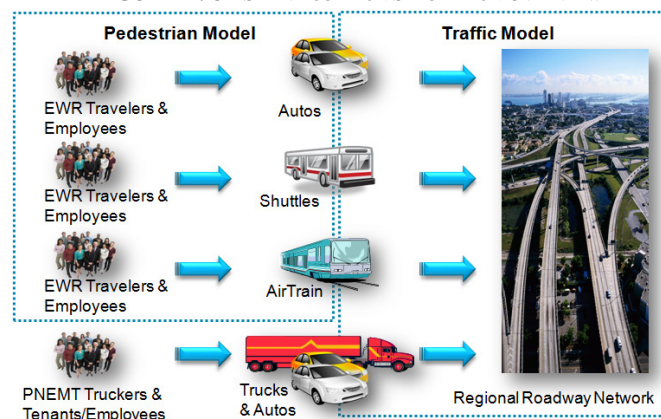
At the end of the calibration and validation effort, it was statistically determined that the CMST traffic properly represents: 1) Operations on the Port Facilities during an evacuation; 2) The evacuation routes and potential bottlenecks; and 3) Analysis potential for queue spillback that would inhibit traffic leave the Port Facilities.

#### D. How Does It Work?

Because it was intended from the start to support comprehensive planning and operations, CMST was architected to directly integrate the separate models into a unified tool. This was accomplished along two dimensions. For user control and interaction, a common operating picture (COP) viewer was developed that allowed for access to each tool to enter input and select scenario characteristics. For actual execution of simulation scenarios, the tool was designed to facilitate the exchange of output and input values between the separate models. Hence, for conducting an evacuation simulation, the output from a pedestrian evacuation scenario is accessible for use as input to the traffic model.

This process is depicted at a high level in Figure II. As shown in the figure, the pedestrian model encompasses the movement of pedestrians from EWR building exits to where the pedestrians enter vehicles. The traffic model takes these results and simulates the entry of those vehicles onto the regional roadway network and their interactions with background traffic. Though pedestrian movement is not modeled at the PNEMT facilities, the vehicles used for evacuation are included in the traffic model.

**FIGURE II. CMST EVACUATION SIMULATION OVERVIEW**

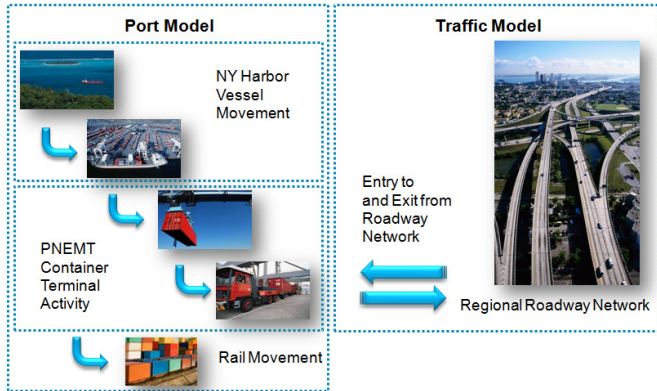


Under this design approach, users can select from a library of previously-run pedestrian scenarios and run several evacuation scenarios, in any combination. For instance, two pedestrian evacuation scenarios can be run with one or more input values changed, and two traffic simulations can be run simultaneously to compare output values to assess the effects of the various input values.

In a similar manner, the port recovery simulation uses output from the port model as input to the traffic model. Users can set up and execute port recovery simulations to examine differences associated with various response actions and system conditions, and the results can be used to assess the effects of the port recovery on the overall roadway network both on the port property and in the region surrounding the facility. The CMST recovery simulation approach is depicted in Figure III.



FIGURE III. CMST RECOVERY SIMULATION OVERVIEW



The port model includes components to simulate the movement of vessels in NY Harbor and to simulate the movement of containers onto and off vessels and through the terminal gates. The port model generates outbound truck trips which are then used as input to the traffic model, and the traffic model is used to simulate the availability of inbound trucks to support terminal operations.

### III. USING CMST

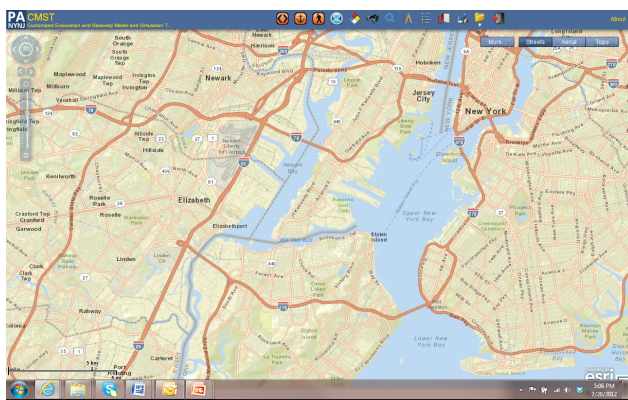
The key design imperative from a user perspective was the requirement to make the tool usable and useful for non-modelers. With this principle in mind, the development team designed a user interface that provides the necessary flexibility to enable users to input and adjust a wide array of input parameters, kickoff simulations and review results.

The underlying interface is a common operating picture (COP) built on a GIS platform, through which users can access all of the CMST functions, interact with geographically coded features and view results in various formats.

#### A. Common Operating Picture

The CMST COP viewer—and by extension, the entire tool—is accessible via the Internet using a standard browser equipped with Flash software. From the home screen, which is shown in Figure IV, the user can access all of the functions of the tool.

FIGURE IV. CMST COP VIEWER HOME SCREEN



#### B. Evacuation Simulations

From this starting point the user can set up a traffic simulation (the vehicular portion of an evacuation or recovery) through a set of pop-up menus similar to the one shown in Figure V.

FIGURE V. CMST TRAFFIC SIMULATION INPUT SCREEN



Users can specify the evacuation (or recovery) context in the top half of the screen and the response plans in the bottom half. Context inputs include the following:

- *Evacuation Scope.* The user can select to simulate an evacuation from either EWR or PNEMT, or both, or the recovery of the port, including PNEMT.
- *Simulation Start Time.* The user can set the event start for the present time or for some date and time in the future.
- *Road Weather.* Here the user can select from a drop down list that sets the weather conditions for the simulation. These include good or light rain, heavy rain, or snow.
- *Traffic Events.* The user can either manually input information regarding traffic events such as accidents, road and lane closures, and congestion, or they can import information from TRANSCOM, the traffic management and information provider for the region. Because events there are frequent, users can also indicate if an event is taking place at the Meadowlands sport complex during the evacuation. Each of these inputs alters the background traffic used in the model.
- *Traffic Modifier Profile.* The tool was primarily intended to support analysis only of a local evacuation of the PANYNJ facilities. However, the user can modify the background traffic to reflect changes in traffic volumes that might result from a wider evacuation. Changes made here are applied to the historical volume and speed data that the model uses for base analysis.
- *EWR Evacuee Profile.* This is where the user selects which output set from the pedestrian evacuation will be used for the simulation. The user can also select the

Pedestrian Simulation button, which takes them to the screen to create new EWR evacuee profiles.

- *PNEMT Evacuee Profile.* The user can input values here for the number of people and vehicles that would be evacuated from each of the terminals in PNEMT.

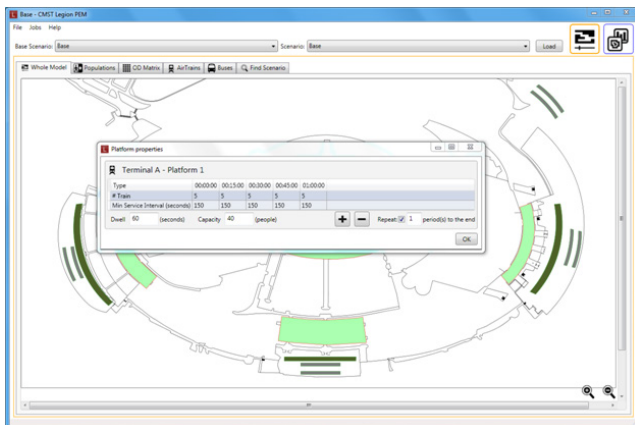
The bottom half of the input window is where the user can set up and run up to four simultaneous simulations. Here the user specifies the range of response actions that are to be simulated. These conditions can be different for each simulation, and are summarized below:

- *Simulation Name.* This is a free-form text field to be used by the user to name each simulation.
- *Traffic Diversions.* Here the user can define any traffic control measures (e.g., lane closures, road closures, etc.) they would like to enforce during the response.
- *PNEMT Operations Actions:* Through this selection the user can alter the outgoing distribution of traffic, the number of lanes open, the processing time per truck, and the number of trucks pulling trailers that will be permitted to leave each PNEMT terminal, and whether contraflow measures will be used.
- *EWR Operations Actions:* The user can alter the outgoing distribution of traffic and set values for the minimum number of occupants in each automobile leaving the airport.

Once the parameters have been set, the user simply clicks the “Start Simulation(s)” button to trigger the execution of the simulation(s). The user can then track the progress of simulations (which usually take less than 1 minute to run) and view results.

Pedestrian simulations are defined and run through a remote desktop connection because the tool used for pedestrian simulation is not available in an on-line (browser-accessible) format. However, the data entry and simulation control mechanisms are equally user-friendly. The screen capture in Figure VI offers a brief look at the user interface for the pedestrian simulation tool.

Figure VI. CMST PEDESTRIAN SIMULATION INTERFACE



As with the web interface used for the management of the overall tool, this interface utilizes an easy-to-use series of drop down menus and data entry fields that allow the user to enter pedestrian information, including the following:

- *Number of Evacuees.* The user can input the total number of evacuees in each of the three EWR terminals. The tool defaults to an average value provided by EWR staff.
- *Evacuee Destination.* Evacuees can be assigned to originate from each terminal and proceed by foot to either curbside or remote pickup by bus, to autos in any of the EWR parking facilities, or to the AirTrain, in any proportion desired by the user.
- *Evacuation Modes.* The user can determine the number, capacity and arrival rate of all evacuation assets.

Once the user has defined the input parameters, they can execute and store the results of each simulation with a variety of naming and keyword identifier options. They can also view the results of pedestrian evacuations to vehicles directly in the pedestrian model interface in order to examine the data at a more detailed level.

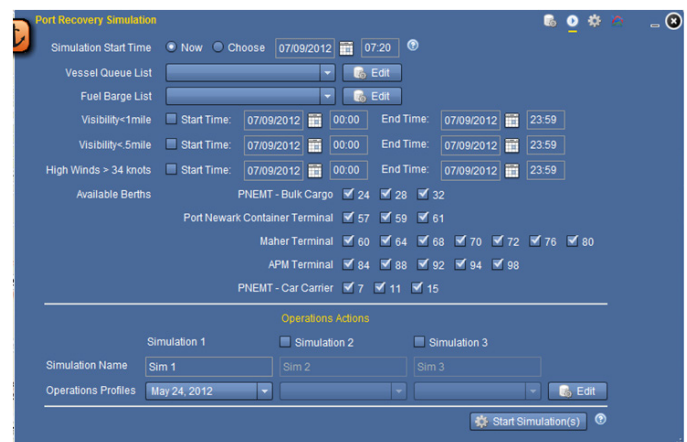
### C. Recovery Simulations

Recovery simulations are configured and triggered in the same manner—and using the same interface—as the vehicular evacuation scenarios. However, the port recovery simulation has two distinct parts.

The first part deals with the simulation of the movement of vessels from anchorage—which is where they would be if the port facilities were closed because of an event—to assigned berths within PNEMT or to other locations within NY Harbor. The second part deals with the landside movement of trucks into and out of the terminals, and to and from the regional roadway network.

Figure VII shows the port recovery simulation user interface main screen used for the configuration and execution of the waterside operations simulation.

Figure VII. CMST PORT RECOVERY SIMULATION INTERFACE



Users can specify the port recovery context in the top half of the screen and the response plans, or “Operations Actions,” in the bottom half. Context inputs include the following:

- *Simulation Start Time.* The user can set the event start for the present time or for some date and time in the future.
- *Vessel Queue List.* From here, the user can select from a list of pre-entered lists of vessels in the model, or select “Edit” to create or modify a list. Within the edit function, the user is able to download a list of vessels currently in the harbor from the US Coast Guard’s Automatic Identification System. The user can then specify a series of characteristics for each vessel, including size, number of containers to be loaded and offloaded, and vessel destination.
- *Fuel Barge List.* The user can select from a list of pre-entered lists of fuel barges in the model, or select “Edit” to create or modify a list.
- *Environmental Conditions.* Through the interface the user can enter information regarding three Vessel Traffic Service (VTS) measures: Visibility < 1 mile, Visibility < 0.5 mile, and High Winds > 34 knots. Additionally, the user can specify when these conditions are expected to begin and end.
- *Available Berths.* Here the user can specify which berths at PNEMT are open or closed during the simulation period.

The bottom half of the input window is where the user can set up and run up to three simultaneous simulations. Here the user specifies the range of response actions that are to be simulated. These conditions can be different for each simulation, and are summarized below:

- *Simulation Name.* This is a free-form text field to be used by the user to name each simulation.
- *Operations Profiles.* Here the user can set values for landside and waterside asset utilization, including the number of entrance and exit lanes available at the three main container terminals within PNEMT, as well as the percent of freight to be moved by rail. The user can also specify the number of tugs and docking pilots available during the recovery simulation, the duration of the harbor shutdown, and whether meeting and overtaking zones will be permitted.

Once the parameters have been set, the user simply clicks the “Start Simulation(s)” button to trigger the execution of the simulation(s). The user can then track the progress of simulations (which usually take less than 1 minute to run) and view results.

Figure VIII shows the port recovery simulation user interface main screen used for the configuration and execution of the waterside operations simulation. By selecting the PNEMT Recovery radial button, the user is presented with the input requirements for the landside recovery traffic impact simulation.

**Figure VIII.** CMST PNEMT RECOVERY TRAFFIC SIMULATION INPUT SCREEN



As with evacuation simulations, users can specify the recovery context in the top half of the screen. Context inputs include the following:

- *Evacuation Scope.* The user is presented with this screen when PNEMT Recovery is selected.
- *Traffic Events.* The user can either manually input information regarding traffic events such as accidents, road and lane closures, and congestion, or they can import information from TRANSCOM, the traffic management and information provider for the region. Because events there are frequent, users can also indicate if an event is taking place at the Meadowlands sport complex during the evacuation. Each of these inputs alters the background traffic used in the model.
- *Traffic Modifier Profile.* The tool was primarily intended to support analysis only of a local evacuation of the PANYNJ facilities. However, the user can modify the background traffic to reflect changes in traffic volumes that might result from a wider evacuation. Changes made here are applied to the historical volume and speed data that the model uses for base analysis.
- *Recovery Profile.* This is where the user selects which output set from the Port Recovery simulation will be used for the landside recovery traffic simulation. The user can also select the Port Simulation button, which takes them to the screen to create new recovery profile.

Once the parameters have been set, the user simply clicks the “Start Simulation(s)” button to trigger the execution of the simulation(s). The user can then track the progress of simulations (which usually take less than 1 minute to run) and view results.

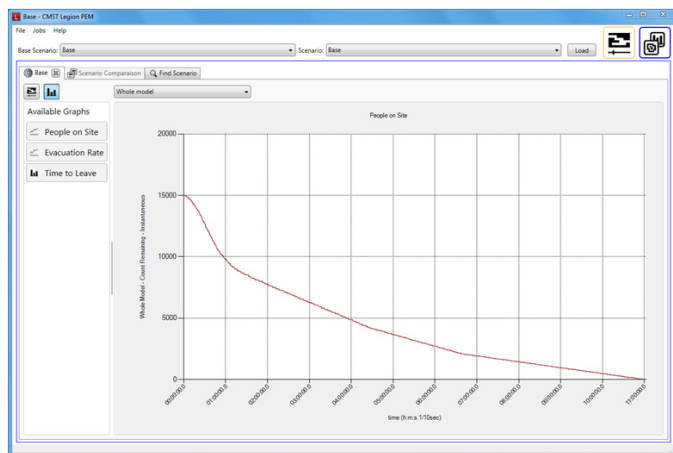
#### D. Presentation of Results

CMST provides several options regarding the presentation of results. All include a combination of graphic depictions of simulation output and access to data files that allow the user to perform secondary analysis.

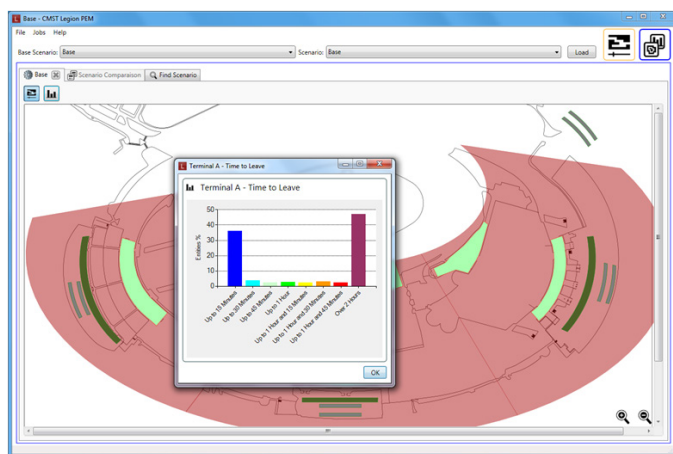


Results from the pedestrian model are viewed through the pedestrian simulation interface. The results can be viewed graphically in different formats, as shown in Figure IX and Figure X below.

**Figure IX. CMST PEDESTRIAN SAMPLE SIMULATION RESULTS**



**Figure X. CMST PEDESTRIAN SAMPLE SIMULATION RESULTS**



The real power of this form of depiction is that it allows for clear, concise presentation to users and decision makers. It permits the user to overlay results from multiple simulations on the same graph so those in need of the information can see not only the total evacuation time, but how the evacuation progresses with time.

The results from the traffic evacuation, traffic recovery, and port recovery simulations are also presented graphically, as depicted in the examples in Figures XI, XII and XIII, respectively.

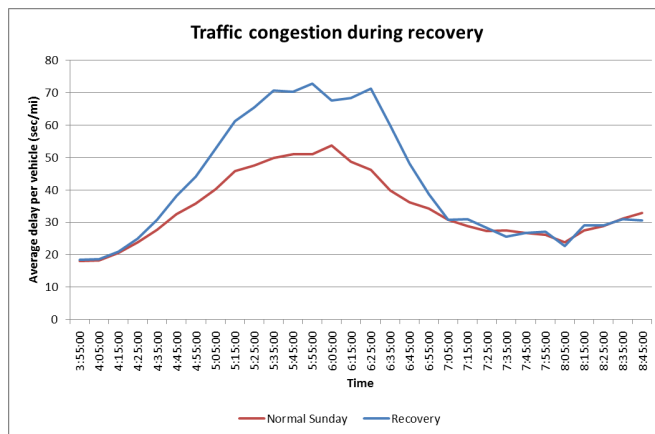
In the output sample in Figure XI, the user is provided curves that represent the number of evacuees remaining on site at EWR and PNEMT throughout the evacuation, and the total time to evacuate each facility. Additionally, the user can place the cursor on either curve to see the number of evacuees remaining at that particular point in time. This allows the user to examine how the evacuation would progress from its starting point.

**Figure XI. CMST EVACUATION TRAFFIC SAMPLE SIMULATION RESULTS**



In the output sample in Figure XII, the user is provided curves that provide a comparison between typical roadway congestion and the congestion that would result from a PNEMT facility recovery operation. In the example, the difference is clearly illustrated by the separation between the two curves—one which shows average delay per vehicle on a normal Sunday and the average delay under the conditions input by the user for the recovery simulation.

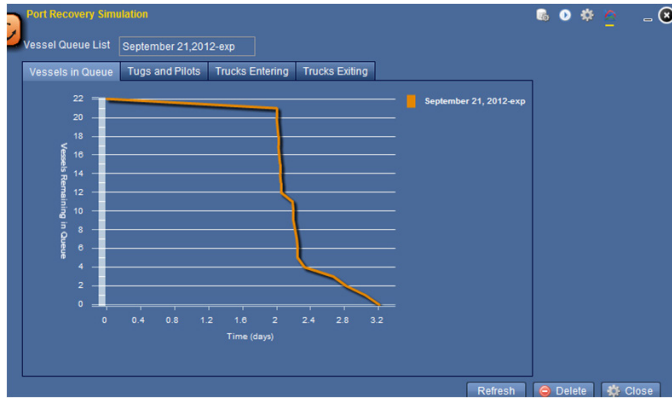
**Figure XII. CMST RECOVERY TRAFFIC SAMPLE SIMULATION RESULTS**



The output sample in Figure XIII shows one dimension of the port recovery simulation output. The “Vessels in Queue” tab offers a view of the profile of the time required to process the vessels in queue and put them in motion towards a specific berth. Additional tabs provide the user with graphical representations of tug and docking pilot use, trucks entering terminal gates, and trucks exiting terminal gates.

As with the evacuation simulation results, the user can place the cursor on either curve to see data for data associated with that particular point in time. This allows the user to examine how the recovery would progress from its starting point.

**Figure XIII. CMST PORT RECOVERY SAMPLE SIMULATION RESULTS**



#### IV. FUTURE APPLICATIONS OF CMST

Owing to its modular design and use of integrated functionality, CMST has the potential to be expanded to encompass additional facilities and a larger geographic area. It can also be adapted to any other location, provided data is available to characterize the traffic on the roadway network,

and local stakeholders are willing to commit to provide the operational information required to define scenarios and execute simulations.

#### ACKNOWLEDGMENTS

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