Traffic Bottlenecks Operational Improvements

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Traffic Bottlenecks: A Primer

Focus on Low-Cost Operational Improvements

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Introduction

The delays arising from traffic congestion are a fact of life in many communities. According to a February 2007 Harris Poll, just over one-third (37 percent) cite traffic congestion as a serious problem in the community, while one-quarter say traffic congestion is a serious problem that is not being addressed. Close to half of all congestion happens day after day at the same time and location. Much of this recurring congestion is due to physical bottlenecks – specific points on the highway system where traffic flow is restricted.

While many of the Nation's bottlenecks can best be addressed through costly major construction projects, there is also significant opportunity for the application of operational and low-cost infrastructure solutions to bring about relief in the short term. This document, ***Traffic Bottlenecks: A Primer – Focus on Low-Cost Operational Improvements***, describes bottlenecks and explores the opportunity for near-term operational and low-cost construction opportunities to correct them.

This Primer is intended to be a dynamic work-in-progress. While updated hard-copy versions will occasionally be made available, an electronic version will be regularly supplemented as new strategies are identified from within the transportation community. The Primer is a key resource for Federal Highway Administration's Localized Bottleneck Reduction (LBR) Program, providing a virtual forum for peer exchange between members of the transportation community interested in alleviating bottleneck congestion. The LBR program, initiated in 2007, is designed to expand the portfolio of bottleneck reduction tools available to transportation agencies to encompass innovative, readily adopted strategies for reducing congestion at bottleneck locations.

The Congestion Problem

Over the past 20 years congestion has grown in every dimension – duration, extent, and intensity. The portion of the day impacted by traffic congestion has grown from 4.5 to 7.0 hours. Peak periods typically stretch from 2 or 3 hours in the morning and evening in metro areas above one million people. Larger areas can see 3 or 4 hours of peak congestion.

The extent of congestion has grown from 33 to 67 percent of travel. This statistic means that congestion affects more of the system. Many cities have a few places where any daylight hour might see stop-and-go-traffic. Weekend traffic delays have become a problem in recreational areas, near major shopping centers or sports arenas and on some constrained roadways.

The intensity of congestion as measured by the average delay penalty (the extra travel made each day due to congestion) has increased from 13 to 37 percent in the past 20 years. In other words, peak-period trips required 37 percent more travel time in 2003 than a free flow trip at midday, up from 28 percent 10 years earlier. Trips to work and school take longer, but so do shopping trips, doctor visits, and family outings.

Congestion is Costing Me How Much?

In the top 85 (of 400) urban areas (i.e., those areas that account for the worst congestion indices) the average annual cost of congestion per traveler (including the cost of time and operating a vehicle) ranges from $222 (small urban areas) to $1,038 (large urban areas) and averages $794.

2005 Urban Mobility Study, The Texas Transportation Institute (TTI), 2005

The consequences of congested roadways in the U.S. are both monetary and societal. The cost of congestion for the 85 urban areas in the Texas Transportation Institute's (TTI) 2005 Urban Mobility Report was estimated to be $63 billion based on the 3.7 billion hours of delay and 2.3 billion gallons of wasted fuel calculated in those areas. This congestion cost to the U.S. economy in 2003 was equivalent to 0.6 percent of the Gross Domestic Product (GDP). Moreover, these congestion costs are growing at 8 percent per year, more than double the growth rate of the economy, so that in 20 years congestion costs are expected to rise to 1.6 percent of GDP. But these published estimates likely account for less than half of the overall costs for transportation congestion. Additional costs include:

- Costs of congestion in rural areas and smaller cities outside of the 85-city TTI sample;
- Loss of productivity due to reduced scale economies and labor market sizes;
- Safety costs;
- Vehicle wear and tear on passenger cars;
- Costs of cargo delays;

- Inventory costs of bigger stocks required by congestion-related unreliability in shipment times; and
- Costs to passengers of having to leave early for a destination because of congestion-related unreliability in travel times.

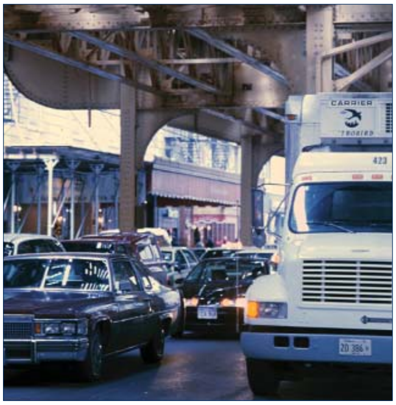
Not only does congestion dampen the economy, it also impacts the way we live: Parents miss events with their children; friends and families find it harder to spend time together; and civic participation is increasingly difficult. Evidence suggests that each additional 10 minutes in commuting time cuts involvement in community affairs by 10 percent.

The root causes of congestion have long been understood, and there is now broad consensus that congestion generally reflects a fundamental imbalance of supply and demand. That is, during hours of peak usage of the transportation facilities most desirable to motorists, the supply of, for example, roadway capacity is insufficient to meet the demand for those facilities. Economists have long understood that such an imbalance stems from inefficient pricing, where the true costs of usage are not reflected in prices paid by the users. For example, travelers are not generally charged for the impact their trip will have on others using the same facility (e.g., increased levels of congestion) or on other members of society (e.g., increased air pollution). In fact, in this country, access to highway travel is, for the most part, rationed by delay.

The imbalance of supply and demand leading to congestion is also impacted by the absolute volume of traffic (e.g., demand) on a given facility relative to its physical capacity (e.g., supply). When we look at traffic congestion from a demand perspective, we are looking at how many vehicles compete for space on a particular facility at a given time. The demand for a facility is a function of individual decisions as to when, where, how, and even if highway travel will take place.

Washington Post, June 2007

A June 2007 article in the Washington Post laments the difficulty parents in outlying suburbs have in attending their kids' evening soccer, t-ball, baseball, and softball games. Parents who are coaches, and have responsibility to be early to set up the field, have an especially hard time, often arriving in their office clothes directly from work. Games are routinely pushed back 30 to 60 minutes; leagues are over taxed because only one, and not two, games can be played per evening on the same field.



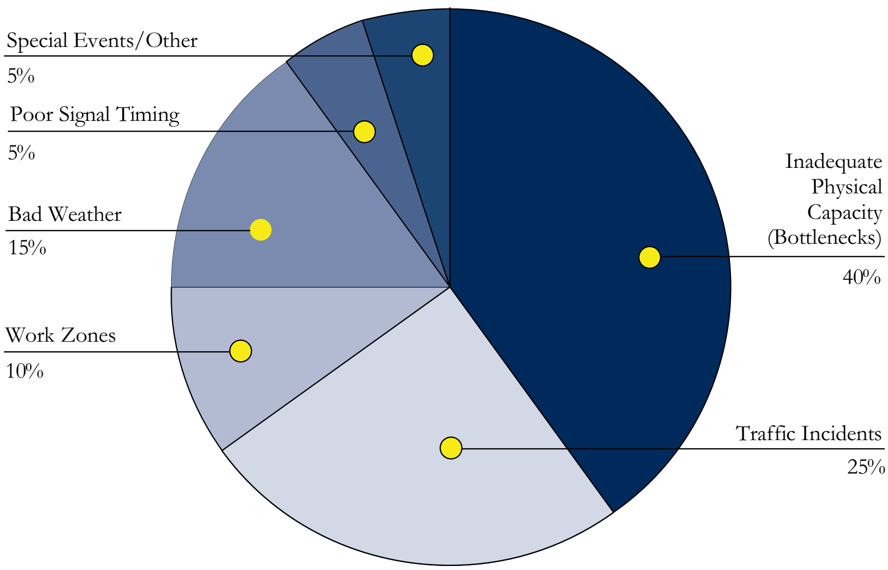
On the supply side, congestion is primarily a function of the physical characteristics of the facility and events that limit the availability of this capacity. Congestion driven by supply side considerations is characterized as either "recurring" or "nonrecurring." This distinction is useful in helping the community of transportation professionals devise strategies that will either mitigate or reduce congestion. Recurring congestion happens in roughly the same time and place on the same days of the week. It results when physical capacity is simply not adequate to accommodate demand during peak-periods. On the other hand, nonrecurring congestion is caused by events such as work zones, traffic incidents, and bad weather. Obviously, when these nonrecurring events occur on an already congested facility the impacts are magnified. Figure 1 presents a pie chart showing the factors that cause on-the-road congestion.

Improvements Are Possible!

"Seven of 18 bottlenecks identified in 1999 – including hot spots in Houston, Albuquerque, Denver, Boston, Los Angeles, and Washington, D.C. – no longer appeared on our ranking of the country's worst chokepoints (due to) major reconstruction projects completed or underway."

American Highway Users Alliance, 2004

Figure 1. Sources of On-the-Road Congestion



Source: http://www.fwha.dog.gov/congestion/describing_problem.htm.

Solving the Congestion Problem

Consistent with the paradigm of its causes, there are four distinct, but nonetheless related strategies available to attack congestion. Table 1 outlines the four strategies and provides examples of specific options for furthering each of them. It is important to note that the strategies, while individually of merit, work best when implemented as a coordinated package of tools.

Bring Supply and Demand into Alignment through Congestion Pricing. Congestion pricing or peak-period pricing, entails fees or tolls for road use that vary by level of vehicle demand on the facility. As with market pricing in other sectors, road pricing helps allocate limited supply – in this case that of available road space.

Table 1. Examples of Strategies to Reduce Highway Congestion

Bring Supply and Demand into Alignment through Congestion Pricing
Road Pricing
Ramp Metering
Corridor Management
Provide Real-Time Travel Information
Provide Better Choices as to How, When, Where, and If to Travel
Provide More Attractive Alternatives to Single Occupant Vehicle Transportation (Including Better Transit, More Telecommuting, or High Occupancy Toll Lanes)
Provide Real-Time Travel Information
Strategically Invest in New Transportation Capacity
Add New Construction on New Alignment
Improve the Management and Operation of the System
Quickly Restore Capacity After Traffic Disrupting Events – Improve the Management of Traffic Incidents – Improve Mobility at Work Zones – Respond Effectively to Inclement Weather Conditions – Plan Ahead for Special Events
Improve the Day-to-Day Operation of the System – Improved Traffic Signal Timing – Operational and Low-Cost Construction Improvements to Relieve Bottlenecks (e.g., restriping)
Provide Real-Time Travel Information to Agencies and System Users

Please Dispose of Gasoline Properly!

Imagine purchasing from 8 gallons of fuel (in a small urban area) to 36 gallons of fuel (in a large urban area) per year, and then throwing it away. In fact, that is one estimate of how much fuel is wasted while idling in congestion per year. At $3.00/gallon, that amounts to $24 to $108 "out of pocket" for every driver in these areas. The average was 28 gallons, or $84.

2005 Urban Mobility Study, The Texas Transportation Institute (TTI), 2005

With user charges assessed at the point of use, greater efficiency results through improved response to market forces. Charges are typically assessed electronically to eliminate delays associated with manual toll collection facilities. Road-use charges that vary with the level of vehicle demand provide incentives to shift some trips to off-peak times, less-congested routes, or alternative modes; or to cause some lower-value trips to be combined with other trips or simply to be eliminated.

Congestion pricing has several important objectives. First, it seeks to balance demand with available capacity, i.e., the supply of road space. Second, it seeks to fairly allocate the costs associated with operating, maintaining, and expanding the transportation system to meet growing travel demand. Third, it seeks to improve operation of the highway system. A fourth objective may include revenue generation.

Provide Better Choices as to How, When, Where, and If to Travel. The goal with this strategy is to reduce the number of vehicles on a given road. This may take the form of promoting alternative commute options such as employee telecommuting options or making transit easier and more attractive to use. Also of interest in managing demand are driver incentive programs that, for example, promote ridesharing and off-peak use.

Strategically Invest in New Transportation Capacity. Although there is significant and widespread demand for new highway capacity, concerns about air pollution, noise, and urban sprawl often stand in the way of expanding the system. Equally significant, adding new capacity can be enormously expensive and physically challenging. Despite the barriers, however, new construction that serves critical strategic purposes will go forward in order to preserve or improve system performance.

Let's see, at $12M per Lane-Mile... You're Talking Real Money!

Severe traffic congestion is pervasive in large regions and is worsening throughout the United States. In the future even small, urbanized areas are likely to experience congestion common in mid-sized areas today. To relieve severe congestion by providing additional capacity, an additional 104,000 lane-miles of capacity (about 6.2 percent of current lane-miles) will be needed. Congestion relief through provision of additional capacity is quite feasible, given current budgets. The benefits of an investment in additional capacity would be substantial. In addition to reduced travel time, other benefits include smoother traffic flow, reduced accidents, improved air quality through lower emissions, lower fuel use and operating costs, more reliable travel, lower logistical costs for manufacturing and delivery, more choices of jobs for workers and businesses, and wider choices for consumers.

Building Roads to Reduce Traffic Congestion in America's Cities: How Much and at What Cost? Reason Foundation, 2006

Although widespread capacity increases are a thing of the past, many of the barriers may be addressed through increased expenditures. Environmental concerns may be mitigated and physical challenges overcome (for example, through tunneling). However, the resources to fund such improvements simply are not available through traditional sources. For this reason, many professionals in the transportation community are enthusiastic about the opportunities potentially afforded by public-private partnerships and road pricing.

Improve the Management and Operation of the System. This area of interest involves better managing the vehicles that are actually on the road, and the road itself. "Smart" roads, traveler information, and improvements to the management and operation of the facility are options available for using the available system more productively and bringing it to peak performance. Management and operations strategies are targeted at managing temporary disruptions (e.g., incidents) in a way that will return the system to full capacity quicker; ensuring more efficient day-to-day operations through coordinated and up-to-date traffic signal timing and operational improvements to relieve bottlenecks; and providing real-time information about the system so that travelers can make immediate decisions about when, where, and how to travel, and transportation agencies can make real-time adjustments to improve system operations.

Effective and efficient management and operation of the system is foundational to all of the above congestion reduction strategies. This is true because as traffic volumes have grown over time and physical capacity has remained relatively constant, the system has become less able to absorb "surprise" – or nonrecurring events. In the realm of managing the highway system, the margin for error is very small and continues to decline. In addition, operational fixes to the system are also helpful in addressing the recurring congestion resulting from bottlenecks and improper traffic signal timing. This is particularly significant in view of the fact that bottlenecks account for 40 percent of congestion and are often difficult to resolve via major reconstruction.

How Are Freight Delays Costly to You?

- Congestion means longer travel times and increased costs in wasted fuel and driver remuneration. To compensate, companies add vehicles, hire more drivers and employees, and extend their hours to accommodate us, eventually passing through these costs to shippers and consumers.
- FHWA estimates these increases (to the company) to be between $25 and $200 per hour depending on the product carried.

The U.S. Department of Transportation Congestion Initiative

In May 2006, the U.S. Department of Transportation (U.S. DOT) announced the National Strategy to Reduce Congestion of America's Transportation Network (otherwise known as the Congestion Initiative). This initiative is focused on making meaningful and near-term reductions in congestion. Because of this initiative, the Department set a goal that calls for reducing congestion, not just reducing the rate of growth of congestion.

The Congestion Initiative includes six areas of interest. Each area includes activities with the potential to both reduce congestion in the short term and to build the foundation for successful longer-term congestion-reduction efforts.

Relieve Urban Congestion. The Department will enter into Urban Partnership Agreements with cities willing to pursue comprehensive, bold, and innovative congestion pricing strategies to reduce congestion. It is important to note that for road pricing to be successful it must be part of a comprehensive package that includes making transit more attractive; providing travel alternatives, such as telecommuting, that reduce the demand for highway transportation; ensuring that the system is operating at peak performance and that proper technology is in place to support effective and efficient application of the pricing strategy.

Unleash Private Sector Investment Resources. The Department is working to reduce or remove barriers to private sector investment in the construction, ownership, and operation of transportation infrastructure.

Promote Operational and Technological Improvements. The Department is working to advance low-cost operational and technological improvements aimed at congestion reduction. It is encouraging and supporting state efforts to 1) provide real-time traffic information to all users; 2) deploy incident management strategies such as the formation of roving response teams and quick clearance and "move it" laws; 3) improve traffic signal timing; 4) improve work zone safety and mobility; and 5) deploy quick fix operational and low-cost construction strategies to address congestion.

Establish a "Corridors of the Future" Competition. The Department is accelerating the development of multistate, multiuse transportation corridors by running a competition to select three to five major growth corridors in need of long-term investment.

Target Major Freight Bottlenecks and Expand Freight Policy Outreach. The Department is working to find and implement solutions to freight transportation and border congestion that will facilitate trade and travel without compromising either highway safety or the vital mission of securing America's borders. This area of interest emphasizes a Southern California Freight Outreach effort that will broker consensus on immediate and longer-term transportation solutions by bringing together key stakeholders.

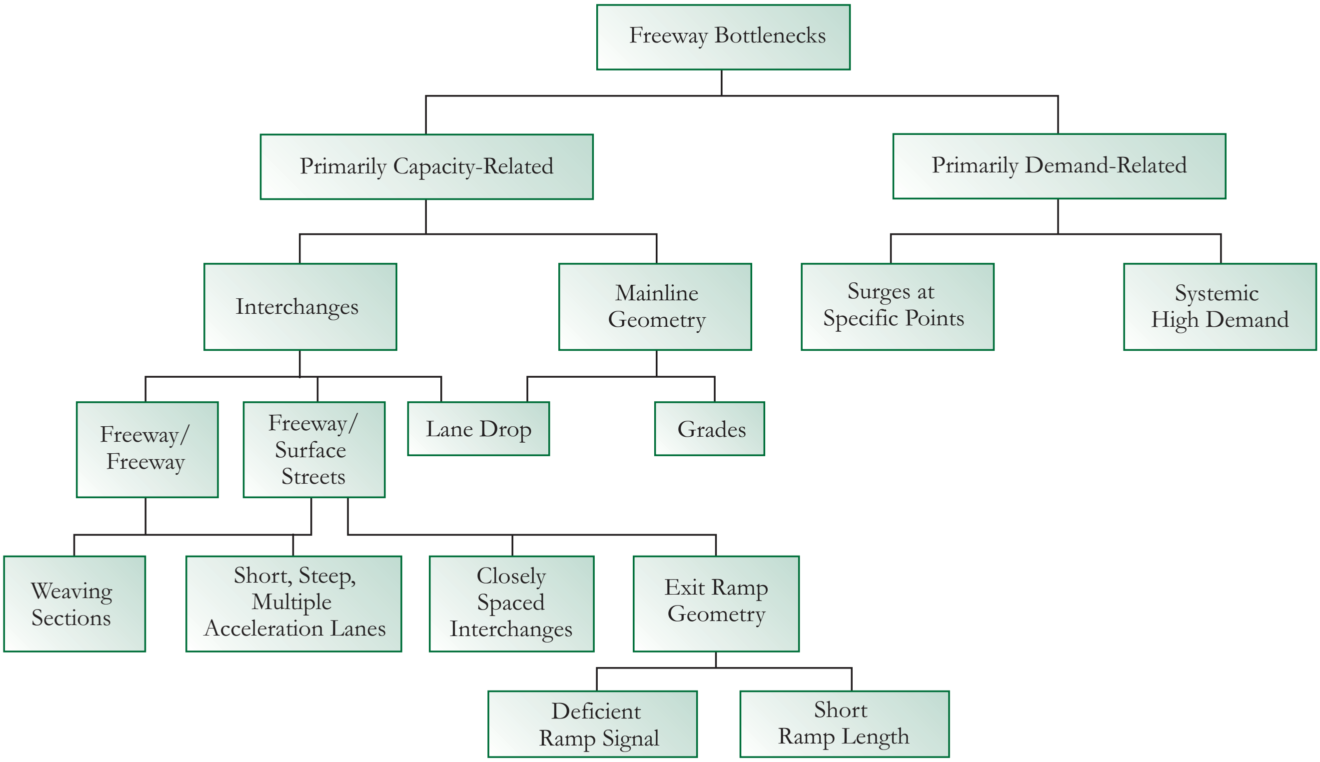
Accelerate Major Aviation Capacity Projects and Provide a Future Funding Framework. The Department is working to address congestion in the aviation system by designing and deploying the Next Generation Air Transportation System. In addition, the Department will advance reforms that lead to better management of airport and airspace congestion.

Understanding Bottlenecks

Traffic bottlenecks are specific physical locations on roadways that routinely and predictably experience congestion because traffic volumes exceed highway capacity. Surge demand higher than can be accommodated by base capacity brings about bottleneck congestion. Bottlenecks are characterized by queues upstream and freely flowing traffic downstream.

Bottlenecks may be compared to a storm pipe that can carry only so much water – during floods the excess water just backs up behind it, much the same as traffic at bottleneck locations. However, the situation is even worse for traffic. Once the traffic flow breaks down to stop-and-go conditions, capacity is actually reduced – fewer cars can get through the bottleneck because of the extra turbulence.

Figure 2. Types of Freeway Bottlenecks



How bad congestion becomes at a bottleneck is related to its physical design. Some bottlenecks were originally constructed many years ago using designs that are now considered to be antiquated. Others that have been built to extremely high design specifications are simply overwhelmed by traffic. Whatever the root cause, operational conflicts can occur at:

- A "lane drop," where one or more traffic lanes are lost. These typically appear at bridge crossings and in work zones. The latter, however, is a nonrecurring event and is usually remedied when the work zone is removed.
- A "weaving area," where traffic must merge across one or more lanes to access entry or exit ramps.
- "Freeway on-ramps" are merging areas where traffic from local streets can join a freeway.
- "Freeway-to-freeway interchanges" are special cases of on ramps where flow from one freeway is directed to another. These are typically the most severe form of physical bottlenecks because of the high traffic volumes involved.
- "Abrupt changes in highway alignment" occur at sharp curves and hills and cause drivers to slow down either because of safety concerns or because their vehicles cannot maintain speed on upgrades. Another example of this type of bottleneck is in work zones where lanes may be redirected or "shifted" during construction.
- "Intended interruptions to traffic flow" are literally "traffic disruptions on purpose" that are sometimes necessary in order to manage system flow. Traffic signals, freeway ramp meters, and tollbooths are all examples of this type of capacity loss.

FHWA Survey Suggests Opportunities for Lower Cost Solutions

Respondents to the FHWA Division Office survey said that 71 percent of bottlenecks were on freeways. Further, 42 percent were interchange related and 36 percent had no specific improvement or plan underway. Full interchange or freeway reconstructions were the most commonly perceived solutions. However, at least a portion of those might qualify for low-cost response actions that can be implemented in the short-term to improve traffic flow.

Recent discussions with several state partners have reinforced their position. Specifically, high-ranking state DOT officials and mid-level staffers engaged in day-to-day operations have all opined that there are "tremendous" and "significant" benefits to pursuing low-cost operational improvements. These benefits range from the direct (reductions in delay, increases in traffic throughput) to the indirect (public confidence and agency image-boosting effects).

Solving Recurring Bottlenecks is a Win-Win Situation for Nonrecurring Incidents Too!

The result of improving a recurring bottleneck location is to provide additional base capacity. Up to 60 percent of all congestion is nonrecurring; i.e., related to events such as accidents, weather, and work zones, etc.

Improving base capacity by addressing recurring bottleneck locations will also benefit nonrecurring events. The capacity loss resulting from the nonrecurring events will be lessened due to the improvements made to the system to benefit the recurring situation.

Addressing Bottlenecks

Bottlenecks have been the focus of transportation improvements – and of travelers' concerns – for many years. On much of the urban highway system, there are specific points that are notorious for causing congestion on a daily basis. These locations – which can be a single interchange (usually freeway-to-freeway), a series of closely spaced interchanges, or lane drops – are focal points for congestion in corridors. Major bottlenecks tend to dominate congestion in corridors where they exist.

Many bottlenecks acquire nicknames from local motorists such as:

- "Spaghetti Bowl" in Las Vegas;
- "Hillside Strangler" in Chicago;
- "Spaghetti Junction" in Atlanta; and
- "Mixmaster" in Dallas.

In the past several years, transportation professionals have come to realize that highway bottlenecks demand special attention. Several national studies have highlighted bottlenecks as a major congestion problem in urban areas. These studies have raised the level of awareness about bottlenecks as a problem, warranting that they be treated as a significant part of the congestion problem.

The American Highway Users Alliance (AHUA) conducted two studies of the Nation's urban bottlenecks in 1999 and 2004. The studies produced rankings of the worst bottlenecks in terms of total delay to travelers and discussed what was being done to fix the problems, where specific improvements had been scheduled. The studies found that nearly all of the worst bottlenecks are major freeway-to-freeway interchanges in large urban areas. The 2004 study updated the rankings and discussed three bottleneck improvement "success stories" – bottlenecks identified in 1999 that were now improved or well under construction.

FHWA's first effort related to bottlenecks was in the freight (trucking) arena. Using the AHUA studies as a starting point, the impact of bottlenecks on truck travel was assessed. Bottlenecks outside of urban areas also were considered (e.g., steep grades). A major finding of this study was that in terms of total delay, the urban bottlenecks – typically thought of as commuter related – also are the major sources of truck delay.

States and regions are beginning to recognize the significance of bottlenecks as well. The Ohio Department of Transportation completed a study of freight (trucking) bottlenecks and the Interstate-95 Corridor Coalition is undertaking a study of all potential bottlenecks in Coalition states. The Atlanta Regional Commission has defined bottlenecks as a specific portion of their Congestion Management Process and is identifying regional and local bottlenecks in their network.

Table 2. The Worst Physical Bottlenecks in the United States 2002

Rank	City	Freeway	Location	Annual Hours of Delay Hours (in Thousands)
1	Los Angeles	U.S. 101	U.S.-101 (Ventura Freeway) at I-405 Interchange	27,144
2	Houston	I-610	I-610 at I-10 Interchange (West)	25,181
3	Chicago	I-90	I-90/94 at I-290 Interchange ("Circle Interchange")	25,068
4	Phoenix	I-10	I-10 at SR-51/SR-202 Interchange ("Mini-Stack")	22,805
5	Los Angeles	I-405	I-405 (San Diego Freeway) at I-10 Interchange	22,792
6	Atlanta	I-75	I-75 south of the I-85 Interchange	21,045
7	Washington (D.C.-Maryland-Virginia)	I-495	I-495 at I-270 Interchange	19,429
8	Los Angeles	I-10	I-10 (Santa Monica Freeway) at I-5 Interchange	18,606
9	Los Angeles	I-405	I-405 (San Diego Freeway) at I-605 Interchange	18,606
10	Atlanta	I-285	I-285 at I-85 Interchange ("Spaghetti Junction")	17,072
11	Chicago	I-94	I-94 (Dan Ryan Expressway) at I-90 Skyway Split (Southside)	16,713
12	Phoenix	I-17	I-17 (Black Canyon Freeway) at I-10 Interchange (the "Stack") to Cactus Road	16,310
13	Los Angeles	I-5	I-5 (Santa Ana Freeway) at SR-22/SR-57 Interchange ("Orange Crush")	16,304
14	Providence	I-95	I-95 at I-195 Interchange	15,340
15	Washington (D.C. Maryland-Virginia)	I-495	I-495 at I-95 Interchange	15,035

Source: *Unclogging America's Arteries: Effective Relief for Highway Bottlenecks,* American Highway Users Alliance, February 2004. Only those bottlenecks that cause an estimated 10 million hours of annual delay are included in this list.

How Do Quick-Fix Bottleneck Solutions Factor Into the National Strategy to Reduce Congestion?

Major reconstruction projects are often required to fully relieve congestion at bottleneck locations. However, the cost of completing such projects is usually enormous and they can take many years to complete. Relatively low-cost geometric and operational improvements (e.g., auxiliary, shoulder, narrow, high-occupancy vehicle, reversible, and contraflow lane designs; and ramp metering) can be implemented to mitigate the effects of a bottleneck.

States such as Maryland have achieved improved system performance by introducing low-cost improvements as bottleneck locations. The Maryland State Highway Administration (SHA) has a dedicated program of about $5.0 million per year for the identification and implementation of low cost traffic congestion improvements at intersections. The program has been well-received by the public and local governments. Projects typically include "quicker fix" type projects that can be done quickly, such as, signal timing upgrades, and adding turn lanes and through lanes at intersections. The Maryland SHA has also has had considerable success with projects to improve freeway ramps and improve freeway merge areas that have reduced congestion bottlenecks at low cost. Other States have also been exploring such quick-fix improvements.

In 2006, the FHWA conducted a scan tour of Greece, Germany, Denmark, the Netherlands, and England for the purpose of examining their respective congestion management practices, policies, and strategies. Whereas, the majority of the focus was on system-wide congestion management practices, some of the knowledge shared was pertinent to quick-fix solutions for bottlenecks and chokepoints.

Implementing low-cost construction and operational strategies to relieve bottleneck congestion can bring relief to travelers by not only reducing recurring congestion but also mitigating the impact of nonrecurring traffic disrupting events at bottleneck locations. For example, consider an accident that blocks a single-lane of traffic. If only two lanes existed prior to the incident, the impact would be greater than if three lanes existed. Therefore, bottlenecks not only affect recurring congestion but nonrecurring congestion as well. The Flip side of this is that strategies to alleviate bottlenecks also will lessen the delay caused by nonrecurring events. Further, because travel time reliability is determined by nonrecurring events, improving bottlenecks also will lead to an improvement in travel time reliability.

Identifying Bottlenecks at the Planning Level

The Maricopa Association of Governments (Phoenix, Arizona) and the Southeastern Michigan Council of Governments (Detroit, Michigan) are two metropolitan planning organizations that have integrated bottleneck identification and analysis into their planning processes. It is critical that this happens to ensure that both short- and long-term funding are available for bottleneck remediation. More information may be found at:

http://www.mag.maricopa.gov/project.cms?item=480; and

http://www.semcog.org/TRANPLAN/Congestion/assets/2030_CongestionMap.pdf.

Common Myths about Bottlenecks

"Bottlenecks are caused only by not enough lanes on an extended highway section."

In the past, recurring congestion was felt to be exclusively a systemic problem (e.g., not enough lanes, a system widening is the only solution), but often, clearing unique bottleneck locations *within the system* demonstrates that the uniform highway segments may not necessarily be underdesigned.

Traditional capital solutions often grew from the misconception that a multilane facility should be designed to alleviate the recurring peak hours each day. The problem is that funding for these large scale projects is limited, and right-of-way is often restricted, such that these projects take a long time (many years) to complete. As a result, recurring congestion historically went untreated, or at least competed against other worthy projects, until funding became available to "catch up" to the problem that had grown from the day the facility opened.

With a shift in the focus away from perceiving that recurring congestion is systemic (and thus treatable with only large projects), we must explore a wider-range of improvement strategies that are possible in the short-term. While these will never replace the need for corridor-wide fixes – especially at the "mega-bottlenecks" such as major freeway-to-freeway interchanges – bottleneck-specific improvements can provide congestion relief.

"Bottlenecks can't be fixed without massive reconstruction."

With the focus of transportation planners on major capital projects, it has been assumed for many years that bottlenecks cannot be fixed without massive reconstruction of an interchange or corridor. There are numerous examples where agencies opted to make lower-cost improvements that made significant improvement in traffic flow.

"Improving a bottleneck won't help traffic flow outside of peak periods."

Because traffic-influencing events like incidents, bad weather, work zones, and special events can happen at any time, congestion is not restricted to peak times of the day. The improvements made at bottlenecks primarily to address peak-period problems will carry over to the times outside of the peak when congestion occurs.

How Can Bottlenecks be Identified and Assessed?

The first step in bottleneck remediation is identifying bottleneck locations and the root causes of the bottleneck. When multimile corridor congestion is prevalent, travel demand models can assist in identifying, separating, and analyzing bottleneck dynamics within the corridor. Traffic analysis tools can mathematically identify the problem areas by analyzing road segments for congestion or poor level of service. Freeways with traffic detection use archived data to identify where and how often bottlenecks occur, and how severe they are. Historical data is used to track if the problem is growing or receding.

Determining the root cause of the bottleneck can be accomplished with a range of tools. Special travel-time runs and videos of areas suspected to be bottlenecks can be used to pinpoint deficiencies. Microsimulation tools can provide a detailed analysis of the specific attributes of the bottleneck(s) and can assist in determining the impacts of alternative solutions. When conducting bottleneck analysis, care should be taken to ensure that:

- Improving traffic flow at the bottleneck location doesn't just transfer the problem downstream – the existing bottleneck may be "metering" flow so that a downstream section currently functions acceptably, but the increased flow will cause it to become a new bottleneck.
- Future traffic projections and planned system improvements are inclusive in the analysis. Safety merits also should be strongly considered.
- "Hidden bottlenecks" are considered. Sometimes, the queue formed by a dominant bottleneck masks other problems upstream of it. Improving the dominant bottleneck may reveal these hidden locations. It is important to take into account the possibility that "hidden bottlenecks" exist at the analysis stage.
- Situations not traditionally considered by models are included. There are several bottleneck problems, i.e., certain types of geometrics and abrupt changes in grade or curvature that can't be analyzed by analysis tools. "Engineering judgment" will need to be exercised to identify those problems and possible solutions.
- Planning and operating agencies all agree on problems and potential solutions. Coordination is needed so that bottleneck improvements can be woven into agency programs and the necessary funding is secured.

How Can Bottlenecks be Fixed?

Short-Term, Low-Cost Improvements

Here is a sampling of operational remediations.

1. Using a short section of shoulder as an additional travel lane.
2. Re-striping merge or diverge areas to better serve demand.
3. Reducing lane widths to add a travel and/or auxiliary lane (e.g., re-striping).
4. Modifying weaving (e.g., adding collector/distributor or through lanes).
5. Metering or closing entrance ramps.

Table 3. Mapping Bottleneck Problems to Mitigation Measures

Bottleneck Types	Mitigation Measures											
	Auxiliary Lanes	Collector-Distributor Road	Paved Right Shoulder	Paved Left Shoulder	Shoulder/ Plus Lane	Re-Stripping to Add More Narrow Lanes	All Purpose Lane (Concurrent or Reversible)	HOV Lanes (Concurrent or Reversible)	Truck Reversible	Ramp Metering	Temporary Ramp Closures	Traffic Diversion Information
Heavy On-Ramp Demand	++	-	+	-	++	+	++	-	+	++	-	+
Weaving Sections	+	+	+	+	+	++	++	++	+	-	-	+
Lane Drops	++	-	++	-	++	++	++	++	+	+	+	+
Tunnels and Bridges	-	-	-	-	-	++	-	+	++	-	-	+
Horizontal and Vertical Curves	++	-	++	++	++	-	++	+	++	+	+	+
Narrow Lanes and Lateral Obstruction	+	+	+	+	+	-	+	+	++	+	+	+
Inadequate Accelerated and/or Decelerated Lanes	++	++	++	-	++	+	+	+	++	+	++	++

++ = good solution + = may be helpful - = not applicable

Source: Adapted from interim materials from NCHRP Project 3-83.

6. Speed Harmonization – the practice of utilizing monitored speed and volume data to adjust speed limits when congestion thresholds are exceeded and congestion and queue forming is impending. This mostly European practice reduces the traffic "shock wave" that results through congested corridors, and has an indirect benefit to bottlenecks and chokepoints. This practice requires overhead gantries.
7. "Zippering" or self-metering that promotes fair and smooth merges. A motorist who is 10th in line knows that he will be 20th to merge into the single lane ahead. This helps to eliminate line jumpers that bull ahead, disrupt the queues, and often block adjacent lanes until they force their way in line. Usually this method of merging requires on-site enforcement, but often is exhibited by regulars who know the process and are willing to abide.
8. Improving traffic signal timing on arterials.
9. Improving arterial corridors using access management principles.
10. High Occupancy Vehicle lanes or reversible lanes.
11. Providing traffic diversion information.
12. Implement road pricing to bring supply and demand into alignment. As public acceptance grows and legislative restrictions are relaxed, pricing will increasingly be viewed by transportation practitioners as a powerful and relatively easy way to implement strategy to address bottleneck congestion.

In 2006, as part of the research conducted for National Cooperative Highway Research Program Project 3-83 ("Low-Cost Improvements for Recurring Freeway Bottlenecks") a series of interviews with state and local transportation personnel occurred. Interviewed representatives were asked to name the low-cost improvements that their agencies have used at bottleneck locations in their jurisdictions. Table 3 was developed from these responses. The results showed that agencies are using a wide range of strategies to improve bottlenecks, most of them low-cost improvements that can be implemented quickly. Strategies include making creative use of existing highway geometry as well as selective additions to it.

The most frequently mentioned low-cost bottleneck improvements either analyzed or implemented by the interviewed agencies were:

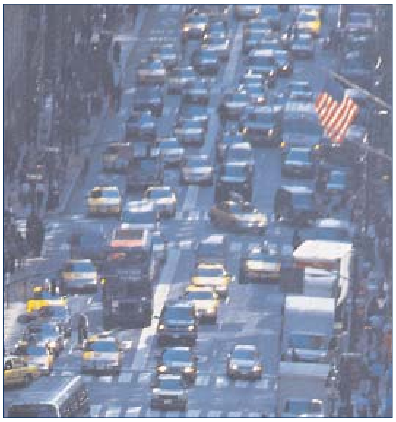
- Ramp metering (7 responses);
- Auxiliary lanes (6); and
- High Occupancy Vehicle (HOV) lanes (4).

In general, the interview responses to this question suggest there is a trend towards favoring the implementation of ramp metering as a low-cost bottleneck improvement. Such systems are particularly attractive since they allow traffic managers to directly control freeway demand levels. This unique capability provides a valuable tool for managing freeway bottlenecks that does not involve large and expensive capacity expansions.

Some of the key questions and considerations in the development of improvement alternatives for bottleneck removal include:

- Is there an inside shoulder that would create a usable traffic lane for a short section of freeway?
- If there are bridges, are they wide enough to accommodate the extra lane while allowing adequate clearance to barriers (2 feet) and an outside shoulder? If not, are they short enough that a loss of shoulder as a breakdown lane would not be critical (500 feet or less)?
- If changes to an entrance or exit ramp or weaving area are considered, will adjusting the position of ramp gores cause geometric problems which must be resolved?
- Are vertical clearance issues, grade-matching, and sight distance problems created?
- If a shoulder is considered for conversion, is there right-of-way (ROW) to allow adding one back for part of the length of the project?
- If the bottleneck movement itself cannot be fixed reasonably, can the other traffic which is affected by it be better accommodated?
- Finally, will the improvement invite enough new traffic to cause immediate breakdown again or is this truly the clearing up of a "kink" in the system, without being a capacity addition which will overload some other part of the facility?[1]

[1] These options quoted directly from recent work by the Texas Transportation Institute: *Freeway Bottleneck Analysis Methodology.*



Examples of How Agencies Are Dealing with Bottlenecks

Many transportation agencies have recognized that low-cost treatments can provide effective congestion relief at bottlenecks. A wide variety of improvements have been implemented and many innovative improvements are emerging. This section provides a snapshot of how transportation agencies are using these strategies to improve congestion at bottlenecks, including:

- Washington State's integrated operations/construction programs;
- Addressing a truck-related bottleneck in Washington State;
- Florida's treatment at an interchange weaving area;
- Maryland's treatment at an interchange bottleneck;
- Low-cost bottleneck improvements in Texas; and
- Georgia DOT's low-cost efforts to improve the Atlanta Downtown Connector.

Washington State Department of Transportation's Integrated Operations/Construction Programs in the Puget Sound Region and Seattle

The Washington State Department of Transportation has used freeway ramp meters in the Puget Sound system for two decades. By providing a regular flow of traffic and lower entering volumes at busy entrance ramps, the meters allow the freeway mainline to carry more volume and at higher speeds. In addition, the greater spacing between entering vehicles has resulted in 30 percent fewer rear-end and sideswipe collisions and lower travel delay.

I-405 and SR 167 are major commuter routes in the south Puget Sound area. A $10 million project to add a new exit ramp from I-405 to southbound SR 167 reduced the stop-and-go traffic from a nearly two-mile backup to less than one-half mile and increased the traffic volumes handled on the ramp by 8 percent and the mainline by 13 percent.

Other minor capacity improvements also have been key to maximizing the returns from the roadway investments. The addition of a "weaving-lane" between an entrance ramp and exit ramp allows merging and exiting traffic to move more smoothly to their destinations. Where traffic patterns have changed since the initial road construction, a short section of additional travel lane can allow a bottleneck to be relieved and provide a technique that uses road capacity more efficiently.

http://www.wsdot.wa.gov/traffic/congestion/.

Addressing a Truck-Related Bottleneck in Washington State

The Puget Sound region in Washington is a place of high truck activity because of the burgeoning international port business. SR 167 in Federal Way exhibited a bottleneck caused by a steep grade that dramatically reducing truck speeds. An additional lane was added on this grade to accommodate slow moving trucks.

Florida Solves Interchange-Related Weaving Problem in Tampa

The interchange of I-75 and Bruce B. Downs Boulevard in suburban Tampa exhibited the characteristics of a bottleneck amenable to a low-cost improvement. One of the major traffic flows is a right turn from the ramp and a quick left turn onto an arterial. The weaving on the cross street caused queuing on the ramp which often backed up to the freeway mainline. The problem was addressed by adding a free right turn lane and a signalized right turn lane. The traffic that needed to make the quick left turn is signed to use the signalized right turn lane. Queuing on the mainline is no longer a problem.

Maryland's Quick Fix at Interstate-70/Intestate-695

A recent project at the I-70/I-695 (Baltimore Beltway) interchange outside of Baltimore was discussed. The eastbound approach from I-70 to I-695 backed up on to the mainline of I-70, restricting through traffic. Widening the entire ramp would have been very expensive due to the need for major bridge reconstruction. Instead the ramp was widened up to the bridge. This provided adequate storage to relieve the backup on to the mainline and did so at a reasonable cost.

Low-Cost Bottleneck Improvements in Texas. The Texas Department of Transportation (TxDOT) has undertaken significant low-cost freeway bottleneck improvements in recent years. These include:

TxDOT District	Freeway(s) And Limits	Description of Bottleneck Improvement(s)
Dallas	EB IH 30, IH 35E to IH 45	Changed exit ramp to Harwood to become entrance ramp from the collector-distributor road.
Fort Worth	NB SH 360 @ Division (SH180)	Converted outside shoulder to auxiliary lane between two closely spaced exit ramps.
Dallas	NB IH 35E, IH 30 to Dallas North Tollway	Addition of two auxiliary lanes by inside shoulder conversion.
El Paso	EB IH 10 @ U.S. 54	Restriped one-lane ramp to two lanes, dropped main lane at exit, added at entrance, added auxiliary lane.
Dallas	EB SH 190 to SB U.S. 750	Restriped to give entrance ramp from SH 190 its own lane onto U.S. 75.
Dallas	NB IH 35E Ramp to Dallas North Tollway	Restriped merge to allow ramp its own lane onto approach to tollbooths.
Dallas	NB-SB IH 35E, LP 12 to IH 635	Converted inside shoulders to travel lanes for 3.0 miles and removed two inside merges.
Dallas	WB IH 30 Ramp to SB IH 35E	Restriped to balance freeway capacity with freeway volumes at merge.
Fort Worth	EB IH 20 to NB SH 360	Added deceleration lane to IH 20 before exit; dropped main lane at exit, added back at SH 360 entrance ramp.
Fort Worth	SB SH 360 to WB IH 20	Auxiliary lanes on SH 360, dropped main lane on IH 20 at SH 360 exit, added lane at SH 360 entrance.
Fort Worth	SB SH 360 @ Division	Closed entrance ramp, forcing traffic through signal, added auxiliary lane to next entrance.
Dallas	EB IH 635 to NB U.S. 75	Widened and restriped left-side ramp from one to two lanes.
Dallas	SB U.S. 75 to WB IH 635	Converted inside shoulder on IH 635 to allow ramp from U.S. 75 its own lane.

Source: Walters, Carol H, Cooner, Scott A., and Ranft, Stephen E., *Looking Again at Bottlenecks on Freeways Evaluating Case Studies in Texas,* November 15, 2004, http://pubsindex.trb.org/document/view/default.asp?lbid=775977.

Georgia DOT's Low-Cost Efforts to Improve the Atlanta Downtown Connector

Georgia DOT has attempted to enhance the I-75/I-85 operations in the past few years. The Downtown Connector is a four-mile section of freeway between the I-75/I-85 merge just north of downtown (Brookwood Interchange) to I-20. It was identified as the nation's sixth worse bottleneck in the 2004 American Highway Users Alliance Bottleneck study.

In late 2003 Georgia DOT re-striped and extended a divider wall to add ramp storage and reduce weaving at three ramps: North Avenue and 10th northbound and Ellis Street southbound. In April 2005 GDOT installed four southbound entrance ramp meters in that section (at Spring Street, Ellis Street, Freedom Parkway, and Edgewood Avenue). The ramp meters saved a weekly average of 17.3 percent in fuel and 22.4 percent in time for the four-hour p.m. peak. Between 2004 and 2005 the number of severe congestion hours was reduced by 37.7 percent.

Two Photos of the Interstate-75/Interstate-85 Bottleneck (Locally Known as the Downtown Connector) in Atlanta, Georgia in the p.m. Peak-Period

Looking southbound from North Avenue.

Looking northbound from Memorial Drive.

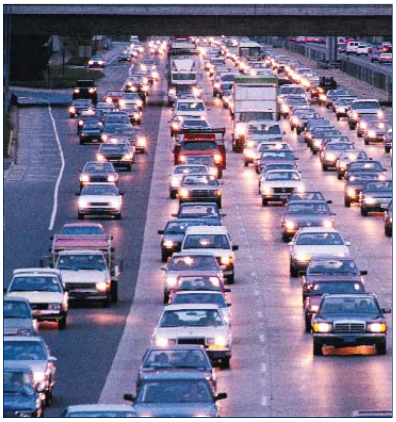
Want More Information?

As the Localized Bottleneck Reduction Program proceeds, we will take the opportunity to add to this document. The LBR Program is just one of several program areas dealing with congestion problems. At present, more information may be found at FHWA's "Focus on Congestion" web page at: http://www.fhwa.dot.gov/congestion/links.htm.

Definitions

Active bottleneck – When traffic flow through the bottleneck is not (further) affected by downstream restrictions.

Auxiliary lanes – Typically, any lane whose primary function is not simply to carry through traffic. This can range from turn lanes, ramps, and other single-purpose lanes, or it can be broadened to imply that a traffic-bearing shoulder can be opened in peak-periods to help alleviate a bottleneck, and then "shut back off" when the peak is over.



Bottleneck – There can be many definitions. Here are a few that are typically used. 1) A critical point of traffic congestion evidenced by queues upstream and free flowing traffic downstream; 2) A location on a highway where there is loss of physical capacity, surges in demand (traffic volumes), or both; 3) A point where traffic demand exceeds the normal capacity; and 4) A location where demand for usage of a highway section periodically exceeds the section's physical ability to handle it, and is independent of traffic-disrupting events that can occur on the roadway.

Capacity – The maximum amount of traffic capable of being handled by a given highway section. Traffic engineers usually speak in terms of "free flow" capacity.

Congestion – The FHWA "Traffic Congestion Reliability" reports define congestion as *an excess of vehicles on a portion of roadway at a particular time resulting in speeds that are slower – sometimes much slower – than normal or free flow speeds. (Congestion is) stop-and-go traffic. Previous work has shown that congestion is the result of seven root causes*[2] *often interacting with one another.* Since a bottleneck is a cause of congestion, congestion cannot be solely analogous to a bottleneck. Congestion is more. For example, a "congested" corridor may harbor multiple bottlenecks or any combination of the seven root causes.

Downstream traffic – Traffic that is beyond (past) the subject point on a highway.

Hidden bottleneck – A highway location where some type of physical restriction is present, but traffic flow into this area is metered by an upstream bottleneck so the location does not appear as a bottleneck under prevailing conditions. Removal of the upstream bottleneck will cause the hidden one to emerge as a new bottleneck.

[2] The seven root causes are bottlenecks (a.k.a. "capacity constraints"), incidents, work zones, weather, poorly timed signals et.al., special events, and over-capacity demand (i.e., daily and seasonal peaks superimposed on a system with a fixed capacity). Some sources cite only six root causes because they see over-demand as an inherent subelement necessary for any of the other causes to exist in the first place. Put another way, absent over-demand there would just be "volume," but not necessarily "congested" volume.

Nonrecurring events – As it pertains to traffic, a delay caused by an unforeseen event; usually a traffic incident, the weather, a vehicle breakdown, work zone, or other atypical event.

Ramp metering – The practice of managing access to a highway via use of control devices such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives. The intent of ramp metering is to smooth the rate at which entering vehicles will compete with through vehicles. Done properly, ramp metering will calm the "mix" that occurs at these junctions.

Recurring event – As it pertains to traffic, a recurring event is a traffic condition (i.e., a bottleneck or backup) that can presume to occur in the same location and at the same time daily, albeit for weekday or weekend conditions. Examples would be peak-hour slowdowns at junction points, intersections, and ramps. One can "plan" for these events because one knows by routine that such events will occur time and again in the same manner and place.

Traffic microsimulation tools – Complex microsimulation tools that rely on input of traffic data, intersection "nodes," facility "links," and the associated parameters of each input, in order to output simulated conditions. By changing the inputs, engineers can test different sizes, characteristics, and out-year scenarios of traffic demand.

Upstream traffic – Traffic that has not yet arrived at the subject point on a highway.

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16. Abstract

While many of the nation's bottlenecks can best be addressed through costly major construction projects (i.e., "mega projects") or costly transportation alternative solutions (e.g., high occupancy vehicle or toll lanes, dynamic pricing, investments in transit alternatives, etc.) there is significant opportunity for the application of operational and low-cost infrastructure solutions to bring about relief either in the short term or as an alternative to big budget solutions.

This primer is one of the signature products of the Localized Bottleneck Reduction (LBR) program, which is administered out of the FHWA Office of Transportation Management. The LBR program is focused on recurring congestion chokepoints (as opposed to nonrecurring congestion problems) and the operational influences that cause them. Operational influences are the highway junction and decision points (e.g., lane drops, weaves, on- and off ramps, signals, intersections, merges, tollbooths, width-restricted underpasses, etc.) that can become overwhelmed by vehicle volume on a recurring basis. The facility itself, at that point, and at predictable recurring times of day, is the capacity limiting determinant. Upstream and downstream of these points, the facility seems capable of handling the volume, and traffic flow tends towards free flow rates. Widening, lengthening, retiming, metering, or bypassing these troublesome locations with intent to generally unclog them can often be done with lower cost, lesser intensive means than traditionally waiting for a complete facility redesign, an out-year project, or a new complementary facility, etc. While pricing, driver incentives, and systemic solutions have their place, so too exists the option to take a fresh look at an old problem and see if there isn't a quicker, less intrusive fix that can be made.

In much the same way that a transportation agency might have an annual safety-spot improvement program to address localized, high-crash problems areas, the agency should also have an annual congestion-relief improvement program to address localized, recurring chokepoints. If the ultimate fix must be a complete overhaul (e.g., high cost replacement, upgrade, or defacto new facility) then so be it; but an agency shouldn't limit itself to only "building our way out of congestion."

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