*FINAL*

# EVACUATION MANAGEMENT OPERATIONS (EMO) MODELING ASSESSMENT:

# TRANSPORTATION MODELING INVENTORY

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## ABSTRACT

This report documents more than thirty surface transportation modeling tools that have been applied or could be applied to evacuation modeling. Each tool represents a tradeoff between desired scope and analytical complexity, ranging from state-to-state coordination tools such as the Evacuation Traveler Information System (ETIS) to detailed traffic micro-simulation models such as the TSIS/CORSIM traffic simulation model. Based upon a comprehensive literature review, the report first provides a summary of evacuation event types and then a description of the three general classes of modeling approaches (macro, meso, micro) currently used to model evacuation events. The modeling inventory includes a description of each modeling tool and cites case studies (if any) where the tool has been used in modeling evacuation events. Some tools have been developed to model specific types of evacuations, others have more general applications. The modeling inventory concludes with an analysis of the tools as they relate to a modeling spectrum according to scope and analytical complexity, including a discussion of how the decisions supported by analysis drive tradeoffs in terms of scale and computational speed.

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# 1.0 INTRODUCTION

Jurisdictions and public agencies across the nation increasingly are engaged in evacuation planning to safeguard their populations from incidents that would require the movement of limited to large groups to ensure their safety. At the same time a variety of commercial, academic and governmental sources offer an expanding range of tools to support efficient evacuation planning. The availability of tools and the advent of (relatively) low-cost, high-performance computing platforms encourage public agencies to consider analytical methods to improve their evacuation planning or operational practices. However, agencies considering the use of analytical tools may have limited experience in modeling and little understanding about how well a particular tool may address the goals of a planned analytical effort or fit within resource constraints such as staff expertise, data requirements, or computational speed.

The U.S. DOT Research and Innovative Technology Administration, Intelligent Transportation Systems-Joint Program Office (ITS-JPO) and the Federal Highway Administration (FHWA) Office of Operations, seek to assist decision-makers in public agencies across the nation with a series of documents designed to provide a broad overview of analytical approaches for evacuation planning. This report, an inventory of tools, is the first of a series documents focused on evacuation modeling. Future deliverables will include a detailed assessment of selected tools and a guidance document for selecting the most appropriate tool for your jurisdiction's use.

This document provides an inventory and categorization of current evacuation modeling tools, surveying a wide variety of methodological approaches. The categorization includes the consideration of tools along a continuum of geographic scale as well as computational complexity. In addition, the categorization considers the capability of the various tools to facilitate decision-making ranging from real-time to planning exercises. The follow-on assessment document will consider the availability and quality of data likely to be used as inputs to specific models, and the potential for model validation against available historical data archives. The inventory and assessment provides the end user (including state and local DOTs and emergency management agencies) with a detailed understanding of the current strengths and weaknesses of modeling tools, both those currently available or in various stages of development.

This report represents the transportation modeling inventory component of the U.S. DOT Evacuation Management Operations modeling assessment project. It documents surface transportation modeling tools that have been applied or could be applied to evacuation modeling.

These tools range in geographic scope and analytical complexity from state-to-state coordination tools such as the Evacuation Traveler Information System (ETIS) to detailed traffic micro-simulation models such the TSIS/CORSIM traffic simulation model. The modeling inventory includes a summary of more than 30 transportation modeling tools that have been used, or can be used, for evacuation modeling. The report includes summary examples of evacuation case studies for each model to enhance reader understanding.

This document is composed of five sections that provide a context for the inventory examining the types of evacuation-related decisions supported by models. First, a discussion of the various types of evacuation events is presented and how each event type drives different analytical requirements in terms of scope, detail and computational speed. The second section provides a summary of the decision-making timeframe and the role of transportation models based upon the amount of time available to implement an evacuation. Third, the three major categories of transportation models are discussed in the context of evacuation events. Fourth, a detailed inventory of identified transportation models is provided. The inventory comprises all models potentially deployed for evacuation decision support and planning. Models currently in development and not widely available for application are not included in the inventory. Legacy tools considered obsolete relative to newer tools are included to provide a historical context. For tools with published evacuation-related studies, a more detailed discussion is provided. Fifth, an analysis of the available models is provided within the context of an overall modeling spectrum, model specialization and scale/speed continuum. Finally, a summary is provided regarding general considerations in the application of transportation modeling tools for evacuation planning and operations.

## 2.0 EVACUATION EVENTS

Evacuations can be associated with a broad range of man-made and natural events. The basic nature of these events, their predictability, frequency, geographic scope, intensity, and other factors define the decisions that must be made by public agencies both in pre-event planning and operational response. Modeling analyses in support of these decisions are also clearly influenced by the nature of the evacuation events themselves. In this section, we utilize a simple taxonomy of evacuation events (man-made and natural) to illustrate the similarities and differences across a range of event types, particularly with respect to geographic impact and the amount of time available to prepare once a specific event is imminent.

Historically, analytical tool development for evacuation planning has targeted specific events rather than general-purpose evacuation modeling. Often, the need for a specific tool to model the impact of an evacuation event is a reaction to an accident that already occurred. (*1*) The Three Mile Island nuclear power plant accident demonstrated the need for local leaders to better plan and prepare for a possible evacuation event; in response, the tool DYNEV was created. (*2*) The development of the HURREVAC tool was a reaction to the presence of hurricanes along the eastern seaboard and the need for government officials to better manage the evacuation of residents. (*3*) As a result of the September 11, 2001, (or 9/11) terrorist attacks and the recent catastrophic hurricanes in the Gulf Region, officials recognize that much of the transportation infrastructure can be considered critical in nature and may already be utilized in the course of normal operations at or near capacity. As a result, Federal, State and local officials place a new emphasis on being proactive in both the planning for, and execution of, evacuation operations for a broader range of evacuation events than historically considered. (*4*), (*5*)

Wolshon's 2005 (*6*) review of evacuation planning, preparedness and response divides evacuation events into two categories: Man-Made Events and Natural Events. According to a Nuclear Regulatory Commission study, man-made events represent approximately 43 percent of evacuation events with natural events representing 57 percent. (*7*) Recently, special emphasis is being placed on man-made events, such as special events, hazardous materials releases, large-scale power outages, and terrorist threats. Counter to the historical trend of developing a specific tool for a particular evacuation type, frequently existing general-purpose transportation models are being adapted to model a range of event scenarios with similar characteristics. We utilize Wolshon's man-made/natural taxonomy in the next two subsections to illustrate similarities and differences in specific attributes of evacuation events.

## 2.1 MAN-MADE

Man-made evacuation events deal with six broad classes: Special Event, Technological, Hazardous Material, Nuclear Power Plant, Terrorist Attack and Dam Break[1]. Wildfires are often the result of human action, but are classified in this document as natural (see Section 2.2). The Special Events class are a special case within the classes of man-made evacuation events, representing repeatable events (e.g., sporting events) that have attributes analogous to some evacuation events. For modeling, these special events are especially important to consider, because they can be used for model calibration and validation.

- **Technological—**An event where there is a breakdown in the technological infrastructure such as a power grid failure. The New York power outage during the Summer of 2003 is an example of this type of event. Small-scale technological events may include rail-based transit systems requiring emergency evacuation due to a communication or power failure.
- **Hazardous Material—**An event where there is a hazardous material involved and is impacting an area where people are present. This could include an accident on a highway involving a tanker-truck or a derailed train car leaking noxious gas.
- **Nuclear Power Plant—**An event taking place at a nuclear power plant requiring evacuation of the surrounding community.
- **Terrorist Attack—**An unknown event involving the potential harm of people and destruction of property caused by a single individual or coordinated attack by a group of individuals. This may involve a hazardous material (nuclear, biological or chemical) or coincide with a technological event.
- **Dam Break—**An event near or next to a dam (or levy) where the potential for quick and serve flooding of a nearby area is possible.
- **Special Event—**An event such as sporting games, festivals and fairs. Generally these events occur either on a regular basis or there is a fair amount of time in order to plan for such an event.

Two key attributes of the classes of man-made evacuation events are illustrated in Figure 1. The figure represents the amount of time generally available to prepare for an event (X axis, *Time to Prepare*) and the relative geographic impact of the event (Y axis, *Scope*). The amount of time to prepare ranges from minutes to days and the scope ranges from a single highway interchange to an entire metropolitan region. Generally, events that are further to the right on the X axis and closer to the bottom on the Y axis are easier to prepare for. For example, special events typically

[1] These classes were adapted from Wolshon, B., et al., *Review of Policies and Practices for Hurricane Evacuation.* Natural Hazards Review, 2005.

allow for multiple days, weeks or months of planning and only impact a small geographic area (a single interchange or a larger freeway segment). Rarely do these events affect an entire metropolitan region. On the other hand, a terrorist event can happen with little or no warning and impact an entire metropolitan region. Therefore, there is little, if any, time to prepare for a terrorist event except for pre-event planning and scenario building.

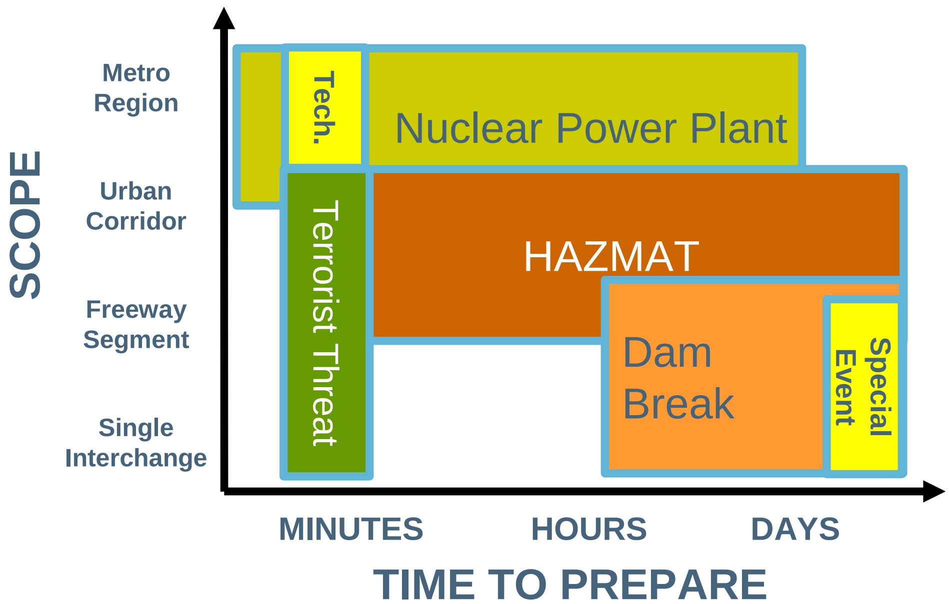


**Figure 1 Man-Made Event Situations**

Transportation modeling associated with man-made events has focused historically on nuclear power plants and special event classes, with the most extensive analytical history relating to the Nuclear Power Plant class of events. In this area, regulations require each nuclear power plant to have an evacuation plan in place that has gone through some modeling process. (*8*) Typically, these models are at the regional level. For special events, local transportation agencies typically conduct an assessment as to the impact of a special event on surrounding transportation facilities. These agencies may use in-house models and spreadsheets to look at generalized impacts on system capacity (for a sporting event) or use detailed microscopic simulation models if the impacts are far more complicated (such as the closing of an interchange for construction). In response to the events of 9/11, more transportation agencies, as well as regional planning bodies, have begun to generate event scenarios for hazardous material and terrorist events. This has generally occurred at the regional level where transportation infrastructure is modeled and then various critical links and nodes are removed to see the impact on traffic.

## 2.2 NATURAL

Natural evacuation events deal with seven broad classes: Earthquake, Volcano, Tornado, Tsunami, Wildfire, Flood and Hurricane[2]. (*9*) These seven classes can occur at any given time or location and may trigger evacuation operations. However, historical data provides good information as to community risk and the likelihood of where these events will occur.

The seven natural evacuation events are documented in Figure 2 below. According to the nuclear Regulatory Commission, wildfires are the largest cause of evacuation events (23 percent) followed by flooding at 20 percent and hurricanes at 10 percent. (*7*) Volcano and tsunami events can impact geographic regions as diverse as the Pacific Northwest, Hawaii, Alaska, and the Pacific U.S. territories. The figure represents the amount of time generally available to prepare for the event (X axis, *Time to Prepare*) and the relative geographic impact of event (Y axis, *Scope*). Hurricanes and tropical storms may be fickle in their course but because the are frequent (one or more every season) and to some degree predictable (in terms of general timing and broad geographic threat) generally lend themselves to lengthy preparations and plan execution. The amount of time available for operational planning with respect to a specific hurricane threat is often days. However, hurricanes or tropical storms may impact multiple jurisdictions and regions. As a result, the relative impact of a hurricane or tropical storm may be quite large and may impact several U.S. states or territories. General flooding from sustained heavy rains and wildfires have a larger range of time to prepare for because they are more predictable based upon current weather conditions and historical data. Conversely, although a flood or wildfire warning may be issued to an entire region, the exact location of this event within the region is unpredictable. Flash flooding is nearly impossible to predict except for issuing broad region-wide warnings. Earthquakes and tornados give the least time to prepare for evacuation operations and safety considerations must be factored into any decisions to effect and evacuation. Earthquakes and the resultant aftershocks are difficult to predict and affect entire metropolitan regions whereas tornados can be broadly predicted as part of an ongoing storm system but difficult to pinpoint the small geographic area directly impacted. Also, tornado events most frequently call for taking shelter in a safe location rather than evacuation.

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[2] These classes were adapted from Wolshon, B., et al., *Review of Policies and Practices for Hurricane Evacuation.* Natural Hazards Review, 2005.

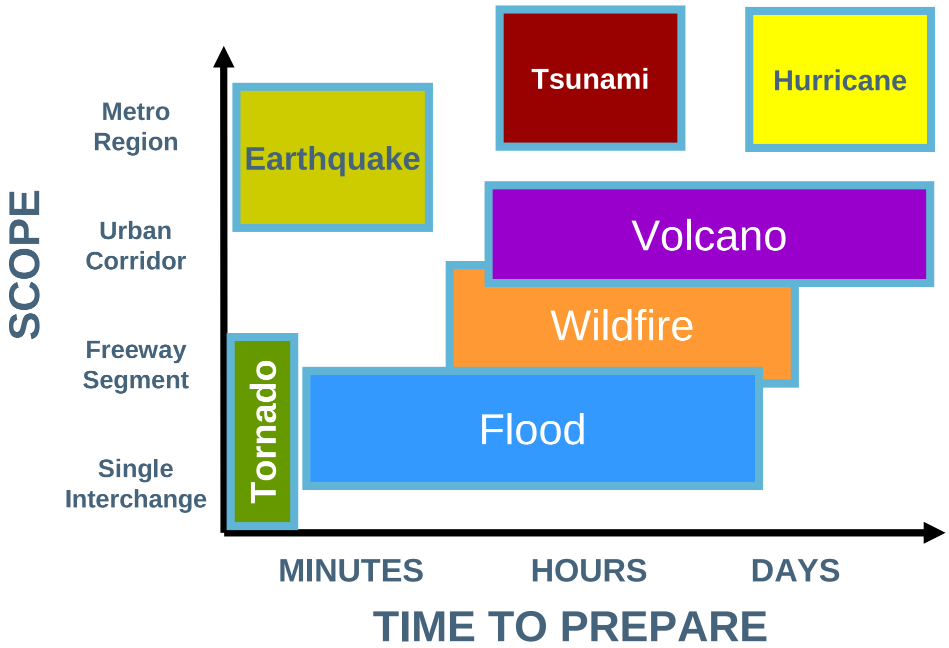


**Figure 2  Natural Event Situations**

The role of transportation modeling with respect to natural events has been historically focused overwhelmingly in the area of hurricane preparation. A number of specialized transportation planning models (ETIS, HEADSUP, HURREVAC) have been developed that were specifically designed for hurricane evacuation events. In wildfire-prone areas, some officials express interest in modeling evacuation routes to ensure all residents can safely evacuate an area if a wildfire threatens population centers. For earthquake and tornado events, only some limited modeling of earthquake scenarios were identified in our literature review. However, no analytical studies of evacuations on transportation networks in response to tornado events were identified. The use of computer modeling tools for these types of event appears to be useful for developing a collection of event planning scenarios with respect to the *ex post* impacts. This would include conducting table-top exercises analyzing critical infrastructure components and what happens if one of these components was destroyed.

## 3.0 DECISION MAKING TIMEFRAME

An important aspect in using a transportation model for evacuation management and operations is the ability for decision makers to collect, analyze and make a range of related decisions with regard an evacuation event. The purpose of this section is to provide a framework with which to consider the context for transportation modeling: a) far in advance of a specific threat (planning); b) in response to a specific imminent threat (operational planning); and c) adapting an operational plan during the course of an evacuation (real-time operations). The breakdown of specific decisions within the event type helps to understand the chain of related decisions and their timing, which is critical for understanding where models and data can be deployed to support these decisions in an effective and timely way.

The type of evacuation events mentioned Section 2.0 lie on a continuum between a *planned event* and a *no-notice event* and is shown is Figure 3 below with six of the events labeled. On the left side are planned events where there is ample advanced notice available to make a decision on evacuating a geographic area. On the right side are no-notice events that occur without warning, are generally unpredictable and provide little time to make a decision about evacuating a geographic region. Generally speaking, it is easier to make fully-informed decisions about evacuations for planned events compared to no-notice events since there is a longer lead time to better understand the impact of the event (long-term planning), select an appropriate response (operational planning), and then implement the evacuation plan (real-time operations).

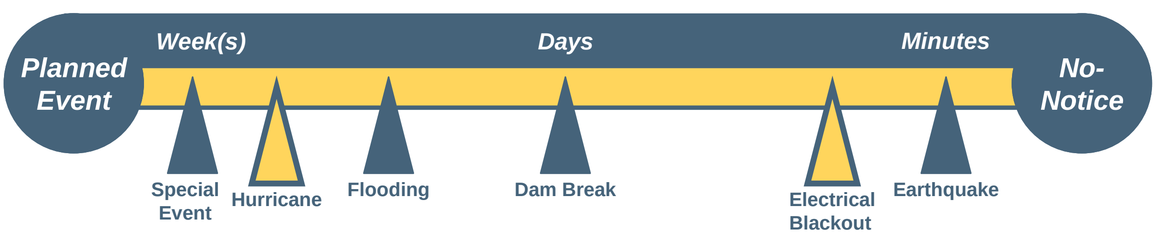


**Figure 3 Event Notification Continuum**

To better understand how these three categories fit into the overall evacuation decision structure, a Decision Making Timeframe Framework was developed the shows the scale and timing of evacuation events as they relate to amount of notification available. This framework is presented in Figure 4 below. This framework segregates the various aspects of evacuation decisions into three key categories: long-term planning, operational planning and real-time operations. These categories are placed on the horizontal axis with a time scale between years (long-term planning) to seconds (real-time operations) and are also represented by the blue, grey and yellow boxes respectively. The width of these boxes roughly indicates which decisions need to be made for each category. For example, long-term planning generally includes regional studies and, time permitting, some aspect of the impact of the possible evacuation events (hurricanes, flooding, earthquakes, etc.). Operational planning includes event impact assessment as well as the decision to implement an evacuation, implement the evacuation plan and some aspect of system monitoring. Real-time operations include system monitoring and system modification. Clearly, there is no distinct point at which long-term planning ends and operational planning begins nor when operational planning ends and real-time operations begin. The height of the boxes indicates at what scale the evacuation decision categories operate and range between a single intersection to a geographical region.

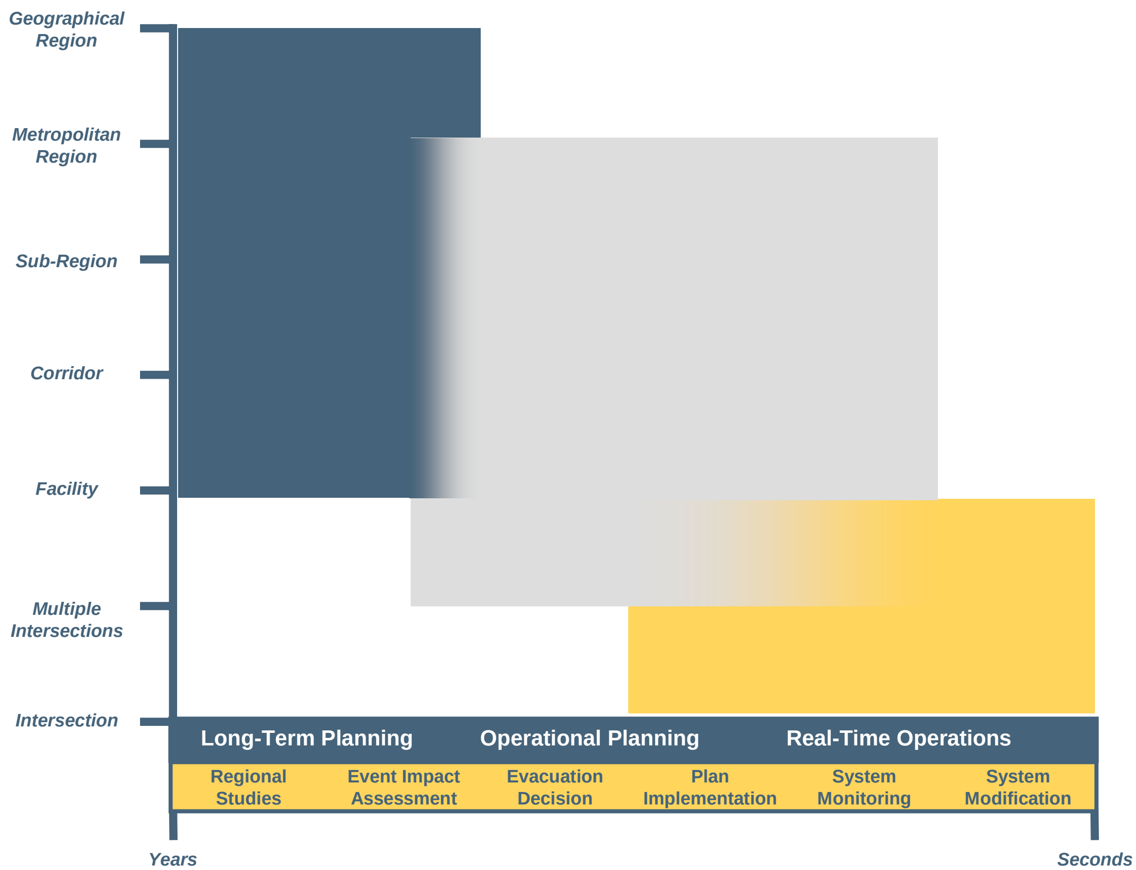


**Figure 4  Decision Making Timeframe Framework**

This framework is useful to better understand the role of transportation modeling with respect to the evacuation event notification time. All events requiring evacuation will include the same categories (long-term planning, operational planning and real-time operations) as well as the decisions that need to be made (regional studies, event impact assessment, evacuation decision, plan implementation, system monitoring and system modification). Also, all evacuation events have years available to conduct regional studies to plan for a possible evacuation event (this is referred to as scenario building) and seconds to monitor system operations (such as traffic signal timing, real-time traffic information, etc.). What will vary for each event will be the available time to make the evacuation decision and the geographic scale at which the decision has to be made.

Two examples of using this framework are provided next and indicated by the larger golden triangles in Figure 3 above. The first is for implementing contra-flow lanes as a result of an impending hurricane evacuation (planned event) and an electrical black out similar to the Northeast blackout that occurred in 2003 (no-notice event). Each discussion includes the types of decisions to be made along with the required information and where transportation modeling tools could be used to help in the decision making process.

## 3.1 CONTRA-FLOW LANE OPERATIONS FOR HURRICANE EVACUATION

The first example of using the Decision Making Timeframe Framework is for the implementation of contra-flow lanes as part of a larger hurricane evacuation event. The process is shown in Figure 5 below. Due to the nature of the hurricane evacuation event, the amount of time available for the operational planning and real-time operations varies between weeks and days (to make a decision to evacuate with a specific contra-flow plan) and hours and seconds (to monitor and modify the system).

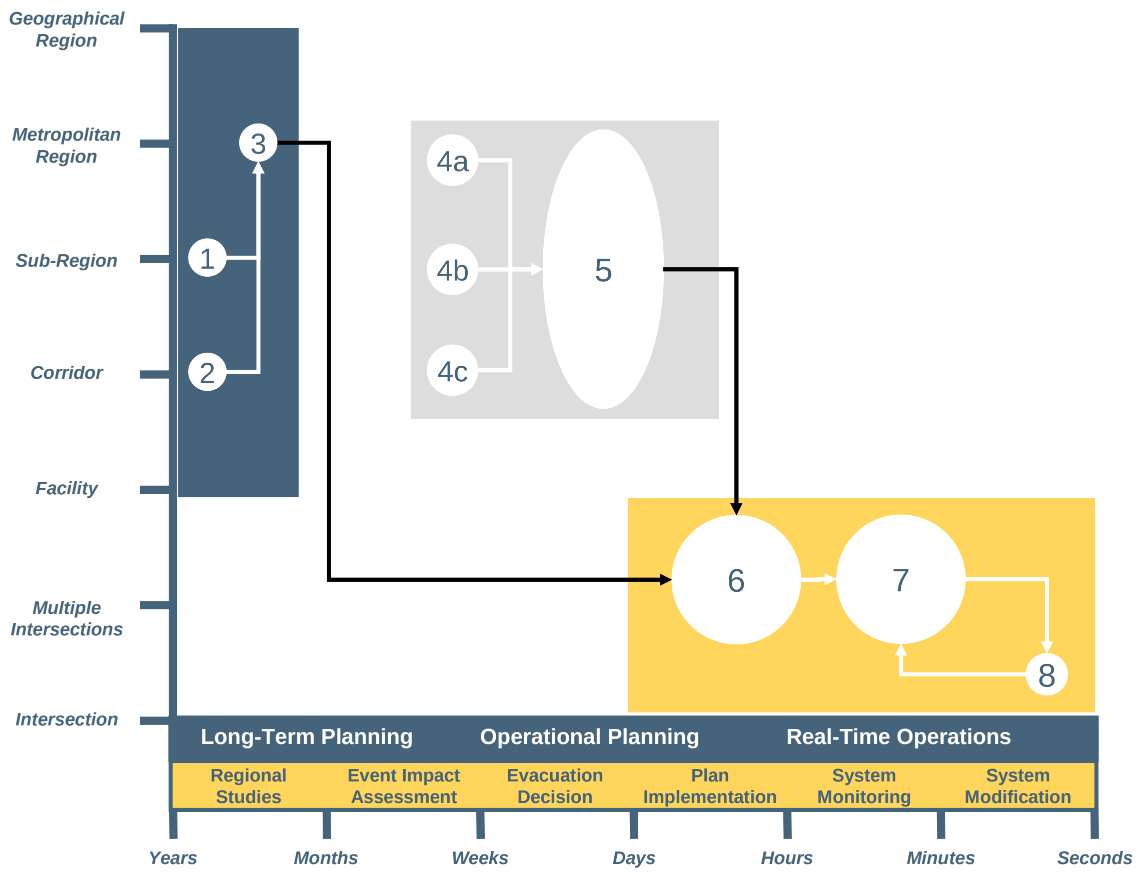


**Figure 5 Contra-Flow Implementation Framework Example**

Long-term planning for the implementation of contra-flow lanes as a result of a hurricane evacuation can begin years in advance at the sub-region and corridor level as various transportation models are used to determine the overall impact of implementing contra-flow lanes at the corridor level (circle 1) as well as conducting sub-regional analysis of evacuation times (circle 2). These types of analyses are fed into a larger metropolitan regional evacuation plan (circle 3) that can be updated on a regular basis with additional data as more evacuation scenarios are analyzed.

Often, this evacuation plan may not be used for a number of years until an evacuation event is potentially imminent based on a specific storm forecast at which time decision makers must focus on operational planning aspects. At this point (grey box in Figure 5), decision makers must rely on the potential impact of an approaching hurricane on the metropolitan region focusing on specific sub-regions that may be more prone to being affected by the hurricane and conditions at the corridor level where the contra-flow lanes will be implemented (circles 4a, 4b, and 4c). This information is collected, analyzed and presented to decision makers who must make the ultimate call as to whether to implement the contra-flow lanes for evacuation (circle 5). At this point, transportation models could be used to better inform decision makers as to the impact of their decisions. For the hurricane evacuation scenario, the time available to collect and analyze the information varies between roughly ten days when the hurricane is first identified to two or three days notice of certain regions being required to evacuate and the decision is made to implement the contra-flow lanes.

Once the decision is made to implement the contra-flow lanes local personnel (e.g., police agencies and department of transportation employees) must be mobilized to implement the plan authorized by the decision-makers (circle 5) and developed as part of the long-term planning activity (circle 3). Individual people will be required to control and operate certain intersections to enable the contra-flow operations (circle 6) as well as monitor the situation (circle 7). Finally, for some key intersections and locations, second-by-second data on current operations (specifically traffic signals) will need to be monitored and modified to insure efficient operations (circle 8). Also, timely information will need to be disseminated to the public regarding traffic conditions and evacuation routes.

## 3.2 Regional Electrical Blackout

The second example of using the Decision Making Timeframe Framework is for the evacuation of a region due to an electrical blackout as occurred in northeast United States in August 2003. The use of the framework for this scenario is shown in Figure 6 below. Due to the nature of an electrical blackout, the amount of time available for the operational planning and real-time operations is drastically smaller than for the hurricane evacuation scenario. In the case of New York City, the electrical blackout began at 4:10pm shutting power to the entire city including all rail-based public transportation systems and traffic signals at the height of rush hour. More than 21 million people were affected. In this situation, the amount of time available to make a decision to evacuate varies between one day to one hour with only hours or minutes to implement a plan. Thus, the primary difference between the two examples provided in this section (and all evacuation events) is the amount of time available for operational planning and real-time operations.

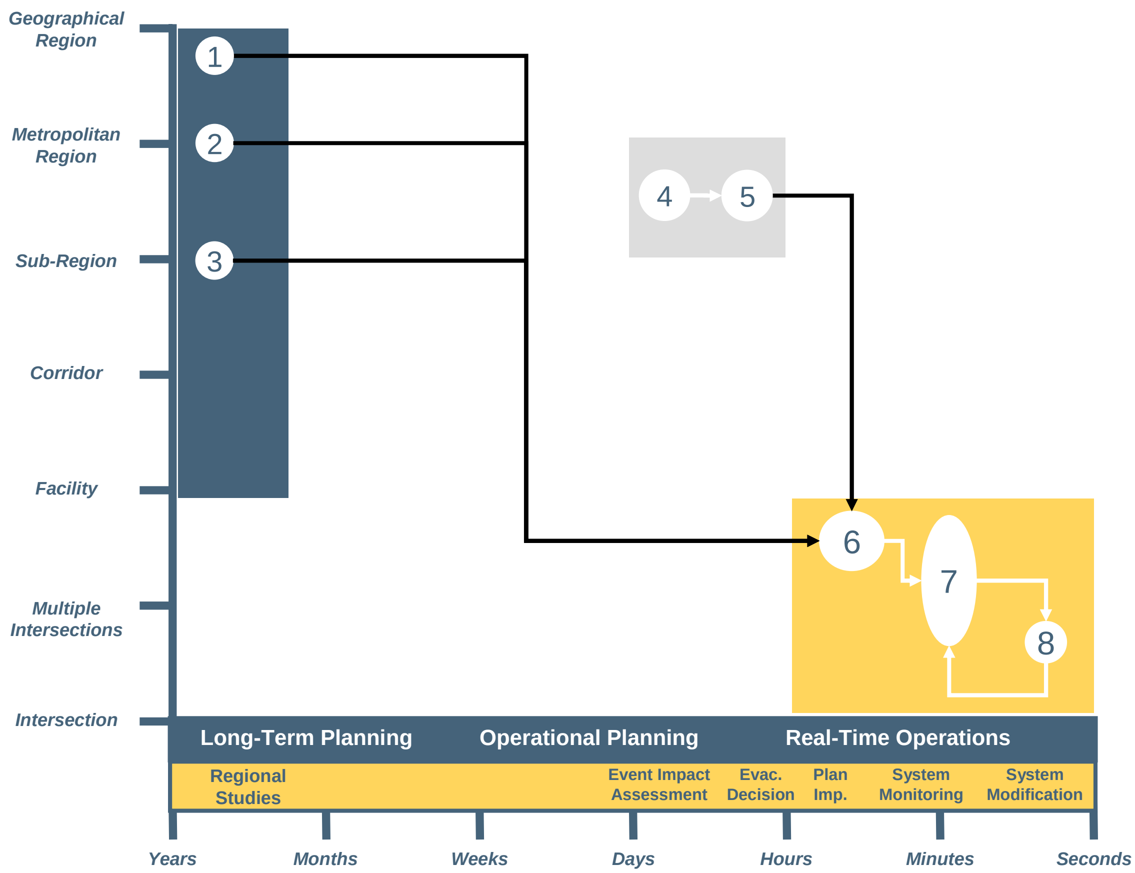


**Figure 6 Regional Electrical Blackout Framework Example**

As with the hurricane evacuation detailed above, the amount of time available for long-term planning can be quite long, up to a number of years. During this time, state and local governments along with regional governing bodies may conduct various scenario building exercises (circles 1 through 3) to better understand the impact of evacuation events culminating with a toolbox of evacuation plans to be used in the future if the need arises. During this stage of long-term planning many types of transportation models could be used to conduct "what if" scenarios of transportation impacts.

When the need does arrive to implement a regional evacuation for a little to no-notice evacuation event, there will be very little, if any, time to consult a transportation model to help make a decision as to the type of evacuation to implement. In this case, leaders will have to rely upon past examples and scenarios evaluated in their toolbox as part of the long-term planning (Circle 4). For New York City, issuing a vehicle-based evacuation order (including cars, buses and trains) was at best impractical since electricity was not available to power the subway, traffic signals or toll facilities. In this situation, a shelter-in-place or pedestrian-based evacuation may be the most reasonable. Regardless, leaders have at best only a few hours to make a decision and disseminate that information (circle 5).

Once the decision is made to implement an evacuation, local personnel (e.g., police agencies and department of transportation employees) must be quickly mobilized to implement the plan authorized by the decision makers (circle 5). Depending upon the evacuation type (vehicle-based, pedestrian or shelter-in-place) individual people will be required to disseminate evacuation information (circle 6) via a number of sources (radio advisories, VMS, loudspeakers, etc), monitor the system to insure safe and efficient operations (circle 7) and finally modify the plan as needed (circle 8).

## 4.0 MODELING APPROACHES

In the two preceding sections, we have concentrated our attention on attributes of the evacuation events themselves and the related chain of decisions that must be made in long-term planning, operational planning, and real-time operations. In this section, we present the attributes of classes of models and their typical applications in terms of geographic scope, data requirements, and computational speed. Understanding the potential of transportation modeling to support decision-making for evacuations hinges on identifying those decisions in the process that best lend themselves to the strengths of a particular modeling approach.

There are three basic approaches to modeling a traffic network: macro, meso and micro. These three approaches are distinguished primarily by their ability to model a geographic area (scale) and the precision of analysis (detail level). Choosing a certain approach is a tradeoff between these two criteria. Figure 7 below shows the different scales at which the three modeling approaches operate.

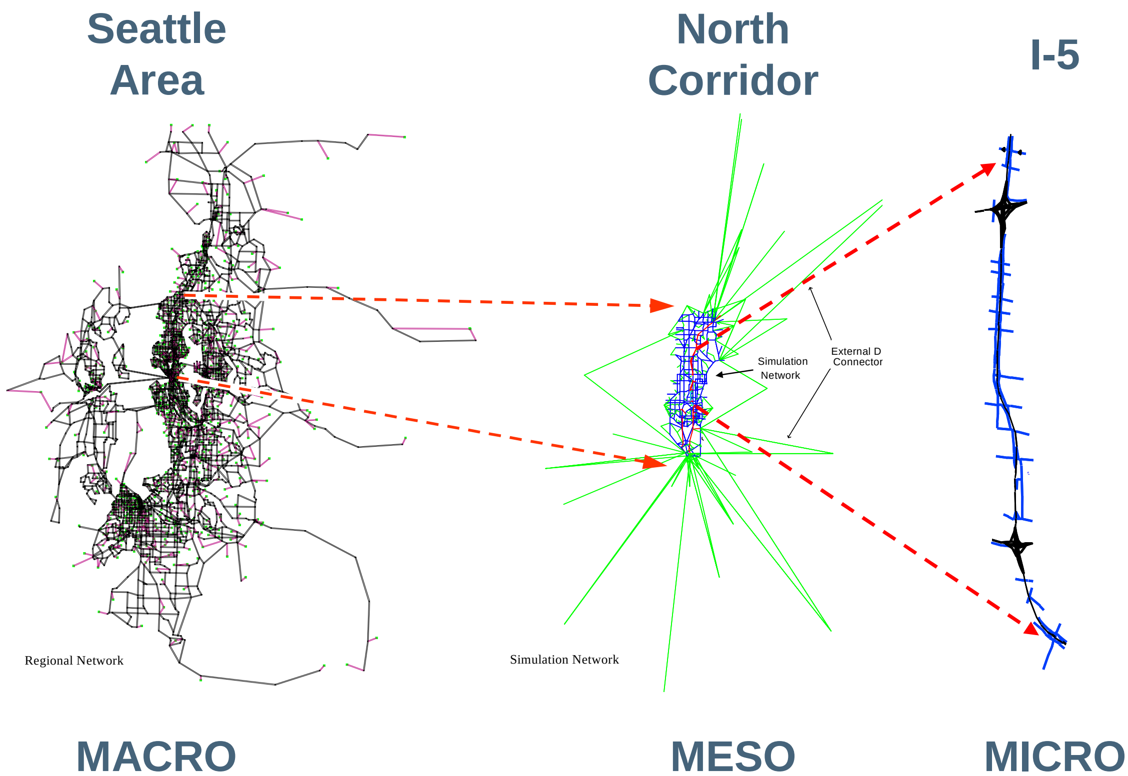


**Figure 7 Modeling Approaches**

On one end of the spectrum are *macro* models which can represent a large geographic area, such as the Seattle metropolitan region. Macro models are able to represent an entire metropolitan region, but cannot represent individual vehicles or people on the network. Also, macro models lack time sensitivity. A sub-category of macro models that is becoming more prevalent are real-time decision support tools. These tools normally provide decision-makers with information about the impact a certain decision may have on the region or locality. Some decision support tools now being developed are stand-alone tools such as ETIS while others incorporate existing modeling tools into a larger decision support tool. Decision support tools are unique in that they are capable of providing information real-time. However, many of the modeling approaches (and tools discussed in this inventory) are not currently designed for real-time application. Thus, many software developers are incorporating real-time analysis aspects into their software packages for future releases.

On the other end of the spectrum are *micro* models which can generally represent only a certain segment of road, such as Interstate 5 between mile markers 23 and 37. Micro models are rarely used to represent large geographic areas, such as an entire metropolitan region, since it would require both a massive amount of input data and computing capability. Also, it is difficult to calibrate a micro model at the regional level. However, micro models are useful in modeling smaller aspects of a network such as a specific corridor or interchange. Micro models also provide very precise results since individual vehicles are tracked on the network for a small time segment (normally $1/10^{th}$ of a second).

*Meso*models fall between these two modeling approaches. Meso models can represent larger geographic areas than micro models and allow for more precise results than macro models. In the figure above, the North Corridor in Seattle has been analyzed using a meso model. Meso models generally represent individual roadway links and vehicles on a network but not individual lanes on each roadway segment.

The Federal Highway Administration has created a comprehensive report that identifies a number of criteria in selecting one tool among many. The Traffic Analysis Toolbox (TAT) includes information a large number of tools ranging from sketch planning to microscopic simulation program. The two tables below are a subset of the TAT focusing solely on the three approaches discussed here. (*10*) Table 1 focuses on operational criteria for four categories to examine when selecting an approach: Analytical Context, Geographic Scope, Facility Type, and Travel Mode. Table 2 focuses on Tool/Cost Effectiveness.

**Table 1 Traffic Analysis Toolbox Operational Criteria**

● Tool adequately addresses criterion; ⃠ Tool poorly addresses criterion; ○ Some specific tools may address criterion

| | Macroscopic | Mesoscopic | Microscopic |
|---|---|---|---|
| **Analytical Context** | | | |
| Planning | ⃠ | ⃠ | ⃠ |
| Design | ● | ● | ● |
| Operations | ● | ● | ● |
| **Geographic Scope** | | | |
| Isolated Location | ○ | ○ | ○ |
| Segment | ⃠ | ⃠ | ⃠ |
| Corridor or Small Network | ⃠ | ⃠ | ⃠ |
| Region | ⃠ | ⃠ | ⃠ |
| **Facility Type** | | | |
| Isolated Intersection | ● | ● | ● |
| Roundabout | ⃠ | ○ | ⃠ |
| Arterial | ● | ● | ● |
| Highway | ● | ● | ● |
| Freeway | ● | ● | ● |
| Reversible Lanes | ○ | ⃠ | ⃠ |
| Toll Plaza | ○ | ○ | ● |
| **Travel Mode** | | | |
| SOV | ● | ● | ● |
| Bus | ⃠ | ● | ● |
| Pedestrian | ⃠ | ⃠ | ⃠ |

**Table 2  Traffic Analysis Toolbox Tool/Cost Effectiveness Criteria**

● High; ⃠ Medium; ○ Low

| | **Macroscopic** | **Mesoscopic** | **Microscopic** |
|---|---|---|---|
| **Tool/Cost Effectiveness** | | | |
| Capital Cost | ⃠ | ○ | ○ |
| Level of Effort | ⃠ | ○ | ○ |
| Popular/Well Trusted | ⃠ | ○ | ⃠ |
| Hardware Requirements | ○ | ○ | ○ |
| Data Requirements | ○ | ○ | ○ |
| Computer Run Time | ● | ○ | ○ |
| Post-Processing Requirements | ⃠ | ● | ● |
| Documentation | ⃠ | ⃠ | ⃠ |
| User Support | ⃠ | ⃠ | ⃠ |
| Key Parameters User Defined | ● | ● | ● |
| Default Values Provided | ● | ● | ● |

## 5.0 EVACUATION MODELING INVENTORY

This inventory of models summarizes a broad (and ongoing) search for surface transportation models employed in a published evacuation-related study, as well as currently available tools marketed with application in evacuation planning and/or operations . To date, this search has revealed more than 40 modeling tools and approaches. Of these, 30 were considered relevant to this inventory (Table 3). The 10 not included represented either duplicate versions of existing tools or tools still in development without a specific product that could be currently obtained and deployed[3]. In short, this inventory includes only tools that are in a form for broad release (not beta) and available to third parties for analysis.

Table 3 provides a number of characteristics about of the 30 modeling tools. The modeling tools are categorized by modeling approach: macro (thirteen tools), meso (five tools), and micro (twelve tools). Tools in *italics* are discussed in more detail in the following sub-sections on each modeling approach because they have one or more published studies using the tool in evacuation-related applications. The primary domain of each tool is provided:

- **Building Evacuation—**Tool designed specifically to model the evacuation of people from buildings.
- **Enclosure Evacuation—**Tool designed to model the evacuation of people from general enclosures (e.g., trains, buildings, airplanes, tunnels).
- **Evacuation Management—**Tool designed for the general evacuation of vehicles.
- **Hurricanes—**Tool designed specifically for hurricane evacuation.
- **Planning—**Tool designed for regional transportation and land use planning.
- **Simulation—**Tool designed specifically to model vehicle movement on a transportation network.
- **Planning/Simulation Hybrid—**Combination of planning and simulation model.

The table also categorizes the type of support available for each tool as Academic, Commercial, Government, or Legacy. Academic means the tool was designed, distributed and supported via an academic institution, such as a University Transportation Research Center. Commercial indicates that the tools are sold and supported by a third-party vendor. Government means the tool is only available to government agencies. Legacy indicates that the tool is no longer actively

[3] One such tool is LA-READY. The LA-READY project will develop a decision support tool for the Los Angeles region. One component of the project is to incorporate an existing modeling tool into the larger decision support system.

supported by any person or organization (although the software may still be available). Finally, current contact information is provided for each tool.

**Table 3 Evacuation Modeling Tool Inventory**

| NAME | DOMAN | SUPPORT | CONTACT |
|---|---|---|---|
| **MACRO** | | | |
| DYNEV | Planning Model | Legacy | www.kldassociates.com |
| *Emme/2* | *Planning Model* | *Commercial* | *www.inro.ca* |
| *ETIS* | *Hurricanes (RT DST*)* | *Government* | *www.fhwaetis.com* |
| EVACNET4 | Building Evacuation | Academic | www.ise.ufl.edu/kisko/files/evacnet/ |
| *HEADSUP* | *Hurricanes (RT DST)* | *Government* | *fhwa.dot.gov* |
| HURREVAC | Hurricanes (RT DST) | Government | www.hurrevac.com |
| MASSVAC | Evacuation Management | Legacy | n/a |
| NETVAC | Evacuation Management | Legacy | n/a |
| *OREMS* | *Traffic Simulation* | *Government* | *cta.ornl.gov* |
| *PCDYNEV* | *Evacuation Management* | *Commercial* | *www.kldassociates.com* |
| REMS | Evacuation Management (RT DST) | Legacy | n/a |
| TEDSS | Evacuation Management (RT DST) | Legacy | hobeika@vt.edu |
| *TransCAD* | *Planning Model* | *Commercial* | *www.caliper.com* |
| **MESO** | | | |
| *Cube Avenue* | *Traffic Simulation* | *Commercial* | *www.citilabs.com* |
| *DYNASMART* | *Traffic Simulation* | *Academic* | *www.dynasmart.umd.edu* |
| Simulex | Evacuation Management | Commercial | www.iesve.com |
| *TRANSIMS* | *Planning/Simulation* | *Commercial* | *www.transims-opensource.net* |
| TransModeler | Planning/Simulation | Commercial | www.caliper.com |
| **MICRO** | | | |
| AIMSUN II | Traffic Simulation | Commercial | www.tss-bcn.com/aimsun.html |
| CLEAR | Evacuation Management | Government | n/a |
| *CORSIM/TSIS* | *Traffic Simulation* | *Commercial* | *mctrans.ce.ufl.edu* |
| DRACULA | Traffic Simulation | Academic | www.its.leeds.ac.uk/software/dracula/ |
| DynaMIT | Evacuation Management | Academic | www.mit.edu/its/ |
| DYNASIM | Traffic Simulation | Commercial | www.citilabs.com |
| EXODUS | Enclosure Evacuation | Academic | fseg.gre.ac.uk/exodus/ |
| *INTEGRATION 2.0* | *Traffic Simulation* | *Academic* | *mctrans.ce.ufl.edu* |
| MITSIMLab | Traffic Simulation | Academic | www.mit.edu/its/ |
| *Paramics* | *Traffic Simulation* | *Commercial* | *www.paramics-online.com* |
| SimTraffic | Traffic Simulation | Commercial | www.trafficware.com |
| *VISSIM* | *Traffic Simulation* | *Commercial* | *www.ptvamerica.com* |

**RT DST = Real-Time Decision Support Tool*

## 5.1 MACRO

The earliest evacuation planning models were developed in response to major incidents such as the Three Mile Island Nuclear Power Plant accident[4]. These models focused on overall travel demands for a defined evacuation area and examined key measures such as evacuation clearance times and overall system capacity. Due primarily to computing power, only macro level models were developed that would describe the overall traffic flow on a link of the network and not the movement of individual vehicles.

Today, macro-level models are still used in evacuation planning and prove useful in analyzing large-scale events such as a hurricane, flooding or nuclear power plant accidents that threaten a large geographic area. Many of the metropolitan-area planning organizations (or MPOs) currently use macro-level forecasting models that could be used for evacuation planning purposes. However, macro-level models are difficult to use if very specific traffic control plans are to be implemented (e.g., reversible lanes) or a better understanding of queue formation on specific roadway links is desired.

Thirteen macro-level models that have been used for emergency evacuation planning. Five of these models (DYNEV, MASSVAC, NETVAC and PDYNEV) were developed specifically for evacuation planning purposes. Emme/2 is a fairly popular macro-level travel forecasting program that is used by transportation planners. EVACNET4 is a software tool designed specifically to model building evacuations and has not been applied to transportation networks. Four of the models (Emme/2, OREMS, PCDYNEV, and TRANSIMS) are actively supported and available for use as an emergency evacuation planning tool. The other four are legacy tools that are not currently supported or available.

In addition, a sub-set of macro-scale models are real-time decision support tools (also referred to as decision support systems). Decision support tools for evacuation planning were developed to assist local leaders and decision makers in the real-time operation of an evacuation event. Researchers identified five macro-scale decision support tools that are relevant to evacuation planning. Three of the five (ETIS, HEADSUP and HURREVAC) are designed specifically for

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[4] The Three Mile Island nuclear power plant accident occurred on March 28, 1979 near Middletown, Pennsylvania. While no deaths or injuries were associated with the accident, it did bring about sweeping changes in regards to commercial nuclear power plants. Among other things, emergency response planning became a major focus area among power plant owners, local agencies, FEMA and the Nuclear Regulatory Commission. Emergency preparedness response plans were developed and event scenario drills tested several times a year.

hurricane events. The other two (REMS and TEDDS) were developed more generally for evacuation management.

### 5.1.1 Emme/2

Inro
Montreal, Quebec
sales@inro.ca

EMME/2 is an urban transportation planning system, offering planners a comprehensive set of tools for traffic and transportation modeling. It provides decision-support capabilities, allowing the simultaneous description, analysis and comparison of several proposed scenarios, and providing methods for evaluating various transportation and land use development alternatives. EMME/2 provides a general framework for implementing a wide variety of travel forecasting models. These can range from the simple implementation of a four-step model to more refined demand models and their integration into a variety of road and transit assignment procedures. Impact and evaluation analysis is also possible. EMME/2 offers the analyst a wide variety of tools for the direct comparison of future scenarios which may reflect changes in the road and transit network or changes in the socio-economic characteristics of the urban area studied. Data can be entered into the model interactively, or in batch mode, and a macro language can automate many modeling tasks. (*11*)

- **Emergency Evacuation Modeling for the Koeberg Nuclear Power Station—**This study examined the mandatory evacuation surrounding the Koeberg Nuclear Power Station located 26 km north of Cape Town, South Africa. Emme/2 was used to estimate the evacuation duration and identify problems related to the road network. Eleven evacuation scenarios were developed and analyzed. Emme/2 was selected because a calibrated network existed and it also enabled a number of scenarios to be quickly developed and assessed. (*12*)

### 5.1.2 ETIS

Federal Emergency Management Agency
U.S. Army Corps of Engineers
www.fhwaetis.com

The Evacuation Traffic Information System (ETIS) is a web-based program that facilitates the sharing of evacuation and traffic information among coastal states in the southeast from Texas to Virginia. The ETIS supports decisions such as evacuation type (e.g., voluntary, mandatory, staged) and implementation of contraflow or lane-reversal operations. The ETIS was originally developed under auspices of the Federal Highway Administration, U.S. Army Corps of Engineers and Federal Emergency Management Agency. Currently, ETIS is supported solely by FEMA and the U.S. Army Corps of Engineers and operated by its private developers, Post, Buckley, Schuh & Jernigan (PBS&J). ETIS is a macroscopic model that was primarily developed to forecast large cross-state traffic volumes. The travel demand forecasting system allows emergency management officials to access the model online and input data specific to their area. The system is capable of estimating evacuation traffic congestion and cross-state traffic flows. (*13*)

### 5.1.3 HEADSUP

The Florida HEADSUP program is used to manage traffic proactively during an evacuation. The capabilities of HEADSUP extend beyond the functionality of the Evacuation Traffic Information System (ETIS); while HEADSUP uses the same information as ETIS, it is more detailed and complete. HEADSUP automatically ingests real-time traffic data from 27 strategically located traffic counters throughout Florida to analyze evacuation conditions and assist in emergency management decisions. Its features include hourly dynamic travel demand forecasts, impact analyses of contraflow lanes, socio-economic statistics on evacuees, a map-based user interface, a traffic model that gradually loads evacuees onto the roadway network, and an archival capability which records when key events occurred during a hurricane evacuation.

### 5.1.4 OREMS

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Knoxville, TN
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OREMS (Oak Ridge Evacuation Modeling System) was developed by the Oak Ridge National Laboratory to estimate evacuation times and assist in the development of evacuation plans for different events or scenarios (e.g. good versus bad weather conditions, day versus nighttime evacuations). OREMS, based upon the CORFLO model, enables users to assess alternate routes, destinations, traffic control management strategies, and evacuee response rates for various scenarios. OREMS estimates evacuation or clearance times, traffic operational characteristics (e.g. average evacuation speed), bottlenecks, and other information necessary to develop evacuation plans and conduct transportation infrastructure vulnerability studies. Researchers from ORNL have identified the need for a decision tool capable of specifically modeling hurricane evacuation activities in more timely and accurate ways. The core of this tool will be the OREMS traffic simulation model and the output will allow identification of areas which are at greatest risk; the development of alternative evacuation plans; the evaluation of traffic operation strategies; and recommendations of the most effective strategies for evacuation such as the use of shoulders and contraflow operations. (*8*)

- **United States Army—**OREMS was originally developed for U.S. Army Chemical Stockpile Emergency Preparedness Program to analyze the feasibility of evacuation in the areas surrounding various army depots. These areas are large (some sites covering over 2,000 square miles) thus a model was needed that would run fast. (*14*)
- **Nuclear Regulatory Commission—**Sandia National Lab, sponsored by the Nuclear Regulatory Commission, is using OREMS to update all evacuation plans for the 60+ nuclear plants in the United States. (*14*)

### 5.1.5 PCDYNEV

Reuben Goldblatt, P.E.
KLD Associates, Inc.
Commack, NY
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The PCDYNEV (Personal Computer Dynamic Evaluation) Evacuation Planning System was initially developed for the Federal Emergency Management Agency (FEMA). PCDYNEV has been used in the United States and abroad to conduct evacuation planning studies for areas near nuclear power stations and chemical weapons disposal facilities and for areas subject to hurricanes. PCDYNEV comprises two components: TRAD, an integrated traffic assignment and distribution model, and IDYNEV, a macroscopic simulation model based on CORFLO which was developed for the FHWA. PCDYNEV effectively combines these two components into an integrated system that includes a computer graphics display in order to provide animations of evacuation scenarios. (*15*)

- **Indian Point Energy Center, New York—**The study examined 14 evacuation scenarios, each with a different combination of conditions that can affect evacuation demand or roadway capacity. Conditions focused primarily on weather events taking place: snow, rain, etc. The results for evacuating the area of interest ranged from slightly more than 7 hours to approximately 12 hours. The use of the model revealed that the difference between evacuation times was directly attributable to the presence of significant highway congestion.(*15, 16*)

### 5.1.6 TransCAD

Caliper Corporation
Newton, MA
www.caliper.com

TransCAD combines a Geographic Information System and macro-scopic transportation simulation platform into an integrated package. TransCAD also includes a specific Evacuation Analysis Procedure for network evacuation simulation. The evacuation analysis procedure reports network clearance time for an evacuation plan and demonstrates how traffic patterns change over time and over space during the evacuation. The dynamic vehicle flow information can be used to locate bottlenecks in the network during an evacuation process, so the evacuation plan under scrutiny can be improved accordingly. The procedure can also be used to evaluate the effectiveness of various evacuation policies and strategies such as the level of evacuation and traffic management operations including reverse lane flows, coordinated signalization, high occupancy vehicle operations and emergency transit service. (*17*)

- **Washington Council of Governments (Washington, DC)—**TransCAD was used to model various evacuation scenarios in the Metropolitan Washington, DC, region. TransCAD was used to generate various evacuation event scenarios in order to better plan for expected evacuation events. As a result of the evacuation of the city after September 11, 2001, some policy guidelines needed to be developed to better understand the staging of moving people out of the city as well as developing implementation guidelines for evacuating people. Four scenarios were explicitly modeled with an additional eight developed but not modeled. (*18*)
- **Kola Nuclear Power Plant (Sweden)—**An integrated system to calculate and visualize optimal evacuation routes was developed using TransCAD. The system calculates and visualizes the optimal flow as to vacate any set of nodes while minimizing a specified cost. (*19*)

### 5.1.7 Other Macro Models

- **DYNEV—**The DYNEV model was developed by KLD Associates, Inc., in the late 1970s and is a macroscopic model used traditionally for simulating evacuation from sites within close proximity to nuclear power plants. Enhancements were made for modeling of regional hurricane planning. DYNEV has been replaced with the PCDYNEV model. (*1*)
- **EVACNET4—**EVACNET4 models building evacuations. EVACNET4 has been designed to be flexible enough to model the evacuation of almost any conceivable structure that may be represented as a network. This includes office buildings, hotels,

skyscrapers, auditoriums, stadiums, retail establishments, restaurants, and schools. Entire structures or selected parts of a structure may be modeled. The cause of the evacuation may be fire, smoke, earthquake, drill or any other reason requiring the quick removal of people from the building. (*20*)

- **HURREVAC—**The Hurricane Evacuation (HURREVAC) computer model was developed by the U.S. Army Corps of Engineers for FEMA specifically for hurricane evacuation. This is an operational decision-support tool assisting decision makers in advance of and during an evacuation. HURREVAC draws information from a wide variety of sources, including the National Hurricane Center, inundation estimates from the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model, and information on the location, remaining capacity, and flooding potential of all the shelters in the area. It also estimates the time required to evacuate an area, which emergency managers use in determining when to commence evacuations. HURREVAC is restricted for use by the official government emergency management community. (*3*)
- **MASSVAC—**MASSVAC provides a macro-level approach to determine traffic clearance times using traffic flow relationships at its core structure. It has been used in several applications, including a test of operational strategies for hurricane evacuations in the Commonwealth of Virginia. Data about community and disaster characteristics, population distribution (including geographic and temporal allocation of the population), and transportation networks are required. (*21*), (*1*)
- **NETVAC—**NETVAC is a fixed-time, macro-level simulation model that gives information about the queue forming process. It was developed as a response to challenges posed by the Three Mile Island nuclear incident. NETVAC uses mathematical relationships between flows, speeds, densities, queue length, and other important traffic variables to simulate the evacuation process. (*21*), (*1*)
- **REMS—**The Regional Area Evacuation Modeling System (REMS) was developed at the University of Florida to estimate the evacuation time and the traffic flow on a given transportation road network by simulation and several network optimization models incorporated into the software. REMS is used to find the optimal allocation of evacuees to shelters based on minimum evacuation time and through the least congested roads.
- **TEDSS—**The Transportation Evacuation Decision Support System (TEDSS) is an outgrowth of the MASSVAC macro-level evacuation planning programs. TEDSS supports various evacuation planning and operation scenarios, such as natural disaster evacuations and man-made disaster evacuations. Evacuees are loaded onto the network based on the type of evacuation carried, the weather condition, and night or daytime, and slowly and quickly escalating evacuation. The user can modify the transportation network to satisfy the evacuation conditions and has the option to change the major routes from

two-way flow to one-way flow. The outputs show the evacuation times, the evacuation routes, and the expected bottlenecks in the network. The model works in real time and can assist the user to change the evacuation plans according to the real world evacuation situation.

## 5.2 MESO

Mesoscopic transportation planning tools evolved from a need for a level of detail needed for microscopic simulation programs and the analysis fidelity not afforded macro-scopic models. Mesoscopic models tend to represent the relative flow of vehicles on a network link, but do not represent individual lanes on the link. Mesoscopic simulation models have been used in evacuation planning primarily as a means more accurately represent congestion conditions and temporal effects than macro models yet still cover a larger geographic region. This allows the modeler replicate congestion development/dissipation cycles during previous evacuation events to better understand steps that should be taken in future evacuation operations.

Researchers found five mesoscopic simulation programs being used for emergency evacuation planning. All but one of the models (Simulex) are designed as general transportation planning tools that can be adapted or applied for evacuation events. Simulex was created to model human behavior within a building during emergency evacuation conditions. Two of the models (Cube Avenue and DYNSMART-P) have been used to model emergency evacuation conditions. TRANSIMS has been identified by two organizations to be used for proposed research projects on better modeling evacuation scenarios. TransModeler, a relatively new mesoscopic tool, has not been used specifically for evacuation modeling. All of these tools are actively supported and available.

### 5.2.1 Cube Avenue

CitiLabs
Oakland, CA
www.citilabs.com

Cube Avenue uses mesoscopic techniques to study traffic flow over time. Analysts specify: a) the level of detail for vehicle, time, and network inputs and b) time increments in terms of minutes or hours. These inputs are used to compute the lowest-cost path for each vehicle unit, based on its departure time, and computes interactions among vehicle units as they travel through the network. Cube Avenue estimates travel speeds based on vehicle density on road segments during each time increment. Because Cube Avenue models time explicitly, time-specific policies, such as variable road pricing or lane closures, can be modeled. (*22*)

- **Houston-Galveston Area Council (Texas)—**The Cube Avenue product was used in the Houston-Galevston area to help local planners and decision makers in the process of emergency evacuation. Officials used the Cube Avenue product following Hurricane Rita where nearly 1.2 million people evacuated the area within a 24-hour period to reproduce the failures seen in the transportation system during this event and to help decision makers develop alternate solutions for when another event like Rita occurs. Cube Avenue is also being used to create an event scenario inventory so that when other events requiring emergency evacuation do arise, local leaders will know what problems to expect and how to better respond. (*23*), (*24*)

### 5.2.2 DYNASMART

University of Maryland
College Park, MD
www.dynasmart.umd.edu

DYNASMART is a mesoscopic traffic simulation program that incorporates dynamic traffic assignment functionality, the ability to predict where and when drivers travel on the road network enabling dynamic control and management systems to anticipate problems before they occur rather than simply reacting to existing conditions. DYNASMART comes in two flavors: DYNASMART-P which is a stand-alone simulation program and DYNASMAT-X designed for real-time applications and hardware-in-the-loop functionality. DYNASMART brings together two major categories of tools that were initially developed along separate tracks for different purposes: 1) Network assignment models, used primarily in conjunction with demand forecasting procedures for strategic (long-term) planning applications; and 2) Traffic simulation models, used primarily for traffic operational studies. DYNASMART enables consideration of an expanded set of measures compared to both macro-level models and micro-simulation analysis tools. This is accomplished by incorporating a richer representation of traveler behavior decisions than a macro model; explicit description of traffic processes and their time-varying properties; and complete representation of the network elements, including signalization and other operational controls. (*25*)

- **Evaluation Of Emergency Evacuation Strategies For Downtown Event Traffic Using A Dynamic Network Model (Minneapolis, MN)—**This research studied the feasibility of applying Dynasmart-P for evaluating the effectiveness of alternative strategies for evacuating the traffic in downtown Minneapolis, MN, under a hypothetical emergency situation that included the evacuation of the sell-out crowd in the Metrodome. The simulation included the modeling of contra-flow lanes. (*26*)

- **Evacuation Operational Planning (Houston-Galveston, TX)—**DYNASMART-P was used in an operational planning project focusing on modeling the evacuation of residents and visitors out of Houston-Galveston area to other Texas cities. The network covers all of central Texas representing 350 zip code zones. The primary objective was to model the effects of contra-flow lanes and make recommendations on how best to manage existing roadway infrastructure during evacuation conditions. (*27*)

### 5.2.3 TRANSIMS

U.S. Department of Transportation
Federal Highway Administration
www.transims-opensource.net

The Transportation Analysis and Simulation System (TRANSIMS) is an agent-based travel simulation system designed to meet the State Departments' of Transportation (DOTs) and Metropolitan Planning Organizations' (MPOs) need for more accurate and more sensitive travel forecasts for transportation planning and emissions analysis. It consists of mutually supporting simulations, models, and databases. By employing advanced computational and analytical techniques, it creates an integrated environment for regional transportation system analysis. TRANSIMS's capability of simulating and tracking travel by individuals makes possible the evaluation of benefits to, and impacts on, different geographies and travel markets. Furthermore, TRANSIMS has the ability to evaluate highly congested scenarios and operational changes on highways and transit systems. TRANSIMS differs from previous travel demand forecasting technologies in its underlying concepts and structure. These differences include a consistent and continuous representation of time; a detailed representation of persons and households; time-dependent routing; and a person-based microsimulator.

- **Integrating a Regional Planning Model (TRANSIMS) With an Operational Model (CORSIM)—**This project used TRANSIMS to develop an interface that allows an analyst to use a micro-scale traffic simulation package, such as CORSIM, to perform operational traffic analysis. This methodology enables TRANSIMS to take advantage of higher fidelity micro-scale models for sub-network analysis and allow CORSIM to use planning inputs such as individual 24 hour travel activities and trip chains. The project was applied to Virginia Tech's main campus in Blacksburg, VA to evaluate this sub area focusing methodology for evacuation purposes. (*28*)

### 5.2.4 Other Meso Models

- **Simulex—** Simulex models movement of people in a building. It is based on real human behavior, using data gathered from video analysis of individuals moving in crowds. Research results from around the world are used to augment the data, giving a unique level of accuracy and an unmatched capability for simulating building evacuation.
- **TransModeler—**TransModeler is hybrid simulation modeling package that combines the features of macro-, meso- and micro-scopic simulation tool into one tool. TransModeler allows the analysts to switch among the level of detail depending upon network size and outputs desired. TransModeler incorporates dynamic routing of trips based upon historical or simulated time dependent travel times, and also models pre-specified trips or turning movements at intersections. It simulates public transit as well as car and truck traffic, and handles a wide variety of ITS functions such as electronic toll collection, route guidance, and traffic detectors.

## 5.3 MICRO

Microscopic simulation models were developed to accurately model transportation systems at the individual vehicle level. Microscopic models move these individual vehicles through a network where the vehicles have their own characteristics and respond to the presence of other vehicles and to traffic control devices. Available computing power and a requirement for extensive data on roadway geometry and traffic control represents the primary limitation of microscopic models. Many transportation agencies currently use microscopic models in conjunction with macro-level models to better understand the impact of roadway geometry modifications on level of service and carrying capacity.

Today, micro-level models are extensively used in evacuation planning to analyze the implementation of innovative roadway management techniques, such as contraflow and reversible lanes on roadways. While micro-level models are limited in the geographic coverage, they are useful in analyzing key bottleneck roadway segments and corridors where the movement of each individual vehicle needs to be represented to better understand the impact on roadway conditions. The use of microscopic simulation has primarily focused on the validation of preconceived transportation evacuation plans and policies. These usually represent the implementation of contra-flow lanes for hurricane-prone cities. In these situations, transportation agencies were concerned with how the policies developed for evacuation would actually play-out in real-world conditions. Microscopic simulation models were used to model these scenarios.

Researchers identified 12 micro-level models that have been used for emergency evacuation planning. Nine of these models were developed for traffic simulation in general, with four having been successfully used in an evacuation-related study. One of the models (EXODUS) was developed to model the evacuation of enclosures, including buses and trains. Five of the models (AIMSUN II, CORSIM/TSIS, Paramics, SimTraffic and VISSIM) are actively supported by a commercial entity. INTEGRATION 2.0 is actively supported, but primarily through a university research environment.

### 5.3.1 CORSIM/TSIS

McTrans
University of Florida
mctrans.ce.ufl.edu

The Traffic Software Integrated System (TSIS) is a collection of software tools for use by traffic engineers and researchers. Originally built as a simple shell around CORSIM, TSIS has evolved into a more complete toolkit. Though used by the FHWA for conducting research, these tools are sold to the public. CORSIM, a comprehensive microscopic traffic simulation, applies to surface streets, freeways, and integrated networks with a complete selection of control devices (i.e., stop/yield sign, traffic signals, and ramp metering). It simulates traffic and traffic control systems using commonly accepted vehicle and driver behavior models. CORSIM combines two of the most widely used traffic simulation models, NETSIM for surface streets and FRESIM for freeways. CORSIM has been applied by practitioners and researchers worldwide over the past 30 years and embodies a wealth of experience and maturity.

- **Regional Traffic Simulation for Emergency Preparedness (Birmingham, AL)—**The CORSIM traffic simulation software was used to create a regional transportation model comprising the major traffic corridors in the Birmingham area. The regional model was used to test and evaluate various emergency management strategies in response to hypothetical incidents in the Birmingham area. Emergency incidents considered include a traffic accident on a major freeway, a building evacuation in downtown Birmingham, and traffic influx into Birmingham due to an emergency at Anniston Army Depot. Response strategies evaluated included traffic diversion, signal optimization, access restriction, and emergency routing. (*29*), (*24*)
- **Contraflow Evacuation on the Westbound I-10 out of the City of New Orleans (New Orleans, LA)—**The Louisiana State University used the CORSIM 5.0 simulation model

to evaluate the effectiveness of contraflow segments on westbound I-10 out of the City of New Orleans. Alternative plans were also developed in this study to compare the effectiveness of the contraflow operation. With the use of CORSIM, traffic flow on the contraflow segment was determined based on the amount of evacuating vehicles leaving the exit nodes. In addition the time and speed to travel the contraflow segment was estimated. The results of analysis demonstrated that the use of contraflow lanes for evacuation out of the City of New Orleans increase traffic flow significantly. (*30*), (*31*), (*24*)

- **Traffic Analysis of North Carolina's I-40 Lane Reversal Plan (Wilmington, NC)—** CORSIM was used to model the operations of the North Carolina DOT I-40 contraflow lanes. The policy to implement contraflow lanes was developed in 2000 but never has been implemented because no evacuations have been called where the contraflow lanes have been needed. The purpose of this study was to examine the overall operations of the contraflow lanes specifically examining: a) transition to contraflow at Wilmington; b) Transition to normal flow at I-95; and c) Operations at intervening interchanges. (*32*), (*24*)

### 5.3.2 INTEGRATION 2.0

McTrans
University of Florida
mctrans.ce.ufl.edu

The INTEGRATION model was initially conceived to simulate both freeways and arterials within a single software model. INTEGRATION was initially developed as a mesoscopic model, then evolved into a microscopic model in 1995. Further enhancements to the model included the incorporation of adaptive signal control, the modeling of transit vehicles and transit priority, and the inclusion of tolls and High Occupancy Lanes (HOVs). The original version also incorporated traffic assignment, and subsequent versions have added multiple routing algorithms and the ability to model ITS, emissions, and incidents and diversions. At the core of the INTEGRATION model is a microscopic representation of vehicles and traffic flow. Vehicle performance is governed by macroscopic traffic flow and assignments, as well as rules for individual car following and lane changing, and other vehicle interactions. (*33*)

- **Evaluating and Improving Evacuation Planning for Regions and Situations (City of Ormond Beach, FL)—**The City of Ormond Beach, FL, used INTEGRATION and ARENA software to assess the traffic impact of evacuation orders for the City of Ormond Beach which is prone to effects of hurricanes. (*34*), (*35*)

### 5.3.3 Paramics

Quadstone Paramics
Boston, MA
www.paramics-online.com

Quadstone Paramics is a suite of micro-scopic simulation modules providing an integrated platform for modeling a range of transportation problems. Paramics is fully scalable and designed to handle scenarios as wide-ranging as a single intersection, through to a congested freeway or the modeling of an entire city's traffic system. The suite of tools includes eight modules that enable the analyst to create networks, estimate origin/destination patterns, and interact with development environment to create customized functionality. Modeller is a fully scalable tool designed to model an entire city's traffic system, a congested freeway, or single intersection. Modeller is at the core of the Paramics software suite and uses the Paramics simulation for all aspects of the simulation process, and for generating a comprehensive range of output Statistics. Modeller can represent aspects of a transportation system including urban, highway, public transport, congested, ITS and HOV. (*36*)

- **Modeling Small Area Evacuation: Can Existing Transportation Infrastructure Impede Public Safety? (Mission Canyon Neighborhood, CA)—**This study was initiated in part because of the Oakland Hills fire of 1991 where 25 people were killed. Many counties have now mapped high fire-risk areas to support special fire attack programs as well as evacuation plans. One aspect of this study is to estimate the time it would take to clear a residential neighborhood if an evacuation is needed. The Paramics simulation model was used to model the Mission Canyon Neighborhood. The entire purpose of the developing tools, so I took it out. (*37*)
- **Microsimulation of Neighborhood Evacuations in the Urban-Wildland Interface (Emigration Canyon, Utah)—**Paramics was used to help create a method for using microscopic traffic simulation to develop and test neighborhood evacuation plans in the urban-wildland interface. The use of Paramics was one component of the overall GIS-based project which mapped the spatial effects of a proposed second access road on household evacuation times. (*38*)
- **Analysis and Modeling of Cape May County Roadway Elevations and Evacuation Routes (Cape May, NJ)—**Paramics was used in this study to determine the evacuation times under varying population, hurricane level, and NJ Routes 47/347 reversal lane operation scenarios for Cape May County, New Jersey. Results of the study show that the current lane reversal plan is ineffective and needs to be revised since the bottleneck

during evacuation would exist south of NJ Route 83, the initiation point of the current reversal plan. (*39*)

### 5.3.4 VISSIM

PTV America
Corvallis, OR
www.ptvamerica.com

VISSIM is a microscopic simulation program for multi-modal traffic flow modeling. It simulates urban and highway traffic, including pedestrians, cyclists and motorized vehicles.

- **An Operational Analysis Of The Hampton Roads Hurricane Evacuation Traffic Control Plan (Hampton Roads, VA)—**The Hampton Roads region of Virginia has developed a hurricane evacuation plan to facilitate the movement of large numbers of vehicles as they attempt to leave the region in advance of a storm. Although the plan considers many aspects of hurricane evacuation, this evaluation focuses on its impacts on traffic operations. A traffic control plan (TCP) was developed that describes the procedures to be followed in the event an evacuation is ordered. Ramps providing access to I-64 are designated as open or closed, and many are metered in an attempt to influence the route choice of evacuees and thereby balance the demand across available evacuation routes. The TCP was evaluated using the VISSIM traffic simulation model to determine the performance characteristics with respect to traffic flow. This study provided analysis for the freeway portions of the evacuation routes. (*24*)

### 5.3.5 Other Micro Models

- **AIMSUN II—**The Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN) is an integrated suite of traffic and transportation analysis tools. It can be used for transport planning, microscopic traffic simulation, and demand and traffic data analysis. It provides an integrated platform for both static and dynamic modeling.
- **CLEAR—** Pacific Northwest Laboratories developed the Calculating Logical Evacuation And Response (CLEAR) model which estimates the time required to clear a certain disaster area for a specific population density and population distribution by simulating the movement of vehicles on a transportation network according to the conditions and consequences of traffic flow. The program also models the distribution of times required by individuals to prepare for an evacuation.
- **DRACULA—**The Dynamic Route Assignment Combining User Learning and MicrosimulAtion (DRACULA) microscopic traffic network modeling suite was

developed at the Institute for Transport Studies, University of Leeds (UK). Applications of this model in progress include the study of congestion based road pricing, real time traffic signal control, dynamic route guidance, segregated busway design, emergency evacuation procedures, and strategic inter-urban modeling. DRACULA can model the effect of policy, demand, and network changes on route and departure time choice.

- **DynaMIT—**DynaMIT is designed to support the operation of an Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS) at a Traffic Management Center (TMC). Sponsored by the FHWA with Oak Ridge National Laboratories (ORNL) as the program manager, DynaMIT was the result of several years of research and development at the Intelligent Transportation Systems Program, Massachusetts Institute of Technology (MIT). Application could also include coordination of evacuation and rescue operations in real-time emergencies (natural disasters, etc.) that could block highway links. In similar fashion to DYNASMART, DynaMIT comes in two flavors: DynaMIT-P which is a stand-alone simulation program and DynaMIT-R designed for real-time applications and hardware-in-the-loop functionality.
- **Dynasim—**Cube Dynasim is a software system allowing planners and engineers to simulate, visualize, and evaluate the effects of proposed changes to the geometry or operating characteristics of the transportation network and impacts of changing land-use and travel demand. Dynasim captures the intricacies of traffic behavior and is able to perform operational analysis of complex traffic flows while emulating the flows of automobiles, trucks, buses, rail, bicycles, and pedestrians.
- **EXODUS—**EXODUS was developed to meet the demands of performance-based safety codes. Based on a set of sub models, it produces people-people, people-fire and people-structure interactions. EXODUS was developed by the Fire Safety Engineering Group at the University of Greenwich. EXODUS comprises a suite of software packages, tailored to the building, maritime and aircraft environments. A rail version of the EXODUS software is currently under development.
- **MITSIMLab—**MITSIMLab is a simulation-based laboratory that was developed for evaluating the impacts of alternative traffic management system designs at the operational level and assisting in subsequent refinement. Examples of systems that can be evaluated with MITSIMLab include advanced traffic management systems (ATMS) and route guidance systems. MITSIMLab was developed at the MIT Intelligent Transportation Systems (ITS) Program.
- **SimTraffic—**SimTraffic, developed by TrafficWare, is primarily used for the simulation of signalized intersections. (*40*)

## 6.0 ANALYSIS

This section provides some initial observations on the types of tools identified in the modeling inventory and their application in evacuation-related studies, and encompasses three areas. The first subsection places specific models on a modeling spectrum based on geographic scope with multi-state analysis on one end and corridor analysis on the other. The second subsection looks at classes of models from a specialization perspective and how they have been used for various applications and the corresponding fidelity or time granularity of analysis. The third subsection presents the typical application (long-range planning versus real-time operations) for each class of model by geographic scale and application speed.

### 6.1 EVACUATION MODELING SPECTRUM

The Evacuation Modeling Spectrum is presented in Figure 8 below. The figure places 14 of the 30 models on a geographic continuum ranging from multi-state level analysis to corridor level analysis. Three characteristics are listed as tradeoffs that must be considered when selecting one of the tools for analysis. Two additional characteristics, cost and maintenance, should also be considered but do not correlate with the geographic continuum.

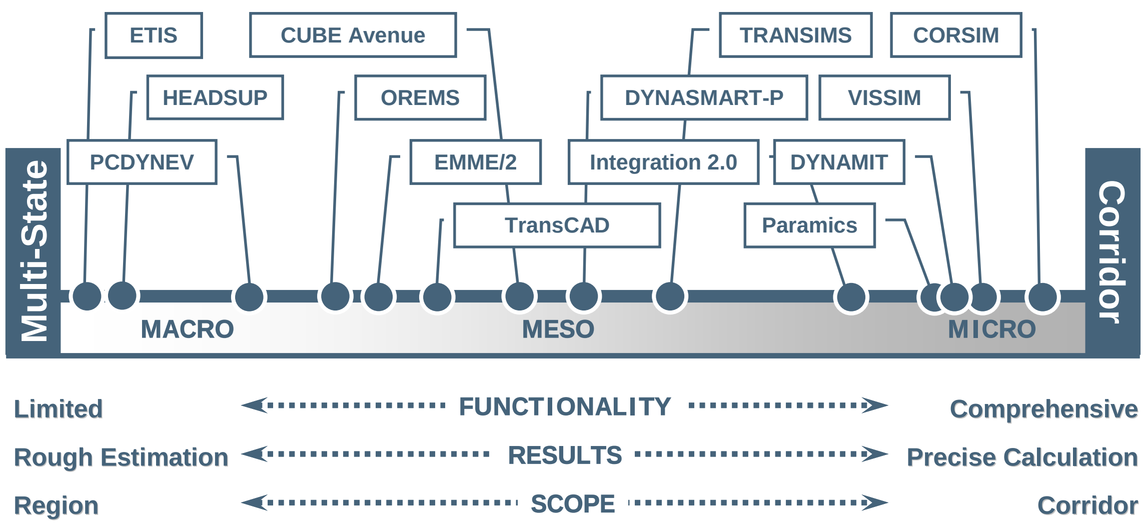


**Figure 8 Evacuation Modeling Spectrum**

The first characteristic considered among the models is functionality. Generally speaking, the functionality of the microscopic simulation models is greater than the macroscopic models. In part this is because the microscopic models were developed as general transportation modeling tool that can be applied to various situations (not just evacuation modeling). While some of the macroscopic tools are used for more general travel demand forecasting and regional modeling, three of the tools (PCDYNEV, ETIS and HEADSUP) were designed and built specifically for evacuation purposes. Thus their functionality is more limiting.

The second characteristic is the desired results. The microscopic tools were designed to provide very precise calculations on a vehicle-by-vehicle basis if necessary. However, these tools also require a large amount of precise baseline data in order to generate the results. Currently, many of the mesoscopic tools include hybrid functionality where the analyst can select the overall time fidelity based upon the desired results. Macroscopic tools do not provide the same precision of results but also do not require the same amount of input data. With respect to results, the tradeoff lies between selecting a model that provides very precise results but also requires a large amount of input data versus a macroscopic model that provides less precise result but also less input data as well.

The third characteristic is scope. Microscopic tools are useful in corridor-level analysis since the ability to calibrate such a model at the regional level is exceptionally challenging. Macroscopic models are designed to analyze an entire region thus their ability to provide region-wide impacts are better. While a macroscopic model could be used to analysis a single corridor, the usefulness of the results will be limited. For example, in analyzing the impact of contra-flow lanes from an operational perspective, a macroscopic model will not provide the necessary detailed results. However, a macroscopic, or mesoscopic, model would be useful in assessing the regional impacts on converting various interstate travel lanes to contra-flow lanes.

Two other important considerations are cost and maintenance. The costs to acquire the models vary a great deal. In some cases the models are provided free (HURREVAC) to any agency interested in using it. However, most cost anywhere from a few hundred to tens of thousands of dollars. In some instances, the model can only be used if the consultant who created it is also hired to do the analysis (PCDYNEV). Maintenance of the model is also an issue. ETIS and HEADSUP require a significant amount of maintenance in order that it is ready to be used in the event of an evacuation order.

## 6.2 MODEL SPECIALIZATION

Figure 9 below presents 16 of the models as they relate to time granularity and application. Time granularity is a function of the smallest analysis time slice the model can handle and ranges between less than one second and hours. The smaller the unit of time in the analysis, the higher the fidelity of the model and the more precise the results. In general, microscopic simulation models operate at 1/10$^{th}$ second granularity whereas many of the macroscopic models operate at a one hour time granularity. The application scale represents whether a model was designed for a specific type of event or is more general in nature.

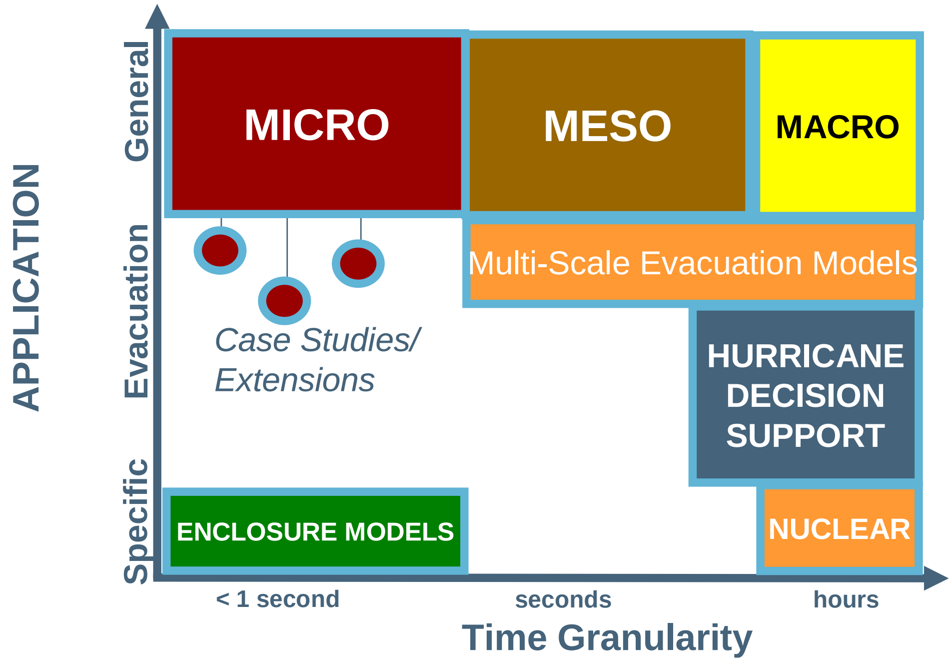


**Figure 9 Evacuation Model Specialization**

In general, most of the commercially available simulation and planning models are designed for general applications but can be applied to evacuation planning situations. All of the microscopic simulation models incorporate a time granularity of 1/10$^{th}$ a second. The mesoscopic models are not as cut and dry. Some of these models (such as TransModeler) have functionality to operate at the micro-level or macro-level depending upon the situation. Two of the models (ETIS and HEADSUP) were designed specifically for hurricane evacuation and provide results at a very low time-fidelity (on the order of one hour for expected volume/capacity ratios). Two models operate at a high fidelity for a specific application (EXODUS and EGRESS). However, both of these models are geared towards enclosure evacuation (buildings, vehicles).

## 6.3 SCALE AND SPEED CONTINUUM

Figure 10 below presents the three modeling approaches as they relate to scale (geographic coverage) and speed (planning and operations). The three modeling approaches are good for conducting off-line "what if" scenarios. In general, the three modeling approaches presented in this inventory of evacuation planning tools have only been used for planning purposes where there is some time delay between the tool being used and the evacuation event occurring. In some cases this time lag is relatively short (days or hours for the use of HURREVAC) or long (months or years when using VISSIM or CORSIM/TSIS).

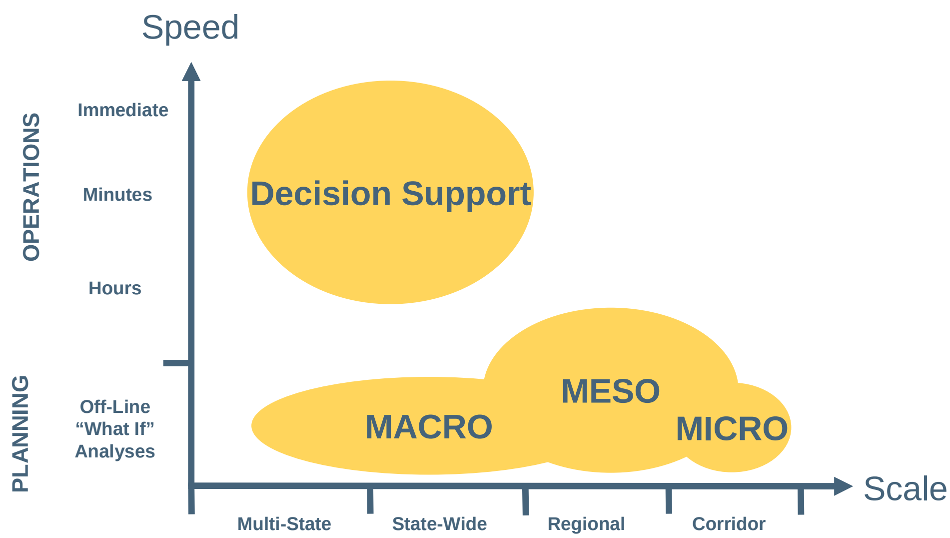


**Figure 10 Evacuation Model Scale and Speed Continuum**

With recent addition of a number of decision support tools, some of these modeling approaches are now being incorporated into the operational management of an evacuation event. Two of the decision support tools (ETIS and HEADSUP) incorporate a macroscopic modeling tool that is able to display county-level evacuation status and current traffic volumes. The future vision for these types of tools is to provide predicted traffic once a database of events has been created. The CUBE Avenue modeling tool is a meso-scale tool that is being incorporated into a larger decision support tool for the Houston-Galveston area to provide some type of operational support for decision makers.

## 7.0 SUMMARY

This modeling inventory documents 30 tools that have been used to conduct some type of evacuation-related analysis. These tools represent three modeling approaches: macro, meso and micro, all of which have a number of strengths and weaknesses which must be examined when selecting a specific tool. Twenty five of the tools are currently supported in some manner (commercial, academic or government) while five are considered legacy systems. Twenty eight of these tools have been used primarily for planning purposes with only two (ETIS and HEADSUP) being used for evacuation operations. These operations tools incorporate a macro-scale approach. None of the operations tools incorporate meso- or micro-level approaches; though CUBE Avenue may be used for operational purposes in the future for the Houston-Galveston region.

The type of events that these tools have been used for are geared primarily towards large-scale, relatively long lead-time evacuation events (hurricanes, special events) representing the easier type of events to plan for. Recently, many of these modeling tools have been used to initiate a "scenario database" of possible evacuation events. Some localities have even begun to test operational scenarios in pseudo-evacuation events such as the clearing of the National Mall after the 4$^{th}$ of July celebration activities.

Prior to September 11, 2001, most of the modeling efforts and tools developed were a reaction to specific events that occurred repeatedly (hurricanes and wildfires) or events whose location was known and impact was potentially devastating to people in the vicinity (nuclear power plant incidents). Afterwards, more emphasis was placed on possible terrorist events and the creation of event scenarios. Also during this time, hurricane-prone regions began to focus more on the efficient evacuation of residents through innovative transportation management approaches (contra flow lanes) or real-time operations.

In the next phase of the study, representative models within each broad class (macro, meso, micro, decision-support) will be obtained for a more detailed assessment. This assessment will include how specific evacuation attributes (e.g, vehicular flow rates) are determined from model inputs. The assessment will include aspects of computational platform requirements, data requirements, as well as cost to acquire and maintain. The detailed assessment will be used primarily to highlight the differences between the classes of models rather than to specifically recommend for or against a specific model. After the assessment is complete, a user guide is planned that will pull together in a summary form all of the findings in the inventory and assessment technical documents.

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