Capacity Project Brief

Operations Guide to Improving Highway Capacity

AUGUST 2012

When considering how to improve highway capacity, decision makers would benefit greatly from being able to compare the capacity gain of operational improvements to that of adding a lane. Applying enhanced models, diagnostic tools, and analytic methodology can provide a more realistic basis for such comparisons. Analysis methods can evaluate improvement strategies cutting across the full spectrum of operations, technology, and design; and they can also provide multiple performance measures that can be used to evaluate different strategies according to their impacts at the point, link, corridor, and network levels. This project developed a guide to using enhanced simulation methods that can test the impact of alternative traffic operations solutions and demonstrate whether or not they solve a problem.

Limited financial resources, high construction costs, environmental considerations, long timelines, and an increasingly complex regulatory process have rendered capacity-adding projects actions of last resort; nevertheless, the continuing growth in urban travel demand will inevitably lead to a need for more physical capacity within the transportation system. Before such projects are undertaken, decision makers, planners, and engineers typically must evaluate alternative operational improvement strategies that can—individually or in combination—eliminate, mitigate, or forestall the need for a more traditional highway construction project.

Dynamic traffic assignment (DTA) methods (simulations) are rapidly being improved and use is increasing. Ideally, such methods would be able to evaluate operations, technology, and design issues simultaneously and produce performance measures at point, link, corridor, and network levels.

SHRP 2 project C05 (Understanding the Contribution of Operations, Technology, and Design to Meeting Highway Capacity Needs) was created to advance the state of practice in this area. This project had three objectives:

1. Quantify the capacity benefits—individually and in combination—of operations, design, and technology improvements at the network level for both new and existing facilities;
2. Provide information and tools to analyze operational improvements as an alternative to traditional construction; and
3. Develop guidelines for sustained service rates to be used in planning networks for limited access highways and urban arterials.

Through these objectives, the project developed methodologies that effectively determine the capacity gain that can be expected from candidate operational improvements relative to the capacity gain that would be provided by constructing an additional lane. A better understanding of the contributions of operations, technology, and design to meet highway capacity needs will be useful in making public investment decisions; planning and evaluating alternative optional improvement strategies; evaluating highway designs; advancing research and professional training; and exploring the benefits of current and future ITS technologies.

SHRP 2
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

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Enhanced Analysis Methodologies

This research project has four primary findings: (1) The capacity effect of traffic operational improvements is related to the network. A similar improvement may have different effects in different locations. (2) Capacity in both freeway and arterial situations is variable, or stochastic. Capacity should be treated as a variable related to other factors, not as a constant. For example, empirical evidence shows that freeway flow breakdowns occur across a range of volumes even at the same location. On arterials, saturation flow rates at signals are observed to vary from cycle to cycle. (3) In saturated real-world networks, spill-over blockage from left- and right-turn bays has an inordinate effect on arterial capacity. Simulation models must be sensitive to this. (4) The real-world consequence of a stochastic freeway or arterial bottleneck is that breakdown conditions vary from day to day. Combined with daily variation in travel demand, this means that real-world drivers make choices based on actual conditions they have encountered across multiple driving days. This research incorporated such a feature into the simulation model.

The primary products of this research are the recognition that the principles described above should be taken into account when estimating the effect of a traffic operational improvement and that enhanced analysis methodologies should be used to carry out such analysis.

Operational Strategies

Table 1 lists 25 operational strategies that were selected from an initial list of more than 100 as being particularly effective in enhancing the performance characteristics of links, corridors, and networks. Some of the strategies are applicable only to freeways, some are applicable only to arterials, and some are applicable in both environments.

Table 1. Non–Lane-Widening Strategies to Improve Capacity

FREEWAY	ARTERIAL	BOTH
HOV Lanes	Signal Retiming	Narrow Lanes
Ramp Metering	Signal Coordination	Reversible Lanes
Ramp Closures	Adaptive Signals	Variable Lanes
Congestion Pricing	Queue Management	Truck Only Lanes
Pricing by Distance	Raised medians	Truck Restrictions
HOT Lanes	Access Points	Pre-Trip Information
Weaving Section Improvements	Right/Left Turn Channelization	In-Vehicle Info
Frontage Road	Alt Left Turn Treatments	VMS/DMS
Interchange Modifications		

Notes: HOV = High Occupancy Vehicle; HOT = High Occupancy Toll; Alt LT = Alternate Left Turn; VMS = Variable Message Sign; DMS = Dynamic Message Sign

Because the practical use of such methods in a real-world environment depends on the ability to implement them, an important question was raised at the start of this project: "What assignment or simulation tools can be considered for this purpose?" DTA modeling tools were targeted because of their unique ability to evaluate network performance under time-varying demand and supply conditions created by various operations-based, design-based, and technology-based strategies. A wide range of network analysis tools is currently available. The research team selected Dynasmart-P and DTALite for enhancement and testing of strategies.

Network Operations Modeling Approach

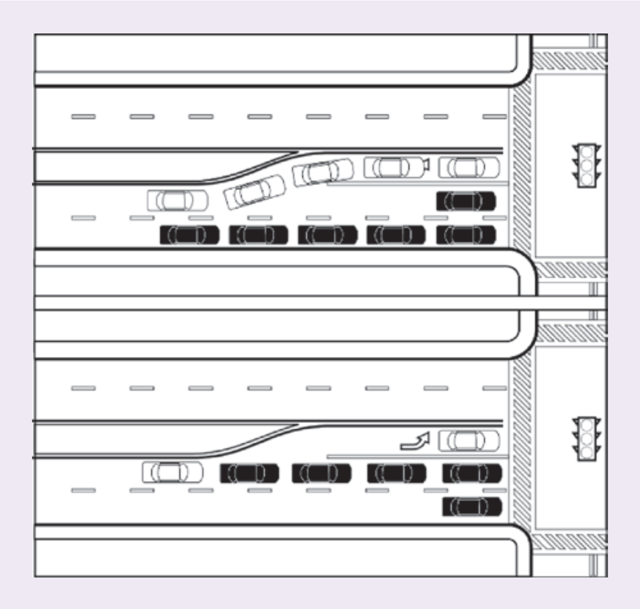
The effectiveness of each operational strategy listed in Table 1 was found to vary according to the context in which it is applied. Physical factors such as network structure as well as the existence and relative proximity of freeway/arterial alternatives have an important influence on a particular strategy's effectiveness; travel desire lines and overall demand levels were also found to have a significant impact. Thus, the effectiveness of a particular operational strategy within a particular network and demand setting could not be reliably estimated from static, location-blind look-up tables. Instead, some form of a travel demand forecasting model was found to be necessary.

Because of their ability to provide a more realistic assignment of traffic in oversaturated networks, DTA models are especially useful for evaluating strategy effectiveness. They recognize that drivers have varying levels of knowledge about the travel time on each of the travel paths available to them, and they also recognize that the effects of congestion and queues can prevent drivers from reaching their destinations in a timely manner.

The capabilities of DTA models overcome some but not all of the limitations associated with more traditional models. A review was conducted of currently available DTA models and none was found to include all the modeling capabilities desired. The internal logic of one of these models (DYNASMART-P) was modified to incorporate several analytic enhancements. This new version of DYNASMART-P also served as the test engine for the validation and demonstration activities that were used during completion of the analytic enhancements.

For an example of how the new model functions, we can look at the way arterial bottlenecks are represented. The approaches to signalized intersections along arterial roadways often include left- and right-turn pockets as a way of separating turn movements and increasing capacity. But when the queue length of through and/or turning vehicles extends beyond the length of the turn pocket, the result is a blockage that prevents upstream vehicles from taking advantage of the capacity that is available at the intersection (Figure 1). This is an important phenomenon to model in oversaturated networks because it directly affects the efficiency and productivity (or sustained service rates) of individual links and turn movements. By incorporating this phenomenon, the enhanced model developed in this project can recognize when queue lengths exceed available storage lengths at these locations and then adjust the downstream discharge rate accordingly.

Figure 1. Traffic Model Enhancements to Account for Short Lane Effects



Strategic Testing

To test the enhanced models and demonstrate the usefulness and usability of the new methodology, two separate networks were used. The first network used was a small subarea of the Dallas/Fort Worth, Texas, metropolitan area; its small size produced great efficiencies in testing and debugging the enhanced DTA models, and also provided a good platform for implementing and evaluating each of the 25 operational strategies presented in Table 1. The second network was a subarea of the Portland, Oregon, metropolitan area—encompassing approximately 210 traffic analysis zones, 860 nodes, 2,000 links, and more than 200,000 vehicle trips initiated during a four-hour weekday time interval between 3 and 7 PM.

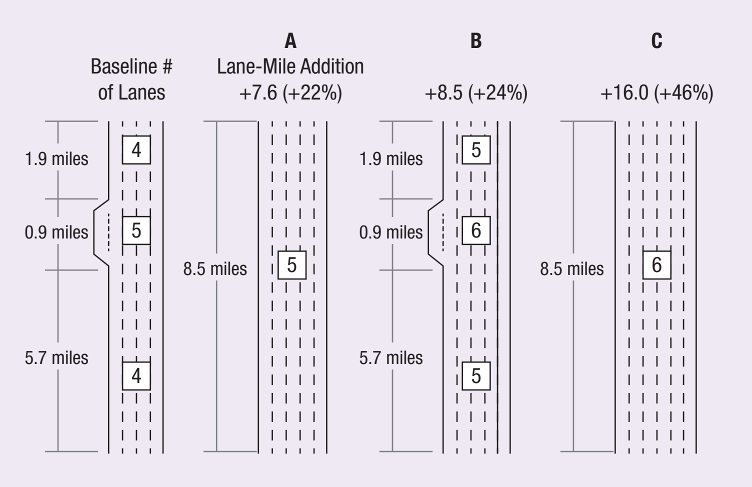
A straightforward method was developed to test the effectiveness of one or more operational strategies either as standalone projects or as alternatives to traditional new construction project(s). In the first step of this method, the location of the operational strategy and/or new construction project to be tested is identified, and a subarea or network that appropriately surrounds the location is established. Next, geometric, volume, and operational characteristics of each link within the subarea are identified and provided as inputs to the DTA model, including stochastic capacity distributions at the geometric or operational bottlenecks; and appropriate link, corridor, and/or network performance measures are established for subsequent evaluation purposes. In order to effectively use the day-to-day learning process and generate results that can be usefully compared, the DTA model has to run under three separate regimes. During the baseline stabilization period (Regime I), the DTA model is run for a period of simulated days to achieve equilibrium under the baseline scenario (that is, without any of the operational strategies or new construction projects that are to be evaluated). The number of simulated days necessary to achieve equilibrium varies according to the characteristics of the network and/or subarea being investigated. For the Dallas/Fort Worth network, the 200-day baseline stabilization period was longer than necessary. This was not a problem in the case of the Dallas/Fort Worth network because the subarea was small and the runtime for each simulated day was very short. For larger networks, a baseline stabilization period of 50 days may be more appropriate.

As an example, consider the capacity addition scenarios shown in Figure 2 that were tested for a southbound freeway corridor section within the Dallas/Fort Worth subarea network. This Figure illustrates the existing (baseline) condition as well as three separate lane addition projects (denoted as A, B, and C) that were contemplated and tested.

In addition to the three lane addition projects identified in Figure 2, four other operational strategy alternatives to the lane addition projects were also evaluated at this intersection:

1. An advanced traveler information system (ATIS) strategy in which the fraction of drivers having access to pre-trip information (for example, via radio, television, and/or websites) was increased from 1 percent to 10 percent;
2. Another ATIS strategy in which the fraction of drivers having access to en-route information (through

Figure 2. Capacity Scenarios (Southbound Freeway Corridor)

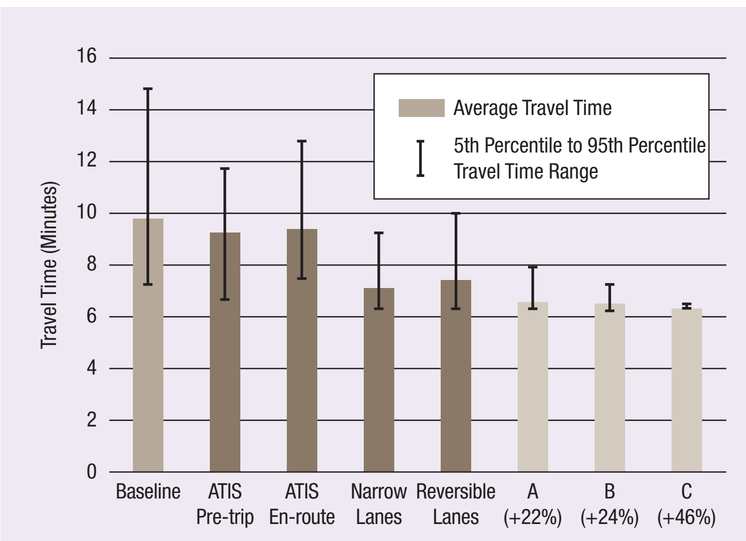


in-vehicle navigation systems, for example) was increased from 1 to 10 percent;

3. An operational modification to the existing baseline condition in which the width of the freeway lanes and shoulder within a critical 3.1-mile section of the southbound freeway corridor was narrowed so that a fifth lane could be introduced; and
4. An operational modification to the existing baseline condition in which one northbound lane was reversed in the same 3.1-mile section during the peak hour so that a fifth lane could be added in the southbound direction.

Figure 3 shows the results of a 20-day comparison based on average travel time in minutes and travel time reliability expressed as the range between the 95th and 5th percentile travel times. The gray bar represents performance for baseline conditions. The black bars represent the effects of individual non–lane-widening strategies. The white bars represent three lane-widening scenarios: (A) five lanes across all three segments; (B) one additional lane across all three segments; and (C) six lanes across all three segments. This graphic demonstrates how tradeoffs for improvement strategies can be examined in terms of their impact to average travel time (expressed as minutes of travel time) and travel time reliability (expressed as the range between the 5th and 95th percentile travel times).

Figure 3. 20-Day Model Results at Corridor Level



Note: ATIS = Advanced Traveler Information Systems

Notice that pre-trip and en-route travel information improved reliability but had little effect on throughput. The narrow lane strategy (which yields more lanes) improved throughput and reliability, but the effects on safety were not evaluated. In some cases (the provision of pre-trip information, for example), travel time reliability associated with the tested option is significantly improved in relation to the base condition, even though the average travel time is largely unaffected. In other cases, such as the narrow lanes strategy and each of the new construction projects, both travel time and travel time reliability are significantly improved by the tested option, although the narrow lane strategy may have negative safety impacts that were not considered in this analysis.

Without the examination and assessment of reliability as a performance measure, a primary benefit of the strategies would go unrecognized, particularly for the non–lane-widening strategies. The results shown in Figure 3 were taken from a test network and should not be considered to be representative of outcomes that can be expected in other applications because they are dependent upon the particular chara cteristics of the network and the travel-demand levels that are being modeled.

Report Availability

The Operations Guide to Improving Highway Capacity will be available online in fall 2012. The enhanced DTA model described in the Guide can be applied within virtually any local network environment with only a few adaptations. t

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