

11. Traffic Analysis and Tools¹

11.1. Description, Challenges and Issues

Over the past years, freeway traffic analysis tools have been significantly improved and advanced in order to meet the needs of emerging freeway planning, design, and operational applications. Simulation continues to advance because of its flexibility and ability to accommodate a wide range of traffic demand, facility configuration, management strategies, and traveler information systems. Simulation enables researchers and practitioners to conduct a wide range of modeling activities. On the other hand, analytical approaches such as those in the Highway Capacity Manual (HCM) have been found to be limited to under-saturated conditions and are typically appropriate for low complexity applications due to their facility-oriented, segment-based methodology and coarse representation of traffic conditions that often fall short in providing accurate and reliable estimation of traffic conditions. However, the HCM procedures have the advantage of simplicity and low application cost which make them attractive for routine applications.

A practical guide to traffic analysis with an emphasis on simulation is being provided by the FHWA with its Traffic Analysis Toolbox consisting of (1) a primer on tools, (2) a guide for the selection of the appropriate tools, (3) guidelines for simulation, (4) guidelines for simulation with CORSIM, (5) case studies, and (6) issues relating to measures of effectiveness (MOEs). As of early 2006, the first three items are available at: <http://ops.fhwa.dot.gov/trafficanalysisistools/toolbox.htm>.

The key challenges for users continue to be the development of a better understanding of the capabilities of existing traffic analysis tools, and the selection of the proper tool(s) for the intended applications. This determination requires both traffic engineering expertise and system-level knowledge of the roadway and traffic system operations. As an example, managing a major multi-year highway construction project requires the understanding of short and longer-term impact of the work zones to the entire transportation corridor. Choosing a suitable freeway traffic analysis tool to assist in developing evolving traffic impacts and in developing effective mitigation strategies remains a challenge. The choice is constrained by knowledge of what tools and program suites are available, knowledge of staff to use the tools, and various budget and time constraints among others.

The relatively high cost for conducting simulation analysis compared to HCM procedures has discouraged some agencies from using simulation. However, cost and time budgets have become lesser factors in recent years, particularly with the urgent need to evaluate complex design and operational strategies for congested networks. In addition, advanced models provide improved usability and direct data acquisition from regional planning and geographic information systems (GIS) applications.

Although both private consultants and public agencies increasingly recognize the benefits of simulation, issues of acceptance of simulation as well as limited understanding of the simulation concepts, strengths, and limitations still exist.

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As these simulation models continue to enhance their capability in modeling complex driver-roadway interactions, the calibration and validation of simulation models remains a critical issue in the successful analysis in freeway projects.

11.2. State of the Art in Technology and Practice

Simulation-based dynamic analysis tools have been increasingly regarded as the primary approach to addressing various freeway operations or operational planning issues. Models with varying simulation time resolutions (such as macroscopic, mesoscopic, and microscopic) are actively being researched and applied. The analytical deterministic approaches in the HCM are commonly used for localized applications, but are less commonly applied in freeway operation analyses. The HCM continues to serve as an important resource for macroscopic or mesoscopic simulation models. These models often estimate intersection or link capacities based on equations or recommended values in HCM.

Freeway simulation applications invoke increasingly sophisticated vehicle-roadway interaction simulation logic rules to represent the driving situation of interest. Emerging critical issues are traffic flow parameters, travel decisions and driving behavior under extraordinary conditions (e.g., extreme weather, disasters, etc.) as well as compliance to traffic advisories and route guidance for normal or unusual conditions. Common applications of simulation analyses conducted for or by public transportation agencies are listed below.

- Identification of freeway bottlenecks and breakdowns for existing and future conditions.
- Determination of the impact of alternative design strategies such as the design of weaving sections, diamond interchange versus SPUI interchange, etc.
- Measuring the impacts of work zones or incidents on a corridor.
- Evaluation of alternative work zone traffic control plans, such as early merge versus late merge.
- Plans for managed lanes or exclusive or restricted facilities (i.e., truck lanes, HOV/HOT.)
- Determination of the need for additional infrastructure such as the number of additional lanes, collector distributor/frontage roads, new interchanges, etc.
- Estimation of the impact of implementing various ITS, traffic control, and demand management strategies.
- Provision of reliable freeway travel time/delay prediction information for dynamic message signs (DMS) and other types of advanced traveler information systems (ATIS.)
- Evaluation of ramp operation strategies (ramp metering, ramp closures, managed ramps.)
- Assessment of the impacts of proposed trip generators.
- Safety analysis under different geometric configurations or weather conditions.
- Evaluation of freeway and ramp bottleneck locations and associated saturation flow rates based on travel forecast information for a planned special event.
- Planning and operation of emergency management and mass evacuation (e.g. contra-flow, phased evacuation) on freeway systems, including the composition of traffic flow, reactions to various freeway advisory devices, etc.

Several dozen simulation-based freeway analysis models exist, but only those used fairly widely by researchers or agencies are discussed below. Models incorporating macroscopic simulation mechanisms include **FREQ**, **FRELO**, **KRONOS**, **SATURN**, **TRANSYT-7F** and **VISTA**. The cell transmission model (CTM) is not a specific tool package, but its simulation

logic has been increasingly incorporated into both freeway traffic simulation, and as an integral part of dynamic traffic assignment (DTA) models.

Mesoscopic simulation logic based models include AMTS, CONTRAM, DYNAMEQ, DYNAMIT, DYNASMART and TransModeler. These models are primarily used to support simulation of dynamic traffic assignment. DTA can be advantageous in providing both short- and longer-term views of freeway operational planning and operational issues by applying either one-pass simulation or iterative dynamic equilibrium analysis. Most mesoscopic models represent individual vehicles which move according to a macroscopic speed-density relationship. The amount of vehicles discharging from an intersection or bottleneck are usually approximated using capacity estimated from past research results or the HCM.

A number of microscopic simulation models have been used in a wide array of freeway analyses and most are under continuous enhancement. Market-ready models include AIMSUN, CORSIM, DRACULA, INTEGRATION, PARAMICS, SIMTRAFFIC and VISSIM. A few others (e.g., FLEXYT-II, HUTSIM, PADSIM, etc.) are in various stages of preparation as of early 2006. Most of these models require network entry traffic volumes to be exogenously provided. This implies that the motorists' travel patterns remain unchanged due to the change of highway geometry or capacity changes, or traffic operation strategies. Some of them include DTA capabilities or interface with DTA-based simulation models to permit the evolution of traffic patterns at different temporal horizons.

The state-of-the-art of simulation-based analysis tools for freeways and traffic networks can be characterized by the following directions:

1. High-fidelity microscopic simulation models continue to improve with expanded and extended vehicle-roadway and vehicle-vehicle interaction logic, motivated by emerging applications (such as managed lanes, late merge work zone control, etc.) as well as available calibration datasets such as the NGSIM dataset.
2. The incorporation of dynamic traffic assignment capabilities allows a simulation model to address both the short- and long-term impact of freeway operation plans. DTA allows for the realistic estimation of corridor-wide traffic flow redistributions resulting from the various demand/supply changes and interactions. This enhancement improves modeling realism because it allows for the network demand to be responsive to roadway capacity changes according to certain equilibrium or route choice assumptions.
3. On-line and off-line applications of simulation models at ITS centers.
4. Application Program Interface (API) environments provided with advanced simulation models allow for the testing of advanced technologies and strategies to manage traffic, such as the development of custom controller or ramp-metering logic.
5. Run-time or off-line integration of microscopic, mesoscopic and macroscopic simulation models allow for a greater modeling flexibility and a wider spatial coverage of the study area, fully exploiting the advantages of both regional mesoscopic and facility/corridor-oriented microscopic models. A number of existing research and commercial efforts may soon demonstrate the advantages of a mixed-scale traffic simulation application.

11.3. Trends and Gaps in Practice

There is a long list of trends and gaps relating to the practice of simulation tools.

Gaps, Issues or Concerns

- ❖ Typically most sophisticated models of large corridors run the slowest and they are probabilistic, therefore multiple runs with various random seeds must be conducted, increasing the cost of the simulation effort.
- ❖ Simulation models require significant effort to calibrate, particularly for large networks. Simulation model users need guidance and training to correctly calibrate these models.
- ❖ Guidance is needed regarding the essential data required to run and calibrate the simulation models for minimum acceptability of model results.
- ❖ Different simulation models define and calculate performance measures or MOEs differently. In addition, the simulation model definitions of performance measures are different from those of the HCM. The way in which MOEs need to be measured in the field in order to calibrate the model is an open question.
- ❖ The behaviors of mainline and ramp traffic in weaving, merging and diverging situations are difficult to calibrate globally in simulation programs because of variances in geometric and other features along the freeway.
- ❖ Several simulators have become available in recent years, so users have difficulty in identifying the best simulators for a given application. For example, mesoscopic simulation models could be more appropriate for alternatives analysis than microscopic simulation models in certain cases. The high cost of acquiring, learning and applying advanced simulators have limited most simulation users to specialize in one or two of them.
- ❖ Most advanced alternatives analysis requires origin-destination (O×D) data. O×D data are expensive to collect by survey (which can be accurate) and highly uncertain if estimated mathematically from typical screen line volume counts. O×D matrices produced by traffic demand estimation models, typically used to estimate demand for planning analysis, have been found to be insufficient as inputs to simulation models for detailed operational analyses.
- ❖ Complex freeway corridor analyses requires the implementation of DTA which can be done with several alternative formulations, likely resulting in varied results.
- ❖ The accurate modeling of the impacts of emerging ITS technologies requires additional research effort.

Trends

- Success has been reported in using automated calibration tools in at least partially calibrating simulation programs. These tools, however, are simulation model specific and have been mainly used in research environments.
- Sensors and ITS infrastructure may be able to collect data that are directly applicable to the calibration and use in simulation analyses.
- The gap among GIS, planning and traffic simulation models is closing for alliances of products, but many popular applications in each area remain incompatible.
- Efforts have started for the real-time use of simulation in traffic management centers.
- Advanced simulation modeling has been conducted for HOV lanes, HOT lanes, and other pricing and management strategies.
- The high impacts of man-made and natural disasters have generated interest in using simulation to model the management of transportation systems under these events including the evacuation and reentry processes.
- The NGSIM is likely to result in new algorithms for implementation in traffic simulation that will increase the reliability and consistency of these applications.

- Interest in simulation modeling has been increasing in the research community as is evident by the recent formation of the TRB Joint Simulation Subcommittee (SimSub or AHB45(1)) that is sponsored by four committees including the Freeway Operations Committee.

11.4. Research Needs

4.1. Relating to Freeway Simulation

1. Establish the ability of models to replicate managed lanes with variable separation from the mainline and assist in choices such as between HOV and HOT options.
2. Acceptance of simulation results by decision makers is a lingering issue.
3. Capacity reduction and other adjustments for work zones, incidents, substandard geometric features, weather, etc.
4. Modeling of over-saturated conditions is inadequate, but such conditions are common.
5. Establishment of less detailed but quicker running and with wider capabilities (i.e., ITS, work-zones, incidents, managed lanes) mesoscopic simulation models.

4.2. Relating to Traffic Simulation in General

❖ Requirements for Simulation Modeling

➤ **Behavioral Modeling**

- Driver response to traffic and route guidance information
- Effects of heavy vehicles, weather, work zones
- Response to HOV and HOT lanes, and to variable congestion pricing
- Response on special events such as bus strike, evacuation, etc.
- Modeling of unsafe driving maneuvers

- **Safety modeling:** Relations between geometry, flow characteristics, ramp metering, operator interventions (via ITS) and incidents or crashes.
- **Noise modeling** needs based on road smoothness, tire noise, traffic volume, etc.
- **ITS modeling:** Incorporate vehicle instrumentation technologies such as collision avoidance, lane departure warning, adaptive cruise control, navigation systems.
- **Measures of Effectiveness:** Standardization of definitions for cross-model compatibility and relationships with HCM's Level of Service.

❖ Calibration and Validation Issues

- How is calibration defined? Does it mean different things to different user communities? Consistent definitions of calibration and validation are needed.
- Calibration does not necessarily mean that the model is valid.
- Is there a disconnect between what data is collected and what data are needed to calibrate or validate the models?
- How well are existing models calibrated?
- How good is good enough for calibration?
- Different types of calibrations: Users, model developers, specific applications.
- Desire for an independent mechanism that collects data and evaluates the validity of the model with the assistance of the model.
- Calibration for a particular model or for a particular application?
- Calibrate model for one day and implement it on another day?
- Benchmarks: Need for baselines for testing and validation.