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Enhanced Role of Activity Center Transportation Organizations in Regional Mobility

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Final Report

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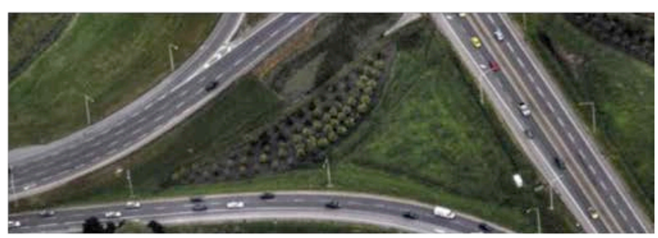
Principal Investigator: Angshuman Guin, Ph.D.

National Center for Transportation Systems Productivity and Management
O. Lamar Allen Sustainable Education Building
788 Atlantic Drive, Atlanta, GA 30332-0355
P: 404-894-2236 F: 404-894-2278
nctspm@ce.gatech.edu nctspm.gatech.edu



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16. Abstract:

This study reviews the practices on the emerging role of major activity center transportation organizations in enhancing activity center and regional transportation. A survey of the major activity centers in the United States was performed with respect to their role and activities in the operation of transportation systems serving the area. The survey indicated limited involvement of activity center transportation management organizations in traffic operations, primarily due to budgetary limitations. Three strategies were identified in this study for possible use by these organizations and a feasibility analysis was performed for each strategy. Feasibility analysis of the connected-vehicle parking management application indicated that it could be a successful strategy, where existing field deployments could be leveraged. The feasibility analysis of the tested predictive analytics based pro-active traffic management strategy showed that this approach would need significant additional development before any field implementation. Feasibility analysis of the Do-Not-Block-the-Box Campaign strategy showed the most encouraging ready-to-deploy results. The nationwide survey indicated positive perceived results from the implementation of the strategy. An objective evaluation using a VISSIM simulation approach demonstrated that Do-Not-Block-the-Box Campaigns can provide improvements in mobility.

GDOT Research Project No. RP 13-16

Final Report

ENHANCED ROLE OF ACTIVITY CENTER TRANSPORTATION ORGANIZATIONS IN REGIONAL MOBILITY

By

Angshuman Guin, Ph.D., Principal Investigator
Michael P. Hunter, Ph.D., co-Principal Investigator
Michael O. Rodgers, Ph.D., co-Principal Investigator
Abhilasha Saroj, Graduate Research Assistant

School of Civil and Environmental Engineering
Georgia Institute of Technology

Contract with

Georgia Department of Transportation

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EXECUTIVE SUMMARY

This study reviewed the practices on the emerging role of major activity center transportation organizations in enhancing activity center and regional transportation. A survey of the major activity centers in the United States was performed with respect to their role and activities in the operation of transportation systems serving the area. While Transportation Management Organizations' (TMOs) involvement in traffic and real-time operations is increasing, the survey clearly indicated that only a minority of organizations are involved. Only seven organizations (13% of respondents) reported involvement in traffic operations, including items such as traffic control improvements, signal timing, signal coordination, optimization of timing, traffic counts, travel time collection, safety improvements, simulation, and bus priority signaling. A higher number of organizations (18 or 42.9% of the respondents) had access to live traffic views from cameras, although these cameras were primarily owned by the local DOTs and other transportation agencies. While five organizations delivered incident reports using email, text messaging, and/or social media, only three organizations reported having a mobile application that provided traffic incidents and real-time transit options.

With the growing need to increase the efficiency of the existing infrastructure, the relatively low participation of TMOs in real-time data and traffic operations would appear to be a missed opportunity. While many challenges exist, including limited budgets, administrative authority of roadway operations, competing priorities, etc., TMOs have the local knowledge needed to best identify and address traffic challenges. Future

TMO efforts should seek to increase involvement in real time data and traffic operations through low-cost solutions and partnerships with other agencies. Alternatives to reducing congestion, apart from traditional Traffic Demand Management (TDM) strategies, should be considered. For instance, as studied in this report, Don't Block The Box (DBTB) campaigns offer a low-cost, minimal technology congestion mitigation and safety measure. Results from both the administered survey and simulation demonstrate that a DBTB treatment can improve intersection operations. DBTB campaigns may also be started on a small scale of only a few intersections, and then scaled as resources permit and local experience justifies additional investment. It is also recommended that, to improve the likelihood of a successful DBTB program, TMOs collaborate with other local agencies and police.

In addition to DBTB programs, TMOs should consider leveraging connected vehicle applications such as the implementation of smart parking management systems, once the basic connected vehicle infrastructure has been implemented by larger transportation agencies. This study revealed dramatic potential improvement in parking management when real-time data is leveraged. Parking management systems that leverage connected vehicles will result in economic, mobility, safety, and other benefits to facility operators, public agencies, commercial businesses, residential areas, and individual and system users.

Finally, the third strategy studied in this research, a data analytics approach for predictive traffic management techniques across a system, is not currently recommended. While there have been anecdotal references where traffic conditions in one area of the network act as a predictor for traffic characteristics in other areas, a successful implementation is not yet clear. While this tested approach likely holds high potential, it remains in the research phase and is not likely a good candidate for immediate implementation by a TMO.

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1 Introduction

Transportation Management Organizations (TMOs) are organizations of private and public enterprises that share the goal of enhancing the movement of people and goods within a defined region. Typically, these associations offer services in activity centers (e.g., shopping or office parks) to reduce roadway congestion through ride sharing, managing parking systems, providing transit shelters, and other similar programs. In addition, while not widely adopted, active involvement in traffic operations has been ongoing at select TMOs for several decades. For instance, according to Loveless and Welch *(1)*, several TMOs began employing Intelligent Transportation Systems (ITS) and Geographic Information Systems (GIS) in the early 1990s. However, ongoing advancements in surveillance, communications, and control technologies present TMOs with increased opportunity to become actively involved in real-time traffic operations, alternative transportation mode use, and traffic-control services in carrying out their mission. As such, TMOs can make promising venues for demonstration projects testing aspects of ITS *(1)*.

1.1 Overview of Project

The research reported within is for the Georgia Department of Transportation-(GDOT) sponsored research study to investigate the emerging roles of major activity center transportation organizations in enhancing activity center and regional transportation.

1.2 Project Objectives

The objectives of this project were to:

- Review the literature and practices on the emerging role of major activity center transportation organizations in enhancing activity center and regional transportation
- Survey major activity centers in the United States with respect to their role and activities in actual operations of transportation systems serving the area
- Support the implementation of road operations strategies under the auspices of the Buckhead CID; and
- Assess the feasibility and effectiveness of activity center management associations in such strategies.

To accomplish these tasks several activities were undertaken. First, two surveys that explored the emerging role of TMOs in regional transportation were undertaken. The first survey focused on TMO involvement in supporting transportation operations and ITS. This survey also collected information on if, and how, TMOs determine performance measurements for their activities, as such data is essential in the development of cost-effective programs, critical in today’s limited funding environment. The survey emphasized activities readily transferrable to other TMOs. The second survey focused on TMO implementation of a specific low-cost congestion countermeasure, Don’t Block the Box (DBTB) campaigns. DBTB treatments represent a low-cost congestion mitigation measure aimed at reducing gridlock readily implementable by

TMOs. Building on this survey, a simulation-based study was undertaken to quantify the potential impact of a DBTB treatment at a congested intersection. Finally, in addition to DBTB, this research explored the use of connected vehicles in the context of parking management systems and data analytics for traffic prediction.

2 Transportation Management Organizations Survey

The primary objective of traffic operations services offered by TMOs is typically congestion reduction in activity centers. Such services may involve the collection and use of real-time operational data, mobile applications, and ITS technologies. In addition, performance indicators such as efficiency, financial accountability, and value of investment/return for such services are critical to the implementation decision process, given the competing needs and fiscally constrained resources of TMOs. Moving Ahead for Progress in 21st century (MAP-21), the 2012 federal transportation bill, highlights the importance of such performance measures *(2)*. The understanding gained from the literature, as discussed in the next section, forms the foundation for the Transportation Management Organization survey completed as part of this research. The survey obtained current national, state, and local TMO traffic operations service information and insights, with a focus on addressing the needs and desires of Georgia TMOs.

2.1 Background: Transportation Management Organizations

Transportation Management Organizations (TMOs) and Business Improvement Districts (BIDs) are non-governmental organizations that seek to address local transportation issues. Local governments, chambers of commerce, or major businesses generally initiate TMOs. TMOs are member-controlled and funded by local businesses that pay membership dues. With a focus on transportation, TMOs seek to increase transportation options, provide financial savings, and reduce both traffic congestion and pollution emissions *(3)*. With some operational differences, TMOs may also be called Transportation Management *Associations*, *Initiatives, or Districts* (TMA/TMI/TMD respectively) *(4)*.

Business Improvement Districts (BIDs) are similar to TMOs, although with a broader emphasis on public service enhancements provided by the business community including, but not limited to, transportation improvements. A BID is a geographically defined organization where "property owners and/or merchants agree to provide an extra level of public service in a specific area by imposing an added tax or fee on all of the properties and/or businesses in the area" *(5)*.

2.2 Prior Surveys

TMOs and BIDs fall across a broad range of sizes and resources. The first published survey of BIDs was performed in 1999 *(5)*. While BIDs provide a variety of services, the only major transportation-related activities performed by a significant percentage of the surveyed BIDs involved managing public parking systems and maintaining transit shelters. A later 2010 survey *(6)* found that most BIDs provided minimal to no transportation services, with only a handful operating downtown shuttles or rideshare programs.

Nine national TMO studies *(7,8,9,10)* have been conducted since 1999, most recently in 2009. The 2009 survey *(10)* found that the top five services offered by TMOs are: promotional materials, employer travel surveys, promotional events, trip reduction plans, and rideshare matching. Approximately 21% of responding TMOs offered mobile and web services, online journey planning, and real-time traffic phone alerts *(10)*. Since the 2009 survey, some TMOs have begun to provide real-time travel alerts, web-based mapping or journey planners, and Parking management services.

While TMOs have traditionally offered few ITS and traffic operations services, several have started projects to influence traffic operations within their region. For example, the Transportation Management Association of Chester County, PA (TMACC) has been studying Transit Signal Priority (TSP) as a way to enhance a bus route along a corridor in Chester County, PA *(11)*. A TSP system can improve transit performance by reducing transit travel time and increasing bus on-time performance *(12)*. Another example is a project in the Morgantown, WV central business district that seeks to improve the overall flow of traffic in the downtown area by continuously monitoring operations and remotely adjusting signal operations. Expected results included reduced delay, shorter vehicle queues, and improved air quality *(13)*.

2.3 TMO and BID Operations Survey

For this study, a national survey of TMOs and BIDs was undertaken. The survey sought to update the current understanding of the state of practice for TMO regional mobility strategies supporting real-time traffic operations and ITS, as well as any performance metrics used to gauge their impact.

The survey had four sections: *background, membership, services,* and *follow-up*. The *background* section collected general information about the organizations including name, classification, and website address. The *membership* section collected information on organization size, membership fees, and approximately how many individuals the organization serves. The *services* section collected information about budgets, services provided by the organization, and performance measurements. This section comprised the majority of the survey. The *follow-up* section allowed survey participants to consent to participate in a follow-up interview. The survey had 30 base questions, with a possibility of an additional 24 conditional questions based on a participant's responses.

2.3.1 Survey Responses

The survey received 52 responses from 174 queried organizations, a 29.9% response rate. Of those 52 responses, some were incomplete, with participants only completing a portion of the survey. In the following discussion, the number of participants that responded to each survey question is indicated. This section presents the key findings from the survey.

2.3.1.1 Geographic Scope

The participants include 31 TMOs, 10 BIDs, 1 university, and 10 participants of other classifications, such as Business Interest Groups and non-profits with a focus on transportation. The median organization age is 24 years. Twenty-seven of the responding organizations are fee-based. Table 1 shows the geographic area served by participant organizations, for those organizations that provided geographic information (38 of 52 responses). As seen, central business districts accounted for the highest percentage, followed by regional, with these two categories accounting for greater than 50 percent of responses.

Table 1: Geographic Scope of Organization's Service Area

What is the geographic scope of your service area?			
Answer Options	**Response Percent (based on 38 responses)**	**Response Percent (in context to all 52 respondents)**	**Response Count**
Central business district / City center / Downtown	32.2%	25.0%	13
Regional	21.1%	15.4%	8
Corridor	15.8%	11.5%	6
Suburban	15.8%	11.5%	6
City	10.5%	7.7%	4
Specialized Activity Center (university, hospital, airport, etc.)	2.6%	1.9%	1
Other (please specify)			12
		Answered question:	**38 (73.1%)**
		Skipped question:	**14 (26.9%)**

2.3.1.2 Annual Budgets

Table 2 shows the average annual budget for the organizations that provided budget information, 42 of 52 responses. Budgets range from under $50,000 to in excess of $5,000,000 per year. The median budget range is $100,000 to $249,000 per year. Also, in response to a separate question, 16 of the organizations reported allocating zero percent of their budget to transportation while 21 organizations reported allocating from 5% to 100% of their budget to transportation.

Table 2: Average annual budget for organizations

What is your average annual budget?			
Answer Options	**Response Percent (based on 42 responses)**	**Response Percent (in context to all 52 respondents)**	**Response Count**
Under $50,000	2.4%	1.9%	1
$50,000 - $99,999	4.8%	3.8%	2
$100,000 - $249,999	38.1%	30.8%	16
$250,000 - $499,999	16.7%	13.5%	7
$500,000 - $749,000	11.9%	9.6%	5
$750,000 – $999,000	0.0%	0.0%	0
$1,000,000 – $1,499,999	7.1%	5.8%	3
$1,500,000 – $1,999,999	0.0%	0.0%	0
$2,000,000 – $4,999,999	16.7%	13.5%	7
$5,000,000 or more	2.4%	1.9%	1
		Answered question:	***42 (80.8%)***
		Skipped question:	***10 (19.2%)***

2.3.1.3 Traffic Demand Management

The participating organizations offered multiple traditional Transportation Demand Management (TDM) services, with 43 organizations of the 52 responding agencies providing TDM information. The services offered by a majority of organizations include rideshare matching, guaranteed ride home, and trip reduction plan preparation. Telecommuting programs, shuttle transit, vanpool services, carshare programs, and coordinated travel planning are other popular services offered. Table 3 shows additional services offered by organizations. Thirty-three out of 46 respondents hired consultants or vendors to run at least a portion of their services, primarily rideshare matching, shuttle transit, guaranteed ride home, and vanpool services.

Table 3: TDM services offered by organizations

Which of the following services do you offer?			
Answer Options	**Response Percent (based on 43 responses)**	**Response Percent (in context to all 52 respondents)**	**Response Count**
Rideshare matching	60.5%	50.0%	26
Guaranteed ride home	58.1%	48.1%	25
Trip reduction plan preparation	51.2%	42.3%	22
Bicycle program	39.5%	32.7%	17
Vanpool services	39.5%	32.7%	17
Shuttle/Local transit	37.2%	30.8%	16
Telecommuting program	34.9%	28.8%	15
Direct rideshare incentives	30.2%	25.0%	13
Coordinated travel plan	27.9%	23.1%	12
Subsidized transit passes	25.6%	21.2%	11
Transit pass sales	18.6%	15.4%	8
Carshare program	18.6%	15.4%	8
Parking services provision	9.3%	7.7%	4
Parking pricing or management	9.3%	7.7%	4
N/A	23.3%	19.2%	10
		Answered question:	**43 (82.6%)**
		Skipped question:	**9 (17.6%)**

2.3.1.4 Traffic Operations

Seven organizations of the 52 that responded indicated involvement in traffic operations, as shown in Table 4. Several organizations were involved in signal operations and data collection. Other traffic operations services included highway and pedestrian safety improvements.

Table 4: Traffic services offered by organizations

What tasks do you perform?			
Answer Options	**Response Percent (based on 7 responses)**	**Response Percent (in context to all 52 respondents)**	**Response Count**
Signal coordination planning	71.4%	9.6%	5
Traffic counts	71.4%	9.6%	5
Traffic control improvements	57.1%	7.7%	4
Signal timing	57.1%	7.7%	4
Optimization of timing plans	57.1%	7.7%	4
Simulation	42.9%	5.8%	3
Travel time	42.9%	5.8%	3
Bus priority signal	28.6%	3.8%	2
Traffic speeds	14.3%	1.9%	1
HOV priority treatment	0.0%	0.0%	0
N/A	0.0%	0.0%	0
Other (please specify)	57.1%	7.7%	4
		Answered question:	**7 (13.5%)**
		Skipped question:	**45 (88.5%)**

In response to several questions, 35 out of 42 organizations reported cooperating or sharing data with local, state, or federal agencies. In additional, 18 organizations had access to traffic cameras or live traffic views, with 12 providing an online location where users could view the camera videos or pictures. Three respondents reported owning and maintaining cameras, while others depended on a Department of Transportation or other agency. Five organizations delivered real-time incident reports through various telecommunications methods, including three that had a mobile application. Four organizations provided web access to the reports. Five organizations use ITS technologies to improve traffic; these technologies include video vehicle detection, variable message signs, EZpass readers, traffic signal control, cameras, and bus and fleet vehicle tracking.

Additionally, only two organizations made use of traffic officers to direct traffic. Six organizations reported having implemented projects pertaining to real-time traffic operations, with 18 additional organizations considering implementing similar projects. The implemented projects relate to real-time shuttle info, traffic incidents, and speed/congestion-level data collection. Cost was the most significant deterrent cited in implementing similar projects.

2.3.2 Performance Measurement

Twenty-one out of 44 respondents tracked performance measurements for transportation services. An additional 13 organizations are considering implementing performance measurements. The service measures reported are found in Table 5. The most common performance measurements were for rideshare matching, telecommuting programs, guaranteed ride home, shuttle transit, and vanpool services. The performance measurements cited by organizations included:

- On-time performance
- Ridership data
- Service users
- Number of registrants
- Vehicle Miles Traveled (VMT)
- Car-free days
- Cost per ride
- Cost per mile
- Surveys of companies to determine mode splits

- Number of signal timing plans developed

Respondents reported using these measures to evaluate and/or alter their services. Specific uses stated by organizations included: vendor performance evaluation; evaluating capacity issues; VMT reduced per program, including estimates of fuel savings and environmental benefits; annual reporting and reports to funders; and identifying, evaluating and developing new and existing programs, including applications for funding, as well as other uses.

Table 5: Services with performance measurements

What services do you have measurements for?			
Answer Options	**Response Percent (based on 18 responses)**	**Response Percent (in context to all 52 respondents)**	**Response Count**
Rideshare matching	61.1%	21.2%	11
Vanpool services	55.6%	19.2%	10
Telecommuting program	50.0%	17.3%	9
Guaranteed ride home	50.0%	17.3%	9
Shuttle/Local transit	44.4%	15.4%	8
Trip reduction plan preparation	38.9%	13.5%	7
Subsidized transit passes	33.3%	11.5%	6
Direct rideshare incentives	27.8%	9.6%	5
Bicycle program	27.8%	9.6%	5
Data collection	22.2%	7.7%	4
Carshare program	11.1%	3.8%	2
Signal timing	11.1%	3.8%	2
Signal coordination planning	11.1%	3.8%	2
Optimization of timing plans	16.7%	5.8%	3
Parking pricing or management	5.6%	1.9%	1
Traffic control improvements	5.6%	1.9%	1
Parking services provision	0.0%	0.0%	0
HOV priority treatment	0.0%	0.0%	0
Bus priority signal	0.0%	0.0%	0
Mobile application	0.0%	0.0%	0
Traffic officers	0.0%	0.0%	0
N/A	0.0%	0.0%	0
Other (please specify)			4
		Answered question:	**18 (34.6%)**
		Skipped question:	**34 (65.4%)**

Table 6 shows the improvements seen by organizations as a result of implementing ITS, GIS, or traffic-related services.

Table 6: Area improvements from organization's services

Have the implementation of ITS, GIS, Traffic operations shown an improvement in:			
Answer Options	**Response Percent (based on 30 responses)**	**Response Percent (in context to all 52 respondents)**	**Response Count**
Reduction in traffic congestion	12.9%	7.7%	4
Reduction in travel time	9.7%	5.8%	3
Congestion	6.5%	3.8%	2
Air Quality	6.5%	3.8%	2
Increased travel speeds	3.2%	1.9%	1
Increased carpooling/vanpooling	3.2%	1.9%	1
Reduction of traffic officers	0.0%	0.0%	0
N/A	77.4%	46.2%	24
		Answered question:	**31 (59.6%)**
		Skipped question:	**21 (40.4%)**

In addition to the direct measures in Table 6, nine organizations track service evaluations through email, online surveys, and personal surveys. These evaluations are primarily conducted annually, but some organizations conducted them twice a year or every other year.

2.4 Summary

As seen, TMOs and BIDs can cover a wide range of areas, from regional to individual corridor, with an equally wide range of budget resources, from under $50,000 to over $5,000,000. A significant percentage is involved in some aspect of transportation, such as ride matching, carshare programs, bicycle and vanpool services, transit and parking assistance, etc. Only a minority actively collected performance metrics on these services, highlighting a potential area for improvement that may help these organizations more efficiently utilize resources. In addition, involvement in real time traffic operations was limited, although there are successes, commonly focused on some aspect of intersection signal control. With ongoing technological innovations becoming widely available, this presents another area of potential advancement. One of the most frequently cited reasons for the limited involvement of TMOs in traffic operation services was budgetary limitations.

3 Case Studies

One of the primary goals of this research effort was to seek specific recommendations implementable by TMOs to more actively participate in improving traffic operations. In response to the findings of the TMO survey, it was evident that to achieve a high likelihood of widespread deployment by multiple TMOs, an operations improvement needs to be low cost, have minimal technology requirements, and target a common operations challenge. Three different strategies were identified and further studied as part of this research in order to investigate their feasibility of use by TMOs for improving traffic operations:

- Don't Block The Box campaigns
- Leveraging connected vehicle initiatives for improving traffic
- Using Predictive Analytics for pro-active traffic management

A brief summary of these studies is provided in this section. More details of each effort are available in Appendices A through D.

3.1 Don't Block the Box Campaigns – Survey (Appendix A)

"Blocking the box" occurs when a vehicle with the right-of-way (e.g., a green indication at a signalized intersection) enters the intersection with insufficient space to exit on the opposite side due to downstream traffic spillback. This vehicle must then stop within the intersection proper, or "box," potentially obstructing the movement of pedestrians and vehicles with right-of-way on conflicting approaches. A "Don't Block the

Box” (DBTB) treatment seeks to reduce the likelihood of drivers entering an intersection when there is insufficient space to exit the box, and thus reduce blocking occurrences and the potential for gridlock.

A “DBTB Survey” was undertaken to examine current and potential future trends in DBTB campaigns across the United States, and to evaluate the potential of DBTB campaigns to act as an economical TMO alternative for traffic management. The survey was sent to a variety of different organization classifications including public works departments, police departments, and TMOs. The “DBTB Survey” received 77 responses from 415 organizations around the nation, an 18.5% response rate. The participants included 29 local jurisdictions (city, county, etc.), 13 police departments, eight BIDs, four TMOs, one state department of transportation, one university, and one Community Improvement District (CID). The remaining participants did not indicate their organization type. Of the 77 respondents, only ten organizations reported an active DBTB program. Seven of the ten organizations started their DBTB campaign after 2010.

Of organizations with DBTB programs, the predominant stated objective of the program was addressing traffic congestion. Other commonly stated objectives included safety (pedestrian, bicycle, vehicle, and local resident) and economic impacts on surrounding businesses. A few key findings included: (1) the cost for installing the DBTB signs and pavement markings at an intersection was generally reported as low, being between $1,000 and $2,000; (2) approximately half of the agencies reported that partnerships with the police department and local jurisdictions were critical in successfully implementing their DBTB campaign; and (3) more than half of the organizations that have a DBTB campaign reported improved traffic operations, with the majority stating observed benefits did not decline over time.

Only 6% of the organizations that took the survey, and did not currently have a DBTB campaign, had previously considered a DBTB campaign. Reasons for not implementing a DBTB campaign included the perceived effort involved, lack of perceived benefits, or lack of support from the city and police departments. Lastly, a significant majority of respondents agreed that if DBTB campaigns were shown to be an economical traffic management alternative, they would consider starting a DBTB campaign to address congestion and safety concerns.

3.2 Understanding Vehicle Blocking Behavior to Assess Feasibility of DBTB (Appendix B)

The DBTB survey revealed that a significant percentage of the TMOs responding to the survey agreed that if DBTB campaigns were shown to be an economical alternative in traffic management, they would consider starting a DBTB campaign to address congestion and safety concerns. This case study explores the potential impact of DBTB treatments at congested signalized intersections.

A traffic simulation model consisting of a signalized four-leg intersection, a six-lane major arterial crossing a four-lane minor street, developed in VISSIM® traffic flow simulation software, was employed to investigate DBTB. To generate blocking opportunities at the intersection, downstream bottlenecks are placed on the major arterial, creating spillback (i.e., queuing) through the intersection box. Major street vehicles follow either blocking behavior (i.e., will enter the intersection box when the exit is blocked by a queue) or non-blocking behavior (i.e., will not enter an intersection if a block would result). The selected behavior is determined randomly according to a user-defined *blocking likelihood*, i.e., the likelihood that a vehicle will exhibit blocking behavior. For instance, a *blocking likelihood* of "zero" precludes any vehicle from entering the intersection if the entry would cause a block to occur, while a *blocking likelihood* of "one" indicates that all vehicles will enter the intersection without concern for the potential to create a block. This modeling approach allows for the exploration of the sensitivity of intersection operations to different levels of *blocking likelihood* and to the impact of a reduced likelihood due to a DBTB treatment.

This study explored the relationship between blocking behavior, increased vehicle delay, and capacity reduction in a single intersection scenario. From the delay and capacity reduction results, it is seen that the impact of blocking can be significant, reaching complete gridlock on intersection approaches. Ultimately, the goal of a DBTB treatment is to reduce the *blocking likelihood* to zero. However, from the result it is seen that a DBTB treatment can significantly improve flow even without achieving the goal of zero blocking. This is particularly true where *blocking likelihood* is reduced from the mid-range (40% to 60%) to less than 20%. This also demonstrates the importance of enforcement programs. While it is not necessary that enforcement eliminate blocking altogether, it must be of sufficient frequency to limit drivers willing to risk blocking to a low percentage of the driving population.

3.3 Parking Solutions Leveraging Connected Vehicle Initiative (Appendix C)

With the rapid growth of interest in the connected vehicle program, private and public sectors need to consider the possibility of leveraging connected vehicle technologies in future planning. This section studies the potential for TMOs to leverage connected vehicle technologies to become involved in transportation operations. Parking management is identified as an initial potential application for TMOs that can be improved dramatically using real-time data with widespread benefits and low-budget resource requirements.

Parking management systems are part of comprehensive parking policies and traffic management systems. Parking management systems have evolved from traditional technologies such as parking meters to advanced wireless networks. The main objective of newly integrated parking management systems is to allow drivers to inquire about parking availability, reserve a space, and even pay for parking upon departure, all from inside an individual’s car. Perhaps the most attractive feature of advanced parking technologies is the ability to guarantee a parking space at the desired location prior to arriving to the parking facility.

There are numerous potential benefits of parking management systems. Facility operators have the potential for both reduced costs and increased revenue. Improvements in efficiency of facility space management and fee collections can increase space utilization, and thus revenue. Furthermore, space reservation systems may serve to attract new customers. Vehicle owners will also enjoy economic benefits. The cost of wasted fuel resulting from waiting in parking facility queues, cruising for parking stalls, and related local street congestion would be mitigated *(14)*. A reduction in number of miles driven and congestion will also contribute to improved environmental conditions through reduced emissions and energy use. Transportation system users who are not directly utilizing the parking facilities will also enjoy the significant benefit from the reduction in parking-related congestion. Impacts will positively affect the community and region as a whole by providing dependable access to parking in highly dense locations, spurring economic activity. Additional benefits with connected vehicle integrated parking systems may include a reduction in police officers managing traffic outside of parking facilities and the ability to remove traditional parking management systems, such as parking meters and pay stations. Potential advancements include the implementation of a "metering" technique for vehicles leaving parking facilities during the peak hour. This technique would be similar to freeway ramp metering, thereby allowing the roadways to operate at maximum efficiency without incurring the throughput losses caused by flow breakdowns and gridlock.

3.4 Investigating Feasibility of Predictive Analytics with Data Mining for Pro-Active Traffic Management (Appendix D)

Using traffic microscopic simulation models, it is possible to generate fairly accurate short-term traffic predictions when changes in flow conditions (crashes, weather conditions, etc.) are updated in the model in real time. However, building these models requires rigorous calibration and validation and significant ongoing maintenance to ensure accuracy. In addition, the speed at which these models can execute is limited by the size of the network (distributed simulation is still an emerging field). With the recent advances in the Big Data field, techniques have evolved in both hardware and software that allow researchers to leverage computationally intensive techniques for extracting useful information out of seemingly disjointed datasets. These techniques leverage parallel computation by dividing larger datasets into smaller manageable datasets and performing parallel computations across a distributed framework. This study applies this same approach to traffic volume and speed data.

There have been anecdotal references in which traffic in one area of a transportation network acts as a predictor for traffic characteristics in another area. This hypothesis was tested by performing a correlation analysis using data across the freeway network in the Metro Atlanta area. While several pairs of stations showed very high correlation in the density data, a closer examination revealed that these correlation values were driven primarily by the daily trends in the data. They did not have any practically significant predictive power regarding anomalous behavior in traffic. The results of this study can be leveraged to investigate the reduction of data storage requirements by identifying redundant detector data that provides limited additional information beyond that provided by similar data. This may be particularly relevant in the context of future connected vehicle data where the data volume is expected to increase by several orders of magnitude. However, for the objective specific to this study, the results are inconclusive. Further research is necessary to subtract out the underlying general trends in the data, separate out the signals for anomalous behavior, and analyze the dataset for potential predictive indicators.

4 Conclusions and Recommendations

While TMO involvement in traffic and real-time operations is increasing, the survey clearly indicated that only a minority of organizations are involved. Only seven organizations (13% of respondents) reported involvement in traffic operations, including items such as traffic control improvements, signal timing, signal coordination, optimization of timing, traffic counts, travel time collection, safety improvements, simulation, and bus priority signaling. A higher number of organizations (18 or 42.9% of the respondents) had access to live traffic views from cameras, although these cameras were primarily owned by the local DOTs and other transportation agencies. While five organizations delivered incident reports using email, text messaging, and/or social media, only three organizations reported having a mobile application that provided traffic incidents and real-time transit options.

With the growing need to increase the efficiency of the existing infrastructure, the relatively low participation of TMOs in real-time data and traffic operations would appear to be a missed opportunity. While many challenges exist, including limited budgets, administrative authority of roadway operations, competing priorities, etc., TMOs have the local knowledge needed to best identify and address traffic challenges. Future TMO efforts should seek to increase involvement in real-time data and traffic operations through low-cost solutions and partnerships with other agencies. Alternatives to reducing congestion, apart from traditional TDM strategies, should be considered. For instance, as studied in this report, DBTB campaigns offer a low-cost, minimal technology congestion mitigation and safety measure. Results from both the administered survey and simulation demonstrate that a DBTB treatment can improve traffic flow. DBTB campaigns may also be started on a small scale of only a few intersections and then scaled as resources permit and local experience justifies additional investment. It is also recommended that, to improve the likelihood of a successful DBTB program, TMOs collaborate with other local agencies and police.

In addition to DBTB programs, TMOs should consider leveraging connected vehicle applications such as the implementation of smart parking management systems, once the basic connected vehicle infrastructure has been implemented by larger transportation agencies. This study revealed dramatic potential improvement in parking management when real-time data is leveraged. Leveraging connected vehicle in parking management systems will result in economic, mobility, safety, and other benefits to facility operators, public agencies, commercial businesses, residential areas, and individual and system users.

Finally, the third strategy studied in this research, data analytics for predictive traffic management techniques across a system, is not currently recommended. While there have been anecdotal references where traffic conditions in one area of the network act as a predictor for traffic characteristics in other areas, a successful implementation is not yet clear. While this tested approach likely holds high potential, it remains in the research phase and is not likely a good candidate for immediate implementation by a TMO.

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Appendix A: Case Study: Don't Block the Box Campaigns

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A.1 Introduction

Traffic congestion negatively impacts quality of life, hampers business activities, and adds to harmful vehicular emissions *(1).* In 2013 alone, traffic congestion cost the United States an estimated $124 billion, a value that is projected to increase 50% by 2030 *(2).* While some congestion may be inevitable, it is critical that congestion not escalate due to gridlock. Gridlock has been associated with aggressive acts from drivers, declines in safety for vulnerable road users, decreased air quality, and negative impacts on the local economy *(3,4,5,6)*. Gridlock can be a particularly significant challenge in areas with higher development densities, such as central business districts, urban corridors, and other areas commonly covered by Transportation Management Organizations (TMOs).

In these areas, gridlock often arises in the form of "Blocking the Box." Blocking the Box occurs when a vehicle with right-of-way (e.g., a green indication at a signalized intersection) enters the intersection with insufficient space to exit on the opposite side due to downstream traffic spillback. This vehicle must then stop within the intersection proper, or "box," potentially obstructing the movement of pedestrians and vehicles from conflicting approaches that have the right-of-way: for instance, blocking a permitted turn movement during the current phase or blocking cross-street traffic if the vehicle remains trapped in the intersection after the current phase terminates. The compounding of multiple blocking events on a congested network can lead to gridlock situations and excessive delays *(7).*

A “Don’t Block the Box” (DBTB) treatment represents a potential low-cost traffic operations mitigation measure that seeks to reduce the likelihood of drivers entering an intersection when there is insufficient space to exit the box, and thus reduce blocking occurrences and the potential for gridlock. Successful implementations of DBTB treatments may be found in several parts of the world and represent a traffic management alternative available to federal, state, and local transportation agencies and groups *(7).* The “DBTB Survey” discussed in this appendix seeks to update the understanding of current trends in DBTB campaigns across the United States.

A.2 Gridlock and DBTB Campaigns

While studies on DBTB operations are limited, the history of using DBTB treatments to avert gridlock dates back to at least 1964, with success of the first recorded DBTB treatment installed in London, England. In the 1970s, the first US DBTB treatments were installed in New York. Since those first installments, DBTB programs have increased in popularity as a gridlock mitigation measure *(7,8).* As of today, many US cities, including Boston, Miami, Austin, San Francisco, Atlanta, etc., have adopted DBTB programs.

Installing DBTB at an intersection is a simple and low-cost process. It consists of implementing a striping treatment adhering to the standards in the Manual on Uniform Traffic Control Devices (MUTCD), as shown in Figure A-1. In addition, signs stating “Don’t Block Intersection” or “Don’t Block the Box” are installed near the intersection. This striping treatment visually warns the driver to avoid queuing within the intersection box. The cost of installing a DBTB treatment involves painting the pavement markings and installing the signs. Based on the survey results (discussed in the following sections) this cost typically ranges from $1,000 to $2,000 with a comparable 20-year maintenance cost. Beyond installation and maintenance, a significant share of the cost of many DBTB programs goes to enforcement, which is typically undertaken by police, parking attendants, or automated gridlock cameras *(7)*. For instance, within the StreetSafe initiative launched in 2013, the Washington D.C. Metropolitan Police Department (MPD) installed gridlock cameras at 20 intersections *(9)*.

Drivers' adherence to DBTB regulations is crucial for the success of DBTB treatments. US traffic codes that enable issuing citations to block-the-box violators generally fall into three categories: 1) obstructing, 2) stopping, and 3) sign laws. The obstructing laws prohibit a driver from entering an intersection that has insufficient space to exit, regardless of the traffic control signal indication. The stopping laws prohibit a vehicle from standing, stopping, or parking within an intersection, unless necessary either to avoid conflict or comply with the directions of a police officer or traffic control device. Lastly, in some states, the sign laws reinforce the stopping laws, restricting the driver from stopping at posted locations *(7).* While most jurisdictions consider blocking-the-box as a moving violation, some cities (e.g., New York) classify it as non-moving to enable both police officers and parking attendants to issue citations, thus greatly increasing the number of people that may enforce DBTB *(11)*. Table A - 1 summarizes the presence of DBTB laws in state traffic codes.

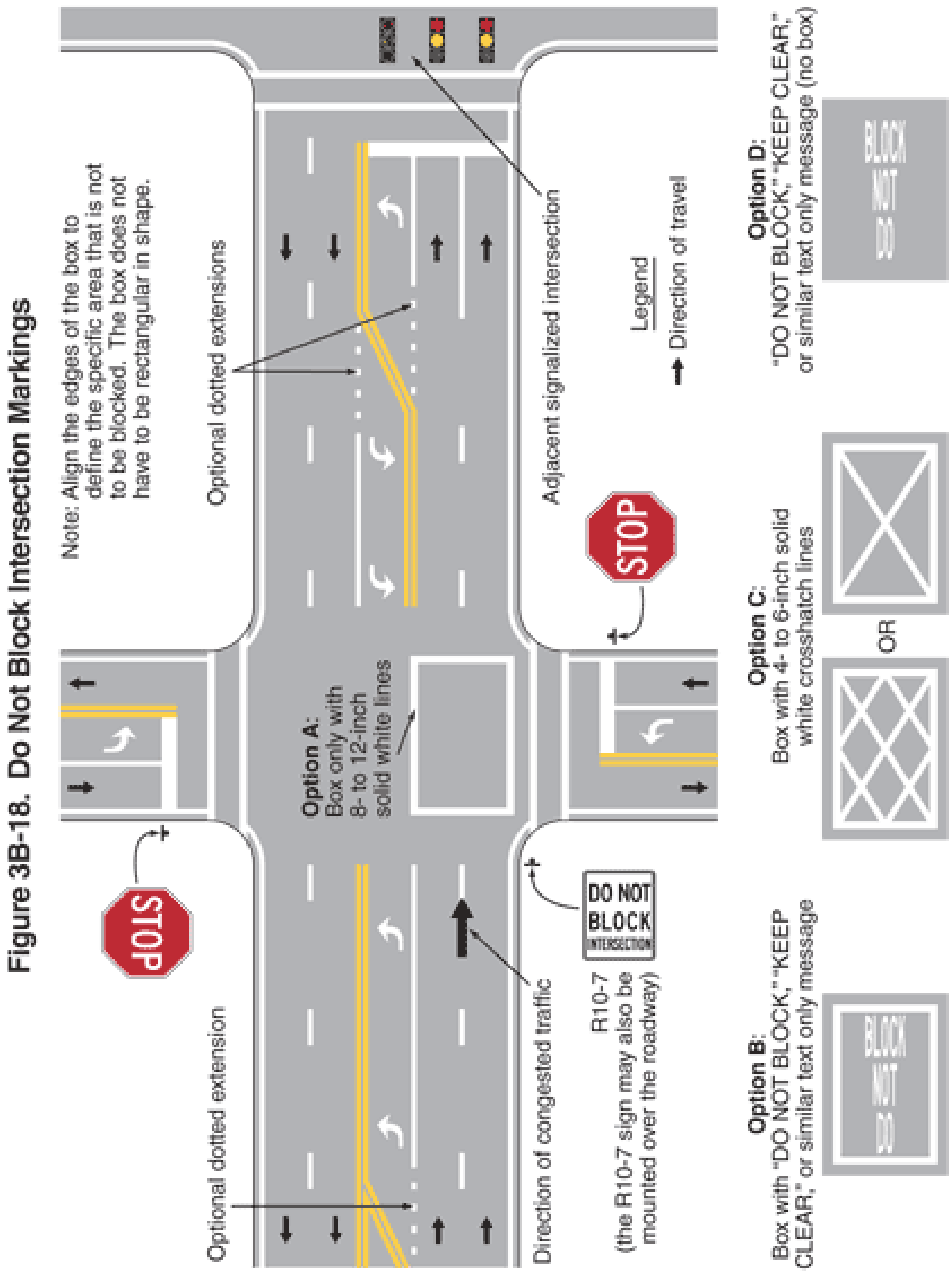

Figure A - 1: MUTCD "Do Not Block Intersection" markings *(10)*

Table A - 1: Summary of Blocking Laws for Every State, Including the District of Columbia *(12)*

State	Obstructing Law	Stopping Law	Sign Law
Alabama, California, Colorado, Georgia, Hawaii, Minnesota, North Dakota, Ohio, Pennsylvania, Washington	✓	✓	✓
Delaware, District of Columbia, Florida, Idaho, Michigan, Nevada, New York, Oregon, South Carolina	✓	✓	
Arizona, Arkansas, Illinois, Kansas, Louisiana, Maryland, Mississippi, Nebraska, New Hampshire, New Mexico, Oklahoma, Rhode Island, South Dakota, Tennessee, Texas, Vermont, West Virginia, Wyoming		✓	✓
Alaska, Missouri, New Jersey, North Carolina, Utah, Virginia	✓		
Montana		✓	
Connecticut, Indiana, Iowa, Kentucky, Maine, Massachusetts, Wisconsin	-	-	-

A.3 Survey

The "DBTB Survey" examines current trends in DBTB campaigns across the United States. Surprisingly, there is only limited information on the effectiveness and potential of box junctions *(13).* This survey and the study reported on in Appendix B helps to address this gap, evaluating the potential of DBTB campaigns to act as an economical alternative for traffic management.

The survey is comprised of three sections. The first collects general information about the participant's DBTB campaign, if applicable, such as organization classification, expenditures, traffic operations and safety improvements sought, implementation challenges, partnerships, and which pavement makings were installed. If an organization considered or stopped a DBTB campaign, the second part of the survey collects information on the reasons for this decision. The final part of the survey collects anticipated benefits and concerns of participants interested in starting or maintaining a DBTB campaign.

The survey was sent to a variety of different organization classifications, including public works departments, police departments, TMOs, and BIDs. The “DBTB Survey” received 77 responses from 415 queried organizations around the nation, an 18.6% response rate. The participants included 29 local jurisdictions (city, county, etc.), 13 police departments, seven BIDs, four TMOs, one state department of transportation, and one university. The remaining respondents did not state their organization type.

Of the 77 respondents, ten organizations reported that they currently have a DBTB campaign, seven of which started their DBTB campaign after 2010. Addressing traffic congestion is the predominant stated issue addressed by DBTB (Table A - 2). Commonly stated objectives also include safety (pedestrian, bicycle, vehicle, and local resident) and economic impacts on surrounding businesses.

Table A - 2 below shows the particular issues addressed by their DBTB campaigns for those organizations reporting a DBTB program.

Table A - 2: Issues Addressed by DBTB

What were the particular issues that were addressed by DBTB?		
Answer Options	**Response Percent (Based on 10 responses)**	**Response Count**
Traffic congestion	90%	9
Pedestrian safety	60%	6
Bicycle safety	60%	6
Vehicle safety	60%	6
Emission standards concerns	10%	1
Health and safety of residents	10%	4
Economic consequences to surrounding businesses	40%	4
Don’t Know	0%	0
Other (please specify)		3
	answered question	**10**
	skipped question	**67**

A.3.1 Public Education Campaign

Six of the ten organizations used a public education campaign to inform the public about the DBTB program. In most cases the organization conducted the public education efforts, although outside partners, such as the police and local jurisdictions, also participated. Public education campaigns incorporated a wide array of media, such as pamphlets, websites, social media, email, radio, and press releases. The public education campaigns were only repeated when it was deemed necessary by the organization implementing the DBTB campaign.

A.3.2 Obstacles

Of the organizations that had a DBTB campaign, most revealed that they did not experience any major implementation obstacles, although some reported difficulty in either getting support from the local police department or getting the public to observe the signs and pavement markings at DBTB locations. One organization sought to overcome the latter issue by placing LED blinker lights on the DBTB signs and making the "X" inside the box larger on the pavement. Table A – 3 shows which partnerships were found critical to the success of their DBTB campaign.

Table A - 3: Partnerships that organizations found critical to the success of their DBTB campaign

Are there any partnerships that your organization found particularly critical to the success of this DBTB campaign?		
Answer Options	**Response Percent**	**Response Count**
Partnership with the local jurisdiction (city, county, etc.)	40%	4
Partnership with the police department	60%	6
Partnership with the state's department of transportation	10%	1
Partnership with the neighborhood associations	20%	2
None	20%	2
Don't know	0%	0
Other (please specify)	10%	1
	answered question	**10**
	skipped question	**67**

A.3.3 Controls

All ten of the organizations that currently have a DBTB campaign installed both signs and pavement markings at their intersections. Seven of the ten organizations (70%) paid for and installed their DBTB signs, while for the remaining three organizations (30%), the DBTB treatments were installed by other organizations. Nine campaigns used option C, pavement marking from the MUTCD guidelines, and one used option B (Figure A - 1). Eight of the ten organizations (80%) paid for and installed their own DBTB pavement markings, and in two cases other organizations did so. Six of the organizations revealed their estimated budget for installing the DBTB signs and pavement markings at an intersection to be between $1000 and $1999.

A.3.4 Enforcement

A number of studies have reported on citations and warnings related to DBTB enforcement (*9*, *11*, *12*, *13*, *14*). However, while the number of blocking events may be partially quantified by tracking citations, the driver time savings due to DBTB enforcement efforts must be estimated through other means. Of the ten respondents with active DBTB programs, six reported active enforcement at their DBTB intersections. Of these, one organization uses automated enforcement, such as cameras, two had specific task forces assigned to enforce DBTB intersections, and three indicated that any police officer can enforce their DBTB intersections. In addition, four of the respondents stated a need for additional enforcement. The fine for the DBTB violations was up to $199, with several reporting fines under $100. In addition to fines, three of the organizations also reported points to the driver’s license for the DBTB violation. Organizations that do not currently have enforcement at their DBTB intersections cited their reasons as limited time and resources, along with no evidence to support the need for enforcement.

A.3.5 Effectiveness

Of the ten responding organizations with active DBTB programs, one observed minimal improvement in traffic operations since the DBTB campaign started, three observed moderate improvements, and six observed significant improvements. However, limited studies were obtained that documented these statements. One of the few studies considered the DBTB treatment implemented by the Boston Transportation Department, in partnership with the Medical Academic and Scientific Community Organization (MASCO) and the Boston Police Department. This study observed a 50% decrease in intersection blocking, and it reported reductions in the range of 22% to 64% in the number of citations after enforcing DBTB treatments (*9, 10*). Two of the ten organizations observed a decline in the benefits over time, while seven others observed no decline. However, only three of the ten organizations (30%) stated recording data to measure and document the improvements caused of the DBTB campaign. Nine of the ten organizations (90%) indicated that they observed a positive public perception regarding their DBTB campaign.

A.3.6 Likelihood of Future Implementation

Five of the 77 organizations (6%) reported considered implementing a DBTB campaign and chose not to proceed. Reasons for choosing to not implement a DBTB program included the effort required, no perceived benefits, a lack of support from the city and police department, or a combination of these factors.

Two of the 77 organizations (3%) are currently considering a DBTB campaign. The benefits that influenced their decision to consider a DBTB campaign include reduction in traffic congestion, increase in pedestrian safety, increase in bicycle safety, increase in vehicle safety, and positive economic impact to surrounding businesses. They also noted the following concerns about a DBTB campaign: cost, city approval, time, effort, and lack of perceived benefits in specific cases.

Finally, the respondents of the survey were asked: if DBTB campaigns were shown to be an economical alternative in traffic management, would their organization consider starting a DBTB campaign to help with congestion and safety concerns? Forty-seven of the 77 organizations (61%) responded to this question, and an overwhelming 79% of the respondents indicated willingness to consider DBTB campaigns. This response clearly demonstrates the need for a comprehensive study that investigates the effectiveness of DBTB campaigns to address traffic congestion and safety.

A.4 Discussion and Conclusion

DBTB is a potential low-cost traffic congestion mitigation measure. The DBTB Survey received 77 responses from 415 queried organizations. The DBTB survey confirmed that the organizations that currently have a DBTB campaign chose to implement it primarily to address traffic congestion and improve safety at the subject intersections. The respondents reported a relatively low cost for DBTB, with estimated budgets for installing signs and pavement markings typically under $2,000. Additionally, about half of the organizations that have a DBTB campaign found that partnerships with the police department and local jurisdictions are critical in the process of implementing their DBTB campaign. The majority of the organizations that have a DBTB campaign found that the level traffic operations has sufficiently improved since their DBTB campaign started, and said that observed benefits did not decline over time. However, five of the organizations that completed the survey had previously considered a DBTB campaign but chose not to go forward with implementation. Noted reasons included the effort involved, a lack of perceived benefits, or a lack of support from the city and police departments.

From the survey it is clear that a significant hindrance to the widespread implementation of DBTB programs is a lack of information quantifying their potential benefits. In addition, documentation of lessons learned from current implementations, such as the importance of enforcement, guidance in intersection selection, etc., is needed to improve the likelihood of a successful program implementation. As seen, 78% of the respondents agreed that if DBTB campaigns were shown to be an economical alternative in traffic management, they could consider starting a DBTB campaign to address congestion and safety concerns.

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Appendix B: Case Study: Understanding Vehicle Blocking Behavior to Assess Feasibility of DBTB

List of Figures

B.1 Introduction

Characteristics of gridlock and strategies to control it have long been topics of interest to researchers *(1-7).* It has been shown that avoiding growth of small, localized gridlock can prevent a network-level gridlock ("jam" state) *(8).* However, there is lack of detailed studies on DBTB treatment performance and efficiency *(9)*. As highlighted in Appendix A, one of the few studies that were identified considered the DBTB treatment implemented by the Boston Transportation Department in partnership with the Medical Academic and Scientific Community Organization (MASCO) and the Boston Police Department. This study observed a 50% decrease in intersection blocking, and it reported reductions in the range of 22% to 64% in the number of citations after enforcing DBTB treatments (*9, 10*). A number of additional studies have also reported on citations and warnings related to DBTB enforcement (*9, 11, 12, 13, 14*); however, while the number of blocking events could be partially quantified by tracking citations, the driver time savings due to DBTB and enforcement must be estimated through other means.

The DBTB survey revealed a significant percentage of the TMOs that responded to the survey agreed, if DBTB campaigns were shown to be an effective, economical alternative in traffic management, they could consider starting a DBTB campaign to address congestion and safety concerns. This section explores the potential impact of DBTB treatments at congested signalized intersections.

B.2 Methodology

A traffic simulation model consisting of a signalized four-leg intersection, a six-lane major arterial crossing a four-lane minor street, developed in VISSIM traffic flow simulation software, was employed to investigate DBTB. To generate blocking opportunities at the intersection, downstream bottlenecks were placed on the major arterial, creating spillback (i.e., queuing) through the intersection box. Major street vehicles may follow either blocking behavior (i.e., will enter the intersection box when the exit is blocked by a queue) or non-blocking behavior (i.e., will not enter an intersection if a block would result). The selected behavior is determined randomly according to a user-defined *blocking likelihood*, i.e., the likelihood that a vehicle will exhibit blocking behavior. For instance, a *blocking likelihood* of "zero" precludes any vehicle from entering the intersection if the entry would cause a block to occur, while a *blocking likelihood* of "one" indicates that all vehicles will enter the intersection without concern for the potential to create a block. This modeling approach allows for the exploration of the sensitivity of intersection operations to different levels of *blocking likelihood* and to the impact of a reduced likelihood due to a DBTB treatment. Implementation of this methodology is described in the reminder of this section.

B.2.1 PTV VISSIM Traffic Simulation Software

The traffic simulation used in this research was implemented in PTV-VISSIM 5.2, a commercially available microscopic transportation simulation package. In this model, traffic flow is based on the Wiedemann's car-following models and rule-based algorithms for lateral vehicle movement (*15,16*). This effort required use of the VISSIM COM (component object model) interface that allows access to the object model hierarchy, with network elements such as vehicles, links, vehicle inputs, etc. (*17*).

B.2.2 Network Layout

The simulation model is shown schematically in Figure B - 1. The left image is a snapshot of the network and the right image is a sketch of the signal layout. Signal A controls the traffic movement at the Major Street and Minor Street intersection. Signals B and C are placed on the major street, downstream of the intersection, to function as traffic bottlenecks.

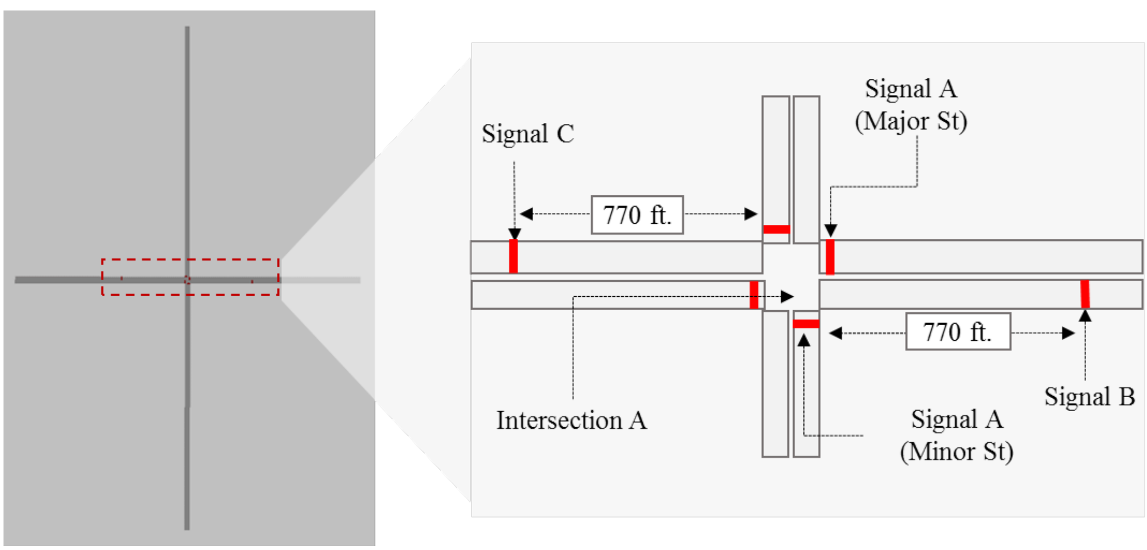


Figure B - 1: Schematic diagram of the network developed in the simulation model

B.2.3 Implementing Blocking Behavior

To simulate a blocking incident a vehicle must enter the intersection when a blocking opportunity exists. That is, traffic spillback (i.e., queuing) from a downstream bottleneck must reach the subject intersection, leaving insufficient space for a vehicle that enters the intersection box to exit. To generate the spillback in this study, fixed-time signal phase lengths were chosen such that the Signal B (or Signal C) hourly capacity is less than that of the upstream Signal A approach. Thus, as the mainline flow increased, the capacity of Signal B (or Signal C) would be exceeded prior to that of Signal A, allowing for the development of a queue between Signal B (or Signal C) and Intersection A.

At several intersections in Atlanta it was observed that not all drivers choose to enter an intersection box when that action could result in blocking. Thus, it is also necessary that the simulation reflect the likelihood of a vehicle entering the intersection box when a blocking opportunity exists. For this simulation, this is referred to as the *blocking likelihood*. To implement *blocking likelihood* in VISSIM, a dynamic assignment of the *vehicle type* attribute of the *vehicle object* is utilized in coordination with priority rules.

B.2.4 Dynamic Assignment of Vehicle Type

Three different vehicle types are defined:

- *Vehicle Type 1* – This vehicle has the default characteristics. All vehicles enter the simulation as a Type 1 vehicle.

- *Vehicle Type 2* – *Vehicle Type 1* with driver behavior to enter an intersection box irrespective of space availability to exit the box. That is, a vehicle that *can create a blocking event*.
- *Vehicle Type 3* – *Vehicle Type 1* with driver behavior that will not enter the intersection when insufficient space exists at the box exit. That is, a vehicle that *will not create a blocking event.*

To implement dynamic assignment of *vehicle type* according to the *blocking likelihood*, each major street approach of the DBTB intersection is divided into two sections: (1) the decision-zone, i.e., the area where vehicles are assigned as *vehicle type 2* or *vehicle type 3*, and (2) the box zone, i.e., the area including the intersection proper and one-vehicle length downstream. The schematic representation of the sections is shown in Figure B - 2.

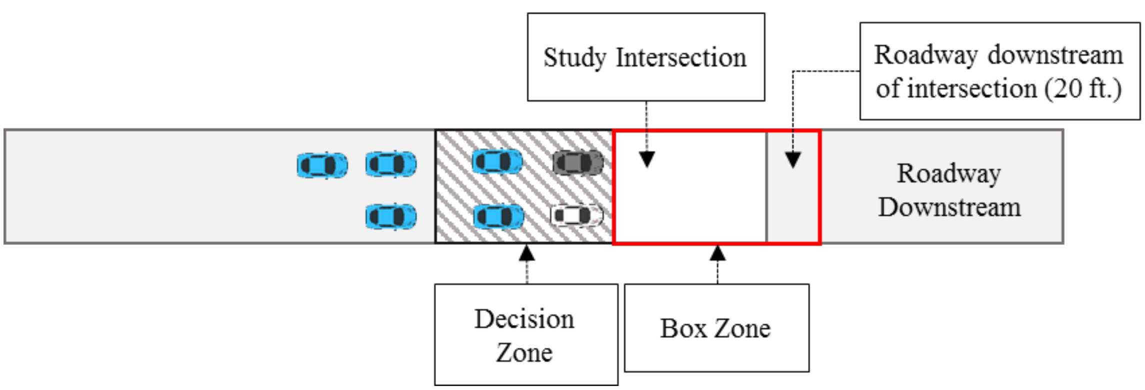


Figure B - 2: Roadway sections of the network on major street approaches to implement DBTB

Dynamic assignment of the *vehicle type* is implemented in VB.Net using the VISSIM COM interface. The first step is to determine if the potential for blocking may exist. This step acts only as a filter, eliminating the need to dynamically assign *vehicle type* when blocking is not possible. While elimination of this filter would not alter the simulation results, it serves to reduce internal calculations required to assign *vehicle type* and significantly enhance the execution speed of the simulation. In the current implementation, a vehicle speed of 15 mph in the box zone was used for this filter.

In the second step of the dynamic assignment process, applied only when the potential for blocking has been indicated, COM is used to identify vehicles within the decision zone using the *approach link number* and *vehicle coordinate* attributes. The vehicle closest to the stop line in the decision-zone is assigned as the lead vehicle. The lead vehicle is then assigned as *vehicle type 2* with a probability of *blocking likelihood*; otherwise, the lead vehicle is assigned as *vehicle type 3*. Those vehicles in decision zone upstream of the leading vehicle are then designated as following vehicles and assigned the same vehicle type as the lead vehicle. The *vehicle type* assignments for the lead and following vehicles are undertaken on a lane-by-lane basis. The assignment of the following vehicle behavior to that of the lead vehicle is based on observation of blocking behavior in Atlanta, Georgia. It was observed that when a vehicle made a decision to block, several vehicles behind that vehicle (i.e., following vehicles) also had a very high tendency to enter the intersection. Future efforts will seek to formalize the relationship between the lead vehicle's *blocking likelihood* and the subsequent following vehicles' *blocking likelihood*.

B.2.5 Implementing Blocking Rules

VISSIM priority rules are used to enable the conditional stopping necessary to implement the desired blocking and non-blocking behavior based on the assigned *vehicle type*. Priority rules are based on the headway and gap conditions of a vehicle at specified location and are specific to a *vehicle type*. Two elements are required to implement a priority rule in VISSIM: 1) a stop line and 2) one or more conflict markers associated with the stop line. In this implementation, the stop line of the priority rule is placed at the stop bar of the major street approach, with the conflict marker placed one vehicle length downstream of the intersection box. Figure B - 3 shows this framework in the model. The minimum headway, defined as the length of the conflict area, is set to extend from the conflict marker to the approach stop bar (yellow area in Figure B - 3). The minimum gap, defined as the time until a conflicting vehicle reaches the conflict marker, is set to two seconds. Thus, if a vehicle is within the area between the stop bar and the conflict marker or within two seconds of the conflict marker, the priority rule will be active and an adhering *vehicle type* will not enter the intersection box. Finally, the priority rule was conditioned on the speed of the subject vehicle type, with approximately 18 mph for the priority rule to apply. In this implementation, only *Vehicle Type 3* adheres to the priority rule. Thus, *Vehicle Type 3* will exhibit non-blocking behavior, while *Vehicle Type 2* will enter an intersection box when the possibility of creating a block exists.

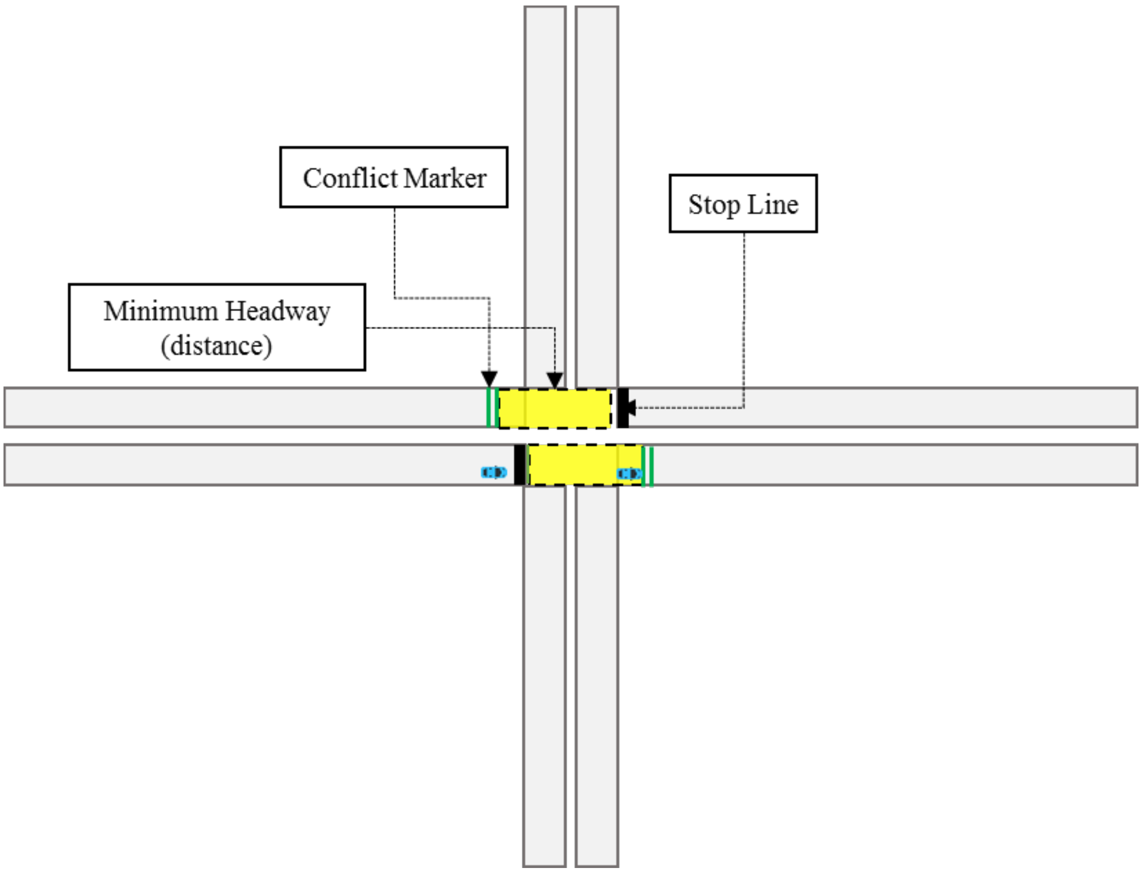
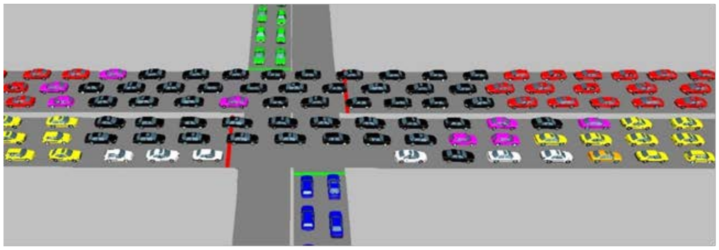


Figure B - 3: Operation of the Priority Rule to incorporate the non-blocking behavior for Vehicle Type 3

Figure B - 4 is a snapshot of the simulation with a *blocking likelihood* of 60%. The image shows *vehicle type* indicated by color. A change in vehicle type associated with the dynamic assignment of vehicles of *Vehicle Type 1* is seen on every lane of the major street. For example, considering Eastbound (EB) traffic, the yellow-colored EB vehicles of *Vehicle Type 1* change to *Vehicle Type 2* or *Vehicle Type 3* in the decision zone. Furthermore, vehicles of *Vehicle Type 2* on the two leftmost lanes of the EB approach block the vehicles on the Northbound (NB) approach, while the vehicles of

Vehicle Type 3 on the rightmost lane exhibit non-blocking behavior and remain out of the box.



Vehicle Colors As per Vehicle Type
EB *Vehicle Type 1* – Yellow
WB *Vehicle Type 1* – Red
NB *Vehicle Type 1* – Blue
SB *Vehicle Type 1* – Green

Lead *Vehicle Type 2* – Purple
Lead *Vehicle Type 3* – Orange
Follower *Vehicle Type 2* – Black
Follower *Vehicle Type 3* – White

Figure B - 4: Simulation run snapshot (60% Blocking Likelihood) showing dynamic assignment of Vehicle Type with change in vehicle color

Figure B - 5 below displays the flowchart of the simulation COM logic for the dynamic assignment of *vehicle type*. This logic is implemented in VB.NET and executed each simulation time step, for each Major Street approach lane.

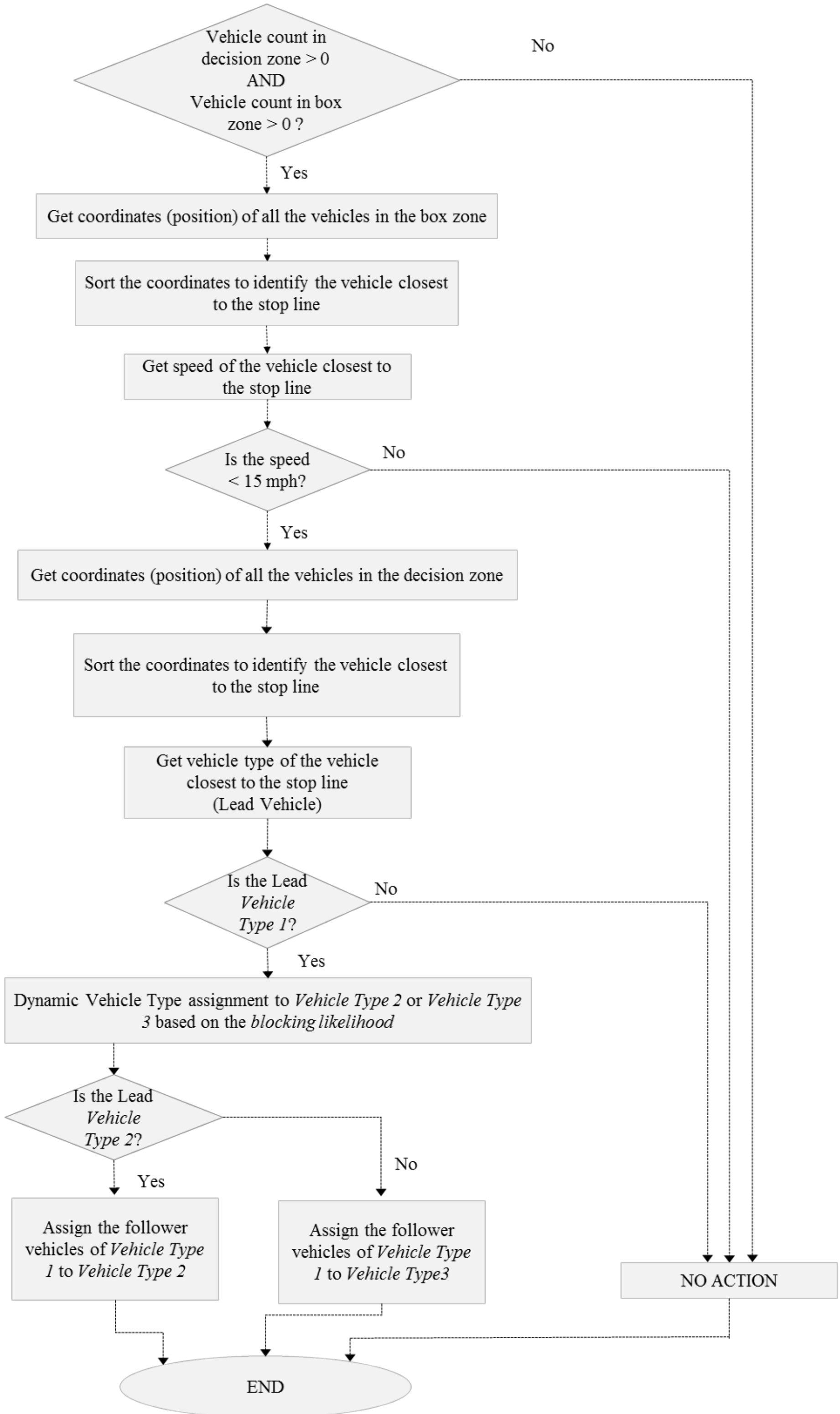


Figure B - 5: Logic flowchart of the DBTB dynamic assignment of vehicle type

B.2.6 Design of Experiment

The base simulation scenario consisted of a three-hour simulation, allowing for the collection of performance metrics during major street near-capacity conditions, overcapacity conditions where blocking could occur, and a recovery period. To accomplish this, the first-hour major street traffic demand was set just below the capacity of the downstream Signals B and C, the second-hour traffic demand was set over the capacity of Signals B and C while under the capacity of the Intersection A major street approaches, and the third hour major street traffic demand was set under the capacity of Signals B and C. The minor street had consistent traffic demand throughout the simulation run. All signals were fixed time. Signals B and C near-capacity (1900 vph) and over-capacity (2600 vph) demands were determined through iterative runs on the base network.

Simulation experiments were conducted to model the delay incurred and the reduction in the number of vehicles processed on the minor street approaches for three under-saturated traffic conditions (100, 200, and 300 vph) as well as oversaturated conditions (standing minor street approach queue throughout the simulation), under various blocking likelihoods (0%, 20%, 40%, 60%, 80%, and 100%). The reduction in the number of vehicles processed when the minor street was oversaturated also represents reduction in minor street capacity during blocking. In all scenarios, only through vehicles are modeled. Ten replicate trials were conducted for each traffic demand with blocking likelihood combination.

B.3 Results

The focus of the simulation results is on the minor street vehicles, since the given scenarios' blocking has minimal impact on the major street performance. As there are no turning movements, a major street vehicle choosing not to block does not compete for space with minor street vehicles turning onto the major street. While the addition of turning movements will allow for the capture of additional interactions, it is not expected to change the overall observed trends.

B.3.1 Delay

Figure B - 6 and Figure B - 7 show the scatterplot and box plots, respectively, for the average delay (sec/veh) over the three-hour run, obtained for the 100 vph, 200 vph, and 300 vph minor street volumes across *blocking likelihoods*. For this analysis, the average vehicle delay was determined for every five-minute interval and the reported average delay is the average of these intervals.

As expected, as the minor street volume increases, the delay values also increase. The *blocking likelihood* of 0% shows the expected delay for no blocking by major street vehicles. As the blocking likelihood increases the delay increases, with the most significant increases in mean delay and variability at 40% and 60%. The higher minor street volumes also have more dramatic increases in delay and variability, as seen in the box plots. These values may be conservative, as the simulation does not reflect that these increasing delays may increase minor street vehicle aggressiveness, resulting in additional blocking as minor street vehicles attempt to force their traversal of the intersection. Figure B - 8 and Figure B - 9 show the scatterplot and box plots, respectively, for the maximum 15-minute average delay (sec/veh). These delay values represent the worst-case performance experienced by vehicles, with instances at the highest *blocking likelihoods* representing complete gridlock with delays approaching one hour. Although the range of average delay values obtained in Figure B - 8 and Figure B - 9 are more than twice than that shown in Figure B - 6 and Figure B - 7, the basic pattern in variation across different blocking likelihood and minor street volumes remains similar.

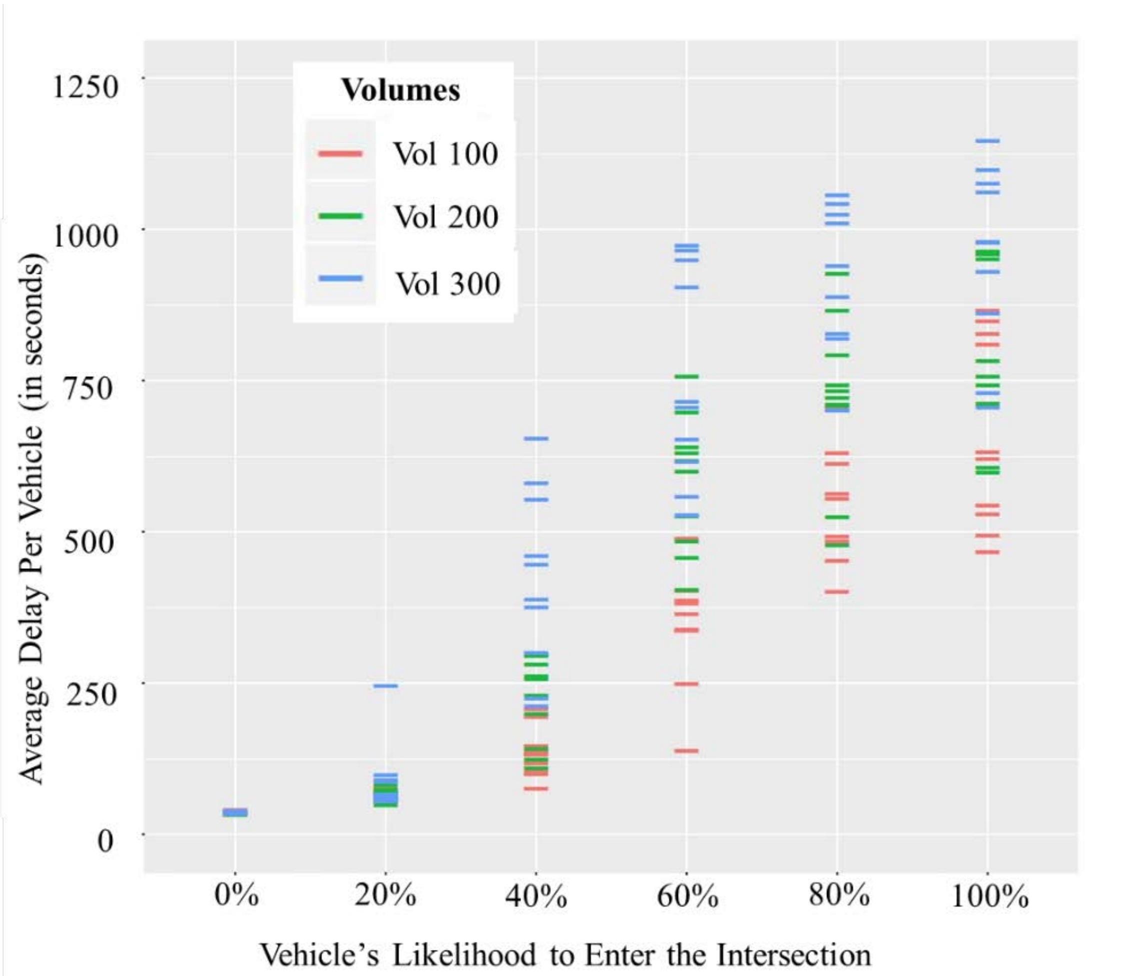
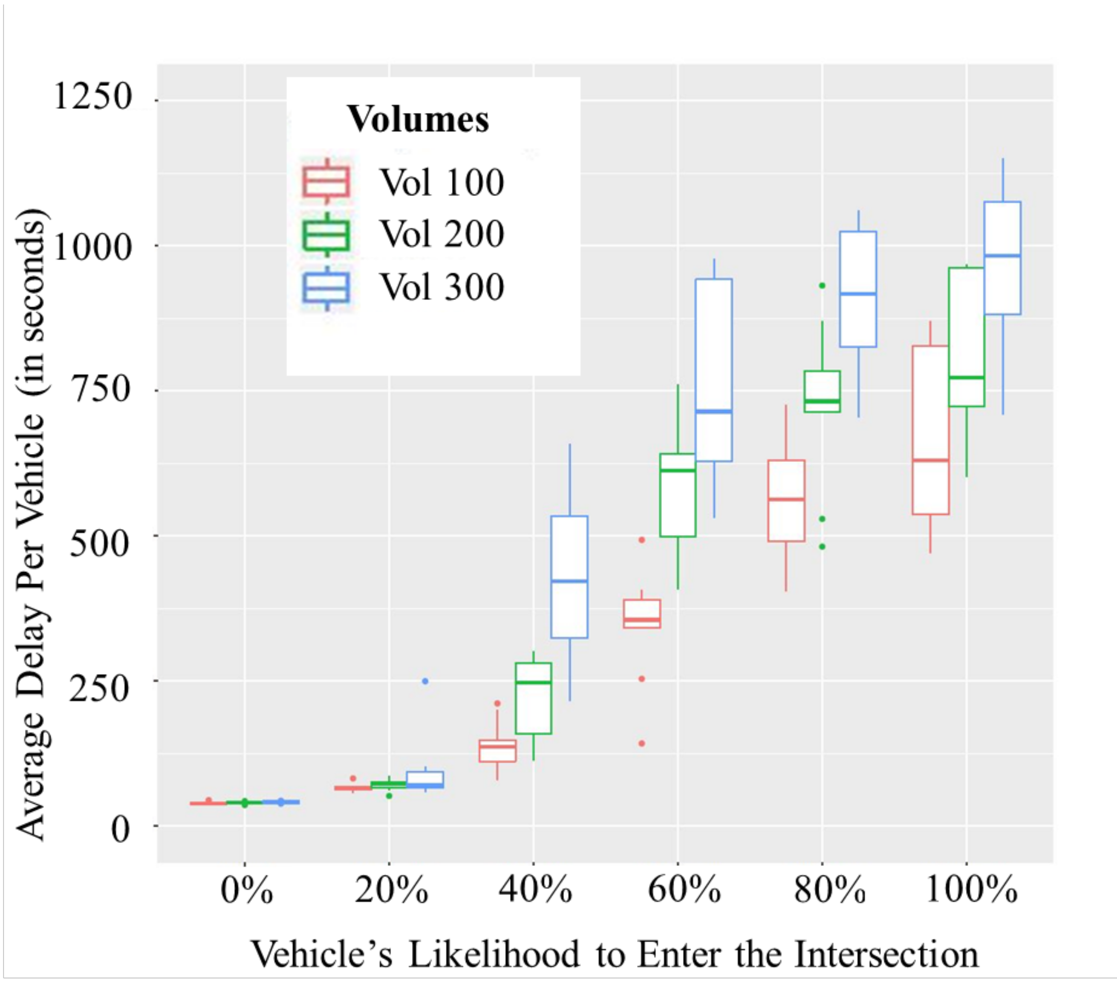


Figure B - 6: Scatterplot of Average Delay (sec/veh) on Minor Street versus blocking likelihood



(b)

Figure B - 7: Boxplot of Average Delay (sec/veh) on Minor Street versus blocking likelihood

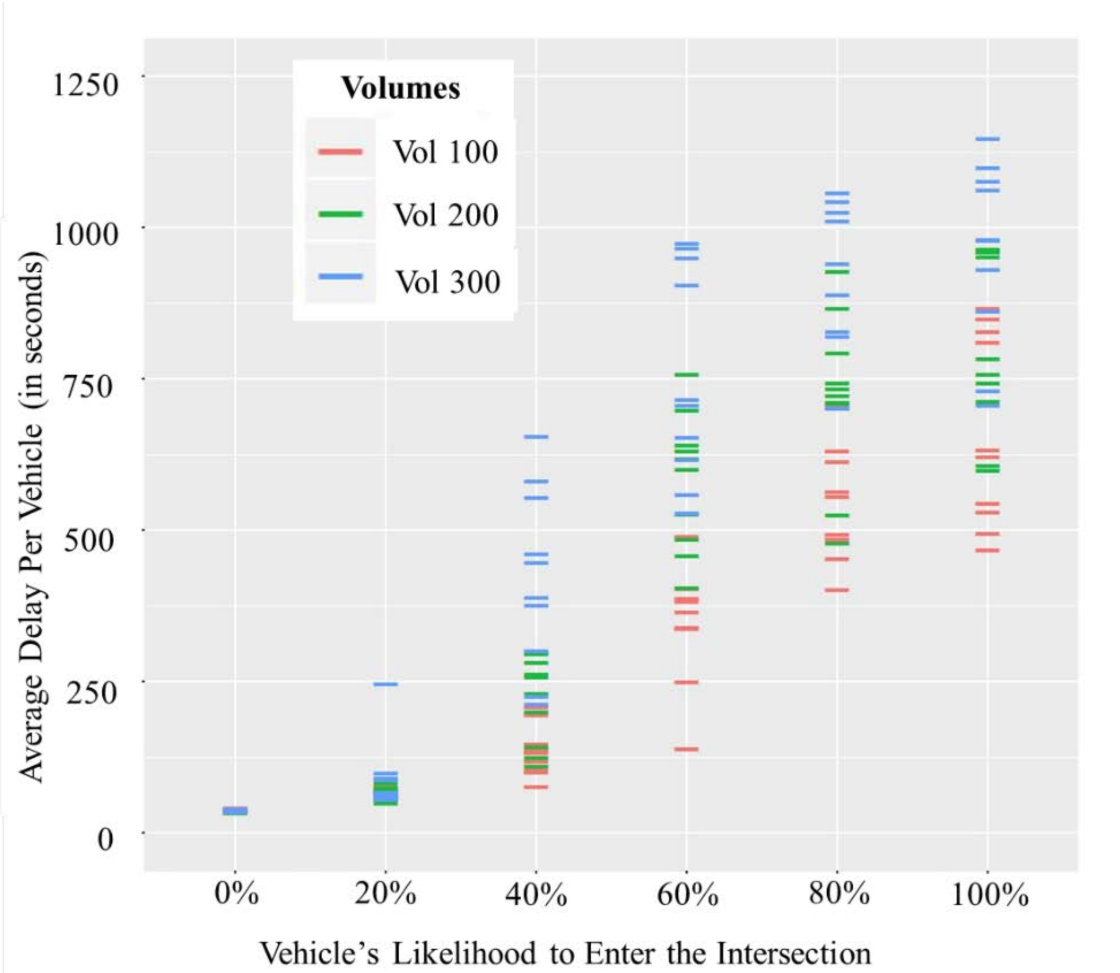


Figure B - 8: Scatterplot of Max 15 min Average Delay (sec/veh) on Minor Street versus blocking likelihood

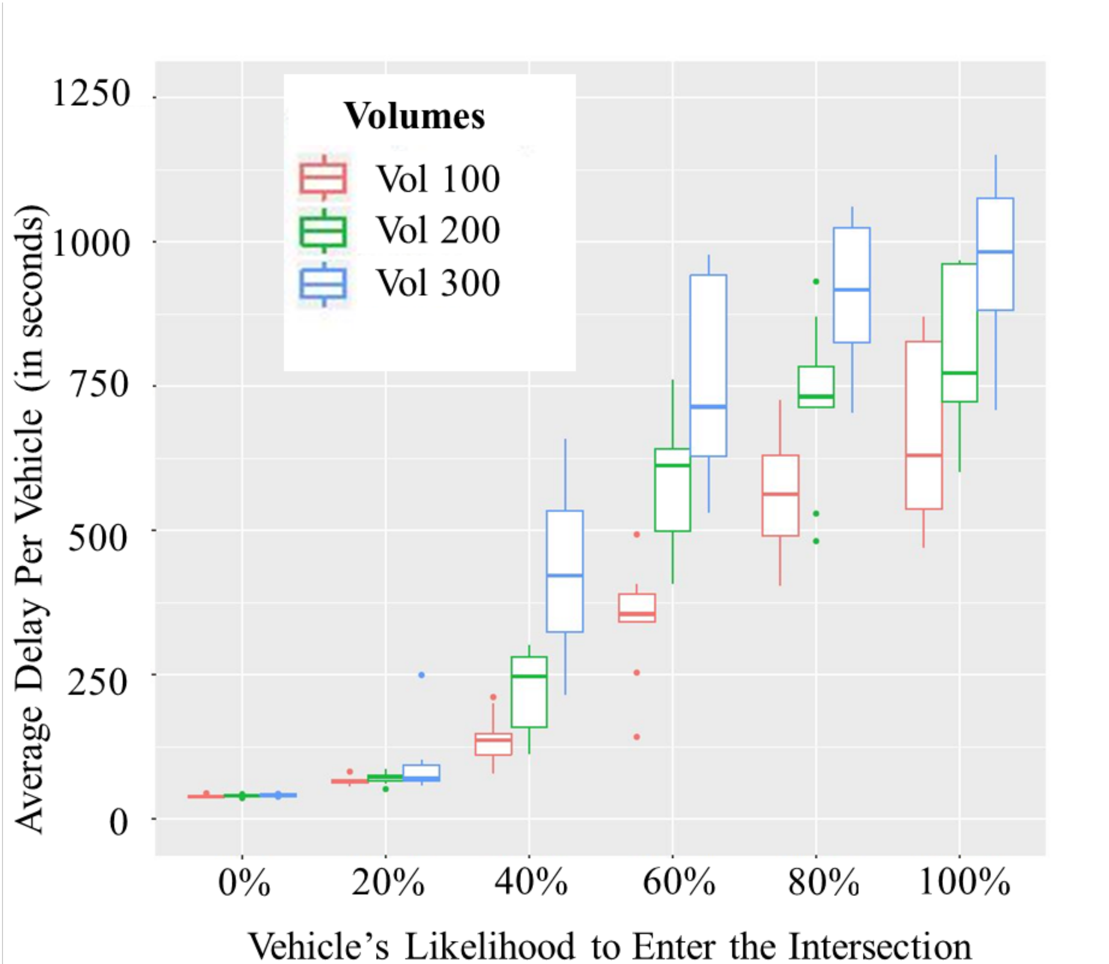


Figure B - 9: Boxplot of Maximum 15 min Average Delay on Minor Street vehicle versus blocking likelihood

B.3.2 Minor Street Capacity Reduction

The results obtained for the oversaturated demand on the side street are shown in Figure B - 10. The scatterplot shows the reduction in minor street processed traffic due to blocking on the major street. Given the oversaturated conditions (i.e., there was a continuous standing queue), minor street processed traffic was approximately 2400 vehicles during the three-hour simulation run (i.e., an hourly capacity of approximately

800 veh/hr), determined as the number of minor street vehicles to traverse the intersection when no major street vehicles were blocking, i.e., *blocking likelihood* of zero. The reduction in traffic processed in Figure B - 10 represents how many fewer vehicles departed the minor street approach during the three-hour run, for the varying likelihoods, with nearly all reductions occurring in the second hour during blocking.

The scatterplots again indicate that the most dramatic reductions in traffic processed occur in the mid-range *blocking likelihoods* of 40% and 60%, with reductions due to blocking equivalent to 60% to 100% of an hour of capacity. Also, agreeing with the prior delay results, nearly complete gridlock is seen in the 80% and 100% *blocking likelihoods* with reductions approaching and exceeding the capacity of the entire second hour of the major street blocking period.

Figure B - 10: Scatterplot depicting variability in the minor street capacity loss across different levels of blocking likelihoods

B.4 Conclusion

This section explores the relationship between blocking behavior, increased vehicle delay, and capacity reduction in a single intersection scenario. From the delay and capacity reduction results, it is seen that the impact of blocking can be significant, reaching complete gridlock on intersection approaches. Ultimately, the goal of a DBTB treatment is to reduce the *blocking likelihood* to zero, or nearly so. However, from the result it can be seen that a DBTB treatment can significantly improve flow even without achieving the goal of zero blocking. This is particularly true where *blocking likelihood* is reduced from the mid-range (40% to 60%) to less than 20%. This also demonstrates the importance of enforcement programs. While it is not necessary that enforcement eliminate blocking altogether, it must be of sufficient frequency to limit drivers willing to risk blocking to a low percentage of the driving population.

While the results highlight the potentially significant impact of blocking, and the improvements that could be achieved through DBTB treatments, several challenges remain in the analysis. The first is regarding model validation. Current validation is limited to observational comparisons with in-field DBTB treatments. However, ongoing data collection efforts are underway to quantify before-and-after DBTB treatment operations, allowing for further model calibration and validation. In addition, the models could be expanded to include multiple intersections (directly capturing gridlock between intersections) and turning movements to reflect potential additional interaction between the cross streets.

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Appendix C: Case Study: Parking Solutions Leveraging Connected Vehicle Initiative

List of Figures

Connected vehicle technologies are experiencing rapid growth and innovation, offering significant new opportunities to TMOs for transportation operations improvement. These technologies encompass a wide array of potential application areas. For instance, the USDOT classifies connected vehicle applications into three groups: safety, mobility, and environmental *(1)*. A primary characteristic of connected vehicle applications is the utilization of real-time communications and data. Real-time data applications offer an ability to increase safety and operational efficiency nationwide *(1)*. To achieve these benefits, though, connected vehicle applications can require extensive infrastructure and substantial capital, which can be a potential barrier to use by many TMOs. However, where a connected vehicle program established by a larger transportation organization exists, TMOs may be able to leverage this technology at potentially minimal cost. For example, parking management (see Figure C - 1) may be dramatically improved using real-time data and, despite limited budgets, is a strong candidate for TMO application. Thus, this appendix focuses on connected vehicle technology in the context of parking management, providing an overview of parking management systems, traditional and future, and their critical nature to TMOs.

Figure C - 1: Parking Management is a part of the Operational Scenarios for Applications for the Environment: Real Time Information Synthesis *(1)*

C.1 Introduction

According to United States census data, the rate of motor vehicle ownership has been increasing for decades *(2)*. Unfortunately, increasing vehicle ownership has resulted in increasing congestion, travel times, and transportation costs for a majority of US urban areas. In congested areas, finding parking can significantly contribute to the total trip time, causing travel times to increase. In addition, as demand and congestion increase, parking becomes a limited and expensive resource, with its limited availability also contributing to air pollution and being a detriment to the quality of urban mobility *(3)*.

The importance of parking at both the transportation system and individual user levels is difficult to overstate. Almost every car trip starts and ends with a parked vehicle. Most vehicles are parked the vast majority of their useful lifetime; parked 80% of the time at home, parked 16% of the time elsewhere, and in operation only 4% of the time *(4)*. Parking inefficiencies can result in many economic, environmental, and safety costs. Of direct relevance to the mission of many TMOs is that inefficient or insufficient parking can result in people avoiding an area or finding other areas that provide the same goods. In particular, parking constraints can damage the attractiveness of city centers to both retail and commercial enterprises *(5)*.

C.2 Parking Management Systems

To address challenges commonly associated with parking in urban and commercial areas, parking management systems should be part of a comprehensive parking policy. Other elements of a comprehensive policy include street parking control, parking fare structure, and parking revenue management systems *(10)*. Parking management systems have evolved from traditional technologies such as parking meters to advanced wireless networks. Today, integrated parking management systems utilizing wireless networks may allow drivers to inquire about parking availability, reserve a space, or pay for parking in advance, all from inside an individual's car *(11)*. Perhaps the most attractive feature of advanced parking technologies is the ability to guarantee a user a parking space at their desired designation prior to arriving at the parking facility. The advantages of such systems are similar to restaurant table reservations, a common concept that has existed for decades. By guaranteeing a table, the patron's wait time (and potential frustration) is decreased and the product is consumed in a more efficient manner. Similarly, when a parking spot is reserved in advance, the user may avoid wasting time and fuel while seeking a parking spot. A greater proportion of the user's time may be expended on their desired task. Importantly, all users of the local roadway network benefit from a reduction in congestion and emissions related to drivers searching for a parking spot. Other attractive features of parking management systems, particularly in the city centers, are their ability to mitigate frustration of visitors unfamiliar with the city center and decreased average trip times, total miles traveled, energy consumption, and air pollution *(9)*.

The parking system operator also benefits from using parking management systems through more efficient utilization of existing infrastructure. Advanced technologies in parking facilities enable entering and exiting vehicles to be processed faster *(11)*. Improving the efficiency of parking facilities allows for maximum utilization of parking spaces and reduced parking-related congestion in the facility vicinity *(11)*. Parking operators also benefit from the shorter queues at parking facility entrances and exits. Transition time (finding correct change, processing a credit card, misplaced parking tickets, etc.) contribute significantly to queuing at access and egress points. Transition times and their associated delays and queues are significantly reduced or eliminated where wireless advanced transactions are utilized. This increase in efficiency also provides higher profit margins for the parking operator by increasing the security of payments and total revenues *(11)*. In addition, traditional systems often require significant staff for parking facility management, interaction with customers, etc. With advanced parking management systems, a computer manages the utilization of parking using coded algorithms *(8)* for transactions with the customer, reducing the overall cost of operations.

C.2.2 Stakeholders

Parking management systems have many potential stakeholders across both the public and private sectors. Both private and public entities manage parking facilities. Private parking facilities are often managed by an associated business or facility (i.e., office building, mall, etc.), although many standalone parking facilities exist. Public parking facilities are similar to privately managed facilities, with the addition that public parking may also include substantial street parking in urban areas.

In urban areas, city governments are critical stakeholders. City governments are typically responsible for parking enforcement on local streets and public parking facilities. Parking revenue contributes to various city infrastructure improvements and new development investments *(11)*. By implementing parking management systems, city governments would reap the benefits of increased revenue as well as reduced traffic congestion around commercial and dense residential areas, increasing the attractiveness of the city.

Transit agencies can also be substantial parking resource consumers. Park-and-ride lots represent a significant opportunity for advanced parking management systems. They enable transit agencies to increase transit use and revenues while reducing vehicle travel, fuel use, and air pollution *(9)*. By investing in parking facilities near transit stations, transit agencies may attract additional vehicle users to transit for a portion of their trip, providing them with an alternative to traveling under congested conditions in downtown city centers *(9)*. Smart parking management technologies may also provide a cost-effective tool to address near-term parking constraints at transit stations *(7)*.

By the nature of their missions, CIDs, BIDs, and TMOs are concerned with the success of the stakeholders listed above. However, they are also direct key stakeholders in parking management, as they often represent a large percentage of private businesses that are dependent on available and efficient parking. These organizations benefit from parking management systems, as member employees and customers receive improved service and reduced stress through guaranteed parking and reduced wait times. An additional benefit for member private businesses is the ability to turn their parking facilities into revenue generators after work hours. For example, in the past, the Georgia Aquarium has allowed their parking facility to be used during Atlanta Falcons home games. In many instances, visitors and residents are unaware that parking facilities at private businesses are open to the public after hours. However, advanced parking management systems can directly connect potential parking consumers with the available facility.

Parking management systems have experienced sustained growth over the last decade, in part due to collaborations between private and public sector stakeholders (6). For example, the smart parking management technology field operational test, conducted at the Rockridge Bay Area Rapid Transit (BART) District station in Oakland, California, is a result of public-private collaboration *(7)*. To promote transit ridership, BART worked with PrivateCarma to help make the parking at their stations more efficient *(7)*. In addition, city governments, transit agencies, private businesses, and improvement districts have contracted with application developers to create applications that conform to their cities/businesses and improve existing parking infrastructure.

Lastly, the federal government has entered as a prominent stakeholder in parking management systems through the connected vehicle program. While many early applications of the connected vehicle program focus on safety applications, there are various other applications such as parking and real-time route guidance that are beginning to experience significant interest and implementation. A common theme among the stakeholders presented in this section is that they would all benefit from reductions in parking-related congestion.

C.2.3 Cost of Inefficient Parking Management Systems

Inefficiencies in parking management systems present costs to the users and operators of parking facilities. A driver's choice of whether to continue to cruise to seek parking is based on several factors: the cost of off-street parking or on-street parking, the cost of fuel, the expected parking duration, the number of passengers, and the perception of the value of time *(12)*. Where parking is inefficient, the driver's decision process may be impacted negatively, with repercussions to many of the discussed stakeholders. For instance, the operators of parking facilities experience reduced income when a facility is not managed properly. Sources of lost revenue include users cheating the system, users that are missed because they are unaware of the rates or locations of the parking facility, or users that avoid a facility due to parking-related congestion. In additional, local business may lose potential customers who go elsewhere to avoid parking frustrations.

The transportation network also experiences an increase in vehicle miles traveled as users seek parking. Finally, the users themselves experience reduced service and higher costs.

The act of cruising for a parking space can cause significant delays in traffic, resulting in lost capacity, obstructions in traffic flow, and signal cycle failures *(12)*. Shoup et al. report that between 1927 and 2001, studies of cruising in congested downtown areas have found that it requires between 3.5 and 12 minutes to find on-street parking, and that between 8% and 74% of the traffic was cruising for parking *(12)*. Comparable studies found similar travel time increases resulting from additional time spent searching for parking in congested areas. In one study, it was determined that over half the cars driving in a city downtown with significant parking problems are cruising for a parking space *(13)*. Another study concluded that inefficient parking accounts for up to 30% of total traffic in city centers *(14)*. While the results of these studies show a wide range of findings, one conclusion is inescapable: parking significantly contributes to the congestion experienced in many major corridors.

C.2.4 Transformations in Parking Management Systems

Early parking management improvements were not considered in the context of a "parking system." Rather, they were necessities of business in commercial and dense residential corridors that, over time, evolved into sophisticated systems. The evolution of traditional and advanced parking management systems is presented to allow a better understanding of past and current trends in parking technologies.

C.2.4.1 Traditional Parking Management Systems

Initially, much of the parking in larger cities was free and there was limited regard for how parking affected the flow of traffic. These polices (or lack of polices) contributed to urban congestion. However, the congestion caused by inefficient parking led to one of the most impactful parking technologies in the 20th century, the parking meter. Parking meters allowed cities and private businesses to enforce not only their parking policy but also regional traffic management policies *(15)*. To access the parking facilities, the consumer would pay for parking using coins or paper money. Such technology was easily applied to surface lots and street parking. Only more recently have meters started accepting credit cards, making the process of parking faster and more convenient for the consumer (and also reducing the incentive for parking meter theft). While meters have been highly successful, they traditionally have not been connected into a system. Thus, the ability to measure the available capacity in parking facilities, or across a street network, was crude at best. During high demand periods, vehicles could be allowed to enter a parking facility or circle a city block and find themselves searching for an available parking stall that may not exist.

Historically, the public sector found it difficult to maintain pace with the technological advances in parking infrastructure, often due to constricted budgets. Public parking operators considered these new technologies only when the cost of implementing them was sufficiently small, benefits were well documented, and adequate budget resources, often in competition with many other needs, could be found. However, many private parking facility operators were able to take advantage of technological advances in parking management more rapidly when they were shown to provide benefits greater than the costs incurred to the business. For example, private operators were early adopters of new technologies introduced to maintain optimal utilization of capacity, either with more advanced algorithms or with sensors placed in the facility: SFpark in San Francisco was one of the pioneers in term of collecting data with sensors *(7)*. Data was compiled monthly to determine where and when prices should be adjusted to achieve the preferred balance of available parking stalls *(7)*. However, a drawback of this technology can be significant implementation costs, as every parking stall must be monitored. ParkNet was introduced as a potential advance to individual stall sensors. ParkNet used mobile parking sensors on its monitoring vehicles, allowing a reduction in the number of sensors that were needed for each parking facility *(16)*. When a vehicle with a mobile sensor was driven around the parking facility it detected cars parked on one side. ParkNet claimed a 95% accuracy in obtaining parking counts *(16)*.

Finally, a common theme in the earliest parking management systems is the human element. Whether conversing with the parking facility attendant, arguing with a parking enforcement office, standing in a parking space to hold it for a friend, or handing off your keys to a valet, human interaction was necessary to handle daily operations in traditional parking management systems. Human-to-human interactions can contribute to the inefficiencies in parking management *(8)*. As time progressed, new technologies in parking management systems, such as smartphones and the Internet, have reduced the human-to-human interaction and increased efficiency.

C.2.4.2 The Internet and Smartphone Parking Applications

Smartphone and Internet-based technologies have dramatically shaped parking systems over the last decade, although the concepts enabled by these technologies have been discussed and piloted for many decades. For instance, in the 1980s the In-Vehicle Parking Meter (IVPM) was introduced. The IVPM was one of the first attempts to create a centralized parking management system *(17)*. The user would connect the IVPM device to a computer and access their account via the Internet, where additional funds could be added using a credit card. The IVPM was an early technology that demonstrated the opportunity to enable parking facility operators to more effectively collect revenue and manage their facilities *(17)*. A more recent Internet application for parking is Parkopedia. This site allows the vehicle user to choose from over 28 million parking stalls in 40 different countries and 6,308 towns *(18)*. Parkopedia is a non-profit organization that uses open source attribution from OpenStreetMap, CKSource, The jQuery Project, Zillow, and Wikimapia *(18)*.

As smartphones become commonplace, parking applications are moving from computers to mobile technology, greatly enhancing ease of use and the adoption rate of such services. Most smartphone parking applications, also called pay-by-phone parking, have been predominantly developed by private businesses. Smartphone-based parking applications improve the efficiency and ease of payment as well assist the customer in locating a parking stall. Smartphone applications also address “meter anxiety” as they provide users with an update of the time they have left in their parking stall and allow them to add time if needed *(19)*. Such applications have also contributed to private sector development of crowdsourcing applications. From users equipped with continuously connected smartphones, the potential for vast real-time data collection, through observation with manual input or device sensors, becomes a reality *(19)*. Mobile crowdsourcing enables data collection through thousands or millions of intelligent probes, collecting data primarily from the surroundings of people's everyday life *(19)*. This mass collection of data may provide helpful resources to the individuals using the application as well as society as a whole *(19)*. Some of the more popular smartphone parking applications are described in the following paragraphs (descriptions are accurate at time of reference; additional reviews should be conducted for future updates and changes).

The *BestParking* application is a parking search engine that directs drivers to low-cost and convenient parking garages and lots in 100 cities and 115 airports throughout North America *(20)*. The user enters the city, location, duration, arrival and departure times into the application and is presented with a map of the nearby parking facilities. The user selects a parking facility and its name, phone number, hours, and rates are displayed. A unique feature of the *BestParking* application is the user's ability to indicate parking preferences, such as valet, self-serve, indoor, outdoor, no cash-only lots, electric vehicle charging, SUV/Minivan, etc. The *BestParking* application also allows the user to set the maximum height of their vehicle. Shortcomings of this application include that the user may not reserve a parking stall or obtain directions to the parking facility, although, if the application is upgraded for a cost of $2.99, directions will be provided *(20)*. Another issue with the application is that it lacks coverage in many major city centers.

The *Parker* application shows the user open parking space locations in more than 30 cities and universities in the US and the UK, while also giving access to information for over 24,000 parking lots and garages *(21)*. The process of selecting a parking facility is similar to the *BestParking* application. The user selects their desired parking location and a map displays available spots or garages. The user may view prices, payment options, and hours of operation for selected facilities. This application includes several advantages such as an alert when the paid parking time is near an end, walking directions back to the parked car, and mobile pay options that allow for adding time *(21)*. In addition, the user receives turn-by-turn voice navigation to the parking facility without having to upgrade.

The *PayByPhone* application allows the user to register and efficiently manage their parking account *(22)*. The user adds their information, such as credit card, name, and vehicle type, to the *PayByPhone* application. When the user finds a parking stall or facility they need only to type in the parking spot number to set a reservation. Similar to the previous applications, a user may find parking spaces and facilities in the proximity of a given location. *PayByPhone* also has the functionally of remotely adding parking time *(22)*. Locations are also limited with this application.

The *SpotHero* application finds and reserves guaranteed daily and monthly parking *(23)*. The difference in the *SpotHero* application is that the user may reserve a parking space without a parking stall number *(23)*. SpotHero has mapping features similar to the other applications. *SpotHero* is limited to a select number of cities.

Other notable parking applications include *ParkWhiz*, *QP* Q*uickpay*, and *ParkMe Parking*.

C.2.4.3 Wireless Communications

Wireless communications are a critical component of current technically advanced parking management solutions. For example, consider a parking application where, as a vehicle approaches a parking facility, a screen appears on the monitor inside the vehicle. From the information presented, the driver can determine if the lot is full and if the price is acceptable. The driver will also be able to make a payment at the touch of a button or simply through a voice command, choosing what accounts (bank, credit, etc.,) will be charged for the parking fee. A notification of payment will be displayed and the driver may enter the parking facility. Digital certificates and digital signatures to authorize payments and verify payment confirmations *(27)* will ensure the efficiency and security of the system.

Such an application is dependent on efficient and secure communications. While parking systems communications may be based on traditional telecommunications networks (land and cellular), because the public sector is currently encouraging the development of the connected vehicles program, development of parking management systems leveraging the connected vehicles program would provide a more robust solution without directly incurring the recurring costs associated with traditional communication technologies.

For connected vehicle parking applications, parking coordination and parking management are the two main categories within the ITS architecture. Both categories have static and dynamic data components *(27)*. The static data is composed of the hours of operation, rates, lot location, lot entrance locations, handicap accessibility features, the lot type (open lot, covered garage, permit parking, contract parking, free parking, paid parking, other), lot capacity (number of spaces), and lot constraints (heights, type of vehicles, etc.). The dynamic data is composed of the current state of the lot (open, closed, near capacity), number of available spaces, and the arrival and departure rate in a given time period. One of the critical components of this application is the parking facility operator interface, as it allows the operator to have control over the prices and the lot itself. Another important component is the detection of the vehicles in the parking facility, because this allows each vehicle to be counted and classified *(27)*.

Japan may be regarded as the most advanced country when it comes to parking management applications using Dedicated Short Range Communications (DSRC). Since 2006, the Smartway Project has been successfully testing DSRC parking demonstrations *(28)*. A difference between the connected vehicle application, described in the previous paragraph, and Smartway is the payment method. Under Smartway, an Integrated Circuit (IC) card reader is used to make the payment, whereas in the connected vehicle program the payments are integrated in the communications system *(28)*.

Other wireless alternatives also exist. For example, the use of vehicular ad-hoc networks (VANETs) has more recently gained attention for information disseminated in a variety of applications, such as parking *(24)*. VANET systems use roadside units (RSU) and onboard units (OBU) to communicate with the parking infrastructure. Parking availability notification and parking spot locator are two useful VANET applications *(25)*.

VANETs may utilize a variety of wireless communication technologies, such as RFID and Bluetooth. While not achieving the seamless parking system integration in the preceding example, RFID and Bluetooth enable fast parking facility access and egress by allowing a user to touch a card on a pad or have an identification sticker scanned to quickly make a payment *(8)*. Contactless smart cards and identification stickers with wireless communication capabilities further reduce transaction time by allowing a user to simply wave their card in front of a reader. Such smart payment systems reduce operation, maintenance, and enforcement costs as well as improve collection rates *(9)*. As noted earlier, a significant benefit of using wireless networks is that users do not have to stop at the gate, reducing traffic congestion issues in and around the parking facility. Based on data from parking facilities that currently use RFID for check-ins and check-outs, there have been considerable reductions in personnel cost by using this technology *(8)*. Bluetooth presents the same benefits as RFID technology, although Bluetooth can typically transfer more information in a more secure manner. *(26)*.

C.3 Benefits Gained from Using Connected Vehicle Parking Applications

In summarizing the potential benefits of connected vehicle parking management systems, it is beneficial to consider the USDOT public mission's main parameters as a guide: economic, mobility, safety, and environmental benefits.

C.3.1 Economic

There are numerous potential economic benefits to parking management systems. As seen, facility operators have the potential for both reduced costs and increased revenue. Wireless connected systems reduce the overall cost of operating a parking facility *(12)*. For example, automation of current labor-intensive tasks would reduce staffing cost. Improvements in efficiency of in facility space management and fee collections can increase space utilization and thus revenue. Furthermore, space reservation systems may serve to attract new customers. Vehicle owners will also enjoy economic benefits. The cost of wasted fuel resulting from waiting in parking facility queues, cruising for parking stalls, and congestion would be mitigated *(9)*. Transportation system users who are not directly utilizing the parking facilities will also experience economic benefits. For instance, delivery services will benefit from reduced on-street congestion resulting from other users' cruising for spaces or parking facility queues extending into the roadway. Enabling faster and more efficient deliveries will increase their revenues and decrease costs. This in turn will benefit the distributor, the seller, and the consumer. Numerous other examples may be listed, highlighting how the economic impacts will positively affect the community and region as a whole. By providing dependable access to parking in highly dense locations, congestion should decrease, spurring economic activity. The economic gains proposed in this section will also allow for better traffic management strategies in and around the parking facility.

C.3.2 Mobility

In recent decades, degrading urban mobility has become an increasingly serious and difficult-to-manage challenge. The quality of life in the urban area is strongly influenced by inefficiencies due to urban congestion *(3)*. Mobility also closely relates to economic factors discussed in the previous section. From a macroeconomic point of view, society pays a very high cost for urban mobility. Each user adapts their travel patterns in an attempt to reduce their personal costs (financial, stress, time, etc.) resulting from the structural deficits of the transport network *(3)*. Wireless parking management systems potentially improve mobility by improving service at both ends of a trip. Interestingly, this is an application where mobility is improved by reducing travel, e.g., cruising related to searching for parking. User and facility management decisions made with real-time availability information reduce drivers' searching, lead to reductions in queue lengths at parking facility access and egress points, and reduce congestion *(9)*.

In addition, the efficiency and mobility of a parking search process currently depends on how well the driver knows the neighborhood and on the quality of the available information *(9)*. Wireless communications such as DSRC in connected vehicles will increase the mobility of unfamiliar and less experienced drivers. In many cases, travelers are weary of going outside their comfort zone when they are in a new city. With the new parking management applications, visitors would be able to locate a parking facility of their choice and reserve parking, making the unfamiliar city more approachable.

C.3.3 Safety

Safety in parking management systems pertains to the physical safety of the users in and around the parking facility. If users feel unsafe in the parking facility or the area around the parking facility, they will find another place to park. Reasons a user may feel unsafe may include vehicle crashes or driving stress related to congestion. As drivers become increasingly frustrated, the likelihood of an incident occurring increases. In addition, it has been shown that the relationship between occupancy of the attractive spots and illegal parking (for example, double parking and obstruction of crosswalks, bus stops etc.) is exponential *(4)*. That is, the harder it is to find a spot, the more likely a user is to commit a parking violation. This in turn creates potential safety challenges for pedestrians, cyclists, delivery trucks, buses, and all other street users. Another safety issue is the payment of parking using traditional methods. There are concerns with robbery when a user has to walk to a pay machine in the dark and handle money in the open. Utilizing wireless communications, a user does not have to leave the safety of their car, thus mitigating robbery concerns.

C.3.4 Environmental

There will be a wide range of environmental benefits resulting from the more efficient parking management systems. The management of parking availability information has repercussions on the decisions taken by drivers and can lead to benefits such as reductions in search time and vehicle displacements, which may result in less pollution and emissions of greenhouse gases *(9)*. There are also environmental benefits in the decrease in vehicle miles traveled (VMT) as vehicle tires are conserved and vehicle maintenance is thus reduced. Other environmental benefits include the removal of paper receipts and plastic permits.

C.3.4 Other Benefits

Additional benefits of connected vehicle integrated parking systems would be the reduction in the need for police officers to manage traffic outside the parking facilities, and the ability to remove traditional parking management systems such as parking meters and pay stations. Another potential benefit could be the implementation of a “metering” technique for vehicles leaving parking facilities during the peak hour. The technique would be similar to demand-based tolling, allowing the roadways to operate at maximum efficiency without incurring the throughput losses caused by flow breakdowns and gridlock.

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Appendix D: Case Study: Investigating Feasibility of Predictive Analytics with Data Mining for Pro-Active Traffic Management

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D.1 Introduction

There has been significant previous research on traffic flow prediction *(1-5)*. Most of the research focused on short-term predictions. The lower frequency patterns are fairly persistent, i.e., there are repetitive patterns of traffic for daily trends (morning and afternoon peaks), weekly trends (e.g., similarities of all Mondays), and seasonal trends (e.g., summer months of June and July have patterns different from winter months of November, December, etc., due to school holidays, workplace holidays etc.). However, due to higher frequency (intra-day) interruptions or noise, it is challenging to ensure prediction accuracy at all times. Interruptions can come in the form of crashes or other incidents on the roadways, a moving bottleneck caused by a slow-moving vehicle, sudden rapid lane changing by an existing vehicle, inclement weather conditions, etc.

Using traffic microscopic simulation models, it is possible to generate predictions of traffic in the short-term when changes in the flow conditions (crashes, weather conditions, etc.) are updated in the model in real time *(6,7)*. However, building these models requires rigorous calibration and validation efforts to ensure accuracy, as well as significant ongoing maintenance to capture changes in control (i.e., signal timing), emerging travel patterns, etc. In addition, the speed at which these models can execute is limited by the size of the network (distributed simulation is still an emerging field).

With the recent advances in the Big Data field, techniques have evolved both in hardware and software that allow researchers to leverage computationally intensive techniques for extracting useful information out of seemingly disjointed datasets. These techniques take advantage of parallel computation by dividing larger datasets into smaller manageable datasets and performing the same computation in parallel across a distributed computational framework. This study applies this same approach to traffic volume and speed data. Traffic speed and volume information is available in most urban areas; for example, in the Metro Atlanta area, infrastructure detectors are part of Georgia NaviGAtor, Georgia's advanced traffic monitoring systems.

D.2 Methodology

A correlation analysis was performed using traffic data across freeway detection stations in the Metro Atlanta region. To ensure uniformity of the data, the choice of detection stations was limited to mainline detectors. The analysis was also limited to comparison across detectors with the same frequency of reporting and comparable spacing between detectors. Density was used as the traffic parameter in the analysis, as it gives more comprehensive information about the state of traffic than volume or speed alone. Also, to reduce the impact of high-frequency perturbations in the data, the densities were computed as an average across all lanes at a detection station rather than on a lane-by-lane basis. Sample detectors were chosen from the I-75/85 downtown connector and from the Northwest part of I-75 (in Marietta) outside the I-285 perimeter, to serve as the lead indicator stations. The downtown connector detectors are expected to serve as lead indicators in the afternoon peak period, since a large number of work-to-home trips originate from this area. The I-75 detectors in Marietta are expected to be the lead indicators in the morning peak period since a large number of home-to-work trips originate from this area. Correlation coefficients were computed between these lead detectors and the detectors in the rest of the system. To investigate the potential for future predictability of the station pairs, correlation coefficients were also computed for data from the remaining detectors that are lagged by 15, 30, 45 and 60 minutes. Essentially, if there is high correlation between a lead detector and another detector lagged by 60 minutes, it would indicate that the first detector can reasonably predict the traffic characteristics that would appear at the lag detector after an hour.

D.3 Results

Table D - 1 shows the top 25 high correlation station pairs for the different lag values. High correlation values are seen as a promising indictor for the ability to apply prediction between these pairs. For a given station pair with a high correlation coefficient, the density values of the two stations are fairly well synchronized. However, from an applicability standpoint, the volumes and speeds need to have similar patterns as well. A closer examination of the density, volume, and speed plots (Figure D - 1, Figure D - 2, Figure D - 3) for several of these station pairs revealed that the patterns appeared to be similar for the majority of the cases; i.e., for the morning and evening peak period patterns. Because “typical” peak patterns for a given area are usually known, predictability is most important where the patterns deviate from the typical patterns. Unfortunately, the pairs did not show any apparent power of matching the anomalous patterns (highlighted in Figure D - 1).

Table D - 1: Top 25 Station Pairs with High Correlations of Densities

stn_x	stn_y	Lag_0 Correlation	stn_x2	stn_y3	Lag_15 Correlation	stn_x4	stn_y5	Lag_30 Correlation	stn_x6	stn_y7	Lag_45 Correlation	stn_x8	stn_y9	Lag_60 Correlation
750509	780011	0.94	750509	11145	0.93	750508	780011	0.92	750509	780011	0.91	750509	10161	0.9
750509	6750983	0.94	750509	11146	0.93	750509	780011	0.92	750509	780012	0.91	750509	10162	0.9
750509	780	0.93	750509	200541	0.93	750509	200541	0.92	750508	780011	0.91	750509	780011	0.9
750509	11145	0.93	750509	780011	0.93	750509	6750984	0.91	750508	2850046	0.91	750509	780012	0.9
750509	11146	0.93	750509	6750983	0.93	750508	6750983	0.91	750509	780	0.9	750508	780011	0.9
750508	11145	0.93	750509	780	0.92	750509	6750983	0.91	750508	780	0.9	750508	780012	0.9
750508	11146	0.93	750508	780	0.92	750508	6750018	0.91	750509	10161	0.9	750508	2850046	0.9
750509	200541	0.93	750508	11145	0.92	750509	6750018	0.91	750509	10162	0.9	750509	780	0.89
750508	200541	0.93	750509	11147	0.92	750508	2851041	0.91	750509	11145	0.9	750508	780	0.89
750508	780011	0.93	750508	11146	0.92	750509	2851041	0.91	750509	11146	0.9	750508	10161	0.89
11126	51109	0.93	750508	11147	0.92	750508	2850046	0.91	750508	11145	0.9	750508	10162	0.89
750509	2851041	0.93	750509	200531	0.92	750509	2850046	0.91	750508	11146	0.9	750509	11145	0.89
750508	2851041	0.93	750509	200540	0.92	750509	1661009	0.91	750509	60114	0.9	750509	11146	0.89
750509	6750018	0.93	750508	200541	0.92	750509	780604	0.91	750509	200531	0.9	750508	11145	0.89
750509	6750984	0.93	750508	780011	0.92	750508	780012	0.91	750509	200540	0.9	750508	11146	0.89
750508	6750983	0.93	750509	2851041	0.92	750509	780012	0.91	750509	200541	0.9	750509	60114	0.89
750508	6750984	0.93	750508	2851041	0.92	750508	200541	0.91	750508	200541	0.9	750509	200540	0.89
750508	780	0.92	750509	6750018	0.92	750509	200540	0.91	750508	780012	0.9	750509	200541	0.89
750509	11147	0.92	750508	6750018	0.92	750509	200531	0.91	750509	780604	0.9	750508	200540	0.89
750508	11147	0.92	750509	6750984	0.92	750508	11146	0.91	750509	1661006	0.9	750508	200541	0.89
750509	200528	0.92	750508	6750983	0.92	750509	11146	0.91	750509	1661008	0.9	750509	780014	0.89
750509	200531	0.92	750508	6750984	0.92	750508	11145	0.91	750509	1661009	0.9	750508	780014	0.89
750509	200534	0.92	750509	10143	0.91	750509	11145	0.91	750509	2850046	0.9	750509	780604	0.89
750509	200538	0.92	750509	11148	0.91	750509	10162	0.91	750509	6750983	0.9	750509	1661006	0.89
750509	200539	0.92	750508	200531	0.91	750508	780	0.91	750509	10143	0.89	750509	2850046	0.89

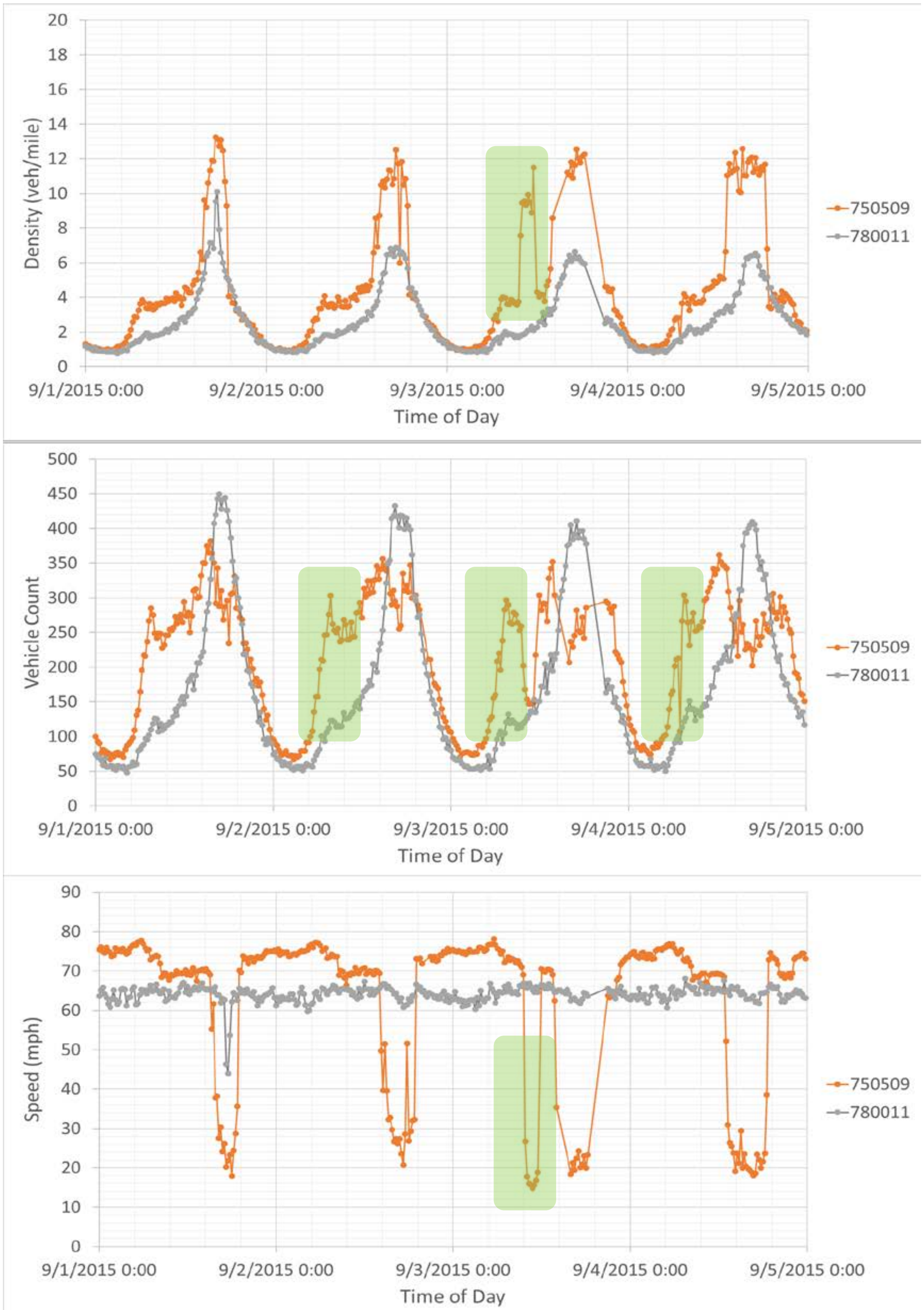

Figure D - 1: Comparison of Time Series for Stations 750508 and 780011

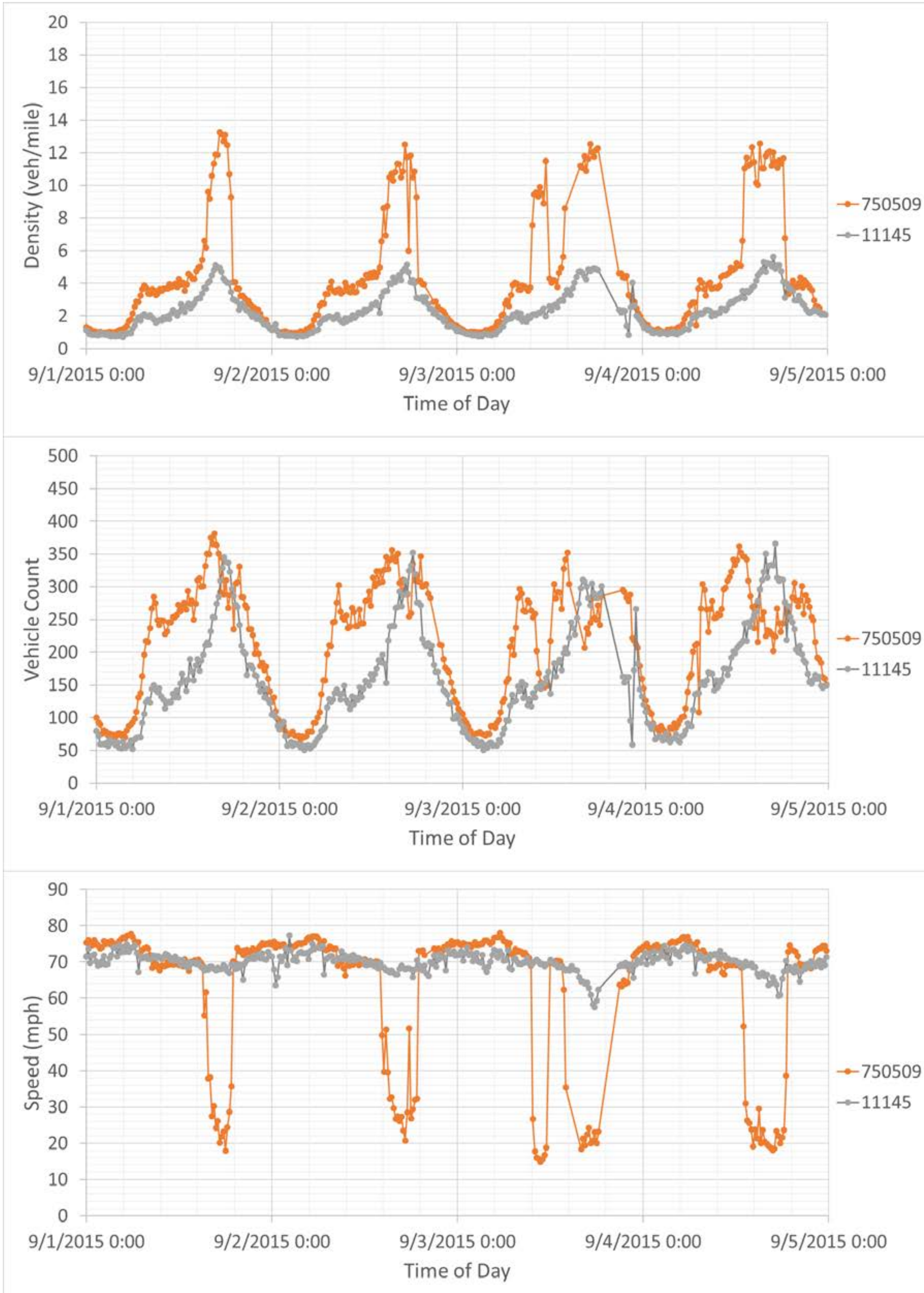

Figure D - 2: Comparison of Time Series for Stations 750509 and 11145

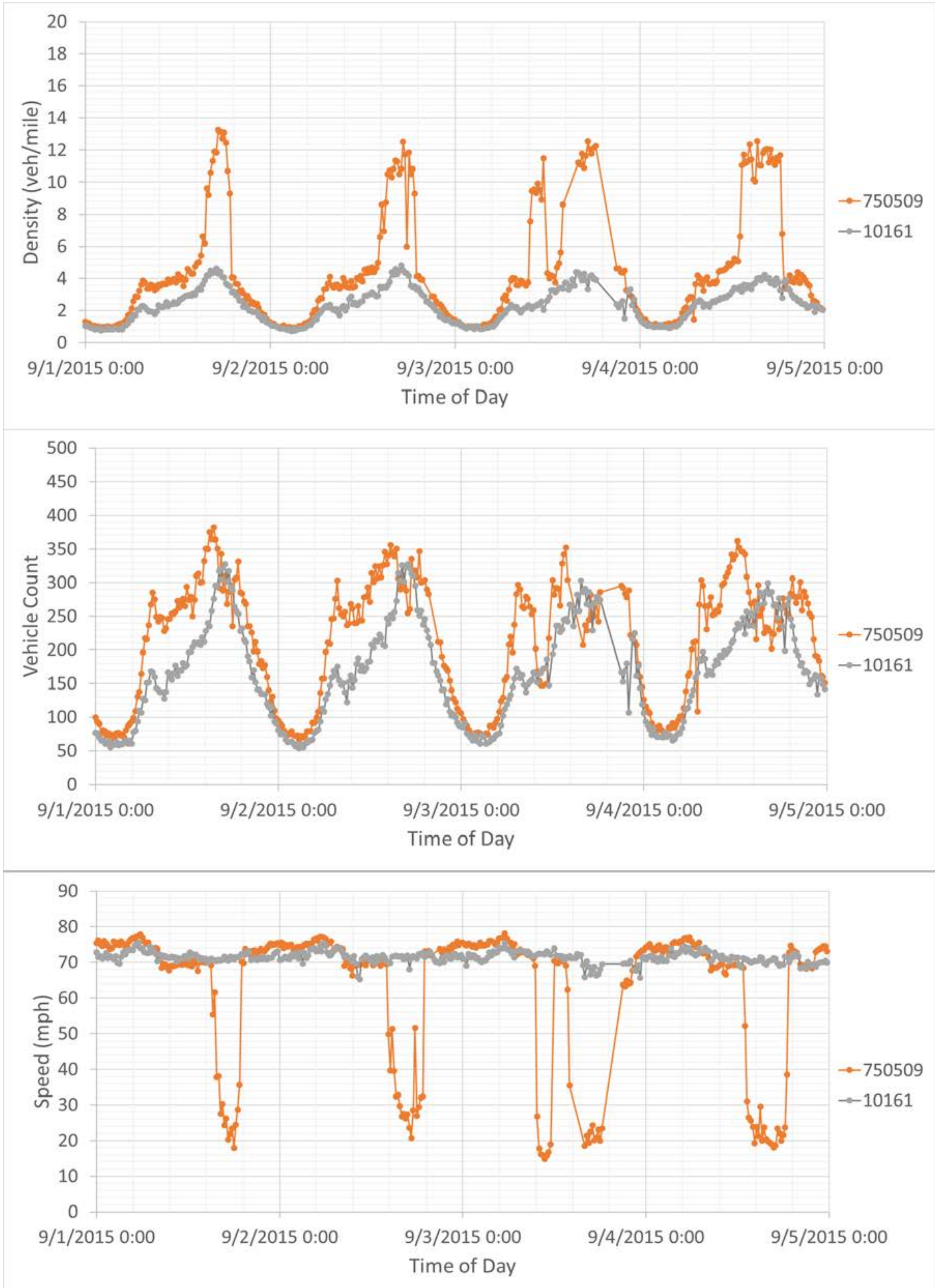

Figure D - 3: Comparison of Time Series for Stations 750509 and 10161

D.4 Conclusion

There have been anecdotal references about traffic on one part of the network being a predictor for traffic characteristics on other parts of the network. This hypothesis was tested by performing a correlation analysis using data across the freeway network in the Metro Atlanta area. While several pairs of stations showed very high correlation in the density data, a closer look revealed that these correlation values were driven primarily by the daily trends in the data, but did not necessarily have any predictive power about anomalous behavior in traffic. In addition, the high correlations seen in the density data did not appear in the speed data. As speed (and thus travel time) are often of higher concern to travelers, the practical value of density correlations is reduced. The results of this study can be leveraged to investigate the possibilities of reducing data storage requirements by identifying data that are repetitive and do not add any further information beyond that already available from detection stations elsewhere in the network. This might be especially relevant in the context of future connected vehicle data where the volume of data is expected to increase by several orders of magnitude. However, for the objective specific to this study, the results are inconclusive. Further research is necessary to subtract out the underlying general trends in the data and separate out the signals for anomalous behavior and then analyze this dataset to mine for predictive indicators.

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