APPENDIX B

Short Summaries of Selected Case Studies

This appendix provides short summaries of selected case studies highlighted throughout this Guidebook and/or in Appendix A. More details of these selected case studies are available in the project technical memorandum "Review of Current Practices and Measures Used to Identify, Classify, Evaluate, and Mitigate Truck Freight Bottlenecks." Note that the "Matrix ID No." in Table B-1 refers to the matrix row number in the accompanying Excel file.

Table B-1. Listing of Case Studies Described in More Detail

Report Title	Agency	Matrix ID No.	Analysis Type(s)[a]	Bottleneck Type(s)[a]
Texas 100 Most Congested Roadways	Texas DOT	8	identifying, evaluating	Congestion, geometrics, work zones
Mobility Investment Priorities	Texas State Legislature	384	Mitigating	Congestion, geometrics, others
Delaware Valley Regional Planning Commission (DVRPC) 2012 Congestion Management Process (CMP)	Delaware Valley Regional Planning Commission (DVRPC)	96	Identifying, classifying, evaluating, mitigating	Congestion
Virginia Statewide Multimodal Freight Study, Phase I	Virginia DOT	204	Identifying, evaluating, mitigating	Congestion
Washington DOT Freight Mobility Plan	Washington DOT	383	Identifying, evaluating, mitigating	Congestion
Existing and Future Truck Delay in Hampton Roads Preparation for Project Prioritization	Hampton Roads Transportation Planning Organization (HRTPO)	206	Identifying, evaluating	Congestion
Positioning Hampton Roads for Freight Infrastructure Funding MAP-21 and Beyond	Hampton Roads Transportation Planning Organization (HRTPO)	205	Identifying, classifying, evaluating, mitigating	Recurring (design), height restrictions, lane width, pavement condition
Oregon State Highway Performance Data and Metrics Related to Freight January 2013	Oregon DOT	215	Identifying, classifying, evaluating	Congestion, geometrics, incidents, capacity

Report Title	Agency	Matrix ID No.	Analysis Type(s)[a]	Bottleneck Type(s)[a]
ODOT Region[a] Corridor Bottleneck Operations Study	Oregon DOT	219	Identifying, classifying, evaluating, mitigating	Recurring, interchange, auxiliary lane
Freight Performance Measures Analysis of Freight-Significant Highway Locations	American Transportation Research Institute (ATRI)	1	Identifying, evaluating	Congestion
Georgia Statewide Freight and Logistics Plan, 2010-2050	Georgia DOT	202, 203	Identifying (202), evaluating, mitigating (203)	Congestion
Southern California Council of Governments (SCAG) Regional Transportation Plan – Congestion Management, Goods Movement, and Truck Bottleneck Strategy	Southern California Council of Governments (SCAG)	87, 87.1, 87.2	Identifying, classifying, evaluating, mitigating	Congestion
Freight Fluidity in Canada	Transport Canada	184, 375, 395	Identifying, evaluating	Congestion
Freight Mobility Efforts in the State of Florida	Florida DOT and partnering agencies	98, 217, 363, 365, 371	Identifying (98), classifying, evaluating, mitigating (217, 365)	Congestion
Preparing for MAP-21 System Performance Measures and Target-Setting Requirements: Lessons Learned in Virginia	Virginia DOT	405	Identifying, evaluating	Congestion, geometrics, work zones
Implementing Freight Fluidity in Maryland: Definition, Procedures and Results	Maryland State Highway Administration	406	Identifying, evaluating	Congestion, geometrics, work zones
I-95 Corridor Coalition: Bottleneck Performance in the I-95 Corridor	I-95 Corridor Coalition	47	Identifying, classifying, evaluating	Recurring, geometrics, lane drops, merging, on/off ramps, interchange, weather
Mitigation of Recurring Congestion on Freeways	–	80	Identifying, mitigating	Recurring
Improving Safety and Operation with Low-Cost Freeway Bottleneck Removal Projects	Texas DOT	162	Identifying, evaluating, mitigating	Recurring, merging, weaving, geometrics, lane drop, on/off ramp, auxiliary lane, interchange
Using GPS Truck Data to Identify and Rank Bottlenecks in Washington State	Washington State DOT	361	Identifying, evaluating	Congestion

Report Title	Agency	Matrix ID No.	Analysis Type(s)[a]	Bottleneck Type(s)[a]
Freight Bottlenecks in the Upper Midwest: Identification, Collaboration, and Alleviation/Identifying and Characterizing Truck Bottlenecks in the U.S. Mississippi Valley Region	University of Wisconsin-Madison, Center for Freight and Infrastructure Research and Education	31, 158	Identifying, classifying, evaluating	Recurring (design), interchange, signalized intersection, lane drop, steep grade
An Initial Assessment of Freight Bottlenecks on Highways	Federal Highway Administration (FHWA)	20	Identifying, classifying, evaluating	Recurring (design), interchange, signalized intersection, lane drop, steep grade
Quantifying the Contributing Factors of Traffic Congestion Using Urban Congestion Report Data	–	164	Classifying, evaluating	Congestion, work zones, weather, incidents
Columbus-Phenix City MPO Congestion Management Process: 2007 Update	Columbus Planning Department	303	Identifying, classifying, evaluating, mitigating	Congestion, incidents, geometrics, lane drop, signal timing
FHWA Recurring Traffic Bottlenecks: A Primer – Focus on Low-Cost Operational Improvements	Federal Highway Administration (FHWA)	16	Identifying, evaluating, mitigating	Congestion, merges, interchanges, geometrics, auxiliary lanes
Identifying, Anticipating, and Mitigating Freight Bottlenecks on Alabama Interstates	University Transportation Center for Alabama (UTCA)	66	Identifying, classifying, evaluating, mitigating	Recurring, interchange, capacity, lane drop, steep grade, geometry
Framework for Analysis of Recurring Freeway Bottlenecks	National Cooperative Highway Research Program (NCHRP)	167	Identifying, classifying, evaluating, mitigating	Recurring (design), geometrics, lane drop, interchange, steep grade, curves, lane width

Texas 100 Most Congested Roadways (39, 40)

The "Texas 100" report identifies and evaluates bottlenecks for urban freeways and arterials in Texas. Since 2009, the Texas A&M Transportation Institute (TTI) has produced a list of the 100 Most Congested Roadways in Texas for the Texas Department of Transportation. Currently, TTI uses private-company speed data solicited through an annual request for proposals. The speed data include annual average speeds (15-minute) for each section of road for every 15 minutes of the day. Annual average daily traffic (AADT) and inventory data (number of lanes, truck percentage, roadway sections) are obtained from TxDOT's Roadway-Highway Inventory (RHiNo) dataset. The steps taken are as follows (1):

1. Obtain volume and speed data by road section;
2. Match speed and volume data;
3. Estimate 15-minute volume counts (to "match" 15-minute speeds);
4. Establish uncongested (free-flow) speeds for performance measure calculation;

5. Calculate performance measures for each 15-minute time period at the direction Traffic Messaging Channel (TMC) level, including annual total delay, annual delay per mile, Texas Congestion Index (TCI) (a form of the Travel Time Index), Commuter Stress Index (CSI) (same as TTI, only directional), excess CO2 Produced (due to congestion), excess fuel consumed, Congestion Cost (wasted time and fuel), and Planning Time Index; and
6. Combine smaller TMC-segment congestion measure values into longer section values to ensure congestion problems are not just from isolated ramps or intersections, and results are analyzed and presented bidirectionally (cross-sectional) because that is generally how transportation projects are implemented. Indices are weighted from the segment level to the longer section level by person-miles of travel (PMT).

Roadways are ranked in total delay per mile to identify bottlenecks. Sections are also ranked by truck delay per mile. In 2011, TTI was directed by the Texas Legislature to serve as a facilitator and coordinator of studies to ensure that 2) projects will have the greatest impact on improving the transportation system and the economy.

Mobility Investment Priorities (MIP) Project (41)

TTI extensively documented possible congestion causes, completed projects, planning efforts to date, public engagement/involvement efforts, and next steps for the most congested sections in each metropolitan area of Texas (based on the Texas 100 rankings) and is presented with maps of the most congested sections by metro. In addition to these congestion reduction plans, TTI created a corridor project checklist for each of these sections to identify the status/need for each mobility strategy grouped in the broad categories of traffic management, travel options, active traffic management, system modification, additional capacity, construction improvements, public participation, and effects (see http://mobility.tamu.edu/mip/corridors-pdfs/austin/CC-AUS-4-IH-35-TTI-072313.pdf for a sample for IH 35).

Delaware Valley Regional Planning Commission (DVRPC) 2012 Congestion Management Process (CMP)(42)

This report described the DVRPC's Congestion Management Process (CMP) and identified, classified, and evaluated bottlenecks in the region and provided mitigation strategies specific to each bottleneck. The DVRPC Congestion Management Process (CMP) considers freight in the criteria analyses for corridors in the region in line with the DVRPC Long-Range Plan (LRP). A range of strategies to reduce congestion are classified in five categories (1):

1. Operational Improvements, Transportation System Management (TSM), and Intelligent Transportation Systems (ITS);
2. Transportation Demand Management (TDM), Policy Approaches, and Smart Transportation;
3. Public Transit Improvements and New Investments;
4. Road Improvements and New Roads; and
5. Goods Movement.

The CMP provides nearly 90 congestion strategies organized amongst 39 families of solutions. In many cases, the congestion improvement strategies have a beneficial impact on truck movements. DVRPC has a CMP Interactive Web Mapping Application www.dvrpc.org/webmaps/CMP/ to facilitate presentation of the corridor/subcorridor information. The Goods Movement strategies also have a direct link to truck freight and include items such as truck parking, and freight capacity investments such as grade-crossing separations and freight intermodal center/yard or freight villages. Appendix A of the CMP also provides the “Criteria and Analysis-Based Strategy Guidance.” In this section, the CMP Objectives are tied to the LRP and criteria (short versions and detailed) are established that relate to each CMP Objective. And then the criteria are connected to appropriate congestion-reducing strategies. Table B-2 shows the criteria and strategy guidance for LRP Goal “Rebuild and Maintain the Region’s Transportation Infrastructure.

Table B-2. DVRPC CMP Objective, Criteria, and Suggested Strategies for DVRPC LRP Goal “Rebuild and Maintain the Region’s Transportation Infrastructure”

CMP Objective	Criteria (Short Version)	Detailed Criteria	Guide to Advancing from Objectives and Criteria to Strategies
Maintain existing core transportation network	1. National Highway System (NHS). 2. Existing passenger transit. 3. Existing freight rail; and 4. Major freight facilities.	• NHS, NHS connectors. • Existing passenger rail (including Amtrak), trolleys, buses, and shuttles with open door service (available to the public). • Existing freight rail lines. • Freight facilities – major rail yards, rail-truck intermodal yards, and ports (one-mile buffer). • Philadelphia International Airport (one-mile buffer).	• **Road System –** Review existing consistent Major SOV capacity-adding TIP projects with draft strategies and Notes. If any may not be consistent, review with corridor or CMS studies. If a project has been found consistent in the past but is no longer fitting with strategies, explain grandfathering in Notes. If any subcorridors with five or more existing Major SOV projects do not have capacity strategies, consider adding road and transit capacity. • NHS freight connectors and freight facilities – Review Goods Movement strategies. • **Existing Transit –** Where three or more runs of bus routes in urban areas or two or more runs in suburban areas during peak periods, or train stations with 500 or more daily boardings, review Transit Infrastructure Improvements, TSP (under signal Improvements family), ITS Improvements for Transit, Shuttle to Station (under New Bus Transit family), TOD (under Land Use/ Transportation Policies family), and Modifications to Existing Transit Routes or Services. • Where congestion is high and transit high, review if appropriate: Passenger Intermodal Center or Garage for Transit Riders, BRT, and New Passenger Rail Investments.

The CMP identifies 30 congested corridors in all and these corridors were divided into subcorridors at a regional planning level resulting in over 100 subcorridors. DVRPC has a CMP Interactive Web Mapping Application www.dvrpc.org/webmaps/CMP/ to facilitate presentation of the corridor/subcorridor information. In addition, DVRPC also has a PhillyFreightFinder (http://www.dvrpc.org/webmaps/phillyfreightfinder/) to pinpoint freight facilities and freight activity in the region.

Virginia Statewide Multimodal Freight Study, Phase 1 (43, 44)

This report provided an overview of Virginia's intermodal freight transportation system. The Commonwealth of Virginia performed this study to place prior studies into a larger multimodal investment context and establish a guiding framework for freight policy and investment strategies in both the short and long term. The study investigated intermodal and multimodal systems and included trucking, railroads, waterways, ports, warehouse/distribution, air cargo, and NHS intermodal connectors.

The report identifies segments that are defined as bottlenecks. Bottlenecks are defines as "whether existing or emerging – prohibit the efficient flow of freight through the system and across the Commonwealth. Bottlenecks are created by a combination of demand to utilize a transportation asset (both freight and passenger), the capacity of the asset, and fluctuations in the demand at different points in time. A bottleneck slows down the system regardless of its mix of passenger and commercial vehicle traffic" (1). The report then identifies Virginia's primary (trucking/highway) freight bottlenecks corresponding to (1):

- Major urbanized regions with high levels of congestion (Northern Virginia, Hampton Roads, Richmond);
- Major national through-travel corridors (I-95, I-81);
- Intersections of major highway arteries (I-495/I-95, I-77/I-81, I-64/I-295/I-95);
- Routes with few or no alternatives (Hampton Roads Bridge Tunnel, Monitor Merrimack Memorial Bridge Tunnel);
- Access into and out of heavily used marine terminal facilities, and segments between marine terminals and related inland facilities and warehouse/distribution centers.

The study identifies truck bottlenecks using a number of different methods, including:

- Ranking by Truck Average Annual Daily Traffic from Virginia statewide truck counts and percentages;
- Ranking by an "AADT Adjusted per Lane" where it is assumed that one truck equals 4.25 cars;
- Truck tonnage (inbound, outbound, internal and passing through) from TRANSEARCH database;
- Investigation of bridge and pavement condition on heavily used freight corridors;
- Investigation of truck crashes by type of facility;
- A prior Federal Highway Administration (FHWA) study on arterial and U.S. highways using Highway Performance Monitoring System (HPMS) and a comparison of modeled demand versus estimated capacity to identify interchange and geometry issues in terms of annual hours of truck delay;
- Truck delay measures from FHWA's Freight Analysis Framework (FAF) (minutes per year); and
- Level-of-service estimates over statewide mobility system.

The study also includes a discussion of highway improvements being implemented or planned in a number of places in Virginia. Planned (or anticipated) improvements often include truck-specific geometric improvements (e.g., truck climbing lanes) or other geometric improvements that will benefit both passenger cars and goods movement.

A novel approach in the study was interviews to over 180 stakeholders representing manufacturing, distribution firms (trucking firms, wholesalers, etc.) and an assortment of retail, mining, agricultural, and other firms. A final notable element in the study is a list of typical freight projects, benefits, and performance metrics for all freight modes. Table B-3 includes just those shown in the report for the "highway" and "all" modes.

Table B-3. Typical Freight Projects, Benefits, and Performance Metrics (Selected)
Adapted from Virginia Statewide Multimodal Freight Study, Phase 1

Project Type	Mode	Transportation Benefits	Metrics
Add general purpose lanes	Highway	Congestion – travel time savings Reliability – reduced incident impact Potential accident reduction	Travel time Nonrecurrent delay Accidents
Add truck-only lanes	Highway	Congestion – travel time savings Reliability – reduced incident impact Potential accident reduction	Travel time Nonrecurrent delay Accidents
Add track/new segment	Rail/Hwy	Congestion – time savings/car cycling Potential reliability – queue impact Diversion to rail reduces highway congestion and impacts	Travel time, cycle time On-time performance Volume, travel time
Upgrade/eliminate grade crossing	Rail/Hwy	Potential speed/travel time savings Accident reduction – reliability savings	Average speed Accidents

Washington DOT Freight Mobility Plan (45, 46)

This report provided an overview of Washington's freight transportation network, including a data-driven benefit analysis of congestion mitigation projects. The main objectives of the plan are to:

1. Prioritize freight system improvement strategies to support the plan's three objectives:
    a. Urban goods movement systems that support jobs, the economy, and clean air for all, and provide goods delivery to residents and businesses.
    b. Washington's competitive position as a Global Gateway to the nation with intermodal freight corridors serving trade and international and interstate commerce, and the state and national Export Initiatives.
    c. Rural economies' farm-to-market, manufacturing and resource industry sectors.
2. Help Washington successfully compete for Federal freight funds by providing a data-driven benefit/cost analysis supporting truck freight and intermodal freight projects that meet Federal criteria and goals.
3. Integrate existing state plans into a single state freight plan to address all freight modes in the state system: truck, rail, marine, and aviation.

WSDOT has been a leader in the area of using global positioning systems (GPS) data from trucks to identify and quantify truck bottlenecks. Over 6,000 trucks were monitored throughout the state daily and methods were developed to quantify congestion and reliability measures (1).

Travel reliability for trucks was divided into three categories: unreliable, reliably slow and reliably fast for each time period of interest. The methods use two Gaussian distributions and a set of rules based on the estimated distribution parameters from the truck data to identify travel reliability condition. Researchers ranked the inadequate segments based on both reliability and congestion measurement performance.

Building from the work described above, WSDOT developed the bottleneck types and criteria shown in Table B-4. Table B-4 is from WSDOT's Washington State Freight Mobility Plan (2). In addition to the bottleneck type and criteria threshold, Table B-4 also documents the implications for freight for each bottleneck type. Table B-5 separates out slow speed bottlenecks on uninterrupted and interrupted facilities because the potential solutions are different. This plan included congested freeway bottlenecks, truck bottlenecks on a traffic-controlled state highway in an urban area, resiliency bottlenecks, legal load bottlenecks, and over-height bottlenecks. Recently, WSDOT has also defined first/last mile connector routes to strengthen the freight system in the State (http://www.wsdot.wa.gov/Freight/EconCorridors.htm).

Table B-4. Categories of Truck Bottlenecks – Adapted from Reference 2

Bottleneck Type	Criteria Threshold	Implications for Freight
Slow Speed	• More than 50% of sampled trucks are traveling below 60% of the posted speed (35 mph on urban freeways)	• Travel time increases
Reliability	• 80th percentile	• Travel times are hard to estimate, leading to poor on-time performance
Resiliency	• Disruptions caused by severe weather, natural disasters (earthquakes), or other causes • Minimum average of at least 5,000 trucks per day on the freight corridor • Truck corridor has had least one full closure lasting longer than 24 hours in a rolling 20-year period	• Facility failure causes large statewide economic impacts for shippers, goods receivers, and carriers
Restricted Access for Legal Loads	• Facility has a posted weight limit below the legal gross vehicle weight of 105,500 pounds or the facility has a posted height limit below 14 feet, the legal height limit for trucks	• Legal truck loads cannot travel on the state truck freight economic corridors
Clearance restriction for over-height loads	• Facility has a height clearance less than 17 feet	• Over-height loads have to take detour routes adding too many additional miles to the trip

Table B-5. Truck Slow Speed Bottleneck Categories – Adapted from Reference 2

Category	Potential Solutions
Congested freeway bottlenecks in urban areas	• Provide traveler information • Improve viability of alternate modes for passenger traffic • Manage demand through variable rate tolling or other strategies • Add strategic capacity
Truck bottlenecks on traffic-controlled state highways in urban areas	• Optimize traffic signal timing to reduce delays • Improve geometrics for large trucks • Add strategic capacity

Table B-6. Categories of Truck Bottlenecks – Adapted from Reference 2

Bottleneck Type	Criteria Threshold	Implications for Freight
Slow Speed	• More than 50% of sampled trucks are traveling below 60% of the posted speed (35 mph on urban freeways)	• Travel time increases
Reliability	• 80th percentile	• Travel times are hard to estimate, leading to poor on-time performance
Resiliency	• Disruptions caused by severe weather, natural disasters (earthquakes), or other causes • Minimum average of at least 5,000 trucks per day on the freight corridor • Truck corridor has had least one full closure lasting longer than 24 hours in a rolling 20-year period	• Facility failure causes large statewide economic impacts for shippers, goods receivers, and carriers
Restricted Access for Legal Loads	• Facility has a posted weight limit below the legal gross vehicle weight of 105,500 pounds or the facility has a posted height limit below 14 feet, the legal height limit for trucks	• Legal truck loads cannot travel on the state truck freight economic corridors
Clearance restriction for over-height loads	• Facility has a height clearance less than 17 feet	Over-height loads have to take detour routes adding too many additional miles to the trip

Table B-7. Truck Slow Speed Bottleneck Categories – Adapted from Reference 2

Category	Potential Solutions
Congested freeway bottlenecks in urban areas	• Provide traveler information • Improve viability of alternate modes for passenger traffic • Manage demand through variable rate tolling or other strategies • Add strategic capacity
Truck bottlenecks on traffic-controlled state highways in urban areas	• Optimize traffic signal timing to reduce delays • Improve geometrics for large trucks • Add strategic capacity

Existing and Future Truck Delay in Hampton Roads Preparation for Project Prioritization (47)

The study builds upon prior work and projects future truck volumes and delays in the Hampton Roads area using a new truck component in the regional travel demand model. The study represents the first time that HRTPO staff have forecast future truck traffic and truck delays. The report notes the distinction between this work and the typical Congestion Management Process (CMP) analysis which includes

[0] Existing and Future Truck Delay in Hampton Roads: Preparation for Project Prioritization, *available:* http://www.hrtpo.org/uploads/docs/Existing%20and%20Future%20Truck%20Delay%20in%20HR%20Final%20Report.pdf.

weekday congestion levels for all vehicles (including trucks). This report provides truck-specific information based on the truck traffic volumes on the roadway segment.

INRIX 15-minute speed data were used for approximately 1,080 miles of the Hampton Roads roadway network. Truck volumes were used from Virginia Department of Transportation (VDOT) classification data. When classification data were not available, estimates from nearby roadway segments on the same route were used. Roadways with the most truck delay (total hours) were ranked and the cost of wasted time and fuel to trucks were computed based on rates from TTI's *Urban Mobility Scorecard*. The threshold for delay was the uncongested speed on the segment.

Future projections of truck volumes and congested/uncongested speeds were obtained from the travel demand model, which was powered by the list of committed transportation projects in the region and the latest population, household, and employment forecasts. Rankings of the following roadway segments were presented in the report:

- Highest 20-year forecast total weekday truck delays;
- Highest 20-year forecast AM peak period truck delays;
- Highest 20-year forecast PM peak period truck delays; and
- 20-year forecast weekday truck delay.

Positioning Hampton Roads for Freight Infrastructure Funding Map-21 and Beyond (48, 49)

The HRTPO conducted this study to address several Federal Highway Administration (FHWA) Moving Ahead for Progress in the 21st Century Act (MAP-21) freight provisions. The report explains that MAP-21 is a multimodal performance-based program designed to address the many challenges facing the U.S. transportation system. The HRTPO conducted this study to position itself for future freight infrastructure funding as part of the MAP-21 initiative. Thus, the first part of this study identified highways expected to be part of the MAP-21 National Freight Network.

For the selected roadways, researchers obtained congestion levels from the HRTPO's latest Congestion Management Process (CMP) document, which used INRIX speed data and Highway Capacity Manual (HCM) methods (when there was no speed data) to conduct the analysis. For roadways with speed data, this CMP study used travel time index (TTI) to measure congestion levels according to the standards displayed in Table B-8.

Table B-8. Congestion Levels for Roadways with Speed Data

Congestion Level		Freeway	Arterial
Low	LOW	TTI < 1.15	TTI < 1.25
Moderate	MOD	1.15 ≤ TTI < 1.3	1.25 ≤ TTI < 1.4
Severe	SEV	TTI ≥ 1.3	TTI ≥ 1.4

Researchers defined deficient bridges as structures with elements that need to be monitored and/or repaired, and they defined functionally obsolete bridges as structures that were built to geometric standards but are no longer used. They identified these bridges in the Hampton Roads network by applying a rating system used by the FHWA, which considers a range of elements, including deck, culvert, and structural conditions, among others.

The research team used various guidelines established in an American Association of State Highway and Transportation (AASHTO) document to analyze height and lane width restrictions. They used additional criteria to analyze pavement condition. Lastly, researchers used congestion thresholds established in a previous HRTPO study to identify freight bottlenecks based on truck delay. They considered roadway segments that experienced more than 30 hours of weekday truck delay per mile to be severely congested.

Oregon State Highway Performance Data and Metrics Related to Freight January 2013 (50)

The research team built on the data-oriented approach used in a previous Oregon freight plan to systematically identify bottlenecks in Oregon. The analysis conducted for this report acts as a proof-of-concept for future implementation. Researchers used two analytical tools for this study: the Highway Economic Requirements System – State version (HERS-ST) and the Oregon Statewide Integrated Model (SWIM). This study does not specifically identify bottlenecks but it does reveal locations with performance issues, which would be the target of further analysis.

HERS-ST model divides delays into three categories (see Figure B-1): Zero-volume delay is caused by geometrics, incident delay is caused by crashes, and congestion delay is caused by capacity issues. The analysis does not consider other types of nonrecurring delays.

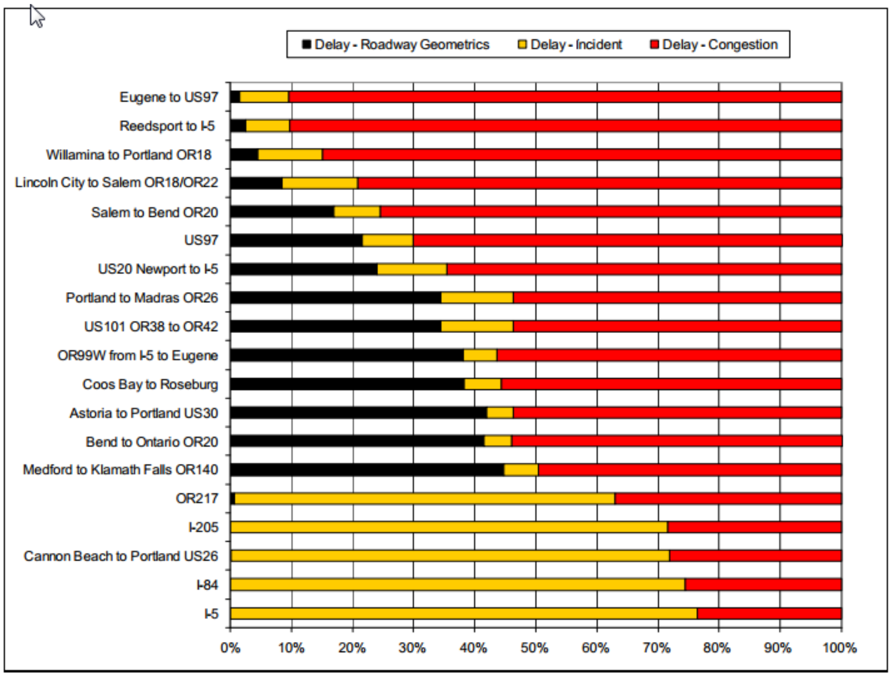


Figure B-1. Corridor Delay by Type

ODOT Region 1 Corridor Bottleneck Operations Study (51)

This document provides a collection of maps, tables, analyses, and recommended strategies for each corridor. Researchers defined bottlenecks as corridor operations that result in a speed of 35 mph or less across all lanes, and they used two tiers of analysis to identify such bottlenecks. The first tier used loop detector and historical crash data to identify bottlenecks for a typical weekday commute during the AM and PM peak periods. The second tier validated this analysis by reviewing existing documentation, available video footage, and field observation.

The research team explains that localized bottlenecks are typically caused by at least one of two factors: 1) decision points (e.g., merging at ramps, weave areas, lane drops) and 2) physical constraints (e.g., curves, underpasses, narrow structures). Figure B-2 displays an example of the information sheets provided for each corridor. These sheets describe each corridor and identify the factors contributing to their congestion, among other information. The document also contains information sheets that describe each bottleneck and recommend improvement strategies (see Figure B-3). In many cases, researchers recommend auxiliary lanes because they improve weaving, which increases capacity and reduces traffic incidents.

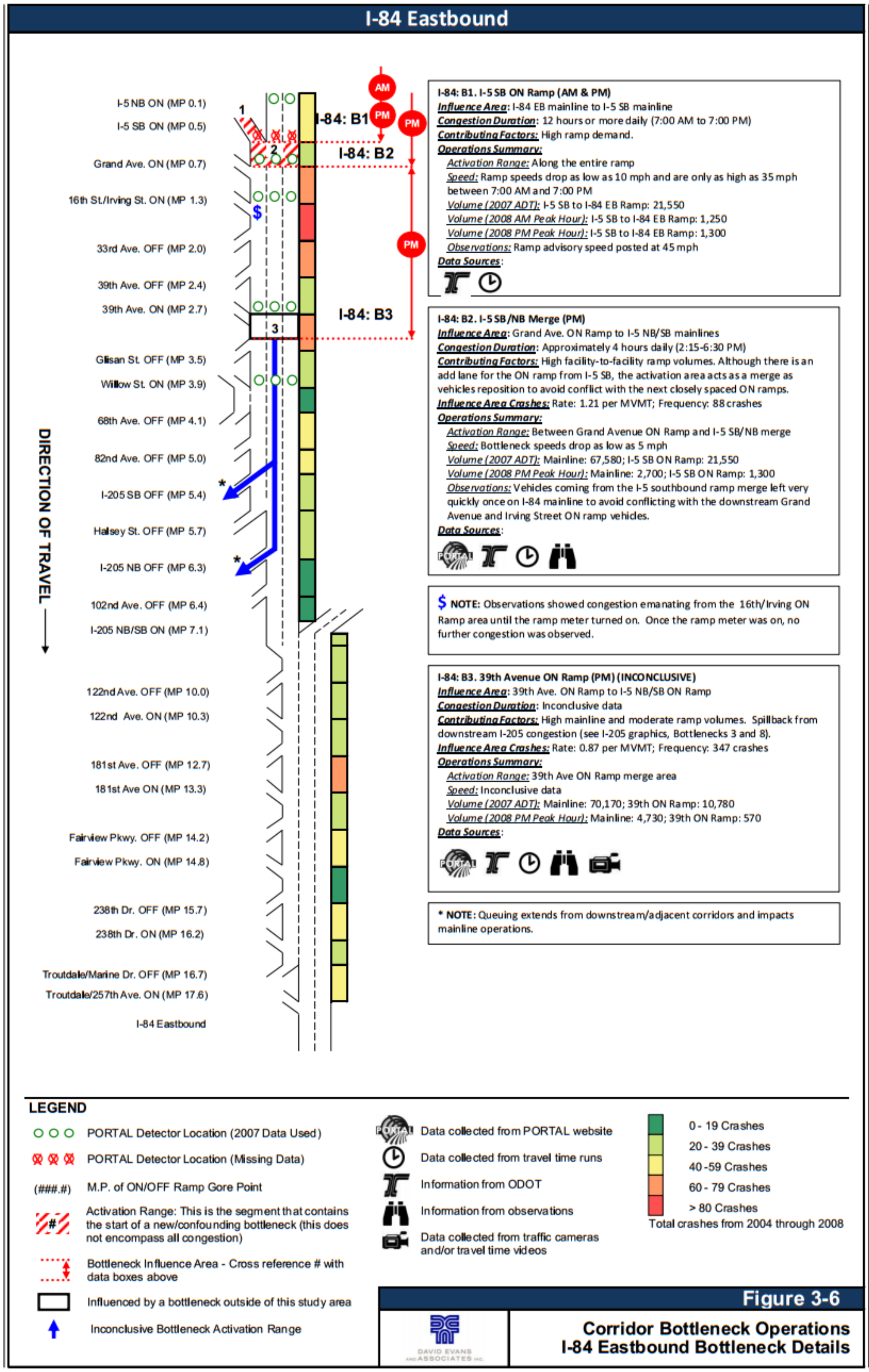


Figure B-2. Sample Corridor Information Sheet

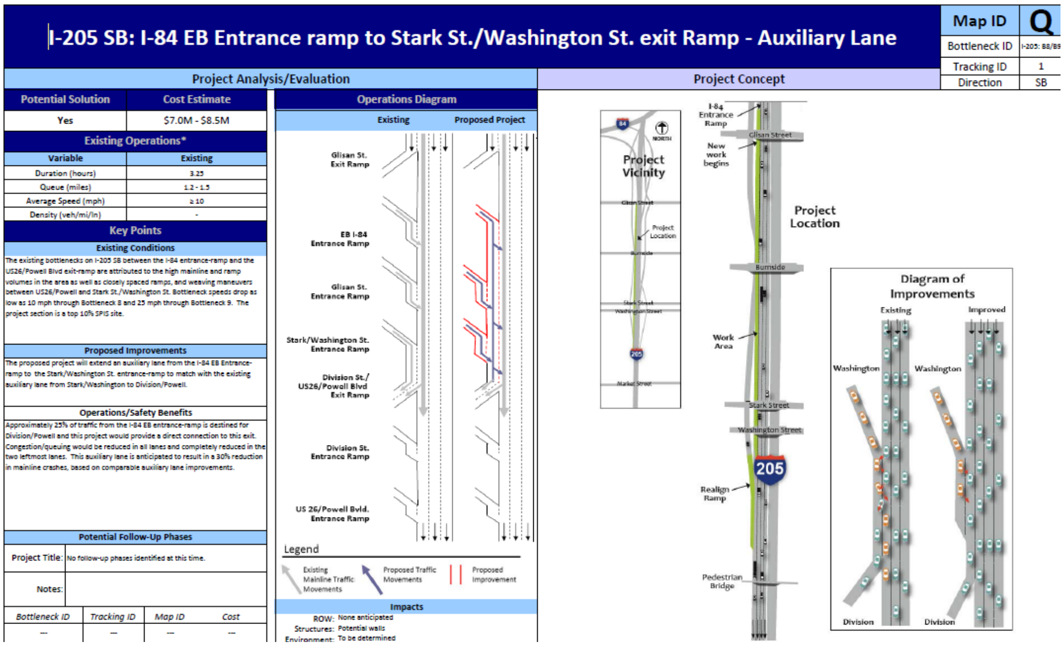


Figure B-3. Sample Project Recommendation

Freight Performance Measures Analysis of Freight-Significant Highway Locations, 2013 Impacts of Congestion on Trucking (52, 53)

Since 2002, the American Transportation Research Institute (ATRI) has partnered with the Federal Highway Administration (FHWA) on the Freight Performance Measures (FPM) initiative. The FPM monitors the performance of selected truck-based freight facilities. The report provides rankings and performance on 100 of the most congested locations and 250 locations are investigated in total.

Locations are not selected by specific criteria but rather are identified as freight-significant based on multiple years of analysis, past research, surveys of private- and public-sector stakeholders and based on speed and volume datasets. The locations are typically urban interstate interchanges. ATRI's "Total Freight Congestion Value" is used to rank the locations, and it is the sum 24-hour sum of the hourly differences between the free-flow speed (set at 55 mph) and average truck speed from GPS data times the number of trucks from which speed data were obtained in that hour.

In a recent report (2), ATRI documented the cost of congestion using four data sources:

1. Truck GPS data from ATRI's Freight Performance Measures (FPM) database;
2. Truck travel times from the FHWA National Performance Management Research Data Set;
3. Truck volumes from the FHWA Freight Analysis Framework (FAF); and
4. Industry financial and operational data obtained from ATRI.

The key findings from ATRI are (2):

1. Trucking industry congestion costs totaled $9 billion in 2013;
2. Total delay in 2013 was 141 million hours, equating to over 51,000 drivers sitting idle for a working year; and
3. Congestion was concentrated in urban areas with 89 percent of costs on 12 percent of the interstate highway mileage.

Statistics and results are provided at the statewide and metropolitan area level.

Georgia Statewide Freight and Logistics Plan, 2010-2050 (54, 55)

The Georgia Department of Transportation (GDOT) recently performed a statewide freight and logistics plan which identified current and projected bottleneck locations on the transportation system. Bottlenecks were identified using congestion estimates of the volume-to-capacity ratio in the base year (2006) and future year (2050) using the GDOT statewide travel demand model. Truck GPS data from ATRI were also used in the analysis to identify congestion characteristics of the bottleneck locations and identify unreliability of the congested roadways using the buffer index measure. A significant amount of variability was identified on GDOT's most congested locations.

In a follow-up analysis, freight improvement project recommendations were identified for the bottleneck locations. Top Bottleneck positions were paired with recently done or proposed improvements to fix the bottleneck locations.

Southern California Council of Governments (SCAG) Regional Transportation Plan – Congestion Management, Goods Movement, and Truck Bottleneck Strategy (56, 57, 58)

These documents describe elements of the SCAG Regional Transportation Plan related to congestion management, goods movement, and bottleneck improvement strategies. INRIX data and he Caltrans Performance Measurement System (PeMS) speed data were used. Caltrans classification count data were used to obtain truck counts and factors from the SCAG Regional Transportation Planning (TransCAD-based) model were used to allocate daily volumes to time periods congruent with the INRIX data. For each bottleneck, the daily congested truck delay was calculated. Then, the list of bottlenecks were ranked by the truck delay indicator and mapped. Finally, the bottleneck locations were overlaid with the planned projects to identify: 1) bottlenecks for which no planned project has been identified, and 2) high-priority bottlenecks for which projects have been identified which may have an impact on the severity of the bottleneck.

In 2012, SCAG adopted the 2012-2035 Regional Transportation Plan/Sustainable Communities Strategy (RTP/SCS) (1). The RTP/SCS includes an appendix on Goods Movement, which highlights priority truck bottlenecks on the highway system (2).

INRIX data were used as the primary speed data source. The speed data were "all vehicles," not just trucks. The Caltrans Performance Measurement System (PeMS) was used as a secondary source of speed data to complement INRIX data. Caltrans classification count data were used to obtain truck counts and factors from the SCAG Regional Transportation Planning (TransCAD-based) model were used to allocate daily volumes to time periods congruent with the INRIX data.

The analysis covered key regional truck highways in the SCAG region and analyses were performed for the morning peak, mid-day, afternoon peak, and night. For each bottleneck, the daily congested truck delay was calculated. Then the list of bottlenecks were ranked by the truck delay indicator and mapped. The next step was to map planned projects in the existing Transportation Improvement Program (TIP) or that had been submitted for inclusion in the Regional Transportation Plan (RTP) by county transportation commissioners.

Finally, the bottleneck locations were overlaid with the planned projects to identify: 1) bottlenecks for which no planned project has been identified, and 2) high-priority bottlenecks for which projects have been identified which may have an impact on the severity of the bottleneck. Ultimately, 44 regional priority bottlenecks were identified that included the highest truck-related annual delay or high-priority bottlenecks identified through the Corridor System Management Plans process and stakeholder involvement process. More details about the bottleneck methodology are documented elsewhere (3).

The 2012-2035 RTP/SCS allocates an estimated $5 billion toward goods movement improvements. The bottleneck relief strategies include ramp metering, extension of merging lanes, ramp and interchange improvements, capacity improvements, and auxiliary lane additions (2).

Freight Fluidity in Canada (59, 60)

Over the past several years, Transport Canada has developed a freight fluidity measure (following excerpted from (1):

- Tracking actual performance of strategic freight routes provides governments and stakeholders impartial evidence-based information of the competitiveness of Canada's supply chains;
- Fluidity indicator is multimodal, integrated supply chain tool that measures individual segments of the supply chains as well as end-to-end transit time of freight flows;
- Emergence of global freight supply chains requires an understanding of the reliability and resiliency of geographically dispersed transportation and logistics systems;
- The results enable Canada to measure its performance within the North American marketplace and
- Inform policy decisions that support economic growth.

The Texas A&M Transportation Institute (TTI) provided technical assistance to Transport Canada in the early development of the fluidity indicators and demonstration of how travel time sources by mode could evaluate supply chains of interest (2). Over time, Transport Canada has obtained supply chain data from multiple modes, including ocean and port, rail, trucking, air and logistics and warehousing.

The rich data allow for the following examples of analysis (excerpted from Reference *1*):

- Effect of routing on marine transit times;
- Identification of bottlenecks/impediments;
- Immediate and residual impacts of disruptions to the transportation network (e.g., weather impacts or port strikes);
- Measuring/analyzing the reliability and variability in transit times;
- Estimating border wait times;
- Measuring carbon footprint; and
- Benchmarking: comparing push versus pull inventory model.

Fluidity results by mode, supply chain and mode are available on an interactive map (https://stats.tc.gc.ca/Fluidity/Login.aspx).

Freight Mobility Efforts in the State of Florida (61-65)

A recent effort by the Florida DOT identifies bottlenecks on FDOT's Strategic Intermodal System (SIS) (1). Bottlenecks in each district are identified using INRIX speed data and performance measures of 90th percentile travel time, free-flow travel time, planning time index and frequency of congestion.

State legislation enacted in 2012 requires an FDOT-led plan to "enhance the integration and connectivity of the transportation system across and between transportation modes throughout the State" (2). The Florida Freight Mobility and Trade Plan (FMTP) Policy Element addresses these requirements with the following four goals (excerpted from Reference 2):

- Increasing the flow of domestic and international trade through the State's seaports and airports;
- Increasing the development of intermodal logistic centers (ILC) in the State;
- Increasing the development of manufacturing industries in the State; and
- Increasing the implementation of compressed national gas, liquefied natural gas, and propane energy policies that reduce transportation costs for businesses and residents located in the State.

The plan identifies key freight issues across all modes and identifies policies already in place that the FMTP should follow while establishing policies, goals, and objectives to move toward the goals above.

Freight-supporting plans and initiatives have also occurred at the local level in Florida to facilitate freight. The South Florida Regional Freight Plan (SFRFP) prioritized critical freight transportation projects for the South Florida region. The SFRFP is integrated with the regional long-range transportation plan (RLRTP), and identifies the top 25 roadway freight needs projects in South Florida (3).

Another example from South Florida is the Application of Congestion Management Process (CMP) Strategies in Miami-Dade County, which has the goal of selecting three corridors out of all those identified in the 2009 Miami-Dade Metropolitan Planning Organization Congestion Management Process (CMP) and apply congestion management strategies (4). The implementation plan succeeds in this goal and quantifies the anticipated roadway improvements for the proposed congestion management strategies. The mitigation strategies include geometric and operational considerations of trucks traveling the selected corridors.

Another local example in Florida is the Tampa Bay Regional Strategic Freight Plan: An Investment Strategy for Freight Mobility and Economic Prosperity in Tampa Bay (5). The plan steps the reader through the regional freight infrastructure and modal assets and identifies a number of freight mobility needs (capacity, operational, maintenance, safety/security). A process is presented for scoring the needs, and the freight corridor-based project needs are illustrated in maps by county. The document concludes with implementation guidance for the freight-related improvements.

Preparing for MAP-21 System Performance Measures and Target-Setting Requirements: Lessons Learned in Virginia (66)

The Virginia DOT contracted with the Texas A&M Transportation Institute (TTI) to develop performance measures and an associated target-setting procedure for the measures on the Virginia Interstate system as a pilot test. Researchers segmented the Virginia Interstate roadways into 199 reporting segments. Performance statistics were computed for each segment and aggregated up to the urban area, VDOT district, and statewide level. There were five project objectives to satisfy the Interstate performance-monitoring needs of VDOT were:

1. Compute the system performance measures developed by the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Performance Management (SCOPM) Task Force on Performance Measure Development, Coordination and Reporting and provided to FHWA;
2. Determine the appropriate threshold to use for delay calculations;
3. Estimate targets for the SCOPM Task Force recommended measures;
4. Document the methodology and process, including calculation procedures and key assumptions; and
5. Document appropriate conclusions and recommendations for next steps.

The estimated performance measures summarized by VDOT District are shown in Table B-9. The measures were also summarized by analysis segment and urban area. More information can be found elsewhere.

Table B-9. Summary of Recommended SCOPM Task Force Measures and Congestion Cost by VDOT District – Interstates Only, 2012 Data

VDOT District[a]	Lane-Miles	Annual Vehicle-Hours of Delay[b] (Thousands) (Ranking)	Annual Vehicle-Hours of Truck Delay[b] (Thousands) (Ranking)	Reliability Index[b] (RI_{80}) (Ranking)	Annual Congestion Cost[b] (Millions) (Ranking)	Annual Truck Congestion Cost[b] (Millions) (Ranking)
Northern Virginia	685 (4)	14,079 (1)	471 (1)	1.43 (1)	596 (1)	89 (1)
Hampton Roads	874 (3)	5,064 (2)	135 (4)	1.19 (2)	197 (2)	23 (3)
Richmond	1,321 (1)	2,127 (3)	126 (5)	1.04 (4)	84 (3)	18 (5)
Fredericksburg	281 (7)	1,603 (4)	139 (3)	1.11 (3)	74 (4)	24 (2)
Salem	493 (6)	910 (5)	180 (2)	1.04 (4)	43 (5)	22 (4)
Staunton	940 (2)	546 (6)	120 (6)	1.01 (6)	27 (6)	15 (6)
Bristol	530 (5)	453 (7)	84 (7)	1.01 (6)	20 (7)	9 (7)
Culpeper	279 (8)	129 (8)	18 (8)	1.01 (6)	4.3 (8)	1.7 (8)

[a] Lynchburg District is not included because there are no Interstate corridors in the Lynchburg District.

[b] Computed using the TTI-recommended uncongested (free-flow) travel time as the agency threshold.

Implementing Freight Fluidity in Maryland: Definition, Calculation Procedures and Results (67)

The Maryland State Highway Administration (SHA) contracted with TTI to develop the concept of freight fluidity for application on Maryland SHA roadways. The concept of a "fluidity indicator" has been popularized by Transport Canada to evaluate the performance of trade corridors and multimodal supply chains. For this ongoing work, and in light of multimodal decision-making needs, TTI developed the following definition of "freight fluidity" for application in Maryland.

> *"Freight fluidity" is a broad term referring to the characteristics of a multimodal freight network in a geographic area of interest, where any number of specific modal data elements and performance measures are used to describe the network performance (including costs and resiliency) and quantity of freight moved (including commodity value) to inform decision-making."*

Just how "fluid" the freight network is can be captured by quantifying performance (including resiliency) and quantity of freight moved. These elements are described in Table B-10. The "geographic area" over which these elements are monitored could be a specific route (e.g., roadway, rail-line, drayage line), supply chain (combination of routes and transload "nodes"), urban area(s), statewide, regional, or global. Researchers have developed calculation procedures for the primary mobility, reliability and quantity performance measures shown in Table B-10. These calculation procedures are also provided in Appendix D for the interested reader. Future work intends to expand the framework beyond just the highway mode and investigate additional data sources to quantify the freight fluidity measures.

Table B-10. The Components of Freight Fluidity *(Mind Your Freight Network "Ps and Qs")*

Components	Description	Selected Suggested Measures/Considerations[a]

Components	Description	Selected Suggested Measures/Considerations[a]
Performance ("Ps")	How well are the segments/nodes and network operating? Where are there bottlenecks in the system?	• Mobility (e.g., travel time, total delay, delay per mile, travel time index) • Reliability (e.g., planning time index) • *Costs*[b] (associated with delay, unreliability, wasted fuel)
	How well does the system (infrastructure, users, agencies) react to disruptions (i.e., how resilient is the system)?	• Resiliency[c] has 4 aspects: • Robustness (ability to withstand disruption, measured in time) • Rapidity (time to respond and recover) • Redundancy (alternate route [capacity] availability/access within a certain travel time) • Resourcefulness (ability and time to mobilize needed resources)
Quantity ("Qs")	How much freight is moved (and where)?	• Volume (e.g., # of trucks, railcars, twenty-foot equivalent units [TEUs]) • Weight (e.g., pounds, tonnage) • *Commodity Value*[b]

[a] These are selected measures and considerations. These measures are ideally obtained by mode and by commodity for complete freight network evaluation.

[b] Costs in the "performance" component and value in the "quantity" component capture the economic impact of freight fluidity.

[c] Resiliency is an element of the "performance" component because current system resiliency is captured in measures of mobility, reliability and associated costs. Note that the "4 Rs" (robustness, rapidity, redundancy, resourcefulness) of resiliency can typically be expressed in time, and hence, delay and associated cost measures. Resiliency is included in the freight fluidity framework here because it is critical for efficient goods movement during system disruptions. Evaluating and improving transportation system resiliency during disruptions serves to better understand and improve performance during challenging times of goods movement.

I-95 Corridor Coalition: Bottleneck Performance in the I-95 Corridor (68)

Researchers conducted this study to establish a set of procedures for monitoring the performance of major bottlenecks in the I-95 corridor. They describe a bottleneck as a specific highway feature that causes routine congestion due to a capacity drop (e.g., lane drop, interchange), volume surge (e.g., on ramp), or both.

To identify bottlenecks in the corridor, the research team used an approach developed in a previous study, which compares speeds at adjacent loop detector stations for the same five-minute period and considers the location a bottleneck if the upstream speed is less than 40 mph, while the downstream speed is at least 20 mph faster than the upstream speed. They used INRIX speed data and Highway Performance Monitoring (HPMS) volume data to conduct the analysis. Researchers estimated delay based on the difference between the measured speed and the reference speed. The reference speed is the 85^{th} percentile speed and is meant to indicate the free-flow speed. Finally, the team used the method established in the FHWA's Mobility Monitoring Project to calculate reliability measures, including travel time index (TTI), buffer time index (BTI), and planning time index (PTI).

Regarding nonrecurrent delay, incident and work zone data was not available for the corridor, but researchers considered weather conditions for the dates with the worst congestion days at each location. They determined that weather was likely a significant factor on those days.

Mitigation of Recurring Congestion on Freeways (69)

Authors explain that reducing congestion through managing traffic generates numerous benefits, including reducing travel times and vehicle queuing, smoothing traffic flow, shortening peak periods, and improving fuel economy. They tested the potential effectiveness of several traffic management systems (e.g., hard shoulders and variable speed limits) on a simulated model of two corridors in Northern Virginia. They selected these strategies based on a literature review that considered proven effectiveness, ease of implementation, and ability to complement other strategies.

Researchers considered data availability and quality, congestion levels, and insight from Virginia DOT staff when they selected the roadway segments for the study. The simulation model was based on the geometric characteristics, ramp volumes, vehicle flows, and speeds of actual recorded conditions. They selected performance measures suited for congested conditions, including ramp queue length, flow, lane occupancy, speed, VMT delay, and fuel economy.

The team tested 24 different scenarios and found that both strategies generated a wide range of benefits. Variable speed limits reduce congestion by delaying the onset of congestion and smoothing traffic flows. Hard shoulders were most effective at increasing average speeds, shortening queue lengths, lowering occupancies, improving average fuel economy, and reducing delay. They also found that these strategies were mutually reinforcing, as they generated more benefits when implemented together.

Improving Safety and Operation with Low-Cost Freeway Bottleneck Removal Projects (70)

Authors explain that low-cost bottleneck removal projects are receiving more attention because they mitigate congestion, improve travel reliability and safety, and can be quickly implemented. Restriping merge areas, converting shoulders to travel lanes, modifying weave areas and on/off ramps, and adding auxiliary lanes are all examples of low-cost bottleneck removal projects. Researchers evaluate projects in Austin, Dallas-Fort Worth, Minneapolis-St. Paul, and Phoenix.

The research team considers a bottleneck a section of freeway where the demand exceeds capacity, resulting in congestion upstream and free-flow conditions downstream. They describe the ideal approach for identifying and evaluating bottlenecks, as well as determining appropriate mitigation strategies and measuring their potential and real impacts. They recommend collecting five types of data, including volume counts, travel times, videotape, drive-through video, and origin-destination data. They explain that the impacts of mitigation projects fall into two categories: 1) operational (e.g., traffic flow, travel speeds, etc.) and 2) safety (e.g., traffic incident rate and severity). Lastly, they emphasize the importance of conducting the analysis both before and after a project is implemented. (Researchers evaluated each case study and found that the projects generated significant operational and safety benefits at little cost. The benefit-to-cost ratios ranged from 400:1 to 3:1, and all sites experienced reduced incident rates.)

Using GPS Truck Data to Identify and Rank Bottlenecks in Washington State (71)

Researchers obtained daily GPS data from about 6,000 trucks throughout the State of Washington. The GPS data indicated truck longitude and latitude and spot (instantaneous) speeds, among other things. The authors reviewed the bottleneck identifying methods used by the American Transportation Research Institute (ATRI) and the U.S. DOT, but they opted not to use either approach because they would not take full advantage of the detailed data available for this study.

The research team adopted a five-step approach to identify and evaluate bottlenecks in the network. First, they segmented the roadway network based on various attributes, including the locations of ramps and intersections and roadway length. Then, they assigned attribute information to each segment, such as speed limits and roadway classification. Third, they assigned each truck's GPS reads to the appropriate segment, while accounting for their travel direction (see Figure B-4). Fourth, they averaged the GPS speed data over time to measure each segments performance and identify bottleneck locations. Lastly, they ranked the bottlenecks based on average speed, geographic location, and Freight Goods Transportation System (FGTS) category.

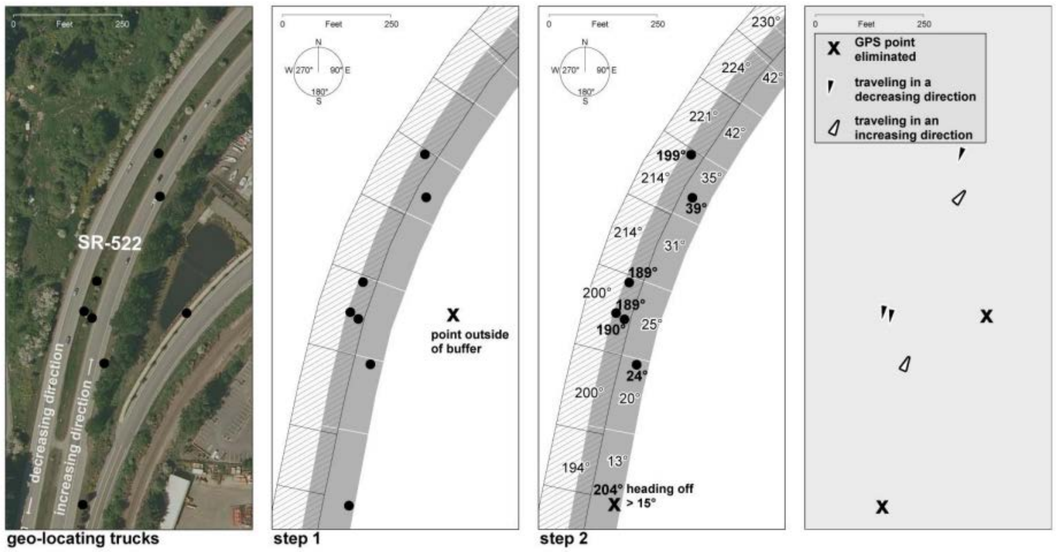


Figure B-4. Steps Used to Geo-Locate Individual Trucks

Freight Bottlenecks in the Upper Midwest: Identification, Collaboration, and Alleviation/Identifying and Characterizing Truck Bottlenecks in the U.S. Mississippi Valley Region (72)

The researchers built on the HPMS-based analysis approach due to data availability. They found HPMS data to be the only consistently and publicly available data source for the regional-level analysis, which covered 10 states. The study considered four types of truck bottlenecks: interchange, lane drop, steep grade, and signalized intersection bottlenecks. Rather than assigning each bottleneck location to just one of the four bottleneck types, researchers considered the possibility of a highway section being associated with more than one bottleneck condition. Researchers also used the performance measure "truck unit delay" to identify bottlenecks, rather than "volume-to-capacity ratio." Three conditions lead to a significant truck unit delay: 1) the presence of exceptionally high truck volume, 2) the presence of exceptionally high hours of delay per vehicle mile, and 3) the combination of the previous two conditions.

To account for interchange bottlenecks, researchers identified bottleneck locations on a corridor by analyzing the sections that were adjacent to a congested section. They connected adjacent sections with similar truck unit delay to build a single congested corridor and determined the bottleneck location to be the section experiencing the most severe delay. Researchers used HPMS data, which indicates both "lane drop" and "signalized intersection" bottleneck types. Lastly, they considered a "steep grade" bottleneck a congested section with more than one mile of steep grades (i.e., grade greater than 4.5 percent).

Table B-11 displays the number of bottlenecks identified for each bottleneck type, and Figure B-5 displays the bottlenecks prioritized by truck unit delay. As Figure B-6 reveals, the interchange constraint accounted for the most significant bottleneck condition, followed by the lane drop constraint. Researchers concluded that steep grade bottlenecks are only associated with a marginal truck unit delay because such sections were mostly located in rural areas where traffic demand and congestion was less intense.

Table B-11. Number of Truck Bottlenecks Identified for the Mississippi Valley Region

Bottleneck Type	On Freeways	On Other Principle Arterials	Total
Interchange	246	0	246
Signalized Intersection	2	727	759
Lane Drop	486	209	695
Steep Grade	4	0	4

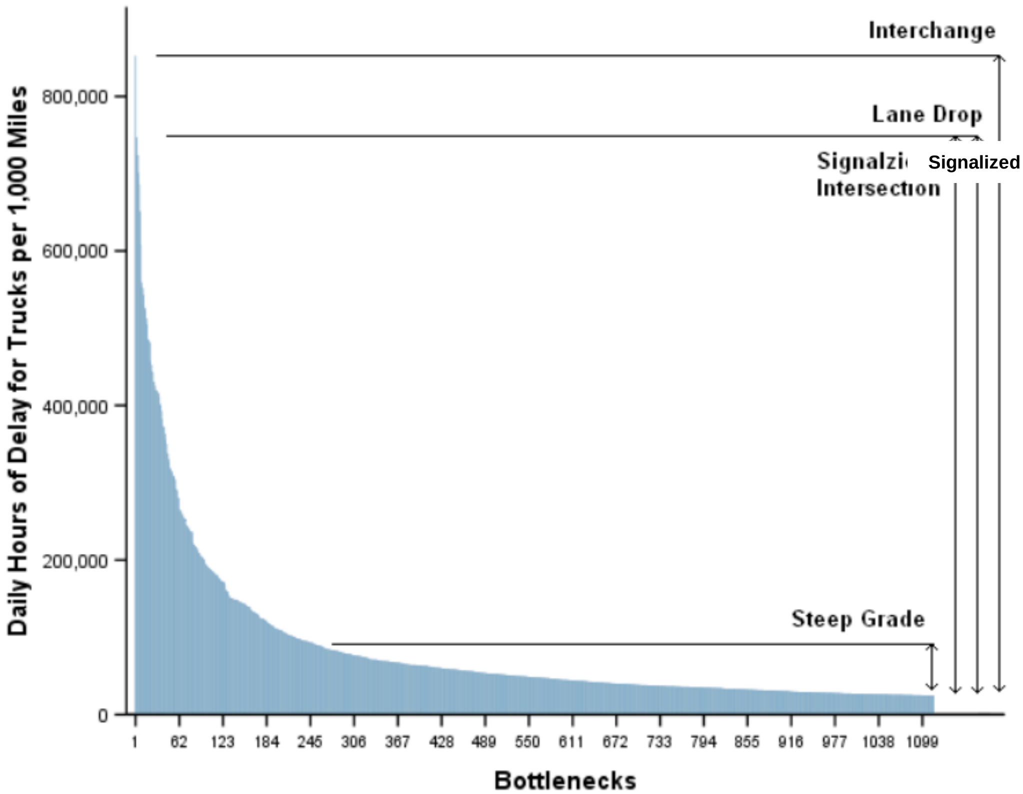


Figure B-5. Distribution of Truck Unit Delay Across Truck Bottleneck Locations

An Initial Assessment of Freight Bottlenecks on Highways (73)

This was the first study to look specifically at the impacts and costs of highway bottlenecks on truck freight shipments on a national basis. Researchers used a combination of three features to define truck bottlenecks: the type of constraint, the type of roadway, and the type of freight route (see Table B-12).

Table B-12. Truck Bottleneck Typology

Constraint Type	Roadway Type	Freight Route Type
Lane-Drop	Freeway	Intercity Truck Corridor
Interchange	Arterial	Urban Truck Corridor
Intersection/Signal	Collectors/Local Roads	Intermodal Connector
Roadway Geometry		Truck Access Route
Rail Grade Crossing		
Regulatory Barrier		

To identify bottlenecks, researchers scanned the FHWA HPMS database for highway sections that experienced a high volume-to-capacity ratio. The HPMS database identified interchanges. Researchers used physical and traffic condition information obtained from the HPMS database to calculate capacity and determine the other constraint types. They used the FHWA Freight Analysis Framework (FAF) database to identify truck volumes for interchange bottlenecks, and they used the HPMS Sample database to calculate truck volumes for the other constraint types. Lastly, they used previously developed equations to calculate truck hours of delay.

Researchers determined that HPMS and FAF data can be used to develop a relatively comprehensive inventory of highway truck bottlenecks. They found that interchange bottlenecks account for the most truck hours of delay in the U.S. They also concluded that the analysis methods used for this study do not adequately account for the congestion effects of traffic weaving and merging at on/off ramps.

Quantifying the Contributing Factors of Traffic Congestion Using Urban Congestion Report Data

This study examines the city of Chicago for a 28-month time period using the Ordinary Least Square regression analysis technique. It presents two key findings: 1) the Urban Congestion Report (UCR) data are suitable for determining the sources of congestion and 2) UCR projects generated data suitable for targeting specific congestion mitigation activities on a city-by-city basis.

The report provides an overview of literature related to performance measurement and/or determining the causes of congestion. Then, it identifies the data obtained from the UCR as VMT, precipitation, construction, and incident data. The methodology uses AM and PM Travel Time Index (TTI) as the dependent variable and VMT, precipitation, number of work zones and incidents, day-of-week, and seasonal demands as the independent variables. Table B-13 displays the study's results. Note that researchers excluded work zones from the PM TTI results due to inaccurate results, which require further investigation.

Table B-13. Independent Variables Impact

Traffic Congestion Source	FHWA Estimate	AM TTI	PM TTI
Bottlenecks	40%	17.80%	33.95%
Work Zones	10%	7.37%	N/A
Weather	15%	27.64%	32.00%
Traffic Incidents	25%	14.74%	16.71%

Available: N/A.

Columbus-Phenix City MPO Congestion Management Process – 2007 Update (74)

The report provides an overview of CMPs based on guidelines issued by the FHWA. It describes each component, including system monitoring and bottleneck identification, performance measures, identifying causes of congestion, identifying and implementing appropriate mitigation strategies, and monitoring the impacts of implemented strategies. Lastly, the report analyzes 20 congested corridors in the area.

Each analysis includes a map displaying the corridor, as well as the severity of congestion and level of service by segment and accident locations. A table displays relevant mitigation strategies and associated impacts on performance measures. Each analysis also determines potential causes for congestion, including geometrics, frequent incidents, lane drops, poor signal timing, and several others.

FHWA Recurring Traffic Bottlenecks – A Primer – Focus on Low-Cost Operational Improvements (75)

This guide is part of a series of documents developed for the Federal Highway Administration's (FHWA) Localized Bottleneck Reduction (LBR) program. The LBR program aims to help bottleneck mitigation efforts by expanding the portfolio of bottleneck reduction tools available to transportation agencies. In particular, it focuses on localized recurring bottlenecks that may only require minor improvements. It promotes the value of focusing mitigation efforts on localized bottlenecks, rather than systemwide projects, because limited funding is available for systemwide projects, and they take a long time to complete.

The guide defines bottlenecks as localized sections of highway where traffic experiences reduce speeds and increase delay due to physical restrictions, too much demand, or both. It describes a variety of localized bottleneck causes and types, as Figure B-6 displays. It provides an extensive overview of merge-related bottlenecks; it describes different types of merging (e.g., recurring or nonrecurring, late or early, etc.), merging principles for drivers, and strategies designed to improve bottlenecks caused by merging issues. It also describes strategies related to other recurring and nonrecurring bottleneck types.

Lastly, this guide identifies potential reasons for agencies not taking full advantage of localized mitigation strategies and provides a framework for establishing or improving such a program. It also identifies specific challenges and obstacles to such an effort and potential solutions.

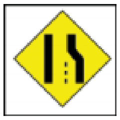
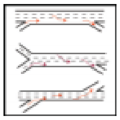
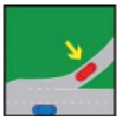
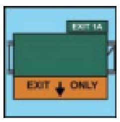
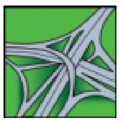
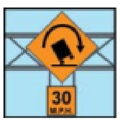
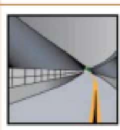
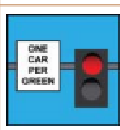
Location	Symbol	Description
Lane Drops		Bottlenecks can occur at lane drops, particularly midsegment where one or more traffic lanes ends or at a low-volume exit ramp. They might occur at jurisdictional boundaries, just outside the metropolitan area, or at the project limits of the last megaproject. 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.

Figure B-6. Common Locations for Localized Bottlenecks

Identifying, Anticipating, and Mitigating Freight Bottlenecks on Alabama Interstates (76)

Researchers used a bottleneck definition from a National Center for Freight Infrastructure Research and Education (CFIRE) report, which defined freight bottlenecks as segments of highway that constrict the efficient movement of trucks, causing significant delay for freight transportation. They used a methodology developed by Cambridge Systematics to identify three types of bottlenecks: capacity (e.g., lane drops), interchange, and geometry (e.g., steep grade) bottlenecks – this methodology classifies bottleneck type based on constraint, roadway, and freight route type. They acknowledged other types of bottlenecks but only included these three types because the study was limited to freeways.

To calculate freight delay at each bottleneck, the research team used data from the National Highway Planning Network (NHPN), the Freight Analysis Framework (FAF), and the Highway Performance

Monitoring System (HPMS). They used a queuing equation, which is dependent on lane and ramp configurations, to calculate freight delay for interchange bottlenecks. They used a different equation to calculate delay for lane drop (capacity) and geometry bottlenecks, although both equations are based on the AADT-to-capacity ratio. They used the passenger car equivalent methodology established in the Highway Capacity Manual to adjust the AADT for potential geometry bottlenecks (see Table B-14). Researchers identified nine total freight bottlenecks, including six capacity bottlenecks and three interchange bottlenecks. They did not identify any geometry bottlenecks, which required a congested roadway to have at least one mile of grade steeper than 4.5 percent.

Table B-14. Passenger Car Equivalents for Geometry Bottlenecks

Up Grade (%)	Length (mi)	E_T Percentage of Trucks and Buses (%)								
		2	4	5	6	8	10	15	20	25
> 4 – 5	>1.00	5.0	4.0	4.0	4.0	3.5	2.5	3.0	3.0	3.0
> 5 – 6	>1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	>1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Framework for Analysis of Recurring Freeway Bottlenecks (77)

This study provided a technical guide for identifying existing and future recurring freeway bottlenecks and determining low-cost geometric and operational improvements. Researchers analyzed the state of the practice based on 14 interviews with staff from agencies in the U.S. and overseas. Researchers found the most common performance measures to be average speed, delay (vehicle-hours), queue length, and duration of congestion; and the most frequently used strategies to be ramp metering, auxiliary lanes, and HOV lanes. Researchers provided different definitions for existing and future freeway bottlenecks. Speed measures are used to identify existing bottlenecks, while projected volume-to-capacity ratios are used to identify future bottlenecks. They also provided three categories of recurrent freeway bottlenecks based on demand and capacity characteristics: 1) demand surge bottlenecks, 2) capacity reduction bottlenecks, and 3) combined demand surge and capacity reduction bottlenecks.