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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP RESEARCH REPORT 854

Guide for Identifying, Classifying, Evaluating, and Mitigating Truck Freight Bottlenecks

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2017

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

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FOREWORD

By William C. Rogers
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NCHRP Research Report 854 provides transportation agencies state-of-the-practice information on identifying, classifying, evaluating, and mitigating truck freight bottlenecks using truck probe data rather than traditional travel demand models. The report embraces a broad definition of truck freight bottlenecks as any condition that acts as an impediment to efficient truck travel, whether the bottleneck is caused by infrastructure shortcomings, regulations, weather, or special events. The comprehensive classification of truck freight bottleneck types described in this report provides a standard approach for state departments of transportation (DOTs), metropolitan planning organizations, and other practitioners to define truck freight bottlenecks and quantify their impacts.

Bottlenecks, situations in which the performance or capacity of an entire system is severely limited by a single component, delay large numbers of truck freight shipments and negatively impact the nation's economy and productivity. Moving Ahead for Progress in the 21st Century Act (MAP-21) requires state DOTs to report how they are addressing freight bottlenecks. Transportation agencies need sound methodologies to define, identify, quantitatively measure, and mitigate truck bottlenecks. Without such methodologies, they will be unable to address truck freight bottleneck issues systematically. Fixing one location may simply shift the bottleneck to another location on the network, with no improvement to the overall corridor performance. Without defining and describing truck freight bottlenecks by categories based on causal and contributing factors, decision makers will be unable to develop cost-effective solutions to address different types of truck freight bottlenecks.

In NCHRP Project 08-98, Cambridge Systematics was asked to develop a guide that (1) classifies truck freight bottleneck categories based on causal and contributing factors (e.g., roadway geometrics, regulatory constraints, traffic controls, weather, and border crossings); (2) describes quantitative measures for each truck freight bottleneck category to determine bottleneck severity, impact, and ranking; (3) develops a scalable methodology for systematically identifying truck freight bottlenecks and evaluating their impact on local, regional, and national network performance; and (4) describes a range of options for solving or mitigating truck freight bottlenecks.

This project produced the following appendices, which are unpublished herein but are available for download from trb.org by searching for "NCHRP Project 08-98":

- Appendix A: Selected Details of State-of-the-Practice Review,
- Appendix B: Short Summaries of Selected Case Studies,
- Appendix C: Data Quality Control Examples,
- Appendix D: Additional Performance Measure Discussion and Analysis Procedures, and
- Appendix E: Truck Bottlenecks and Geometrics

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Guide for Identifying, Classifying, Evaluating, and Mitigating Truck Freight Bottlenecks

The demand for truck transportation increases alongside population growth, economic growth, and increases in trade. As truck transportation shares infrastructure with passenger vehicles, increases in demand for truck transportation negatively impact passenger traffic. Similarly, increases in passenger traffic negatively impact truck transportation. The combination of truck and passenger traffic outstripping capacity is a key driver of congestion, which is experienced as truck bottlenecks in the freight community. Truck bottlenecks also can be caused by issues ranging from vehicle size and weight restrictions to roadway geometry to weather impacts and to truck bans. To address the issue of truck bottlenecks systematically, national, state, and regional transportation agencies are developing methodologies to define, identify, quantitatively measure, and mitigate truck bottlenecks. This is the first step in empowering decision makers to develop cost-effective solutions to address different types of truck freight bottlenecks.

This Guidebook provides state-of-the-practice information to transportation professionals on identifying, classifying, evaluating, and mitigating truck bottlenecks. The bottleneck analysis described in this Guidebook is focused on utilizing truck probe data rather than traditional travel demand models. The primary application for the methodologies is evaluation of truck bottlenecks for prioritizing investment decisions. Examples of truck bottleneck analysis and notable practice highlights are provided throughout the Guidebook and are intended for two primary audiences:

1. Transportation planners that are conducting freight-related analysis or developing freight-related planning documents and
2. Research and operational staff that are interested in developing freight bottleneck analyses relevant for transportation planning processes.

For these audiences, the Guidebook is designed to serve the following purposes:

- Define a common language related to truck freight bottlenecks;
- Classify truck freight bottleneck categories based on causal and contributing factors;
- Describe truck bottleneck state-of-the-practice;
- Provide highlights from several case studies related to truck bottlenecks;
- Describe data sources used for truck bottleneck analysis;
- Provide a spatially scalable methodology for identifying truck freight bottlenecks;
- Describe quantitative measures for truck freight bottleneck categories for determining bottleneck severity, impact, and ranking and subsequent decision-making;
- Describe mitigation options for truck freight bottlenecks; and
- Describe how to integrate freight bottleneck analysis into the planning process.

This Guidebook embraces a broad term for "truck freight bottlenecks" as any condition that acts as an impediment to efficient truck travel, leading to travel times in excess of what would normally occur. This definition encompasses a wide range of events and conditions, all of which add time to the delivery of truck freight shipments, from the time those shipments leave their origin to the time they arrive at their destination.

The Guidebook describes two methodologies:

1. A travel speed-based delay methodology and
2. A process- or operation-based delay methodology.

The methodologies are scalable in multiple ways, and this allows the agency performing the analyses to use its available data resources regardless of the source or size of those resources. In addition, the same analytical approach works whether the analysis is performed for an entire state highway network, a regional network, or even a specific city. The recommended approach can be applied to a single road segment, multiple roads within a geographic corridor, an entire region, to all roads in the state, or to all roads in a multistate region.

Travel Speed-Based Delay

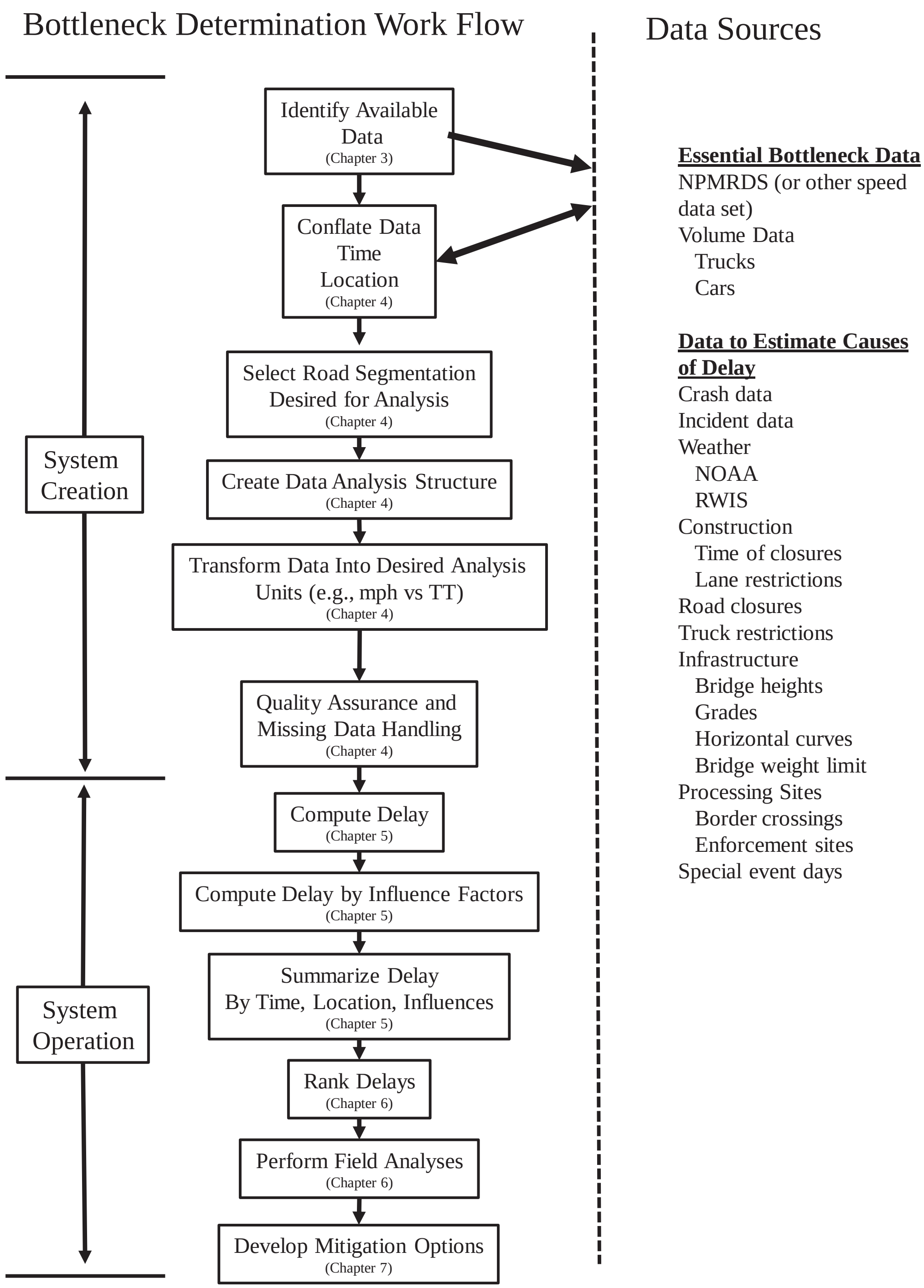
The travel speed-based delay methodology consists of six generalized steps, as shown in Figure S-1. Several of these steps can be performed simultaneously in terms of computer processing, but are discussed separately in different chapters in this Guidebook.

As shown in Figure S-1, the first step in the travel speed-based delay truck bottleneck methodology is to identify, collect, quality check, organize, and link the various data sources available to the agency that are needed to identify and quantify bottleneck locations. This step involves conflation to match probe speed data to roadway volume data for subsequent analysis. Conflation is the process of combining geographic information from overlapping sources, while minimizing redundancy and reconciling data conflicts. It is necessary for computing performance measures for truck bottleneck analysis when the speed and roadway volume data are provided on different networks. The process of conflation is facilitated by using a geographic information system (GIS) to import and compare segments of the roadway speed data network with the traffic volume inventory. By combining vehicle speed and truck and passenger car volume data, agencies can compute when and where congestion occurs along with the relative size of the delays (in vehicle-hours and truck-hours) that each congestion location causes. It also is possible to track the frequency with which congestion forms.

For analysis purposes, these different referencing systems must be connected during conflation. All the data to be used in the bottleneck analysis must be transformed into a common data structure that describes the conditions, such as speed, weather, and work zones, to be found on defined road segments during defined time periods.

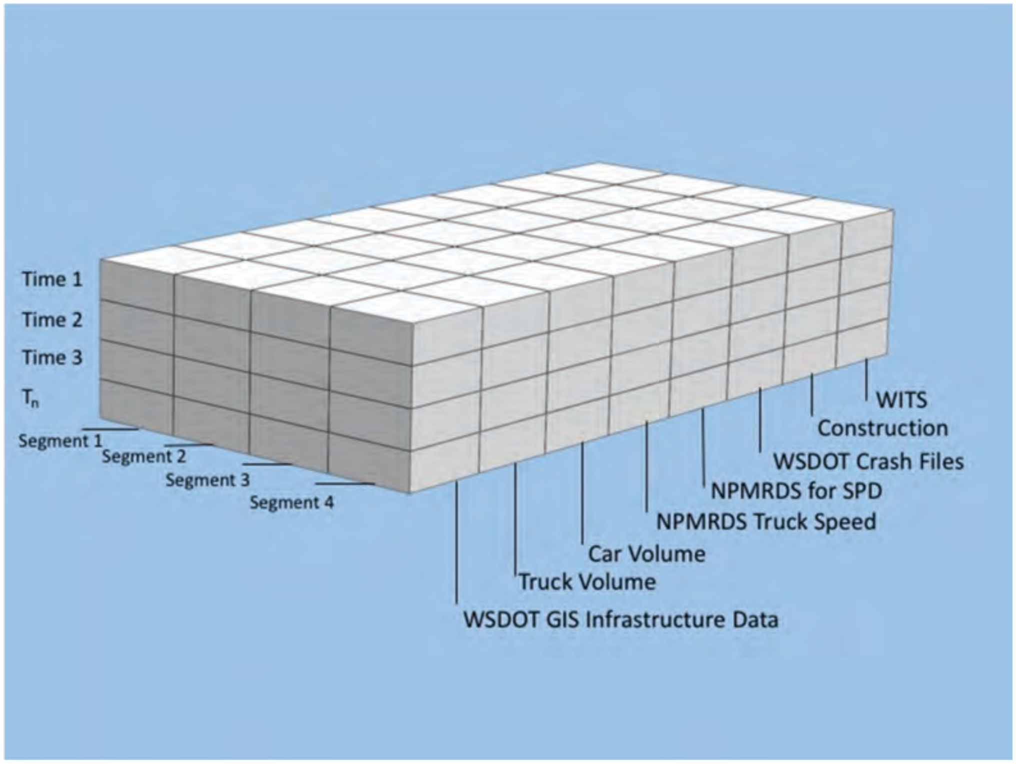
To analyze truck bottlenecks across multiple dimensions, this Guidebook describes a cube structure, as shown in Figure S-2, that incorporates traffic speed, travel time, and volume data, as well as all other data needed to describe what is happening on the roadway. If these different variables (i.e., car travel time, car speed, car travel rate, truck travel time, truck speed, and truck travel rate) are thought of as the third dimension of the above matrix structure, the data structure can be envisioned in the cube, where:

- The vertical axis of the cube is time (and date);
- The horizontal axis is the roadway segmentation (location) in the order in which a vehicle would drive a given road (the left most column being the first road segment traversed, followed by the second column, and continuing to additional columns); and
- The depth of the cube consists of different variables.



NPMRDS = National Performance Management Research Data Set.
NOAA = National Oceanic and Atmospheric Administration.
RWIS = Road Weather Information System.
TT = travel time.

Figure S-1. Travel speed-based bottleneck identification and quantification methodology.



Note: NPMRDS is noted in this example, but any travel time (or speed) data source could be used. (WSDOT = Washington State Department of Transportation; WITS – Washington Incident Tracking System; SPD = speed.)

Figure S-2. Schematic of data analysis structure with congestion causation factors.

A separate cube would exist for each direction of travel for a given roadway. An initial step in the travel speed-based process is to conduct an analysis that defines the size and scope of the travel speed-based congestion bottleneck problem throughout a study area. The next step is to select a subset of the identified bottleneck locations to perform more detailed analyses to examine the effectiveness of different approaches to mitigating those bottlenecks. These detailed analyses can take into account key details about each study location (e.g., current local transportation improvement plans) that cannot be readily incorporated into an automated statewide analysis. With the aid of a GIS, these statistics can be displayed graphically to highlight the key delay locations.

The cubic structure allows simple computations of travel speed delay by location and time period for any given roadway for which volume and speed data are available. With the aid of a GIS, these statistics can be displayed on a map to highlight the key delay locations. Figure S-3 provides an example of how a large volume of vehicle delay data was displayed on Interstate 65 in Indiana. The y-axis shows the mileposts along I-65. The x-axis is the number of vehicle-hours of travel less than 45 miles per hour (mph). The multicolored waves in the figure represent the amount of delay at each milepost on the Interstate. Moving from left to right along the waves provides the delay for each month in the year from January to December.

Process-Based Truck Delay

Another major category of bottleneck causes of is process-based truck travel delay, which includes locations that either force trucks to use longer, more circuitous paths than passenger cars would take if making that same trip, or require trucks to carry less cargo than they would

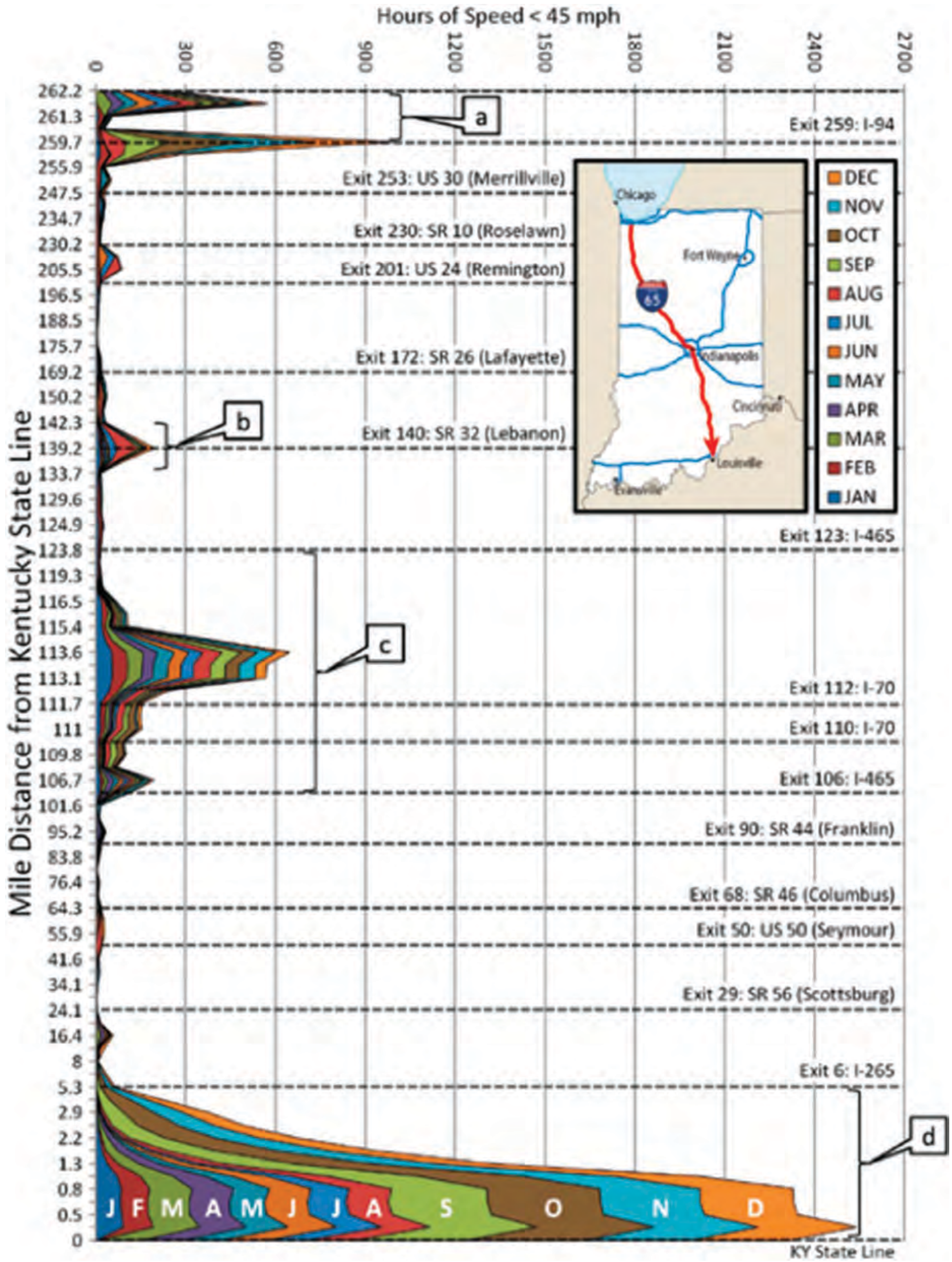


Figure S-3. Vehicle delay on Interstate 65 in Indiana.

otherwise carry if not legally restricted from doing so. Both situations force trucks to travel additional miles, increasing the cost of freight delivery as a result of both additional labor hours and additional mileage driven. In addition, higher truck-miles of travel (TMT) increases fuel use and produces negative environmental emissions.

A key difference between the methodology for process-based truck bottlenecks and travel speed-based truck bottlenecks is that process-based truck bottlenecks require an understanding of impacted truck trips, given the truck restriction. Therefore, the analysis for process-based truck bottlenecks is sometimes referred to as a "trip-based" analysis in contrast to the "facility-based" analysis described earlier for travel speed-based truck bottlenecks.

The methodology for estimating process-based delay is shown in Figure S-4. The methodology includes a system creation component and a system operation component. The system creation component includes identifying available data and identifying truck trips impacted by the operations-based delay. The system operation component estimates the delay of the impacted truck trips, ranks bottlenecks by type, and then develops mitigation options associated with each type of delay.

The cubic data structure also can be used as an effective tool for identifying the costs of many process-based delays. In this case, it must be used in concert with additional information that describes the size of truck movements, the nature of those movements, and data on the locations and attributes of the specific truck restrictions being evaluated. For example, using GIS software, the cube analysis structure can help compute travel times and travel-time reliability over alternative travel paths.

Once the data analysis cube for travel speed-based and process-based delays has been constructed, it is possible to compute the wide range of delay-related performance statistics that can be used to rank and quantify truck freight bottlenecks. To identify the potential causes of truck

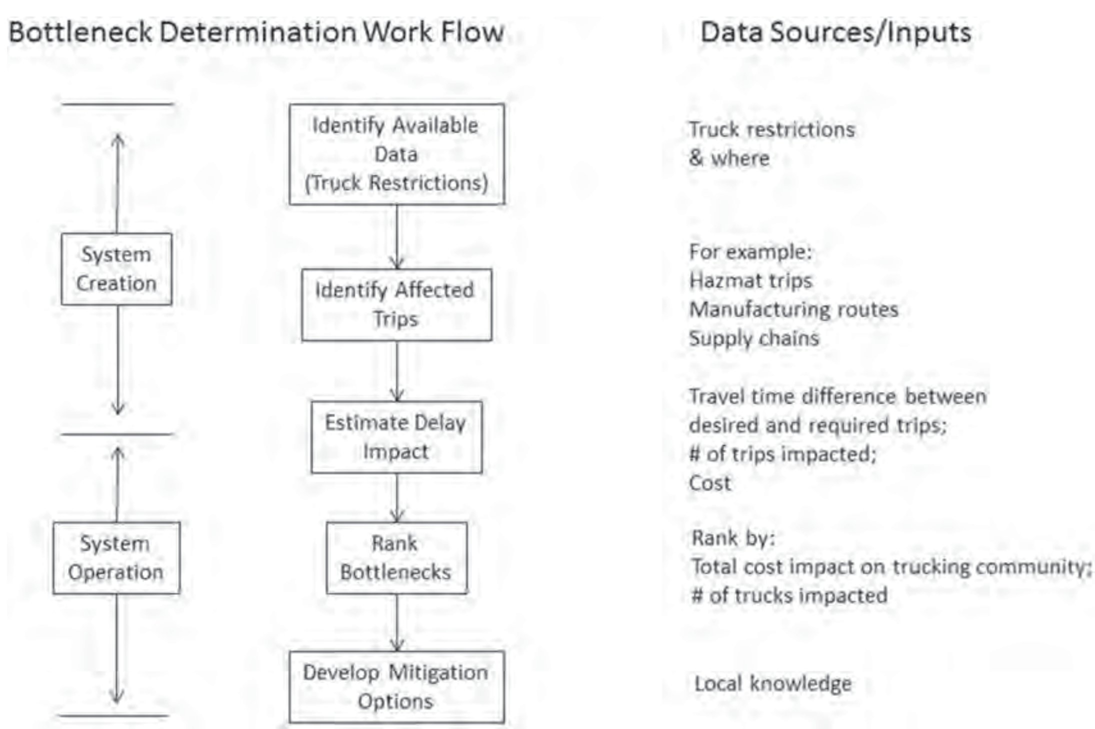


Figure S-4. Process-based truck bottleneck classification and quantification methodology.

bottlenecks, it is necessary to link the variables that describe potential bottleneck factors to the time and location data that describe vehicle volume and speed.

The desktop analysis described above can be combined with field analysis to fully analyze select bottlenecks. In many cases, the field analysis relies on the same tools and reports that are available to the desktop analysis but involves a deeper examination of a limited number of roadway segments. The field analysis also typically incorporates additional data into the bottleneck analysis that may not be available for an entire study area. In other cases, these additional data must be collected specifically for the field analysis. In still other cases, agency staff that work in the area can describe in detail some of the contributing causes of local bottlenecks. Taking advantage of this local knowledge is an important part of the field analysis process. In the end, these additional data sources are developed to provide more depth to the analysis about why observed bottleneck patterns are occurring and how those delays might best be mitigated.

After causation has been evaluated, ranking supports the prioritization of mitigation actions. No one ranking system is appropriate for all uses. Each performance measure (e.g., truck delay, total delay, expected travel rate or reliability, or the frequency with which congestion occurs) can be used to effectively rank locations. Each of those resulting rankings will likely be different. What these different rankings indicate is that the importance of any one bottleneck changes depending on which bottleneck attributes are most important to an individual decision maker.

The Guidebook also provides a section on mitigating truck bottlenecks in which is described that there are a large number of potential approaches to mitigating the identified truck bottlenecks. A selected approach typically is a function of the following considerations:

- The causes of the delays,
- The geographic and geometric attributes of that location,
- The operational characteristics of the roadway,
- The organization of the agencies working on that facility and other facilities that influence the operation of that roadway,
- The operational systems currently implemented on the road (or in the larger region that have been demonstrated effective and/or have public support), and
- The type of funding available.

Typically, mitigation for truck bottlenecks can be divided into a number of categories on the basis of the basic causes/attributes of delay. These include the following:

- Recurring congestion (too much traffic volume),
- Nonrecurring congestion or delays,
- Geometric deficiencies,
- Operational deficiencies, and
- Event congestion.

Each of these causes of delay requires different types of mitigation, and the design and implementation of those mitigation efforts depends on the organization and operational relationships of the various transportation agencies and political jurisdictions that operate the road or that provide services in that geographic region.

The Guidebook covers different possible mitigations related to bottlenecks caused by roadway design and geometrics, different types of volume and congestion limitations, disruption such as incidents and weather, and policy restriction such as truck size weight rules. The Guidebook also describes approaches for focusing mitigation by sorting bottlenecks based on if the bottlenecks are for trucks only or if they impact all vehicles. The truck-only bottlenecks often involve road geometrics limitations for large vehicles, which are detailed in the Guidebook. The use of transportation agencies' asset inventories is presented as a tool to tie infrastructure-related truck bottlenecks to roadway attributes.

Finally, the Guidebook describes how truck bottleneck analysis can be incorporated into typical planning studies. The typical planning study is composed of existing and future conditions, identification of needs and solutions, analysis of solutions/recommendations, and outreach. For bottleneck analysis to be fully considered, it should be a part of each of these activities in a number of different ways. Table S-1 shows how typical components of these studies can include specific elements of the truck bottleneck analysis.

Table S-1. Incorporation of truck freight bottleneck analysis into planning studies using generic tasks.

Task in Planning Study	Incorporation of Truck Freight Bottleneck Analysis
Existing Conditions	Essential data collected for bottleneck analysis (speed and volume) can be used as part of the description of existing conditions. See Chapters 3 and 4 of this Guidebook. Desktop analysis to identify and quantify bottlenecks (Chapter 5 of this Guidebook) can be used to describe existing conditions for trucks on the road network.
Future Conditions	Travel demand models can be augmented by using bottleneck analysis as the source of delay estimates in base year, then increasing delay proportional to increases in volume-to-capacity (V/C) ratios provided by travel demand models.
Identification of Needs	The causal analysis described in Chapter 6 can be used to identify needs in the system. For example, if a large percentage of truck bottlenecks are caused by crashes, then this indicates the need for safety improvements.
Identification of Solutions to Consider	Mitigation options described in Chapter 8 of this Guidebook can be used as a source of solutions to consider for the planning study. Field analysis described in Chapter 7 of this Guidebook also can be used to identify solutions.
Analysis of Solutions and Development of Recommendations	The ranking of causes of bottlenecks (see Chapters 6 and 7 of this Guidebook) can be used to prioritize solutions that are recommended. For example, if the majority of truck bottlenecks at a particular location is based on weather, then solutions that are targeted toward improving the road's ability to handle inclement weather may be given a 30 percent increase across a scoring method for solutions.
Outreach	Draft results of bottlenecks analyses should be presented to public- and private-sector stakeholders to validate locations of bottlenecks, severity of bottlenecks, potential causes of bottlenecks, and mitigation options to consider for addressing bottlenecks.

CHAPTER 1

Introduction

This Guidebook provides state-of-the-practice information to transportation professionals on identifying, classifying, evaluating, and mitigating truck bottlenecks. The bottleneck analysis described in this Guidebook is focused on utilizing truck probe data rather than traditional travel demand models. The primary application for the methodologies is evaluation of truck bottlenecks for prioritizing investment decisions.

This Guidebook serves the following purposes:

- Defines a common language related to truck freight bottlenecks;
- Classifies truck freight bottleneck categories based on causal and contributing factors;
- Describes truck bottleneck state-of-the-practice;
- Provides highlights from several case studies related to truck bottlenecks;
- Describes data sources used for truck bottleneck analysis;
- Provides a spatially scalable methodology for identifying truck freight bottlenecks;
- Describes quantitative measures for truck freight bottleneck categories for determining bottleneck severity, impact, and ranking and subsequent decision making;
- Describes mitigation options for truck freight bottlenecks; and
- Describes how to integrate truck freight bottleneck analysis into the planning process.

Examples of truck bottleneck analysis and notable practice highlights are provided throughout the Guidebook. The Guidebook is intended for two primary audiences:

1. Transportation planners that are conducting freight-related analysis or developing freight-related planning documents and
2. Research and operational staff that are interested in developing freight bottleneck analyses relevant for transportation planning processes.

1.1 Key Themes in Truck Bottleneck Analysis

There are a number of overarching themes and observations related to the state-of-the-practice in truck bottleneck analysis. Highlights of these observations are listed in this chapter to give practitioners an overview of key issues related to truck bottlenecks.

1.1.1 Classification Structure Is Needed

Truck bottleneck classification is not an exact science. There is a need for the development and clarification of a truck bottleneck classification scheme. Many of the resource write-ups in Appendix B are associated with “classifying bottlenecks.” While on the surface it appears there are many examples available, upon review of the references, there are often bottleneck terms used interchangeably or other nomenclature issues that could be remedied with a uniform classification structure (as introduced in Chapter 2).

1.1.2 Identification of Truck Bottleneck Cause

Not only is truck classification a challenge, there is not always clear identification of truck bottleneck cause. Many studies identify or evaluate truck bottlenecks and rank specific locations (typically with some form of a delay measure), and then a secondary (project-level) analysis and/or other data sources are necessary to identify key issues/problems that may cause a truck-specific bottleneck. In practice, there are typically project-level quantitative and qualitative evaluations needed to identify truck bottleneck causes. This secondary project-level analysis is an element of the truck bottleneck analysis process described in this Guidebook.

1.1.3 Connecting Mitigation Strategies for Specific Truck Bottleneck Causes

There often is not a clear quantifiable link between mitigation strategies and a specific bottleneck cause. For congestion mitigation, this may not be a concern as mitigation strategies that alleviate congestion for all vehicles also benefit truckers. However, there is a need to quantify the benefit of bottleneck improvements to truckers, particularly for situations due to restrictions (i.e., geometric or height restrictions or truck bans). The Guidebook proposes a method for doing this in Chapter 6.

1.1.4 Truck Bottleneck Analytics Are Generally Consistent and Scalable

There are a number of practices in the literature related to facility-based mobility analysis that include a truck component (e.g., ranking roadway sections by truck delay per mile). These practices generally integrate speed and volume data sources, and these practices are scalable from roadway sections to longer sections to urban area or statewide analyses.

1.1.5 Trip-Based Versus Facility-Based Analysis

Many of the travel speed and congestion-related bottlenecks analyze particular segments or facilities. Congestion measures such as delay, travel time index (TTI), or planning-time index (PTI) (reliability) are then ranked for the corridors. However, the trucking industry is more concerned about trips and delivering goods from point A to point B. In some ways, a facility-based analysis approach misses the trucking decisions that are part of the origin-destination decisions that truckers must make. There is a need for analytics that consider the origin-destination pairs and evaluates trip planning and specific routes in comparison to one another. Methods for doing these analyses are described in this Guidebook in Chapter 5. The authors of this Guidebook believe that understanding how to manipulate the increasingly ubiquitous probe data sources for trip-based analysis will become more important in the future as these datasets become even more prevalent and computing power and computing knowledge increase.

This dynamic can be illustrated through considering a speed analysis for a corridor. An analysis could focus solely on the speeds on the

Case Study Highlight

Over the past several years, Transport Canada has developed a freight fluidity measure. The measure is multimodal. Transport Canada has developed an integrated supply chain tool that measures individual segments of the supply chains as well as end-to-end transit time of freight flows. Over time, Transport Canada has obtained supply chain data from multiple modes, including ocean, as well as port-related, rail, trucking, air and logistics and warehousing to power the fluidity measure. More details are provided in Appendix B.

corridor or an analysis can be considered for a corridor and its parallel facilities. In this second case, the analysis is much more similar to an analysis that examines the travel time between the initial and termination points of a corridor. The determination of the bounds of the analysis is often influenced by the perspective of the party conducting the analysis. A state DOT may only look at state-owned roads without consideration of local roads. A metropolitan planning organization (MPO) may only examine roads within its jurisdiction rather than alternative routes that may be outside of its jurisdiction.

1.1.6 Truck-Specific Data Sources

The transportation industry has benefitted greatly in recent years from the increasing abundance of probe speed data. However, the user must clearly understand this data source and what implications it can have on a truck bottleneck analysis. Ideally, truck-specific speed data would be obtained and, depending upon the truck bottleneck application, speed data specific to single-unit and/or combination-unit trucks may be desirable. The breadth of coverage of the speed data also needs to be considered. For example, coverage of first-mile and last-mile connectors is typically important in speed analyses of regional networks, so there needs to be special examination of the speed data set to confirm that these roadways are included.

Similarly, truck volumes are needed to combine with the speed data to create truck delay statistics. Truck volume sources can be local automatic traffic recorders, weigh-in-motion sites, planning models, and/or even the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS). The key is using the best available truck-specific data for the truck bottleneck study. A specific area of concern is the use of average daily truck volume values. These may be appropriate for some generalized analyses. However, when analyzing nonrecurring truck delay, a more discrete truck volume set is needed. For example, to examine the delay impact of a crash, it is ideal to obtain the specific truck volume data that occurred at the time of the crash. Alternatively, the needed truck volume data can be estimated using the annual average daily traffic (AADT) value combined with seasonal, daily, and hourly factors related to the type of roadway where the crash occurred. Information on truck factors can be found in the Highway Capacity Manual (1). These nuances and data sources are described in more detail in Chapters 4 and 5.

1.1.7 Computation of Reliability Measures

There are a number of possible sources for "all vehicles" speeds or even truck-specific speeds. The industry would benefit from recommendations on what reliability measures are most useful for truck bottleneck analyses, computational procedures, and weighting by truck vehicle miles traveled (VMT), including temporal and spatial aggregation guidance. Details for computing truck reliability measures are provided in Chapters 5 and 6, along with Appendix D.

1.1.8 Engaging Trucking Stakeholders

Many of the resources related to truck bottlenecks relied upon engaging truck companies and associated stakeholders. These stakeholders are intimately familiar with the roadway shipping lines and impediments that impact their daily schedules—they are a key resource for public agency professionals. Practitioners will ideally remember to engage this

Case Study Highlight

Recent work by the Virginia Department of Transportation (VDOT) identified truck bottlenecks throughout the state. A novel approach in the study was the interviewing of over 180 stakeholders representing manufacturing, distribution firms (truck firms, wholesalers, etc.) and an assortment of retail, mining, agricultural and other firms. Respondents indicated congestion was the most prominent concern, followed by the driver shortage and then high fuel costs. The predominant solution proposed by respondents was some form of added capacity. More details are provided in Appendix B.

valuable stakeholder when identifying truck bottleneck locations as well as mitigation strategies. Engaging truck stakeholders is particularly important for first-mile and last-mile connectors, where truck speed data are typically less available. This engagement can occur through convening large group meetings, one-on-one interviews, or electronic survey processes. TRB's *NCFRP Report 25: Freight Data Sharing Guidebook* (125) has guidance on obtaining information and data from freight organizations.

1.1.9 Mapping Tools Are Effective at Illustrating Truck Freight Bottlenecks

Several resources were found that included interactive maps and/or analytics to provide information for truck bottlenecks investment decisions. These mapping and GIS tools really help to tell the truck bottleneck story to decision makers and policy makers.

1.2 Classifying Truck Bottlenecks

This Guidebook embraces a broad term for "truck freight bottlenecks" as any condition that acts as an impediment to efficient truck travel, leading to travel times in excess of what would normally occur. This definition encompasses a wide range of events and conditions, all of which add time to the delivery of truck freight shipments, from the time those shipments leave their origin to the time they arrive at their destination.

This broad view starts with the general understanding of the term "bottleneck"—a place where traffic congestion routinely forms. This routine congestion may be caused by a lack of roadway capacity for the typical peak traffic volumes on that road section (commonly called "recurring congestion" in the literature).

The definition of truck delay is extended in this Guidebook to include factors other than traffic congestion that increase the travel time for truck trips. These additional factors include issues such as:

- Additional trip distances caused by deficient bridge design (height, weight, width, etc.);
- Additional miles caused by load restrictions, whether seasonal weight limits or for hazardous materials; and
- Truck processing delays at sites such as weigh stations, border crossings, marine terminals, rail yards, warehouse/distribution centers, etc.

Case Study Highlight

The University of Maryland Center for Advanced Transportation Technology (CATT) Laboratory Vehicle Probe Project Suite is an example of a suite of visual tools and dashboards to support operations, planning, analysis, research, and performance measures using probe data in concert with other agency transportation data. http://www.cattlab.umd.edu/?portfolio=vehicle-probe-project-suite.

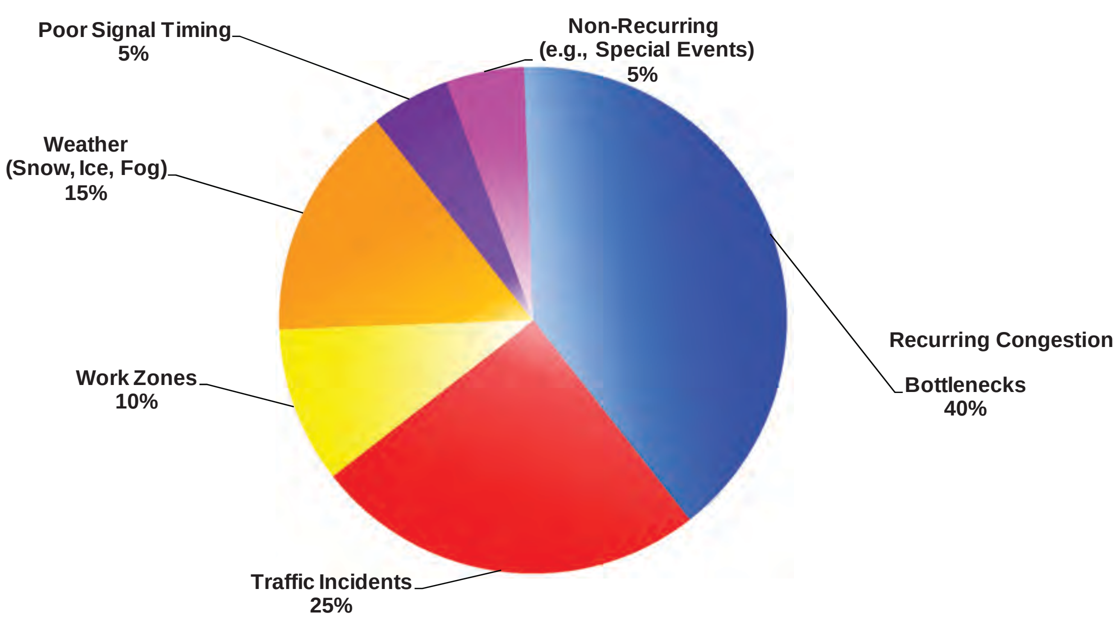
Classifying truck bottlenecks needs to occur first due to different analysis methods for travel speed-based and process-based truck bottlenecks. The suggested bottleneck classification is designed to describe locations that add travel time to truck trips while simultaneously describing the causes of those delays because the causes of the delays relate directly to the options for eliminating or mitigating them, and thus eliminating or mitigating the delay itself. The following outlines bottleneck classifications:

- Travel speed- and process-based: Are the bottlenecks caused by congestion and travel speed limitations or increased VMT?
- Recurrent and nonrecurrent: Is the bottleneck a daily occurrence?

Table 1-1 and Figure 1-1 provide key characteristics of travel speed-based delay. Travel speed-based delay is defined as locations where delay occurs as a result of oversaturated traffic conditions, temporary loss of operation capacity, or because roadway design causes truck-only delays.

Table 1-1. Classification of travel speed-based delay truck bottlenecks.

Cause of Travel Speed-Based Bottleneck	Bottleneck Type
Truck bottlenecks caused by simply too much traffic volume	• Peak-period traffic • Roadway geometrics (lane drop) • Steep grades/terrain • Special event traffic • Seasonal traffic volumes • Surge truck traffic from unloading of large container ships
Truck bottlenecks caused by temporary loss of operational capacity	• Work zones • Weather • Poor signal timing • Traffic incidents • Processing delays (toll booths, weight enforcement stations, terminal gates, international border crossings)
Truck-only bottlenecks (delays) caused by roadway limitations due to vehicle characteristics	• Roadway geometrics • Steep grades • Tight curves • Narrow lanes



Source: FHWA Office of Operations, Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation, September 2005. (126)

Figure 1-1. Sources of delay for all vehicle types (trucks and autos), national level, all vehicle types.

Notable resources related to classifying bottlenecks are described in Appendix B and include:

- An Initial Assessment of Freight Bottlenecks on Highways.
- Quantifying the Contributing Factors of Traffic Congestion Using Urban Congestion Report Data.
- Oregon State Highway Performance Data and Metrics Related to Freight.
- Positioning Hampton Roads for Freight Infrastructure Funding MAP-21 and Beyond.
- Freight bottlenecks in the Upper Midwest: Identification, Collaboration, and Alleviation/ Identifying and Characterizing Truck Bottlenecks in the U.S. Mississippi Valley Region.
- Oregon Department of Transportation (ODOT) Region 1 Corridor Bottleneck Operations Study.

These delays can also be caused from processing activities that occur at key freight locations.

Table 1-2 provides key characteristics of process-based delays. Process-based delay is defined as locations that force trucks to use longer, more circuitous paths than passenger cars would take if making the same trip, delays at specific locations related to freight, such as terminal gates, or requirements that trucks carry less cargo than they would otherwise carry if not legally restricted.

The suggested bottleneck classifications start with "travel speed (typically roadway congestion)" bottlenecks (recurring), because those delays are shared with cars and, therefore, the benefits from improvements made to mitigate those delays will be viewed differently by agencies funding the required mitigation.

The travel speed-based bottlenecks are further divided into three subcategories:

1. The first subcategory is locations where congestion forms primarily as a result of too much base traffic volume.
2. The second subcategory is locations where "temporary" operational limitations decrease operational capacity below traffic volume levels that would otherwise be able to operate without congestion.
3. The third subcategory of travel-speed bottlenecks is where only trucks are slow because of their larger size and performance characteristics reduce their mobility on a road as compared to cars. These bottlenecks are due to roadway geometrics (grades, tight turns, narrow roads) that are difficult for trucks.

Table 1-2. Classification of process-based delay truck bottlenecks.

Impact of Process-Based Bottleneck	Bottleneck Type
Rerouting	• Low bridge heights • Truck weight restrictions • Hazardous materials restrictions
Making additional trips	• Spring thaw load restrictions when no alternate routes • Truck size (length) and weight restrictions
Truck bans or restrictions	• Time-of-day restrictions • Truck pick-ups and deliveries in off-hours
Truckers having to search/wait for loading zones/parking	• Having to make inefficient movements such as circling a block, because the last-mile facilities (e.g., parking, load zones, terminal gates) are not suitable, lack capacity or poorly managed

The second broad category of truck bottlenecks encompasses operational process-related delay situations in which the attributes of the trucks, or the cargo they carry, result in travel times longer than passenger vehicles traveling from the same origin to the same destination would experience. Low bridge heights, truck size/weight restrictions, terminal queues, and truck bans are a sampling of examples that cause operational process-related delays.

Definitions were also developed for "Identifying," "Classifying," "Evaluating," and "Mitigating" bottlenecks to guide the proper identification and categorization of the selected case studies, many which are discussed in this Guidebook. The following definitions were used:

- **Identifying Bottlenecks.** Locating where bottlenecks are in the transportation system based on qualitative and/or quantitative methods.
- **Classifying Bottlenecks.** Associating a cause to the truck bottleneck.
- **Evaluating Bottlenecks.** Estimating the extent, duration, and/or severity of the truck bottleneck; sometimes this is augmented with bottleneck rankings and can be part of the identification process or a separate (more detailed) analysis.
- **Mitigating Bottlenecks.** Exploring potential truck bottleneck(s) solutions or analyzing existing mitigating efforts.

1.3 Overview of Truck Bottleneck Data Considerations

Data that can aid in determining the causes of bottlenecks are as follows:

1. Collision Data. How regularly do incidents occur on a specific corridor? For reliability purposes, have trucks rerouted to avoid uncertainty created by high-incident locations, and if so, what type of additional time and/or VMT are associated with the alternative route?
2. Weather Data. Are there seasonal travel pattern differences that create bottlenecks? (Consider high-incident locations).
3. Freight Facility Gate Data (ports, rail yards, intermodal facilities, border crossings, at-grade railroad crossings, etc.). Is the data capturing the peak months for goods movement?
4. Special Event Data. How does special event traffic impact truck corridors?
5. Work Zones Data (closures, detours, reduced lane widths, rough pavement, speed restrictions, etc.). Are there higher incident rates or longer travel times due to detours?
6. Operational Restrictions Data (time-of-day delivery restrictions, peak-hour fees, etc.). Are there hours of operations restrictions related to noise ordinances, limited gate hours at ports, curbside parking restrictions, higher toll rates, and/or other impediments that add to the travel time?
7. Truck Parking Data. The availability and usage of truck parking can provide information, particularly in metropolitan areas, on the origin-destination pairs for trucks. Additionally, the lack of sufficient truck parking causes trucks to add mileage to their trips as they search for parking. This is a form of process-based delay.
8. Roadway Features Data (grades, lane widths, turning radii, signage, pavement/striping/markings condition, etc.).
9. Data based on input from the trucking industry and transportation agency staff.

The ultimate use/application of the output from an analysis drives the data processing procedures, as well as data collection and data reduction decisions. The primary application for the methodology discussed in this Guidebook is the determination of truck bottlenecks for prioritizing investment decisions. While that sounds relatively straightforward, there are still important considerations for the data analyst that will impact data collection, data reduction, and data processing steps.

It is not always possible to obtain data at the spatial and temporal granularity for the specific location(s) of interest. Table 1-3 illustrates the spatial and temporal data availability tradeoffs that are rather commonplace in performing truck bottleneck studies when complete data are not available. Note that these tradeoffs are applicable for both volume and speed data. Speed (or travel time) and volume data are the most common (and critical) for truck bottleneck analyses.

1.3.1 Guiding Principles of Truck Bottleneck Analysis

A variety of technologies and methods are used to estimate truck bottlenecks. The methods generally include direct measurement of travel time and delay, derivation (virtual probes) of travel time and delay, and a combination of direct measurement and model use. While more detailed analysis procedures are provided in Chapters 5 and 6 and Appendix D for all the topical areas touched upon below, this section is meant to simply provide some guiding principles and general overview (2) to familiarize the reader with key concepts before more details are provided in later chapters.

In light of the literature and current practice, the following criteria are established that a measurement procedure should meet:

- Congestion performance should be primarily assessed from the user's perspective, not the facility's. Travelers experience the whole trip; isolated portions of it influence trip performance but the whole experience is important to travelers. This criterion implies that travel times be the basis for performance measures for congestion. Using travel times also is consistent with how freeway performance measurement is conducted and travel times resonate with the general public; they are easy to communicate.
- The best way to develop travel times is to measure them directly. Technologies that track individual vehicles accomplish this, as do agency probes. Global Positioning Systems- (GPS-) based methods may or may not; these currently are used by private vendors who employ proprietary data reduction methods, and it is difficult to know if they develop travel times from

Table 1-3. Speed and volume spatial and temporal data availability considerations.

	Data Availability	
	Spatially	**Temporally**
Most desirable are…	….actual data for the specific site(s) of interest…	…and/or data at desired time granularity to satisfy the application (e.g., annual, hourly, 15-minute, 1-minute).
Less desirable are…	…estimated data from similar site(s)…	…and/or data aggregated over time because desired granularity not available.

Source: Margiotta, R., B. Eisele, and J. Short. *Freight Performance Measure Approaches for Bottlenecks, Arterials, and Linking Volumes to Congestion Report,* Federal Highway Administration, Report No. FHWA-HOP-15-033, Washington, D.C., August 2015. Available: http://www.ops.fhwa.dot.gov/publications/fhwahop15033/fhwahop15033.pdf. (2)

tracking individual vehicles over a distance or use instantaneous vehicle speed measurements. If vendors ever develop data based on true origin-destination traces for individual vehicles, then directly measured travel times will be available.

- Travel times should be measured continuously—or nearly so—to develop distributions of travel times. Having access to the complete travel time distribution allows the calculation of reliability and provides a more complete picture of performance.
- Delay at individual signals, or at other specific bottleneck locations along a corridor, should be measured. The ability to identify specific bottlenecks along a corridor is a vital step in performance management. Therefore, a "drill-down" capability to identify where problems exist, once the performance of the arterial corridor is established, is needed.

1.3.2 Corridor-Wide Travel Time Data Reduction

After a distribution of travel times is established, a wide variety of performance measures can be created. The first step in developing corridor-wide measures is to work out the segmentation of the corridor so that the data can be properly reduced. Because of issues of "time-distance displacement" in combining data, the corridor should not be excessively long: 10 miles is a reasonable maximum. (If travel times from multiple segments are added to get the route travel time for a given time period, this will not correspond to the travel time measured from a vehicle's perspective, which will pass over downstream segments at different times.) Above that, care must be used in interpreting the results.

In all likelihood, the corridor (i.e., longer analysis reporting segment) of interest will be longer than the data collection segments that comprise it. Therefore, a method for combining the measurements for the data collection segments (e.g., where a reidentification detector is located or the segments on which GPS-based travel times are reported) into the corridor is needed. Four methods can be used:

1. The most direct method is simply to track the travel times of individual vehicles throughout the length of the entire corridor and develop the travel time distribution from them. This currently is only possible with the reidentification technologies. It is the "purest" of the methods as the corridor travel time is directly measured. However, there are problems with this approach:
    a. Sample sizes may be small, because of vehicles entering and leaving the corridor at different points.
    b. Due to the possibility of travelers making intermediate stops at activities along the corridor, some recorded travel times will be excessively long. Statistical procedures have been developed to weed out these long trips, but they are post hoc in nature and may result in excluding sound data. (3) These problems can be minimized by keeping the corridors reasonably short in length, even shorter than the 10 miles recommended above.
2. Develop travel time distributions for each data collection segment first, and then combine to get the corridor distribution. The moments of the distributions for the individual data collection segments are calculated. These include the following metrics for both travel time and space mean speed: minimum and maximum values; 1st, 5th, 10th, 15th, 20th, 25th, 30th, 40th, 50th, 60th, 70th, 75th, 85th, 90th, 95th, and 99th percentiles; mean; and variance. Corridor metrics are simply the sum of the data collection segment metrics. Past research has found that travel times on adjacent segments are not statistically independent (i.e., they are assumed to be correlated), and hence variances and percentiles cannot be added (but means can) (4, 5, 6). Recent work by Isukapati et al. suggests that in practice, they can be additive (7). However, their work is based on examining a single freeway corridor with relatively uncongested conditions—the applicability to congested and/or arterial conditions is unknown.

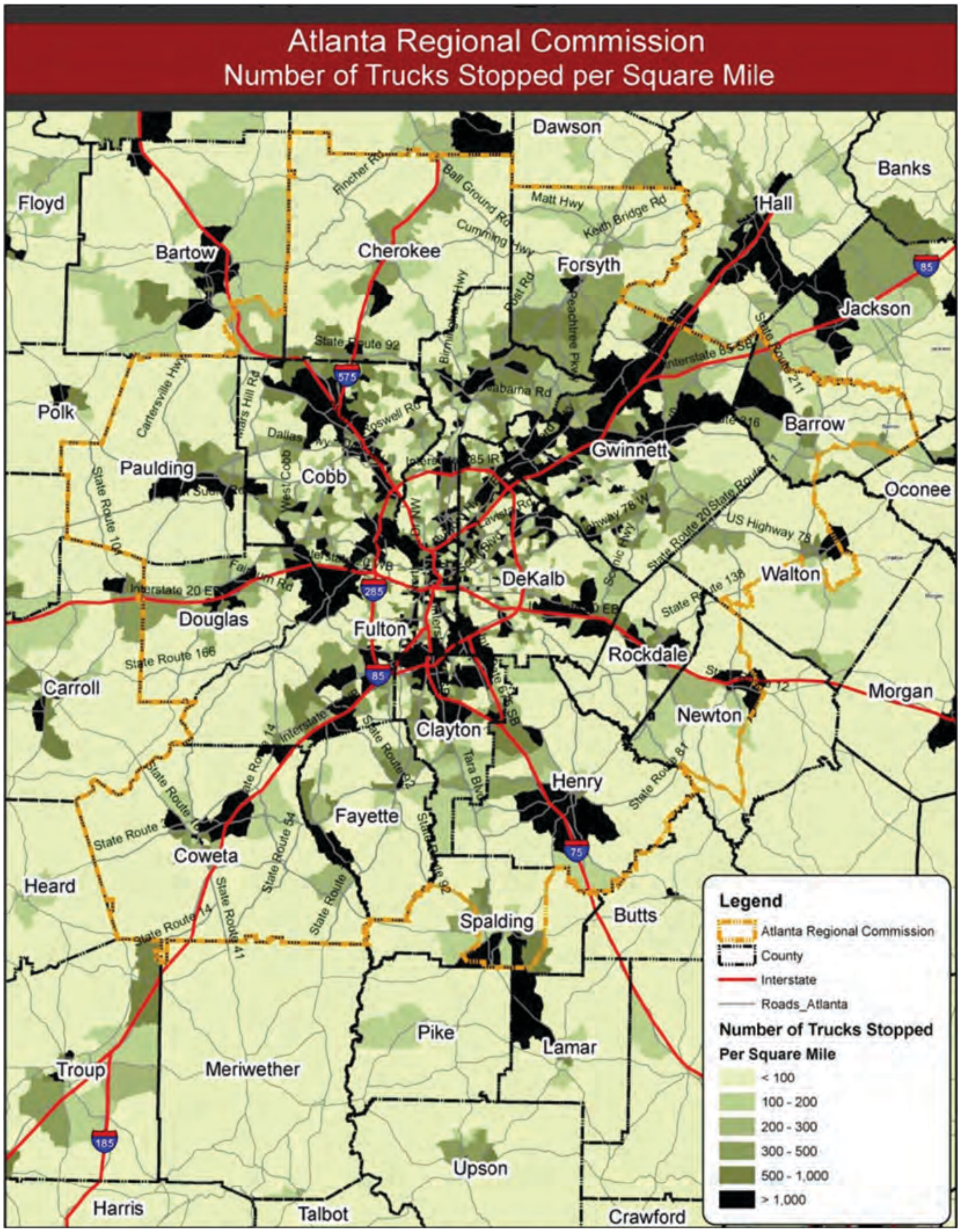
3. Develop corridor-wide travel times first, and then create the corridor distribution from them. In this approach, a corridor travel time for each time epoch (e.g., every 5 minutes) is created. These travel times are then the observations in the travel time distribution from which congestion and reliability metrics are created. This method avoids any thorny statistical problems with combining distributions and most closely resembles data collected from direct observation of travel times from end to end.
4. Apply the virtual probe or trajectory method. This is not a distinct method but an extension to method No. 3 above, which has the problem of not precisely replicating the passage of vehicles over the facility in time and space. [Method No. 2 also suffers from this time-distance displacement but there is no easy way to address it for percentiles; mean values could be used, however (8).] This is less of a problem for relatively short facilities, such as the recommended 10 miles. However, as trip lengths extend, the problem becomes exacerbated.

Based on this assessment of travel time data reduction, the following recommendations are made (9).

a. Using the principle that the best way to develop travel times is to directly measure them, Method No. 1 should be the preferred method, but it has limitations because of small sample sizes and interrupted trips. It also is applicable only to the reidentification data collection technologies. Therefore, the preferred approach is Method No. 4, especially for long corridors. Method No. 3 will suffice for corridors that are not longer than 10 miles.
b. Adding segment distributions to obtain percentiles, which are the basis for most reliability metrics, is not recommended for facility performance. Serious theoretical questions exist that have not been adequately addressed with empirical evidence, and there appears no simple way of accounting for the time-distance displacement problem with this method. Additional research may override this recommendation or develop adjustments for its application.
c. If only mean travel times are desired, then adding mean segment travel times to obtain facility travel time is acceptable.

There are several sources of truck origin-destination data that can be used to combine with corridor-specific data. Truck origin-destination data is available through travel demand models. It can also be extracted from commodity flow databases. There are also techniques to develop truck origin-destination data through truck GPS data by tracking individual trucks between sequential locations where the data show them to be stopped for extended periods of time. Figure 1-2 shows a map of truck trip origins and destinations identified in the Atlanta metropolitan region using truck GPS data. Understanding these origin-destination patterns is particularly important for situations when there is a desire to consider through-trucks trips relative to internal truck trips or situations where the impacted jurisdictions need to be identified. Understanding origin-destination patterns is also important for process-based delays to determine the specific type of rerouting that occurs due to restrictions such as a low clearance bridge, weight-restricted roads, or other truck bans.

Additionally, with the availability of truck origin-destination data through commodity flow databases and more recently with transactional data, there is the ability to match the corridor-level delay analysis with key elements of larger goods movement patterns. This allows for the impact of truck delays to be better understood within the context of supply chains and broader economic activity.



Source: Georgia Department of Transportation (GDOT) Freight & Logistics Plan, 2011. (54)

Figure 1-2. Truck trip origins-destinations in Atlanta Region identified using truck GPS data.

CHAPTER 2

Overview of Truck Bottleneck Analysis Steps

This chapter provides an overview of the primary steps involved in conducting the truck bottleneck analysis. As described in the prior chapter, the speed data focus throughout these methods is truck probe speed data because they are the most cost-effective and widely available data source for most transportation agencies. Traditional travel demand models can also be used to conduct truck bottleneck analysis, but these models are limited to analyzing recurring travel speed-based bottlenecks only.

Congestion locations are important to both trucks and cars. However, the patterns (time periods) and significance (number of vehicles delayed) of congestion occurring at specific locations may be very different for trucks than for cars. That is, at some locations, the majority of delayed vehicles may be cars, whereas at other locations, perhaps due to roadway limitations related to a truck's size or performance, the delayed vehicles may be mostly trucks. Consequently, truck congestion must be analyzed both in conjunction with congestion for cars and separately, as effective departmental decision making requires an understanding of the differences. For example, an agency might prioritize projects that reduce delay if it knows that a disproportionate amount of that delay is experienced by high-value truck movements.

Many of the commonly analyzed commuter bottlenecks (and commuter bottleneck indexes) focus on the morning and afternoon commute peak periods where total vehicle volumes are highest. Truck percentages during these periods of the day can vary, but typically these do not represent the highest truck percentage periods. On the other hand, bottlenecks during the middle of the day may disproportionately impact trucks more than other periods as the truck percentages during the middle of the day tend to be higher than during commute periods. This is particularly relevant for urban bottlenecks caused by crashes during off-peak periods and rural bottlenecks caused by crashes.

The methodology is scalable by geography, so it can be applied to point locations, individual corridors, or statewide road networks. The scalable methodology for identifying, ranking, and mitigating travel speed-related bottlenecks, introduced earlier, consists of the six steps as shown previously in Figure S-1. The scalability of the analysis also allows for allocation of benefits to local, state, regional, and national stakeholders which can inform the investment setting processes of similarly scaled transportation agencies. This scaling also allows for information to be extracted regarding the need for private savings relative to public costs.

Several of these steps can be performed simultaneously in terms of computer processing, but are discussed separately in this Guidebook (e.g., computing delay by road segment and then sorting those segments by the amount of delay computed). These same procedures—and thus the same basic software tools—are also used to identify, quantify, and rank bottlenecks for total traffic volume. The majority, but not all, of the performance metrics appropriate for truck bottlenecks also are applicable for bottlenecks related to total volume. The primary difference is that because the travel patterns of trucks are different than those of cars, bottlenecks that are most important for trucks may not be the most important ones for total volume. The same methods are usable to rank segments by truck volume if reliable vehicle classification data are available.

The suggested approach described here is scalable in several ways. First, it allows the agency performing the analyses to use its available data resources regardless of the source or size of those resources. In addition, the same analytical approach works whether the analysis is performed for an entire state highway network, a regional network, or even a specific city. Second, even within an agency, the suggested approach can be applied to a single road, multiple roads within a geographic corridor, an entire region, to all roads in the state, or to all roads in a multistate region.

The suggested approach also accounts for the fact that not all of the data sources identified in this report will be available to all agencies. It is not possible to perform analyses for which no data exist, but other analyses that do not rely on those missing data can still be performed. The suggested approach is specifically designed to allow agencies to extend their analysis capabilities as new data resources become available.

The suggested approach is specifically designed to allow agencies to extend their analysis capabilities as new data resources become available.

Finally, the suggested approach starts with an automated process that identifies and ranks the "most significant" bottlenecks within the study area. Detailed analyses are then performed on only the most important, highest-priority bottleneck locations. This approach has been successfully used by states for many of their performance management systems. For example, state DOT pavement management systems routinely describe the condition of a state's roadways and produce both aggregated summaries of the entire state's system pavement performance and an initial list of priority locations in need of repair and rehabilitation. Depending on the available budget, a limited number of these locations are examined in detail to produce "actual" design documents for those pavement repair and rehabilitation projects. The more money that is available for pavement maintenance, the more projects that are designed at this detailed level. At this detailed level, analysis is needed early because a good design engineer can optimize a design far better, and with far more specific inputs, than is possible at the statewide level.

The approach proposed here is the same. An automated process identifies the list of bottleneck locations, their relative rank in terms selected by the agency, and the probable causes of their performance deficiencies. From this list, the agency can then select the projects that most effectively fit into the agency's mission and budget for further analysis of detailed bottleneck mitigation. These selected projects then receive additional, detailed design attention, allowing the agency to select the most appropriate approach to bottleneck mitigation given the many factors that apply to any project. The number of these designs and the resulting projects chosen for funding will scale to the resources available within that agency.

CHAPTER 3

Identify and Assemble Data

The first step in the truck bottleneck methodology is to identify, collect, quality check, organize, and link the various data sources available to the agency that are needed to identify and quantify bottleneck locations. The more and better the data available, the better the results of the analysis. However, useful results can be obtained with even modest data resources.

3.1 Truck Bottleneck Data Considerations

Speed data are available from a number of sources. Based on the state-of-the-practice findings related to the growth of probe-vehicle speed data sources and their use, this Guidebook focuses on how to use probe data to identify truck freight bottlenecks. Availability of probe-vehicle data sources will become more temporally and spatially prevalent in the future. Although probe data are the focus of this Guidebook, it is important that Guidebook users be aware of selected characteristics of other available travel time data sources.

Table 3-1 provides a synopsis of the major types of speed data collection methods/systems for travel time and selects derivative products. All types except for GPS-based data require that agencies deploy and maintain field equipment. What is notable in Table 3-1 is that probe-vehicle sources are scalable agencywide; they offer the ability to perform truck bottleneck analyses at the roadway, region, metro, state, or even national level. In comparison to other technologies, this scalability is where probe-vehicle sources really shine. This will only improve as these data increase in availability.

The most significant issue in terms of scalability for GPS-based data occurs on higher-classification roadways. On these roads, there are often sample sizes that are too small to develop summary information on vehicle speeds.

As indicated in Table 3-1, in comparison to other technologies, probe-vehicle methods have smaller sample sizes, which impacts the ability to characterize the travel time distribution. Sample size and travel time distribution is better from sensors in the field because they typically collect more detailed samples. As GPS-based data methods improve, the concerns of limited sample size may be mitigated, particularly on higher classification roadways.

It is important to note the “virtual probe” travel time option that is discussed in Table 3-1. In this case, the analyst “traces” a modeled vehicle through time and space along a facility of interest to obtain an estimate of travel time through the corridor. From these estimated travel times, the travel time distribution for an entire corridor can be estimated. While this method is good for specific corridors, it can become cumbersome and more complex to apply over large spatial networks.

The data types identified in Table 3-1 represent those that are available as of the writing of this report. It is possible that vendors currently offering vehicle probe data based on roadway

Table 3-1. Comparison of travel time data collection technologies, derivative products, and selected data characteristics.

Technology	Sample Size	Characterized Distribution of Travel Times	Ability to Scale Agencywide
Reidentification of vehicles (ALPR, pavement sensors, toll-tag readers)	Excellent	Excellent	Poor
Reidentification with MAC address matching (Bluetooth)	Good	Good	Fair
GPS-based data (commercial vehicle probe)	Fair	Fair (but improving)	Excellent
Virtual probe	Excellent	Excellent (but derived)	Excellent
Agency-driven probe vehicles	Poor	Poor	Poor

Sources: Remias, Stephen M., Alexander M. Hainen, Christopher M. Day, Thomas M. Brennan, Jr., Howell Li, Erick Rivera-Hernandez, James R. Sturdevant, Stanley E. Young, and Darcy M. Bullock, *Performance Characterization of Arterial Traffic Flow with Probe Vehicle Data*, Transportation Research Record: Journal of the Transportation Research Board, No. 2380, Transportation Research Board of the National Academies, Washington, D.C., 2013 (127), with "virtual probe" assessment added by Cambridge Systematics, Inc.; and Margiotta, R., B. Eisele, and J. Short. *Freight Performance Measure Approaches for Bottlenecks, Arterials, and Linking Volumes to Congestion Report,* Federal Highway Administration, Report No. FHWA-HOP-15-033, Washington, D.C., August 2015. Available: http://www.ops.fhwa.dot.gov/publications/fhwahop15033/fhwahop15033.pdf (2).
ALPR = automatic license plate readers.

segments will provide individual vehicle data that allow constructing travel times between origins and destinations (O/Ds). These O/D travel times would be directly measured rather than synthesized.

In terms of GPS-based data, evaluations from the University of Maryland and Virginia Center for Transportation Innovation and Research (VCTIR) suggest that the accuracy of these data are questionable on arterial streets that have very congested, oversaturated conditions (multiple cycle failures). Accuracy problems also exist on lower-order functional classes, where probe samples are likely to be small. (10) For the purposes of performance monitoring and bottleneck identification, where the primary interest is in the relative rankings and trend analysis of truck bottlenecks, the accuracy problem is not as severe as for other uses such as traveler information. As vendors gain more experience in collecting and processing travel time data, the accuracy problem may be minimized, but there is no guarantee of that happening. For the moment, users need to be aware of the accuracy problems especially when making benefit estimates.

The impact of truck bottlenecks in monetary terms can be estimated by translating bottleneck delay data into dollars. There are several sources of estimates of the cost of truck travel delay such as the FHWA Highway Economic Requirement System and the American Transportation Research Institute's *An Analysis of the Operational Costs of Trucking: 2015 Update* (128). The monetary impact of delay can also be estimated based on the type of cargo that is being delayed. Commodity flow data and transactional data can be used for these types of estimates.

3.2 Potential Data Sources

At a minimum, data are needed on the performance and use of the road system. That is, how fast are vehicles (and in particular, trucks) moving, where are they being delayed, and how many of them are using the roads and/or being delayed?

Once the ability to compute delays can be accomplished, more effective bottleneck analysis can be performed if data also are available that describe the potential causes of delay. These include "temporary" events, such as:

- Vehicle crashes and other incidents,
- Construction activities,
- Bad weather, and
- Special events.

Not all state agencies and MPOs will have these data available. In addition, for many of the cases where states have these data, they will not be uniformly available for all geographic regions in the state. This is an acceptable circumstance as travel speed bottlenecks can still be identified without these data, but the agencies will find that more work is required to understand the causes of those bottlenecks if these data are not available.

Finally, data that describe physical limitations in the roadway infrastructure that can cause delay also are desired. These items include geometric and terrain features that can slow vehicles—especially loaded trucks. Examples of data items [often found in part in state DOTs and MPOs geographical data (GeoData) catalogs] that could be gathered and included in the data system are as follows:

- Roadway geometric limitations (e.g., narrow lane widths, low-height bridges);
- Grades steep enough to affect truck speeds;
- Activities that delay vehicles (e.g., toll booths, weigh stations, international border crossings); and
- A lack of truck-specific, last-mile facilities such as parking or load zones.

A list of potential data sources for each bottleneck classification type is provided in Table 3-2. By obtaining data on these activities and roadway features and placing them within the truck bottleneck data analysis structure, it is possible to develop automated procedures that allow agencies to not only readily compute the presence, size, and frequency of congestion bottlenecks, but also to obtain good insight into the causes of those bottlenecks.

It should be noted that the vast majority of these data are from public sources. While there is much data that exist in the private-sector freight community, the challenges in obtaining, analyzing, and aggregating sufficient data across enough companies typically makes the private sector an inefficient source for conducting a comprehensive analysis. Data from freight transactions is becoming increasingly available and can provide detailed information on O/D patterns, but they do not provide the temporal or roadway detail that is most useful for bottleneck analysis. Additional information on the use of private-sector freight data can be obtained from *NCFRP Report 25: Freight Data Sharing Guidebook* (125).

3.3 Description of Key Data Sources

3.3.1 Vehicle Speed and Travel Time Data

States and MPOs currently have access to data sets that can provide estimates of where congestion is occurring on at least a portion of their roadway system. At a minimum, every state DOT and MPO has access to the NPMRDS made available by FHWA. These data provide estimates

Table 3-2. Potential data sources for each bottleneck classification type.

Bottleneck Category	Bottleneck Type	Example Data Sources
Travel Speed-Based Bottlenecks	Peak-period traffic	State DOT Traffic Count Data
	Roadway geometrics (e.g., lane drop) and attributes (e.g., tunnels)	State DOT Roadway Inventory Database
	Steep grades/terrain	State DOT Roadway Inventory Database
	Special event traffic	State or Regional Visitors and Convention Bureau
	Seasonal traffic volumes	State DOT Traffic Count Data
	Work zones	State DOT Construction and Maintenance Logs
	Weather	National Weather Service
	Poor signal timing	Local Traffic Management Center
	Vehicle crashes or other traffic incidents	State DOT Crash Database
	Tight curves	State DOT Roadway Inventory Database
	Surge traffic from unloading container ships	Port Vessel Schedule Data, Port Activity Data (e.g., PierPass in Southern California)
	Narrow lanes	State DOT Roadway Inventory Database
Process-Based Bottlenecks	Low bridge heights	State DOT Roadway Inventory Database
	Truck weight restrictions	State DOT Roadway Inventory Database
	Hazardous materials restrictions	State DOT Roadway Inventory Database
	Load restrictions when no alternate routes (e.g., spring thaw)	State DOT Oversize/Overweight (OS/OW) Permit Office
	Truck size (length) restrictions	State DOT OS/OW Permit Office
	Time-of-day restrictions	Local Municipalities, Truck Operators
	Truck pick-ups and deliveries in off-hours	Local Municipalities, Truck Operators
	Node-based delays (toll booths, weight enforcement stations, border crossings)	State Highway Patrol, Facility Operators, Local Customs Office
	Having to make inefficient movements such as circling a block due to unsuitable trip end facilities (e.g., parking, load zones)	Local Data Collection Efforts

of travel times at which vehicles operate on the entire National Highway System (NHS). Other probe-vehicle or sensor datasets can also be used to estimate speed or travel times.

The NPMRDS provides estimates of travel times for passenger cars, trucks, and all vehicles combined for each directional segment of the NHS for every 5 minutes of the year. The exception is when no instrumented vehicles report using those segments during that five-minute interval. In that case, the NPMRDS provides no estimate of the road's performance at that location for that time interval (vehicles carrying GPS or cellular devices that report their speed and location to a service provider that shares the data with the firm providing the NPMRDS data to U.S.DOT.). Understanding where the holes are in the available performance data (irrespective of the source) and deciding what to do about those holes are key tasks in the quality assurance task described in Section 4.6.

Table 3-3 shows a sample of an NPMRDS. The NPMRDS is provided in two parts. The first part is a Traffic Message Channel (TMC) static file that contains TMC information that is updated only as necessary (see Table 3-3a). The second part is a database file set of average travel times (in seconds) of passenger, freight and combined for NPMRDS roadways geo-referenced to TMC location codes (see Table 3-3b). It includes travel speed measurements [collected 24 hours a day in 5-minute increments (epochs) when available] from GPS or cellular devices in the traffic stream.

Other roadway performance data sources also can be used to provide estimates of vehicle travel times/speeds. Data sets similar (or in greater detail) to the NPMRDS are available from a number of private-sector firms, and these can be used in place of, or as a supplement to, NPMRDS. Data from agency-supported fixed sensors, such as roadway loops, also can be used to supplement the vehicle probe data. ITS (intelligent transportation systems) detectors are particularly noteworthy because they have the capability to provide both speed and volume data (classified by vehicle length) if managed appropriately. These data also can be used independently, or they can be combined with the NPMRDS to create a richer roadway performance data set.

Table 3-3. Sample NPMRDS data.

a. TMC Static File

TMC	Direction	Admin_ Level_1	Admin_ Level_2	Admin_ Level_3	Distance (miles)	Road Number	Road Name	Latitude	Longitude
101N04099	Eastbound	U.S.	Illinois	Cook	3.27285	I-90	Kennedy Ex	37.9615	-121.6961
101N04100	Westbound	U.S.	Illinois	Lake	0.88324	I-290	Eisenhower	37.9906	-121.6972

b. Travel Time File

TMC	Date	Epoch	Combined	Passenger	Freight
101N04099	04022012	33	105	99	123
101P04099	04022012	78	98	92	125
101N04100	04022012	5	46	38	51
101N04100	04022012	31	45	39	52

The key is that each state or MPO has access to data that allow the identification of travel speed-related bottlenecks. Using the NPMRDS—or other available data sets—states and MPOs can compute at a minimum when, where, and to what extent delays are occurring for both cars and trucks throughout the NHS.

3.3.2 Volume Data

Volume data provide two things in a typical bottleneck analysis:

1. An estimate of the "usage" of a roadway because not all roadway segments are the same and
2. A way to perform weighted averages for index measures to produce facility, regional, or area-wide statistics.

As with vehicle travel time and speed data, there are multiple sources of truck and traffic volume data that are available to state agencies and MPOs. Truck and traffic volume data can be obtained from the HPMS data that states submit to FHWA each year. The HPMS submittal describes AADT on each roadway segment of the NHS, as well as the percentage of trucks using those roadway segments.

However, there are some challenges with using HPMS data as the source for truck classification data. The data tend to be 2 to 5 years old and based on a few days of classification counts. Much of the truck percentage data available on HPMS segments are actually estimates. The method for estimating truck percentages varies and can range from using truck percentages from counts nearby the segment to using truck percentages of roadways with similar functional classification. This limits the accuracy of the count data in terms of calculating truck delay. HPMS data can be supplemented by using other sources that provide broader coverage over time and functional classification such as weigh-in-motion data and closed caption television.

Ideally, the vehicle classification count data would have a much higher level of temporal resolution than average annual conditions. Thus, if HPMS data are the primary source for truck and traffic volumes, additional effort is needed to understand how traffic volumes vary over time at each roadway segment. State DOTs perform some level of short-duration truck and traffic volume counting, and these counts are frequently supplemented by continuously operating, permanent counters. Both of these data collection efforts provide volume estimates at a minimum hourly resolution. The combination of these data sources serves as the basis of the annual traffic estimates submitted in the HPMS (e.g., AADT and truck percentages). They also can be used to estimate the time-of-day traffic volume profiles present on roads.

Other potential sources of time-of-day volume data (by vehicle classification) include daily volumes from a roadway inventory database and classification data from national-level sources such as FHWA. More information regarding each of these methods can be found in recently completed FHWA research. (11)

3.3.3 Other Data Sets

To complete the data analysis structure needed for comprehensive bottleneck analysis, a variety of other data sets will also be needed. As noted earlier in this section, these data include data on temporary operational capacity reductions that can cause delays to form, such as:

- Vehicle crashes and other incidents. Most state DOTs have a safety branch that collects and makes available crash data. Figure 3-1 is an example of site to order crash data from the Iowa Department of Transportation. Another example is the multi-agency Regional Integrated Transportation Information System (RITIS), which allows participating agencies to access

Source: http://www.iowadot.gov/crashanalysis/index.htm.

Figure 3-1. Crash database example from the Iowa Department of Transportation.

information on incidents, including the types of vehicles involved and the timeline of the incident.

- Construction activities. State DOTs track and announce construction and roadway closures and often store this information. Figure 3-2 is an example of an announcement from the Washington State DOT of work zone activity.
- Bad weather. Historical weather data can be ordered from NOAA. Figure 3-3 is an example of an order for 15-minute precipitation data.
- Special events.

For process-based delays such as port gates, border crossings, intermodal railyards, weigh stations, and toll plazas, facility-specific data sets are needed. For port gates, most terminal operators maintain information on the dwell time of trucks within the port gates. Video cameras are typically needed to measure delay of vehicles waiting outside the port gates. In theory, truck GPS data can also be used to estimate the times that individual trucks spend waiting in line at

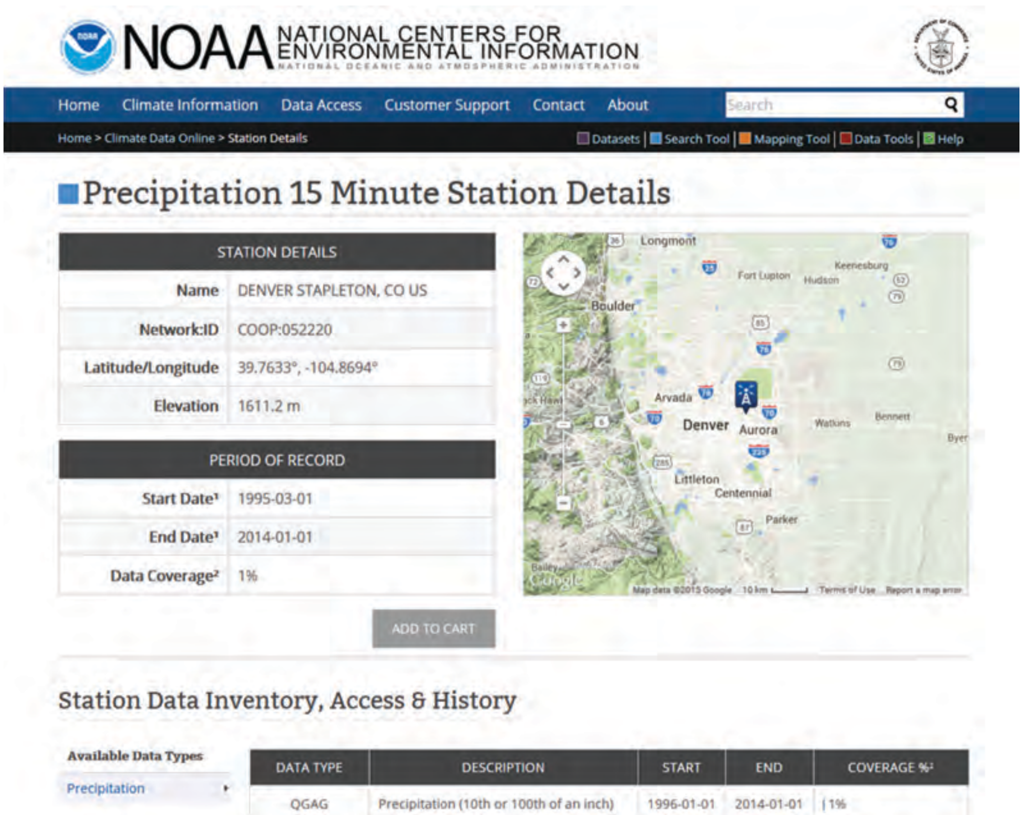
Washington State Department of Transportation

FREIGHT TRAVEL ADVISORY: I-90 Snoqualmie Pass Vicinity July 13 - 17

LOCATION: I-90, both directions between mileposts 56 to 64.

DETAILS: Loads over 12 feet wide are prohibited eastbound from 8 p.m. to 9 a.m. each night from Monday night, July 13 through Friday morning, July 17. Loads over 10 feet wide are prohibited westbound from 8 p.m. to 9 a.m. each night Monday night, July 13 through Friday morning, July 17.

Figure 3-2. Work zone log output from the Washington State DOT.



Source: http://www.ncdc.noaa.gov/cdo-web/search.

Figure 3-3. Example of a weather data order from NOAA.

port gates and dwell times inside port gates. However, in practice, the level of geographic precision needed to conduct this type of analysis makes the use of truck GPS data for these purposes challenging.

Similarly, most border crossing facility operators maintain data that estimate delay approaching border crossing facilities along with border crossing time at the facilities. Truck GPS data can be used at these locations with appropriately located screenlines that allow for the measurement of time that passes between upstream and downstream locations from a border crossing facility. This process would provide information on a combined wait time and processing time at these facilities. Alternatively, roadside truck surveys can be used to collect information from truck drivers on their estimates for time spent waiting to travel to border crossing locations and time spent being processed at these facilities.

Weigh stations feature two types of truck delay. There is the delay that occurs when traveling on the weigh-in-motion portion of the station when trucks are not asked to stop at the station. Then, there is the processing time for trucks that are stopped at the station. The delay on the weigh-in-motion portion of the station occurs on the approach to the weigh station where trucks must slow down even when there is no traffic or trucks may become queued at these locations when the volume of trucks exceeds the capacity at these locations. These speeds can be identified using the truck GPS methods mentioned throughout this chapter. There are not any standardized sets of data that measure the processing time for trucks that stop at weigh stations, but it could be estimated through either observation or roadside truck surveys. Speeds at toll plazas can also be estimated using truck GPS data.

These data sets can be quite large and contain many data items. Not all of the data items present in the base data systems should be brought into this analysis process. That is, not all variables in the vehicle crash records are needed in the bottleneck analysis data structure.

Finally, comprehensive truck bottleneck analysis requires information about the various types of physical disruptions that affect truck travel. These include:

- Roadway geometric limitations (e.g., narrow lane widths, low-height bridges);
- Grades steep enough to affect truck speeds;
- Activities that delay vehicles (e.g., toll booths, weigh stations, international border crossings); and
- A lack of truck-specific, last-mile facilities such as parking or load zones.

Many of the physical disruption data elements are available through state DOT roadway inventory systems. Others will require independent research and data assembly activities. As with the other data sets, the availability of these data statewide (or regionwide) is not a requirement for performing useful truck bottleneck analyses. However, the more of these data available for analysis, the more robust the outcome of the truck bottleneck analysis will become.

CHAPTER 4

Organize Data

4.1 Organizing the Speed and Volume Data (Conflation)

"Conflation" is the process of matching probe speed data to roadway volume data for subsequent analysis. It is necessary for computing performance measures for truck bottleneck analysis when the speed and roadway volume data are provided on different networks.

"Conflation" is the process of matching probe speed data to roadway volume data for subsequent analysis.

The first step in the conflation process is determining which roadway network will serve as the base network for conflation. The base network is the roadway network, which gets the attributes from the other network loaded on it. Generally, the base network should be the network that more closely aligns with the purpose for the analysis. Because datasets are large and processing time can be lengthy, it is important to consider if any records can be eliminated (i.e., by excluding some functional classes to speed processing time).

The process of conflation is facilitated by using GIS information to import and compare the end points of the speed data roadway network with the traffic volume inventory. Quality control is a necessary step to ensure that the data from the speed network aligns with the volume network. More information on conflation can be found in recently available research. (12)

By combining vehicle speed and truck and passenger car volume data, agencies can compute not only when and where congestion occurs, but the relative size of the delays (in vehicle-hours and truck-hours) that each congestion location causes. It also is possible to track the frequency with which congestion forms. These delay statistics are the primary congestion bottleneck identifiers. By summarizing these data at the location level and using a GIS, it is possible to illustrate on a map the locations of the largest congestion bottlenecks and to develop tabular summaries of the relative sizes of those locations. Figure 4-1 illustrates how a GIS map can be used to illustrate the locations of congestion bottlenecks.

Likewise, performing trends over years, agencies also can produce top improvement locations year over year. These locations provide insights into where top delay reductions occur, typically from capacity improvements and/or construction completion. An example is shown in Figure 4-2. Note that red is used in Figure 4-1 to highlight the poor-performing segments, while green is used in Figure 4-2 to accentuate the communication of improved segments.

To compute the locations and relative sizes of bottleneck locations, it is necessary to link the available vehicle volume and speed (or travel time by segment) data in a manner that allows the computation of delay statistics. The difficulty of this task is that different data sets tend

Source: *2013-2014 Indiana Mobility Report: Summary Version*, available from http://docs.lib.purdue.edu/imr/ on December 20, 2014 (129).

Figure 4-1. Top 20 Interstate segments by total delay.

to use different location referencing systems and time-reporting periods. The specific issues associated with linking databases are:

- **Point versus segment data.** Some data that describe vehicle performance on roads (e.g., vehicle speeds) are reported for a point in space. Other data may be reported as travel times over a specified distance (a roadway segment).
- **Different location referencing systems.** Many state highway agencies reference locations on roads by route number (or name) and milepost. Other mapping systems reference location by X/Y coordinates. GISs use a series of defined lines and nodes to describe roads. Other location systems use roadway segment IDs with specific naming conventions.
- **Direction of travel information.** Some highway representations combine both directions of travel into a single road segment description. Other highway representations split the two directions of travel into two separate descriptions, even when those different directions of travel are physically connected.
- **Different road segment definition.** One system might define a road segment as consisting of uniform traffic volume extending from an on-ramp to the next off-ramp. A different system

Source: *2013-2014 Indiana Mobility Report*: *Summary Version*, available from http://docs.lib.purdue.edu/imr/ on December 20, 2014.

Figure 4-2. Top 20 Interstate improved segments from 2012 to 2013 by total delay.

might be based on pavement type, which might change several times within that uniform traffic volume segment and might not have the same end point as the volume-based system.

- **Different time-referencing approaches.** In some instances data describe a specific point in time (e.g., "a vehicle was traveling at 65 mph at 11:07:25 at this location"). In other cases, data are reported as the average of, or total number of, multiple vehicles passing a point during a given time interval (e.g., "the traffic volume at a defined point in the road was 2,300 vehicles from 6:00 a.m. to 7:00 a.m.") The time interval in which these summarized data are reported can vary from very short, such as 20 seconds for urban freeway systems, to very long, such as the AADT volume reported within HPMS.

For analysis purposes, these different referencing systems must be connected during conflation. All the data to be used in the bottleneck analysis must be transformed into a common data structure that describes the conditions to be found on defined road segments during defined time periods.

When conducting truck bottleneck analysis, one straightforward choice for a roadway segment and time period data structure is the organizational structure used for the speed data set

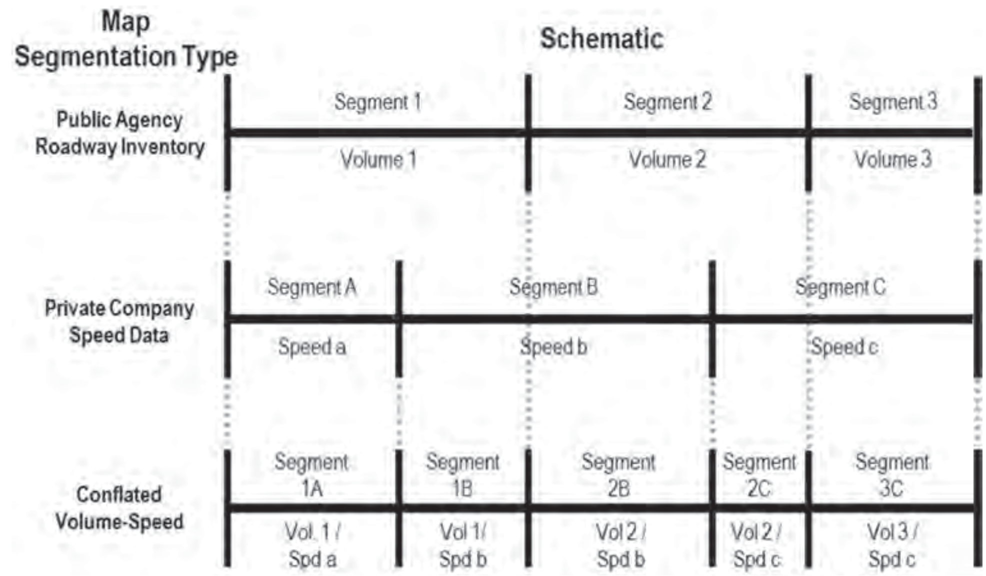


Figure 4-3. Illustration for conflating different road segments.

an agency plans to use for its bottleneck analysis (e.g., NPMRDS or other vendor). Speed data can be transformed to fit the road segments for which volume data are available or both data sets can be transformed into a third roadway segmentation system. This last option, forming a “composite” segmentation system, is illustrated in Figure 4-3. The “best” of these transformation options will depend on the data available to each state.

4.2 Travel Time (Speed) Data Organization

The roadway segmentation system the NPMRDS uses is the TMC protocol, which is commonly used by Internet mapping companies. TMC segments are directional so that travel times are provided by direction of travel. A GIS shape file that defines each segment is provided along with the NPMRDS travel-time data. The shape file indicates the start and end points of each TMC segment, including the X/Y coordinates of those end points. The NPMRDS dataset also provides a variable that lists the length of each segment. This allows users to convert the reported travel times into estimates of the average speed of the cars, trucks, or “all vehicles” combined as they travel over that TMC, if they desire that statistic for analytical purposes.

The result is that the NPMRDS data can be organized into a file structure that looks like the matrix in Table 4-1, where each cell in the matrix contains the travel-time value for that TMC segment for that 5-minute period. The NPMRDS provides data for cars and trucks separately so that separate matrices can be created for car travel times and truck travel times. It also provides an “all vehicle” travel-time estimate. Using the length provided for each roadway segment, it also is possible to transform the travel-time data into average speed or travel rate statistics for each TMC segment and time period.

If these different variables (i.e., car travel time, car speed, car travel rate, truck travel time, truck speed, and truck travel rate) are thought of as the third dimension of the above matrix structure, the data structure can be envisioned as a cube, as shown in Figure 4-4, where:

- The vertical axis of the cube is time (and date);
- The horizontal axis is the roadway segmentation (location) in the order in which a vehicle would drive a given road (the left most column being the first road segment traversed, followed by the second column, and continuing to additional columns); and
- The depth of the cube consists of different variables.

Table 4-1. Example data structure for use of NPMRDS: travel-time data by segment and time period.

	Segment Length					
Time Period	Road Segment 1	Road Segment 2	Road Segment 3	Road Segment 4	…	Road Segment n
Time 1						
Time 2						
Time 3						
Time 4						
Time 5						
Time 6						
…						
Time n						

Note: The travel-time matrices as above can be by car, truck, or "all vehicles" combined when using NPMRDS data.

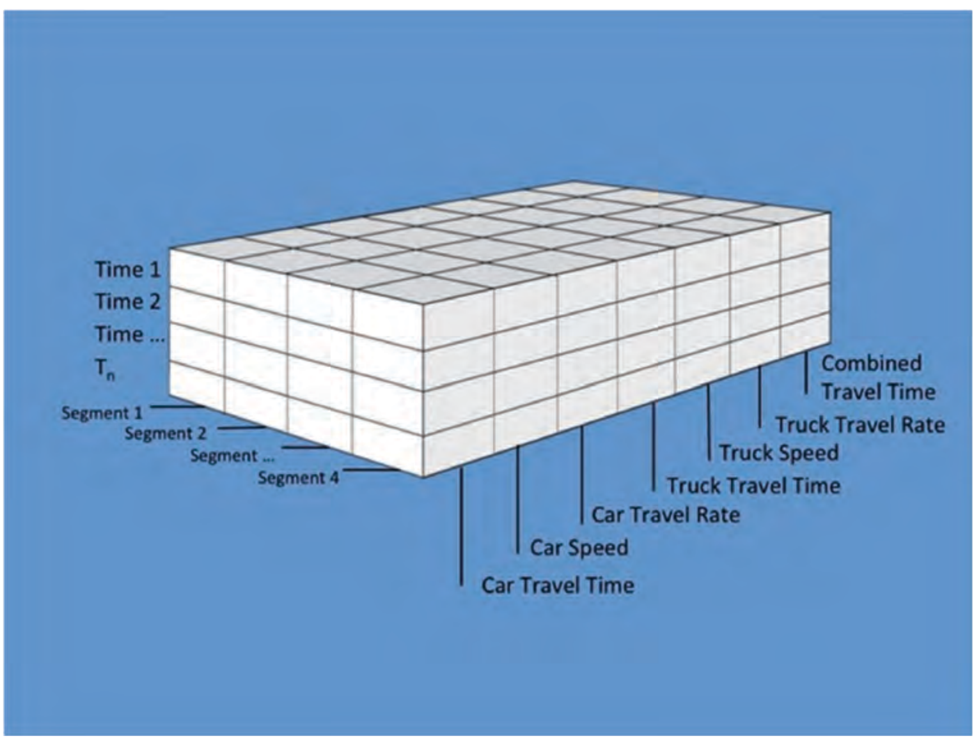


Figure 4-4. Example of preliminary cubic data structure.

A separate cube would exist for each direction of travel for a given roadway.

Each cell of the cube describes a specific aspect of what happens on that road segment at that time period. Additional variables (depth to the cube) to be added to this basic cubic structure are discussed later in this report. These additional variables describe other aspects of what occurs on each road segment during each time period. Previous published work by the Texas A&M Transportation Institute illustrated this concept as a "freight box," which is expandable to multiple freight modes, commodities and associated performance measures. (13) The term "cube" is used in this Guidebook.

4.3 Volume Data Organization

The HPMS submittal describes AADT volume on each roadway segment of the NHS, as well as the percentage of trucks using those roadway segments. As described in Section 3.2, there are challenges in using HPMS data in terms of accuracy, especially on lower classification roadways and in the need to develop truck volume data by time of day.

Another issue with using HPMS is the need to conflate the HPMS segmentation with the segmentation used by the speed data (e.g., NPMRDS). For example, the HPMS defines new segments differently than the TMC system used by the NPMRDS (and some data providers). As a result, analytical procedures must be developed to convert the HPMS data into traffic and truck volume estimates that apply to the road segments defined by the NPMRDS.

At a minimum this includes determining how to split HPMS traffic volumes by direction and time of day. The NPMRDS allows roadway performance to vary every 5 minutes. Ideally, truck and traffic volume data also should be available at this temporal level of disaggregation. However, converting the annual HPMS statistics describing average annual conditions to estimates of conditions for every 5 minutes of the year requires either considerable amounts of data or the application of a series of assumptions and transformations. Supplemental data available to the roadway agencies that are not included in the HPMS can be very useful in this process.

State DOTs and MPOs do not have detailed car and truck volume data at 5-minute aggregations for each TMC or HPMS segment. However, since the primary use for the 5-minute data at the statewide level is to compute delay to identify the major locations where delay is occurring, high precision in these 5-minute values is not necessary. What is needed at this point in the truck bottleneck identification process is a reasonable measure of roadway use that can be applied in conjunction with the probe travel time (speed) data to estimate the size of the observed traffic delays. At this stage in the analysis, the focus is the big picture of computing where major delays occur. Of less concern is the precision of those numbers. Therefore, making professionally reasonable, consistent assumptions is sufficient. For those locations selected for bottleneck mitigation, additional truck and traffic volume data should be collected to ensure the reliability of the engineering and operational designs that come from that work, but that detailed level of traffic volume accuracy required for engineering design is not necessary for the majority of miles of roadway in the NHS simply for bottleneck identification and initial quantification.

The most straightforward approach is to assume a time-of-day traffic pattern (preferably a time-of-day pattern that changes by day of week)

Case Study Highlight

Each year the Texas A&M Transportation Institute develops a "100 Most Congested Roadways" list for the Texas Department of Transportation (TxDOT). Researchers use probe vehicle speeds and volume data from TxDOT's Roadway Inventory. A number of performance measures are produced, including total delay per mile for ranking the statewide reporting segments. Reporting segments are also ranked by truck delay per mile. Elements of this case study are highlighted throughout this Guidebook. More details are provided in Appendix B about the study, and Appendix D includes detailed calculation procedures, including the use of time-of-day volume profiles used to match with the 15-minute speed data.

and apply that pattern to the AADT and truck percentage estimates submitted under HPMS. See the Texas A&M Transportation Institute case study highlight above for reference to the appropriate appendices for calculation procedures and an application of these methods.

A more complex (and better, where the data are available) approach is for the highway agency to develop and apply separate time-of-day patterns for trucks and cars, as well as adjustments for day of week and month of year, to the average annual daily volume and truck percentage estimates from HPMS and/or the statewide roadway inventory database, which commonly has these data elements. These adjustment factors are ideally developed so that they apply to roadways on the basis of the function of each road, that road's location in the state, the rural/urban nature of the traffic on that road, and the observed traffic patterns within that state.

It should also be noted that theoretically, probe data can also be used to estimate truck volumes. This can be done by estimating the fraction of trucks that are included in the truck probe data set and expanding the number of "pings" at a particular location to a full estimate of truck counts based on this estimated fraction. This technique has not yet been applied to any notable count databases, but has been applied only to specific truck count locations.

4.3.1 Use of Paired Speed-Volume Observations from Detector Data

Where permanent, continuous traffic and vehicle classification counters are located on or close to the TMC segments being studied, data from those devices should be used to develop even better traffic and truck volume estimates for nearby analysis segments.

For example, many public transportation agencies have roadway ITS detectors to monitor traffic conditions and operate the transportation system. The benefit of these detectors is that they typically can provide very disaggregate data (lane-by-lane, minute-by-minute) for a specific location. If that location is the specific location for which a truck bottleneck is of interest, the analyst benefits from having very good speed and volume information for analysis and decision making. These data are sometimes called "paired speed-volume observations" because the speed and volume data are collected and available over the same time period. With ITS detectors, vehicle classification data is typically available based on vehicle length. Conversion factors are needed to estimate truck volumes and classifications based on vehicle length data.

For truck bottleneck analysis (and prioritization), it is preferred to have the "paired speed-volume observations" occur over a representative time period for the locations of interest. This ensures that they will not rank artificially higher (if measured during a highly congested month/season) or artificially lower (if measured during a relatively low-congestion month/season). Adjustment factors for factor groups and/or representative sites to the data collection site can aid in selection of the "representative" time period to target for analysis.

4.3.2 Assigning Short-Term Volume Count to Continuous Travel-Time Data

Another common data scenario is when traffic volumes are available from a short-term volume count (e.g., 48 hours) and continuous travel-time data are available from a commercial source. Continuous means that the travel-time data are available throughout the year (e.g., for each 5-minute period such as the NPMRDS). A short-term volume count typically implies that data are obtained by road tubes or some other means.

As discussed, the application here is summarizing annual bottleneck statistics to prioritize truck bottleneck areas. In this case, there is a need to "adjust" the short-term truck volume count to the same granularity of the travel-time data, which are available throughout the year in this example. The short-term volume count must be adjusted seasonally (hour of day, day of week, and month of year).

The following procedure from the AASHTO *Guidelines for Traffic Data Programs* can be used to convert a short-term volume count (with at least 24 hours of data) into an estimate of AADT. (14)

1. Summarize the count as a set of hourly counts;
2. Divide each hourly count by the appropriate seasonal traffic ratio (or multiply by the appropriate seasonal traffic factors); and
3. For each hour of the day, average the results of Step 2, producing 24 hourly averages and then sum the 24 hourly averages to produce estimate AADT.

This procedure assumes traffic factors are available from continuous monitoring sites that are the reference site for the segment of interest. Traffic volume by vehicle class (e.g., single-unit and combination trucks) is estimated using a similar procedure where the factors used in Step 2 are those developed by vehicle classes of interest. More details about this procedure are available elsewhere. (15, 16)

4.4 Select Roadway Segmentation

A key element to successful truck bottleneck analysis is the determination of the appropriate segmentation of the roadway network for the desired analyses. A roadway "analysis segment" is made up of multiple smaller segments. These smaller segments could be TMCs, roadway inventory segments, or some other spatial determination. To assess the regional nature of truck bottlenecks in an urban area, it is desirable to combine short adjacent segments of the roadway network that have similar congestion patterns. By combining short but similar roadway segments, one can identify "big-picture" urban congestion patterns and the most congested locations in the region. When looking at very detailed congestion data on short segments, one can sometimes miss the bigger picture. A more focused, follow-up analysis of the most congested locations will likely analyze these shorter segments to better understand the specific causes of congestion and possible mitigation strategies.

Therefore, longer analysis segments (composed of short, adjacent segments) are recommended for the purposes of regional congestion reporting and identifying potential truck bottleneck locations. Traffic levels, congestion patterns, and traffic operation are relatively consistent along these congestion reporting segments. A defined segment should not include a mix of free-flowing traffic and congested traffic.

. . . longer analysis segments (composed of short, adjacent segments) are recommended for the purposes of regional congestion reporting and identifying potential truck bottleneck locations.

Ultimately, the use and context of the congestion measures are the key determining factors in the definition of reporting segments. For example, a statewide congestion analysis geared to identifying most congested roadways and truck bottlenecks will likely have longer reporting segments than an arterial street facility-based analysis that is geared toward identifying most congested intersections.

Table 4-2 provides key steps for roadway segmentation appropriate for truck bottleneck analyses in urban areas. Additional information can be found in research on the topic. (17)

4.5 Create Truck Bottleneck Data Analysis Structure

Now that there is a basic understanding of where speed and volume data sources originate, the discussion will return to the cube structure introduced in Section 4.2. Not only traffic speed, travel time, and volume data need to be incorporated into the cube-shaped data analysis

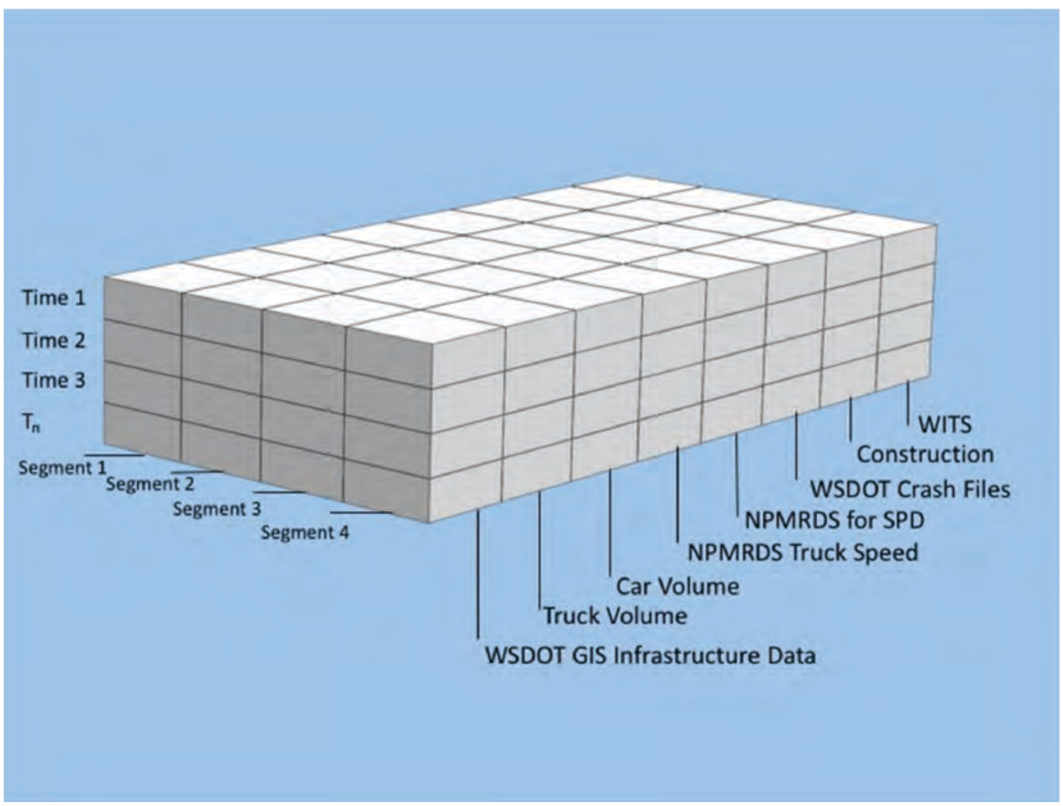
Table 4-2. Key Steps in roadway segmentation for different roadways/areas.

Roadway/Area Type	Key Steps for Roadway Segmentation
All Roadways	• Short segments should be combined into a reporting segment where traffic levels and resulting congestion patterns are relatively consistent. • Reporting segments are almost always defined uniquely for each direction of travel. The possible exceptions are where (1) both travel directions have similar congestion patterns or (2) the scale (e.g., statewide or multiregion) of the analysis is conducive to more aggregate reporting.
Freeways and Access Controlled Highways	• In most cases, a freeway reporting segment will include multiple entrance and exit ramps. • Freeway segment endpoints are typically entrance or exit ramps from/to another freeway or major cross street, as this is where roadway characteristics, traffic levels, and congestion patterns are most likely to change. • Freeway segments in dense, built-up areas typically range from 3 to 5 miles in length. These sections also are likely to have more frequent ramp access points. • Freeway segments in less dense, suburban or exurban areas typically range from 5 to 10 miles in length. These sections are likely to have less frequent ramp access.
Arterial Streets	• In most cases, an arterial street segment will include multiple signalized intersections. • Arterial street segment endpoints are typically major cross streets, as this is where roadway characteristics, traffic levels, and congestion patterns are most likely to change. • Arterial street segments in dense, built-up areas typically range from 1 to 3 miles in length. These sections also are likely to have higher levels of intersection density. • Arterial street segments in less dense, suburban, or exurban areas typically range from 3 to 5 miles in length. These sections are likely to have lower levels of intersection density.
Rural Areas	• Longer reporting segmentation is appropriate (e.g., intercity).

structure. All data that describe what is happening on the roadway needs to be incorporated into that structure. Thus, the next step in the data organization effort involves expanding the data stored within the cube structure to include data on the events that affect roadway performance. By obtaining data on these activities and roadway features and placing them within the data analysis cube structure, it is possible to develop automated procedures that allow agencies to not only readily compute the presence, size, and frequency of travel speed bottlenecks, but also to obtain good insight into the causes of those bottlenecks. Under this approach, the cube structure shown in Figure 4-4 expands to include these additional variables, as illustrated in Figure 4-5.

These additional data sets also need to be conflated—that is, matched by time and location to the volume and speed/travel-time data—as described in Section 3.3 for volume and speed data. For some data sets—such as the locations of low-height bridges—this is a fairly simple task. For other data sets, this can be a more difficult task. For example, the fact that data show snowfall at a given airport (a location for which weather data can be readily obtained) does not mean that the weather conditions at that airport accurately reflect the weather conditions on a given roadway segment 20 miles away.

This weather example also highlights the fact that it can be difficult to determine exactly what data should be placed in the data analysis cube. Continuing the weather example, although it is helpful to know about snowfall at a given time and location, a better statistic would be the amount of snow actually on that pavement section at that time. This is important because if 2 inches of snow have fallen, that snow may well linger on the pavement long after the snow has stopped falling, continuing to cause traffic to slow.



Note: NPMRDS is noted in this example, but any travel time (or speed) data source could be used.

Figure 4-5. Schematic of data analysis structure with congestion causation factors.

Another example is crash data. It is often relatively easy to assign crash data to a specific road segment and time period. However, the cube analysis structure will be more useful if additional information about that crash is available. For example, data could be added to the cube to describe:

- The duration of the crash at the scene,
- Whether the crash blocked travel lanes or occurred on the side of the roads, and
- Whether injuries or fatalities occurred.

Many of these variables can be obtained from crash records. Additional data on roadway events can be obtained from incident response databases. Linking and cross-referencing these different databases and placing the appropriate data from them into the cubic data analysis structure are substantial data management tasks.

Chapter 6 in this Guidebook illustrates how these causation variables can be used to identify the factors that influence the formation of congestion and delay at each bottleneck location. Note that at the desktop level of analysis, it is only possible to identify potential causes of congestion. It is not possible to directly identify causation, especially because many factors work in concert to cause bottlenecks. That is, rain, a crash, and high volumes may all be present, complicating the task of assigning specific proportions of the observed delay to any one causation factor.

Finally, it is important to once again recognize that "perfect data" are not necessary to gain considerable benefit from this desktop analysis process. For example, having access to crash data but not to incident response data will still allow an agency to determine whether vehicle crashes are likely contributing substantially to delay at a particular location. The better the data, the more robust and accurate the outputs from the initial desktop bottleneck analysis process; but even with limited data sets, considerable insight into bottlenecks can be gained through the use of the cube data structure. Additional insight can be obtained at chosen bottleneck locations by performing detailed, site-specific analyses.

> It is important to . . . recognize that "perfect data" are not necessary to gain considerable benefit from this desktop analysis process.

4.6 Data Quality Control

Prior to data analysis, it is important that the analyst perform quality control of the datasets to ensure certain specifications are met. The quality control process typically includes one or more of the following actions (18):

1. Reviewing the traffic data format and basic internal consistency;
2. Comparing traffic data values to specified validation criteria;
3. Marking or flagging traffic data values that do not meet the validation criteria;
4. Reviewing marked or flagged traffic data values for final resolution; and
5. Imputing marked, flagged, or missing traffic data values with "best estimates" (while still retaining original data values and labeling imputed values as estimates).

The AASHTO *Guidelines for Traffic Data Programs* (19) describes these quality control processes in more detail and the interested reader is referred there for further information. Of particular interest are the definitions for traffic data quality measures, including:

- Accuracy,
- Completeness (also referred to as data availability),
- Validity,
- Timeliness,
- Coverage, and
- Accessibility (also referred to as usability).

More specifically, AASHTO spells out validation criteria for vehicle count, classification, and weight data from detector sources.

In some cases, quality control by visual inspection is valuable. Visual inspection is helpful when it is not easy to automate the quality control with business rules. Sometimes the human eye is more adept at identifying reasonableness in data-time series, for example, graphing speed or volume plots by time for a variety of days in the month on the same graphic or looking at lane-by-lane speed and volume relationships on the same graph. Visual inspection of graphics like this allow the analyst to identify places where more “drill-down” analyses may be warranted if something suspicious is found. More examples are documented elsewhere. (20)

As previously discussed, probe speed data are a cost-effective source for systemwide data collection. With the increased and widespread use of probe speed data for truck bottleneck analyses, quality control of these data sources is of particular interest. Appendix C of this Guidebook uses the FHWA NPMRDS as an example to illustrate quality control considerations for a probe speed dataset.

CHAPTER 5

Identify and Quantify Truck Freight Bottlenecks

This chapter describes how to conduct analyses to identify and quantify truck bottlenecks. The first three subsections describe how to conduct this analysis for travel speed-based delay with the final subsection describing how to conduct this analysis for process-based delay. While many of the individual steps overlap, these delay calculations can be computed independently, in series, or in parallel. In most jurisdictions, delay will be larger for travel speed-based delay relative to process-based delay. However, calculating process-based delays will be important in certain circumstances where roadway geometric characteristics and operations are perceived to impede truck mobility.

5.1 Identifying Travel Speed-Based Truck Bottlenecks

The delay computations serve as the basis for the primary desktop analyses that should be performed to identify freight bottlenecks. The basic concept of the "desktop analysis" is that the state highway agency or MPO is able to perform an automated analysis that identifies the most significant bottlenecks across the state or region. The advantage of such an analysis is that it can be done relatively efficiently for a wide variety of locations. The disadvantage is that it requires data from across that wide range of locations. Therefore, such an analysis cannot account for detailed, site-specific data that can be collected only at individual locations (e.g., approach volumes and turning movements by lane group at a signal). Essentially, the desktop analysis takes the data available statewide (or regionwide) and computes the variety of statistics mentioned above. Table 5-1 summarizes the statistics that should be computed and which will be used to identify travel speed-related freight bottlenecks. Further information on recommended performance measures, including cost calculations, is discussed in Appendix D.

All of these statistics also should be examined within the context of:

- The time of day,
- The day of week, and
- The time of year.

For example, just the total delay for a given roadway segment is not the only interest. Of interest also is:

- The size and proportion of delays that occur on weekdays versus weekends;
- Whether delays occur only during the a.m. or p.m. peak period or throughout the day;

Examples of Bottleneck Identification, Quantification, and Ranking

- Virginia's Statewide Multimodal Freight Study, Phase I.
- Washington Department of Transportation Freight Mobility Plan.
- Using GPS Truck Data to Identify and Rank Bottlenecks in Washington State.
- I-95 Corridor Coalition: Bottleneck Performance in the I-95 Corridor.
- Columbus-Phoenix City MPO Congestion Management Process: 2007 Update.
- Identifying, Anticipating and Mitigating Freight Bottlenecks on Alabama Intersections.

Table 5-1. Measures recommended for bottleneck identification and quantification.

Measure	Short Description
Total Delay per segment	Vehicle-hours or person-hours per segment
Total Delay per Mile per Segment	Vehicle-hours or person-hours per mile of segment (which normalizes segments of different length when comparing across segments of varied length)
Hours of Delay per Truck	Vehicle-hours or person-hours of delay normalized by the number of trucks (typically reported weekly or yearly)
Frequency of Congestion per Segment	How often time intervals of speed data are congested
Total number of Hours When Congestion Is Present	Time that congestion occurs; in its simplest form it is a sum of time intervals meeting a congestion threshold
TTI	A dimensionless ratio of the actual travel time to the uncongested travel time
PTI	A dimensionless ratio of the 95th percentile travel time to the uncongested travel time (reliability measure)
Planning-Time Index 80th (PTI80)	A dimensionless ratio of the 80th percentile travel time to the uncongested travel time (reliability measure)
Commuter Stress Index (CSI)	Same as TTI except for the peak direction rather than both peaks
Value of wasted time and fuel due to congestion for each segment	Computed as the difference in travel time and fuel use during congestion minus the travel time and fuel use during uncongested conditions and then multiplied by value of time and dollars per gallon of fuel to estimate costs

- Whether delays occur only during some times of the year (e.g., only during the summer) or throughout the year; and
- How these delays differ for trucks in comparison with all vehicles.

Understanding the temporal variation in the frequency of congestion formation is a major initial step in identifying and understanding freight bottlenecks, but it is just the start of the bottleneck analysis process.

> These detailed analyses can take into account key details about each study location (e.g., current local transportation improvement plans) that cannot be readily incorporated into an automated statewide analysis.

The basic outputs from the desktop analysis define the size and scope of the travel speed-based congestion bottleneck problem throughout the state or region. Starting from these results, the roadway agency can then select a subset of the identified bottleneck locations to perform more detailed analyses to examine the effectiveness of different approaches to mitigating those bottlenecks. These detailed analyses can take into account key details about each study location (e.g., current local transportation improvement plans) that cannot be readily incorporated into an automated statewide analysis.

This is very similar to the way that pavement management systems (PMSs) typically operate. PMSs typically estimate the size of the pavement deterioration problem, identify the locations most in need of repair, and provide crude cost estimates for making improvements to those deteriorating pavements. These estimates serve as useful planning information and as a means for prioritizing where more detailed analysis is needed. But additional, site-specific analysis is required to determine the "correct" engineering response for each deteriorated pavement section, as that correct response depends on a variety of factors outside of those included in the PMS. And because these detailed analyses require time and money, they are only performed for a limited subset of locations, which are selected in large part on the basis of the prioritization achieved with the initial outputs from the PMS.

Although the desktop system is designed to identify and quantify bottleneck locations throughout the state, the same process can be used for a much smaller geographic area—such as a corridor or region. The *Indiana Mobility Report* (129) analysis results shown in Figure 5-1 are an example of this type of desktop analysis performed for a specific corridor. Figure 5-1 shows that the largest congestion location on I-65 occurs between mileposts 0 and 2 (identified with a "d" in Figure 5-1) and that congestion at that location is far worse from September through December than during the rest of the year. Additional bottlenecks also are apparent near mileposts 113 (location "c"), 139 (location "b"), 260 and 262 (location "a"). These four locations are obvious places where additional, site-specific analysis would be performed to better understand the causes of that congestion and consequently the best strategies for mitigating that congestion.

5.2 Options for Computing Travel Speed-Based Delay

The key statistic that will be used to identify truck travel speed bottlenecks is the amount of delay trucks face on the defined road segments. The definition of delay is "the difference between the amount of time it actually takes and the amount of time the trip should have taken, whenever a trip takes longer than it should." The "time a trip should take" also is called the "threshold" travel time, and any time beyond this threshold incurs delay. [It is suggested that delay be defined in terms of speed (when average speed drops below a specific value), but the computation of delay is actually a measure of time—meaning that computed delay uses the travel-time statistic, not the corresponding speed statistic. Use of speed as the threshold definition allows easier comparison of performance across roadway segments of different lengths.]

Delay can be computed from the origin to the destination of a trip, or it can be computed for any given road segment, where the "trip time" is simply the time to traverse that road segment. These are values that can be computed from the NPMRDS and similar data sets.

To effectively identify and rank truck bottlenecks, it is necessary to consider both delay and the number of trucks (or other vehicles) that experience that delay. The primary performance metric used to identify truck bottlenecks is therefore computed as:

[1] Truck Delay = (Truck Travel Time Threshold − Actual Truck Travel Time) ∗ Truck Volume

Where:

- *Truck Volume* is the volume of trucks experiencing that actual travel time;
- *Truck Travel-Time threshold* is the travel time at which that roadway segment "should" operate to not generate delay for the delay metric being computed; and

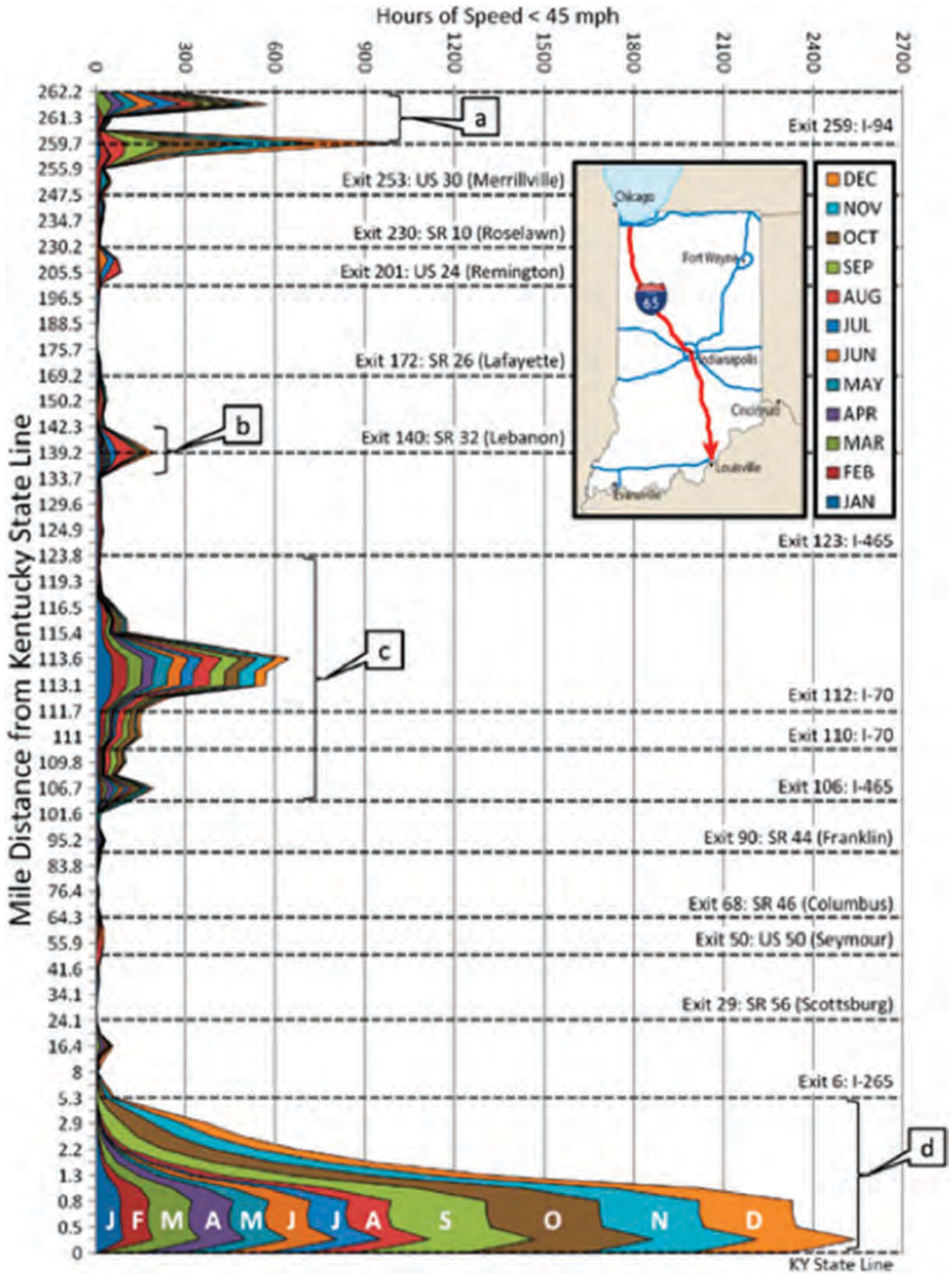


Figure 5-1. An example illustrating vehicle delay along a corridor—by month.

- *Actual Truck Travel Time* is the travel time experienced by trucks using that road segment for that time period.

Delay only occurs when formula [1] returns a positive value. A negative value means no delay is occurring, and it is discarded from further computations.

The computation of formula [1] can be accomplished by using the combined truck volume and NPMRDS data described above using the data structure shown in Figure 4-5.

Delay occurs whenever speed drops below a set threshold. A significant issue in identifying bottlenecks is defining the threshold at which delay occurs. The project team recommends computing delay for four different speed thresholds. The four recommended delay thresholds are as follows:

1. Delay from free-flow (uncongested) speeds (D_F):

$$[2]\ D_F = (\text{Truck Travel Time at Free-Flow}) - (\text{Actual Truck Travel Time})$$

2. Delay from the speed limit (D_S):

$$[3]\ D_S = (\text{Truck Travel Time at the Speed Limit}) - (\text{Actual Truck Travel Time})$$

3. Delay from the maximum efficiency (D_E):

$$[4]\ D_E = (\text{Truck Travel Time at the Speed that Maximizes Throughput}) - (\text{Actual Truck Travel Time})$$

4. Delay from Target Value (D_T):

$$[5]\ D_T = (\text{Travel time at a Defined Speed Set as a Target}) - (\text{Actual Truck Travel Time})$$

Each of these thresholds has a different meaning and answers a different analytical question. One or more of these measures may be selected to rank and prioritize improvements. The determination of which threshold to use is generally a function of four interrelated considerations:

1. Local Policy—ensuring measures can be communicated in terms applicable to policy goals. Consideration should also be given to compatibility of threshold across agencies and U.S.DOT guidance related to performance measures for truck movement.
2. Sensitivity analysis that ensures computed delay matches public perception (e.g., if a selected threshold of 45 mph results in very little congestion in a large urban area, there could be perception concerns).
3. The relationship between a "threshold" (extent of the delay problem that exists) and a "target" (extent of delay that is unacceptable to community/region/state).
4. Data availability (e.g., statewide probe dataset or roadway inventory).

Delay at free-flow indicates the amount of travel occurring at speeds below which vehicles desire to travel on each road. It takes into account the fact that trucks and other motorists do not always desire to travel at the speed limit even when conditions are good. (Sometimes free-flow speed exceeds the speed limit. Sometimes free-flow speeds are slower than the speed limit, depending on the terrain and geometric conditions of the roadway.) When speeds drop below "free-flow" they indicate conditions are causing motorists to drive more slowly than they prefer.

Delay computed using the speed limit as the threshold value indicates that road conditions have dropped below the speed at which the road is legally intended to operate. This definition is particularly useful for comparing delay across roads operated by different agencies that might have different congestion relief policies as it allows an "apples to apples" comparisons of different roads.

Delay from maximum efficiency recognizes that maximum vehicle throughput typically occurs at speeds slightly below the speed limit. Thus, maximum use of the facility occurs at this speed, and agencies often use operational controls to maintain vehicle speeds at this value when demand is very high to maximize use of the facility. This measure reports only that delay which represents a loss of roadway throughput efficiency.

Delay from a target value is specifically designed to allow an agency to analyze delay versus their adopted policies. Many agencies set specific operating targets for roads. In this last case *the adopted target performance value becomes the threshold used in the delay computation.* On very heavily congested urban freeways, these targets are often policy statements based on the level of improvements that are considered technically, financially, and politically feasible. The key is that "targets" are agency adopted values against which performance is intended to be compared locally. Consequently, they are very useful for reporting agency performance, and are readily compared across different agencies, but caution should be used in these comparisons because the target thresholds are likely to be very different.

The key is that "targets" are agency adopted values against which performance is intended to be compared locally.

When choosing between these four slightly different definitions of delay, the state or roadway agency should use whichever definition is appropriate for that specific analysis, report, or submission. Additional information about thresholds and target values, and their distinction, can be found elsewhere. (21) Table 5-2 summarizes the four delay thresholds including a brief description and some typical/specific examples of these thresholds in mobility analysis practice. Regarding the selection of the "correct" or "best" delay threshold, recent work sponsored by FHWA provides a recommendation as follows. (22) For congestion performance monitoring, the key outcome is the ability to track changes over time, that is, "are things better or worse?" If that is the case, any of the above strategies are reasonable if they are held constant over time. Reiterating the principle for performance measurement mentioned earlier—the best way to develop travel times is to measure them directly—the preference is an empirical approach using the data. If sufficient data are not present, then the speed limit is recommended.

In practice, it is important to be aware that the amount delay that is calculated is directly correlated to the reference speed that is used. The reference speed is the base speed below which all other speeds are considered to be delay. For example, if an Interstate reference speed is 55 miles per hour (mph), then a vehicle that travels at 54 mph would be considered to be a vehicle that experiences a minor level of delay.

The decision of which reference speed to use will be made separately by each transportation agency similar to how each agency will select the performance measures that work best for its organization. Use of a lower reference speed (e.g., 35 mph on an Interstate) implies that he agency is focused on extreme levels of congestion on the roadway of interest. Use of higher reference speeds is appropriate for agencies that are trying to identify congestion broadly across their roadway network of interest. Table 5-3 shows the general relationship between each of the four delay methods and the amount of calculated delay for a hypothetical 1-mile Interstate segment.

5.3 Sample Outputs of Truck Bottleneck Travel Speed-Based Delay Calculations

The cubic structure shown in Figure 4-5 allows simple computations of travel speed delay by location and time period for any given roadway for which volume and speed data are available. Delay data can then be summarized by roadway segment. For example, total annual truck delay by road segment can be computed for each segment of a corridor, and for each road segment in the NHS.

With the aid of a GIS, these statistics can be displayed on a map to highlight the key delay locations. An example of such a map is shown in Figure 5-1. This Figure shows the hours of delay on the x-axis and the miles from the Indiana-Kentucky state line on the y-axis. The multicolored peaks represent the amount of delay experienced on the corridor with each color representing a

Table 5-2. Characteristics of suggested delay thresholds.

Delay Threshold	Description	Typical/Specific Examples
Delay from Free-Flow (Uncongested) Speeds	Free-flow (uncongested) speed computed as: • Reference speed from private company data provider; • Percentage of free-flow speed (e.g., 85% of reference speed); and • Level of service (LOS)	TTI's *Urban Mobility Scorecard*[a] and Texas 100 Most Congested Roadways[b] List (use private company reference speeds)
Delay From the Speed Limit	Speed limit	Speed limit is a common element of statewide roadway inventories
Delay From the Optimum Efficiency	Based on the optimum throughput or capacity at the location Sometimes referred to as maximizing "productivity" of the roadway	WSDOT's Gray Notebook[c]
Delay from Target Value	Incorporates community vision and goals into the delay computation and fixes the threshold as the community target of what constitutes unacceptable delay	Minnesota DOT arterial work computed unacceptable delay as that which exceeded an established target value[d]

[a]Schrank, D, B. Eisele, T. Lomax, and J. Bak. *2015 Urban Mobility Scorecard,* August 2015. Available: http://mobility.tamu.edu/ums. (49)
[b]*Texas 100 Most Congested Roadways* List. Texas Department of Transportation. Available: http://www.txdot.gov/inside-txdot/projects/100-congested-roadways.html. Last Accessed: April 10, 2015. Note that the full ranking of all segments throughout Texas beyond the top 100 are available here: http://mobility.tamu.edu/most-congested-texas/. (23)
[c]*The Gray Notebook,* Washington State Department of Transportation, 2014, http://www.wsdot.wa.gov/Accountability/GrayNotebook/SubjectIndex.htm. (130)
[d]Developing Twin Cities Arterial Mobility Performance Measures Using GPS Speed Data, Minnesota DOT, May 2013, http://www.lrrb.org/media/reports/201314.pdf. (131)

Table 5-3. Relationship between delay method and amount of calculated delay for hypothetical one-mile Interstate segment.

Delay Method	Reference Speed (mph)	Actual Speed (mph)	Amount of Calculated Delay per Vehicle (Minutes)
From Free-Flow Speeds	70	35	0.86
From the Speed Limit	55	35	0.62
From the Optimum Efficiency	45	35	0.38
From Target Value	50	35	0.51

separate month in the year. The delay is shown to peak in four urban areas labeled from “a” to “d” where “a” represents delay in the Indiana portion of the Chicago (IL) metropolitan area, “b” represents delay in the Lebanon metropolitan area, “c” represents the delay in the Indianapolis metropolitan region, and “d” represents the delay in the Indiana portion of the Louisville (KY) metropolitan area. Delay also can be summarized in tabular formats, such as in Table 5-4, taken from the Texas 100 Most Congested Roadways List (23) produced by the Texas A&M Transportation Institute for the Texas DOT every year.

Delay estimates produced for individual segments also can be combined to examine patterns along entire corridors. Figure 5-2 shows another Figure from the Indiana Mobility Report. (24) It illustrates the trajectory of a vehicle through space and time. The x-axis represents ten segments along a route, while the y-axis represents the progression of time. The shaded rectangles show which segment a vehicle is on during different points in time. For example, between 5:05 and 5:10, the vehicle moved along Segments 2, 3, and 4. Between 5:10 and 5:15, the vehicle moved from Segments 4 and 5.

Indiana used its delay analysis to understand not just the total amount of delay by location on I-65, but when it occurs during the year. This allows the state to better understand the cause of the congestion and thus apply strategies to mitigate that congestion.

Because trucks have different travel patterns than cars, it is important to compute delay separately for cars and trucks, as well as for both cars and trucks combined. The relative importance of locations where delays occur will differ for cars versus trucks. That is, the ranking of delay locations for trucks (worst to best) will be different than the ranking for cars or the ranking for both cars and trucks combined. The topic of ranking bottleneck locations is discussed in more detail in the next chapter of this Guidebook.

Table 5-4. Example table from *Texas 100 Most Congested Roadways (23).*

2014 Rank	2014 Rank Truck	Roadway	From	To	County	Annual Hrs of Delay per Mile	Annual Hrs of Truck Delay per Mile	TCI	PTI	CSI	Annual Congestion Cost (Millions)	Truck Congestion Cost (Millions)
1	4	IH 610	IH 10/ US 90	IH 69/ US 59	Harris	1,184,702	70,579	2.43	8.70	3.20	$81.35	$17.12
2	1	IH 35	US 290 N	SH 71	Travis	950,795	116,251	2.54	10.00	3.33	$196.14	$72.12
3	2	US 59	IH 610	SH 288	Harris	777,146	72,937	2.01	9.54	2.12	$105.22	$32.15
4	11	US 75	IH 635	Woodall Rodgers Freeway	Dallas	719,128	47,205	1.72	7.29	2.02	$145.12	$33.74
5	5	IH 35E/ US 77	SH 183	IH 30	Dallas	708,365	70,187	1.96	7.63	2.46	$79.65	$25.25
6	8	US 59	IH 10/ US 90	SH 288	Harris	666,494	55,325	2.34	10.73	3.48	$50.26	$13.9
7	7	IH 635	IH 35E/ US 77	US 75	Dallas	615,132	61,099	1.68	9.83	2.03	$129.08	$41.86
8	6	IH 35W/ US 287	28th St/ SH 183	IH 30	Tarrant	606,750	65,782	2.17	11.68	2.59	$67.06	$22.84
9	14	IH 45	IH 610	IH 10/ US 90	Harris	535,229	35,570	1.63	7.50	1.95	$47.04	$11.08
10	10	IH 35E/ US 77	IH 635	SL 12 N	Dallas	535,025	48,827	1.89	10.16	2.18	$37.33	$11.33

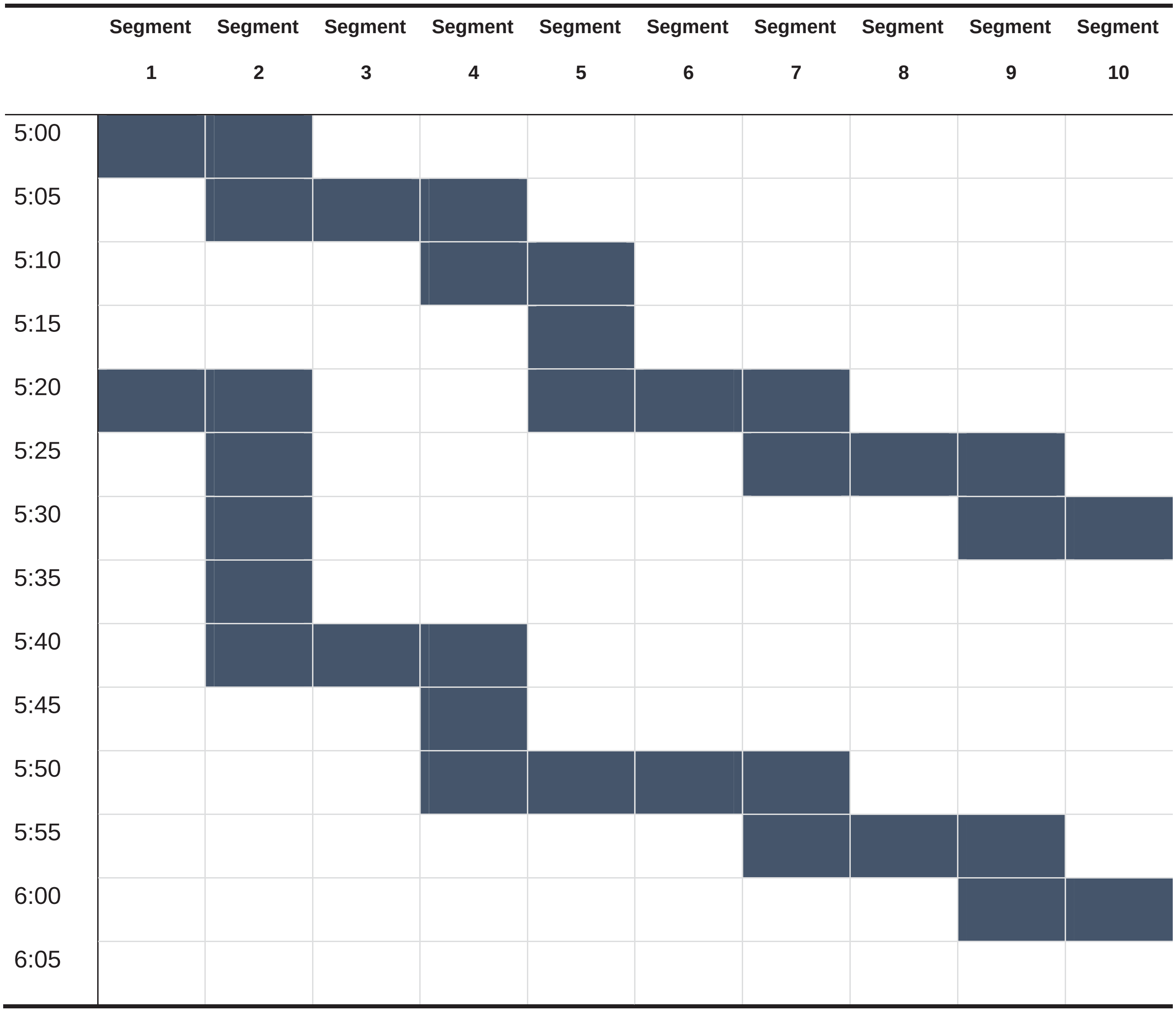


Figure 5-2. Travel-time matrix with trajectories shown.

The combined abilities to identify congestion locations on the basis of actual vehicle speeds and to compute and compare truck delays differently from passenger vehicle delays is one of the advantages of using the NPMRDS (or other datasets that provide truck-specific data) for congestion-related bottleneck identification.

Delay can be reported in many ways, and not simply in terms of truck-hours of delay versus passenger vehicle-hours of delay or total hours of delay. Each of the basic delay computations can be:

- Reported for each segment,
- Normalized to delay per mile for each segment, and
- Normalized to delay (hours) per vehicle or type of vehicle using a segment.

Segments also can be examined in terms of how reliable they are, that is, how frequently does delay occur? Does a road segment become congested only on rare occasions, or does it become congested routinely?

Each of these statistics can be computed from the basic cube data structure. Reporting and examining these different measures is part of evaluating the relative importance of a bottleneck, as well as determining what approaches should be applied to help mitigate that delay. This is because these different ways of reporting/describing delay provide insight into the conditions trucks actually experience and can be used to understand how each bottleneck affects the scheduling and cost of truck trips.

Delay also can be computed for trips that extend across more than one roadway segment. The travel-time/speed matrix structure shown in Figure 5-2 can be used to compute travel times for trips across multiple segments by using what is often called a "trajectory," "trace," or "stair step" algorithm (note that this is the method described in No. 4 of Section 4.4).

Each column in the Figure 5-2 matrix represents a road segment (e.g., TMC). The multi-segment trip traverses from Segment 1 to Segment 2 and on through Segment 10. The travel time in the first cell (5:00 for Segment S1) indicates when the "virtual vehicle" arrives in road Segment S2. The travel time in that segment at that arrival time is then used to compute when the virtual vehicle arrives in Segment 3. This process continues until the vehicle arrives at the final segment of the trip. In the schematic shown in Figure 5-2, the second trace (shown in blue) experiences significant congestion at Segment 2 relative to the first trace.

> For example, by tracing the route from a major manufacturing center to the major port in the state, it would be possible to not only understand the travel-time distribution that trucks making that trip experience, but also to identify the specific congestion points that truck trip passes through and the delays experienced in comparison to the overall time.

The total time for each trip can be determined for each virtual start time. These can then be aggregated to determine the mean travel time, the distribution of those travel times, and the reliability of that trip. These statistics can then be compared with the threshold or expected travel time for that trip, with the difference between the actual and threshold travel times defined as "delay." This type of analysis allows the roadway agency to determine the effects of location-specific delays on longer trips and the effects of those delays on the overall travel reliability of trucks.

A good way to summarize the effects of bottlenecks on truck travel is for state agencies to define key truck trips and then monitor the reliability of those trips over time. This allows the impacts of the specific points located in the bottleneck identification process to be expressed in terms of increased travel time and travel-time reliability for key freight movements. For example, by tracing the route from a major manufacturing center to the major port in the state, it would be possible to not only understand the travel-time distribution that trucks making that trip experience, but also to identify the specific congestion points that truck trip passes through and the delays experienced in comparison to the overall trip time.

> By computing a secondary path between the origin and destination, the analyst also can determine the resiliency and redundancy of that road network between those important freight destinations, as well as the costs that are imposed on trucks that use the secondary path.

It is also possible to compute alternative travel paths from the selected origin (the manufacturing center in the above example) and the destination for that freight movement (the port). By computing a secondary path between the origin and destination, the analyst also can determine the resiliency and redundancy of that road network between those important freight destinations, as well as the costs (travel-time differentials and changes in travel reliability) that are imposed on trucks that use the secondary path.

> [Process-based truck bottlenecks] force trucks to use longer, more circuitous paths than passenger cars would take if making that same trip, or they require trucks to carry less cargo than they would otherwise carry if not legally restricted from doing so.

5.4 Calculating Process-Based Delay

5.4.1 Overview of Process-Based Delay Categories

The second major category of causes of truck travel delay includes locations that either force trucks to use longer, more circuitous paths than passenger cars would take if making that same trip, or they require trucks to carry less cargo than they would otherwise carry if not legally restricted from doing so. Both situations force trucks to travel additional miles, increasing the cost of freight delivery as a result of both additional labor hours and additional mileage driven. In addition, higher TMT increases fuel use and produces negative environmental emissions.

Four subcategories of problem locations, defined below, are identified within this broader classification of process-based delays. Each subcategory is defined by the type of adjustment a trucking firm must employ in response to a restriction on normal truck operations. The four selected subcategories consist of restrictions that require:

- Rerouting;
- Making additional trips;
- Changing the time of day when trucks operate or the type of truck that may be used; and
- Trucks having to search or wait for loading zones, terminal access, or parking because those facilities are not available or suitable.

The first subcategory includes restrictions such as low bridge heights or weight restrictions imposed on both bridges and entire roadway segments that cause trucks otherwise operating within normal truck height and weight regulations to reroute to less than optimal routes because the direct route does not meet height or load standards. Also included in this subcategory are hazardous materials restrictions that cause trucks carrying specific, high-impact cargo to travel additional distances to avoid road segments from which those hazardous materials are prohibited.

The second subcategory includes restrictions that cause trucks to make additional trips. For example, in northern tier states, spring thaw load restrictions may be applied to roads for which there are no "alternative routes." As a result, more truck trips are needed to carry a given amount of cargo. Similarly, truck size (length) restrictions that limit otherwise legal trucks from using specific roads may require the use of smaller trucks, increasing freight costs and impacts (e.g., many urban areas limit both the size and weight of trucks operating on downtown streets, forcing delivery companies to off-load larger, long-haul trucks for the last-mile delivery process).

The third subcategory includes time-of-day restrictions. In this case, truck pick-ups and deliveries must be made in off-hours, increasing costs by decreasing a trucking firm's ability to cost-effectively distribute their labor and equipment resources.

The final subcategory includes trucks having to make inefficient movements such as circling a block, because the last-mile facilities (e.g., parking, load zones) are not suitable, lack capacity, or are poorly managed. It also includes node-based delay that occurs at locations such as port gates, border crossings, intermodal rail yards, weigh stations, and toll plazas.

The "cubic data structure" described in Section 4.2 and shown in Figure 4-4 is an effective tool for identifying the costs of many of these delays. However, it must be used in concert with additional information that describes the size of truck movements, the nature of those movements, and data on the locations and attributes of the specific truck restrictions being evaluated.

For example, using GIS software, the cube analysis structure can help compute travel times and travel-time reliability over alternative travel paths. However, the cube structure does not contain information on the origins and destinations for which alternative paths must be computed, nor does it contain information describing the size of those movements. Similarly, although the cube structure can be used to compute the travel time and reliability of making trips at different times of the day (e.g., typical business hours versus off-hours delivery

Case Study Highlight

WSDOT recently completed a Freight Mobility Plan. In this Plan, WSDOT identifies five types of bottlenecks with associated criteria thresholds, and how these bottleneck types impact freight movement. The five bottleneck types are slow speed, reliability, resiliency, restricted access for legal loads, and clearance restriction for over-height loads. This bottleneck classification covers both travel speed-based and process-based delay truck bottlenecks. More details are available in Appendix B.

. . . the travel speed-based delay methodology (Chapter 5) can provide insights to the "trip-based" analysis performed for process-based delay analysis, and vice-versa. If the data, methods, and means are readily available to conduct the "facility-based" analysis described, it is encouraged and often beneficial.

timeframes), nothing in the cube analysis structure describes the nontravel-time costs associated with moving trips to late-night hours.

Therefore, analysis of many process-based delays requires information and tools in addition to the cube data structure. It should be noted that the travel speed-based delay methodology can provide insights to the "trip-based" analysis performed for process-based delay analysis, and vice-versa. If the data, methods, and means are readily available to conduct the "facility-based" analysis described, it is encouraged and often beneficial.

5.4.2 Process-Based Truck Bottleneck Methodology

A key difference between the methodology for process-based truck bottlenecks and travel speed-based truck bottlenecks is that process-based truck bottlenecks require an understanding of impacted truck trips, given the truck restriction. Therefore, the analysis for process-based truck bottlenecks is sometimes referred to as a "trip-based" analysis in contrast to the "facility-based" analysis described earlier for travel speed-based truck bottlenecks.

Figure 5-3 shows a flowchart of these steps showing both the bottleneck determination work flow at left and associated data sources at right. The system creation portion of the process refers to the estimation of total delay in the system, while the system operation portion of the process refers to the allocation of this delay to various causes, locations, vehicle types, and time of day. The identification of truck bottlenecks occurs in the system creation process. The classification, evaluation, and mitigation of truck bottlenecks occur in the system operation portion of the process.

Case Study Highlight

Recent research sponsored by VDOT used "trip-based" performance measures and analyses. VDOT sponsored the research to evaluate system performance on the statewide Interstate system to demonstrate how systemwide mobility and reliability measures can be computed and how targets can be set. Private-sector data were obtained for each 15-minutes of the entire analysis year (2012) and paired with traffic volumes and roadway inventory data. The analysis employed a "trip-based" analysis by computing reliability measures as a function of the distribution of travel time trajectories (as described in Chapter 5) through the analysis segments. More details are available in Appendix B.

5.4.3 Identify Affected Truck Trips

There are two keys to understanding and quantifying the impacts of process-related truck bottlenecks. The first is understanding the truck restrictions that exist and where they are located. The second is understanding the costs those restrictions impose on trucking movements. Therefore, the first requirement is understanding what types of truck restrictions need to be tracked and then collecting data on where and when those restrictions occur.

While many techniques can be used to illustrate where these restrictions occur, incorporating the restrictions into the cubic data analysis structure allows the agency to take advantage of the same analytical computations available for the travel speed-based bottlenecks. In particular, it is possible to use GIS software to not only show where truck restrictions are physically located but also to compute travel times.

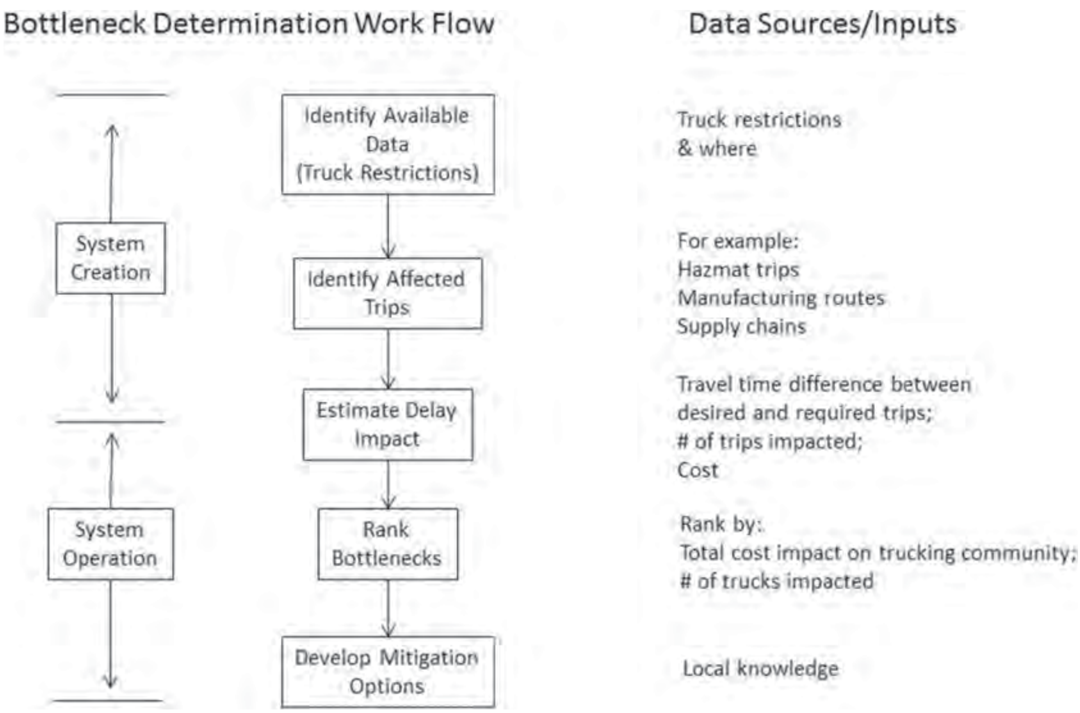


Figure 5-3. Process-based truck bottleneck identification and quantification methodology.

The discussion of desktop bottleneck analysis suggested that the state DOT identify key truck trips occurring in the state. For example, these can be from major manufacturing areas of the state to major ports, intermodal yards, or the state border on the Interstate connecting with major cities in neighboring states. For the analysis of truck restrictions, it is necessary to refine the identification of "key truck trips" to specifically include the types of truck trips that are affected by these restrictions.

For example, for hazardous materials shipments, there is a specific interest in the origins and destinations of hazardous materials shipments. For truck load restrictions, the interest is typically in specific commodities that move on the roads for which—and during the time periods when—load restrictions apply. It is also important to obtain an estimate of the number of these trips being made.

Using the same GIS that allows visualization of where truck restrictions are located, it is possible to compute travel paths for the truck trips that are affected by the various truck restrictions. Where these paths pass through the truck restrictions, this can now be visualized.

Case Study Highlight

An ongoing project for the Maryland State Highway Administration (SHA) is defining and implementing freight fluidity for Maryland to inform investments on the freight network. The project has developed a freight fluidity definition, trip-based calculation procedures for selected truck trips, and preliminary results. Future work will expand the methods to other modes, while investigating additional data sets for informing the process. More details are available in Appendix B on this project, and the calculation procedures are included in Appendix D.

5.4.4 Quantitatively Measure Delay Impact

The determination of the path through the restricted roadway is just the first step in estimating the cost of that restriction. For truck restrictions that actually prohibit that movement (e.g., a low-height bridge or a hazardous materials prohibition preventing a truck from using a given road segment), the GIS must be used to determine the best alternative travel path from the origin to the destination that does not include the restricted roadway segment.

Comparing the [desired and actual path travel times allows for] the direct computation of the time and distance penalty imposed on the trucking community.

Once alternative paths have been developed, the analyst can then compute the travel distances, the travel times, and the trip reliability measures for both paths—the "desired" path and the "actual" path required by the restriction. Comparing the two paths and the differences in travel-time distance allows the direct computation of the time and distance penalty imposed on the trucking community.

Multiplying the dollar costs associated with the added travel time and mileage by the number of trips produces the increased trucking cost for the longer path required by the truck restriction. A wide range of dollar costs can be considered depending on which cost components are included in the analysis. (25)

For a "simple" restriction such as a low-height bridge, it is only necessary to estimate the number of vehicles that exceed the height limit, compute the cost of the reroute necessary for those trucks, and multiply those two values. It is not really necessary to understand the full trip paths of those trucks, unless the route is so long that many truck trips have to use entirely different roads to avoid the low-height bridge. In that case, it is necessary to understand the length of each of those alternative paths to estimate the trucking cost imposed by the low-height bridge.

For truck weight restrictions, trucking firms may be able to take one of two actions, depending on the location of the road restriction relative to the O/D of the affected trips. Trucks may react to load restrictions by continuing to use the weight-restricted roads while carrying lighter loads. Alternatively, they may take an alternative path with a full load. (This is possible only if such a path exists. That may not be possible if the only road leading to either the origin or the destination is one of the weight-restricted roads.) Discussing actual behavior with the trucking firms affected by the weight restriction will indicate which behavior to model for specific trips.

In either case, it is again a fairly simple matter to compute the trucking cost of the weight restriction. The cost is simply the added mileage and travel time required to make either longer or more trips as a result of the weight restrictions. The difficult part of this computation is determining the number of trips affected by the weight restriction. Note that analysis of OS/OW permitted loads is not addressed by this approach, but can be analyzed using similar techniques.

CHAPTER 6

Classifying and Evaluating Truck Freight Bottlenecks

6.1 Overview of Potential Causes of Truck Bottlenecks

This chapter describes the process of identifying the causes of the bottlenecks that were identified using the methodology described in Chapter 5. These causes can include recurring congestion, weather, crashes, construction, and a wide variety of other causative factors. In most cases, these causes can be identified based on a quantitative analysis conducted at a desktop using available data. In other cases, this needs to be combined with field analysis to refine the understanding of the bottleneck. Similarly, a combined desktop and field analysis can be used to rank truck bottlenecks.

Travel speed-based delay for all vehicles has been studied extensively by several research projects. Figure 6-1 shows a distribution of the causes of travel speed-based delay for all vehicles on all types of roadways from previous research conducted by FHWA. Recurring congestion, traffic incidents, and weather were found to be responsible for 90 percent of all vehicle delay. Due to definitional differences, for this previous research the causal category "recurring congestion" was referred to simply as "bottlenecks."

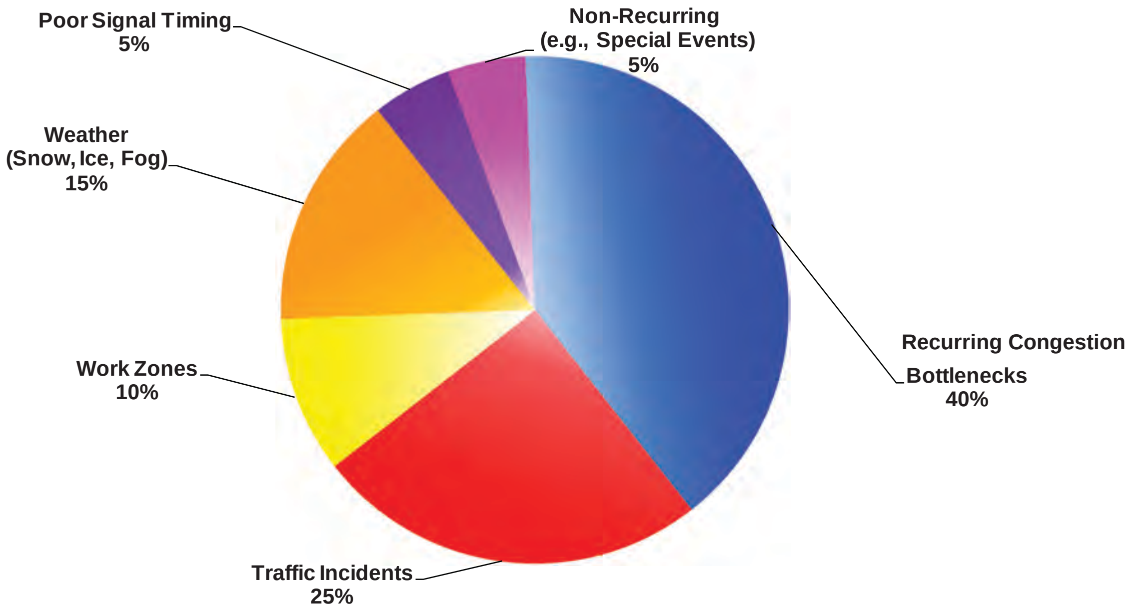
The increased use of vehicle probe data has made the calculation of truck-specific travel speed-based delay more accurate and similar distributions of delay can now be developed for truck activity. This chapter is structured to examine this through the following sections:

- **Section 6.1.** Overview of Potential Causes of Truck Bottlenecks,
- **Section 6.2.** Identify Causes of Travel Speed-Based Truck Bottlenecks,
- **Section 6.3.** Ranking Travel Speed-Based Bottlenecks,
- **Section 6.4.** Identify Causes and Rank Process-Based Truck Bottlenecks, and
- **Section 6.5.** Conduct Field Analysis to Refine Bottleneck Understanding.

6.2 Identify Causes of Travel Speed-Based Truck Bottlenecks

Identifying the potential causes of truck bottlenecks is a process of overlaying the timing of bottlenecks with the timing of other activities that have the potential to cause the bottleneck. For example, if a bottleneck is identified between 11:00 a.m. and 11:30 a.m. on a Monday morning at a specific location, then information on truck and auto volumes, crashes, weather, and construction should be examined during the same time period to determine which of these factors had the potential to have contributed to the bottleneck.

Additional factors should also be considered depending on the specific type of location where the bottleneck occurred. For example, for locations near port terminals, additional factors can



Source: FHWA Office of Operations, Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation, December 2013.

Figure 6-1. Causes of travel speed based bottlenecks for all vehicles.

include operating hours of gates. For locations on arterials, turning movement counts at intersections may need to be examined.

Another consideration is often the need to maintain a corridor approach in identifying causes of bottlenecks. In some cases, relieving a bottleneck at one location shifts the bottleneck to a downstream location without providing broader system benefits. This is particularly possible when considering efforts to alleviate bottlenecks based on congestion. Alternatively, bottleneck relief may also result in higher speeds which exacerbate road geometry or safety issues along a corridor. To estimate systemwide impacts of bottleneck mitigation efforts, typically a travel demand model is needed. Additionally, outreach to roadway users can be used to determine how relieving specific point bottlenecks will impact other elements of the transportation network.

6.2.1 Example of Analysis to Identify Potential Causes

This subsection provides a simplified example of how to calculate the causes of truck bottlenecks. Specifically, the example highlights how to determine the amount of truck delay caused by a vehicle crash. The example is conducted using three hypothetical segments (Segment 1, 2, and 3) over a 1-hour period that is divided into 6 10-minute time intervals. The three segments are continuous segments along a single route in a single direction such that Segment 3 follows Segment 2 and such that Segment 2 follows Segment 1. All segments are assumed to be 1-mile long.

Table 6-1 shows truck speeds in miles per hour by time interval for each of the three road segments and six time periods. The reference speed for each of the segments is assumed to be 60 mph. Any time intervals showing speeds that are recorded below 60 mph are assumed to be congested. The congested time intervals are highlighted in yellow for each time segment.

Table 6-2 shows truck volumes for those same road segments and time periods. These volumes are typically available as estimates through state DOT vehicle classification counting programs. Truck volumes can also be developed through special counts collected specifically for the purposes of bottleneck analysis.

Table 6-1. Truck speeds on three road segments by time interval.

Time Intervals	Segment 1 Speeds (mph)	Segment 2 Speeds (mph)	Segment 3 Speeds (mph)
11:00 a.m. – 11:10 a.m.	60	60	40
11:10 a.m. – 11:20 a.m.	60	40	60
11:20 a.m. – 11:30 a.m.	60	20	60
11:30 a.m. – 11:40 a.m.	60	20	60
11:40 a.m. – 11:50 a.m.	60	40	40
11:50 a.m. – 12:00 p.m.	45	60	30

Table 6-3 shows the calculation of delay along each of the three segments for the six time intervals. This is calculated by using the difference between the time taken to travel the segment using the reference speed and the time taken to travel the segment during the actual 1-hour period. This is calculated separately for each 10-minute interval. The travel times are calculated as the distance divided by the travel speed.

Table 6-4 shows the timing of the crash that occurs on the roadway. Specifically, it shows that a crash occurred on Segment 2 between 11:10 a.m. and 11:20 a.m. This crash blocked a lane of traffic which was cleared between 11:30 a.m. and 11:40 a.m. with traffic returning to normal speeds by 11:50 a.m. Information on crashes is available in state crash databases. Information on incident clearance times is sometimes maintained by state DOTs. However, this data is stored at different levels of detail in different organizations. In some instances, it may need to be estimated based on the time it takes for speeds to return to the reference speed or clearance time of other similar incidents. This is discussed in greater detail in Chapter 3.

Table 6-5 illustrates which of the delays shown in Table 6-3 has been "influenced" by the known crash. Not all of the delay that was calculated can be attributed to the crash. In particular, delay that occurred on Segment 1 which is upstream from the crash cannot be attributed to the

Table 6-2. Truck volumes on three road segments by time interval.

Time Intervals	Segment 1 Truck Volumes	Segment 2 Truck Volumes	Segment 3 Truck Volumes
11:00 a.m. – 11:10 a.m.	100	90	85
11:10 a.m. – 11:20 a.m.	110	100	95
11:20 a.m. – 11:30 a.m.	130	120	115
11:30 a.m. – 11:40 a.m.	125	105	95
11:40 a.m. – 11:50 a.m.	110	105	95
11:50 a.m. – 12:00 p.m.	90	85	80
Total Truck Volume	**665**	**605**	**565**

Table 6-3. Calculation of truck delay hours on three road segments by time interval.

Time Intervals	Segment 1 Truck Delay	Segment 2 Truck Delay	Segment 3 Truck Delay	Total Truck Delay
11:00 a.m. – 11:10 a.m.	0.0	0.0	0.7	0.7
11:10 a.m. – 11:20 a.m.	0.0	0.8	0.0	0.8
11:20 a.m. – 11:30 a.m.	0.0	4.0	0.0	4.0
11:30 a.m. – 11:40 a.m.	0.0	3.5	0.0	3.5
11:40 a.m. – 11:50 a.m.	0.0	0.9	0.8	1.7
11:50 a.m. – 12:00 p.m.	0.5	0.0	1.3	1.8
Total Truck-Hours of Delay	**0.5**	**9.2**	**2.8**	**12.5**

Table 6-4. Timing of vehicle crash and incident clearance.

Time Intervals	Segment 1 Crashes	Segment 2 Crashes	Segment 3 Crashes
11:00 a.m. – 11:10 a.m.	–	–	–
11:10 a.m. – 11:20 a.m.	–	Crash Occurs	–
11:20 a.m. – 11:30 a.m.	–	Lane Blocked	–
11:30 a.m. – 11:40 a.m.	–	Crash Cleared	–
11:40 a.m. – 11:50 a.m.	–	Scene Clear	–
11:50 a.m. – 12:00 p.m.	–	–	–

Table 6-5. Truck-hours of delay "influenced" by the crash.

Time Intervals	Segment 1 Delay Influenced by Crash	Segment 2 Delay Influenced by Crash	Segment 3 Delay Influenced by Crash	Total Delay Influenced by Crash
11:00 a.m. – 11:10 a.m.	0.0	0.0	0.0	0.0
11:10 a.m. – 11:20 a.m.	0.0	0.8	0.0	0.8
11:20 a.m. – 11:30 a.m.	0.0	4.0	0.0	4.0
11:30 a.m. – 11:40 a.m.	0.0	3.5	0.0	3.5
11:40 a.m. – 11:50 a.m.	0.0	0.9	0.8	1.7
11:50 a.m. – 12:00 p.m.	0.0	0.0	1.3	1.3
Total Truck-Hours of Delay	**0.0**	**9.2**	**2.1**	**11.3**

crash. Additionally, delay that occurs in time periods before the crash occurred cannot be attributed to the crash. The total delay attributable to the crash is 11.3 truck-hours of delay which is lower than the total 12.5 hours of delay that was calculated in Table 6-3. The delay statistics computed in Table 6-5 can then be aggregated to estimate total delay in each segment, or total delay in specific time periods, or delay in some combination of segments (e.g., a defined urban corridor or urban area) for defined time periods (e.g., the a.m. peak period).

The summary values shown in Table 6-5 also can be aggregated on the basis of whether specific causation variables were present. For example, in Table 6-5, of 11.3 observed vehicle-hours of delay, 8.3 hours occurred when a crash was present in Segment 2 (Time Periods 11:10–11:20, 11:20–11;30, and 11:30–11:40. Consequently, just over 66 percent of the delay occurred when a crash was present. This does not mean that crashes "caused" 66 percent of all delay in this example, but it does suggest that crashes might be a significant contributor to freight delays observed at this location.

Additional desktop analysis can be done to explore these relationships further. For example, data for these segments on other days at these same times could be analyzed to compare the amount of delay normally present without a crash. The number and duration of crashes occurring along this stretch of roadway also could be computed and reviewed.

As mentioned earlier, more than one variable is often present when congestion occurs. For example, Table 6-6 shows when heavy rain was influencing the congestion measured in Table 6-2. Some of that rain occurred at the same time that a crash was present (Time Periods 11:20–11:30 and 11:30–11:40). Table 6-7 updates the "influence" characterization. Time periods and segments influenced only by rain are colored light blue. Time periods influenced only by the crash are shaded yellow. Time periods influenced by both factors are shaded a light orange.

If the truck-hours of delay within each of these categories is aggregated and any delay associated with a specific influencing factor is assigned to that factor, then the total delay is computed as follows:

- **Crash –** 8.3 truck-hours (0.8 + 4.0 + 3.5) (influences up to 66.4 percent of all delay);
- **Rain –** 10.5 truck-hours (4.0 + 3.5 + 0.9 + 0.8 + 1.3) (influences up to 83.7 percent of all delay);
- **No Cause –** 12.1 truck-hours (5.0 + 7.1) (9.6 percent of all delay has no "other cause" identified except volume); and
- **Total Delay –** 12.5 truck-hours.

If the individual delays associated with each factor are simply added, the total will exceed the actual total delay (20.0 truck-hours versus 12.5 truck-hours). However, the relative size of the

Table 6-6. Timing of weather incidents.

Time Intervals	Segment 1 Weather	Segment 2 Weather	Segment 3 Weather
11:00 a.m. – 11:10 a.m.	Sunny	Sunny	Sunny
11:10 a.m. – 11:20 a.m.	Sunny	Sunny	Sunny
11:20 a.m. – 11:30 a.m.	Sunny	Rain	Rain
11:30 a.m. – 11:40 a.m.	Sunny	Rain	Rain
11:40 a.m. – 11:50 a.m.	Sunny	Rain	Rain
11:50 a.m. – 12:00 p.m.	Sunny	Rain	Rain

Table 6-7. Identification of multiple causes of truck bottlenecks (truck-hours).

	Segment 1 Truck-Hours of Delay	Segment 2 Truck-Hours of Delay	Segment 3 Truck-Hours of Delay	Total Truck-Hours of Delay
11:00 a.m. – 11:10 a.m.	0.0	0.0	0.7	0.7
11:10 a.m. – 11:20 a.m.	0.0	0.8	0.0	0.8
11:20 a.m. – 11:30 a.m.	0.0	4.0	0.0	4.0
11:30 a.m. – 11:40 a.m.	0.0	3.5	0.0	3.5
11:40 a.m. – 11:50 a.m.	0.0	0.9	0.8	1.7
11:50 a.m. – 12:00 p.m.	0.5	0.0	1.3	1.8
Total Truck-Hours of Delay	**0.5**	**9.2**	**2.8**	**12.5**

Crash Rain Crash and Rain

delay numbers provides good insight into the types of conditions that are present when delay forms. "Shared" delay also can be evenly (or otherwise analytically) divided between delay influencing factors to provide insight into the relative significance of different congestion influencing factors. For example, if all "shared" delay is evenly divided between influencing factors, then delay is computed as follows:

- **Crash** – 4.6 truck-hours (36.5 percent of delay here when "shared" delay is evenly divided, but it could influence up to 66.4 percent of all delay);
- **Rain** – 6.8 truck-hours (53.8 percent of delay here when "shared" delay is evenly divided, but it could influence up to 83.7 percent of all delay);
- **No Cause Identified** – 1.2 truck-hours (9.6 percent of all delay has no "other cause" identified except volume); and
- **Total Delay** – 12.5 truck-hours.

These same data can be presented in graphic formats that are easy for decision makers to understand, such as shown in Figure 6-2.

The availability of the analytical NPMRDS (or other similar datasets), in combination with other data sources, will allow significant investigation of the factors that cause or affect the size and timing of truck bottlenecks.

Roadways that are not designed to a truck's size and performance characteristics can result in truck delays, which can be analyzed in terms of a roadway's attributes. Many attributes can be extracted from asset and spatial data catalogs (GeoData) maintained by DOTs and MPOs. The analysis of causation in this situation is where the roadway performs adequately for cars but poorly for large vehicles. Roadway attributes identified in the catalogs can include grades, horizontal alignment, intersection type, and other geometrics. Chapter 7 expands on this approach.

Case Study Highlight

A study was performed by the I-95 Corridor Coalition to identify, classify, and evaluate all vehicle bottlenecks to establish baseline performance measures for a corridor spanning several Northeast states. INRIX speed data and FHWA HPMS volume data were used to conduct the analysis. Regarding nonrecurrent delay, incident and work zone data were 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 significance factor on those days. More details are in Appendix B.

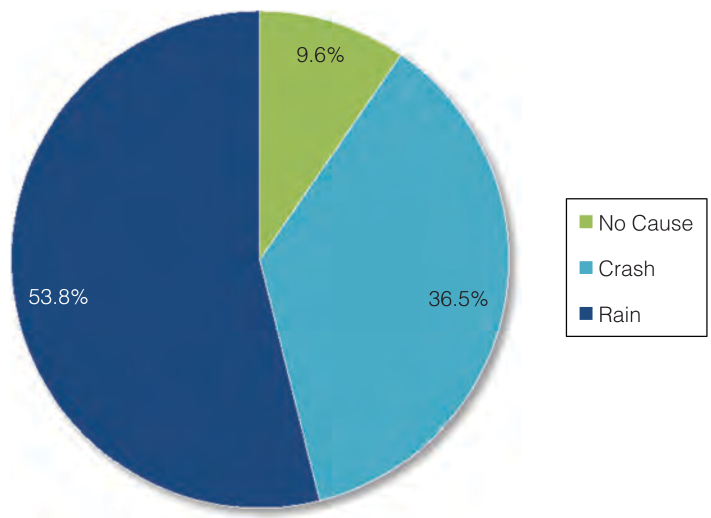


Figure 6-2. Delay by congestion influencing factor.

This section provided a data analysis illustration with a simplified example. Appendix D provides more detailed analysis procedures for the calculation of performance measures. Namely, Section D-3 of Appendix D provides segment and route calculation procedures.

6.3 Ranking Travel Speed-Based Bottlenecks

The most straightforward way to rank the causes of travel speed-based truck bottlenecks is in decreasing order of total truck delay. For the example presented in Section 6.2, a simple ranking of causes would be as shown in Table 6-8. Travel speed-based bottlenecks can also be ranked across multiple locations in a similar fashion with locations that have the most delay having the highest ranking.

There are several examples of bottleneck rankings that have been developed. The American Highway Users Alliance develops the annual report, *Unclogging America's Arteries* (132), which includes a list of the top 50 worst truck bottlenecks in the U.S. The ranking is based on annual truck-hours of delay at freeway segment locations. The list also includes information on average queue length, annual lost value of time, and annual fuel wasted. Table 6-9 shows the top 17 truck bottlenecks from 2015 based on this report.

Another example of the ranking of bottlenecks is shown the *Texas 100 Most Congested Roadways List* (23) analysis from 2014 (Table 6-10). This table shows the 10 most congested bottlenecks

Table 6-8. Ranking of causes of truck bottlenecks at single location.

Cause of Truck Bottleneck	Hours of Truck Delay	Ranking
Rain	6.8	1
Crash	4.6	2
No Cause Identified	1.2	3
Total Truck-Hours of Delay	**12.5**	**N/A**

Table 6-9. American Highway Users Alliance ranking of top truck bottlenecks.

National Rank	State	Urban Area	Location	Queue Length (miles)	Annual Total Delay (hours)	Annual Lost Value Of Time (US $)	Annual Fuel Wasted / Potential Savings (gallons)
1	Illinois	Chicago	I90 between Roosevelt Rd and N Nagle Ave	12.0	16,900,000	$ 418,000,000	6,370,000
2	California	Los Angeles	I405 between SR22 and I605	4.1	7,100,000	$ 191,000,000	1,819,480
3	California	Los Angeles	I10 between Santa Fe Ave and Crenshaw Blvd	6.9	6,900,000	$ 187,000,000	2,231,840
4	California	Los Angeles	I405 between Venice Blvd and Wilshire Blvd	5.2	6,300,000	$ 169,000,000	1,961,960
5	California	Los Angeles	US101 between Franklin Ave and Glendale Blvd	4.4	5,400,000	$ 146,000,000	1,761,500
6	California	Los Angeles	I110 between Exposition Blvd and Stadium Way	4.3	5,400,000	$ 145,000,000	1,855,880
7	California	Los Angeles	US101 between Sepulveda Blvd and Laurel Canyon Blvd	3.8	3,600,000	$ 96,000,000	1,047,800
8	New York and New Jersey	New York	Lincoln Tunnel between 10th Ave and John F Kennedy Blvd	2.6	3,400,000	$ 87,000,000	1,730,300
9	New York	New York	I95 between I895 and Broadway	3.1	3,000,000	$ 82,000,000	1,545,700
10	Texas	Austin	I35 between East Riverside Dr and E Dean Keeton St	3.0	3,000,000	$ 73,000,000	1,776,320
11	California	Los Angeles	I5/I10 between N Mission Rd and US101	2.0	2,300,000	$ 62,000,000	966,680
12	California	San Francisco	I80 between US101 and Bay Bridge	1.9	2,200,000	$ 59,000,000	797,680
13	California	Los Angeles	I10 between La Brea Ave and National Blvd	2.2	2,100,000	$ 57,000,000	551,720
14	California	Los Angeles	I5 between S Eastern Ave and Euclid Ave	2.0	2,100,000	$ 56,000,000	992,160
15	Massachusetts	Boston	I93 between I90 and US1	1.9	2,100,000	$ 58,000,000	1,980,680
16	California	Oakland	I80 between I580 and Ashby Ave	2.0	1,900,000	$ 50,000,000	691,860
17	Washington	Seattle	I5 between Madison St. and Exit 168A	1.6	1,600,000	$ 45,000,000	619,840

in Texas, ranked by the total number of hours of delay occurring annually, with those statistics normalized on a per mile basis to account for the fact that each reporting segment has a different length. The "worst" bottleneck in Texas under these criteria is the Interstate 610 road segment from Interstate 10 to Interstate 59. However, if Table 6-10 is sorted in terms of annual truck-hours of delay per mile, this road segment is only the fourth worst Texas roadway segment. The worst truck delay segment is Interstate 35 from U.S. Route 290 north to State Highway 71. Similarly, if segments were ranked on the basis of annual congestion cost, the ranking would again be different.

No single ranking system is appropriate for all uses. Each performance measure (e.g., truck delay, total delay, expected travel rate or reliability, or the frequency with which congestion occurs) can be used to effectively rank locations. Each of those resulting rankings will likely be different. What these different rankings indicate is that the importance of any one bottleneck changes depending on which bottleneck attributes are most important to an individual decision

Table 6-10. Texas 100 most congested roadways.

Rank	Roadway	From	To	County	Annual Hours of Truck Delay per Mile	Annual Truck Congestion Cost
1	I-35	U.S. 290N	SH71	Travis	108,645	$72.33
2	I-610	I-10	U.S. 59/I-59	Harris	68,893	$20.99
3	U.S. 59	I-610	SH 288	Harris	51,604	$23.64
4	I-635	I-35E/U.S. 77	U.S. 75	Dallas	49,538	$33.59
5	I-10/U.S. 90	N. Elridge Pkwy	Sam Houston Tollway W	Harris	48,855	$13.43
6	I-345/US75/ I-45	Woodall Rodgers Freeway	U.S. 175	Dallas	46,744	$9.36
7	U.S. 59	I-10/US90	SH 288	Harris	45,469	$11.60
8	I-10/U.S. 90	I-610	I-45	Harris	44,400	$21.17
9	I-45	Sam Houston Tollway N	I-610	Harris	39,713	$31.08
10	I-10/U.S. 90	Sam Houston Tollway W	I-610	Harris	38,295	$21.27

Source: *Texas 100 Most Congested Roadways List.* Texas Department of Transportation. Available: http://www.txdot.gov/inside-txdot/projects/100-congested-roadways.html. Last Accessed: April 10, 2015. Note that the full ranking of all segments throughout Texas beyond the top 100 are available here: http://mobility.tamu.edu/most-congested-texas/. (23)

maker. Rankings can even be created that are based on the relative (potential) causes of those delays—e.g., where are the largest freight bottlenecks where incidents have played a role in the size of that delay?

Because this is an automated process, rankings can be developed for a variety of defined subsets of the highway system. Arterials can be ranked differently from freeways. Rankings can be computed by geographic portion of the state. They can be computed for roads exclusively within a given MPO's jurisdiction. They can even be computed for specific categories of road, such as for priority truck routes.

The outcome of these different ranking systems is better decision support. If the state legislature is interested in having congestion relief projects in different parts of the state, then rankings can be developed for those different geographic regions. If money is set aside for arterial improvements, congestion rankings can be developed for just those eligible roadways.

Finally, an agency may wish to remove some types of truck delay from consideration in the ranking system. For example, delays caused by bad weather might be removed from a ranking intended to identify

> . . . delays caused by bad weather might be removed from a ranking intended to identify places to spend congestion relief money, whereas those same delays might be expressly highlighted to support the implementation of better road weather management activities. . . .

places to spend congestion relief money, whereas those same delays might be expressly highlighted to support the implementation of better road weather management activities, even if those activities are not applied exclusively to those road segments.

The size, scope, and ranking of bottlenecks also change depending on exactly how the roadway segment encompassing the "bottleneck" is defined. Where does the bottleneck start? And where does it end? Given detailed data, it is easy to follow the formation, growth, and eventual dissolution of a given bottleneck on any particular day. On the basis of that specific observation, the analysis can determine the exact length and duration of the congestion. However, the congestion that forms today (e.g., 1.5 miles long, lasting for 90 minutes) is different from the congestion that forms tomorrow (e.g., 0.3 miles long, lasting 20 minutes) and from what forms next Friday afternoon (e.g., 12 miles long, lasting 6 hours, thanks to a crash involving a rolled truck hauling fuel).

Different bottleneck definitions for a specific location will result in different analytical outcomes. For example, if the bottleneck segment described above is defined as being 12 miles long, the estimated total delay for the segment will be larger than if the bottleneck is defined as being only 0.5 or 1 miles long. But the total delay per mile computed for the longer bottleneck location will be much lower than if the bottleneck is defined as one of the shorter distances, because much of the longer segment is not as congested as the shorter road segments that are closer to where congestion typically starts—the actual "bottleneck" itself.

Complicating the definition of the road segments for which bottlenecks will be computed is that numerical analyses can only be performed for roadway segments for which data are available. This means that it is not always possible—from existing data—to accurately measure the actual length of a queue associated with a truck bottleneck. This is a limitation of the NPMRDS and other probe speed datasets. These probe datasets typically describe the average travel time for the entire segment for which data are reported. For example, a truck may travel at 70 mph over the first 4.5 miles of a 5-mile-long segment, but then fight through stop-and-go traffic over the last half-mile, averaging 15 mph. The result is a reported travel time (~5.86 minutes) that accurately reflects the travel time over the entire segment and that can be converted to an average speed estimate of ~51 mph. However, while the delay measurements based on that travel time and speed are correct, the data limit the ability to directly identify the very slow speeds and queue that formed over the last half-mile of that segment.

Case Study Highlight

Since 2002, the American Transportation Research Institute (ATRI) has partnered with 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 in the United States. Locations are not selected by specific criteria for inclusion in the study, 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. More details are included in Appendix B.

One common way of reporting roadway segments—especially when delay or travel time is used as the bottleneck ranking statistic—is to group smaller segments into modestly long road segments that stretch from one major interchange to another. The contiguous small segments that make up these larger reporting segments typically have similar numbers of lanes and operating characteristics. They generally do not contain known geometric bottlenecks (for example, caused by major merging movements or lane drops) in the middle of the defined segment. They can range from 4 to 15 miles and constitute a length of roadway that might logically be turned into a major construction or improvement project. Additional details about segmentation are covered in Section 4.4 of this Guidebook.

Table 6-11 taken from a recent FHWA webinar about the use of the NPMRDS (26), gives an example of these longer reporting segments provided by Wisconsin DOT. In Table 6-11, road segments range from 5 to 15 miles. They are defined as occurring from one major interchange to

Table 6-11. Performance measures reported for longer segment lengths.

Travel Time Report

Milwaukee Freeway Peak Travel Times: 2014 Spring Quarter

Map Link	Planning Time Index (PTI)	Highway	From	To	Distance Miles	Normal Travel Time Minutes	Worst Peak Travel Time Minutes	Worst Peak
1	1.18	I-94 EB	WIS 67	US 18	15.3	14.2	16.7	AM
2	1.20	I-94 WB	US 18	WIS 67	15.4	14.2	17.1	PM
3	2.36	I-94 EB	US 18	Zoo interchange	7.4	8.0	18.9	PM
4	1.26	I-94 WB	Zoo interchange	US 18	7.4	7.5	9.4	PM
5	2.45	I-894 WB	Hale interchange	Zoo interchange	6.2	6.8	16.7	AM
6	1.75	I-894 EB	Zoo interchange	Hale interchange	5.5	6.0	10.5	PM
7	1.39	I-43NB/894EB	Waukesha County Line	Mitchell interchange	9.1	9.9	13.8	AM
8	1.41	I-43SB/894WB	Mitchell interchange	Waukesha County Line	7.5	8.2	11.5	PM
9	2.19	I-94 EB	Zoo interchange	Marquette interchange	5.2	6.0	13.1	AM
10	2.14	I-94 WB	Marquette interchange	Zoo interchange	5.9	6.7	14.4	PM
11	1.49	US 45 NB	Zoo interchange	Waukesha County Line	8.3	9.1	13.5	PM

another. The information in this table can be used to rank bottlenecks, based on subtracting the normal travel time from the worst peak-travel time. Each location can then be ranked based on this differential. In this example, the interchanges do not need to be freeway-to-freeway movements but can simply be locations at which major changes in traffic volumes occur. Some local insight is typically needed to create these longer segments, but insight gained by reviewing the performance of the shorter segments also can help guide the definitions of these longer reporting segments.

Longer segments are particularly useful in the basic bottleneck identification and ranking process—that is, the "desktop" analysis. The use of longer segments limits the size of the output tables, which reduces the time needed for staff to review them. Moderately long segments also help ensure that total delay is effectively captured. Once completed, the desktop analysis results support a fairly quick and effective ranking process.

On the basis of those results, agencies can then perform more detailed analyses that look at roadway performance within these longer segments. These "field analyses" are performed only for the highest-priority roadway segments. Each agency decides how many and which of these identified bottleneck sections it will study in more detail. In this way, the desktop analysis helps agencies manage their work load and helps ensure that the resources they apply to more detailed studies are efficiently allocated.

6.3.1 Desktop Analysis of Bottleneck Impacts on Travel Times

One other way to examine the importance of identified bottlenecks is to examine their impacts on truck trip travel times. This can be accomplished by first using knowledge of the key freight movements in the state to develop a list of important freight O/D. For example, these movements could be from one of the major manufacturing centers in a state to a major port, or to the state border on an Interstate that leads to a major shipping destination for the commodities in question.

It is then possible to compute paths or "trips" from the origin to the destination of each key freight movement. By using the cube analysis structure that describes the potential causation factors for truck bottlenecks (as illustrated earlier in Figure 4-5), agencies can compute travel times with these paths. Then, by computing travel times over these paths for multiple days and start times, it is possible to compute the travel-time reliability of these key freight movements.

It also is possible to determine which bottlenecks each of the trips passes through and the amount of time lost to those bottlenecks for each of the trips. Examining the delays in each bottleneck versus the total trip time and total trip reliability allows the analyst to understand the relative importance of each bottleneck in relation to the travel-time reliability of the key freight trips in the state or region.

6.4 Identify Causes and Rank Process-Based Truck Bottlenecks

. . . to examine [noncongestion-related] bottlenecks, the analyst starts with an understanding of the cause of the truck delay.

The ranking and cause analysis for process bottlenecks is somewhat different than the straightforward ranking analysis for congestion bottlenecks. First, to examine process bottlenecks, the analyst starts with an understanding of the cause of the truck delay. The analysis process is based on the specific type of trucking restriction (e.g., low-height bridge) required by a known problem (e.g., a given bridge does not meet standards—which is known though agency records and is likely an item that trucking firms complain about to the agency).

The ranking process involves examining the relative size of the various deficiencies. Different rankings could be computed on the basis of the different performance statistics mentioned above:

- Total cost imposed on the trucking community or
- Number of trucks inconvenienced by a given restriction.

More likely, however, process bottlenecks will be ranked on the benefit-to-cost ratio of the required mitigation, and that requires an understanding of the appropriate mitigation for each process bottleneck.

6.5 Conduct Field Analysis to Refine Bottleneck Understanding

The desktop analysis provides the ability to quickly describe, scope, and rank truck bottlenecks across an entire region or state. It also allows a state or region to quickly grasp the overall delay trend (i.e., are hours of delay increasing or decreasing over time?).

However, the limitations imposed by the need to have widely available, consistent data sources precludes the desktop analysis process from incorporating all of the local detail that is needed to perform the effective planning and engineering required to cost-effectively mitigate bottlenecks. In addition, understanding the overall trend always begs the questions, “Why is that trend occurring?” and “How does that trend apply to this particular location of interest?” Answers to those questions typically require more site-specific analysis.

. . . [the field analysis] relies on the same tools and reports that are available to the desktop analysis, but it involved a deeper examination of a limited number of (usually contiguous) roadway segments.

Consequently, the desktop analysis process is designed to be only the start of the bottleneck analysis effort. It provides enough information for the agency to effectively select the locations on which to perform more detailed analyses. The next step in the bottleneck identification and evaluation process is conducting those detailed field analyses.

The field analysis starts with the results from the desktop analysis. In many cases, it relies on the same tools and reports that are available to the desktop analysis, but it involves a deeper examination of a limited number of (usually contiguous) roadway segments. The field analysis also typically incorporates additional data into the bottleneck analysis that are not available statewide. In some cases these data already exist at the field study location but are not available at other parts of the state. This commonly occurs when the field study is performed on a major urban corridor, where large amounts of data already exist because of existing traffic management systems or because other studies performed in the area have collected those data. In other cases these additional data must be collected specifically for the field analysis. In still other cases, agency staff that work in the area can describe in detail some of the contributing causes of local bottlenecks. Taking advantage of this local knowledge is an important part of the field analysis process. In the end, these additional data sources are developed to provide more depth to the analysis about why observed travel patterns are occurring and how those delays might best be mitigated.

Case Study Highlight

A recent study by the Hampton Roads Transportation Planning Organization (HRTPO) identified freight bottlenecks for highways that are expected to be part of the National Freight Network and forecast likely future truck bottleneck locations. In this field analysis, researchers considered many aspects that could cause bottlenecks, including defining deficient bridge structures, identifying height and lane width restrictions, pavement condition, and truck delay on the highway network. More details are in Appendix B.

As a starting place for the field analysis, the results from the desktop analysis describe when and where bottlenecks are occurring and provide insight into the factors that influence the formation and size of the resulting truck delays. Starting at this point allows the analyst to progress from a simplistic understanding of the factors that influence bottlenecks to a more detailed understanding of exactly what is causing bottlenecks on the priority corridors/location they are studying.

For example, in the field analysis, the analysts might look at not just the overall amount and general timing (e.g., a.m. versus p.m. peak delay) of the delay reported for the large roadway segment, but they might examine the exact timing and formation of that delay on specific days, examining details such as the following:

- Where within the larger reporting segment does a bottleneck form, and how does it propagate from that initial bottleneck location?
- Is congestion routinely forming at one or more specific points within the study corridor, or is it forming throughout the corridor because of simply too much volume?
- Is the delay occurring at specific points in the corridor because of known geometric attributes (e.g., high ramp volumes, or major weaving movements)?
- Does congestion form randomly in time and space as a result of vehicle crashes?
- Are crashes within the corridor randomly distributed or are they concentrated in specific locations, and if they are in specific locations, what are the attributes of those crashes and the locations where they are occurring?

It is common to specifically collect data for field analysis. For example, the agency might collect a new vehicle classification-based traffic count to obtain better truck volume data. Truck volume data available at the statewide level might be weak in a location selected for more detailed analysis, and improving the estimate of truck delays might make collecting those data important.

It is common to specifically collect data for field analysis.

Similarly, the agency might obtain data on factors such as transportation system management and operations (TSM&O) strategies being conducted within that corridor. These data would be used to inform the analyst whether specific bottleneck mitigation strategies already were being implemented in the study corridor. The availability of those services would then set in motion additional analyses, such as the response time of the existing incident management program, the nature of the crashes that resulted in the largest delays, and the size and scope of those incident management efforts.

Case Study Highlight

The Oregon DOT recently identified all vehicle bottlenecks and recommended mitigation strategies for five corridors in Oregon in response to FHWA's Localized Bottleneck Reduction (LBR) Program. The first tier of the two-tier analysis used loop detector and historical crash data to identify bottlenecks for a typical commute during the morning and afternoon peak periods. The second tier validates this analysis by reviewing existing documentation, available video footage, and field observation. The research team identified typical causes of the localized bottlenecks and suggested improvement strategies. More details are in Appendix B.

Staff familiar with the adopted local plans and local political and organizational working relationships must contribute their knowledge of these plans and relationships to the field study.

The analyst could then compare the observed congestion patterns and statistics with the existing traffic management efforts on those roadways, as well as compare those outcomes with the state-of-the-art or state-of-the-practice for mitigating the types of congestion identified in the study area. For example, if the field analysis indicated that a significant portion of "worst" travel days occurred when truck-involved crashes occurred, and the review of the incident management system did not include heavy-duty tow trucks, then one obvious mitigation approach would be to offer ways to speed access for those larger response vehicles.

A good field analysis also includes agency staff who work in the geographic region containing the bottleneck along with private-sector freight stakeholders that operate trucks or ship goods on the roadways of concern. Agency staff familiar with the adopted local plans and the local political and organizational working relationships must contribute their knowledge of these plans and relationships to the field study. Understanding the local organizational relationships is often a key to successful implementation of bottleneck mitigation efforts. Leveraging existing plans and local interests can greatly speed the implementation effort and frequently decrease the cost of bottleneck mitigation. Therefore, partnering with local agencies, reaching out to local stakeholders, and working across silos can help with the field analysis.

Private-sector freight stakeholders can provide many pieces of valuable information in the truck bottleneck evaluation process. Most notably, they can provide information on the causes of why trucks slow down at a certain location, including road curvature, grades, lane width, or other safety concerns. For process-based delays, they are critical for understanding how truck patterns are altered due to regulations, including weight restrictions, truck bans, time-of-day restrictions, and other causes of truck delays. At this point in the analysis, it is generally a good practice to allow the private sector to comment on the accuracy of the analysis and provide input on some of the causes of what has been identified in the data.

The outcome of these more detailed analyses is insight necessary to determine the types of improvements that are required to reduce the observed congestion. This mitigation is discussed in the next chapter of this Guidebook.

CHAPTER 7

Options for Mitigating Truck Bottlenecks

The bottleneck identification and mitigation process involves sorting truck bottleneck causes and matching them to mitigation strategies. Typically, state and local jurisdictions focus on truck bottlenecks on the National Highway Freight Network, the State Highway Freight Network, and local (e.g., MPO, county, city) road networks. Mitigation for bottlenecks can be either operational changes, infrastructure improvements, or a combination of both. Appropriate mitigation approaches correspond to the boxes in the flow chart in Figure 7-1.

This chapter describes options for mitigating a wide range of truck bottlenecks. It is structured with the following sections:

- **Section 7.1.** Matching Mitigation Options to Bottleneck Causes,
- **Section 7.2.** Mitigation Options for Recurring Congestion,
- **Section 7.3.** Mitigation Options for Nonrecurring Congestion,
- **Section 7.4.** Mitigation Options for Operational Deficiencies,
- **Section 7.5.** Mitigation Options for Geometric Deficiencies,
- **Section 7.6.** Mitigation Options for Special Event Bottlenecks, and
- **Section 7.7.** Examples of Truck Bottleneck Mitigation Efforts.

7.1 Matching Mitigation Options to Bottleneck Causes

There are a large number of potential approaches to mitigating the identified truck bottlenecks. A selected approach should consider the following:

- The causes of the delays,
- The geographic and geometric attributes of that location,
- The operational characteristics of the roadway,
- The organization of the agencies working on that facility and other facilities that influence the operation of that roadway,
- The operational systems currently implemented on the road (or in the larger region that have been demonstrated effective and/or have public support), and
- The type of funding available.

There is no simple, automated process that can determine the "best" mitigation strategy for any given bottleneck. The selection of the appropriate strategy requires knowledge of all of the above factors. For example, an analysis that focuses on mitigating air quality impacts of bottlenecks will seek strategies that reduce truck VMT in addition to reducing truck idling. This can include

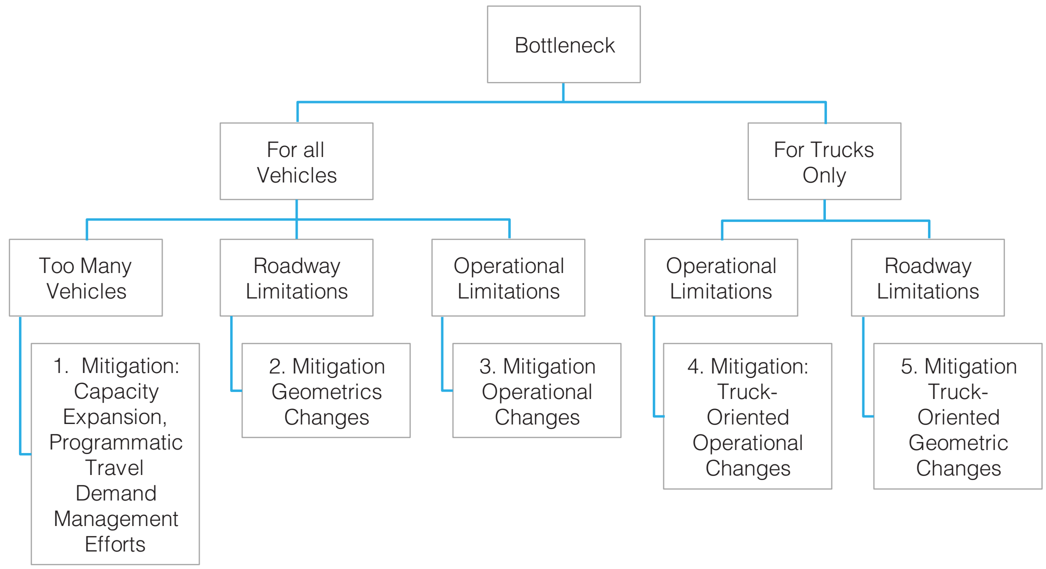


Figure 7-1. Mitigation approaches for all vehicles and trucks only.

providing incentives to have more trucks operate during nighttime periods where congestion is minimal. Truck emissions factors will need to be applied to various mitigation strategies to determine which one(s) are the most effective.

Typically, mitigation for truck bottlenecks can be divided into a number of categories on the basis of the basic causes/attributes of delay. These include the following:

- Recurring congestion (too much traffic volume),
- Nonrecurring congestion or delays,
- Geometric deficiencies,
- Operational deficiencies, and
- Event congestion.

Each of these causes of delay requires different types of mitigation, and the design and implementation of those mitigation efforts depends on the organization and operational relationships of the various transportation agencies and political jurisdictions that operate the road or that provide services in that geographic region.

The subsections below briefly describe each of these categories of bottlenecks and illustrate typical mitigation strategies that agencies frequently consider to mitigate the resulting freight delays.

Table 7-1 summarizes the mitigation options to consider for each truck bottleneck type. It should be noted that the selection of mitigation options should be done in cooperation with both public-sector and private-sector freight stakeholders. It is particularly important to be proactive with the private-sector community (including shippers) to ensure that the mitigation option will likely have the intended impact on the bottleneck.

The remainder of this chapter discusses mitigation options in greater detail.

Case Study Highlight

A number of freight mobility efforts have been performed in the state of Florida by the Florida DOT and its partnering agencies. One example is the Tampa Bay Regional Strategic Freight Plan: An Investment Strategy for Freight Mobility and Economic Prosperity. The plan steps the reader through the regional modal assets and identifies a number of freight mobility needs (capacity, operations, maintenance, safety/security). A process is presented for scoring the needs; the freight corridor-based project needs are illustrated in maps by county in the region. The document concludes with specific implementation guidance for recommended freight-related improvements. More details are in Appendix B.

Table 7-1. Summary of mitigation options to consider for each truck bottleneck cause.

Cause Of Bottleneck	Mitigation Measure Options to Consider
Recurring Congestion	• Add capacity • Reversible/convertible two-way left-turn lanes • ITS solutions: ramp metering, real-time traveler info (e.g., sharing peak demand data), appointment systems, load-matching, etc. • Travel demand management (TDM) solutions: truck tolling, off-peak-hour delivery options, etc. • Truck mode shift to rail, water, or air modes • Variable speed limits during shoulder periods of recurring congestion • Managed travel lanes to allow for shoulder running • Automated platooning of trucks and/or autos
Traffic Incidents	• Real-time traveler info via mobile devices and CMS • Advanced closure notifications • Queue detection and warnings before known bottlenecks, especially where site distance is limited • Install CCTV at high-incident locations to allow for faster response time • Traffic control, such as alternative routing information and alternative timing plans for signalized intersections • Crash investigation sites and refuge areas • Gate/border crossing technology improvements, such as appointment systems, RFID readers, congestion-based toll. Preregistered toll options, etc. • Truck tipping warning signs
Work Zones	• Advanced closure notification • Coordinated traffic control and real-time traveler information
Weather	• DOT coordination with NOAA to provide real-time traveler information • Ice detection, warnings, and anti-icing on bridges and roads • Winter maintenance programs (snowplowing, avalanche control, and deicing) • Runaway truck ramps

(continued on next page)

Table 7-1. (Continued).

Cause Of Bottleneck	Mitigation Measure Options to Consider
Poor Signal Timing	• Signal synchronization • Signal prioritization for trucks • Right-/left-turn lane additions • Appropriate truck turning radii • Improve site distance (remove obstructions, improve lighting, etc.) • Improve geometry at signalized intersections, including continuous flow intersections, diverging diamond interchange, etc.
Nonrecurring—Special Event Traffic	• Outreach and coordination with trucking industry • Signage where appropriate • Real-time traveler information • Managed travel lanes to allow for shoulder running • Adaptive traffic control • Peak-hour signal timing
Geometric—Up And Down Grades, Super-Elevations	• Truck climbing lane • Truck deceleration lane • Runaway truck ramp • Leveling or changing slopes • Tunnels
Geometric—Horizontal Curves	• Reconstruct to standard • Increase signage and lighting • Queue detection and driver warnings • Truck bypass
Geometric—Lane Drops	• Extend length of lane • Construct auxiliary or passing lane
Geometric – Short On- or Off-Ramps	• Extend length of ramp • Add deceleration or acceleration lane • Construct auxiliary lane • Consider use of shoulder to extend ramp

Table 7-1. (Continued).

Cause Of Bottleneck	Mitigation Measure Options to Consider
Geometric—Merge/Diverge Congestion	• Add auxiliary lane • Interchange consolidation via collector-distributor system • Restriping merge/diverge areas to provide additional lanes • Ramp metering • Syncing arterial signals to moderate flow of traffic merging onto and exiting the mainline • Separate truck/auto traffic
Geometric—Narrow Bridges	• Widen travel lanes on bridges • Widen shoulders on bridges
Geometric—Tunnels	• Reconstruct to add necessary height and/or adequate travel lane widths and shoulder widths
Geometric—Narrow Travel Lanes	• Restripe to widen travel lanes • Consider use of shoulder or widening
Process Delays—Gate/Weigh Station Processing	• Gate/border crossing technology improvements, appointment systems, radio frequency identification (RFID) readers, congestion-based tolls (CBT) preregistered toll options, etc. • Weigh stations: consider weigh-in-motion devices to improve enforcement, reduce processing delays, and prevent queue spillover onto mainline travel lanes • Increased gate or booth staffing
Process Delays—Parking Shortage And Access Management	• Increase number of truck parking spaces • Utilize “smart parking strategies” that provide information on location and timing of available truck parking spaces • Allow for reservations to be made for truck parking spaces • Optimize driveway location and design for truck access • Design frontage roads for freight facility access

(continued on next page)

Table 7-1. (Continued).

Cause Of Bottleneck	Mitigation Measure Options to Consider
Process Delays—Permit Acquisition	• Increase processing time for permit acquisition • Allow for broader application of current permit categories • Reduce number of trip types for which a permit is required • Automate permit acquisition process
Process Delays (Other)—Truck Prohibitions/Route Restrictions: Size/ Weight, Hazardous Materials, And Oversized Loads	• Investigate reason for prohibitions/restrictions • Match truck routes with appropriate infrastructure considering height and weight limits

7.2 Mitigation Options for Recurring Congestion

Recurring congestion is congestion that routinely occurs at the same locations and same time periods. It is caused when more traffic (and truck) demand is present than the road can serve. The following four basic approaches to mitigating recurring congestion are:

1. Capacity expansion,
2. Operational improvements,
3. TDM, and
4. Provision of alternative capacity.

> Capacity expansion is a common approach to an imbalance of travel demand and roadway capacity.

Capacity expansion is a common approach to an imbalance of travel demand and roadway capacity. Roadway agencies have historically looked to expand the number of lanes on roads that experience routine congestion. This is still a reasonable approach when the cost of that expansion is modest and when continued growth in travel demand is forecast. However, in many parts of the country road expansion is prohibitively expensive or politically unfeasible. As a result, other approaches to capacity expansion also are commonly explored.

> . . . retiming traffic signals can lead to a considerable increase in vehicle throughput on arterials.

One such approach consists of operational improvements. For example, retiming traffic signals can lead to a considerable increase in vehicle throughput on arterials. For arterials that serve large truck movements, retiming signals to meet the acceleration profiles of the trucks using that arterial can result in better traffic progression on the arterial and consequently increased vehicle throughput and decreased congestion and delay.

A variety of other operational and geometric improvements are applicable to different location-specific conditions. Common operational improvements on freeways that agencies frequently implement include:

- Ramp meters,
- Variable speed limits,

- Active traffic management, and
- Lane restriping.

On arterials, operational improvements designed to increase throughput can include:

- Signal retiming;
- Improved channelization; and
- Adding or changing traffic controls (e.g., replacing a signal with a roundabout, or removing stop signs that do not meet warrants).

The third approach to decreasing a recurring bottleneck is *TDM*. TDM involves modifying the options, incentives, and disincentives that shippers and travelers have with regard to travel through the bottleneck. The intent is to shift demand from the periods that are congested to modes, routes, or times of the day where or when additional capacity is available. For example, carpool incentives that cause drivers of single-occupancy cars to share rides with other people using that roadway reduces vehicle demand in the corridor without changing actual person throughput. The reduction in vehicle demand causes reductions in congestion for all vehicles, including trucks.

TDM involves modifying the options, incentives, and disincentives that shippers and travelers have with regard to travel through the bottleneck.

Similarly, shifting traffic to noncongested periods allows the shifted traffic to travel during less congested periods, while lowering congestion during the congested periods. Time-of-day shifts may be achieved through a variety of informational and incentive-based programs and can be applied to both truck and car travel. For example, some urban areas (e.g., New York) have instituted nighttime freight delivery programs in which incentives encourage freight delivery services to move to evening hours. (27) These programs target both the trucking industry and the companies receiving the freight shipments. The New York program showed how late-night deliveries saved all parties time and money for their goods delivery by decreasing the time required to travel from the distribution center to the destinations, decreasing the distance between truck parking and the goods' ultimate destination (i.e., decreasing the time required to move the goods from the truck to the store and for the store to handle the delivery). Consequently, trucks moved from congested periods to uncongested periods, resulting in lower congestion levels for all concerned and decreased cost for the freight deliveries.

TDM programs can be almost infinitely creative. They can involve both incentive programs, to encourage travel behavior that lowers travel during congestion time periods and on congested facilities, and disincentive programs, designed to discourage travel behavior during those periods and on specific facilities. They can be targeted at both shippers and travelers (e.g., congestion pricing on tolled facilities). They also can be targeted at the customers of the shippers (e.g., cost incentives at ports to pick up containers during off-peak hours).

The final category of capacity improvements is the *provision of alternative capacity*. This category is essentially a combination of all three of the above categories but is applied to other transportation facilities that serve as alternatives to the congested facility. A good example of this approach is integrated corridor operations. On an integrated corridor, parallel roadways are operated in a coordinated fashion. As one road begins to reach capacity, traveler information systems inform travelers of the availability of better-performing, parallel roadways that serve the same

Case Study Highlight

The Delaware Valley Regional Planning Commission (DVRPC) 2012 Congestion Management Process (CMP) report identified, classified, and evaluated bottlenecks in the region and provided mitigation strategies specific to each bottleneck. One particular DVRPC CMP objective is "maintain existing core transportation network," and several of the criteria and strategies relate to freight and goods movement. DVRPC also has a PhillyFreightFinder to pinpoint freight facilities and freight activity in the region. More details are in Appendix B.

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corridor. The operational controls on those roads are then optimized to accept increased travel demand as travelers shift their route to take advantage of the parallel facilities. This approach also includes making improvements to alternative modes so that mode shifts may more readily occur to decrease demand on the congested facility.

7.3 Mitigation Options for Nonrecurring Congestion

Many bottlenecks form not because demand increases traffic volumes beyond the design capacity of the roadway, but because a disruption on that roadway causes functional capacity to fall below the actual demand. The most common disruptions are:

- Vehicle crashes;
- Other types of incidents (e.g., debris on the road, disabled vehicles, police activity on the side of the road);
- Construction and maintenance activity (work zones); and
- Bad weather.

The appropriate actions that reduce the formation of bottlenecks under these circumstances include both actions designed to reduce the occurrence of these events (e.g., changes that reduce the frequency and severity of crashes) and activities meant to restore roadway capacity after one of these events (e.g., incident response activities and snow and ice control efforts).

The specific activities taken are a function of the local nature of the events. For example, snow and ice control are not useful activities to consider in Los Angeles, but they certainly are in Buffalo.

A desktop analysis and early field analysis performed for a road segment in Buffalo might show that a large portion of delay occurs in the winter when snow has fallen. That knowledge should lead to a review of the snow plow, snow removal, and winter weather traveler information systems in use. Such a review would entail not only the activities taking place, but also the interactions among various agencies that work to mitigate winter snow conditions.

Information on handling winter snow activities would be obtained from national resources such as the U.S.DOT Clarus effort. This would then be compared to information on road weather programs in Buffalo, and, where appropriate, changes to the current program would then be implemented. It is only at this local level of detail that appropriate mitigation can occur.

Similarly, in Los Angeles, it might be shown that vehicle crashes contribute extensively to corridor delay. Just as Buffalo already has an extensive winter roadway program, the Los Angeles metropolitan area already has an extensive incident response program. But if the field analysis showed that incidents were still contributing significantly to delays, additional attention would likely be warranted on ways to both lower crash rates and reduce the delays those crashes create.

Similarly, if work zones were a significant cause of bottleneck delays, the agency would examine the current work zone management practices, compare those practices with the state-of-the-art and state-of-the-practice activities, available through FHWA and other national organizations, and implement changes as appropriate for local conditions. These conditions would include the available budget, the roadways where work zones were operating—which, in turn, would affect the appropriate work zone management activities that could/should be implemented—and the local agency responsibilities and interactions to be accounted for in the design of a work zone management plan.

The field analysis would examine both current local incident response efforts and the national guidance available through FHWA, the Strategic Highway Research Program 2 (SHRP 2), and other national bodies.

7.4 Mitigation Options for Operational Deficiencies

Operational deficiencies occur when the existing operational control system is not working as well as it could be or when substandard roadway geometrics or a lack of adequate loading and unloading facilities force trucks to slow. This results in reduced roadway capacity, and therefore, many of these situations also are identified as recurring congestion, as noted above. The classic definition of an "operational deficiency" is when the signal system on an arterial is not well timed. In such a case, the roadway serves fewer vehicles than it could, and those vehicles experience far more delay than they should. When this occurs, simply retiming the signals on the arterial can significantly decrease vehicle delay at relatively modest cost.

Operational deficiencies occur when the existing operational control system is not working as well as it could be or when substandard roadway geometrics or a lack of adequate loading and unloading facilities force trucks to slow.

Operational improvements oriented toward cars might also improve truck mobility. If the roadway in question is a high-volume truck route this might increase the priority for roadway infrastructure funding to address the bottleneck but typically the operational improvements will not be specifically truck-oriented.

Some operational mitigation approaches specifically address trucks. These approaches may be relevant on freight routes. One approach is *to adjust supply and demand* through pricing. (28) Congestion or peak-period pricing uses fees or tolls for road use, which can vary by vehicle size. This can change the truck travel patterns and demand on a roadway. The congestion pricing toll "rings" as found around a number of European cities with different pricing for trucks are an example of this approach.

Another operational approach is to provide trucks alternatives as to how, when, where, and if to travel. The objective of this approach is to reduce the number of vehicles on a given road during congested times. For trucks this can include off-hour deliveries and expanded terminal hours such as for seaports as well time-of-day truck travel and size restrictions. A related approach is Active Traffic management (ATM), which can open and close lanes and allow trucks at certain times or in certain lanes. (29) Time-of-day noise restriction and modifying oversize and overweight rules for truck can also change their operational travel patterns.

Technology-based operational solutions can also reduce operational bottlenecks. Examples of such applications for trucks include retiming of traffic signals in high-activity freight areas so they better match the acceleration patterns of trucks, and freight-oriented traveler information, such as the U.S.DOT's Freight Advanced Traveler Information System (FRATIS), (30) that helps truckers to avoid areas and times of congestion.

A good field analysis can often identify other operating improvements that, if implemented, should result in significant improvements in overall operations. These may include minor geometric changes (restriping), the addition of a load zone, changes in operating controls (e.g., when reversible roadways change directions, or the methods used to close, safety check, and then reopen those roadways in the opposite direction), and adoption of new policies that improve operations (e.g., limiting construction activities to times of lower traffic volume).

Fixing operational deficiencies also can include modest geometric improvements. An example is the addition of truck climbing lanes in hilly regions. Such a change does not increase the speed of heavily loaded trucks, but it does provide lightly loaded trucks the ability to

Case Study Highlight

A study performed for the Texas DOT documented how safety and operations are improved with low-cost freeway bottleneck removal projects. The study recommends collecting five types of data, including volume counts, travel times, videotape, drive-through video, and origin-destination data. Researchers emphasize the importance of conducting the analysis both before and after a project is implemented. The benefit-to-cost ratios of the projects ranged from 400:1 to 3:1 for the four projects evaluated, and all the sites experienced reduced incident rates. More details are in Appendix B.

Exhibit 7.1. Truck ramps.

Source: Tennessee DOT.

Source: Colorado DOT.

pass slower moving vehicles. Similarly, deceleration lanes on steep downhill grades allow trucks to maintain lower speeds and control. Another common feature, runaway truck ramps, can be installed on steep downhill sections. These ramps protect against crashes that commonly occur when a truck's brakes fail or during inclement weather, such as snow and ice, when trucks lose traction. (See Exhibit 7.1.)

7.5 Mitigation Options for Geometric Deficiencies

Roadway design features (tight curves, narrow lanes, etc.) that slow travel for all vehicles can be identified by slow travel independent of roadway volumes. Mitigation is typically an update of the physical roadway infrastructure. As with the mitigation for too many vehicles, any fix oriented toward cars will also improve truck travel if the updated geometrics address truck dimensions and operating characteristics. It is important to consider a design vehicle that is a truck if the roadway is a significant freight route.

Mitigating truck bottlenecks from geometric deficiencies is particularly important, because trucks have different operating characteristics from cars. Some of these differences include:

- Trucks occupy more horizontal and vertical roadway space;
- Trucks require more room for turns;
- Trucks require more roadway to brake and stop; and
- Depending on the power-to-weight ratio, trucks can have notably different acceleration and characteristics and performance on grades.

Roadways that are not designed to truck characteristics can result in truck-only delays and bottlenecks. Mitigation approaches addressing this type of bottleneck need to identify a roadway's attributes that reduce a truck's speed (and reliability). Two sources can provide general information on roadway design characteristics and limitation that either cause or contribute to bottlenecks. One is the geometric roadway design manuals that address different design standards, often using truck design vehicles [for example, a wheel base 40 truck (WB-40)] for different sizes and types of trucks. In particular, a truck's performance limitations are linked to tight curves, hills, and some types of intersections. A commonly used source of geometric design information, with chapters on trucks, is the AASHTO "Green Book": *A Policy on Geometric Design of Highways and Streets.* (31)

The crash and safety literature provides a second perspective into roadway attributes that contribute to reduced truck performance. Attributes tied to more frequent truck safety concerns can be at locations which, in the worst case, cause a crash that slows or closes a road. More commonly, the same locations are also places that are more difficult for truck operations, requiring prudent drivers to slow and drive more carefully. In many cases, these are locations that are not problems for cars and a truck-specific bottleneck analysis is required to find infrastructure problems. For example, locations with inadequate vertical curves can contribute to truck rollovers but may not be problems for cars simply because trucks (such as tractor-trailer combinations) are vulnerable due to their height and high center of gravity. (32)

Based on the safety and roadway design literature (more information is in Appendix E), roadway attributes that can slow trucks as well as example infrastructure mitigation approaches to improve those locations (example are also found in Table 8-1) include the following:

- **Tight turns** can cause truck drivers to slow or maneuver to avoid having the truck's wheels track off the roadway or even off the pavement. An infrastructure fix is to increase the turn's radius which can be as simple as adding more pavement, or difficult if it requires major construction or demolition of existing structures.
- A **vertical curve** is where there is an intersection between two slopes on a roadway (i.e., rolling roads are an example). Typically trucks have to travel vertical curves more slowly than cars because of their weight-to-power ratio and their acceleration and braking characteristics. Another aspect of vertical curves that can cause truck delays is sight distance which, at night, also impacts the effective distance for a truck's headlights. Vertical curves can be modified to change a road's profile and grade. This tends to be costly but this cost does vary depending on maximum and minimum gradients, required sight distance criteria; surrounding land and topography; and other roadway features such as horizontal curves.
- A **horizontal curve** is a primary truck safety and design consideration. Truck travel that is too fast for a horizontal curve can cause trucks to skid off of the road or overturn. (33) The American Transportation Research Insititute (ATRI), for example, mapped roadway nationally that had a high frequency of large truck rollovers. (34) Notable horizontal curve problems for trucks are freeway on- and off-ramps. (35) There are number of possible mitigations for horizontal curve limitations, including warnings, enhancing delineation along the curve, providing adequate sight distance, widening the roadway, improved or restored super elevation (the road's cross section), or just modifying the horizontal alignment.
- In general, **narrow lanes** can reduce a trucks driver's margin of error in operating larger vehicles. Mitigation can include lane widening if there is right-of-way available or adding median barriers.
- **Tunnels and bridges** often have limitations similar to narrow lanes. Mitigation can include reconstruction to add height or width.
- The **number of lanes,** particularly on single lane roads, can delay trucks, because truck have difficulty passing slower vehicles, which causes queues to form. Lane drops are difficult locations for trucks because their slow acceleration rates and length make it more difficult to merge into traffic. Mitigation can include adding a lane, extend lanes to remove lane drops, or adding passing lanes on single lane roads.
- **Narrow shoulders** can slow truck travel because there is limited area to maneuver to avoid crashes and they also reduce the ability of a truck to turn at intersections. Mitigation can include shoulder widening if there is right-of-way available.
- Both **up and down grades** can reduce truck's speed. Because of a truck's power-to-weight limitation many trucks are slow going uphill. Truck drivers also brake going downhill to avoid going too fast. Mitigation of bottlenecks due to grades can be costly and include leveling and

changing the road slope, adding truck climbing lanes, or using tunnels to bypass the grades. Emergency runaway truck ramps also improve truck safety on steep downhill grades.

- **Intersections and merges** can be difficult for large vehicles. Intersection design can vary considerably but, for trucks, intersections on highways with partial or no access control present significant operational and safety concerns. Signalized intersections can also create truck bottlenecks particularly if not timed for a truck's slower acceleration patterns. Short freeway on-ramps or off-ramps can be a problem because trucks accelerate more slowly into traffic. There are many mitigation approaches for intersections. Fixes include altering signal timing, changing intersection angles and turn radius, lengthening ramps, adding turn lanes, and widening shoulders or medians. Another option is conversion to a roundabout.
- **Additional roadway factors** may impact truck travel independent of cars but may be harder to isolate using roadway attribute data. These factors could include poor sight distances, divided as opposed to undivided highways, and multiple driveways (due to access control). Knowledge of these factors can be used to make a field visit more effective.

7.6 Mitigation Options for Special Event Bottlenecks

Special event congestion is "routine" in that it occurs as a result of increased traffic volumes associated with specific events. However, the events themselves do not occur during normal weekday commute times and may only occur a limited number of times during the year.

Two specific types of "event" congestion delays are recreational travel and major event travel.

Two specific types of "event" congestion delays are recreational travel and major event travel. Recreational travel (trips to the beach or ski areas) are generally predictable by day of week and time of year. They tend to involve very heavy directional traffic volumes on one or two days of a week (to the beach on Thursday and Friday evenings, and home on Sunday afternoon and evening).

Freight bottlenecks form when these large traffic movements increase the background traffic. Mitigation typically includes deployment of traffic control plans specifically intended to handle the expected recreational traffic patterns, placement of incident response teams during peak recreational movements, and TDM efforts aimed at shifting the recreational travel to other modes (e.g., buses to ski areas) or less congested periods (e.g., "leave by 11 a.m. if you want to avoid the Thanksgiving exodus") based on analysis of historical travel patterns. The field analysis can provide the historical travel information needed to develop, optimize, and deploy these mitigation approaches.

Major event traffic tends to be even larger and more directional relative to typical background traffic. For example, large sporting events or public festivals (e.g., Fourth of July fireworks) attract very large crowds to the stadium area or park during the hours before the event start, and then a major exodus occurs when the event concludes. Typical mitigation involves the development of special traffic management plans, specifically designed to meet the size and timing of expected traffic. These plans typically involve hiring and deploying traffic management personnel and equipment.

7.7 Examples of Truck Bottleneck Mitigation Efforts

Many state DOTs have programs and budgets designed to locate, prioritize, and fix bottlenecks for all vehicles. There are a number of approaches to address roadway congestion, including capacity expansion, incident removal, and programmatic TDM. Typically, state DOTs fund travel speed-based approaches that improve travel for all vehicles and are not focused specifically on trucks. While the volume of trucks, or the importance of the road as a freight route, might change the funding priority of a bottleneck, in most cases, truck flow is improved simply because travel flow for all vehicles is improved.

MPO CMP plans were found to be a common place for truck bottleneck mitigation efforts due in part to their responsibility for air quality conformity, but also due to their role in retaining and creating jobs and promoting economic sustainability. In these instances, improving goods movement is typically a part of the larger long-range plan, and the project screening and prioritization process often considers goods movement benefits. Another observation is that CMP analyses typically focus on the most congested portions of the day (peak periods) and in many cases that is not when trucks are out on the road; therefore, some of the truck impact may not be captured in typical CMP analyses. The following documents provide good examples of how to mitigate truck bottlenecks. More information on each of these studies is provided in Appendix B.

- Delaware Valley Regional Planning Commission (DVRPC) 2012 Congestion Management Process (CMP);
- Application of Congestion Management Process (CMP) Strategies in Miami-Dade County;
- Tampa Bay Regional Strategic Freight Plan;
- Southern California Council of Governments (SCAG) Regional Transportation Plan—Congestion Management, Goods Movement, and Truck Bottleneck Strategy;
- Mitigation of Recurring Congestion on Freeways;
- Improving Safety and Operation with Low-Cost Freeway Bottleneck Removal Projects; and
- Framework for Analysis of Recurring Freeway Bottlenecks.

7.7.1 Florida DOT Example of Mitigating Truck Bottlenecks

Many transportation agencies have asset inventories in GeoData catalogs that can be extracted and analyzed using GIS software. (36, 37) Figure 7-2 is an example roadway GeoData catalog for the Florida DOT. The use of these databases with GIS software enables spatially

Source: http://www.dot.state.fl.us/planning/statistics/gis/roaddata.shtm.

Figure 7-2. Example GeoData catalog from the Florida DOT.

linking segments identified as a bottleneck to different geometric characteristics of that roadway segment.

7.7.2 Washington State DOT Example of Mitigating Truck Bottlenecks

Specific roadway attribute data can be used to indirectly or directly identify possible bottleneck causation. For example, Table 7-2 lists general infrastructure attributes that potentially impact truck operations and associated roadway geometric infrastructure attributes as found in the Washington State Department of Transportation's (WSDOT's) GeoData catalogs.

Some roadway attributes such as steep grades can be readily assigned as a source of truck delay. Other causes, such as intersection type, may only be suggested by the GIS process and will require a field check and local knowledge to develop bottleneck causation.

This case study is an example of a desktop exploration of a truck bottleneck using a GIS software desktop and WSDOT's GeoData catalog (Figure 7-3). Ideally, this process will be followed up with local knowledge and a field check.

The Figure 7-3 bottleneck location is a rural section of Interstate 90 in Washington State (roughly mileposts 79.0 to 80.5). The roadway is a divided highway and is two lanes each way with a posted speed limit for trucks of 60 mph. Probe GPS data from WSDOT's Freight Performance Measurement Program (38) indicates that, for westbound travel, an average truck travel speed is 48 mph with 38 percent of trucks traveling below 60 percent of posted speed limit. WSDOT considers this roadway segment a freight corridor of the highest importance with an average volume of 6,000 trucks per day [State Freight and Goods Transportation System (FGTS) truck tonnage classification of T-1 with more than 10 million gross ton per year].

A GIS-based exploration of the attributes of this roadway section suggests a number of roadway attributes that might slow trucks and create this bottleneck:

- The GeoData catalog indicates the roadway is a divided highway with standard lanes and shoulder widths and without any special lanes (such as a truck climbing lane). The legal speed limit for this roadway section for trucks (60 mph) can also be found in the catalog.
- In WSDOT's data catalog, the terrain for this roadway section is noted as *rolling*. Extraction of vertical alignment data shows a 3.75 percent grade around milepost 77.0. The typical maximum allowable grade on Interstates is 6 percent.
- The horizontal alignment data indicate the roadway has a tight curve also around milepost 77.0 (on the grade).
- The DOT's mapping functions and intersection inventory indicate an intersection at milepost 77.2, which has an on-ramp resulting in merging traffic. This ramps merges from a weigh station that indicates, when the station is open, many trucks are trying to merge into traffic. An on-ramp just upstream serves all traffic (milepost 77.8).
- At the top of the curve, the GeoData catalog identifies a 250-foot-long bridge over a river (milepost 76.05). Considerable extra information is available from WSDOT as to the bridge's height and width and for any bridge-related truck restrictions.

This GIS analysis indicates a variety of roadway attributes that can slow trucks include a merging from a weigh station, a merge with all traffic, a curve on a grade, and a bridge.

This is an example of how detailed roadway attributes can support an analysis of roadway characteristics and can assist in analyzing bottlenecks. This type of analysis is better supported by specific short roadway segments (on the order of 1 mile or so in length), which allows a focus on and identification of specific roadway attributes. Longer segments (such as found for many of the TMC segments in rural area as used by NPMRDS) are less usable when analyzing specific roadway geometrics.

Table 7-2. Bottleneck characteristic and supporting data in WSDOT's GeoData catalog.

Bottleneck Characteristic	Roadway Feature Measured	Supporting Variables Available in WSDOT's GeoData Catalog
Truck swept path width (turn area)	Tight curves at intersections cause trucks to track off the roadway	• Horizontal alignment • Intersection information
Vertical curves	Alignment of rolling roads with sight distance and headlight distance limitations	• Roadway Vertical Alignment • Design Speed Vertical Curves
Horizontal curves	Radius of tight curves that can contribute to running off the road or rollovers and a need for trucks to slow down	• Roadway Horizontal Alignment • Design Speed Horizontal Curve Where Design Speed Is Greater Than or Equal to 20 • Roadway Design Speed Horizontal Curve Where Design Speed Is Less Than 20
Lane width	Roads with narrow lanes slow trucks	• Lane Width • Roadway Special Use Lanes (Truck Climbing Lanes, Acceleration Lanes) • Medians
Number of lanes	Two-way, two-lane roads and lane drops can be slower for trucks and passing slow vehicles is a challenge	• Number Of Lanes • Roadway Special Use Lanes (Truck Climbing Lanes, Acceleration Lanes) • Medians
Shoulder width	Width of shoulder—narrow shoulders contribute to slow truck travel	• Shoulders Width (Inside And Outside)
Grades	Uphill grades slow a truck because of truck power-to-weight limitation Downhill grades require trucks to brake to avoid excess speeds	• Terrain Type • Vertical Curves • Special Use Lanes (Climbing Lanes) • Grades (Calculated Using Readily Available Outside Data)

(continued on next page)

Table 7-2. (Continued).

Bottleneck Characteristic	Roadway Feature Measured	Supporting Variables Available in WSDOT's GeoData Catalog
Intersections and ramps (curb return radii at intersection and ramps)	Certain intersections can be difficult for trucks due to tight turning radii, poor sight distance and signal timing that does not match a truck's acceleration rates	• Intersections Type (Signalized Or Nonsignalized and Other Information) • Ramps • Turn Lanes • Functional Class
Other Information	Truck relevant route and other travel factors that might support a field analysis	• Freight and Goods Transportation Systems Routes (Truck Relevant Routes) • Truck AADT • Divided Highways • Urban-Rural • Bridges • Mileposts

Figure 7-3. Bottleneck location with example roadway GIS attribute data – intersections, grade, and mileposts.

CHAPTER 8

Incorporating Truck Bottleneck Analysis into the Planning Process

This chapter describes how to incorporate truck freight bottleneck analysis into typical planning study documents. This is followed by several examples of truck freight bottleneck analysis and how they were—or could be—incorporated into planning studies.

8.1 Incorporation into Study Documents

There are several types of planning studies that can benefit from incorporation of a truck bottleneck analysis. These studies include:

- Statewide, MPO, and local freight plans;
- Statewide, MPO, and local general long-range transportation plans;
- Freight-intensive corridor studies;
- Local and regional truck route designation studies;
- Modal diversion studies for freight;
- Statewide, regional, or corridor-specific safety studies;
- Multimodal bottleneck analyses;
- Emissions estimation studies requiring detailed speed inputs; and
- Economic development studies focused on infrastructure improvement.

The tasks used to implement planning studies tend to fall into a set of activities that can be used as a pivot point with which to understand the relevance of truck bottleneck analysis. Table 8-1 shows how truck bottleneck analysis can be incorporated into tasks that are typically associated with planning studies.

8.2 I-95 Truck Bottleneck Analysis in North Carolina

For the North Carolina DOT I-95 Economic Impact Study, a truck bottleneck analysis was conducted to identify bottleneck locations along the corridor. As a first step, a truck GPS dataset containing spot speeds for activity during June 2012 was produced, and all data points that fell along the I-95 corridor in North Carolina were compiled. The roadway was segmented bi-directionally at each mile of the 182 centerline miles to produce a shapefile with 364 bi-directional segments. The compiled data points were then matched to the 364 1-mile road segments. Within each of the 364 data bins, the data were separated further by day of week (Mo–Sun) and hour of day to produce 61,320 data bins.

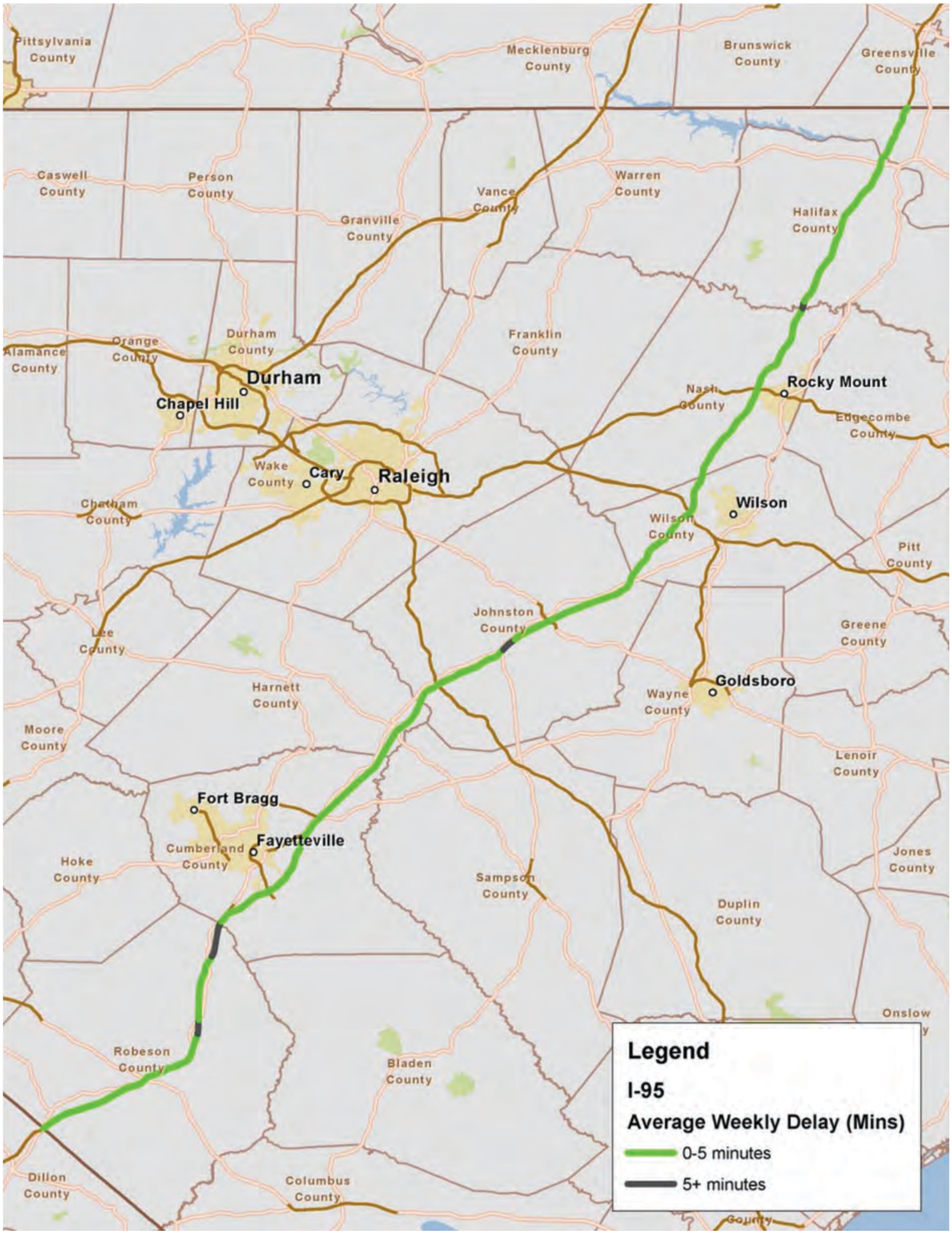
An average speed was produced for each bin and the results were scanned for congestion. The scan focused on data bins where average speeds within a segment fell below 85 percent of the free-flow speed at some point during a week. For this analysis, free-flow speed was considered to

Table 8-1. Incorporation of bottleneck analysis into planning studies using generic tasks.

Task in Planning Study	Incorporation of Bottleneck Analysis
Existing Conditions	• Essential data collected for bottleneck analysis (speed and volume) can be used as part of the description of existing conditions. See Chapters 3 and 4 of this document. • Desktop analysis to identify and quantify bottlenecks (Chapter 5 of this document) can be used to describe existing conditions for trucks on the road network.
Future Baseline Conditions	• Travel demand models can be augmented by using bottleneck analysis as the source of delay estimates in the base year, then increasing delay proportional to increases in V/C ratios provided by the travel demand model.
Identification of Needs	• The causal analysis described in Chapter 6 can be used to identify needs in the system. For example, if a large percentage of truck bottlenecks are caused by crashes, then this indicates the need for safety improvements.
Identification of Solutions to Consider	• Mitigation options described in Chapter 8 can be used as a source of solutions to consider for the planning study. Field analysis described in Chapter 7 can also be used to identify solutions.
Analysis of Solutions and Development of Recommendations	• The ranking of causes of bottlenecks (see Chapters 6 and 7) can be used to prioritize solutions that are recommended. For example, if the majority of truck bottlenecks at a particular location are based on weather, then solutions that are targeted towards improving the road's ability to handle inclement weather may be given a 30 percent increase across a scoring method for solutions.
Outreach	• Draft results of bottleneck analyses should be presented to public-sector and private-sector stakeholders to validate locations of bottlenecks, severity of bottlenecks, potential causes of bottlenecks, and mitigation options to consider for addressing bottlenecks.

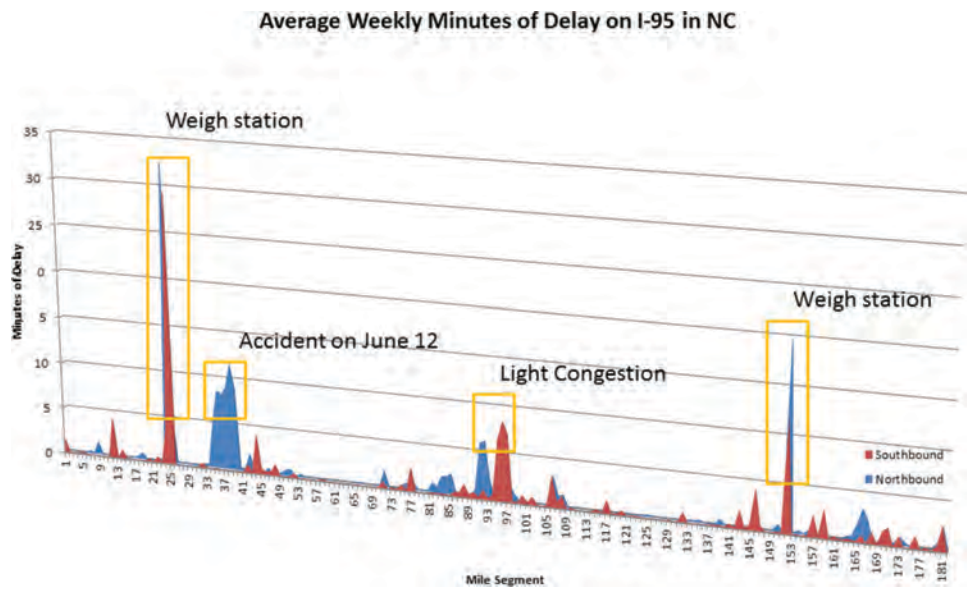
be the maximum average speed across all one hour time bins. Bins that fell below the 85 percent criteria were flagged for further congestion analysis, which included a calculation of average minutes of delay per week. Of the 61,320 bins, 1,491 showed this level of congestion.

A total of 15 of 364 segments experienced delays greater than 5 minutes per week using the methodology described above. The locations where the delays occurred are shown in Figures 8-1 and 8-2. Figure 8-1 is a map that illustrates noticeable, measurable delay found during this scan.



Source: NCDOT I-95 Economic Impact Analysis.

Figure 8-1. I-95 Truck bottleneck locations in North Carolina based on truck GPS data.



Source: NCDOT I-95 Economic Impact Analysis.

Figure 8-2. I-95 truck bottlenecks in North Carolina by mile segment.

Figure 8-2 offers a more detailed look of where and why weekly minutes of delay occurred. Based on the data displayed in Figure 8-2, the areas where the greatest minutes of delay occurred on the corridor were two weigh stations. Based on overlapping crash data with the truck bottleneck analysis periods, it was determined that delay also occurred due to an accident in Robeson County, as well as due to light congestion in Johnston County.

On June 12 and 14, 2012, the corridor had the highest number of congested mile-hours (82) while June 24 had the least number of congested mile-hours (6). For context, there were a total of 8,736 mile-hours on the corridor in June 2012, meaning that on the most congested day, roughly one percent of mile-hours was congested. For the month, there were a total of 1,268 congested mile-hours out of 262,080 total mile-hours of travel.

Most of the noticeable areas of congestion on the corridor are directly related to weigh stations and likely do not impact passenger vehicles. Four of the top five mile segments that have congestion are adjacent to a weigh station facility a few miles north of Lumberton. The lower speeds appear in the database at those locations as trucks slow down to exit or increase speed leaving the weigh station. It is possible that queues extending onto the highway at these weigh stations contribute to the lower speeds.

These four weigh station segments taken together account for 396 congested mile-hours, which represents 30.9 percent of the total monthly congested mile-hours for the corridor. Mile segment 152 also contains a weigh station and contributed 154 congested mile-hours (12.1 percent of monthly total). Table 8-2 lists the 20 mile segments with the highest congestion levels.

Regarding time of day, the highest levels of congestion occur between 10 a.m. and 3 p.m. As noted in the preliminary congestion scan, much of that congestion is related to weigh stations. Thus, given that weigh station activity is generally heaviest during the midday hours, this analysis further validates the findings of the preliminary congestion scan. A day-of-week analysis reveals that Tuesday has the highest number of congested mile-hours (273) and Sunday has the lowest number (39). Tables 8-3 and 8-4 describe these results further.

Table 8-2. Top 20 congested locations on I-95 in North Carolina based on truck GPS data.

Top 20 Locations	Mile Segment	Number of Days with Some Congestion (0 to 30)	Number of Hours with Some Congestion (0 to 720)
1	24_N	21	124
2	25_S	22	120
3	152_N	23	90
4	24_S	23	75
5	25_N	23	73
6	152_S	21	64
7	95_S	5	20
8	181_N	13	19
9	97_S	11	19
10	181_S	13	18
11	93_N	6	17
12	71_N	13	15
13	48_S	11	15
14	97_N	11	15
15	94_S	4	14
16	96_S	4	14
17	92_N	3	13
18	106_S	9	12
19	71_S	10	10
20	91_N	3	10

Source: NCDOT I-95 Economic Impact Analysis, 2013.

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Table 8-3. Congestion by hour of day on I-95 in North Carolina based on truck GPS data.

Hour		Number of Mile-Days of Congestion
Begin Hour	End Hour	
0	1	3
1	2	6
2	3	7
3	4	11
4	5	9
5	6	28
6	7	49
7	8	61
8	9	84
9	10	98
10	11	121
11	12	112
12	13	124
13	14	120
14	15	111
15	16	90
16	17	99
17	18	51
18	19	35
19	20	22
20	21	12
21	22	10
22	23	2
23	24	3

Table 8-4. Congestion by day of week on I-95 in North Carolina based on truck GPS data.

Day of Week	Number of Mile-Hours of Congestion
Monday	160
Tuesday	273
Wednesday	239
Thursday	258
Friday	210
Saturday	89
Sunday	39

Source: NCDOT I-95 Economic Impact Analysis, 2013

8.3 Mapping of Truck Speeds in Indianapolis

Figure 8-3 shows truck speed data in a subarea of Indianapolis at the intersection on I-70 and I-465. This Figure shows the spot speed of thousands of truck speeds using truck GPS data provided by the ATRI. This data has been mapped to aerial information, which allows for overlapping of land use data, truck count data, and other vehicle activity data.

These data also show thousands of red dots in the subarea, which highlight truck parking locations. This is a strong indication of the locations where internal-external and external-internal truck trips are being generated in the subarea. The facilities nearby these dots are the specific locations that are most heavily impacted by the truck congestion that has been identified.

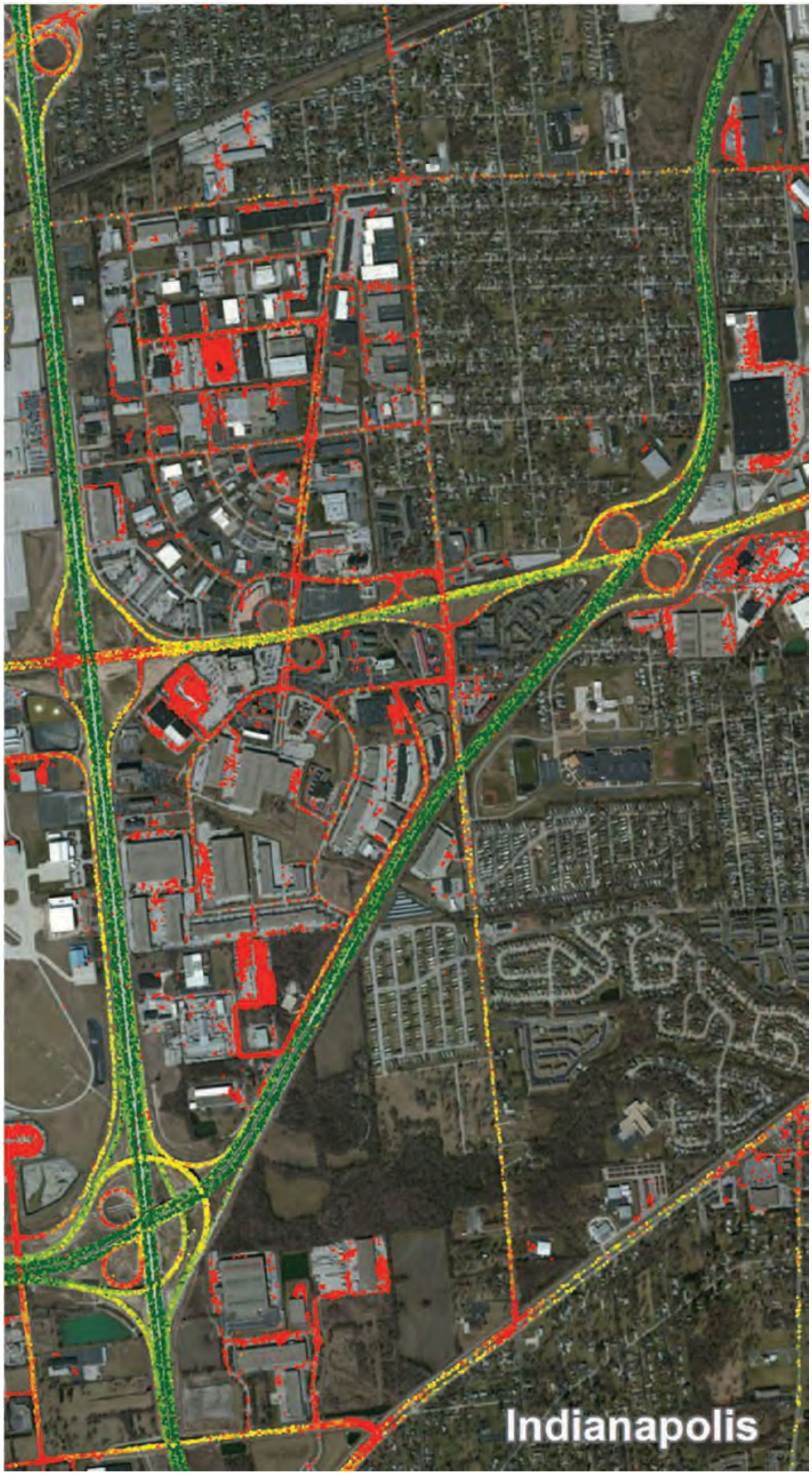
8.4 Truck Bottleneck Analysis in Downtown Valdosta, Georgia

Truck speeds and delay in downtown Valdosta were measured using FHWA NPMRDS as part of a study of downtown truck traffic. The NPMRDS provided average truck and total vehicle speeds on NHS routes in the U.S. Both U.S. 84 and U.S. 41 are part of the NHS network. Truck congestion in the downtown area was analyzed using truck speed data during the afternoon peak period of 5:00 p.m. to 6:00 p.m.

Figure 8-4 shows the average weekday truck speeds in April of 2015 during the afternoon peak period. Average truck speeds along U.S. 84 range from about 15 to 35 miles per hour. In downtown Valdosta, average speeds are generally under 25 miles per hour. Similarly, truck speeds along U.S. 41 Business from SR 31/Madison Highway south of downtown to SR 125/Bemiss Road north of downtown average between 15 and 35 mph. Average speeds along U.S. 41 Business south of Madison Highway are significantly higher as it is further removed from the core of the city. This compares to a range of posted speed limits on U.S. 41 that drops down to 25 mph within downtown and rises to 45 mph outside of downtown.

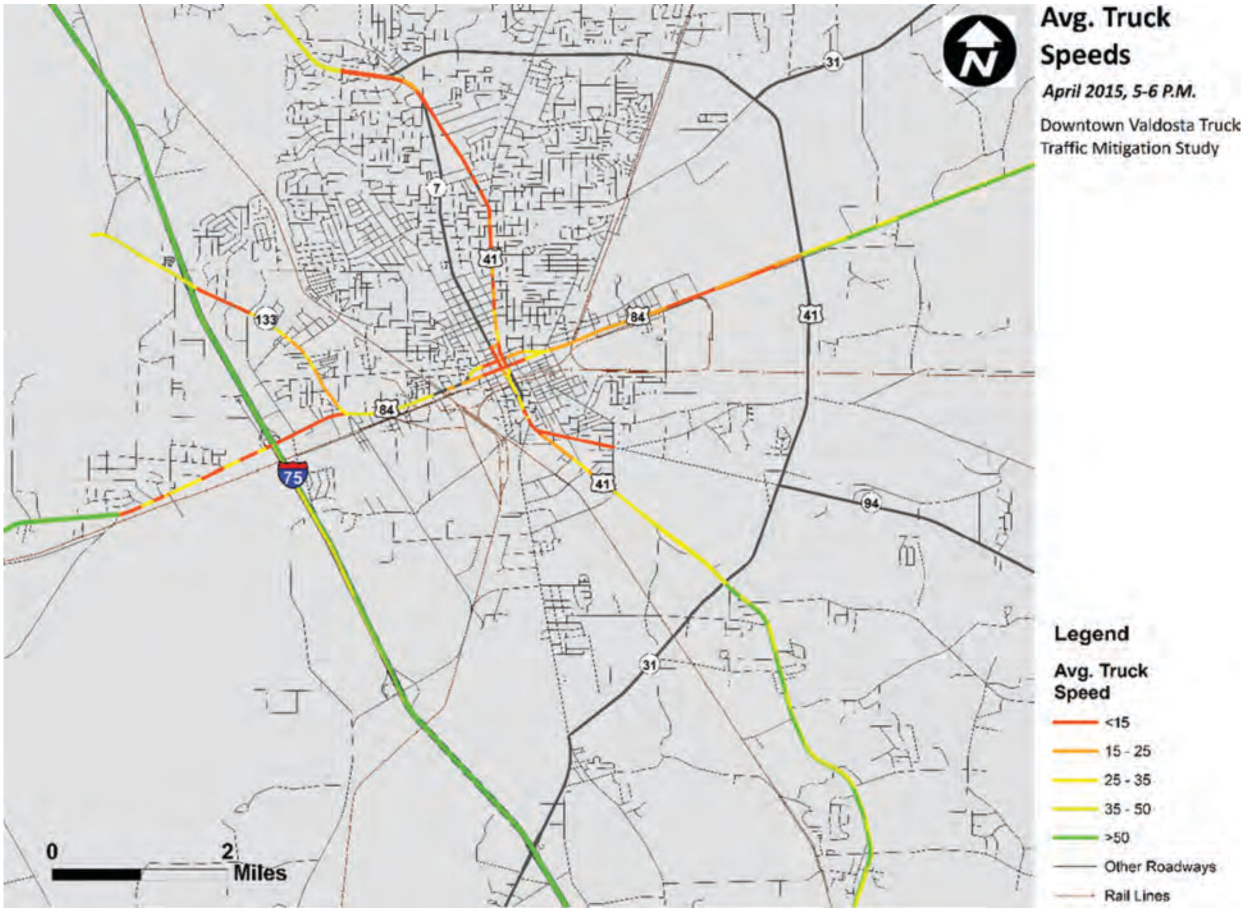
Truck delay was then estimated by combining truck count data with truck speed data. Truck delay is measured as the difference between actual travel time and free-flow travel time multiplied by the hourly truck volume. The formula for calculating delay is as follows:

$$\text{Truck Delay} = [(\text{Distance}/\text{Actual Truck Speed}) - (\text{Distance}/\text{Free-Flow Truck Speed})] * \text{Hourly Truck Volume}$$



Source: ATRI Truck GPS Data, 2015.

Figure 8-3. Bottleneck map in Indianapolis subarea with roadway GIS attribute data, I-70 and I-465.



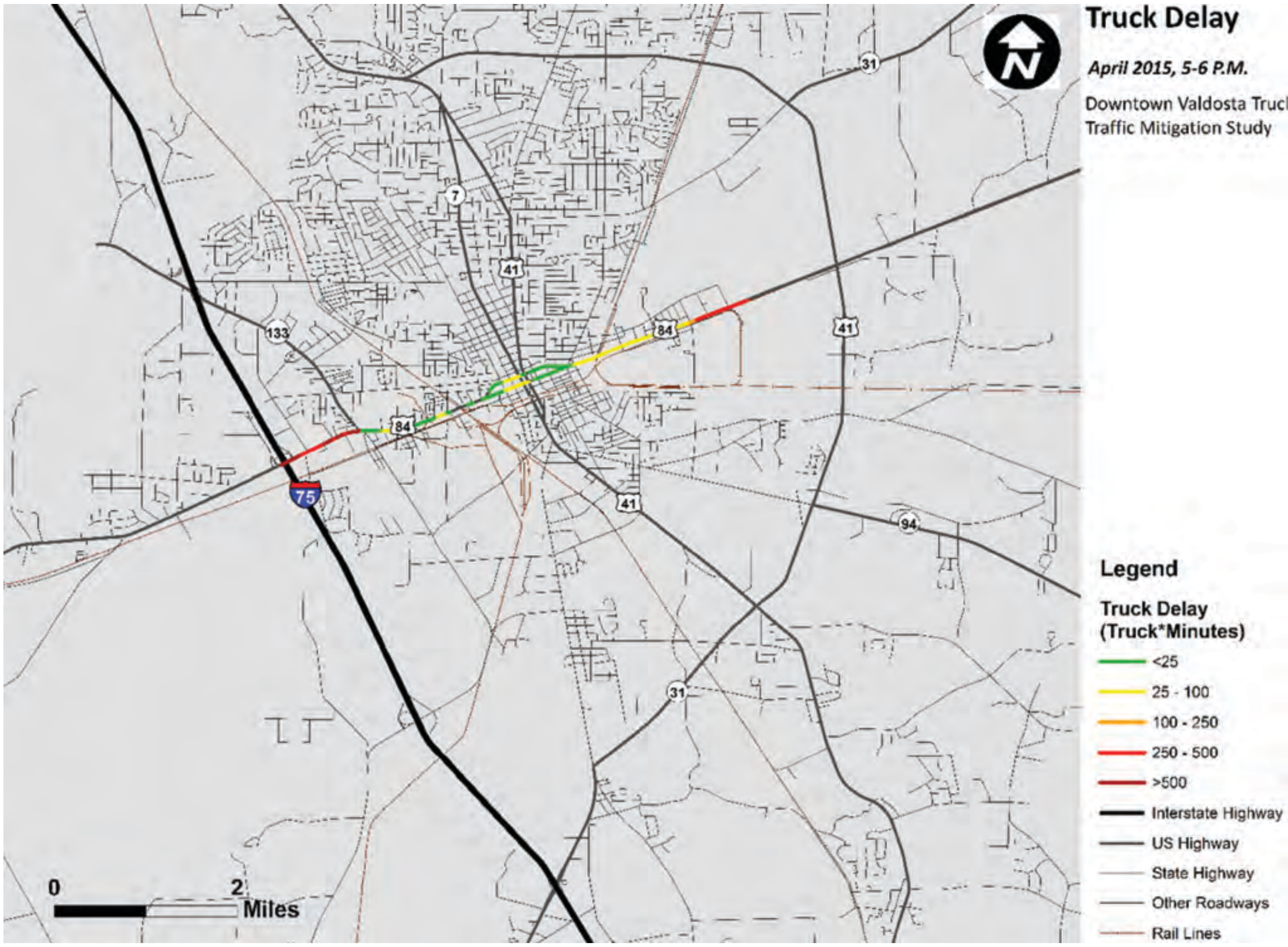
Source: Downtown Truck Traffic Mitigation Study, Valdosta-Lowndes County MPO, 2015.

Figure 8-4. April 2015 average weekday truck speeds, 5–6 p.m.

Truck delay through downtown Valdosta was found to be relatively low. As depicted in Figure 8-5, for the month of April of 2015, delay along U.S. 84 is much higher outside of the core downtown area. The most significant delay on U.S. 84 occurs in two locations: (1) between SR 133/Street Augustine Road and I-75 and (2) between Clay Road and U.S. 41/Inner Perimeter Road as shown.

8.5 Truck Bottleneck Analysis in Idaho Statewide Freight Plan

A truck GPS analysis was conducted in Idaho to identify truck bottlenecks. It was also overlapped with truck volume data provided by the Idaho Transportation Department to identify the most critical truck bottleneck locations in the state. Based on the analysis, the stretch of I-84 from Caldwell through Boise is the only stretch of highway in Idaho that experiences congestion on a recurring basis. The section of I-84 east of this segment to the interchange with I-84 is also heavily utilized, with average daily truck traffic between 5,000 and 6,000 vehicles. These portions of the Interstate system serve the largest urban area in the state and link it to the Salt Lake City market, including intermodal facilities, and destinations further east. The remaining Interstate segments in Idaho all carry between 1,000 and 5,000 trucks per day. In addition to the stretch of



Source: Downtown Truck Traffic Mitigation Study, Valdosta-Lowndes County MPO, 2015.

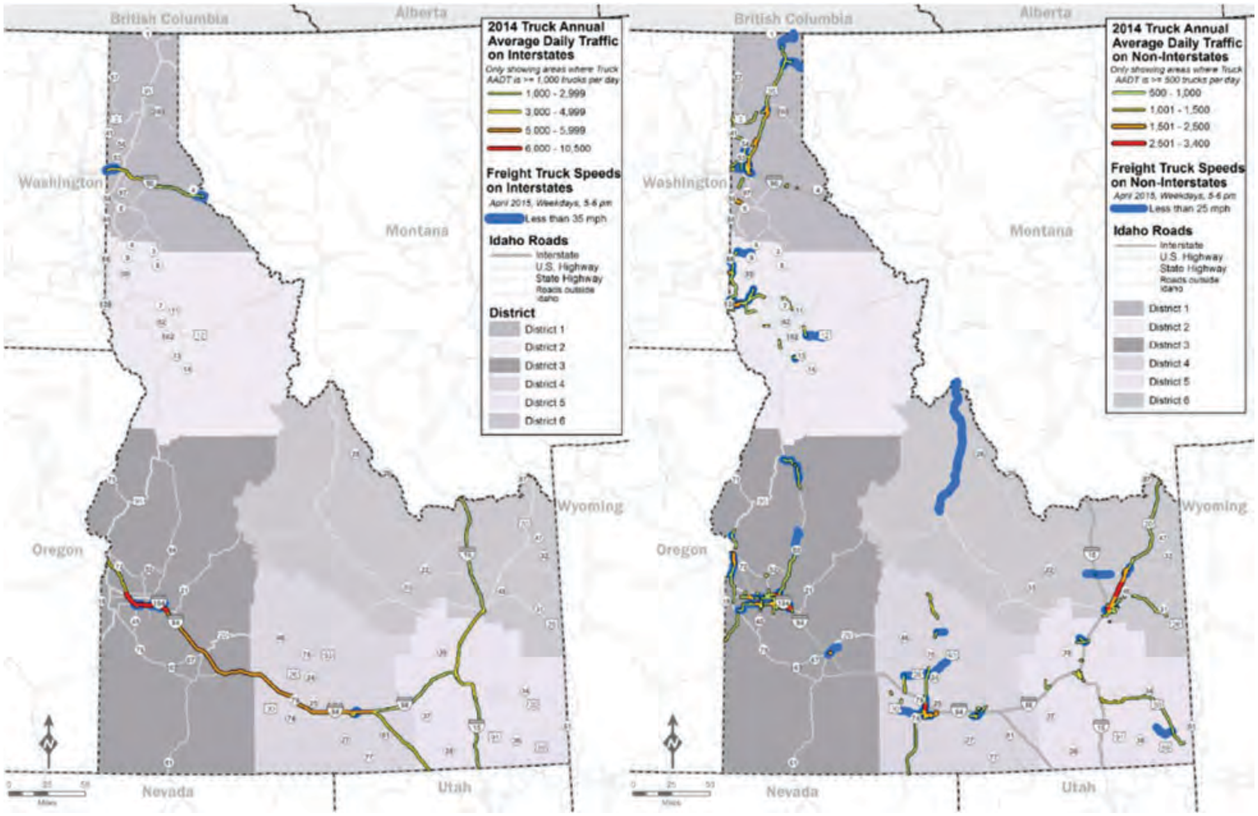
Figure 8-5. Truck minutes of delay per day in evening peak, April 2015, 5:00–6:00 p.m.

I-84 identified above, truck speeds are also low on I-90 at both the Oregon and Montana borders, as well as a short stretch of I-84 near Burley.

The low truck volumes on I-90 for this time period indicate that the slow speeds are likely due to other vehicle congestion caused by rush hour (near Coeur d'Alene) and terrain (near Montana). Burley and Oakley to the south are important industrial and agricultural areas with numerous freight-reliant industries and truck AADT above 5,000, indicating that at least some of the slow speeds are likely due to freight-related congestion as trucks enter and leave the Interstate.

The highest non-Interstate truck volume is found on U.S. 20 north of Idaho Falls. Segments of this route carry an average of 3,400 trucks per day. Areas with high truck AADT and low speeds include the Twin Falls area, eastern Boise, U.S. 20 north of Idaho Falls, and the Coeur d'Alene area. Figure 8-6 shows truck volume and locations where speeds were below 35 mph on the Interstate system, or below 25 mph on the state highway system, between 5 p.m. and 6 p.m. on weekdays in April 2015.

The locations of truck bottlenecks in Idaho were later confirmed through a series of outreach efforts, including a combination of group stakeholder meetings and one-on-one interviews. Specifically, these maps were presented in both environments for comment by private-sector freight community members and public-sector transportation agency staff.



Source: NPMRDS, ITD.

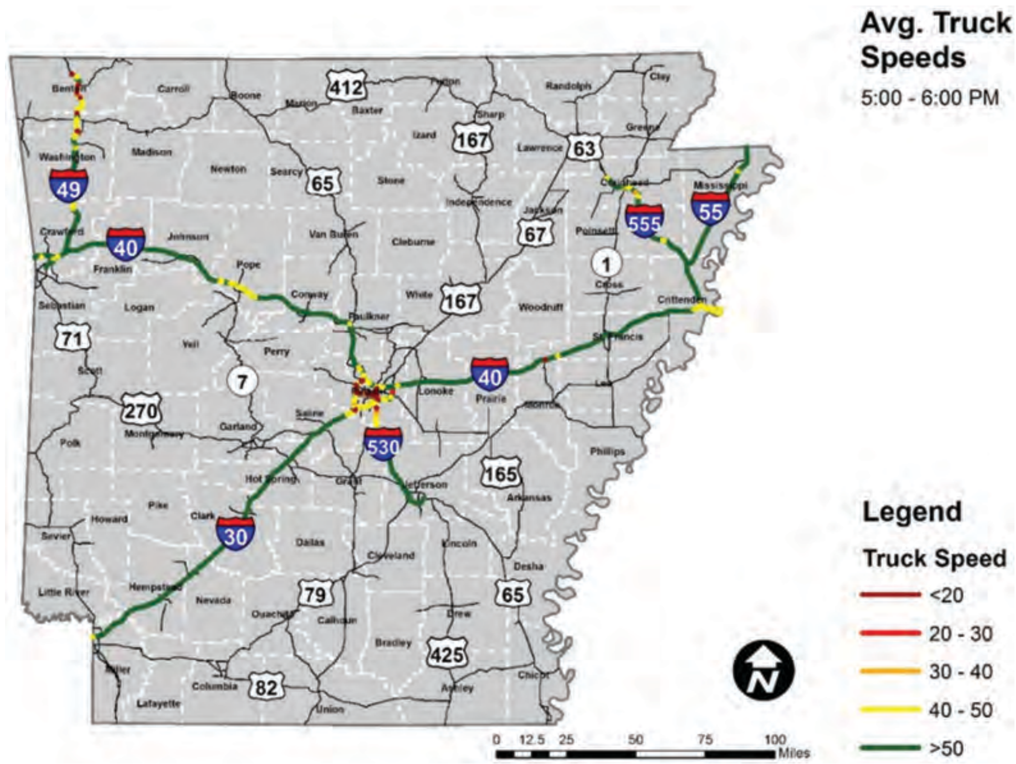
Figure 8-6. Truck speeds below 35 mph (Interstates) and 25 mph (non-Interstates) in p.m. peak and truck AADT.

8.6 Truck Bottleneck Analysis in Arkansas

Truck GPS data from March of 2015 were used to determine truck speed performance throughout Arkansas. The GPS data were used to determine average truck speeds during different periods throughout the day on both Interstates and non-Interstates. They also were used to determine difference between truck speeds during congested periods and free-flow periods.

Figure 8-7 shows truck speeds on Interstates in Arkansas during the 5:00 p.m. to 6:00 p.m. afternoon peak period in March of 2015. Much of the truck congestion on the state's highway system was found to be centered on the Little Rock metropolitan area. Average truck speeds in Little Rock generally are between 25 and 35 mph in the peak directions of travel. There also are truck mobility challenges in other population centers, notably northwest Arkansas (in the cities of Fayetteville and Bentonville) and the Jonesboro metropolitan area. In particular, I-49 in northwest Arkansas between Fayetteville and Bentonville has relatively significant truck congestion during the peak periods. Much of I-49 between these two cities consists of only two lanes in each direction, which is likely a contributing factor. I-555 in Jonesboro also shows some truck congestion during the peak periods, though not to the same extent as the Little Rock and northwest Arkansas regions. Much of I-555 also consists of two lanes in each direction.

Truck GPS was also used to estimate truck speed reliability of the Arkansas Interstate system. Reliability is a measure of the variation of truck speeds over a long time period. Truck speed reliability is a critical operational issue for shippers and truck fleet operators. It causes trucks to build in a significant buffer time in to their delivery windows to ensure that they meet the desired level of on-time performance for their shipments.



Source: ATRI truck GPS data, consultant analysis.

Figure 8-7. Average p.m. peak-hour truck speeds on Interstates.

Reliability was calculated by using the average truck speed and standard deviation of truck speeds for each highway link. From these values, the percent deviation is calculated by dividing the standard deviation of truck speeds by the average truck speed and multiplying the resulting value by 100 percent using the following formula:

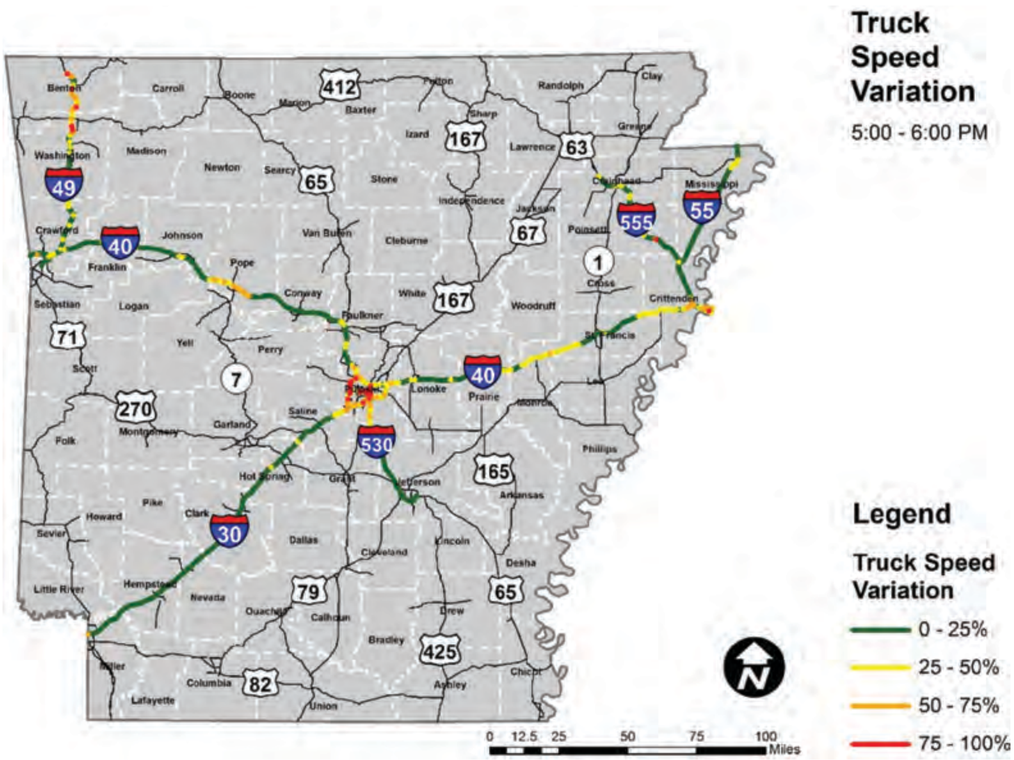
$$\text{Truck speed reliability} = (\text{Truck Speed Standard Deviation})/(\text{Average Truck Speed}) * 100\%$$

Truck speed reliability values that are close to 0 percent indicate that truck speeds do not vary greatly during the observation period. Values that are close to 100 percent indicate that truck speeds vary significantly.

Figure 8-8 shows the truck speed reliability on the Arkansas Interstate system during the p.m. peak hour. Locations of low truck reliability are similar to locations that exhibit high levels of congestion. In the Little Rock region, truck speeds on portions of the Interstate highway system are estimated to vary by as much as 75 percent to 100 percent during the p.m. peak period.

Truck speeds show significant variation in some other parts of the state as well, particularly northwest Arkansas, Jonesboro, and the west Memphis regions. In northwest Arkansas, portions of I-49 near Bentonville show relatively high variations in truck speed, though not to the extent observed in Little Rock. Truck speeds along sections of I-40 near West Memphis and I-555 near Jonesboro exhibit truck speeds that vary by as much as 50 percent to 75 percent during peak periods.

The I-40 corridor between Little Rock and Memphis is notable in that it exhibits much higher levels of unreliable truck speed locations relative to truck congestion locations. This indicates that, while congestion on the corridor is not a daily occurrence, the variation in truck speeds is causing significant impedance to truck activity on I-40.



Source: ATRI truck GPS data, consultant analysis.

Figure 8-8. PM peak-hour truck speed reliability on Arkansas Interstates.

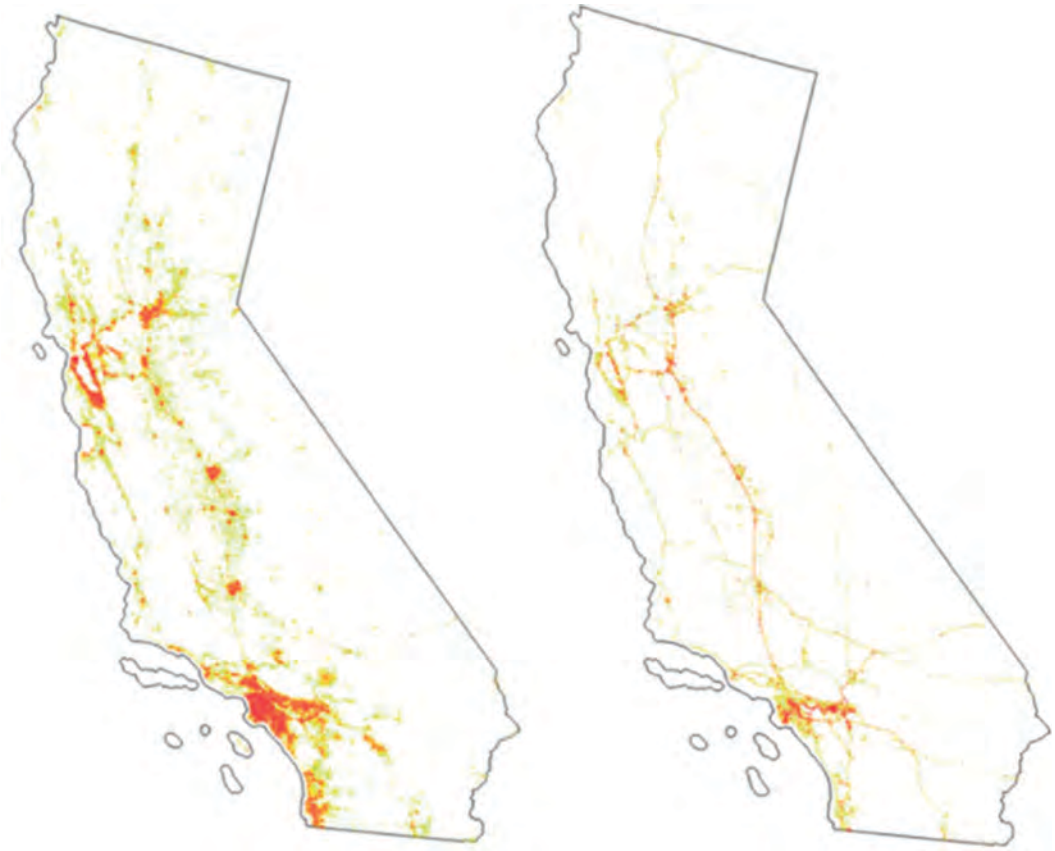
8.7 Truck Parking Analysis in California

Truck GPS was also used to conduct a truck parking analysis in California. Lack of truck parking is a potential cause of process-based truck delay through the additional time and distance that may be driven as truck drivers search for parking. In this example, every square mile in California was scanned to identify regions with high levels of truck parking. Medium- and heavy-duty trucks were scanned separately. As shown in Figure 8-9, medium-duty truck stops tend to be more diffuse and in urban areas. Separate analysis showed that heavy-duty truck parking tends to be along major highways.

A "zoomed in" view was used to examine the heavy-duty parking locations. Figure 8-10 shows heavy-duty truck parking concentrations in northern Alameda County. The analysis was used to identify both expected and unexpected locations of industrial activity. Stakeholders at these locations are most heavily impacted by truck bottlenecks in the region. These stakeholders can be included in outreach activities that are used to determine the causes of bottlenecks and propose potential mitigation actions for these bottlenecks.

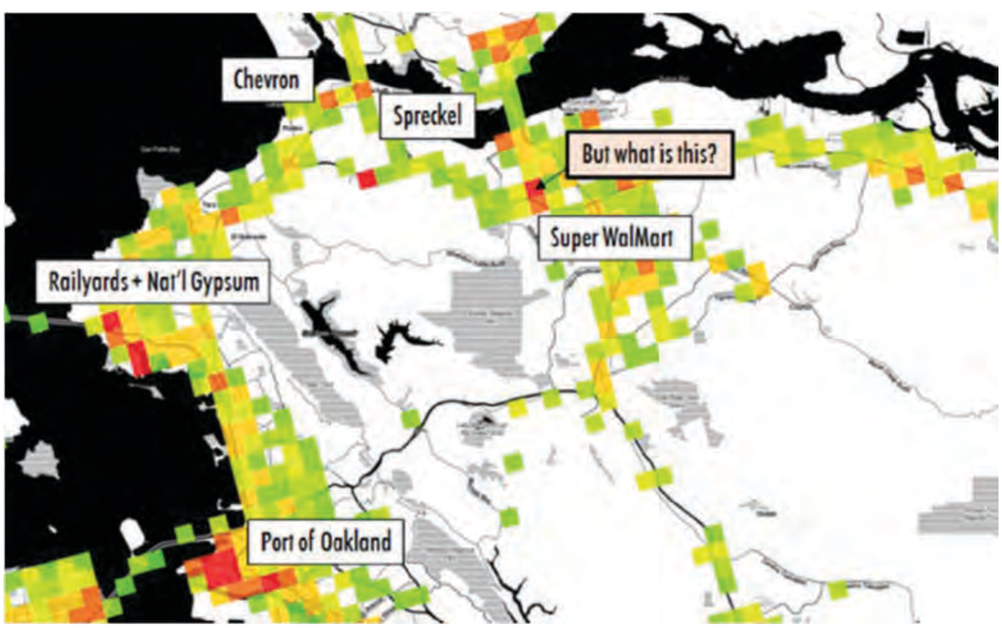
8.8 Truck Bottleneck Analysis in Georgia

A truck bottleneck analysis was conducted as part of the Georgia Statewide Freight & Logistics Plan. Truck GPS data was used to estimate truck travel speeds throughout the state during four time periods. This example demonstrates the breadth of analyses that can be done using truck GPS data. Figure 8-11 shows the truck speeds mapped for the morning peak period for the state. It shows that the primary bottleneck locations are in the Atlanta metropolitan region, which were then featured in a series of maps such as the morning peak truck travel speed map shown



Source: *Scanning California for Truck Stops*. StreetLight Data. http://blog.streetlightdata.com/truck-stop-index. Accessed December 9th 2016.

Figure 8-9. Heat map of truck stops for medium-duty trucks in California.



Source: *Scanning California for Truck Stops*. StreetLight Data. http://blog.streetlightdata.com/truck-stop-index. Accessed December 9th 2016.

Figure 8-10. Heavy-duty truck stops in northern Alameda County.

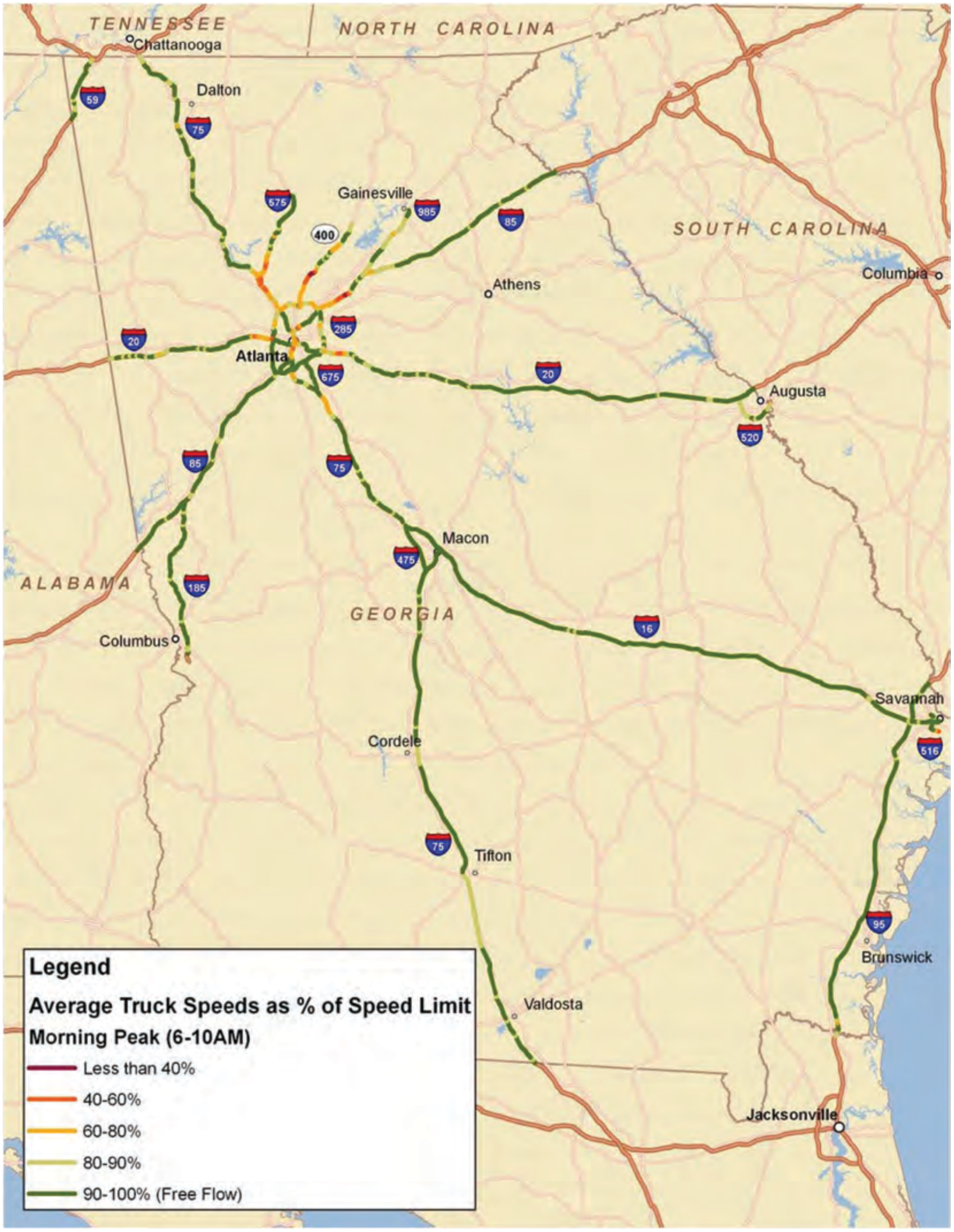


Figure 8-11. Average truck speeds as a percent of speed limit (morning peak period).

in Figure 8-12. The truck speed analysis was also used to identify the key congested corridor segments in the Atlanta metropolitan region. These are shown in Figure 8-13.

For each of the congested corridor segments, a series of maps was developed and analysis was conducted to provide detailed information on the nature of the bottlenecks. Table 8-5 shows the average truck speeds on each segment during each period of the day. Figure 8-14 shows the average speed by time period by milepoint, truck travel speed reliability by milepoint, and reliability by time of day for the entire congested corridor in the westbound and eastbound direction for a 6-mile segment on I-20 in Atlanta.

Source: GDOT Freight & Logistics Plan, 2012.

Figure 8-12. Average truck speeds as a percent of speed limit in Atlanta Metropolitan region using truck GPS data (morning peak).

Figure 8-13. Map of congested corridors in Atlanta metropolitan region based on truck GPS data.

Table 8-5. Summary truck speed statistics on congested corridors in Atlanta metropolitan region based on truck GPS data.

Corridor	Direction	A.M. Peak Average Speed	Midday Average Speed	P.M. Peak Average Speed	Off-Peak Average Speed
I-20 Miles 47-52	EB	38.2	52.6	54.6	58.7
I-20 Miles 47-52	WB	56.8	56.7	51.0	56.8
I-20 Miles 66-72	EB	59.5	58.2	39.9	56.9
I-20 Miles 66-72	WB	47.0	55.5	54.0	57.0
I-75 Miles 217-231	NB	55.9	59.5	55.0	61.7
I-75 Miles 217-231	SB	62.9	60.4	47.1	62.2
I-75 Miles 243-251	NB	40.1	52.5	39.7	55.7
I-75 Miles 243-251	SB	51.9	51.5	38.0	56.2
I-75 Miles 257-275	NB	61.7	60.2	39.3	60.1
I-75 Miles 257-275	SB	45.7	58.6	58.8	62.0
I-85 Miles 95-110	NB	60.6	59.9	48.3	60.4
I-85 Miles 95-110	SB	43.5	57.7	57.0	61.8
I-285 Miles 8-15	Inner Loop	54.5	58.9	55.7	59.5
I-285 Miles 8-15	Outer Loop	58.6	56.5	42.8	58.3
I-285 Miles 21-35	Inner Loop	50.9	56.6	37.0	57.5
I-285 Miles 21-35	Outer Loop	50.9	56.1	40.0	58.1
I-285 Miles 46-50	Inner Loop	60.5	60.5	58.0	61.6
I-285 Miles 46-50	Outer Loop	54.2	57.7	46.3	58.1
GA 400 Miles 7-20	NB	58.3	59.8	52.7	60.0
GA 400 Miles 7-20	SB	40.1	57.7	50.4	60.4

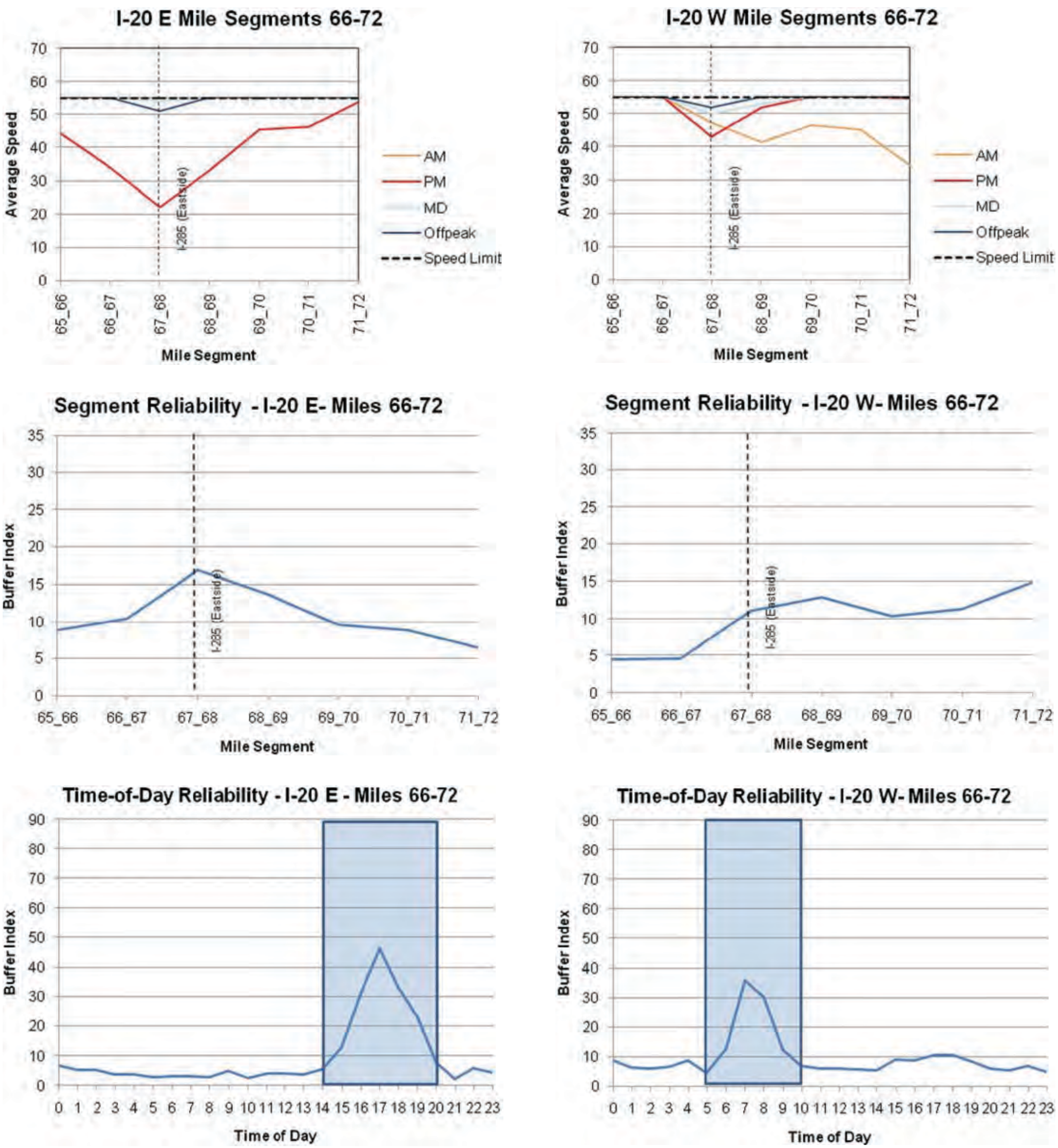


Figure 8-14. I-20 average speed, segment and time-of-day reliability based on truck GPS data.

CHAPTER 9

Conclusions

This research demonstrates an advanced method for identifying, classifying, evaluating, and mitigating truck bottlenecks based on utilizing truck probe data. This method allows for evaluating truck bottlenecks for prioritizing investment decisions. The method differs from the use of travel demand models in three key ways in terms of the types of results generated: (1) truck probe data allows for identification of a much broader set of bottleneck locations (e.g., truck bottlenecks based on crashes and weather); (2) truck probe data allows for analysis of actual bottleneck locations as opposed to derived bottlenecks; and (3) truck probe data only allows for analysis in a base year as opposed to travel demand models which can also be used to estimate future bottlenecks.

The key conclusions from this Guidebook are as follows:

- A uniform classification structure is described that can provide consistency to bottleneck definitions used in future analyses.
- Truck probe speed data can be used in conjunction with other data sources (e.g., crash data, weather data, volume data) to identify the causes of bottlenecks. In practice, there are typically project-level quantitative and qualitative evaluations needed to identify truck bottleneck cause.
- The methodology presented in this Guidebook can be used to demonstrate the benefit of bottleneck improvements to truckers, policy decision makers, and the general public. This is particularly true for bottlenecks based on operational restrictions (i.e., geometric or height restrictions or truck bans).
- There are a number of practices in the literature related to facility-based mobility analysis that include a truck component (e.g., ranking roadway sections by truck delay per mile). These practices generally integrate speed and volume data sources, and these practices are scalable from roadway sections to longer sections to urban area or statewide analyses.
- Truck probe data is a relatively new data source. However, it is already among one of the most accurate data sets typically available to freight planners. Calculating delay from the probe data is equally reliant on accurate truck count data. Attention must be paid to ensure that truck count data is accurate in order to ensure that truck bottleneck analyses are useful for planning purposes.
- Truck probe data provide a valuable window into actual truck reliability performance. This provides an extra dimension to standard bottleneck analysis which typically pivots off total delay estimates.
- Engaging truck stakeholders remains a critical part of the truck bottleneck analysis methodology. In particular, stakeholders can confirm locations of bottlenecks, assist in determining why truck bottlenecks are occurring, and provide a sense of which mitigation efforts to consider for truck bottlenecks.

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Definitions and Acronyms

This section includes definitions and acronyms used throughout this guidebook. A more complete list of freight-related acronyms can be found in the National Cooperative Freight Research Program Report 47, *Freight Transportation Data Architecture: Data Element Dictionary.*

Definitions

Average Annual Daily Truck Traffic (AADTT) – The total volume of truck traffic on a highway segment for one year, divided by the number of days in the year.

Bottleneck – A section of a highway or rail network that experiences operational problems such as congestion. Bottlenecks may result from factors such as reduced roadway width or steep freeway grades that can slow trucks.

Conflate – The process of combining geographic information from overlapping sources so as to retain accurate data, minimize redundancy, and reconcile data conflicts.

Distribution Center (DC) – The warehouse facility which holds inventory from manufacturing pending distribution to the appropriate stores.

Gross Vehicle Weight (GVW) – The combined total weight of a vehicle and its freight.

Hazardous Material – A substance or material which the Department of Transportation has determined to be capable of posing a risk to health, safety, and property when stored or transported in commerce.

Hours of Service – Ruling that stipulates the amount of time a driver is allotted to work.

Hub – A common connection point for devices in a network. Referenced for a transportation network as in "hub and spoke" which is common in the airline and trucking industry.

Intermodal terminal – A location where segments between different transportation modes and networks connect. Using more than one mode of transportation in moving persons and goods. For example, a shipment moved over 1000 miles could travel by truck for one portion of the trip, and then transfer to rail at a designated terminal.

Level of Service (LOS) – A qualitative assessment of a road's operating conditions. For local government comprehensive planning purposes, level of service means an indicator of the extent or degree of service provided by, or proposed to be provided by, a facility based on and related to the operational characteristics of the facility. Level of service indicates the capacity per unit of demand for each public facility.

Line Haul – The movement of freight over the road/rail from origin terminal to destination terminal, usually over long distances.

Node – A fixed point in a firm's logistics system where goods come to rest; includes plants, warehouses, supply sources, and markets.

Port Authority – State or local government that owns, operates, or otherwise provides wharf, dock, and other terminal investments at ports.

Radio Frequency (RFID) – A form of wireless communication that lets users relay information via electronic energy waves from a terminal to a base station, which is linked in turn to a host computer. The terminals can be placed at a fixed station, mounted on a forklift truck, or carried in the worker's hand. The base station contains a transmitter and receiver for communication with the terminals. When combined with a bar-code system for identifying inventory items, a radio-frequency system can relay data instantly, thus updating inventory records in so-called "real time."

Reliability – Refers to the degree of certainty and predictability in travel times on the transportation system. Reliable transportation systems offer some assurance of attaining a given destination within a reasonable range of an expected time. An unreliable transportation system is subject to unexpected delays, increasing costs for system users.

Shipper – Party that tenders goods for transportation.

Ton-mile – A measure of output for freight transportation; reflects weight of shipment and the distance it is hauled; a multiplication of tons hauled by the distance traveled.

Vehicle Miles of Travel (VMT) – A unit to measure vehicle travel made by a private vehicle, such as an automobile, van, pickup truck, or motorcycle.

Warehouse – Storage place for products. Principal warehouse activities include receipt of product, storage, shipment and order picking.

Acronyms

AADT	Average Annual Daily Traffic
AADTT	Average Annual Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
ALPR	Automatic License Plate Readers
ATA	American Trucking Association
ATM	Active Traffic Management
ATRI	American Transportation Research Institute
CATT	Center for Advanced Transportation Technology
CBT	Congestion-Based Tolls
CMP	Congestion Management Process
CMV	Commercial Motor Vehicle
CPM	Congestion Management Program
CSI	Commuter Stress Index
CVO	Commercial Vehicle Operations
DC	Distribution Center
DVRPC	Delaware Valley Regional Planning Commission
FAF	Freight Analysis Framework
FGTS	Freight and Goods Transportation System
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FPM	Freight Performance Measures
FRATIS	Freight Advanced Traveler Information System

GeoData	Geographical Data
GIS	Geographic Information Systems
GPS	Global Positioning System
GVW	Gross Vehicle Weight
HPMS	Highway Performance Monitoring System
HRTPO	Hampton Roads Transportation Planning Organization
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation System
LBR	Localized Bottleneck Reduction (FHWA program)
LOS	Level of Service
MPG	Miles per Gallon
mph	Miles per Hour
MPO	Metropolitan Planning Organization
MUTCD	Manual on Uniform Traffic Control Devices
NHS	National Highway System
NOAA	National Oceanic and Atmospheric Administration
NPMRDS	National Performance Management Research Data Set
O/D	Origins and Destinations
ODOT	Oregon Department of Transportation
OS/OW	Oversize/Overweight
PMS	Pavement Management System
POE	Port of Entry
POS	Point of Sale
PTI	Planning Time Index
PTI80	Planning Time Index 80th
RFID	Radio Frequency Identification
RITIS	Regional Integrated Transportation Information System
RWIS	Road Weather Information System
SCAG	Southern California Council of Governments
SHA	State Highway Administration
SHRP 2	Strategic Highway Research Program, Phase 2
SPD	Speed
TDM	Travel Demand Management
TEU	Twenty-Foot Equivalent Unit, a standard size intermodal container
TMC	Traffic Message Channel
TMT	Truck Miles Traveled
TSM&O	Transportation System Management and Operations
TT	Travel Time
TTI	Travel Time Index or Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
UFC	Uniform Freight Classification
V/C	Volume-to-Capacity Ratio
VCTIR	Virginia Center for Transportation Innovation and Research
VDOT	Virginia Department of Transportation
VMT	Vehicle Miles of Travel
WB40	Wheel Base 40
WITS	Washington Incident Tracking System
WSDOT	Washington State Department of Transportation

APPENDICES

This project produced the following appendices, which are not published herein but are available for download from trb.org by searching for "NCHRP Project 08-98":

- Appendix A: Selected Details of State-of-the-Practice Review,
- Appendix B: Short Summaries of Selected Case Studies,
- Appendix C: Data Quality Control Examples,
- Appendix D: Additional Performance Measure Discussion and Analysis Procedures, and
- Appendix E: Truck Bottlenecks and Geometrics.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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