Recurring Traffic Bottlenecks:
A Primer

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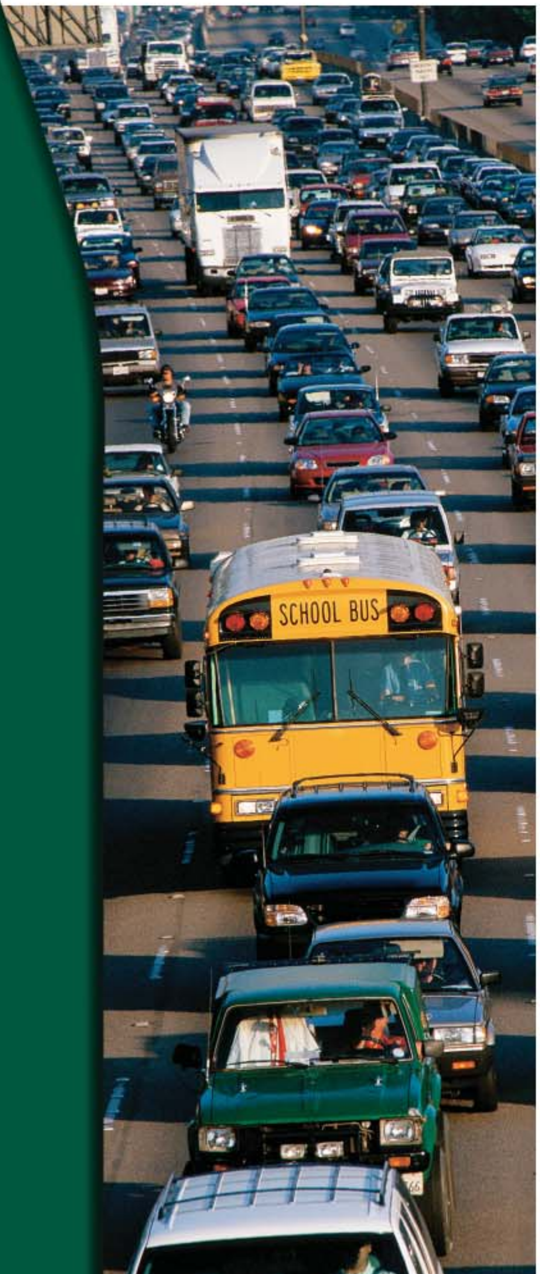
Recurring Traffic Bottlenecks: A Primer

Focus on Low-Cost Operational Improvements

U.S. Department of Transportation
Federal Highway Administration



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This is the updated, 3rd version of this document. The first version is FHWA-HOP-07-130, and the second version is FHWA-HOP-09-037.

While many of the nation's bottlenecks are addressed through costly major construction projects (i.e., "megaprojects") or costly transportation alternative solutions (e.g., HOV or HOT lanes, dynamic pricing, investments in transit alternatives, parking and commuter incentive programs, et al.) there is a significant opportunity for the application of operational and low-cost "fixes" at spot-specific locations.

This Primer is the signature product of the Localized Bottleneck Reduction (LBR) Program, which is administered out of the Office of Operations, Office of Transportation Management, at FHWA HQ in Washington, D.C. The LBR program is focused on relieving recurring congestion chokepoints (as opposed to nonrecurring congestion causes) and the operational influences that cause them. Widening, lengthening, retiming, metering, or bypassing these problem areas to unclog them can often be done with lower cost, less intensive "footprint" means than traditionally waiting for a complete facility rebuild or an out-year project.

In much the same way that transportation agencies might have an annualized safety-spot improvement program, e.g., a "top 10 list" of high accident locations, so too should they have an annualized congestion-spot program. If the ultimate fix need be a complete facility overhaul, then so be it; but an agency needn't limit itself to only "building our way out of congestion."</td></tr>
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Exhibits

Executive Summary

Introduction

When Did "Plan on Being Delayed" Become Part of Our Everyday Lexicon?

The delays arising from traffic congestion seem an unavoidable frustrating fact of life. Or are they – unavoidable, that is? Why must we accept to allow 30 minutes for what should be a 15 minute drive? In today's world, motor trips increasingly factor in dwell time to sit in traffic delay that is caused not by us, mind you, but by "others" who, if they would only get out of our way, would free up that trip to its rightful duration.

Most every driver, at some point or another, has experienced the frustration of traffic congestion. Congestion is caused by many factors, including physical bottlenecks – locations on the highway system where the physical layout of the roadway cannot process the traffic that wants to use it. While many of the nation's bottlenecks can only be addressed through costly major construction projects, there is a significant opportunity for the application of operational and low-cost infrastructure solutions to bring about relief at these chokepoints. This document, *Traffic Bottlenecks: A Primer on Low-Cost Operational Improvements*, describes such facility breakdowns and explores the opportunity for near-term operational and low-cost construction opportunities to correct them. This document is the third-generation Primer in a series of advancing bottleneck activities, and is a key resource for Federal Highway Administration's Localized Bottleneck Reduction (LBR) Program, which provides a virtual forum for peer exchange between members of the transportation community interested in alleviating bottleneck congestion. The LBR program, initiated in 2006, 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.

> ***Unclog That Bottleneck!***
>
> The root cause of recurring congestion is in fact bottlenecks and not necessarily uniform highway segments. We need to fix the "bends, kinks, and cavitations" in the traffic "plumbing" before deciding to build more and bigger highways.

Traffic, Like Weather, is an Ever-Evolving "Front"

According to a February 2007 Harris Poll, one-quarter of respondents say traffic congestion is a serious problem that is not being addressed. But please don't tell the thousands of practicing traffic engineers, planners, and road workers. It's just that much like weather forecasting, traffic management is a dynamic moving target that makes it an ever-evolving profession. And like weather forecasting, we are getting better and better at it, but remain at the whim of unrelenting "fronts."

Travel Time Index (TTI)

The TTI is one of the primary metrics used to measure congestion. It is the ratio of the actual travel time divided by the travel time under free flow conditions. A TTI of 1.2 means that a trip takes 20 percent longer than it would under ideal conditions.

Planning Time Index (PTI)

The PTI is a measurement of travel time reliability, which tell us how travel times for the same trip vary from day to day because of disruptions like incidents, bad weather, and work zones.

Source: 2010 Urban Congestion Trends Report.

With increasing attention, transportation professionals have come to realize that highway bottlenecks – specific points on the highway system where traffic flow is restricted due to geometry, lane-drops, weaving, or interchange-related merging maneuvers – demand special attention. Bottlenecks are localized sections of highway where traffic experiences reduced speeds and delays due to physical restrictions, too much demand, or both. The most severe ones tend to be freeway-to-freeway interchanges or systemic congestion, i.e., a corridor- or region-sized problem. However, many recurring bottlenecks are small, localized "hot spots" that may only require minor improvements. Examples include lane narrowing, short acceleration ramps, abrupt changes in highway design, and traffic signal deficiencies. To bring focus to this type of congestion, FHWA has established the LBR Program to promote the benefits of low-cost, quick-response solutions to recurring, localized bottlenecks (http://www.ops.fhwa.dot.gov/bn/index.htm).

The 2010 Congestion Report (http://www.ops.fhwa.dot.gov/publications/fhwahop11024/index.htm) defines "Travel Time Index" (TTI) and "Planning Time Index" (PTI) as two measures of how congestion affects one's on-road experience; namely, that a free-flow trip of a certain time will take several minutes longer under congested conditions (see box). The fact that a trip takes longer under congested conditions is not a startling concept, but the purpose of the annual report is to present an objective, data-measured comparison of how congestion is increasing, or in some cases receding, due to a constantly changing menu of causes and/or mitigation techniques. Indeed, the 2009 report showed declines in these measures for the prior two years. Performance and trend data like those presented in the Congestion Report will be a prerequisite as the highway transportation community moves towards adopting a Performance Management approach to selecting and funding projects. What is Performance Management? In a nutshell, it is monitoring the performance of the highway system in a variety of "goal areas," evaluating projects to see what has been successful – or not – and using that knowledge to plan for future improvements.

"Bottlenecks" and not "Insufficient Facilities" is Increasingly the Problem

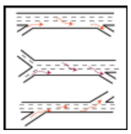
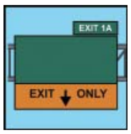
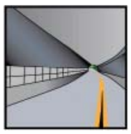
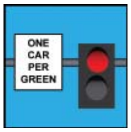
In the past, recurring congestion was felt to be a systemic problem ("not enough lanes"). It is true that additional lanes are usually needed in conjunction with bottleneck improvements to handle the additional traffic that is now freed up, but the root cause of recurring congestion is in fact bottlenecks, not uniform highway segments. Exhibit 1 shows these subordinate locations. Traditional capital solutions grew from this mindset, resulting in extensive corridor-wide improvements. The problem is that funding for these large scale projects is limited and they take a long time (many years) to complete, so recurring congestion goes untreated until funding becomes available.

However, if agencies shift their focus from recurring congestion being systemic (and thus treatable with only large projects) to being caused by specific chokepoints, a wider range of improvement strategies are possible, especially in the short term. While these will never replace the need for corridor-wide fixes – especially at the "megabottlenecks" such as freeway-to-freeway interchanges – bottleneck-specific improvements can provide effective congestion relief.

The recent economic downturn has caused a major shortfall in revenues to transportation agencies due to reduced tax collections. The low-cost nature of LBR strategies has made them highly attractive alternatives to traditional large-scale capacity expansion projects for agencies seeking "to do more with less." Especially when combined with other low-cost operations and demand management strategies, LBR strategies are a major tool for addressing congestion cost effectively.

Versions 1 and 2 of the Bottleneck Primer introduced, and then raised the level of awareness about how LBR programs could deal with congestion, respectively. This Primer constitutes "Version 3" and is focused on providing highly specific guidance for agencies to follow in developing and advancing LBR programs.

Exhibit 1. Common Locations for Localized Bottlenecks

Location	Symbol	Description
Lane Drops		Bottlenecks can occur at lane drops, particularly midsegment where one or more traffic lanes ends or at a low-volume exit ramp. They might occur at jurisdictional boundaries, just outside the metropolitan area, or at the project limits of the last megaproject. Ideally, lane drops should be located at exit ramps where there is a sufficient volume of exiting traffic.
Weaving Areas		Bottlenecks can occur at weaving areas, where traffic must merge across one or more lanes to access entry or exit ramps or enter the freeway main lanes. Bottleneck conditions are exacerbated by complex or insufficient weaving design and distance.
Freeway On-Ramps		Bottlenecks can occur at freeway on-ramps, where traffic from local streets or frontage roads merges onto a freeway. Bottleneck conditions are worsened on freeway on-ramps without auxiliary lanes, short acceleration ramps, where there are multiple on-ramps in close proximity and when peak volumes are high or large platoons of vehicles enter at the same time.
Freeway Exit Ramps		Freeway exit ramps, which are diverging areas where traffic leaves a freeway, can cause localized congestion. Bottlenecks are exacerbated on freeway exit ramps that have a short ramp length, traffic signal deficiencies at the ramp terminal intersection, or other conditions (e.g., insufficient storage length) that may cause ramp queues to back up onto freeway main lanes. Bottlenecks could also occur when a freeway exit ramp shares an auxiliary lane with an upstream on-ramp, particularly when there are large volumes of entering and exiting traffic.
Freeway-to-Freeway Interchanges		Freeway-to-freeway interchanges, which are special cases on 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.
Changes in Highway Alignment		Changes in highway alignment, which 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 shifted or narrowed during construction.
Tunnels/ Underpasses		Bottlenecks can occur at low-clearance structures, such as tunnels and underpasses. Drivers slow to use extra caution, or to use overload bypass routes. Even sufficiently tall clearances could cause bottlenecks if an optical illusion causes a structure to appear lower than it really is, causing drivers to slow down.
Narrow Lanes/Lack of Shoulders		Bottlenecks can be caused by either narrow lanes or narrow or a lack of roadway shoulders. This is particularly true in locations with high volumes of oversize vehicles and large trucks.
Traffic Control Devices		Bottlenecks can be caused by traffic control devices that are necessary to manage overall system operations. Traffic signals, freeway ramp meters, and tollbooths can all contribute to disruptions in traffic flow.

Understanding Bottlenecks

What Exactly is a "Traffic Bottleneck"?

Webster's Dictionary defines a "bottleneck" as: i) a narrow or obstructed portion of a highway or pipeline, or ii) a hindrance to production or progress. Certainly the elemental characteristics of traffic bottlenecks exist in these descriptions. However, a road does not necessarily have to "narrow" for a bottleneck to exist (e.g., witness bottlenecks caused by a weave condition, sun glare, or a vertical climb). A bottleneck is distinguished from congestion in that it occurs at a specific location, and not pervasively along the entire corridor.

Traffic bottlenecks (hereafter, bottlenecks) have a myriad of causes. The most egregious ones tend to be freeway-to-freeway interchanges, but we all know that smaller, lesser chokepoints are frustrating too. Bottlenecks can be areas where traffic is merging, diverging, or weaving, or where other physical restrictions exist like narrow lanes, lack of shoulders, steep grades, and sharp curves. The fact that many recurring locations are "facility determinate," i.e., the design condition contributes to the resulting congestion. Facility design is a tangible feature that can always be improved; however the cost or the necessary right-of-way may be prohibitive. Alternately, demand can be reduced so that the bottleneck performs better. The LBR program is focused on the infrastructure side.

"Good News" and "Bad News" About Fixing Bottlenecks

The FHWA estimates that 40 percent of all congestion nationwide can be attributed to recurring bottlenecks (i.e., inadequate physical capacity) and another 5 percent is attributable to inefficient traffic signalization. The good news is that all these things are potentially correctable with mitigation strategies and roadway improvements. The bad news is that there are many, many candidate locations, and agencies are fiscally constrained on how much they can do. A tabulation of the top 25 bottlenecks, compiled by INRIX in the National Traffic Scorecard 2010 Annual Report, is shown in Exhibit 2. Their analysis uses raw data which comes from their historical traffic data warehouse along with discrete "GPS-enabled probe vehicle" reports from vehicles traveling the nation's roads – including taxis, airport shuttles, service delivery vans, long-haul trucks, and consumer vehicles.

Exhibit 2. The Worst Physical Bottlenecks in the United States (2010)

2010 Rank	Area	Road/Direction	Segment/Interchange	State	Length (Miles)	Hours Congested	Average Speed When Congested
1	New York	Cross Bronx Expressway WB/I-95 SB	Bronx River Parkway/Exit 4B	NY	0.35	116	11.3
2	New York	I-95 NB	U.S. 9/U.S. 1/U.S. 46/Exit 72	NJ	0.42	109	9.2
3	Chicago	Dan Ryan Expressway/I-90/I-94 WB	Canalport Avenue/Cermak Road/ Exit 53	IL	0.40	105	11.3
4	New York	Cross Bronx Expressway WB/I-95 SB	I-895/Sheridan Expressway/Exit 4A	NY	0.51	133	13.0
5	New York	Cross Bronx Expressway WB/I-95 SB	White Plains Road/Exit 5	NY	0.28	105	12.1
6	New York	Harlem River Drive SB	3rd Avenue	NY	0.16	98	10.6
7	Chicago	Dan Ryan Expressway/I-90/I-94 WB	Ruble Street/Exit 52B	IL	0.12	115	14.5
8	Chicago	Dan Ryan Expressway/I-90/I-94 WB	18th Street/Exit 52C	IL	0.41	107	13.4
9	New York	Cross Bronx Expressway WB/I-95 SB	Westchester Avenue/Exit 5	NY	1.15	91	11.7
10	Los Angeles	Hollywood Freeway/U.S. 101 SB	Vermont Avenue	CA	0.62	117	16.7
11	Los Angeles	San Diego Freeway/I-405 NB	I-10/Santa Monica Freeway	CA	1.23	91	14.1
12	New York	Harlem River Drive S	2nd Avenue/125th Street/Exit 19	NY	0.22	110	13.0
13	Chicago	Kennedy Expressway/I-90/I-94 EB	Ohio Street/Exit 50B	IL	0.38	100	14.2
14	Chicago	Dan Ryan Expressway/I-90/I-94 WB	Roosevelt Road	IL	0.22	111	16.4
15	New York	Van Wyck Expressway/I-678 NB	Hillside Avenue/Exit 6	NY	0.12	103	15.2
16	New York	Van Wyck Expressway/I-678 NB	Liberty Avenue/Exit 4	NY	0.52	86	12.8
17	Chicago	Kennedy Expressway/I-90/I-94 EB	Lake Street/Exit 51A	IL	0.43	107	15.3
18	Los Angeles	Hollywood Freeway/U.S. 101 NB	Alameda Street	CA	0.27	102	14.0
19	Los Angeles	Hollywood Freeway/U.S. 101 NB	Spring Street	CA	0.14	110	16.4
20	San Francisco	CA 24 WB	Gateway Boulevard/Exit 7A	CA	1.12	66	11.8
21	New York	Harlem River Drive NB	Lower Level Washington Bridge	NY	0.11	108	14.1
22	New York	I-95 NB	NJ 4	NY	0.81	81	12.1
23	New York	Major Deegan Expressway/I-87 NB	153rd Street/River Avenue/Exit 6	NY	0.29	79	11.6
24	Los Angeles	Hollywood Freeway/U.S. 101 SB	Melrose Avenue	CA	0.35	97	17.3
25	New York	Gowanus Expressway/I-278 EB	NY 27/Prospect Expressway/Exit 24	NY	1.32	107	16.5

Source: INRIX National Traffic Scorecard 2010 Annual Report. http://scorecard.inrix.com/scorecard/Top100Bottlenecks.asp.

Understanding Merging at Recurring Bottlenecks

This guidance document focuses on "localized" recurring bottlenecks (i.e., point-specific or short corridors of congestion due to decision points such as on- and off-ramps, merge areas, weave areas, lane drops, tollbooth areas, and traffic areas); or design constraints such as curves, climbs, underpasses, and narrow or nonexistent shoulders.

The Difference in Merging for Recurring and Nonrecurring Conditions

Merging maneuvers at recurring bottlenecks are essentially "cat herding" with implicit rules (often local in culture or habit) at best. Typically, not much guidance is given – everyone is "on their own." Drivers "suddenly" encounter taillights ahead and slow, then "swarm" to get past it, whereas, in a nonrecurring event, there is more apt to be advance warning and instruction in the form of orange cones, signs, flagmen, or police. There is often direction to motorists how ("Take Turns"), where ("Merge Here"), and even what ("All Lanes Thru") to do/expect, and there can even be enforcement (of lane jumpers) or simply order (traffic cops) from chaos. One might argue "What's the difference? I'm in bumper-to-bumper traffic regardless!" The great difference is the greater potential (in nonrecurring) for herding those cats.

Controlling the chaos of lane merging is fundamental to advanced traffic operations strategies. Ramp metering has long been used to limit the number of merges at a recurring bottleneck in order to prevent breakdown of traffic flow. In non-recurring situations the "dynamic lane merge" or "lane control" is increasingly used where an incident or work zone has "stolen" a lane. This strategy proactively directs motorists to both slow down and to get into the appropriate travel lane well in advance of the problem. Active Traffic Demand Management (ATDM) strategies take and advantage of lane control as well as other types of actions to balance demand and available capacity. Several U.S. examples of this strategy already exist and more are planned: I-35W in Minneapolis and U.S. 2 in Seattle have functioning systems. I-66 in Virginia has an older system in place that will be upgraded over the next few years

Which is Best? "Early" or "Late" Merging?

Can a better recurring merge be developed? Merging takes place at-speed or "at-crawl." The former is most often associated with free flow on-ramp maneuvers, while the latter is most often associated with bumper-to-bumper congestion. In either condition the motorist has the additional choice to merge "early" (upstream) or "late" (at point of confluence). This creates a matrix of four possible merge conditions; 1) at-speed "early;" 2) at-speed "late;" 3) at-crawl "early;" and 4) at-crawl "late." To further complicate things, guidance concerning where, when, and

So You Think You Can Merge?

Are you a "profiteering" lane merger, who seeks only your own personal gain, or are you an "altruistic" driver who yields to others for the benefit of all? Are you an "early merger" (upstream of the point of confluence) or "late merger" (at the last possible moment)? Are you "left-brain" or "right-brain; " Republican or Democrat; plastic or paper? In the end, there is no right or wrong, legally speaking. When and how one merges is more a study in human behavior, and less a study in efficiency.

Recurring Congestion –

"Close to half of all congestion happens day after day at the same time and location."

Source: http://www.fhwa.dot.gov/congestion/describing_problem.htm.

how best to merge can vary from modest to no forewarnings in recurring conditions to fully deployed Traffic Control Plans (TCP) in nonrecurring conditions. Given that this Primer is focused on the recurring bottleneck genre, the purpose of this section was to research if early or late merging was best for these noncontrolled situations; i.e., when no active TCP exists.

What Instruction is Given to Motorists?

On the whole, drivers are typically left to their own strategies as to how to merge together at recurring chokepoints. Personal preference, impatience, frustration, speed differentials, and other human and vehicular traits conspire to influence safety and reduce efficiency. Altruistic drivers are unselfish and yield – in varying degrees – to proactive drivers, who seek only their own benefit to cut in line. The only real conclusion that can be drawn is suggested by the similarity in methodologies used in the work zone studies. Specifically, in setting up "Dynamic Work Zones" these are essentially systems that are "on" when traffic volumes are high and "off" when traffic volumes are low. The mere fact that all of these trials presumed to set up – and study – a "late merge" scenario speaks to the engineering community's penchant towards this method over the "early merge" option for stop-and-go conditions. One theme, however, remained constant. Regardless of the amount of forewarning and direction given to motorists (e.g., "light" guidance in recurring situations and "heavy" guidance in nonrecurring situations) personal preference seemed to win the day. Absent absolute enforcement, motorists were observed to – or opined to – merge when and how they preferred, with less regard for any instruction.

Early Attempts to Direct Motorists How to Merge

When the Interstates were built in the 1960s and 70s there was often "instruction" by local engineers and the media of how to engage Interstate ramps, acceleration and deceleration lanes, etc. Of course, at that time, traffic was less congested on the whole, and the merging and diverging were essentially lessons in how to enter and exit Interstates. Academia has touched on queue theory, gap analysis, and related safety-oriented aspects, but none of these studies have focused much on educating motorists how to merge efficiently, unless one considers a "queue" or a "traffic stream" as an entity that can deduce instruction. Nevertheless, the academic community has essentially confirmed, via queuing theory and microsimulation that the discharge rate after the merge governs congestion on the segment. In layman's terms, there is a finite capacity of the single lane downstream of the constriction. Very little of what happens upstream can refute the laws of physics; that only one vehicle can occupy the discharge space at a time; and in a jammed situation, the lead vehicle does so from essentially a crawl speed.

Excepting for some basic, generic instruction in states' drivers manuals ("wait for a safe gap in traffic" – typ.) little has been done at the national level to educate

drivers how to merge safely and efficiently, as compared to other national education efforts promoting seat belt compliance, school zone safety, traveler information, or pedestrian rights and practices. The perceived reason for this may simply be the expectation that there will always be drivers who feel they know best how and when to merge in a queue, irrespective of any instruction to the contrary. The altruistic view is to leave gaps, yield to your neighbor, take your turn but don't force your turn, and generally don't deny him or her entry into your lane. The more proactive view is to take first opportunity to cut in line, perhaps "line jump" to chase whichever line seems to be moving, and scuttle the principles of any orderly manner. Anecdotal evidence from many local traffic blogs and an Internet search finds strong sentiment from both camps as to why they think their method is best.

Merge Principles

How can we increase the efficiency of merging prior to the discharge point? In two words – be orderly. Not surprisingly, safety improves too. It is repeatedly shown that traffic is inherently safer when all vehicles are traveling at or near the same speed. Think of an orderly progression on a crowded escalator. Everyone is safely cocooned because they are going the same speed. Now imagine the bumping and chaos that would occur if impatient folks pushed past others.

Principle #1: "Go Slow to Go Fast"

"Go slow to go fast" is an increasingly trendy expression in traffic circles. It speaks to the seemingly paradoxical idea that if we slow down the rate of our "mixing" we can get past a constriction faster. A well known example (actually the winning entry in a 2006 contest to demonstrate the meaning of "throughput maximization") is the "rice" experiment. In the first case, dry rice is poured all at once into a funnel. In the second case, the same amount is poured slowly. Repeated trials generally conclude about a one-third time savings to empty the funnel via the second method. And, it should be noted, there is a tipping point reached as one graduates from a v-e-r-y slow pour, to a medium pace, and so on. What lesson does the rice experiment teach us about traffic? The densely packed rice (or traffic) in the first trial creates friction in the literal sense and the practical sense, respectively. The denser the traffic, the smaller the safety cushion around each driver, and the more cautious (i.e., slower) he becomes. A classic "bell curve" diagram also serves to explain how traffic throughput reaches an apex up to the point where traffic friction and conflict conspire to begin a decline in the rate of throughput and speed. There exist some examples of validation of this principle at intersections (e.g., traffic signalization, roundabouts, vehicle detection) that demonstrates that slowing or stopping some traffic benefits the aggregate flow, and is far better than the free-for-all converse. In the bottleneck and corridor genres, we have ramp metering and speed harmonization, respectively, providing examples on freeways.

Principle #2: Keep Sufficient Gaps

Keeping sufficient (or ideally, the largest possible) gaps leads to uniform and free(er) traffic flow. Gaps allow for small adjustments in braking, accelerating, and drifting. The larger the gap, the lesser the "ripple" affecting adjacent and following vehicles, which otherwise would react by slowing. Gap maintenance (and thus, lane reliability) is achieved on-purpose in high-occupancy vehicle (HOV) lanes or high-occupancy toll (HOT) lanes; by selective admittance in the former, and by dynamically shifting the price every few minutes in the latter. The target benefit is to allow qualifying vehicles the guarantee of a free flow trip, versus the hit-or-miss prospect in the adjacent general purpose (GP) lanes. Both cases have the added (and intended) benefit of removing vehicles and or person-trips from the GP lanes too; so all traffic streams win when these practices are employed. Absent out-and-out violators who can muck up the system, agencies can tweak the lane mandates to keep the systems running at optimum levels. How does this apply to localized bottlenecks? Theoretically, the same "gapping" principles would hold true in backups; to wit, leaving progressively larger gaps would allow for progressively better progression. (Taken to the extreme, no "bottleneck" would even exist!) The point is that in congested situations the constant brake-tapping in bumper-to-bumper traffic works to self-perpetuate the problem. No one can get much momentum before he or she has to react to the vehicle directly ahead or adjacent. The ripple effects are short, abrupt, and inefficient. The obvious problem with this is that human nature simply won't allow for the patience and orderliness to make this work. The second that I create a sufficient gap between me and the car ahead, some "profiteering" lane jumper will fill it. Which is a nice segue into the next principle; zippering.

"Zippering"

Principle #3: Zippering

Unlike principle #2, which is noted to be fairly impractical to expect, this one could easily be melded into our regular practice; namely, to take turns, or "zipper" merge at the front of the line. The fairness – and simple visualization – of this principle speaks for itself. And there is already precedence that we have been schooled in this; witness the "Yield" condition and many recurring locations where this is the unwritten rule; newcomers quickly adapt! Advocates of zipper merging are proponents of "late" merges; i.e., staying in your lane until the last possible moment and taking turns to get through the chokepoint nozzle. One enterprising fellow in California has gone so far as to adorn his car with a zipper graphic and messages promoting this method.

Is Murphy Right? Does the Other Lane "Always Move Faster"?

How many times have you observed (or seemed to observe) that "the other lane is moving faster" only to get into that lane and then watch the first lane move past you? Actually, you are at the whim of "observation selection bias" which essentially

opines that one will selectively conclude a result only on the basis of a distortion of data; in this case, your distorted sampling of only the cars that are moving, and less so the ones that aren't. So, does cutting in line help you?

Imagine two lanes of cars. The left lane (L) is the continuous lane and the right lane (R) is dropping. You are 6th in line in R lane. If everyone stays put and "zippers" then the zipper order is L, R, L, R, etc. Your neighbor to your left is 11th and you will be 12th to merge. If, however, you "early merge" and cut in front of him into the L line, then you will now be 11th to merge, the person behind you (formerly 14th) moves up to 12th, and you neighbor drops to 13th. You win. Your neighbor loses. But the guy behind you benefits most.

Now consider the same scenario except the zipper order is R, L, R, L, etc. In the orderly scenario you would be 11th and your neighbor is 12th. If you cut in front of him, the guy behind you moves up to 11, you are now 12th, and your neighbor is now 14th. You neighbor really loses (drops two slots) and the guy behind you (formerly 13) really wins; he gains two spots – again.

Congratulations! In both scenarios you have definitely improved the slot for the guy behind you! You may or may not have improved your slot. And in either case, you made your neighbor mad! And in the end, all the jockeying you have done may have been canceled by someone ahead of you. So maybe it's better to leave Murphy's Law to "anything that can go wrong, will" and let zippering be the fair and simple solution to traffic backups.

Principles Put Into Practice: Variable Speed Limits and Speed Harmonization

Variable speed limits (mostly tried in work zones; i.e., nonrecurring conditions) and the European concept of "speed harmonization" (nonwork zones) both intend to "harmonize" traffic by regulating speeds. In the latter case, a series of overhead gantries gradually adjust speeds through congested highway segments in order to flatten the sinusoidal effect of traffic speeds bouncing between open sections and interchanges. Speed harmonization is typically effected as the open highway approaches the denser central business district. A great expense is incurred by the cost of the overhead, spanned gantries, the necessary detectors, the interconnectivity, the necessary operational overhead, and the sheer number of gantries required along the multikilometer corridor. "Go slow" (harmonize) can therefore be used as a strategy as a means to move more traffic than otherwise might have gotten by. Several tests of speed harmonization are in the planning stages throughout the United States.

For example, the Minnesota DOT has deployed a variable speed limit system on I-35W in Minneapolis in conjunction with a "priced dynamic shoulder lane" (PDSL).

Exhibit 3 shows a schematic of how the system operates. The features of this comprehensive system include:

- During the off-peak hours the lanes are not tolled and open to general traffic with the exception of northbound from 42nd Street to downtown;
- Two-plus carpools, vanpools, transit, motorcycles travel toll free;
- Dynamically priced based on demand;
- PDSL operates as a priced lane during peak periods to maximize capacity on existing roadways;
- Electronic signs alert drivers whether the PDSL is open or closed; and
- Variable speed limits are set in the adjacent nontolled lanes.

Exhibit 3. Typical Section of MN I-35W Northbound Priced Dynamic Shoulder Lane (PDSL)

Source: MnDOT.

Minnesota I-35W Planned Overhead Signage Showing Priced Dynamic Shoulder Lane and Variable Speed Limits

PDSL Opened

PDSL Closed

Source: Simulated Photos.

What is FHWA Doing to Promote Congestion Relief and Bottleneck Mitigation?

With regard to congestion, the Federal Highway Administration (FHWA) promotes a number of efforts to help reduce congestion on the nation's highways. Together with our state partners, who implement these strategies, these efforts can allow for more informed decisions, better coordination, and quicker actions to mitigate the problems.

Recurring Congestion Program Strategies

Tolling and Pricing. Value pricing entails fees or tolls for road use which vary by level of vehicle demand on the facility. Fees are typically assessed electronically to eliminate delays associated with manual toll collection facilities.

Public-Private Partnerships. Public-private partnerships (PPP) refer to contractual agreements between a public agency and private sector entity that allow for greater private sector participation in the delivery of transportation projects. FHWA is working with our partners in the public and private sector to further investigate these promising partnerships.

Real-Time Traveler Information. This is "decision-quality" information that travelers can access, understand, and act on to choose the most efficient mode and route to their final destination. Timely and detailed information about traffic incidents, the weather, construction activities, transit and special events, all aid in improving travel time predictability, better choices, and reduced congestion.

Corridor Traffic Management. When congested traffic conditions occur on one roadway, travelers typically respond by shifting to another route, selecting a different roadway (freeway versus surface street), adjusting their trip to another time of day, or remaining on their current route encountering significant delays. The proactive use of managed lane strategies, alternate routing of traffic, and proactively managing and controlling traffic within freeway corridors offer are a few useful approaches.

Arterial Management and Traffic Signal Timing. Signal timing should correspond to the current traffic patterns. Often signals are initially timed, but not readjusted when traffic patterns change. This results in inefficiency and unnecessary delays. Goal: work with state and local agencies in congested metropolitan areas and encourage best practices for improved traffic signal timing.

Active Traffic Management. In layman's terms, "actively managing the traffic" means to make real-time adjustments to the facility to manage the speed, density, or safety conditions thereon. Active Traffic Management (ATM) or Active Transportation Demand Management (ATDM) are brother and sister terms, wherein, the former is typically applied only to the roadway facilities, and the latter is typically a broader integration of a larger pool of related activities, like transit, parking, and driver-behavior elements. ATM enhancements involve some sort of "smart highway" feature that uses real-time speed, vehicle-count, or even vehicle-occupancy data to open or close certain lanes, adjust the speeds on the mainlines, or vary the candidacy to even be in certain lanes (e.g., HOV, HOT, truck-only, etc.) in the first place.

Nonrecurring Congestion Program Strategies

Traffic Incident Management. This utilizes a combination of public safety functions and traffic management functions – it requires cooperation between various public agencies to reduce congestion by clearing traffic crashes and removing stalled vehicles. FHWA is championing laws, policies, and practices that speed up the clearance of major and minor incidents that create congestion.

Work Zone Management. This program is working to "make work zones work better" by providing transportation practitioners with high-quality products, tools, and information that can be of value in planning, designing, and implementing safer, more efficient, and less congested work zones.

Road Weather Management. This program seeks to better understand the impacts of weather on roadways, and promote strategies and tools to mitigate those impacts.

Highways for LIFE. Highways for LIFE is all about building faster, safer, with better quality, less cost, and causing less work zone congestion. The purpose of Highways for LIFE (HfL) is to advance longer-lasting highway infrastructure using innovations to accomplish the fast construction of efficient and safe highways and bridges. The three goals of HfL are to improve safety during and after construction, reduce congestion caused by construction, and improve the quality of the highway infrastructure.

The Localized Bottleneck Reduction Program – Focus on Recurring Congestion

In concert with the above focus areas, FHWA's Localized Bottleneck Reduction (LBR) Program is entirely aimed at reducing recurring congestion. The LBR Program *promotes operational and low-cost bottleneck mitigation strategies* to improve mobility at

specific locations. Managed by the Office of Operations, the program serves to bring attention to the root causes, impacts, and potential solutions to traffic chokepoints that are recurring events; ones that are wholly the result of operational influences. The goal of the program is to *raise awareness* of bottlenecks at the state level and *promote low-cost, quick-to-implement geometric and operational improvements* to address recurring chokepoints. The LBR Program has several activities underway, including:

- This Primer, which is in its third iteration, providing an overview of the wide range of operational and low-cost strategies available to reduce congestion at bottlenecks and provides guidance for agencies implementing LBR programs;
- A compendium of state best practices in bottleneck identification, assessment, countermeasures, and evaluation, including how bottlenecks are treated in the annual planning and programming processes;
- Version X of the Traffic Analysis Toolbox which focuses on focusing on what analysis tools are available, necessary and productive for localized congestion remediation; and
- State-specific workshops for state and local agencies to learn and share information on localized bottleneck reduction strategies and how they can be incorporated into their respective planning processes.

Benefits of Localized Bottleneck Improvements

The LBR Program focuses on operationally influenced bottlenecks – small, localized "hot spots" where the design of the roadway itself becomes the constricting factor in processing traffic demand, resulting in recurring delays of generally predictable times and durations. Megaprojects required to resolve major bottleneck problems and systemic congestion (e.g., entire corridor rebuilds, multimile lane additions, and systemwide improvements) are far and above the focus of this program area. Unfortunately, when weighed against these larger, more visible projects, localized bottleneck problems often receive lower priority for funding or are put off entirely until they can be implemented as part of the larger, all-encompassing project. However, in this day and age of fiscal constraints, with agencies facing over-escalating costs and increasingly limited right-of-way, it is evident that "business as usual" in resolving congestion problems no longer applies. Low-cost bottleneck mitigations have several advantages that can help agencies deal with these developments:

- **They address current problems and therefore have high visibility.** Agencies are under increasing pressure to do something immediately about congestion problems. Because low-cost bottleneck treatments are small in scale, they can be implemented quickly, so benefits start accruing immediately.

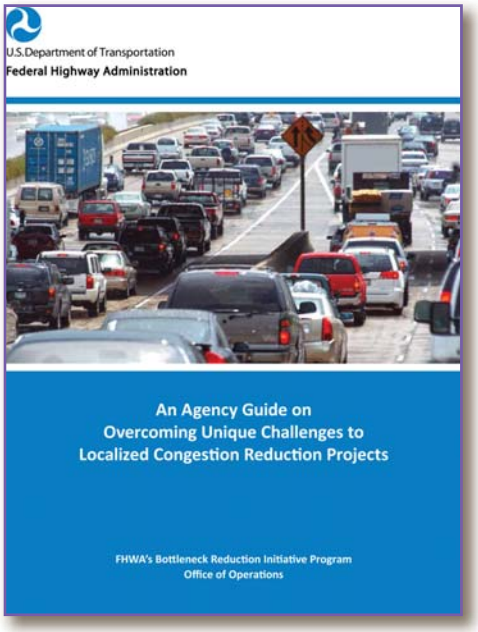
- **They are highly cost-effective and usually have positive safety impacts.** Low-cost bottleneck treatments could mitigate or reduce crashes within weaving and merging areas, thereby increasing the cost-effectiveness relative to safety merits.
- **They will be required as transportation funding for megaprojects becomes more constrained.** Major reconstruction projects are often justified as the only valid solutions to relieve congestion at the worst bottleneck locations. However, the cost of executing such projects is usually enormous. Low-cost bottleneck improvements provide an effective way to stretch scarce resources.
- **Lower cost means more locations can be addressed.** More spot solutions can be implemented throughout a region, addressing more corridors than just a few large projects.
- **They are less invasive on the physical and human environments.** The environmental footprint of low-cost bottleneck projects is very low, both in terms of disruptions during construction and final design.
- **They are not necessarily just short-term fixes.** For some low-cost treatments, congestion benefits will play out over many years, not just a few. In fact, when combined with other forms of treatment (e.g., demand management and operations), they may be part of a long-term solution for a problem location or corridor.
- **They may be considered part of major reconstruction projects to address current problems.** Some state DOTs have successfully incorporated low-cost bottleneck treatments within the context of larger, multiyear reconstruction projects.

Getting Started: How to Structure a Localized Bottleneck Reduction Program

What is Stopping Us From Fixing Bottlenecks?

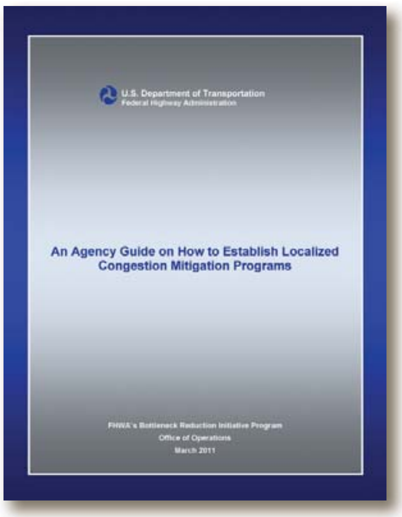
States have cited a number of barriers to establishing bottleneck-specific or similar programs that target chokepoint congestion:

- **A predisposition for large scale, long-term congestion mitigation projects.** Traditional transportation planning and programming efforts are often predisposed toward major capital improvement projects to relieve congestion such as corridor-widening or massive reconstruction of an interchange. There is also no shortage of demand management strategies designed to fight the congestion battle, such as HOVs, tolling and pricing, transit alternatives, and ridesharing programs. But the onerous processes involved in many of these initiatives can squeeze out smaller programs.
- **Lack of program identity.** Unless there is a formal program identity, bottleneck remediation is usually relegated to a few projects completed as part of an annualized safety program, or as a subordinate part of larger, other purposed projects.
- **Lack of a champion.** Many successful state or metropolitan planning organization programs are the result of one or more persons taking charge to either mandate or adopt a program. High-level administrators often set the policy direction and strategic initiatives for their agencies, while midlevel managers' production reflects their priorities and skills in executing those initiatives.
- **Lack of resources.** Many state agencies are finding themselves overworked and understaffed. Although the return on investment for LBR projects are high, agencies often do not have the in-house resources necessary to conduct detailed analyses required to evaluate and prioritize the large number of potentially competing projects. With limited resources, agencies are relegated to hiring consultants and/or universities to conduct detailed project analysis.
- **Lack of funding.** With many state agencies experiencing major budget shortfalls, lack of funding continues to be an often cited barrier to implementing new programs.



http://www.ops.fhwa.dot.gov/publications/fhwahop11034/index.htm

Want to know more about how to get an LBR program off the ground?



http://www.ops.fhwa.dot.gov/publications/fhwahop11009/index.htm

- **Responsibility has not been assigned.** Not part of ongoing planning and programming processes. Localized bottleneck mitigation projects are not often included in the ongoing planning and programming processes for most agencies. Others struggle with how best to identify problem locations, assess existing conditions, and quantify the impacts of proposed remedies, as there is no structured process in place. For example, in developing their structured LBR program, Michigan DOT cited challenges regarding how best to justify and evaluate project impacts while creating a level playing field for application of LBR funding across each of their seven regions.
- **A culture of historical practices.** Many agencies face institutional challenges in changing their current business practices. For example, one agency dutifully executed an annualized "safety" program and looked only at crash rates in determining their annual top 10 list of projects. After instituting a congestion mapping process, they identified several significant stand-alone chokepoints that did not correlate with their high-crash mapping. Thereafter, high-congestion hot spots competed with high-accident hot spots on their unified top 10 list of projects.

In addition, even if there is agreement that an LBR should exist, barriers often exist for implementing specific projects, including:

- **Design challenges.** LBR treatments may sometimes require "nonstandard" designs. Seeking exceptions to design standards is often tedious with no guarantee that they will be approved.
- **Safety challenges.** Even if design issues are resolved, safety issues may still be present. For example, eliminating a shoulder to obtain an extra through lane may have safety implications.

Tackling the Challenges and Barriers to Fixing Bottlenecks

The FHWA publication, *An Agency Guide on Overcoming Unique Challenges to Localized Congestion Reduction Projects,* provides more guidance for agencies wishing to implement an LBR program. This report presents and describes examples of institutional, design, funding, and safety challenges that agencies face when trying to develop unique solutions to localized congestion problems. The main questions that this guidance helps an agency address are:

1. What are the most common barriers and challenges with addressing localized congestion problems?
2. What are some case study examples that highlight how barriers and challenges were overcome?
3. What are some of the key factors in successful implementation of localized bottleneck projects?

Overcoming Challenges to Implementing LBR Projects

Through a series of case studies, documented in An Agency Guide on Overcoming Unique Challenges to Localized Congestion Reduction Projects, states and MPOs have developed innovative ways to overcome the common barriers to LBR projects. (Exhibit 4.) The case studies identified the most common barriers and challenges with addressing localized congestion problems and the key factors in successful implementation of localized bottleneck projects.

Exhibit 4. Examples of How Agencies Have Addressed Localized Bottleneck Issues

	Challenge Description	Case Studies	Outcome
Institutional	Having a project champion.	Dallas, TX Kansas City, KN	+: 20+ projects due to DOT/MPO champions. +: Governor passes bill allowing buses on shoulders.
	Disposition towards megaprojects.	Minneapolis, MN Manchester, NH	+: Similar benefit for $7 versus $138 million projects. +: Expedited work at Exit 5 as part of megaproject.
	Project planning and programming requirements.	Danbury, CT Austin, TX	+: Restriping at Exit 7 improved flow significantly. +: Multidisciplinary group mitigating congestion.
	Lack of training/understanding on how to develop a successful project.	Dallas, TX LBR workshops	+: Freeway Bottleneck Workshop. +: Federal outreach workshops building consensus.
	Knowledge of problem locations that can be fixed with low-cost solutions.	Phoenix, AZ Dallas, TX Little Rock, AR	+: Regional bottleneck study. +: Aerial freeway congestion mapping. +: Operation Bottleneck program by MPO.
	A culture of historical practices.	Saginaw, MI	+: Successful roundabout at I-75/M 81 interchange.
	Deficiency with internal and external coordination (design/operations).	New York, NY	+: PFI functional groups.
	Can't implement projects without being in approved regional/state plans.	Rhode Island DOT	+: Creation of the Strategically Targeted Affordable Roadway Solutions (STARS) program.
	No incentive or recognition for successful low-cost bottleneck reductions.	Dallas, TX	+: Engineers performance evaluation includes bottlenecks.
	Will the proposed solution work – lack of confidence.	Florida DOT	+: Trial fix with cones made permanent with striping.
Design	Design exception (DE) process is difficult.	Pittsburgh, PA	+: New shoulder to avoid DE, Academy at I-279.
	"Nonstandard" design is considered a deal-breaker.	Minnesota DOT	+: Creation of "flexible design" concept.
	Problem is too big and nothing short of a rebuild will fix it.	Plano, TX	+: Implement auxiliary lane on U.S. 75 at SH 190.
	Spot treatment will move problem downstream and not improve mobility.	Renton, WA	+: SR 167 spot fix near Boeing reduces congestion.
	Standard design practices contribute to bottleneck formation.	Fort Worth, TX	+: I-20/SH 360 fix defies AASHTO basic lanes policy.
Funding	There is no dedicated funding category for this type of project.	Mississippi DOT Nebraska DOT	+: I-10 shoulder use after Katrina improves flow. +: ITS funds for ramp gates to fix U.S. 75 bottleneck.
	Low-cost solution may blur or preclude need for bigger project.	Dallas, TX	+: I-635 early action doesn't stop $3B megaproject.
	Don't understand if alternate funding categories can be used.	Virginia DOT Ohio DOT	+: STARS program uses safety $ to target congestion. +: Safety funds include congestion index.
	Lack of available resources (e.g., DOT striping crews) for implementation.	Dallas, TX	+: District striping contract implements small fixes.
Safety	Hesitancy to implement solution that does not follow standard design.	Minnesota DOT	+: Mobility crisis from I-35 bridge collapse.
	Perception that safety is compromised with low-cost, nonstandard fixes.	Texas DOT	+: Average 35 percent crash reduction for 13 projects in Texas.
	Lack of shoulders takes away necessary refuge areas.	Arlington, TX	+: Crash reduction at SH 360/Division.
	Lanes that are not full width create safety issues for large trucks.	Dallas, TX	+: I-30 Canyon truck rollovers basically eliminated.

Options for Structuring a Bottleneck Improvement Program

The goal of the FHWA's Localized Bottleneck Reduction Program is to raise awareness of bottlenecks at the state level and promote low-cost, quick to implement geometric and operational improvements to address recurring chokepoints. There are no set guidelines for establishing an LBR program and no two programs will look the same. State DOTs, MPOs, or local transportation agencies are the traditional organizations who lead LBR efforts as part of larger missions of the organization. Many times, the state may identify bottlenecks and work closely with MPOs to integrate these projects into the TIP and other targeted funding sources such as CMAQ and safety. Other times, low-cost bottlenecks can be addressed programmatically at the state DOT level by reviewing existing plans and programs and look for opportunities to include LBR improvements and strategies.

Examples of how transportation agencies have structured LBR programs include the following:

- **Periodic Special Program or Initiative.** For example, in 2007, the Minnesota DOT was asked by the Legislature to develop a rapid turnaround plan to identify low-cost, quickly implementable projects that were not already identified by the traditional planning and programming processes. In a matter of months, this unique approach led by the Traffic Management Center engineers basically "brainstormed" low-cost, candidate projects that were nagging problems, but for whatever reasons, had never landed on traditional Capital Improvement Programs. In 2008, the Central Arkansas MPO undertook "Operation Bottleneck," a campaign to openly solicit public input of candidate locations, but one that has a finite life span.
- **Incorporating Bottlenecks into Other Programs.** At the state DOT level, low-cost bottlenecks can be addressed programmatically even without a special program or initiative. One approach is to conduct a review of existing plans and look for opportunities to include LBR improvements in them. For example:

Caltrans, as part of their Corridor Management Process, includes the identification of bottlenecks and potential short-term fixes as part of an overall and long-term strategy for making corridor improvements.

Ohio DOT added a congestion-based index ranking to their annual identification of spot safety problems for the Federal Hazard Elimination Program (HEP).

Washington State DOT recognizes bottlenecks and chokepoints as an integral part of their project planning and development process. The recent Moving Washington initiative incorporates LBR concepts into a coordinated program to address congestion. At the planning stage in their Highway System Plan, WSDOT considers bottlenecks together with traditional corridor improvements under the "Congestion Relief" category. Congestion relief projects are ranked using the benefit/cost ratio, contribution to performance goals, and other qualitative factors, and compete on these bases with projects in other categories in the Highway System Plan: Preservation, Safety, Environmental Retrofit, Economic Vitality, and Stewardship.

At the metropolitan planning organization level, the short-term nature of LBR projects meshes well with the Congestion Management Process (CMP) and "planning for operations," which are new initiative areas for planners. As planners' perspectives broaden to include these short-term views of the system (in addition to the traditional long-range view), an LBR program makes perfect sense from a planner's viewpoint, LBR improvements would be another aspect of the CMP process. Because an LBR program should be data- and performance-driven, it is a logical complement to a CMP; the same data should be used for both purposes. In fact, within the context of the CMP, it may useful to make the two processes seamless, at least at the MPO level.

- **Formal Low-Cost Bottleneck Improvement Program (ongoing).** Another option is to establish a defined bottleneck program within the agency. For example, Virginia DOT (VDOT) has implemented the Strategically Targeted Affordable Roadway Solutions (STARS) Program, which is a safety and congestion program that partners state, planning district and local transportation planners, traffic engineers, safety engineers, and operations staff to identify "hot spots" along roadways where safety and congestion problems overlap and are suitable for short-term operational improvements. Following VDOT's success, the Rhode Island DOT (RIDOT) created its own version of the STARS program to meet its low-cost bottleneck program needs.

Potential Issues with LBR Bottleneck Treatments

In addition to barriers that inhibit the creation of a LBR program, issues related to implanting LBR strategies also exist. Agencies have cited the following barriers associated with LBR strategies:

- **Compliance with State Implementation Plans (SIP) for Air Quality Conformity.** SIPs set forth the state's strategy for getting its air quality within National Ambient Air Quality Standards (NAAQS) and keeping it there. They include a large variety of project types, including transportation projects, and extensive emissions modeling is undertaken to estimate their impact. There is a great deal of uncertainty as to how an LBR project might affect the SIP: does the entire SIP have to be redone, does emissions modeling just for the LBR project have to be performed, or can the emissions impacts be assumed to be small enough that they can be ignored? Such occurrences must be dealt with on a case-by-case basis by agencies wishing to undertake bottleneck projects. One point worth noting: if air quality conformity in a location precludes or discourages major capital expansion (e.g., additional lane-miles), the type of improvements in a localized bottleneck program clearly do not fall in this category.
- **Compliance with Long-Range "Design Concepts."** In some cases, a design concept or goal has been formally established for a roadway of corridor. The thought is that any improvements should be part of that concept. When the design concept is institutionalized, it may be difficult to deviate from it with an LBR treatment that does not match. Agencies must decide and weigh the benefits themselves whether the cost of doing smaller bottleneck solutions in the short term is against the cost of waiting for a more complete solution. This decision can be difficult, especially for agencies without a good appreciation for the typical benefits and costs of smaller bottleneck solutions and how long those benefits might last.
- **Compliance with Design and Safety Standards.** LBR treatments tend to be of a smaller scale than typical capital improvement projects. This means that the redesign is usually not made to existing design standards, which depending on the funding source, may require a formal design exception. Further, even if a design exception is not needed, safety problems may be introduced by the LBR treatment, especially if the identified problem is congestion-oriented. To address this issue, LBR treatments need to be assessed for potential safety impacts prior to implementation. Also, a Roadway Safety Audit of the design would be beneficial. Based on the review, additional mitigation of safety impacts may be warranted, or a close monitoring of crash experience at the site may be used. Finally, agencies should be in contact with the FHWA Division offices throughout the process as design review may be required, depending on circumstances.

Identifying and Assessing Bottlenecks

Where Are the Bottlenecks and How Severe Are They?

Every highway facility has decision points such as on- and off-ramps, merge areas, weave areas, lane drops, tollbooth areas, and traffic signals; or design constraints such as curves, climbs, underpasses, and narrow or nonexistent shoulders. In many thousands of cases, these operational junctions and characteristics operate sufficiently and anonymously; however, when the design itself becomes the constricting factor in processing traffic demand, then an operationally influenced bottleneck can result.

The degree of congestion at a bottleneck location is related to its physical design. Some operational junctions were constructed years ago using design standards now considered to be antiquated, while others were built to sufficiently high design standards but are simply overwhelmed by traffic demand. The following sections provide some guidance on how to identify bottleneck locations.

Direct Observation

At the local level, engineers and planners are often aware of problem locations because they can directly observe the congestion they cause. Soliciting the input of local transportation personnel has been used successfully by many States in identifying bottleneck locations. Once the locations are identified, the nature of the problem can be assessed. Exhibit 1 on Page 4 previously presented some examples of the types of geometric and highway features related to bottlenecks; these can be used as a screen to identify the specific problem that causes the bottleneck.

Minnesota DOT successfully combined expert judgment, data analysis, and modeling to develop a list of bottleneck projects to be undertaken in as part of their congestion management activities. This process was accomplished in a span of three months from late January 2007 through mid-April 2007 (see Exhibit 5). The overriding strategy for this process was to identify smaller-scope, lower-cost projects that could be delivered within two years and would *significantly relieve congestion without pushing it further downstream.*

Exhibit 5. MnDOT Project Screening Process

Projects Lists

- Metro Area Managers
- Safety Capacity Projects
- Consultant List

Data Sources

- Freeway Congestion Maps
- Arterial Congestion Maps
- Metro District 10-Year Plan
- Metro Area Managers

Screen #1 (Binary)

A. Project cost < $15M
B. Project not in 3-year TIP
C. Could require Project Memo or lesser environmental documentation
D. Annual hours of delay > 25,000 hours of congestion
E. Freeway or Arterial > 2 hours of congestion
F. Arterial relieves parallel congested freeway or directly responsible for freeway congestion

Screen #2 (Qualitative)

A. Project implementation/design readiness
B. Cost range
C. Congestion benefit (weighted delay)
D. Traffic management for construction
E. Future demand changes
F. Relieves congestion without adverse downstream effects

Expert Workshop

Short-range congestion projects prioritized by expert group during half-day workshop

Recommended Demonstration Projects (19 Projects Totalling $60.8M)

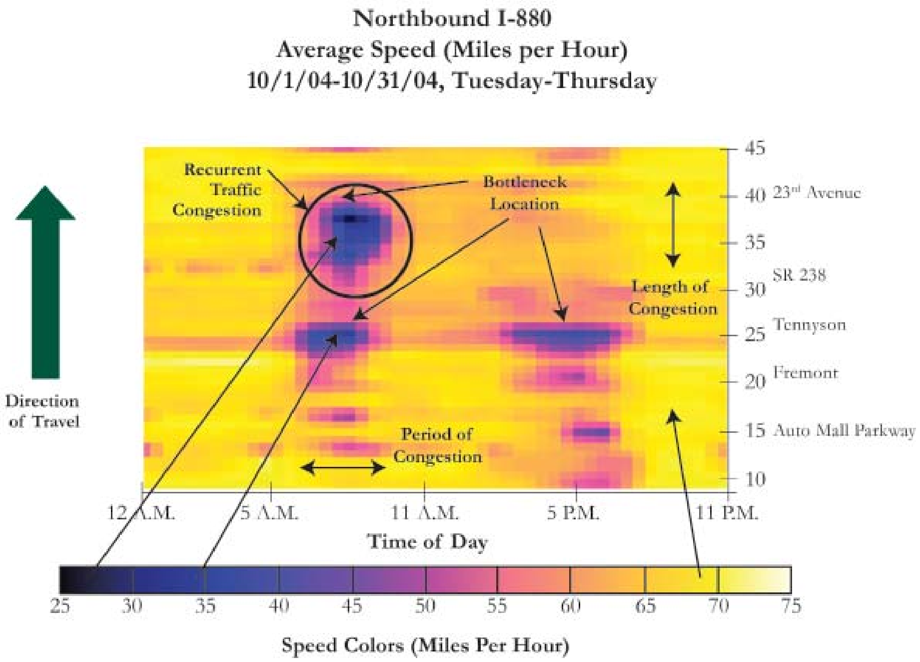
A. Geometric sketches
B. Type and scope of project (diversity of project type)
C. Congestion impacts
D. Safety impacts
E. Estimated benefit to cost ratio

Use of Data to Identify and Rank Bottlenecks

Empirical data is highly useful for both identifying a "candidate pool" of potential bottleneck locations as well as for ranking bottlenecks by the severity of the problems. Often this is a two step process:

1. Scan for potential bottlenecks using relatively simple methods. Most states have data systems capable of matching traffic volumes with roadway capacity and these can be used to perform the initial scan.
2. Perform more detailed analysis using travel time data or more sophisticated modeling methods. Here we want to produce objective estimates of congestion levels at each of the potential bottlenecks as well as to identify the root cause of the problems. Travel time data from detectors on urban freeways is now widely available through the activities of traffic management centers. Exhibit 6 shows an example of how these data may be used to identify bottlenecks. Special travel time runs, aerial photography, or video of suspected bottleneck areas can also be used to pinpoint sources of operational deficiencies. Finally, private vendors are now offering vehicle probe-derived travel time data that can be used for congestion analysis and bottleneck identification on virtually all highways.

Exhibit 6. Using Freeway Detector for Bottleneck Analysis



Analyzing Bottlenecks

Bottleneck analysis is necessary to study not only the subject location, but also the impacts of potential bottleneck remediation on upstream and downstream conditions. The analysis will justify action to correct bottlenecks, confirm the benefits of bottleneck remediation, or check for hidden bottlenecks along a corridor. 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.

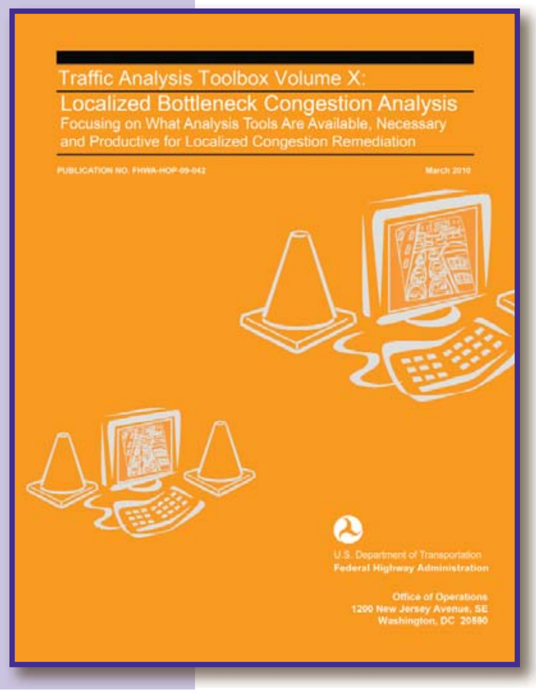
- Future traffic projections and planned system improvements are inclusive in the analysis. Safety merits also should be strongly considered.

- "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 of "hidden bottlenecks" during the analysis stage.

- Conditions not traditionally considered by models are accounted for. There are several bottleneck conditions, such as certain types of geometrics and abrupt changes in grade or curvature, that can't be analyzed by current analysis tools. Engineering judgment will need to be exercised to identify those problems and possible solutions.

These methods were successfully used to identify bottlenecks in the I-95 Corridor (Exhibit 7).

The topic of Volume Ten of the Traffic Analysis Toolbox is on Localized Bottleneck Congestion Analysis, focusing on what analysis tools are available, necessary, and productive for localized congestion remediation. This Federal publication (FHWA-HOP-09-042) discusses when, where, and how to study small, localized sections of a facility (e.g., on/off-ramps, merges, lane drops, intersections, weave, etc.) in cost-effective means. Some chokepoints are obvious in their solution; add a turn lane, widen a stretch of highway, retime a signal, or separate a movement by adding a 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. This document provides the guidance that specifies the choice of analysis tools and inputs necessary to analyze localized problem areas.



This document provides the guidance that specifies the choice of analysis tools and inputs necessary to analyze localized problem areas.

Exhibit 7. Using Vehicle Probe Data for Bottleneck Analysis

A study for the I-95 Corridor Coalition used private vendor travel time data from INRIX, combined with agency traffic counts, to conduct an analysis of major bottlenecks along the corridor. The study used the data in the following way:

- Scan INRIX data for potential bottlenecks.
  - ♦ Speeds < 40 mph for time slice of interest for all of 2009.
- Combine adjacent links.
- Map and identify the physical features that are bottlenecks.
  - ♦ Interchanges (mainly freeway-to-freeway);
  - ♦ Bridges; and
  - ♦ Toll facilities.
- Merge in volumes; compute delay and other performance measures (reliability and queue length).
- Estimate effect of bottlenecks on long distance trips.

Localized Bottleneck Reduction Strategies

Types of LBR Treatments

The following is a sampling of short-term, low-cost operational and geometric improvements. All of these remedies address operational deficiencies, as opposed to other congestion mitigation efforts that address driver choice, travel demand, corridor-wide upgrades, or simply (but expensively) building our way out of congestion.

- **Shoulder conversions.** The FHWA is currently studying the efficacy and prudence of using improved roadway shoulders to address congestion in particularly challenging situations. The safety implications of using shoulders, versus the congestion relief tradeoff of same, is first-and-foremost at the discussion of this strategy. This involves using a short section of traffic-bearing shoulder as an additional travel lane. Shoulder conversions are appropriate between interchanges or to provide lane congruency with adjacent sections. The improved shoulder should be rated for use as a travel lane. Practical challenges exist as to designing controls for part-time use versus 24/7 use.
- **Restriping existing pavement in merge or diverge areas** to provide additional lanes or to improve lane balance, provide an acceleration/deceleration lane, extend the merge/diverge area, or improve geometrics to better serve demand.
- **Minor interchange modifications.** Adding a new auxiliary lane to connect closely spaced interchanges, extending the length of an exit lane to store queues from a ramp terminus, and providing exit-only or "slip ramps" in advance of a major interchange are three examples. Note – major interchange modifications (e.g., an entire interchange rebuild) would tend to be outside the purview of the "localized" solutions found in this Primer.
- **Lane width reductions.** This involves reducing lane widths and restriping to add an additional travel and/or auxiliary lane.
- **Modify weaving areas** by adding collector/distributor or through lanes.
- **Ramp modifications.** These could include ramp metering; widening, extending, closing, or consolidating ramps; or reversing entrance and exit ramps to improve operations.
- **Speed harmonization (variable speed limits).** This is the practice of adjusting speed limits when congestion thresholds have been exceeded and congestion and queue forming is imminent. Speed harmonization can also

be used to promote safer driving during inclement weather conditions. This mostly European practice reduces the traffic "shock wave" that results through congested corridors, thereby delaying the onset of a breakdown in traffic conditions. The result is decreased headways and more uniform driver behavior, which indirectly benefit bottlenecks and chokepoints.

- **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.
- **Improve traffic signal timing on arterials.** Also, traffic signal timing improvements at ramp terminal intersections will prevent ramp queues from backing up onto freeway main lanes.
- **Access management principles** to reduce vehicular conflicts (hence, delays) on arterial corridors
- **Roundabouts.** Roundabouts may be used in place of stop sign or signal controlled intersections, including replacing signalized intersections at ramp termini.
- **Innovative intersection and intersection designs.** A variety of new designs are being implemented around the country (see below).
- **High-Occupancy Vehicle (HOV) or reversible lanes.**
- Provide **traveler information** on traffic diversions.
- **Implement congestion pricing.** Congestion pricing entails charging fees or tolls for road use that vary by level of vehicle demand on the facility. The objective is to bring supply and demand into alignment.

Innovative Intersection and Interchange Design Treatments[1]

In the past several years, several nontraditional designs have been developed for signalized intersections and interchanges. The alternative designs for intersections all attempt to remove one or more of the conventional left-turn movements from the major intersection. By removing one or more of the critical conflicting traffic maneuvers from the major intersection, fewer signal phases are required for signal operation. This can result in shorter signal cycle lengths, shorter delays, and higher capacities compared to conventional intersections. Exhibits 8 and 9 show examples for two of these innovative designs.

[1] Additional information on innovative intersection and interchange design treatments may be found at: http://www.fhwa.dot.gov/publications/research/safety/09060/.

Exhibit 8. Vehicular Movements at a Continuous Flow Intersection

One such intersection design is the Continuous Flow Intersection, which eliminates one or more left-turn conflicts at a main intersection. This is achieved through dedicated left-turn bays located several hundred feet prior to the main intersection, which allow left-turning vehicles to move at the same time as through traffic. The left-turn traffic signal phase is eliminated, allowing more vehicles to move through the main intersection and thus reducing traffic congestion and delays. These at-grade intersections achieve traffic flow similar to grade-separated interchanges, but at a considerably lower cost. Other innovative intersection designs include:

- Displaced left-turn (DLT) intersection;
- Median U-turn (MUT) intersection;
- Restricted crossing U-turn (RCUT) intersection; and
- Quadrant roadway (QR) intersection.

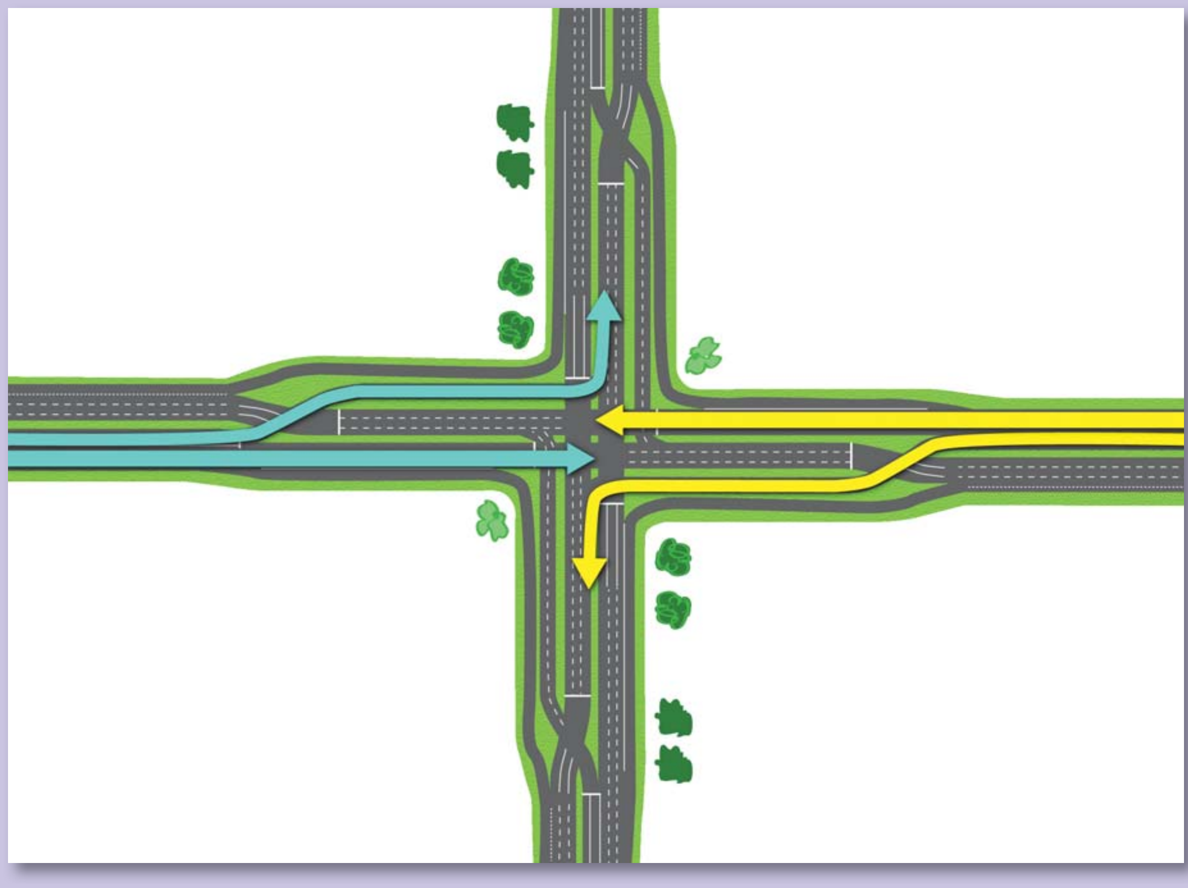
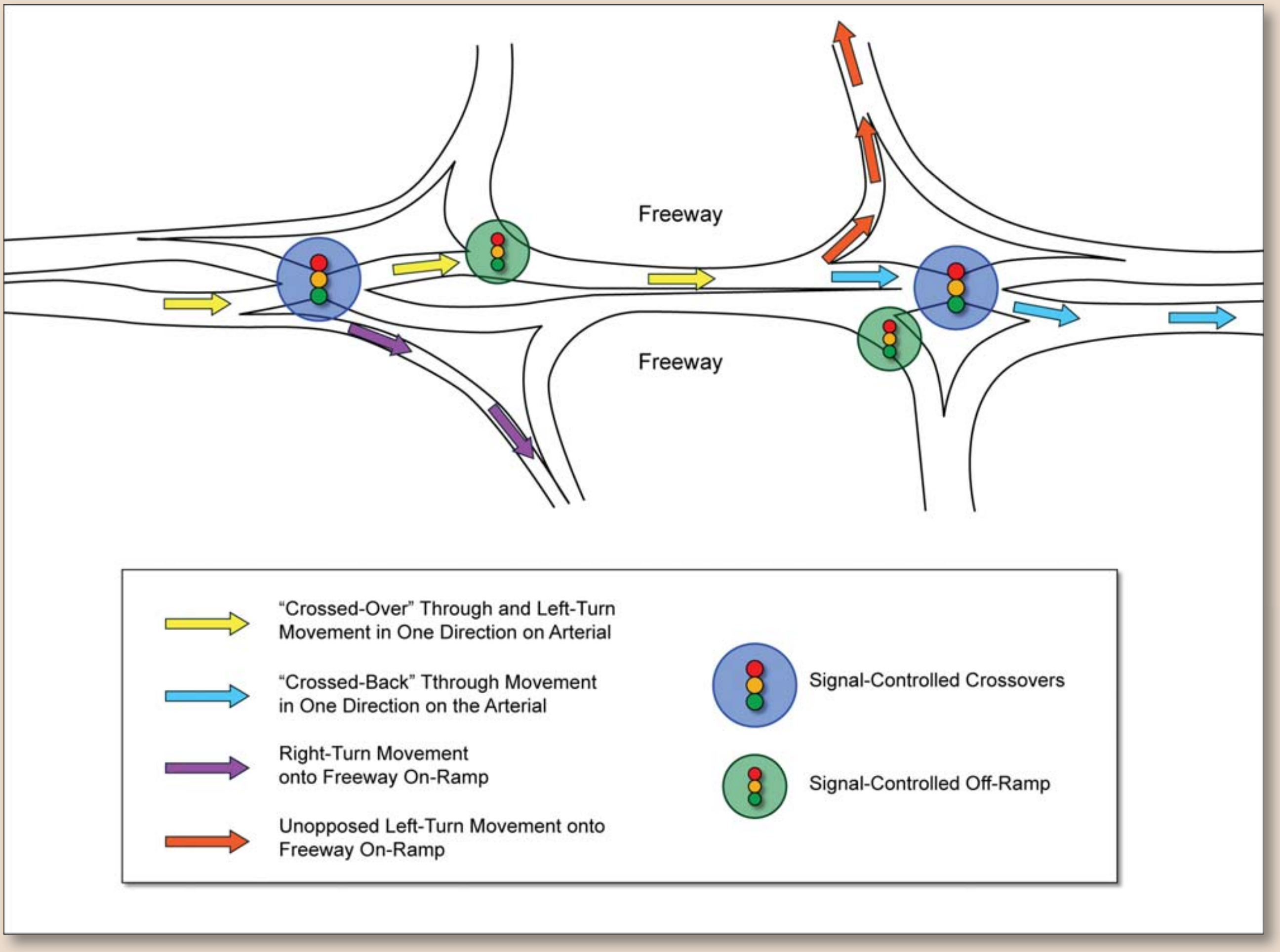


Exhibit 9. Crossover Movement in a DCD Interchange

The double crossover diamond (DCD) interchange, also known as a diverging diamond interchange (DDI), is a new interchange design that has much in common with the design of a conventional diamond interchange. The main difference between a DCD interchange and a conventional diamond interchange is in the way left and through movements navigate between the cross street intersections with ramp. The DCD design accommodates left-turning movements onto arterials and limited access highways while eliminating the need for a left-turn signal phase at signalized ramp terminal intersections. On the cross street, the traffic moves to the left side of the roadway between the signalized ramp intersections. This allows drivers of vehicles on the cross street who want to turn left onto the ramps the chance to continue to the ramps without conflicting with opposing through traffic and without stopping.



Success Stories: How Agencies Are Deploying LBR Treatments and Developing Programs

Successful LBR Treatment Applications

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. The following section provides expanded explanations of how these transportation agencies used strategies to improve congestion at bottlenecks. Exhibits 10 through 14 present summaries of these successful LBR treatments. Exhibit 15 highlights how VDOT's STARS program approaches the LBR problem.

Exhibit 10. Successful LBR Treatments –
Improvements: Austin, Texas U.S. 183

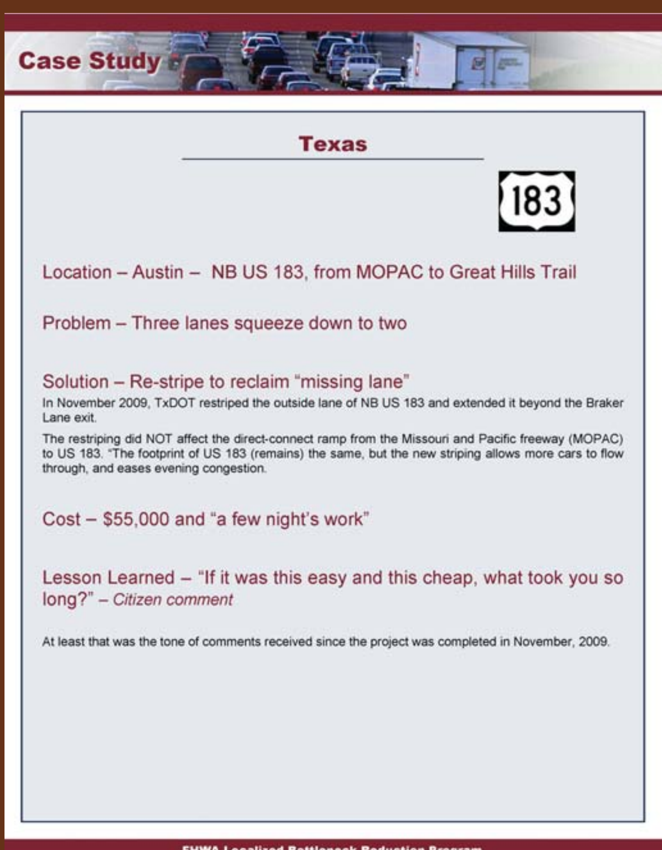


Exhibit 11. Successful LBR Treatments –
Improvements: Arvada, Colorado

Case Study

Colorado

Location – City of Arvada *(NW suburb of Denver; 8th most populous city in CO at ~ 110,000 persons)*

Grandview Avenue, and railroad, at Wadsworth Boulevard

Problem – Train traffic routinely halts vehicular traffic and poses safety problems for emergency responses

Train traffic (especially) and vehicles on Grandview Avenue would routinely block traffic on Wadsworth Boulevard. Emergency response in the vicinity was complicated and expensive, requiring two calls at all times – one for each side of the tracks – in the event that a train would come through.

Traffic backed up on NB Wadsworth prior to the project. Restaurant (blue roof) had to be relocated.

The new Grandview Bridge, "Gateway to Olde Arvada"

Solution – Grade Separation

Wadsworth Boulevard was lowered 25 feet and now passes under Grandview Avenue and the Northern Railroad. A wide median "gap" on Grandview Ave. will accommodate the future "Gold Line" (planned) commuter rail line. A pedestrian plaza (above, on Grandview) was also accommodated. The $32M** project ran from October 2006 to December 2008. Ironically, an early 1900's trolley originally ran on Wadsworth underneath Grandview, but was removed in the 1950's, and Wadsworth Boulevard was raised, creating the precursor to the subject problem; so the re-lowering of Wadsworth Blvd. was merely a full-circle remediation of this intersection. Much of the cost was given to easing the impact of the project. A local restaurant next to Grandview Avenue was relocated from the footprint of the project. The driving public felt minimum inconvenience during the project; roadway traffic on Wadsworth Blvd. was detoured to a temporary alignment which allowed three lanes in each direction to pass the project. Railroad traffic was detoured to a "shoofly" (i.e., temporary RR bridge). The underpass now serves as a "Gateway to Olde Arvada" (i.e., downtown) and a shining success story for CDOT.

Lesson Learned

While $32M and two years' construction may not seem the conventional definition of a "low cost, low impact" remediation, don't tell that to the City of Arvada and CDOT. The highly visible, publicly praised project was an unequivocal success in terms of solving a long-standing bottleneck problem!

** *($19M in federal and state formula funds, $6M from Arvada, and most of the remainder from federal earmarks)*

FHWA Localized Bottleneck Reduction Program

Exhibit 12. Successful LBR Treatments –
Improvements: Saginaw, Michigan

Case Study

Michigan

Location – Saginaw County, Michigan

I-75/M-81 Interchange in Saginaw County, Michigan.

Problem – Heavy truck traffic, inefficient signal operations, and truck overturns

Multiple problems existed at this former tight diamond interchange. Operationally, the interchange suffered from heavy truck traffic on the M-81 corridor, inefficient signal control at the ramp terminals, and safety problems as a result of sharp left turns to and from the ramps that contributed to all-too frequent truck overturns. Backups routinely occurred on M-81 as a result. The interchange also included a bridge for M-81 over I-75 that was in "critical condition."

Roundabout Solution at I-75/M-81

Solution – Construct roundabouts at diamond interchange ramp terminals

Given very limited resources, the Michigan Department of Transportation chose an innovative design approach with roundabouts replacing the signalized tight diamond ramp terminals. The project included reconstruction of the bridge, construction of roundabouts (which included bypass lanes) at the ramp terminals, and removal of the traffic signals. At $5.1 million, this solution represented a cost savings of $6 to 7 million over a typical reconstruction, primarily because right-of-way needs were considerably smaller compared to other proposed alternatives. The interchange reconstruction was completed during CY 2006. Simulation studies have shown that the "roundabout solution" has reduced delays by 58 percent, reduced fuel consumption by 25 percent (which has reduced air pollution emissions), and improved operational level of service from LOS D to LOS A, with no visible traffic back-ups. The roundabout design also provides a much higher degree of safety than the signalized layout, and as designed is much easier for commercial vehicles to traverse. Initial public negativity and skepticism were combated through nonobligatory aesthetic enhancements and educational campaigns, including an editorial rebuttal to a negative article about roundabouts that appeared in the Saginaw News. Ultimately, the initially lukewarm reception of the design concept was replaced by public acceptance and accolades for the completed project.

Lesson Learned

This project demonstrates how an innovative design approach – which often receives initial, dubious reception – can ultimately be realized with constructive public promotion and project massage.

FHWA Localized Bottleneck Reduction Program

Exhibit 13. Successful LBR Treatments – Improvements: Metroplan MPO/Little Rock Region

Case Study

Arkansas

"Operation Bottleneck"

Metroplan MPO (Little Rock region) conducted surveys – online, at public meetings, and via ads in the local newspapers – to solicit public comments in 2009. Local media was enlisted to help promote the effort. Over 3,000 responses were received – in four weeks! Many responses validated already-planned projects. Some immediate actions were taken, such as foliage removed or cut back to improve sight distances, or missing or damaged signs were installed. In the short term, local governments will continue to use the information to:

- Consider new or additional traffic signage and signals
- Enhance signal coordination
- Support minor intersection improvements
- Improve access-conflict (i.e., access management) situations as opportunities present

Dave Ward Drive, Conway - "You have to stop at every traffic light between Hogan and I-40."

East Main & South Pine in Cabot - "Almost impossible to make a left turn or go straight from either direction on East Main Street."

Solutions

Staff aggregated, and then disseminated the information to the locally responsible agencies. In some cases, regionally cooperative tasks were undertaken (i.e., a consultant was tasked with reviewing more-complex traffic signal operations; corridor studies and/or spot-specific projects will be realized, etc.) in direct response to the most accessible complaints. In other cases, Operation Bottleneck will influence regional-level decisions on major widenings and other transportation investments in the longer-term future. Operation Bottleneck makes government actions more directly responsible to citizens by providing thousands of people a chance to let their voices be heard.

Lesson Learned

Public comment is invaluable in validating concerns and providing an outlet for the public to be heard. Action items confirm to the public that the agency is listening and can provide a response.

FHWA Localized Bottleneck Reduction Program

Exhibit 14. Successful LBR Treatments – Improvements: Pittsburgh, Pennsylvania

Case Study

Pennsylvania

Location – Pittsburgh, Pennsylvania

I-279 at the Carnegie Interchange in Pittsburgh, Pennsylvania.

Problem – Inadequate acceleration lane

The existing slip on-ramp from Academy Street onto southbound I-279 has been a major traffic bottleneck and high accident location for many years. The on-ramp did not have an acceleration lane to allow for the smooth merging of traffic entering the freeway. Thus, vehicles often came to a complete stop to wait for an acceptable gap in traffic. With high Interstate traffic volumes and typically high travel speeds, the existing configuration created an unsafe and inefficient merge condition. Accident rates at this location were high and traffic queues would regularly back-up on the ramp. Mainline traffic would also be slowed by driver uncertainty and friction created by the interchange. To further compound the problem, the freeway has two lanes in the southbound direction at the ramp location but widens to three lanes further downstream, making the ramp location even more evident as a bottleneck.

Study Area (map "for placement only")

Solution – Convert shoulder to full-use lane

Traditional improvements such as widening the freeway were infeasible economically because they would require widening the bridge piers for the overhead road. Therefore, PennDOT and FHWA devised a low-cost solution which involves converting the existing right shoulder into a third freeway lane and re-striping the existing ramp to allow oncoming traffic to continue onto the freeway without stopping. The added third lane will be extended to tie in with the existing third lane of mainline traffic 800 feet downstream. The work will entail milling and resurfacing the shoulder to accommodate traffic, re-striping the ramp and mainline, and making minor changes to the ramp taper, with an estimated cost of $250,000. The project will completely remove the merge condition and bottleneck at the freeway entrance and eliminate ramp and mainline queues. Although the conversion of the shoulder will result in no shoulder presence for the length of the new lane segment, it was determined that a design exception was appropriate given the significant operational and safety benefits to result from the change. The work was scheduled to be completed in October 2007.

Lesson Learned

This project demonstrates that low-cost, low-impact bottleneck improvements can make significant improvements in traffic flow.

FHWA Localized Bottleneck Reduction Program

Exhibit 15. Success Spawns Success:
Virginia's STARS Program Spurs Rhode Island to Develop Its Own STARS Program

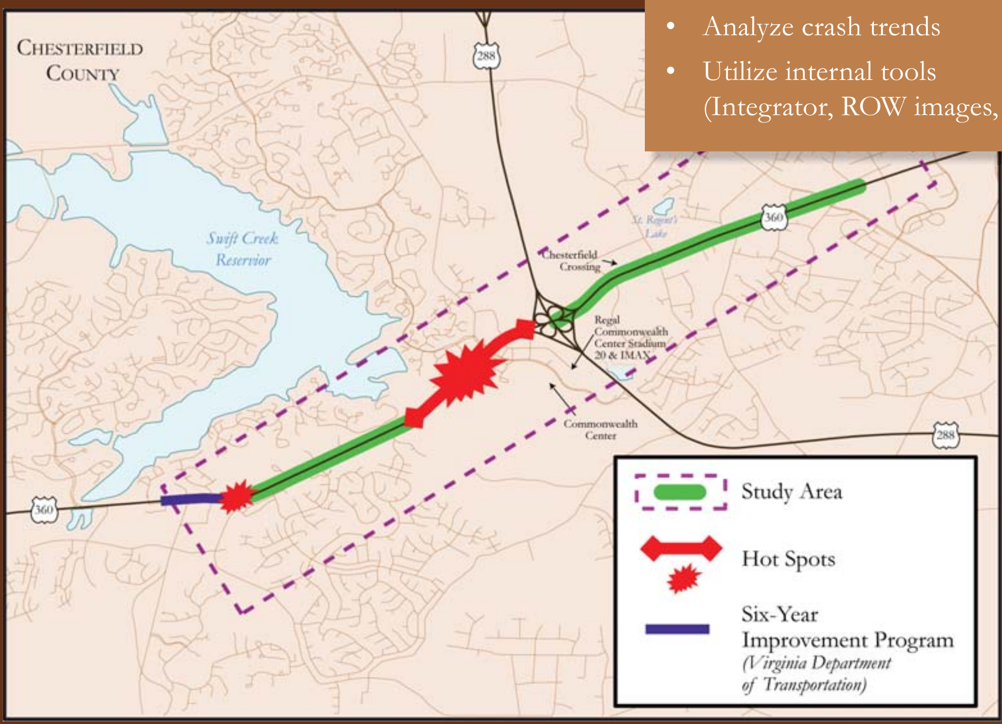
In 2007, the Virginia Department of Transportation (VDOT) developed the STARS (Strategically Targeted Affordable Roadway Solutions) program. VDOT noticed that during the course of conducting screening analysis for crash hotspots for its Highway Safety Improvement Program (HSIP), many locations also had a congestion or bottleneck problem. It was decided that in addition to safety, mobility problems should also be included in the screening process.

Identifying Study Locations

Step 7 – Refine High-Priority Corridors

Identify Safety and Congestion Hot Spots

- Conduct preliminary safety and congestion assessment
- Field inspection
- Analyze crash trends
- Utilize internal tools (Integrator, ROW images, 1/4 mile crash densities, etc.)



Learning of interest from Rhode Island DOT (RIDOT), FHWA facilitated a peer exchange with VDOT. This led to RIDOT developing a companion program, RISTARS. By identifying both safety and mobility problems simultaneously, projects that would otherwise be conducted separately are combined. Further, it is often true that fixing safety problems have a positive benefit for mobility, and vice versa.

Successful LBR Program Development

Unless transportation agencies make low-cost bottleneck improvements an explicit presence, it is likely that they will be overlooked or delayed; either deemed part of a "larger" problem, or unnecessarily postponed to some indefinite out year. There are many ways to combat this:

- **Create a unique bottleneck program area.** By developing an annual "named" program, agencies can effectively identify, fund, and most importantly, advance low-cost treatments. A stand-alone program also has the added benefit of demonstrating to the public that the agency is actively engaged in fighting congestion.
- **Undertake occasional "special projects" to focus on bottlenecks.** Low-cost bottlenecks can be addressed through occasional "special projects." For example, the Minnesota DOT conducted a "one-time" special compilation of projects meeting certain candidacy requirements. In much less than one year, MnDOT developed a highly accelerated process for bottleneck identification and prioritization, which led to many effective projects that were implemented in the following two years.
- **Integrate consideration of low-cost bottlenecks into existing programs.** Low-cost bottlenecks can be addressed programmatically even without a special program. By making them part of ongoing planning and processes, the can be part of an agency's congestion arsenal.

The following provide comparisons of how different state agencies have incorporated low-cost bottleneck projects into their planning and programming processes:

- The **California Department of Transportation** (Caltrans) does not have a formal bottleneck planning process; rather, bottleneck issues are addressed at the district level as part of the regional planning process. Much of Caltrans' operational planning is guided by the Transportation Management System Master Plan, which sets forth the types of strategies that should be pursued in improving congestion. In much of California's metropolitan areas, traffic congestion is a 24/7 occurrence, and traffic management is a 24/7 job. Bottlenecks are tweaked "in real-time" as part of their Corridor System Management Plans (CSMP), which are developed for some of California's most congested transportation corridors. System monitoring and evaluation is seen as the foundation for the entire process because it cannot only identify congestion problems, but also be used to evaluate and prioritize competing investments. Caltrans does not have a direct funding for bottlenecks, although bottleneck projects are routinely programmed through the CSMP process.

- In **Ohio**, bottlenecks are part and parcel of the overarching Ohio Department of Transportation (ODOT) Highway Safety Program (HSP), which ranks all candidate projects and drives the statewide highway project selection and scheduling process. Beginning in 2002, ODOT developed a "congestion mapping" division that uses volume/cost (V/C) ratios developed from traffic data recorders and roadway inventory. About the same time, ODOT administration pushed for an annual process of overlaying congestion index and safety index "hot spots." As a result, congestion hot spots now have a "voice" in the process regardless of crash indices, and congestion-related problems now compete for attention in the HSP listing. Specifically, highway sections with V/C ratios greater than 1.0 are considered "congested" and are added to the listing. Sections with V/C between 0.9 and 1.0, but outside the cities of Columbus, Cincinnati, and Cleveland, are also added. After ODOT headquarters completes their statewide effort of congestion mapping and safety indexing, the respective District engineers are responsible for developing countermeasures for their top-listed candidate projects. District Safety Review Teams sort projects into three scales – low (less than $100K and quickly implementable), medium ($100K to $5M and one to two years), and high (greater than $5M and necessitating more than two years to implement) – and then compete with other projects having the same scale but in other districts.

- **Minnesota DOT** (MnDOT) was originally driven to explore low-cost congestion relief projects because of budgetary restrictions, but soon realized that these projects could be implemented very quickly and, as a bonus, were highly visible and popular with the public. In much less than one year, MnDOT developed a highly accelerated process for bottleneck identification and prioritization, which led to many effective projects in the following two years. MnDOT also found that because of lower costs, it could identify multiple locations throughout the region and "spread around" bottleneck reduction projects in a fair and equitable manner. This process consisted of completing a study, which included a five-step process to narrow potential projects into a recommendation list to the state legislature. Evaluation of completed projects produced high benefit/cost ratios, usually greater than 8:1.

- The **Maryland State Highway Administration** (SHA) has a dedicated program of about $5 million per year for the identification and implementation of low-cost traffic congestion improvements at intersections. The program's genesis tracks to when SHA asked "what can be done if and when a megaproject's 'no-build' alternative is chosen?" The program has been well received by the public and local governments. Projects typically include low-cost projects that can be implemented 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 merge areas that have reduced congestion bottlenecks at a low cost.

- In **Florida**, there is not a "bottleneck" planning process, per se; rather, bottleneck-related issues are addressed as part of the Florida Department of Transportation's (FDOT) standard planning process. The planning process, which is managed by the FDOT Systems Planning Office, begins with needs identification conducted at the district level, then projects are developed and proposed for the Cost Feasible Plan. The Cost Feasible Plan is adopted and projects are ranked for inclusion into the 5-year or 10-year programs. Traffic data and the statewide model are used to identify deficiencies, but it is the responsibility of the districts to identify and resolve hot spots.
- **Washington State DOT** has no direct funding for bottlenecks, but formally recognizes "bottlenecks and chokepoints" in their project planning and development process and devotes a portion of the Washington Transportation Plan (WTP) to them. At the planning stage, WSDOT considers bottlenecks together with traditional corridor improvements in a category called "Congestion Relief" – bottlenecks do not have their own category for assessment or funding. The Congestion Relief projects are ranked (prioritized) using the benefit/cost ratio and other qualitative factors.

- Additionally, the "Moving Washington" initiative, a special 10-year program, specifically recognizes the importance of the short-term low-cost improvements that are the hallmark of LBR projects. In "Moving Washington," Tier 1 projects are "immediate, low-cost, operational fixes." Another aspect of "Moving Washington" relevant for LBR programs is its reliance on performance measurement – not just to identify problems but to assess to the impacts of completed projects. More information on the use of performance measurement by WSDOT may be found in their "Gray Notebook": http://www.wsdot.wa.gov/accountability/GrayNotebook.pdf.

Want More Information?

The LBR Program is just one of several program areas dealing with congestion problems. More information may be found at FHWA's "Focus on Congestion" web page at: http://www.fhwa.dot.gov/congestion/links.htm.

The LBR Program has a comprehensive web site with additional information (http://www.ops.fhwa.dot.gov/bn/lbr.htm) and resources (http://www.ops.fhwa.dot.gov/bn/index.htm).

Definitions

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 (specifically, traffic congestion) – FHWA's Traffic Congestion and Reliability Report defines 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 of congestion.

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 physical bottlenecks (a.k.a. "capacity constraints"), traffic 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 sub-element 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, a work zone, or other atypical event. Even if planned in many cases, like work zones and special events, they are irregular and not predictably habitual in location and duration.

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 one 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.

Traffic Bottlenecks – Localized sections of highway where traffic experiences reduced speeds and delays due to recurring operational conditions or nonrecurring traffic-influencing events.	
Occurrences	**Recurring:** "Predictable" in cause, location, time of day, and approximate duration. **Nonrecurring:** "Random" (in the colloquial sense) as to location and severity. Even if planned in some cases, like work zones or special events, these occurrences are irregular and are not predictably habitual or recurring in location.
Causes	**Recurring: Operational Causes –** A "facility determinate" condition wherein a fixed condition (the design or function of the facility at that point) allows surging traffic confluence to periodically overwhelm the roadway's physical ability (i.e., capacity) to handle the traffic, resulting in predictable periods of delay.
Examples	**Recurring:** Ramps, lane drops, weaves, merges, grades, underpasses, tunnels, narrow lanes, lack of shoulders, bridge lane reduction, curves, poorly operating traffic signals.
Supplementary Terms (applies to either type)	**"Active" bottlenecks –** When traffic "released" past the bottleneck is not affected by a downstream restriction (i.e., queue spillback) from another bottleneck. "Hidden" bottlenecks – When traffic demand is metered by another upstream bottleneck(s); i.e., either a lesser or nonexistent bottleneck that would increase or appear, respectively, if only unfettered
Identification of (applies to either type)	Motorists typically refer to bottlenecks in terms of added time delay when compared to the same nondelayed trip, but engineers and agencies also measure performance data: average speed (travel time), lane densities, queue lengths, queue discharge rates, vehicle miles of travel (VMT), and vehicle hours of travel (VHT).
Measurement of (applies to either type)	Data is collected using manual techniques (e.g., floating cars, aerial photography, or manual counts from video recordings) or from dynamic surveillance (e.g., detectors, radar, video, etc.) collected in real time. Modeling, especially microsimulation, can be used to study the impacts of bottleneck remediation on upstream and downstream conditions.
Classification of	**Recurring:** Type I – Demand surge, no capacity reduction (typically at freeway on-ramp merges). Type II – Capacity reduction, no demand surge (typically changes in freeway geometry; lane drop, grade, curve). Type III – Combined demand surge and capacity reduction (typically in weaving sections). **Nonrecurring:** Usually classified by the type of event (e.g., incident, work zone) and severity of impact (e.g., duration of the number of lanes lost, closed, or impassable).
Signature Trigger	**Recurring:** Bottleneck is due to over-demand of volume (i.e., peak-hour conditions). The bottleneck clears from the rear of the queue as volume declines. **Nonrecurring:** Bottleneck is due to loss of capacity due to an incident, or short-term over-demand due to a spot event. The bottleneck clears from the front or rear of the queue, depending on whether the cause is incident-related (former) or volume-related (latter), respectively.
Disappears when	**Recurring:** When volume over-demand drops back to manageable levels for available capacity (i.e., when off-peak conditions return). **Nonrecurring:** When dynamic event is removed; queue should dissipate, thereafter.

Traffic Bottlenecks – (continued)
Localized sections of highway where traffic experiences reduced speeds and delays due to recurring operational conditions or nonrecurring traffic-influencing events.

Practical Mitigations:	Recurring: Corridor Congestion	Recurring: Localized Bottleneck	Nonrecurring
	Dynamic pricing	Use shoulder lane	Improve incident response capabilities; reduce incident impact; reduce on scene time for clearing incidents; reduce facility “downtime” during the event. In work zones, maintain maximum number of open lanes during peak times; shorten durations using innovative methods and contracting practices; minimize number of times a section is an active work zone by combining improvements (e.g., paving and safety) and using highly durable materials; employ least intrusive detour(s). Pre-plan for and coordinate special events to adequately and efficiently handle event traffic, including not only the main event but the subordinate deliveries, VIP access, emergency response, and pre- and post-event activities. Have predetermined detour plans for particular sections of highway in the event of weather- or incident-related events, including available tools (i.e., arrows, sign stands, VMS boards, public information conduits, etc.).
	Transit alternatives	Restripe weave area	
	Ridesharing, telecommuting	Improve merge area	
	High-occupancy lanes	Widen, extend, remove, or consolidate ramps	
	Successive ramp metering	Individual metered or signalized ramp	
	New construction	Improve signalization or intersection design	
	Install frontage roads	Install frontage road	
	Traffic demand management (TDM) techniques	Effect “speed harmonization” as in Europe	
	Build park-and-ride lots	Encourage “zippering”	
	“Downtown“ or cordon\congestion pricing	Use access management techniques	
	Provide traveler information	Provide traveler information	
	Proactive signal timing plans (including adaptive control)		

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