Traffic Analysis Toolbox Volume X:

Localized Bottleneck Congestion Analysis

Focusing on What Analysis Tools Are Available, Necessary and Productive for Localized Congestion Remediation

PUBLICATION NO. FHWA-HOP-09-042

March 2010

U.S.Department of Transportation
Federal Highway Administration

Office of Operations
1200 New Jersey Avenue, SE
Washington, DC 20590

NOTICE

The publication of this document was sponsored by the U.S. Federal Highway Administration under contract DTFH61-06-00004, awarded to Cambridge Systematics, Inc.

QUALITY ASSURANCE STATEMENT

Technical Report Documentation Page

1. Report No. FHWA-HOP-09-042	2. Government Accession No.	3. Recipient’s Catalog No.

4. Title and Subtitle Localized Bottleneck Congestion Analysis: Focusing on what analysis tools are available, necessary, and productive in localized congestion remediation	5. Report Date March 2010
	6. Performing Organization Code
7. Author(s) Albinder Dhindsa, Cambridge Systematics, Neil Spiller, FHWA	8. Performing Organization Report No.
9. Performing Organization Name and Address Cambridge Systematics, Inc. 555 12th Street, Suite 1600 Oakland, CA 94607	10. Work Unit No.
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address US Department of Transportation Federal Highway Administration/Office of Transportation Management 1200 New Jersey Avenue S.E. Washington, D.C. 94607	13. Type of Report and Period Covered
	14. Sponsoring Agency Code HoTM

15. Supplementary Notes
Contact: Neil Spiller, FHWA, HoTM, 202-366-2188, neil.spiller@dot.gov

16. Abstract

In the past, much, or all, of recurring congestion was felt to be a systemic problem ("not enough lanes") but much of the root cause of recurring congestion is in fact subordinate locations within a facility; i.e., "bottlenecks" and chokepoints. Elsewhere on the same facility and during the same hours, the facility runs free. This document is meant to discuss when, where and how to study small, localized sections of a facility (e.g., on/off ramps, merges, lane drops, intersections, weaves, etc.) In cost-effective means. Some chokepoints are (or seem) obvious in their solution; add a turn lane, widen a stretch of highway, retime a signal, or separate a movement by ramp. However, the solution can often lead to hidden or supplementary problems; hidden bottlenecks, disruptions upstream, or undue influence on abutting accesses, etc Analyzing localized sections of highway is different from analyzing entire corridors or regions. Micro simulation analysis products vary in their target applications and purported results. This document will provide guidance that specifies the choice of analysis tools and inputs necessary to analyze localized problem areas. It also provides some guidance as to when analysis it warranted, and what data inputs are required.

17. Key Words Bottleneck, chokepoint, micro simulation, localized	18. Distribution Statement.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages 36	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed pages authorized**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Table of Contents

List of Tables

List of Figures

1.0 Introduction

A significant portion of the nation's traffic congestion problems can be attributed to recurring congestion at specific locations on roadways – conditions that cause bottlenecks. There is now broad consensus that poorly functioning subordinate sections of a facility – rather than the entire facility being "undersized" – is more often than not the predominant problem. In layman's terms, often only the "misfiring" parts of the facility need attention, rather than the much more costly solution of starting over by replacing it or widening it.

A variety of mitigation techniques can reduce the frequency and impact of localized bottlenecks (further defined in Section 2.0). These techniques can range from the most intense (e.g., microsimulation product applications) to the least intense (e.g., sketch planning) with several iterations of tools in between; e.g., simple data summarizations, the Highway Capacity Manual analysis (HCM), empirical analysis, and deterministic tools.

The crux of this document is to help agencies decide which analysis techniques to apply and how. But how should an agency choose which bottleneck analysis tool to apply? Which tools are correctly aligned with which challenges? How should an agency decide when to use a particular bottleneck analysis tool, and when is microsimulation warranted?

This bottleneck analysis tool selection guide was developed to help transportation agency managers decide which analysis is appropriate; and how to apply it cost-effectively. Thoroughly considering these decision-support tools can assure the most efficient use of agency resources to provide the highest level of service (LOS). This guide consists of the following sections:

- **Section 1.0 – Introduction.** How are bottlenecks caused? What should be the role of bottleneck analysis in decision-making? What bottleneck mitigation strategies are available?

- **Section 2.0 – Background and Discussion.** This section prompts the reader to define the study area through some main criteria.

- **Section 3.0 – What to Analyze?** The next step is to decide what level of analysis is appropriate. The availability of resources guides the formulation of alternatives.

- **Section 4.0 – What Level of Analysis is Warranted?** This section guides the selection of the most appropriate class of modeling tool.

- **Section 5.0 – Levels of Analysis.** What are the various options available to analyze congestion, and specifically, localized congestion?

- **Appendix A – Worksheet.** This reference tool guides transportation professionals to identify the appropriate category of modeling tool.

Applying this document and the worksheet will create additional analytical consistency and uniformity across state departments of transportation (DOT), Federal, regional, and local transportation agencies.

2.0 Background and Discussion

The term "bottlenecks," in the context of this guidance, is hereafter confined to the genre of "recurring" traffic bottlenecks, as opposed to "nonrecurring" ones. Recurring bottlenecks are predictable in cause, location, time of day, and approximate duration; e.g., the ones that we encounter in our everyday commutes. Nonrecurring bottlenecks are random (in the colloquial sense) as to location and severity. Examples include crashes, weather events, and even "planned" events, such as work zones and special events, all of which are irregular in occurrence and location.

Let's dispense with nonrecurring bottlenecks for a moment. Nonrecurring bottlenecks are more prone to empirical study; i.e., based on or characterized by observation and experiment instead of theory. Said bottlenecks trigger traffic control plans (TCP) that are either premeditated or reactionary to the event. Tweaking the plan can improve it either in real-time or "for the next time" it is needed. "Dynamic Lane Merges" (DLM) are increasingly being tested, empirically, to increase the safety and efficiency of nonrecurring bottlenecks. DLMs essentially are active traffic management plans that "kick in" when excessive queues are detected, say in work zones. Messages are enacted that display proactive information on how and when to merge. The messages shut off when the queues begin to dissipate. Recurring bottlenecks, however, have historically been studied by the academic community using non-empirical means, like microsimulation.

A "localized" recurring bottleneck may be considered to be a defined event (i.e., cause) in a defined location; e.g., a lane drop, a weave, an intersection, or an off- or on-ramp. For example, repeat congestion at one movement of an interchange over a couple of hours each day would be "local," whereas a "mega" bottleneck or systemic congestion would be considered to be an undersized interchange, and is not the focus of this guidance.

It hardly needs to be said that in the "mega" case, micro simulation is always warranted due to the complexity of the facility or facilities. However, it is recognized herewith that lesser problems typically require comparatively lesser study and solutions. The key is finding the cutoff point at which project execution meets project need, decision-justification, and budget, both in terms of project analysis and project implementation. For example, the insufficiency of a left turn phase at a ramp terminal (causing queuing back down the ramp to the mainline) would not warrant a full-blown study of the mainline, as much as it would warrant an adjustment of the signal timing.

2.1 Common Causes of Bottlenecks

Recurring, localized bottlenecks occur any time the rate of approaching traffic is greater than the rate of departing traffic. The causal effect can usually be attributed to the existence of at least one of two factors:

- **Decision points,** such as on and off-ramps, merge areas, weave areas, lane drops, tollbooth areas, and traffic signals; or

- **Physical constraints,** such as curves, underpasses, narrow structures, or absence of shoulders.

Recurring bottlenecks usually disperse from the rear of the queue, as the volume crush dissipates and the confluence regains its ability to process the traffic more or less under free flow conditions. Nonrecurring bottlenecks, as a point of differentiation, can disperse from the front or rear, depending on whether the cause is incident-related (e.g., crash or work zone) or volume-related (e.g., special event crush load), respectively.

One can even imagine a compounded situation, where a decision point (off-ramp) is preceded by a physical constraint (sharp curve). This type of bottleneck congestion is more complex to mitigate because both the decision point and physical constraint must be addressed to deal with the bottleneck. Further, it is difficult to predict the largest contributor if there are multiple causes.

Each bottleneck cause has its own mitigation strategies. To select the appropriate strategy, planners must understand the bottleneck's causes before attempting to prescribe solutions, which will be discussed in Section 3.0.

2.2 What Role does Analysis Play?

As transportation agencies continue to seek innovative, cost-efficient solutions to reduce and eliminate bottlenecks, analysis of alternatives has become a necessary decision-support process.

By definition, the planner models the study area and measures the performance of several preselected criteria. If no improvements were made ("no-build" scenario), how would the corridor operate in the future? Conversely, what effects would be incurred if the alternatives were implemented? Alternatives analysis can be developed to compare operational forecasts under different scenarios.

Because analysis is useful for so many stages of the decision-making process, a variety of methods exist. It is important to note that the methods vary greatly; no one tool can model all scenarios or proposed improvements. Thus, selecting the appropriate tool based on the goals and objectives of the project is critical, and is the focus of this guidance.

2.3 Bottleneck Mitigation

In some cases, the most cost-effective ways to relieve bottlenecks are through the simplest geometric or operational improvements. Many of these solutions can be executed as safety projects, Federal-aid non-exempt projects, or even maintenance activities. When applied properly, these strategies can produce very high benefit-cost ratios because of the smaller footprint solution, the lower-cost design solution, and the lower life-cycle cost, including planning, design, construction, operations, and maintenance. Some of the more common low-cost mitigation strategies include the following:

- **Signal retiming.** Many congested corridors can achieve bottleneck reductions by simply optimizing the timing of traffic signals or their timing offsets between intersections.

- **Restriping.** Remarking traffic lanes to add auxiliary lanes or acceleration/deceleration lanes can increase capacity or redirect volume more efficiently. Some of the common restriping techniques include preventing weaves or sharp turns that cause slowdowns; restriping lanes to provide more, although slightly narrower lanes; or converting short sections of shoulders into travel lanes.

- **Signage and Signals.** Signs and signals can be designed to purposely restrict specific movements to the benefit of others (i.e., STOP sign, YIELD sign at the minor approaches) or prohibit inefficient movements (i.e., restrict U-Turns or left turns crossing heavy opposing traffic). On the flipside, these strategies also can be used to prioritize heavy movements to prevent bottlenecks from forming (i.e., right turn on red, and providing exclusive left-turn signals).

- **Installing Loop Detectors.** Installing loop detectors ahead of traffic lights can help reduce queuing by dynamically prioritizing the busiest approaches on-demand.

- **Ramp or Driveway Removal (or Modification).** Closing, relocating, metering, or combining ramps, especially low-volume ones, can unclog some traffic streams. In the case of ramp modifications, temporary closures can test a hypothesis. The ramp could always reopen if the cure is worse than the symptom.

In other cases, more costly solutions might be necessary, including rebuilding or redesigning the area in the vicinity of the bottleneck location. These strategies also can produce significant benefit-cost ratios, but the cost will always be higher than the strategies listed previously. These strategies may have high life-cycle financial costs (planning, design, construction, operations, and maintenance) or social costs (such as forcing drivers to relearn lane directions or turns). Regardless of the nature of the cost, these improvements must be planned well before their implementation, because they are costly and difficult to undo. The following project examples include:

- **Washington State DOT Integrated Operations/Construction Programs in Puget Sound Region and Seattle.** A new exit ramp was constructed along I-405/SR 67 to minimize weaving.

- **Post Street Restriping Project.** In San Francisco, California, Post Street between Kearny Street and Montgomery Street was a two-way street that was converted to a one-way street to increase its capacity during the p.m. peak-period.

There are many successful case studies of transportation agencies implementing low-cost, high-cost, or a combination of solutions to relieve recurring, localized congestion. The Federal Highway Administration’s (FHWA) web site http://www.ops.fhwa.dot.gov/bn/index.htm has many other brief examples of localized bottleneck solutions.

3.0 What to Analyze?

This may seem an unnecessary question; i.e., the obvious answer would seem to be "the problem!" However, the purpose of this section is to remind agencies that secondary and tertiary impacts may result.

The transportation industry has dozens of infrastructural and operational strategies for mitigating congestion, including priced-tolling, high-occupancy lanes, telecommuting, public transit, and driver incentives like car-sharing and parking strategies, to name but just a few. At the highest levels, models and simulations offer the chance to test out congestion mitigation strategies without expensive construction or pilot projects. Using the appropriate simulation tools, planners can estimate the future conditions of a specific site with and without the mitigation strategies.

But a microsimulation study may be "overkill"; or not. For any analysis to be effective, it must consider the entire area affected by the bottleneck. For example, changing the signal timing at a frequently congested intersection may eliminate bottlenecks at the site, but if this improvement causes impacts to the neighboring intersections, this may not be a wise strategy. A large enough area must be considered to ensure that the analysis can account for all of the contributing and resulting factors. The questions below can help gauge the geographic/spatial extent of the analysis.

3.1 What Does One Mean By "Localized?"

For a bottleneck to be localized (per the definitions outlined in section 2.1) the factors causing that bottleneck *ideally* should not influence upon, or be influenced by, any other part of the transportation system; however, in a practical sense, the planner should consider any impact to the closest up- or downstream entity. If your bottleneck is deemed to be "the entire corridor" or something greater, then it is not intended to be covered by this guidance.

For a much more detailed discourse on this subject, please refer to FHWA's web site on this subject at http://www.ops.fhwa.dot.gov/bn/index.htm and download or request the document "Recurring Traffic Bottlenecks: A Primer." FHWA publication number FHWA-HOP-09-037.

3.2 Is the Study Area Large Enough to be Meaningful?

One must fully consider the size of the study area in determining the scope of analysis that is necessary.

For example, consider an apparently isolated congested intersection. Suppose that modeling it as a roundabout, or simulating impacts of signal timing adjustments, or restriping, eliminates or greatly reduces the occurrence of bottlenecks. The planner knows this because he or she observes the simulated traffic and no longer sees bottlenecks congesting the study area. The planner then prepares to recommend a mitigation technique, but is unable to quantify the effects of these strategies. The travel time for a car through the roundabout, even under the worst conditions, is one minute or less. How can the planner make a meaningful case for one strategy over another if the results of each are only negligibly different? In this instance, localized

Highway Capacity Manual (HCM) analysis may be more cost effective than a microsimulation product.

However, suppose that in resolving the bottleneck at this intersection it threatens to cause new bottlenecks to form downstream. If the original analysis is localized, its impacts would only be observed at the simulated intersection. If the study area is expanded, the opportunity to improve the entire system would be plausible (discussed below), and the measurable differences between compared strategies is likely to be starker. This is where simulation analysis is likely to make a meaningful contribution.

3.3 What Elements Need to be Analyzed?

Understanding the breadth of the analysis is critical to assessing what level of analysis is justified.

- What are the impacted limits of the study?
- Are upstream and downstream facilities impacted?
- What alternatives can be considered?
- How many hours of congestion are present? What is the optimal outcome?
- How will the public be impacted?
  - Will they accept the temporary inconvenience of work zone?
  - Will they accept the changes in routine; i.e., new routes?
  - Are businesses on board?
- What degree of precision do the decision-makers require?

4.0 What Level of Analysis is Warranted?

An agency with unlimited resources could possibly study – and unnecessarily overanalyze – some proposed physical and operational improvements. Studies require time and cost. There have been many projects wherein low-cost congestion solutions were based on qualified engineering studies (perhaps only sketch planning was necessary) and were executed in the course of time savings and/or cost savings, without execution of a complicated simulated analysis. Conversely, modeling invariably provides a more detailed analysis. Agencies should consider the pros and cons of substituting sketch planning-level studies against a potentially marginal benefit of higher-level analysis. In short, the cost differential may be one factor but should not be *the* factor.

A clear understanding of both the study area and resources available for the project should fairly guide the decision of how much analysis is necessary.

There are two sides to this coin.

- The level of analysis should roughly correlate to the size of the problem. However...

- ... by their very nature, these are low-cost, “low hanging fruit” problems that nevertheless have potentially huge benefits in terms of reducing hours of delay. Even the simplest change may incur a significant operational change elsewhere on a facility.

An agency should not scrimp on the resources necessary to make a knowledgeable decision; meaning that if the complexity of the project, or the level of public discourse is inordinately high, the agency should prepare for a thorough analysis, and possibly a very involved public presentation and discussion, especially in locations near private entrances and land owners.

Some mitigation strategies do indeed lend themselves towards “obvious” solutions or even real world experimentation. Closing a low-volume driveway or ramp can always be reversed if necessary. Tweaking signal timing may indeed be cheaper than building a model and adjusting the simulated signal timing. On the other hand, structural changes to a freeway facility are too costly to rebuild or reverse; experimentation in these cases is not a wise option.

Another important consideration that must be made is the availability of good data. Often, no or little data are available, making a significant portion of the analysis cost devoted to collecting data. An agency also must weigh the cost and necessity of data collection as part of the overall cost, against the fidelity of the analysis results. The agency must include this consideration; is there sufficient data available for the level of study that this project warrants?

4.1 Project Guidelines

Every congestion mitigation strategy comes at a cost. This cost includes the hard costs of analysis, design, materials, and labor; and the soft costs of user impact, public opinion, and life-cycle costs. Building an overpass is an expensive operation. But mitigation strategies also carry sensory and learning costs too. Drivers who frequently traverse a specific corridor will have an adjustment period as they relearn their familiar route with the new overpass. All of these considerations must be weighed when considering to model. Ultimately, the agency’s available resources, both in terms of preproject (e.g., analysis, public opinion, opportunity) and postproject (e.g., project cost, public acceptance, project life-cycle costs, interconnectivity, etc.) will decide how much project analysis is appropriate.

4.2 Small Corrections and Operational Changes

Many mitigation strategies have implementation and learning costs low enough to justify qualified engineering judgment in the real world. These include the following:

- **Adjusting the timing of existing signals.** The timings can be tweaked again, or reset to original settings.

- **Placing new signs or signals.** Signs can be tweaked either in message or relocation; removing or rebuilding signals is a significantly harder task (See “Note” below).

- **Some aspects of lane restriping.** Safety, above all else, should be addressed; but in essence, the striping could be tweaked.

- **The installation of loop detectors.** The detectors will not inherently disrupt traffic; only the application of their data will.

In cases where the bottlenecks are absolutely isolated from upstream and downstream influences, and the study area is small, it may be sufficient for the agency to commit only enough resources *and decision* necessary to implement the strategies listed above.

Note: In the context of the message above, bear in mind that signal optimization software exists that can model intersection operation at less expense than a full simulation analysis.

4.3 Large and Infrastructural Changes

Most projects have implications that are too high to risk without considering even the least amount of analysis, if only to concur, justify, or present findings in a manner that warrants a responsible decision. Most agencies would agree that simulation is a necessary step in larger project execution, as in these examples:

1. The construction of new facilities, such as auxiliary or mainline lanes and overpasses;
2. Complex movements, such as weaves, or the introduction of new movements; and
3. Any changes in required driver behavior, such as converting two-way roads to one-way roads, or other major redirections of flow, may be considered as "non-traditional" solutions requiring other levels of outreach and marketing with local officials and the motoring public.

As has been said before, these changes are expensive to implement, and would be prohibitively more expensive to undo or change. Agencies save money by spending resources up front to analyze simulations, and only implementing these major changes once.

4.4 Public Support and Justification

Of course, not every case is so clear. Planners and approving boards and councils are stewards of the public trust and budget. They must consider which strategies are appropriate for the area, and estimate the potential cost and impact of each strategy. A good rule of thumb is that the level of analysis should correlate to the perceived level of total mitigation cost. A computer-aided rendering of a before-and-after proposal may be its own justification to use micro simulation to present a proposed project to the public.

5.0 Levels of Analysis

The planner must select the most appropriate type of analysis tool. This section introduces the variety of analysis tools, and discusses the circumstances when one might be preferable over another. This section also introduces a set of project characteristics to consider.

5.1 Categories of Analysis Tools

There are numerous types of tools to fit projects of different sizes, scopes, and objectives. Depending on the project, there might be more than one suitable tool, or the project might require more than one tool (from more than one category) simultaneously. These tools can typically be characterized as presented below.

Sketch Planning Tools

These tools produce order-of-magnitude estimates of travel demand, operations, and delay. They are sometimes used to prepare preliminary budget estimates or similar. They can be as simple as look-up tables or basic design criteria found in design or planning tenet manuals. They are limited in scope, analytical robustness, and presentation capabilities.

Empirical Observations

Collecting even the simplest field data or observing particular driver habits can go a long way towards assessing a particular problem. Maybe the observation of *when* or *why* drivers slow, yield, merge, or otherwise react to a bottleneck can help to propose a plan of action. Perhaps the observation that some motorists are bypassing a bottleneck via an adjacent collector-distributor road or local network can lead to a conclusion. Keep in mind that the more detailed the data collected or available, the greater the opportunity to employ a more thorough analysis later on.

Equation Tools

Equation tools contain an analytical procedure that is static and closed-form. In such cases, the analyst will enter several inputs into the model, and the tool will produce singular outputs that provide information on the expected operational conditions on that facility; i.e., specific questions “in” will render specific answers “out,” if you will. Data outputs from such tools can include the facilities’ LOS (delay, speed, density). Such tools are simplistic; the outputs of the tool are typically not fed back into the model as new inputs, but rather, new equations are run. The same inputs will always yield the same outputs; random variations are not accounted for. Examples of equation tools include the Highway Capacity Software (HCS) and SIDRA (software for evaluating and designing roundabouts).

Equation tools are very appropriate for localized study areas like a single intersection or a highway section. Equation tools also are appropriate for a quick-and-dirty preliminary analysis that may lead to or warrant a future, more detailed analysis.

Deterministic Tools

Deterministic tools vary from equation tools in that deterministic tools can go beyond providing information of the traffic conditions present on the facility – they can help analyze operational and signal timing components. Deterministic tools also are closed-form and non-iterative; they do not necessarily use logical, advancing, or repeating investigation that iteratively builds upon a prior result, until a complete computer “run” is delivered. But in a deterministic system, every action or cause produces a predictable reaction or effect, and every reaction, in turn, becomes the cause of subsequent reactions. Given that the HCM has more than 30 chapters covering everything from driveways to highways, there are several qualifying sections that are “deterministic” in their application.

Traffic signal optimization tools also vary in complexity and are deterministic tools. Many of these tools have the ability to optimize signal phasing and timing plans for isolated signal intersections, arterial streets, or street networks. This may include capacity calculations, cycle length, or splits optimization, including left turns, as well as coordination/offset plans. Some deterministic tools also can optimize the ramp metering rates for freeway ramp control. The most advanced traffic optimization tools are capable of modeling actuated and semiactuated traffic signals, with or without signal coordination. Examples of such tools include Synchro and TRANSYT.

Deterministic tools are appropriate for a corridor, a series of intersections, or grid urban network.

Stochastic Tools

Stochastic modeling is the counterpart to deterministic modeling and introduces randomness. There is some indeterminacy in the future evolution of the analysis, as described by probability distributions. The product can generate either totally random outcomes, or, as is typically the benefit of the product, can predict more-probable ones. These tools can evaluate the evolution of traffic congestion problems on transportation systems. By dividing the analysis period into time slices, a simulation model can evaluate the buildup, dissipation, and duration of traffic congestion over time. Simulation models, by evaluating entire systems of facilities, can pinpoint the interference that occurs when congestion builds up at one location before it impacts other locations. Also, traffic simulators can model the variability in driver/vehicle characteristics.

Stochastic tools are most appropriate for analyzing complex systems; advanced operational strategies; mitigation techniques (i.e., adjustments of ramp metering parameters); or larger study areas (typically not more than 100 square miles).

There are three different subcategories of simulation models, as discussed below.

Macroscopic Models

Macroscopic models take place on a section-by-section basis rather than tracking individual vehicles, and therefore operate on the basis of aggregate speed/volume and demand/capacity relationships. Validation of macroscopic simulation models involves replication of observed congestion patterns. Macroscopic models have considerably less demanding computer requirements than other stochastic models. They do not, however, have the ability to analyze transportation improvements in as much detail as other stochastic models; and do not consider trip generation, trip distribution, and mode choice in their evaluation of changes in transportation systems.

Microscopic Models

Microscopic models simulate the movement of individual vehicles, based on theories of car-following and lane-changing. Microscopic models also do an increasingly good job of simulating the geometrics of the facility. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process); and are tracked through the network over small time intervals (e.g., one second or fraction of a second). Upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. In many microscopic simulation models, the traffic operational characteristics of each vehicle are influenced by vertical grade, horizontal curvature, and superelevation (based on relationships developed in prior research). The primary means of calibrating and validating microscopic simulation models is through the adjustment of driver sensitivity factors. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be completed.

Mesoscopic Models

Mesoscopic models utilize data that is more general than microscopic models, but represent traffic components in higher detail than macroscopic models. The mesoscopic models' unit of traffic flow could be the individual vehicle or groups of vehicles. These models can handle large network grids of nodes and links, and can provide for diversionary routes and volume adjustments. Mesoscopic tools can assign vehicle types and driver behavior, or base their behavior on the roadway characteristics.[1] Their movement, however, is governed by the aggregate characteristics of the link or traffic group or cells.[2] Mesoscopic model travel predictions take place at an aggregated level, and do not consider dynamic speed/volume relationships for individual system components (vehicles in most cases).

5.2 A Word about Microsimulation Tools

For all their prowess in number crunching, simulation tools have some caveats. First and foremost, microsimulation analysis is a specialty field and not a standard staff duty. These tools often require a plethora of data, considerable error checking, and the potential for manipulation by one or more of the basic data inputs. Calibration can be complex and time-consuming. Secondly, using them is not a "magic bullet" to be blindly accepted. The algorithms are often vendor-copyrighted and may not have universal acceptance by the professional community. There is no national consensus on the design of a simulation-tool approach. Simulation models assume "100 percent safe driving" and often assume the most direct route selection regardless of human behavior patterns or reaction. This is ***not*** an indictment of simulation tools – merely a caution towards the old adage "data in equals data out" and the fact that special training is required for each differing model that exists.

Microsimulation analysis might be entirely warranted when the complexity of the bottleneck has significant, and not merely incidental, impacts on weaving or upstream and downstream traffic. Other applications might be when the rate of a ramp meter discharge is impacting, or when route changes are impacted.

---

[1] Jayakrishnan, R., H. S. Mahmassani, et al., 1994, *An Evaluation Tool for Advanced Traffic Information and Management Systems in Urban Networks*, Transportation Research C.

[2] Ben-Akiva, M., 1996, *Development of a Deployable Real-Time Dynamic Traffic Assignment System, Task D Interim Report: Analytical Developments for DTA System*, ITS Program, Cambridge, Massachusetts, MIT ITS Program.

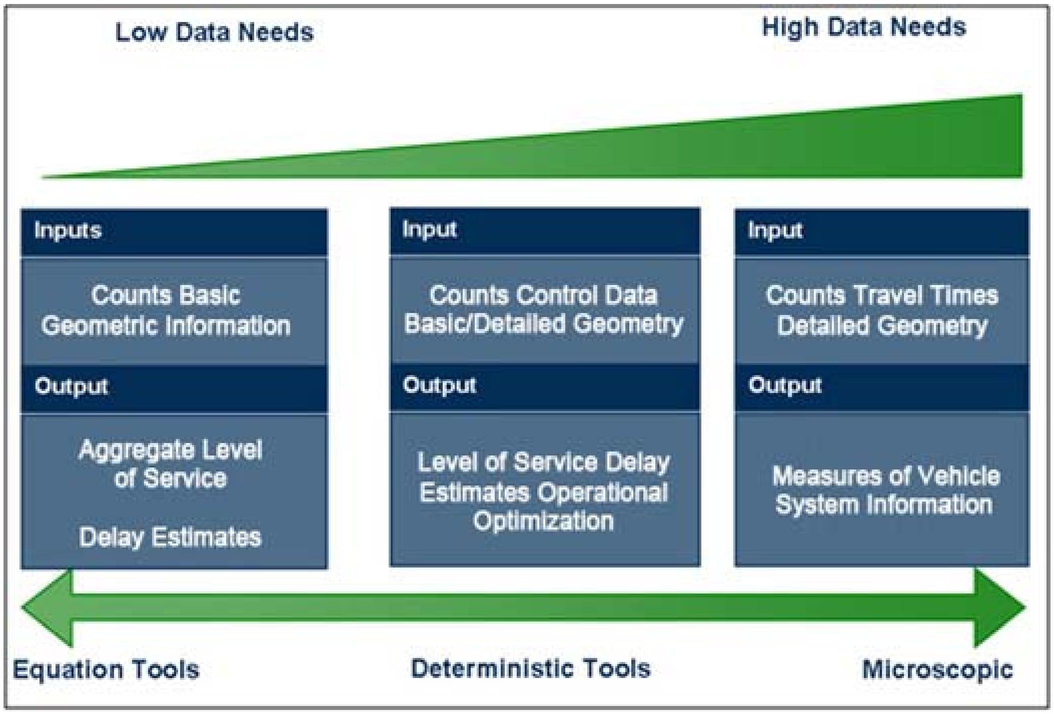

Figure 1. Relative Tool Complexity

5.3 Case Study in Tool Selection: Sacramento SR 65/I-80 Interchange Analysis

Overview

Recurrent, localized bottlenecks occur at the SR 65/I-80 interchange near Sacramento, California because of high traffic volumes and the inefficient geometry of the eastbound to northbound loop connector. Bottlenecks occur in the southbound SR 65 to westbound I-80 in the a.m. and p.m. periods and in the eastbound I-80 to northbound SR 65 in the p.m. The interchange is a Type F-6 freeway-to-freeway interchange. The bottlenecks and their effects are confined by Post Mile (PM) 2.6 and 7.1 on I-80 and PM 4.9 and 6.2 on SR 65.

Existing and forecast peak-period volume data is available for both mainlines and connectors.

The following four alternative solutions are being considered:

- **Alternative 1 –** Add a high-occupancy vehicle (HOV) flyover connector in both directions along the troublesome quadrant. Add an additional lane in each direction from the intersection for three overcrossings in either direction.

- **Alternative 2 –** Replace the eastbound I-80 to northbound SR 65 loop connector with a new flyover connector. HOV connectors would not be constructed. Add an additional lane in each direction from the intersection for three overcrossings in either direction.

- **Alternative 3 –** Add both flyover connectors proposed in Alternatives 1 and 2, as well as the additional lanes in each direction.

- **Alternative 4 –** The No-Build alternative.

Approach

Let us consider the case using the following seven criteria:

1. **Area of Influence –** The congestion is caused by geometric restrictions at a single interchange, but its effects are felt for as long as 4.5 miles upstream on I-80.

2. **Facility –** The facility under consideration is a single freeway interchange.

3. **Availability of Data –** Existing and forecast peak-period volumes are available.

4. **Mitigation Strategies –** The mitigation strategies under consideration include HOV lanes, geometric improvements, and new facilities.

5. **Scope –** The project overview does not state a project scope, but if capital improvements are under consideration, it can be assumed that this project is scoped for the long term.

6. **Performance Measures –** To analyze this situation, one would want to include interchange-wide vehicle throughput and person-mobility (number of persons served through this interchange) to compare the different design alternatives. The overall vehicle-miles of travel (VMT) and vehicle-hours of travel (VHT) can be calculated to gauge mobility and delay. Finally, speeds from the specific connector movements also may be useful. Due to the constrained study area limits, calculating travel time and delay would not be as meaningful or representative.

7. **Cost Effectiveness –** The project overview does not state restrictions on ease of use, so it can be assumed that this is not a prohibitive factor.

Analysis Results

The bottlenecks are localized and are caused by both driver behavior and design factors. The addition of the new flyover ramps (new structures) prompted the use of simulation, since other tool types may be more suitable to model changes in the current structure (i.e., lane widening, lane addition, grade reduction), instead of new links.

More specifically, microscopic simulation analysis would best fit this project's analytical needs. In this case, the project analyst selected *Paramics* traffic microsimulation software to model the interchange.

Modeling each alternative in *Paramics,* the analyst saw that Alternative 3 (both the HOV connector and eastbound to northbound flyover) would serve the most vehicles and people by year 2040. According to the microsimulation analysis, this alternative would serve about 83,000 to 84,000 vehicles during the a.m. and p.m. peak-periods, respectively. This alternative also had the least number of miles traveled relative to the number of vehicles served; between 96,000 to 100,000 vehicle-miles for about 83,000 to 84,000 vehicles per peak-period. The removal of the loop connector would shorten the distances traveled by the eastbound to northbound commuters, thus bringing some fuel consumption and air quality benefits.

Appendix A. Tool Selection Worksheet

Freeway

Depending on the needs of the project, modeling a freeway might require having field data on car-following and lane-changing behavior, but in most cases, default values from the tools should suffice. Some projects might require intense network coding, depending on the study area size and complexity. Table A.1 summarizes the characteristics of different tool types under multiple criteria.

Arterial

Depending on the needs of the project, modeling an arterial may need to include transit operations. Table A.2 summarizes the characteristics of different tool types under multiple criteria.

Roundabout

Depending on the needs of the project, modeling a roundabout might require modeling conflicting volumes. Some projects might include interaction intersections, isolated intersections, or both. Some projects demand comparing geometric configurations. Browse below (Table A.3) to find the category of tool that best fits your specific project.

Signalized Intersections

Depending on the needs of the project, modeling a signalized intersection might require pedestrian behavior. Some projects might transit signal priority, while others might not. Browse below (Table A.4) to find the category of tool that best fits your specific project.

Table A.1 Freeway Characteristics of Different Tool Types under Multiple Criteria

Characteristic	Equation	Deterministic	Macroscopic	Microscopic	Mesoscopic
Level of detail	Only for analyzing broad criteria based on theoretical capacity constraints; only geometric component is number of lanes and grade.	Only for analyzing broad criteria based on geometric capacity constraints; geometry used as physical capacity limits.	Regional travel demand patterns.	Vehicle Interactions, detailed geometry and operational elements (i.e., ramp meters, HOT lanes) may be modeled.	Limited Vehicle Interactions, detailed geometry and operational elements modeled.
Calibration effort	None.	Minor – Not many driver or roadway characteristics to change.	Medium – No calibration needed unless analyst must use innovative techniques to mimic some nonsimulatable strategies.	Significant – Localized bottlenecks can be represented in great detail, so traffic counts, travel times, and bottleneck extents need to be calibrated.	Significant – Localized bottlenecks can be represented as aggregate delay functions that represent slow down; average speed of vehicle groups/link performance must be calibrated.
Methodology	Static equations.	Capacity-based standard equations.	Speed/density relationships and localized volume/ratios are utilized.	Vehicle-to-vehicle interactions and interactions with geometry modeled.	Vehicle interactions usually modeled based on average speed density relationships of vehicle groups or links.
Recommended Application	Capacity determination.	Preliminary feasibility studies.	Regional TDM analysis.	Detailed and accurate representation of bottlenecks; reconstruction/construction staging, alternative analysis, diversion analysis.	Series of localized bottlenecks and possible diversion.
Dynamic traffic assignment	None.	None.	None.	Available.	Available.
Ease of use	High.	High.	Medium.	Low.	Low.
Graphical representation	Basic diagrams.	Moving vehicles with geometric constraints.	Link volumes only.	Detailed geometry, vehicle movements, and dynamic performance measures.	Detailed geometry, limited vehicle details, and aggregated dynamic performance measures.
Input data requirements	Easy to find inputs.	Counts, overlays (design files or aerial photos).	Counts, geographic information layers.	Counts, aerials/design files, travel times, and bottleneck details.	Counts, aerials/design files, travel times, and bottleneck details.
Weaving and merging	Theoretical capacity estimates.	Physical/geometric capacity constrained.	Volume/capacity representation only.	Represented through vehicle interactions and geometry modeling.	Represented through aggregated speed density relationships.

Characteristic	Equation	Deterministic	Macroscopic	Microscopic	Mesoscopic
Sight distance requirements	Theoretical estimates independent of freeway characteristic, demand, or design.	None.	None.	None.	None.
Performance measures	LOS, capacity, estimated delay.	Volumes, speeds, LOS, capacity, estimated delay.	Volumes, LOS.	Volumes, LOS, delay, and speeds.	Volumes, LOS, delay, and speeds.

Table A.2 Arterial Characteristics of Different Tool Types under Multiple Criteria

Characteristic	Equations	Deterministic	Macroscopic	Microscopic	Mesoscopic
Level of detail	Only for analyzing broad LOS criteria based on theoretical capacity constraints. Only geometric component usable is number of lanes and grade.	Only for analyzing broad LOS criteria and delay estimates based on operational systems, such as traffic signals, stop signs, and lanes.	Low level of detail due to large coverage areas.	Detailed.	Only for analyzing broad LOS criteria based on theoretical capacity constraints. Only geometric component usable is number of lanes and grade.
Calibration effort	None.	Volume-based calibration.	Volume-based for large study areas, but cannot be used for specific location calibration.	Significant – Localized bottlenecks can be represented in great detail, so traffic counts, travel times, and bottleneck extents need to be calibrated.	Significant – Localized bottlenecks can be represented as aggregate delay functions that represent slow down; average speed of vehicle groups/link performance must be calibrated.
On-street parking	As standard capacity reduction.	As standard capacity reduction.	As standard capacity reduction.	As standard capacity reduction.	As standard capacity reduction.
Vehicle interaction with pedestrians	None.	None.	As standard capacity reduction.	As standard capacity reduction.	As standard capacity reduction.
Road markings	Number of lanes.	Number of lanes with rough geometry.	No markings – Only capacity constrained by number of lanes.	Number of lanes.	Number of lanes.
Transit	None.	Only operational characteristics such as signal preemption.	Some tools have the capabilities.	Some tools have the capabilities.	Some tools have the capabilities.
Lane restrictions	As capacity constraints.	Yes.	Yes.	Yes.	Yes.
Traffic signal operations	Only standard delay.	Detailed timing plans can be modeled.	Detailed timing plans can be modeled.	Detailed timing plans can be modeled.	Detailed timing plans can be modeled.
Traffic density	Capacity-based only.	Based on broad volume capacity relationships.	Can be shown over time.	Can be shown over time.	Can be shown over time.
Individual travel time	None.	Low utility of individual travel times.	Tracked on a segment-by-segment basis.	Tracked individually.	Tracked individually.

Characteristic	Equations	Deterministic	Macroscopic	Microscopic	Mesoscopic
Delay	Capacity-based estimates.	Based on operational elements like signals, speed limits, etc.	Based on operational elements like signals, speed limits, etc.	Based on operational elements like signals, speed limits, etc.	Based on operational elements like signals, speed limits, etc.
Graphical representation	Diagrammatic representation.	Fairly detailed geometric representation.	Detailed.	Detailed; animations available.	Detailed; animations available.
Input data requirements	Counts, configuration.	Counts, signal timings, traffic, restrictions.	Counts, signal timings, traffic, restrictions.	Counts, signal timings, transit schedules, traffic, restrictions.	Counts, signal timings, transit schedules, traffic, restrictions.
Vehicle categories	Represented as Passenger Car Equivalents (PCEs).	Represented as PCEs.	Classification based on vehicle type, although vehicle dynamics cannot be modeled.	Classification based on vehicle type.	Classification based on vehicle type.
Intersection right-of-way	None.	None.	Can be modeled.	Can be modeled.	Can be modeled.

Table A.3 Roundabout Characteristics of Different Tool Types under Multiple Criteria

Characteristics	Equations	Deterministic	Macroscopic	Microscopic	Mesoscopic
Level of detail	Only for analyzing broad LOS criteria based on theoretical capacity constraints. Not always sensitive to all geometric constraints.	Only for analyzing broad LOS criteria based on theoretical capacity constraints. Geometric components typically used include number of lanes, dimensions of the access points and the circulatory roadways, and grade.	No known tools with roundabout capabilities.	Vehicle operations and geometry modeled.	No known tools with roundabout capabilities.
Range	Single location.	Single location.	N/A	Multiple locations; in series or separate.	N/A
Methodology	Gap acceptance models*	Utilizes linear or exponential empirical regression models based on circulating and entry flows, geometric characteristics, and sometimes driver behavior.**	N/A	Vehicle-to-vehicle interactions and interactions with geometry modeled.	N/A
Performance measures	Capacity, delay, and queuing estimation.	Capacity, delay, and queuing estimation.	N/A	Travel time, VHT/VMT, and animations.	N/A
Conflicting volumes	Calculates conflicting flow rates or circulating flow rates as a function of turning movement volumes.	Calculates conflicting flow rates or circulating flow rates as a function of turning movement volumes.	N/A	Calculates conflicting flow rates or circulating flow rates as a function of turning movement volumes.	N/A
Ease of use	Easy.	Easy.	N/A	Complex, labor-intensive.	N/A
Lane characteristics	Single lane only.	Number of lanes and lane widths are inputs.	N/A	Details can be coded into network.	N/A
Number of approach legs	Not sensitive to geometric parameters.	Serve as inputs; more emphasis on entry flows than number of entry/access points.	N/A	No limits; details can be coded into network.	N/A
Angle of approach legs	Not sensitive to geometric parameters	Sensitive to entry angle and radius – serve as inputs to calculation	N/A	No restrictions, details can be coded into network	N/A

Characteristics	Equations	Deterministic	Macroscopic	Microscopic	Mesoscopic
Study area size	Only analyzes performance of individual approaches to single roundabout; no multiple roundabout interactions	Certain software can analyze multiple roundabout interactions or roundabout interactions with other intersections of various control types.	N/A	Can analyze multiple roundabout interactions or roundabout interactions with other intersections of various control types.	N/A

*"Roundabouts in the United States," NCHRP Report 572, Transportation Research Board, National Academies, 2007.

**Appendixes to NCHRP Report 572: Roundabouts in the United States, Transportation Research Board, National Academies, 2007.

Table A.4 Signalized Intersection Characteristics of Different Tool Types under Multiple Criteria

Characteristics	Equations	Deterministic	Macroscopic	Microscopic	Mesoscopic
Level of detail	Only for analyzing LOS based on capacity constraints. Only needs number of lanes and grade.	Only for analyzing LOS based on capacity constraints. Only needs number of lanes and grade.	Uses geometric and volume information as inputs; common outputs are LOS, delay, and queue length.	Needs volume, trip distribution, and geometrics as inputs; common outputs are travel time, VHT/VMT, and delay.	Needs volume, trip distribution, and geometrics as inputs; common outputs are travel time, VHT/VMT, and delay.
Signal type	Pretimed.	Pretimed and actuated.	Pretimed, actuated, and coordinated.	Pretimed and actuated.	Pretimed and actuated.
Signal optimization	None.	None.	Available.	None.	None.
Intersection type	Isolated intersection with four legs maximum. Basic operations only.	Isolated intersection, with four legs maximum. Basic operations only.	Can be in isolated, in series, or grid system.	Can be in isolated, in series, or grid system.	Can be in isolated, in series, or grid system.
Performance measures	LOS, capacity, and delay.	LOS, capacity, lane-by-lane volumes, timing, queue lengths, delay, stops, average speed, and throughput.	LOS, capacity, lane-by-lane volumes, timing, queue lengths, delay, stops, average speed, and throughput.	Throughput, travel time, and delay.	Throughput, travel time, and delay.
Roadway conditions	Number of lanes, grade, timing.	Number of lanes, grade, and timing.	Number of lanes, grade, timing, pedestrian, transit, parking factors.	Number of lanes, grade, timing.	Number of lanes, grade, timing.
Multicycle modeling	None.	None.	Available.	Available.	Available.
Methodology	LOS assessment for signalized intersections based on delay caused by the signal.*	LOS assessment for signalized intersections based on delay caused by the signal.	LOS assessment for signalized intersections based on delay caused by the signal.	Vehicle-by-vehicle simulation, and then aggregated together.	Vehicle-by-vehicle simulation, and then aggregated together.
Pedestrian behavior	Can estimate the LOS for pedestrians at signalized intersections.	Can estimate the LOS for pedestrians at signalized intersections.	Can estimate the LOS for pedestrians at signalized intersections.	None.	None.
Transit signal priority	None.	None.	Basic settings available.	Available with custom programming.	Available with custom programming.
Unusual geometry	Not supported.	Not supported.	Allowed.	Allowed.	Allowed.
Graphical representation	Simple diagram of three- to four-way intersections.	Simple diagram of three- to four-way intersections.	Moderate details; no vehicles shown.	Detailed; vehicles may be shown.	Detailed; vehicles may be shown.

Characteristics	Equations	Deterministic	Macroscopic	Microscopic	Mesoscopic
Intersection coding	Easy.	Easy.	Moderate; requires some detailed field info.	Data and labor intensive.	Data and labor intensive.
Lane restrictions	Only capacity constraints.	Only capacity constraints.	Only capacity constraints.	May restrict certain vehicle types.	May restrict certain vehicle types.

* Draft Working Paper NCHRP Project 3-85-12, Guidance for the Use of Alternative Traffic Analysis Tools for Highway Capacity Analysis, Chapter 16: Signalized Intersections, University of Florida Transportation Research Center, December 2007.

U.S. Department of Transportation
Federal Highway Administration
Office of Operations (HOP)
Mail Stop: E86-205
1200 New Jersey Avenue, SE
Washington, DC 20590
Web site: http://ops.fhwa.dot.gov

Publication #FHWA-HOP-09-042