Freight Bottlenecks in the Upper Midwest: Identification, Collaboration, and Alleviation

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ABSTRACT

Freight movements throughout the Mississippi Valley region are complicated by the presence of recurring congestion along the highway, rail, and port freight networks. This congestion has several deleterious effects on freight carriers, commuters, governments, and markets. State departments of transportation (DOTs) in the Mississippi Valley Freight Coalition are looking to identify the points of concern along their networks and make plans to improve congested conditions.

In some areas, congestion is a result of physical conditions in the network that constrict efficient freight mobility. These conditions are defined here as various types of “freight bottlenecks.” In an effort to identify the locations of these bottlenecks and their effect on freight flows, this research considers flow throughout the networks designated as freight routes, determines locations wherein physical or operational constraints exist, and calculates the truck delay associated with the existing conditions.

The highway bottleneck locations calculated through geographic information system (GIS) analysis are verified through communication with state transportation engineers and planners in the Mississippi Valley region. Through these discussions, alternative methodologies are considered and site-specific conditions are further detailed by those interviewed. The bottleneck locations found in this study are also cross-checked against state projects planned for alleviating known bottleneck conditions.

This presentation will discuss the methodologies developed to identify freight bottleneck locations, the process of collaborating with state DOTs to verify these locations, and the inventory of alleviation projects that are already planned or recommended by the research team to address these highway freight bottlenecks.

Key words: freight transportation—Mississippi Valley Freight Coalition—traffic bottlenecks
INTRODUCTION

The freight that passes through the Mississippi Valley Region is high volume and has a substantial impact on the economy of the region. According to the Bureau of Transportation Statistics-sponsored Commodity Flow Survey, trucks carried almost 2.5 billion tons of freight across the highways of the 10 states of the Mississippi Valley region in 2002. Efficient movement of freight through this region is critical to the economic competitiveness of the nation. However, previous studies indicate that the existence of recurring highway bottlenecks in this region has been jeopardizing the reliability and efficiency of freight movement significantly, which calls for an immediate remedy.

In an effort to alleviate the impact of traffic bottleneck to freight movement through the Upper Midwest, this study performs a comprehensive analysis to identify, characterize, and prioritize the regional truck bottlenecks. Identification and characterization of freight bottlenecks in the Upper Midwest will enable member states of the Mississippi Valley Freight Coalition to take appropriate action to relieve existing bottlenecks. Through prioritization of the bottlenecks identified in the study, coalition members can plan to address freight bottleneck solutions in a way that will be optimal to the region’s economic well-being.

STATE OF KNOWLEDGE

The significant increases in travel time, extra cost, and environmental pollution caused by bottlenecks have warranted several studies on bottleneck identification, prioritization, and alleviation. The primary focus of these studies is on the temporal and spatial distribution of bottlenecks on the traffic network. There are generally three approaches to bottleneck analysis that differ by the types of data used for analysis.

The first approach is based on rich traffic data obtained from loop detectors along major corridors, including count of vehicles, occupancy of detector, and speed. One way of using such data is to construct the curves of cumulative vehicle counts and occupancy of detectors at each site and to investigate the bottleneck formation by comparing the curves visually (Cassidy and Bertini 1999; Bertini and Myton 2004). Based on the speed contour map, an alternative method identifies the bottleneck condition through the direct inspection of measured speed (Chen et al. 2004; Ban et al. 2007). Usually, a threshold value is applied to distinguish free-flow condition and bottleneck condition, which is derived from empirical knowledge or selected to best match the identification results and ground truth. As loop detector data are typically collected for specific sites, this approach is usually used for bottleneck analysis at the local scale.

The second bottleneck analysis approach is based on truck global positioning system (GPS) data. For example, using GPS data points obtained from 25 portable GPS devices provided to trucking companies by the Washington State Department of Transportation, McCormack and Hallenbeck (2006) developed a series of benchmarks to examine the roadway segment performance, including speed, mean speed, and speed of various percentiles. Particularly, the data points from four of the GPS devices placed on Boeing trucks traveling in a routine route were used to identify the locations where delays happened as indicated by a slower speed. More recently, a freight performance study sponsored by the American Transportation Research Institute (Short et al. 2009) examines the truck delay on the worst 30 U.S. freight bottlenecks identified from a Federal Highway Administration study. The delay is calculated based on the difference between free-flow speed and average speed measured from GPS data. An assumed study length is employed when calculating the interchange bottleneck delay, which ranges from 2 to 3 miles extending from interchange location.
The third bottleneck analysis approach utilizes the Highway Performance Monitoring System (HPMS) data. This has been perhaps the most widely adopted method for identifying bottlenecks due to the fact that HPMS is available for all states and provides a consistent source of traffic-related information throughout the national highway network. The HPMS datasets consist of two databases: the Universe database, which provides basic physical and traffic information on all sections of all major roads, and the Sample database, which is a statistically selected sample of Universe sections with detailed geometry and operation information reported and a limited number of roadway sections. As one of the earliest studies to identify bottlenecks on a national basis, Cambridge Systematics, Inc. (1999) scans the HPMS database for freeway segments with high ratios of traffic volume to available highway capacity, by which a preliminary list of candidate bottlenecks are developed. The Cambridge Systematics, Inc. (2005) made an initial effort to investigate the national freight bottlenecks by using the HPMS data and Freight Analysis Framework (FAF) data. In its report “An Initial Assessment of Freight Bottlenecks on Highways: White Paper” (hereafter referred to as White Paper), not only are the locations of bottleneck identified, but also a comprehensive typology is developed in this study to characterize freight bottlenecks. The report presents several lists of freight bottlenecks ranked by annual hours of delay for trucks for each type of bottleneck.

STUDY METHODOLOGY

In the present study, the authors are building on the HPMS-based analysis approach and develop a systematic framework to identify, characterize, and prioritize truck bottlenecks in the Mississippi Valley region. The authors favored the HPMS-based approach over other approaches due to data availability. HPMS data are found to be the only consistently and publicly available data source for the regional-level analysis that covers 10 states.

Figure 1 provides an overview of the proposed bottleneck analysis methodology. Due to the common data source used, the method follows the same bottleneck typology defined in the White Paper (2005) and considers four types of truck bottleneck conditions: interchange, lane drop, steep grade, and signalized intersection bottlenecks. However, as opposed to assigning each bottleneck location to exactly one of the four types of bottlenecks, the authors recognize the limitation of the HPMS data and consider the possibility of a highway section being associated with more than one bottleneck condition.

The method also differs from that used in the White Paper (2005) in how highway sections are scanned and identified as potential bottleneck locations. In the White Paper, sections with a high ratio of volume to capacity during peak hour are selected as candidate bottleneck locations. In the analysis, the authors use truck unit delay (total hours of delay for trucks per mile) instead. Truck unit delay is considered as a more suitable measure for the study because it captures the delay for all commercial motor drivers using per mile of a given highway segment. It was considered to more directly capture the congestion impact to freight movement.
Because the truck unit delay is determined by the severity of bottleneck and the presence of truck traffic volume at a bottleneck location, three conditions lead to a significant truck unit delay:

- The presence of exceptionally high truck volume
- The presence of exceptionally high hours of delay per vehicle mile
- The combination of the previous two conditions

The last condition could be referred to as a general bottleneck as both passenger cars and heavy trucks passing the location would be stuck in traffic queue and experience increase in travel time and decrease in speed. Many of the state DOTs and metropolitan planning organizations have performed extensive highway congestion studies and identified such bottlenecks. However, the first condition, which describes the case where slight traffic congestion happens, but a high volume of trucks accumulates the unit truck delay, is usually overlooked in general bottleneck study. By taking truck volume into the consideration, this study contributes to develop a compressive inventory of freight bottlenecks in the region.

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Our delay estimation is based on equations borrowed from a previous study by Margiotta et al. (1999), who developed a series of equations to estimate hours of delay and speed on each section by using a simplified queuing-based model, QSIM. This model incorporates several advanced features, including the use of queuing analysis, accounting for temporal distribution and daily variation of traffic flow, and so on. On the other hand, there are limitations by using this method to estimate hours of delay for trucks, one of which is the potential overestimate of exposure of truck trips to delay. By multiplying the truck volume with the unit delay estimated from the equations, it is assumed that truck trips follow the similar temporal distribution as passenger car trips. However, most commercial motor carriers make great efforts developing strategies to reschedule and/or reroute picking up and delivering works in order to avoid known recurring bottleneck. This might lead to the underlying difference in temporal distribution patterns between truck trips and passenger car trips, suggesting an overestimate of truck delay.

Because interchange bottlenecks usually cause system congestion, simply examining the sections with significant truck unit delay on freeways would identify many spatially closed bottlenecks, which are actually located on a congested corridor as a result of one interchange bottleneck. In order to account for the system impact of interchange bottlenecks, we also develop a corridor congestion growing method to identify the bottleneck locations on corridors. Starting from the sections with high truck unit delay, the neighboring sections are examined to determine if similar congestion patterns exist. By assuming the continuously congested traffic is caused by one bottleneck, the sections immediately adjacent to each other having similar unit delay are connected to build one congestion corridor. The location where vehicles experience the severest delay on a corridor is selected as the bottleneck location. To qualify the bottleneck as an interchange bottleneck, a further inspection is performed to search for the closest interchanges from either end of the section along the congested corridor, with a maximum searching length threshold.

Realizing the fact that the interchange configuration varies significantly from case to case and the most congested location caused by an interchange might be out of its physical scope, the maximum searching length is determined through a sensitivity analysis. The sensitivity analysis is designed to study how total interchange delay grows by including longer extent of highways from interchange location. The vehicle hours of delay is calculated for each leg connecting to an interchange, and the total interchange delay is obtained by summing up vehicle delays on every leg together. The length included in calculation for each leg increases from 0.5 mile to 3 miles with a 0.5 mile increment. By visually inspecting the change of additional total delay and additional vehicles miles traveled (VMT) caused by including longer extent for all interchanges in the region, a sharp decrease of additional interchange delay with slight drop in additional VMT is observed when the length included grows from 1 mile to 1.5 mile. The difference in trends indicates that congestion around interchange locations tends to be alleviated significantly out of a 1 mile scope. After several rounds of empirical tests, the authors finally used 1 mile as the search length to attribute interchange constraint to a bottleneck.

The identification of the other three types of bottlenecks follows the definitions in White Paper (2005). The location qualified as a freight bottleneck is examined to determine if a change of number of lanes on neighboring sections or if at least one at-grade signal exists by using HPMS data, which features the location as lane-drop bottleneck or a signalized intersection bottleneck, respectively. The steep-grade bottleneck is characterized as a congested section with more than 1 mile of steep grades (i.e., grade greater than 4.5%). By investigating all constraints identifiable from HPMS data on each bottleneck, the potential causes leading to congestion are explored.
RESULTS AND CONCLUSIONS

After applying the proposed bottleneck analysis method to the 2006 HPMS data for the 10 states in the Mississippi Valley region, the authors arrive at a master list of regional freight bottlenecks with all constraints checked for each bottleneck. Table 1 shows the number of locations identified for each type of bottleneck condition. The truck bottlenecks are further prioritized by the truck unit delay associated with the existing conditions (see Figure 2 for the distribution of truck unit delay and its range for each type of bottlenecks). The prioritization result of bottleneck identification further confirms that the interchange constraint accounts for the most significant bottleneck condition, followed by the lane-drop constraint. The steep-grade bottlenecks are only associated with a marginal truck unit delay because such sections are usually located in a rural area in the study region where general traffic demand is not intense and congestion is not as severe as that in urban area. However, the great length of sections with steep grade tends to aggravate this issue and might warrant the concerns when the travel demand increases.

Table 1. Number of truck bottlenecks identified from 2006 HPMS data for the Mississippi Valley region

<table>
<thead>
<tr>
<th>Bottleneck Type</th>
<th>On Freeways</th>
<th>On Other Principle Arterials</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interchange</td>
<td>246</td>
<td>0</td>
<td>246</td>
</tr>
<tr>
<td>Signalized Intersection</td>
<td>2</td>
<td>727</td>
<td>729</td>
</tr>
<tr>
<td>Lane Drop</td>
<td>486</td>
<td>209</td>
<td>695</td>
</tr>
<tr>
<td>Steep Grade</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 2. Distribution of truck unit delay across truck bottleneck locations
This ranked list also facilitates the verification of identification results with various sources, including the knowledge from state transportation engineers and planners, user nominations, and previous study results. As driven by the same database in different years, the study results provides a good match with the identification results in White Paper (2005). It also confirms the user-nominated bottleneck locations obtained from a series of surveys with truck drivers and dispatchers in selected states. However, as pointed out by local experts in some states, our methodology fails to identify certain bottleneck locations that reside on highway segments not present in the HPMS sample data. This is a data and methodological limitation that needs to be addressed by supplementing the HPMS-based analysis with local knowledge.

In summary, this study develops a framework to identify, characterize, and prioritize freight bottlenecks on a regional level in the Upper Midwest area. Particularly, the truck unit delay measure is proposed as a truck bottleneck indicator and a congestion corridor growing method is incorporated in the analysis framework to account for the system congestion caused by interchange bottleneck. As the output of this freight bottleneck study, a ranked list of truck bottlenecks serves to stimulate cross-sector dialogue among freight planners and operators and provides a basis to devise the optimal alleviation plan for the greatest benefits for the region.
REFERENCES


