

Examining the Speed-Flow-Delay Paradox in the Washington, DC Region:

**Potential Impacts of Reduced Traffic on
Congestion Delay and Potential for Reductions in
Discretionary Travel during Peak Periods**

Final Report

December 2008

Prepared for the Federal Highway Administration



**U.S. Department of Transportation
Federal Highway Administration**

Prepared by:

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Foreword

Highway studies have determined that once traffic volumes exceed the capacity of the roadway, the system can rapidly “break down” to the point where all traffic slows markedly, and the capacity and throughput of the roadway drops precipitously. This study examines traffic volumes, speeds and delays at various freeway traffic counters in the Washington, DC region to specifically evaluate congested versus uncongested travel. The observations identify the specific “tipping point(s)” at which free-flow traffic “breaks down”, and conversely estimate the volume of traffic that would have to be reduced in peak periods to keep traffic free-flowing. The study also examined survey data to estimate the number and percent of trips that people take in peak hours on our freeways that are discretionary trips. Finally, the study briefly reviewed empirical findings on experiences with congestion pricing in the US and abroad.

This report will be of interest to policymakers who are concerned about highway congestion and approaches that can be used to reduce congestion. It will also be of interest to transportation planners and engineers who are interested in empirical verification of traffic engineering principles.

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Dr. Robert Winick, Principal, Motion Maps developed the approach and led the traffic evaluation procedure, with technical assistance from Nikola Ivanov and Michael Pack of the University of Maryland CATT Laboratory. Ms. Hikari Yukiko Nakamoto performed the SAS trip chaining analysis of the survey and developed the analysis tables.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams "metric ton")	(or Mg (or "t"))
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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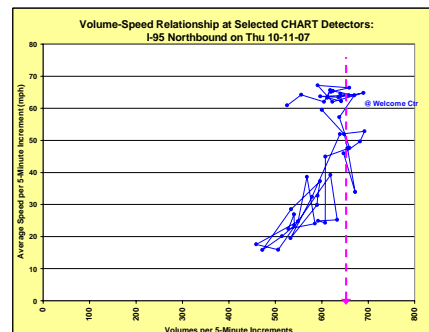
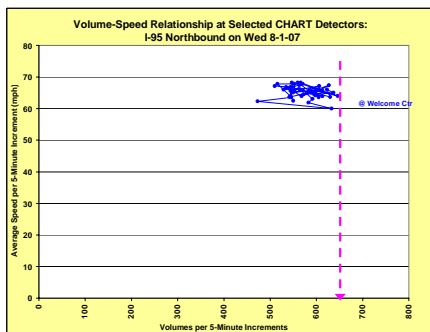


Executive Summary

Traffic congestion and delay have become an endemic component of commuting life in the Washington DC region. To many, the unpredictability of travel time is almost more annoying than delay- one day a 10 mile trip may require 20 minutes, and the next day 45 minutes. Because the system is so near capacity, and exceeding capacity in some areas, a minor incident or a rainstorm, or simply too much traffic, causes major breakdowns and systemic delays. In this research study we demonstrate that there is a way to restore reliability and predictability to our highway system, without spending billions on new lanes of traffic.

Traffic congestion in the Washington, DC area, especially congestion on our freeways, costs our residents every day in terms of wasted time, fuel, and increased air pollution, including green house gases that are a primary cause of climate change. Highway studies have determined that once traffic volumes exceed the capacity of the roadway, the system can rapidly “break down” to the point where all traffic slows markedly, and the capacity and throughput of the roadway drops precipitously. The Federal Highway Administration commissioned this study to specifically evaluate congested versus uncongested travel on some of the major roadways in the metropolitan Washington region, to identify the specific “tipping point(s)” at which free-flow traffic “breaks down”, and conversely, the volume of traffic that would have to be reduced in peak periods to keep traffic free-flowing. The study also examined travel behavior based on the Metropolitan Washington Council of Governments Household Travel Survey, to estimate the number and percent of trips that people take in peak hours on our freeways that are discretionary trips. With appropriate incentives or disincentives, many of these discretionary trips could be shifted to off-peak hours or otherwise deferred. Finally, the study reviewed empirical findings on experiences with congestion pricing in the US and abroad, to provide ranges of estimates of the amount or percentage of traffic that could be shifted out of the peak period or encouraged to use ride-sharing through a comprehensive pricing and transportation demand management program.

The traffic analysis (Section 2) focused on a 12.9 mile segment of I-270, a 10.5 mile segment of I-95, and two independent count locations on the Capital Beltway for the evening rush hours (PM Peak).¹ The study compared speeds and volumes in the summer and on holidays to dates and times in September and October, when the system can be observed to “break down”. This pair of figures is one of many examples – the left-hand figure shows volumes (horizontal axis) and speeds (vertical axis) on August 1, the right-hand shows October 11, when a short “spike” in demand generates an extensive period of lower volumes and lower speeds.



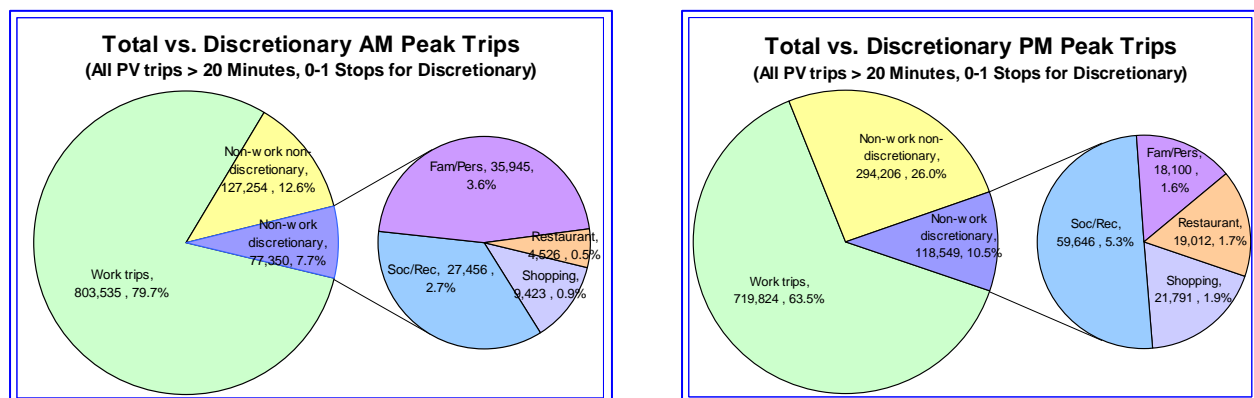
¹ The analysis also examined volume and speed for two segments in the morning rush hour (AM Peak).

A main finding of this study has been that if relatively small changes can be made in peak demand (volume) through various programs and strategies, such as congestion pricing, then two beneficial things can happen: (1) there can be relatively large decreases in congestion and delay, especially at key choke points, and (2) there can be increased through-put along those roads during peak times of travel – thus by effectively managing the demand more travelers can be served per time period with the available fixed-supply of roadway capacity.

The analysis has shown that in many instances the amount of needed demand reduction can be on the order of five to ten percent of the peak period flow. However, there still may be a particularly difficult bottleneck in a corridor that would need reductions on the order of 15 to 20 percent. While demand reduction and operational strategies may be able to go a long way in improving the flow at those locations so that capacity is exceeded less often and/or recovery is quicker, there still may need to be localized geometric or lane use changes at those locations to routinely have freer flowing traffic at those troublesome locations.

We established that in general a 10 to 14 percent decrease in traffic on congested freeways will reduce delay by approximately 75 to 80 percent. For example, on I-95, an average traveler during the peak period would save 110 seconds each day, or about 5.3 cents per vehicle mile for that 10.5 mile stretch of road. During the most congested peak hour, the average savings in delay would be 310 seconds per person per day, or about 14.6 cents per vehicle mile. On I-270, the average traveler would save 220 seconds during the full peak period, or about 8.5 cents per vehicle mile. During the peak hour on I-270, a traveler would save about 340 seconds for that almost 13 mile stretch, or about 13.2 cents per vehicle mile. Those savings per traveler, multiplied by all drivers, multiplied by 250 work days, yields millions of dollars in annual time savings from reduced delay for these two roadways alone.

In Section 3 we establish that from 7.7 percent (AM Peak) to 10.5 percent (PM Peak) of the longer trips in personal vehicles (PV) are typically discretionary. The definition of discretionary trips includes restaurant visits, family/personal trips, shopping trips and social/recreational trips. Discretionary trips, by definition, should be fairly easy to divert to non-peak times or to routes other than freeways. We do not expect to divert all discretionary trips, but the 7 to 10 percent gives us a substantial base to start from, as we aim for a 10 to 14 percent reduction.



In Section 4 we demonstrate that modest pricing signals for private vehicles can reduce traffic enough to significantly reduce congestion and save time for all drivers, while at the same time

increasing the “people-carrying capacity” of the roadway. Experiences across the country and around the world have found that charging a modest toll for single-occupant vehicles while improving the availability of carpools, vanpools and transit can create significant shifts in travel behavior, in the ranges necessary for the DC area.

It therefore appears feasible to restore and maintain free-flow on the freeways in the Metropolitan Washington area, without adding capacity (except to alleviate selected bottlenecks), by applying congestion pricing to the major facilities, and at the same time increasing transit, carpool and vanpool programs. The combination of diverting most discretionary trips to other times and diverting an additional five to ten percent of personal vehicle work trips to HOV modes should achieve the needed 10 to 14 percent overall decrease in traffic needed to achieve major reductions in delay.

Such a system would require phased implementation and experimentation to identify workable technologies and appropriate rates to achieve the desired result.² (Implementation strategies are beyond the scope of this study, but many different proposals have been evaluated for the Washington region.) Rates could be adjusted up or down, to ensure the roadway is used to near-maximum capacity, without exceeding capacity to the point of breaking down and failing. Revenues collected could be used to improve HOV alternatives as well as maintain the roadways, address choke points and bottlenecks, and improve alternate routes. Finally, travelers in the region would truly benefit and travel in confidence, knowing that they can reliably predict their travel time on a daily basis.

² It is significant to note that the MWCOG Climate Change Report, approved by the COG Board November 12, 2008, mentions both evaluation of financial incentives such as congestion pricing and incentives for expanded transit use to reduce Vehicle Miles Traveled (VMT) and greenhouse gases (page 61). www.mwcog.org/publications

1. Introduction: Work Order Objectives

The Federal Highway Administration (FHWA) supports operational improvements to reduce delay and congestion throughout the country. In many cases it has been determined that relatively minor reductions in peak traffic can result in major reductions in delay for all travelers. The FHWA wanted to test this premise for the Washington, DC region, and engaged SAIC (supported by the Louis Berger Group) to carry out the research study. The study approach is designed to answer specific research questions, as summarized in the Tables below.

The first objective of this research is to produce empirical evidence of the changes in rush hour traffic demand (volumes) and delays for weekdays in early August, relative to other months of the year, in the Washington, DC metropolitan area. The three broad questions to be answered for this objective and the approaches to answering the questions are:

Research Question	Approach
What is the amount and percentage of reductions in weekday peak period traffic on freeways in (early) August in the Washington, DC area, when traffic congestion is reduced significantly relative to other (non-summer) months? (Section 2)	Evaluate traffic count and speed data at selected locations at different times and dates, ideally where (and when) GPS probe data are available to demonstrate free flow and congested conditions.
What is the relationship between peak period and peak-hour traffic reduction and delay reduction on freeways, i.e., how much delay might be reduced by various levels of reductions in traffic? (Section 2)	Graph and analyze speed – volume relationships to determine “tip points” for congestion and delay versus free flow conditions
Given the above relationships, how much traffic needs to be taken off freeways operating at various levels of congestion in the metropolitan area, to restore free flow during rush hours? (Section 2)	Calculate values and percentages for selected locations from analysis, above, extrapolate to larger regional relationship

The second objective is to identify the approximate numbers and proportions of persons traveling on the congested freeways who may be able to shift their time of travel to off peak periods, or shift their mode of travel to high-occupancy vehicles. The three questions to be answered and the approaches are:

Research Question	Approach
What is the share of travel that is made for various purposes other than commuting on congested freeways during peak periods in the Washington, DC area? (Section 3)	Perform in-depth analysis on Metropolitan Washington Council of Governments (MWCOC) 1994 Household Travel Survey ³ – identify trip chains by time of day, by trip purpose, and travel time.

³ MWCOC conducted a detailed household travel survey in 2007 but the data will not be available until mid-2009, and thus was not available for this study

Research Question	Approach
What share of these travelers may have some flexibility to shift their time of travel to off-peak periods? (Section 3)	Identify subsets of survey with greater likelihood to be able to shift travel times, review literature for appropriate definitions of “discretionary trips”
What is the potential for other modes (e.g., transit, vanpools, carpools, etc.) to attract additional mode share, if free-flow service on all freeways were guaranteed to these modes through aggressive and active traffic management strategies such as congestion pricing? (Section 4)	Conduct literature review on travel demand management and mode shifts in analogous situations, summarize results



2. Traffic Delay Comparisons

The first research question is: What is the amount and percentage of reductions in weekday peak period traffic on freeways in (early) August in the Washington, DC area, when traffic congestion is reduced significantly relative to other (non-summer) months? Correspondingly, the general question was to determine the relationship between volume, speed, and delay on the freeway system. As part of the analysis not only did the Study Team look at traffic during August versus non-summer months but also other time periods such as holidays and non-school days to develop the speed –volume relationships.

The Study Team evaluated PM Peak traffic volume and speed data at selected locations along I-95, I-270 and I-495, derived from operational data from the CHART advanced transportation management system of the Maryland DOT, and archived by the University of Maryland. The first two of these corridors are radial with respect to regional travel, while the third one is part of the main circumferential route within the region. A generally similar analysis approach was used for each corridor. First, graphical summaries of the variation of average speed by time-of-day at each detector, and cumulative delay along the analysis segment were developed to identify the best potential days for analysis: (a) “August lite” volumes and delay, (b) September and October typical volumes and delay, and (c) special days with unusual traffic demand and/or use patterns. Second, the consistency in average speed and cumulative volumes at sequential detectors were studied to identify peaking patterns along the corridor as they relate to roadway features, such as bottlenecks or lane drops. Third, the analysis examined the paired-relationship between concurrent observations of volume and average speed to better understand how the relationship varies under various circumstances. The analysis demonstrates the following:

- Peak period volumes are generally lower and delays less intense in August compared to peak period volumes and delays during typical conditions found in September and October. However the lower volumes do not always lead to reduced delay due to non-recurring events , for example, in the case of I-95, one of the sample dates in August included an incident, which led to widespread delays.
- Graphs and analysis of speed – volume relationships identified “tip points” where a small amount of extra volume precipitates large amounts of delay from what moments before was a free-flow condition. The analysis found different “tip points” for each segment, which may vary due to differences in roadway layout and/or the mix of types of traffic. **Unique aspects of this analysis have been to trace this phenomenon along a series of detectors, as well as to tie the results back to specific times of generally known variations in travel demand.**
- Commonalities were identified to generally extrapolate to the broader region answers to the third research question of, given the above relationships, how much traffic needs to be taken off freeways operating at various levels of congestion, to restore free flow during rush hours?
- **The key finding is that if relatively small changes can be made in peak demand (volume) through various programs and strategies, such as congestion pricing, then two beneficial things can happen: (1) there can be relatively large decreases in congestion and delay at key choke points, and (2) there can be increased through-put along those roads during peak times of travel – thus by effectively managing the demand more travelers can be served per time period at higher speeds with the available fixed-supply of roadway capacity.**

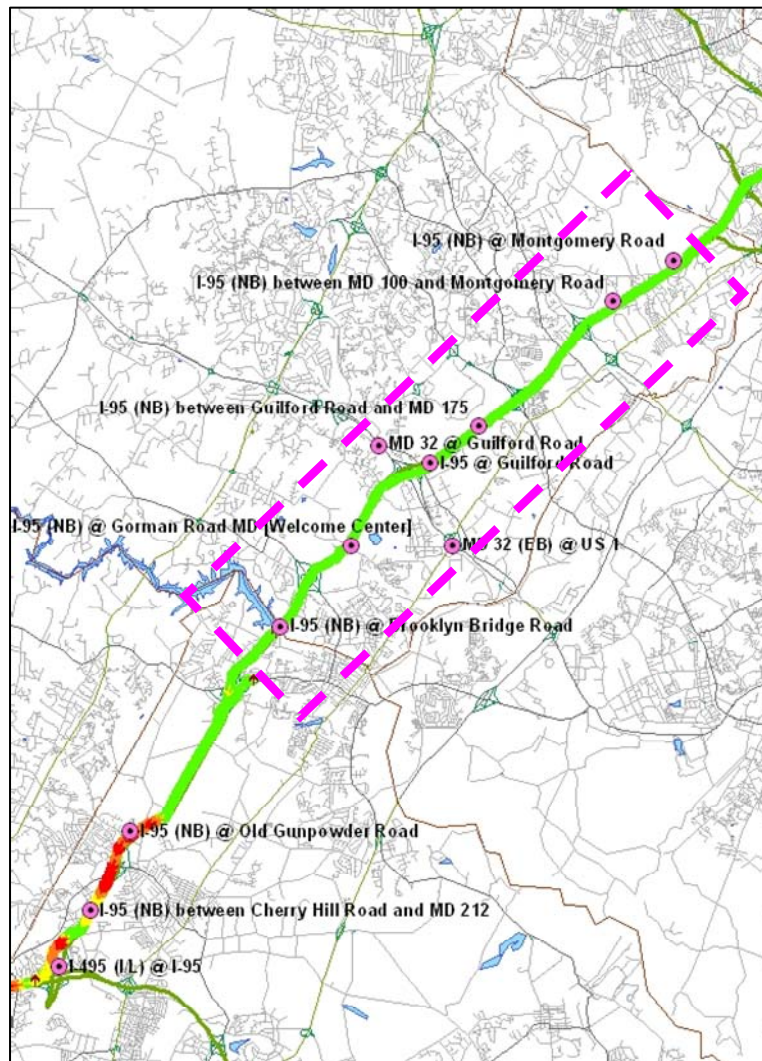
The summary analysis for each of the three corridors is presented separately below. Additional detail on I-270 is provided in Appendix A.

A separate analysis of AM Peak traffic volumes and speeds was also performed. AM Peak volumes are typically lower than PM Peak volumes, and the locations of the traffic detectors are not as conducive to a delay analysis. This analysis is located subsequent to the I-495 analysis.

I-95 Northbound for PM Peak Period

I-95 Corridor: General Locations of Detectors

The CHART system of the Maryland DOT operates a set of traffic flow detectors along the I-95 Corridor between the Baltimore and Washington, D.C. beltways. The five-minute summaries of the volume and average speed are archived by the Center for Advanced Transportation Technology of the University of Maryland (UMD-CATT). This analysis focuses on data from the six detectors of Brooklyn Bridge Road to Montgomery Road on I-95. Two other working detectors that were not included in the detailed analysis are located on I-95 near I-495, the Capital Beltway. The length of the I-95 analysis section is approximately 10.5 miles with a consistent directional cross-section of four lanes in each direction. The evaluation only included the six sites identified on the display below and does not include the two sites shown on MD 32.



Traffic Characteristics

As part of our analysis, the Study Team examined various traffic characteristics obtained from measured variations in five-minute volumes and five-minute average speeds at each of the six detectors of the analysis section. The data is nominally collected “24 x 7 x 365”, or twenty-four hours a day, 7 days per week, for 365 days per year. The operational requirements of CHART, the program for which the data is collected does not need to have data from each and every detector for each and every time increment. Some detectors and/or parts of the communication system are more reliable in the collection of the traffic flow data than others. That typically results in small gaps of one or a few observation time periods and sometimes for hours and even days on end in the archived data. Nevertheless, generally speaking there is an adequate amount of reliable data to identify various traffic characteristics including: (a) variation in volume by time of day that is used to define the “peak traffic volume periods”, (b) comparative speed range that can be used to define different degrees of congestion, such as free-flow/uncongested, slowing, slow, or jammed or stop-and-go conditions, and (c) section delay, the difference between the time it would take to travel the section at the observation time compared to the time it would take to travel that same distance at the speed-limit (Speed-Limit-Travel-Time, SLTT) or when traveling at free-flow. This characteristic can have its own peaking patterns that may be similar to or differ from volume-peaks.

The traffic characteristic of cumulative “section delay” for a typical Thursday and Friday in October are plotted and are shown in Figure 2-1 below. At the speed limit of 65 mph in this section it takes about 9 minutes and 30 seconds (570 seconds) to travel the approximate 10.5 miles. However, for a traveler beginning this section about 10 minutes before 5 PM on Friday 10-12-07, the amount of calculated section delay was about 540 seconds, or about 9 minutes more than the expected SLTT of 9 minutes, 30 seconds.

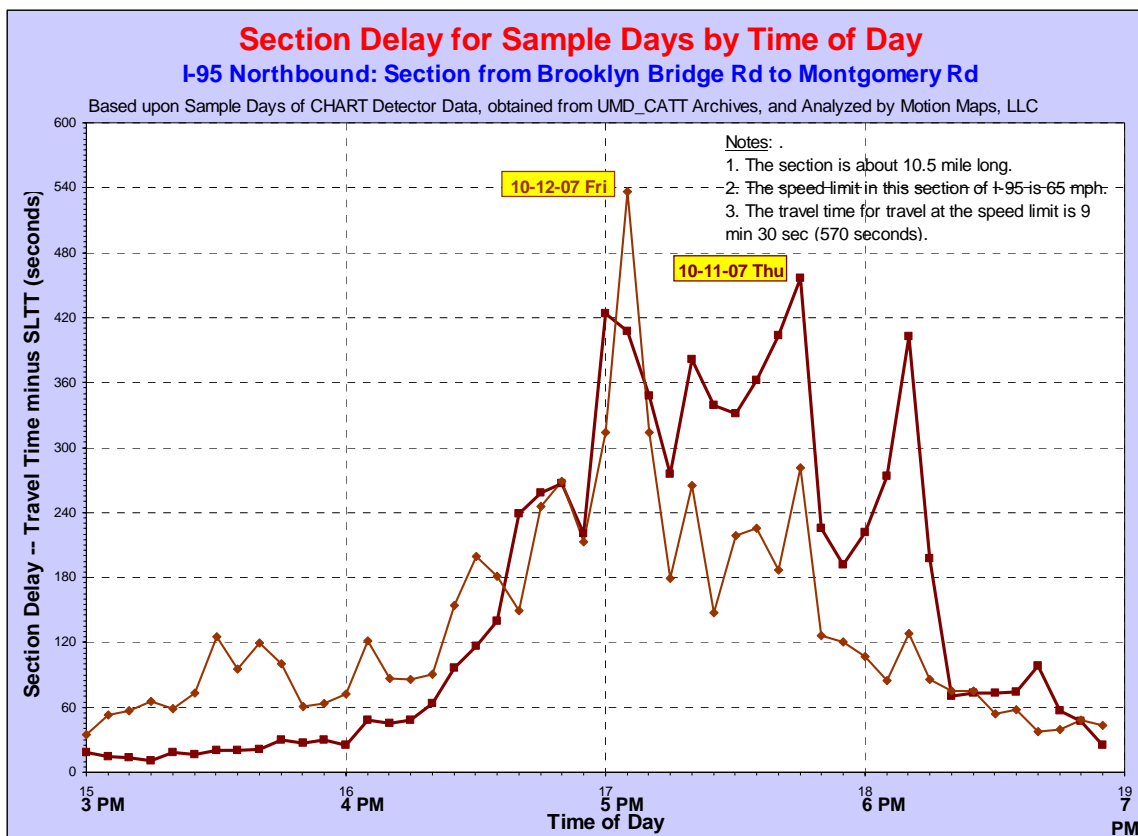


Figure 2-1

A good understanding of the patterns of variation in delay may assist in identifying and analyzing the effectiveness of strategies aimed at managing the delay. For example, as shown in Figure 2-1, congestion on Thursday, 10-11-07 in this section was more prolonged and occurred later in the afternoon relative to congestion shown for Friday 10-12-07, that was more peaked and started earlier in the afternoon. Examination of archived data for other pairs of Thursdays and Fridays would show a similar set of relative peaking patterns. Thus, strategies that address differences between days of the week will help address the effectiveness of strategies trying to restore freer flowing traffic.

The second characteristic considered was the length or duration of the peak period. During the light traffic days of early August, the duration of the peak within the peak period is about 90 minutes (about 4:30 to 6:00 PM) as shown in Figure 2-2 below. For Wednesday 8-1-07, even though section delay was very light, for most of the 5 to 6 PM period, it was somewhat slower than the other times of day. However, for a typical October day of 10-11-07, the traffic data shows that the section delay was much slower and longer in duration extending to about 7:00 PM. During the summer it seems that relatively more people leave work earlier and do not stay as late as they do in October. Thus, strategies that account for seasonal as well as time-of-day patterns of travel behavior will be more effective than those that do not do so.

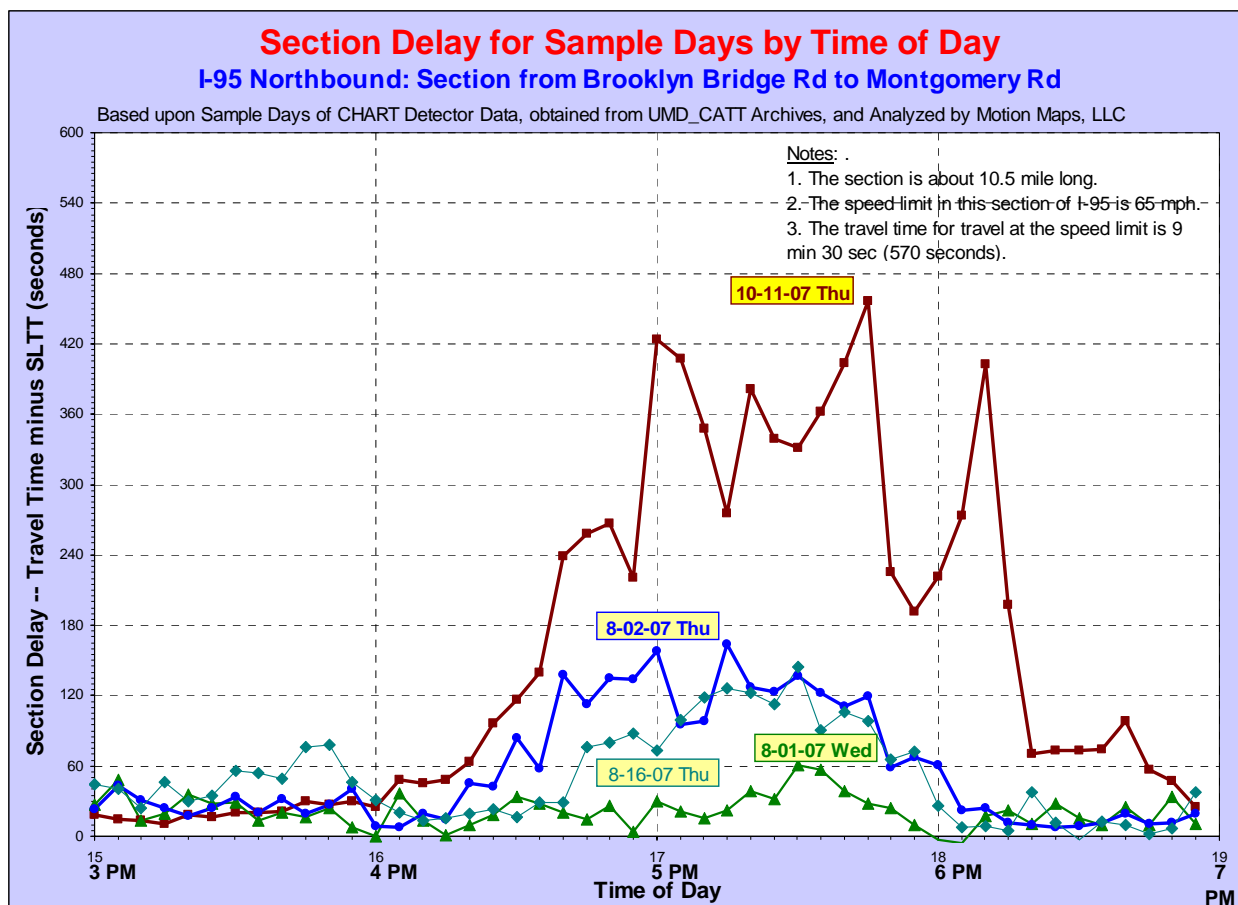


Figure 2-2

A third traffic characteristic that affects traffic volume, speed, and delay is that of trip purpose and the effect trip purpose has on the temporal and spatial distribution of travel demand. An interesting illustration of this can be seen by examining the section delay characteristics for another day that same week in October, that of the Columbus Day Holiday of Monday 10-8-07. Even though Federal offices and some schools in the region and vicinity of this section were closed, section delay is seen in Figure 2-3 in the 3:30 to 5 PM time period. It is inferred that enough people did not have their usual trip purpose of a work trip heading home that afternoon. Instead, many people attended mostly to personal business and shopping, that is typical for that holiday. However, during the usual commute peak time of 5 to 6 PM, the section delays were as light as they are during the light demand days of August. Strategies for restoring freer flowing traffic need to address trip purpose too.

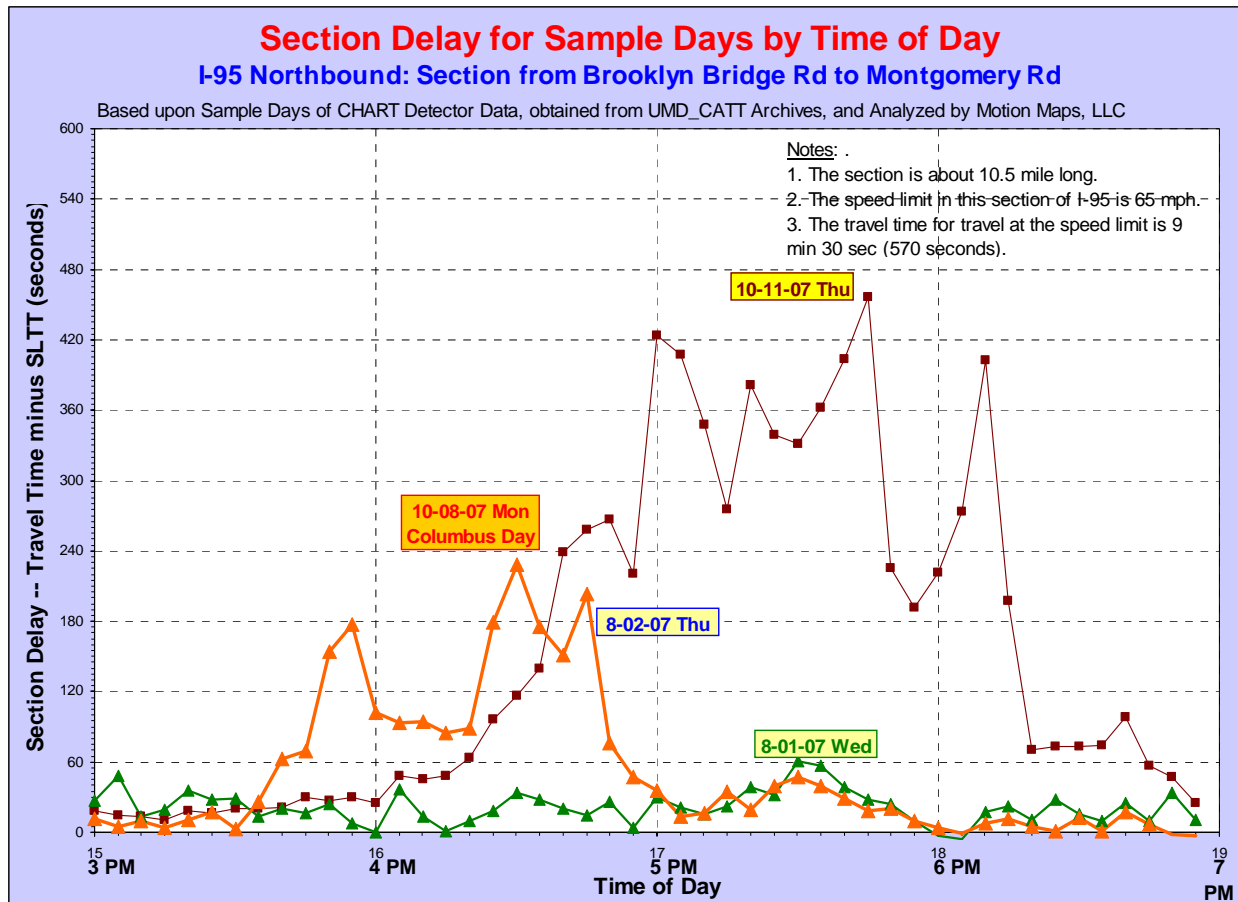


Figure 2-3

Volume-Speed-Delay Relationships

The overall data set for this section of I-95 was also analyzed in more depth to address the first research question of, how much traffic needs to be taken off freeways operating at various levels of congestion to restore free flow during rush hours?

To address that question the Study Team has taken the approach of first needing to “boil-down” the time-of-day variation in section delay to one indicator of delay. The measure of average delay per 5-minute increment over the 4-hour peak period was selected as the representative indicator of delay. Thus, the patterns of section delay from the prior three figures were reduced to one four-hour average. For example, the day with the most peak section delay of those shown

in the prior figures was that of Thursday,10-11-07, and averaging over the entire four hours results in a value of about 156 seconds of average delay over the four-hour peak period in excess of the SLTT. That is an indicator measure for the entire analysis section of 10.5 miles. In addition, we have a measure of the variation in demand along the section for that four-hour period by adding up the cumulative volumes observed at each detector. For example, nearly 30,000 vehicles passed the detector at Brooklyn Bridge Road as the traffic the entered the section from the south heading northbound in the four-hour peak period on Thursday 10-11-07, while about 24,000 vehicles left the section at the north end at Montgomery Road during the four-hour peak period.

In Figure 2-4a the Study Team graphed the average section delay versus the total four-hour volume for each detector for the several example days being considered. The analysis results shown here have the three “August-lite” samples with less peak-period volume and less peak-period section delay than the two selected “Mid-October” sample days. Figure 2-4a also shows that there is a generally consistent relationship among the different detectors across the sample days – generally speaking as the volumes decline or increase there appears to be a linear relationship to the values of average delay.

While Figure 2-4a tends to show the “traditional relationship” of volume versus delay – more volume – more delay, however, examination of other examples of “special days” tends to indicate that the nature of the relationship between volume and average delay is more complex.

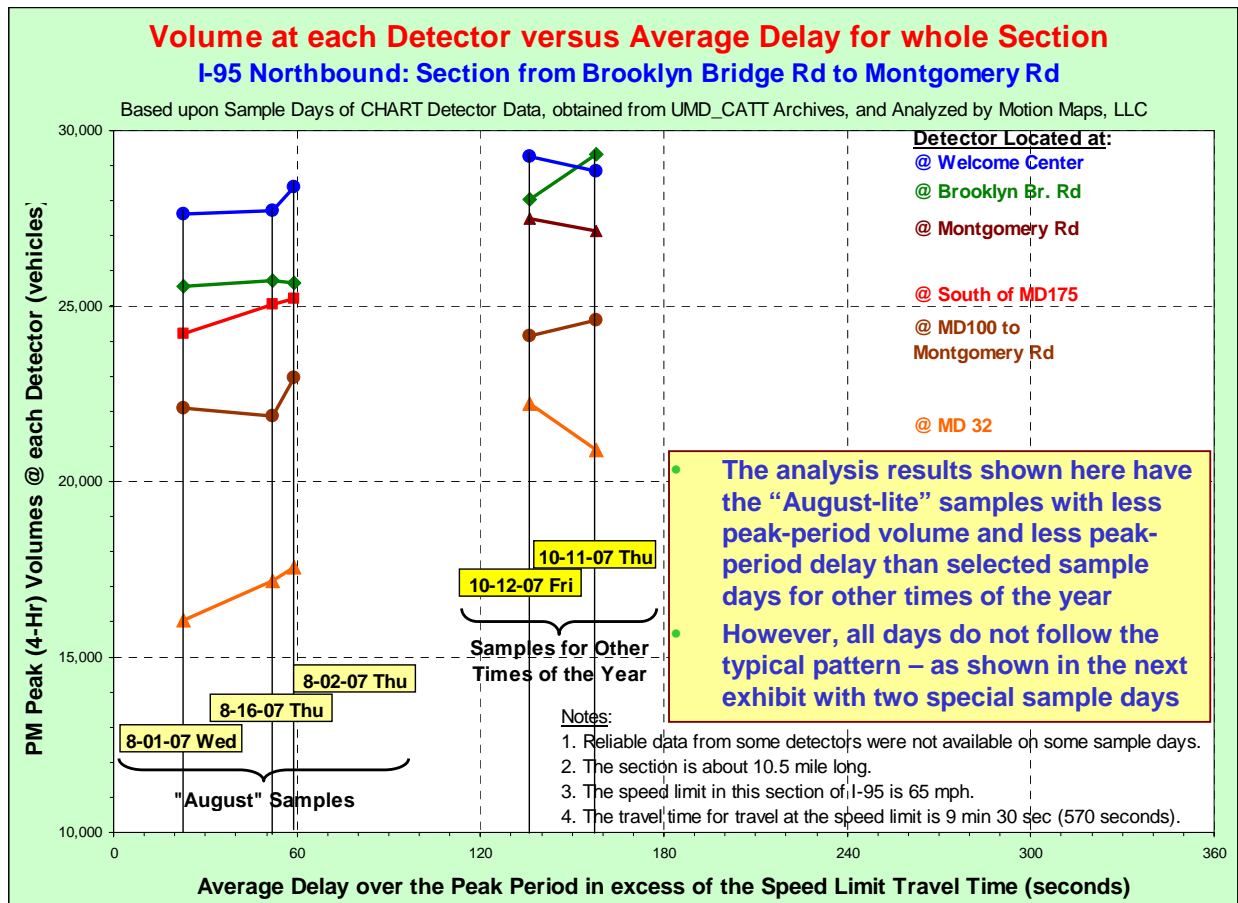


Figure 2-4a: Examination of Volume – Delay Relationships

Figure 2-4a, for 3 of the 5 detectors for the two typical October days the volumes and average delay show an “inverse relationship” - when section delay increases, the total volume throughput declines somewhat. On examining the similar results for two special days – that of incident conditions on Thursday 8-9-07 and of Columbus Day on Monday 10-8-07, in Figure 2-4b we see that for the former, significantly different patterns of regional demand can result in volumes and section delay that are different than usual, while for the latter, the section delays increase significantly with little change in volume – in fact the volumes appear to be somewhat lower relative to the typical days of October, but significantly greater than the August-lite days. While the “connecting-of-the-dots” as illustrated in Figure 2-4b does nominally provide for what seems to be a larger continuum of conditions, it is not clear whether a more extensive analysis of many more samples would result in the relationship that is depicted.

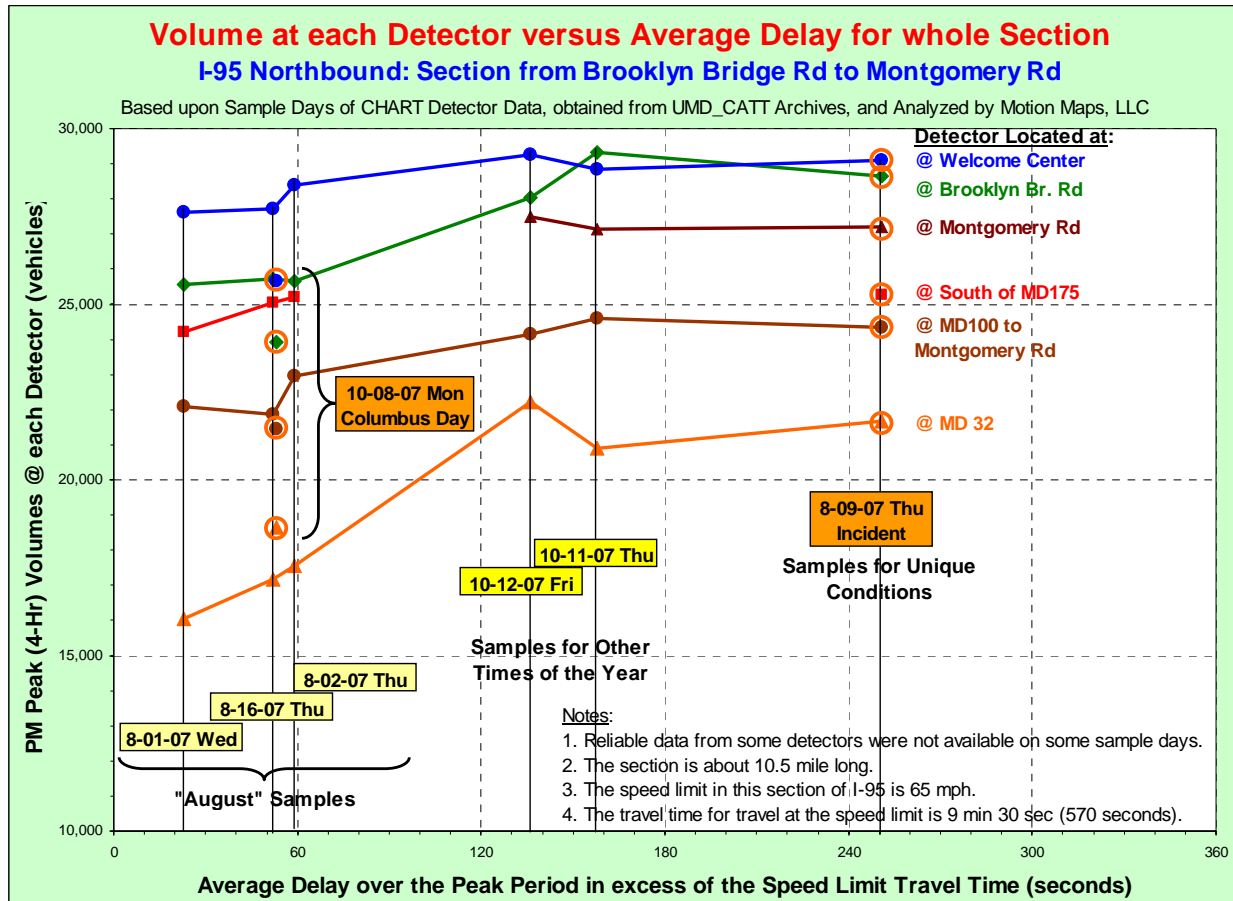


Figure 2-4b: Examination of Volume – Delay Relationships with More Data

Returning to comparing the October to August samples, a reduction of about 10% of the volume (about 3,000 vehicles in the four hours) at the Brooklyn Bridge Rd detector may be sufficient to return traffic there to freer flowing conditions, while at the next detector of the Welcome Center, a reduction of traffic of about 4%, or about 1,150 vehicles may be sufficient. At the northernmost detector at Montgomery Road about an 8% volume reduction or about 2,000 vehicles appears to be needed. Being able to achieve significant reductions in section delay based upon volume reductions at MD 32 may require a reduction of about 20% or 4,500 vehicles. Perhaps the significant amounts of ramp-to-ramp turning movements and weaving of traffic are creating more conflicting movements at the MD 32 interchange area.

Comparison of Paired-Values: The next part of the analysis examined the paired-relationships between concurrent observations of volume and average speed. It has been found that the data analyzed both for the system of detectors along the analysis section as well as for each detector generally replicate the types of patterns associated with the volume-speed-density curves of the Highway Capacity and Quality of Service Manual (HCQSM). However, the Study Team thinks that this analysis has a few aspects that distinguish it from the work that underlies the HCQSM. In particular, unique aspects of this analysis have included: (a) tracing this phenomenon along a series of detectors, along this 10.5 mile section, as well as (b) tying the results back to specific dates and times of generally known variations in travel demand.

In Figure 2-5 and Figure 2-6 for each detector the paired-values of volumes (x-axis) and average speed (y-axis) per each 5-minute summary interval are plotted, respectively first for a typical day in August (8-1-07) and then for a typically congested day at another time of the year, shown here as October (10-11-07). Four hours of such data for each day are shown in this case for each of the six detectors. The following observations are noted based upon Figure 2-5 and Figure 2-6:

- For each detector, 5-minute volumes and average speeds are plotted for a typical day in August and October.
- The 8-1-07 sample day (Figure 2-5) shows several relatively tight clusters of points – one cluster for each detector.
- In Figure 2-5 there is a wide range of 5-minute volumes varying from about 300 to about 650 vehicles.
- In Figure 2-5 there is a more narrow range of average speeds, compared to Figure 2-6, varying from about 40 to about 70 mph.
- In Figure 2-5 the vast majority of the 5-minute paired data sets have average speeds of 55 mph or faster (free-flowing) and only a handful of points show “slowing” average speeds in the 40 to 55 mph range. There was no 5-minute time period that had “slow” or “very congested” average speeds.

- However, now examining the 10-11-07 sample day (Figure 2-6) 5 of the 6 clusters of points are relatively widely dispersed with the tightest cluster being data from the detector between Maryland 100 and Montgomery Rd.
- In Figure 2-6, the range of volumes is still just as wide compared to that of Figure 2-5 varying from about 350 vehicles to about 700 vehicles per 5-minute interval, but the range has shifted to the right by about 50 vehicles more for the set of paired-values.
- In Figure 2-6 there is a much wider range of average speeds per 5-minutes compared to those shown in Figure 2-5, with about half of the paired-values being faster than the free-flowing speeds of 55 mph or more, with the other half or so of the observations having slower average speeds, which are widely and somewhat evenly dispersed between about 55 mph to ones as low as 15 mph for 5-minutes.

In Figures 2-5 and 2-6 there are 576 independent sets of paired-values of 5-minute volumes and average speed (4 hours, times 12 observations per hour, times 6 detectors, times 2 days). If all of those points were put on one graph and the different marker shapes and color-codes for the detectors were not shown, then the reader would find it just about impossible to discern the relationships among the volumes and average speed that are there. In the remainder of the analysis we do the opposite of that and highlight similarities and differences for paired-graphs for the pair-values of volume and average speed for 3 of the 6 detectors. Those paired-graphs demonstrate a general consistency with HCQSM findings and they are used to estimate the “tip capacity” that breaks down the flow of traffic and creates significant delays.

Figure 2-5: Wednesday, Aug 1, 2007

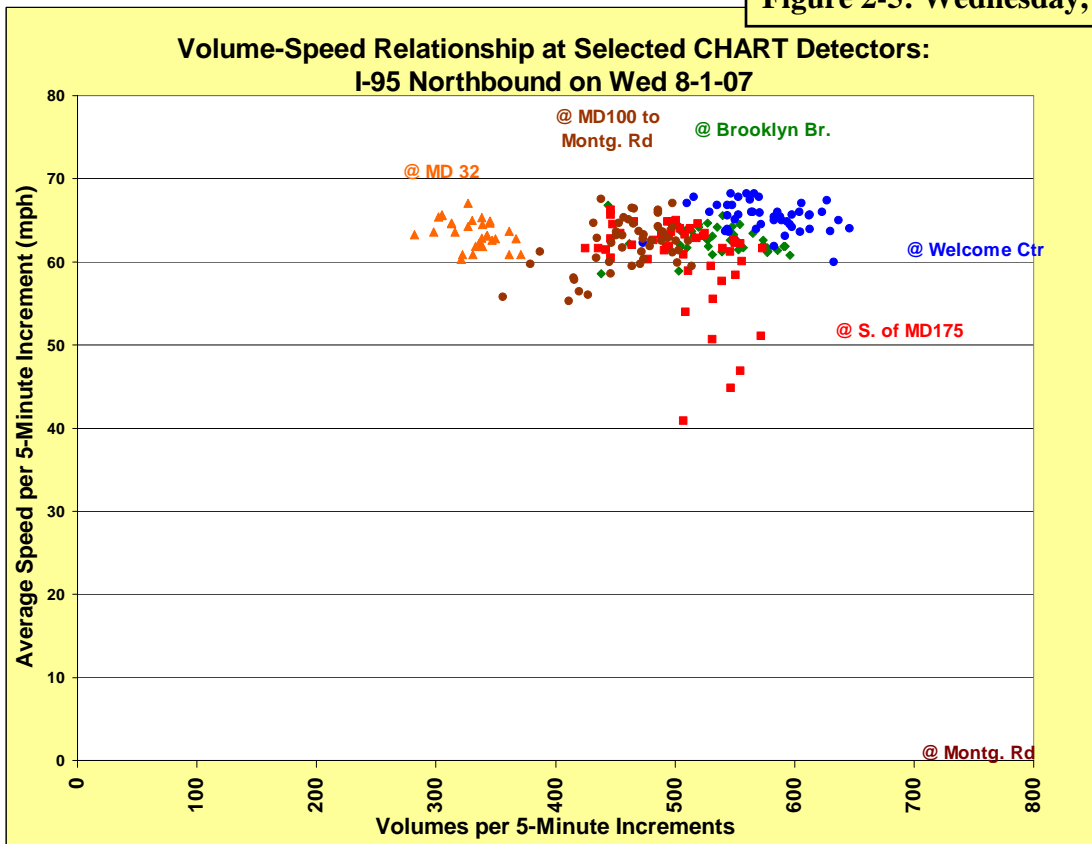
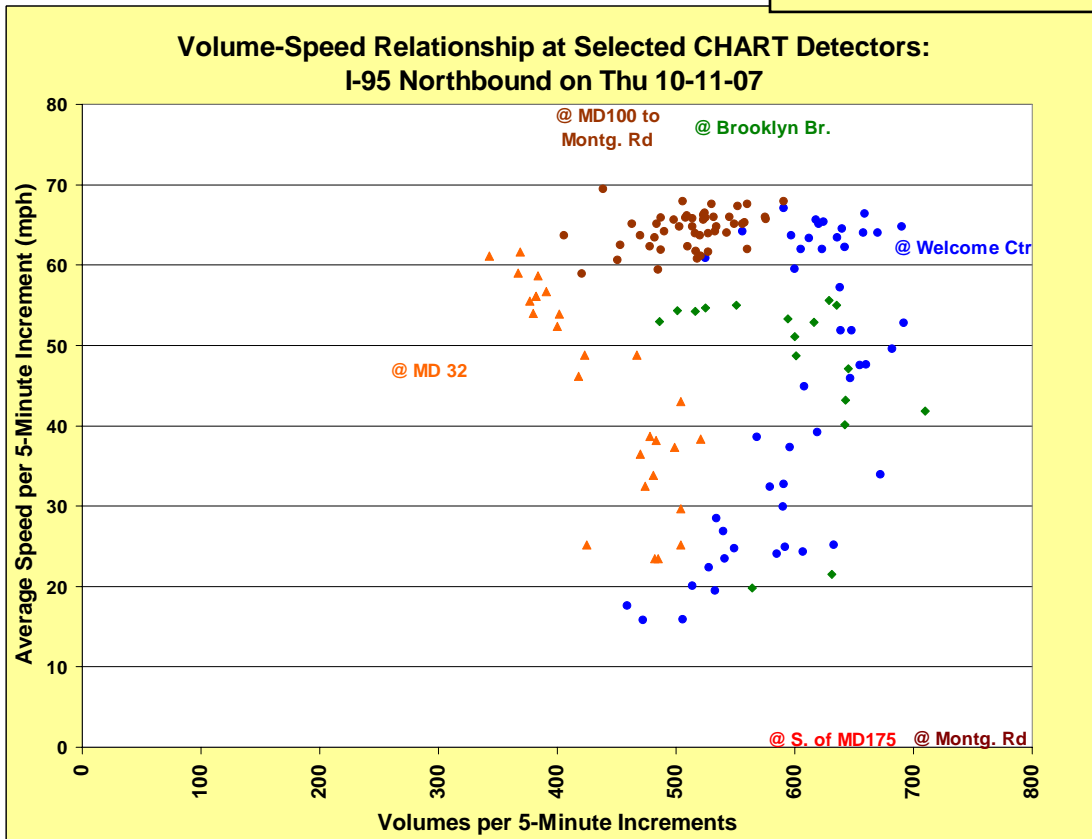


Figure 2-6: Thursday, Oct 11, 2007



The questions addressed in the remaining three sets of paired-graphs are: (1) does temporally increasing travel demands, reflected by marginally higher and higher 5-minute volumes, result in traffic congestion?, and (2) if it does, what are the specific values of demand (high volumes) that we should manage to avoid through application of various strategies, so as to maintain the freer-flowing traffic conditions?

On the following page, just the 5-minute paired-values of volume and average speed of I-95 at the Welcome Center are plotted paying attention to the temporal sequence of the observations, which is graphically illustrated by the line that is “connecting-the-dots”. In Figures 2-7 and 2-8 it is demonstrated graphically that a small degree of marginally increasing demand (volume) is a main ingredient that results in the precipitation of congested and slow average speeds for one or more of the subsequent 5-minute time intervals. A key conceptual consideration is to examine the relationship among the different paired-values of the quantity of the traffic flow (volume) relative to the quality of the traffic flow (average speed) sequentially through time.

It has long been observed and reported in the HCQSM and elsewhere that when the quantity of flow is very high approaching the capacity of the roadway that further small increases in the quantity of flow can result in a quick and sustained reduction in the quality of the traffic flow, as measured by the average speed. That in turn has a negative feedback on subsequent time intervals when the same quantity of flow can no longer be served and queues form back upstream from the point of constriction. A series of relatively closely spaced detectors summarizing flow characteristics at relatively short time intervals can generally discern such traffic flow behavior, as illustrated in Figure 2-7 and 2-8 although the fixed location of the detector may not be exactly where the traffic flow initially broke down.

Another factor in precipitating a sudden decrease in traffic speed is usually some random event such as very short-term driver inattentiveness. Drivers taking their eyes off the road ahead for a very small interval may result in drivers braking extra hard when their eyes are back on the road and perceive that the vehicles ahead are now too close. That hard braking can cause the driver behind to react in a similar fashion, and the driver behind that one to do the same, and so on. A “shock-wave” of brake lights ahead can quickly propagate upstream at speeds that approach that of the forward movement of the traffic flow. This phenomenon of a “reverse compression shock wave” moving back upstream in the flow, at speeds of 100 mph or more relative to the forward speed of the vehicles can result in minor and even severe crashes taking place.

In Figure 2-7 for 8-1-07 it shows that at the “Welcome Center” detector on I-95, the maximum 5 minute volume approaches but does not exceed about 650 vehicles per 5-minute interval. However, in Figure 2-8 the 5-minute volumes initially start to exceed the capacity, which is somewhat elastic. However, for a short period of time the flow is not a sustained enough flow to cause an immediate break down. Shortly afterward the volume increases again and there is enough sustained volume and within a twenty minute period to cause the average speed decreases to about 25 mph and then 10 minutes later it decreases again to about 15 mph. It then took over an hour and a half more before the average speeds returned to free flow levels at about 7 PM. The maximum observed flow at this location was about 690 vehicles, enabling the maximum flow per lane to be calculated. In the I-95 section there are 4 through lanes. Expanding the 5-minute volume of 690 vehicles by 12 (12 – 5 minute time periods per hour), the hourly maximum volume is about 8,300 vehicles per hour. Dividing by the 4 lanes gives a maximum volume of about 2,075 vehicles per lane per hour. This corresponds well with the HCQSM’s maximum volume of 2,400 passenger cars per lane under ideal condition. If the I-95 data is

adjusted for trucks and the peak hour factor, the recorded maximum traffic volume is close to the theoretical HCQSM maximum flow.

In Figure 2-8 it should also be noted that during congested flow the traffic flow is much lower at the slower speeds. As traffic becomes congested there is a drop in the maximum flow rate of 10 to 20% versus the flow rate just prior to a traffic breakdown. By avoiding traffic breakdown not only does the traffic travel at higher speeds, but under the non-traffic breakdown conditions a higher throughput volume may be maintained, serving more travelers in less time.

Marginally Higher Volumes Cause Congestion?

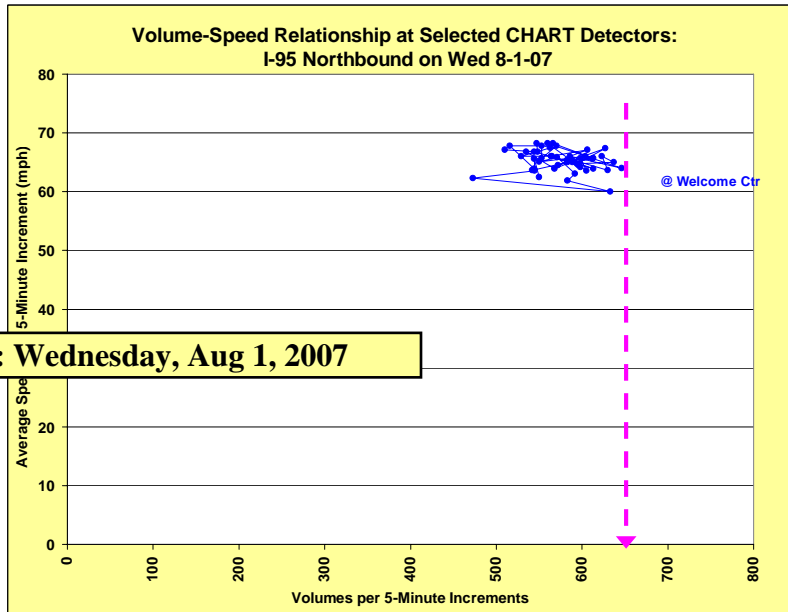


Figure 2-7: Wednesday, Aug 1, 2007

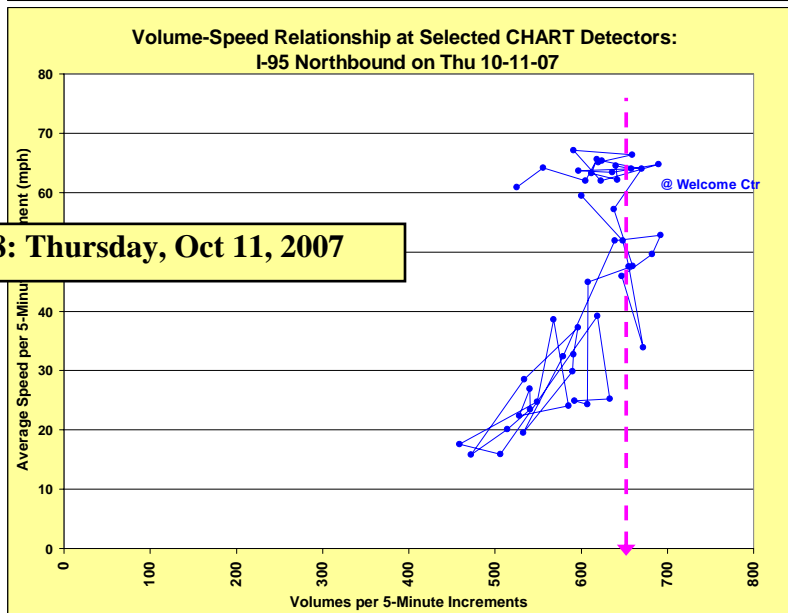


Figure 2-8: Thursday, Oct 11, 2007

- Figure 2-7 shows that traffic at the “Welcome Center” flows freely when the volume (demand) is less than 650 vehicles per 5-minutes.
- The connect-the-points-graph (Figure 2-8) shows that marginally higher volumes of between 650 and 700 vehicles seems to result in a break-down of flow to speeds to under 20 mph and lasts for two hours.

- However, as shown in the next set of paired-graphs on the following page, for the downstream detector at MD 32, the breakdown there might have instead been the cause.

Each Freeway Segment has its Own Capacity

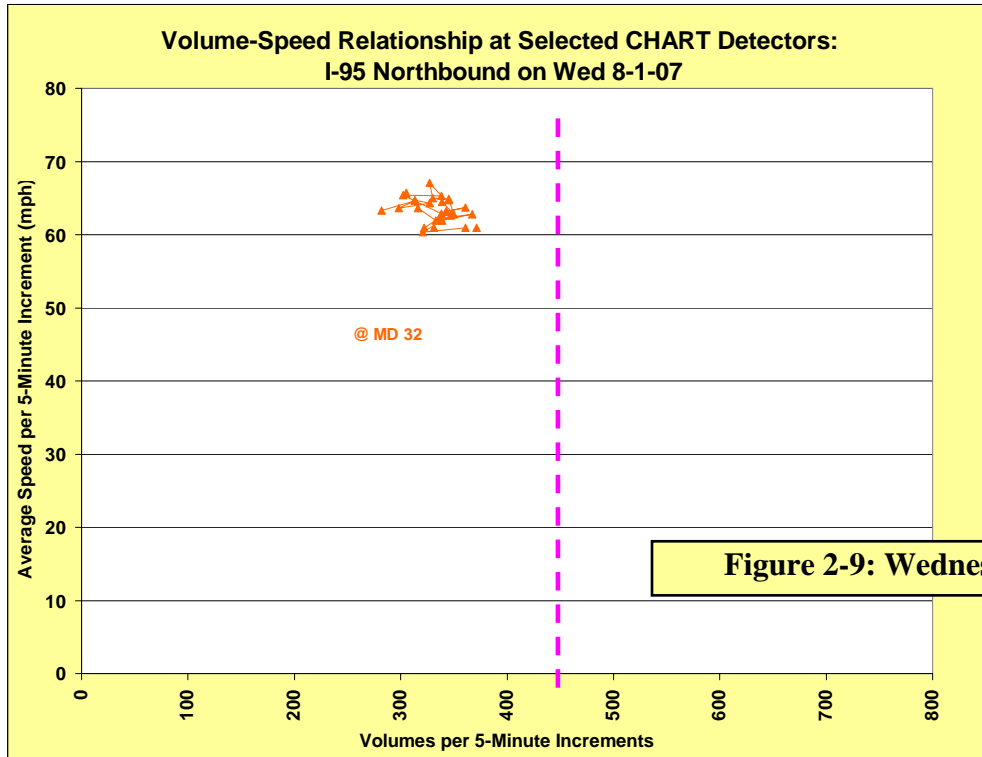


Figure 2-9: Wednesday, Aug 1, 2007

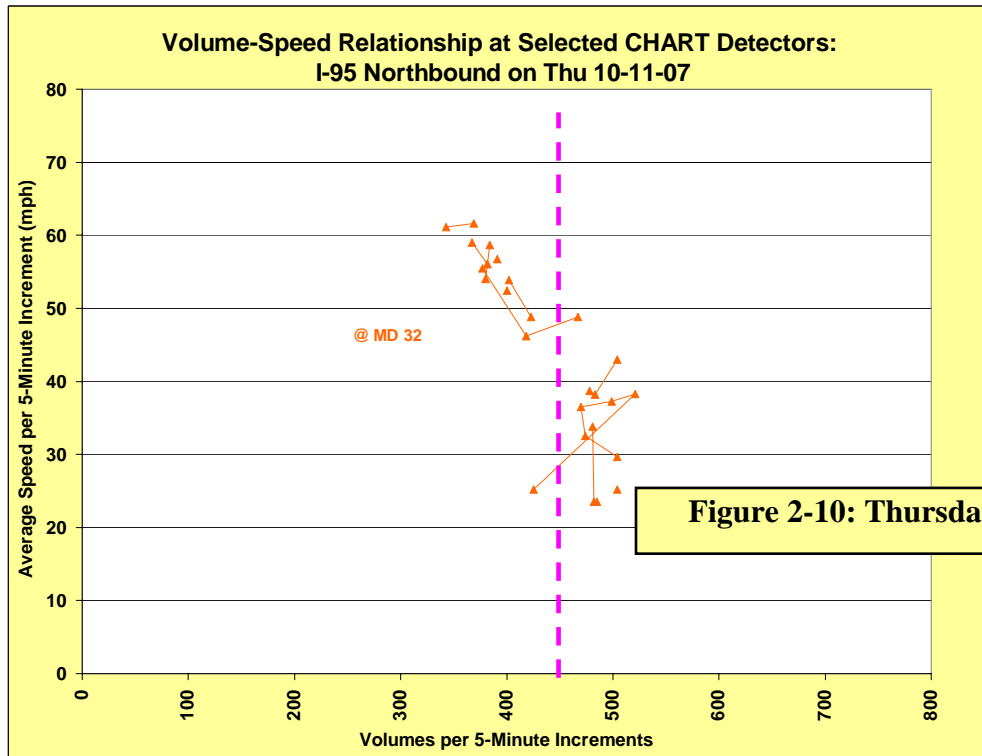


Figure 2-10: Thursday, Oct 11, 2007

- Figure 2-9 shows that at the MD 32 detector when volumes stay under 400 vehicles per 5-minutes there is no slowdown; at 450 vehicles there is a local slowdown without enough spill-back to affect the traffic flow at the “Welcome Center” segment.
- However, in Figure 2-10, at a demand of 500 or more vehicles per 5-minute period at MD 32, the queue may be long enough to back-up upstream and precipitate a slowdown upstream in the Welcome Center segment of the roadway section.

In Figures 2-11 and 2-12 we again are able to show and estimate the maximum flow for the roadway section just prior to congestion breakdown. Figure 2-12 also demonstrates the 10 to 20% reduction in traffic flow due to being in a congested flow versus a non-congested flow. The relationships shown in this series of figures are important to understanding and estimating the reductions in delay with very modest reductions in traffic volumes.

Next Freeway Segment also has its Own Capacity

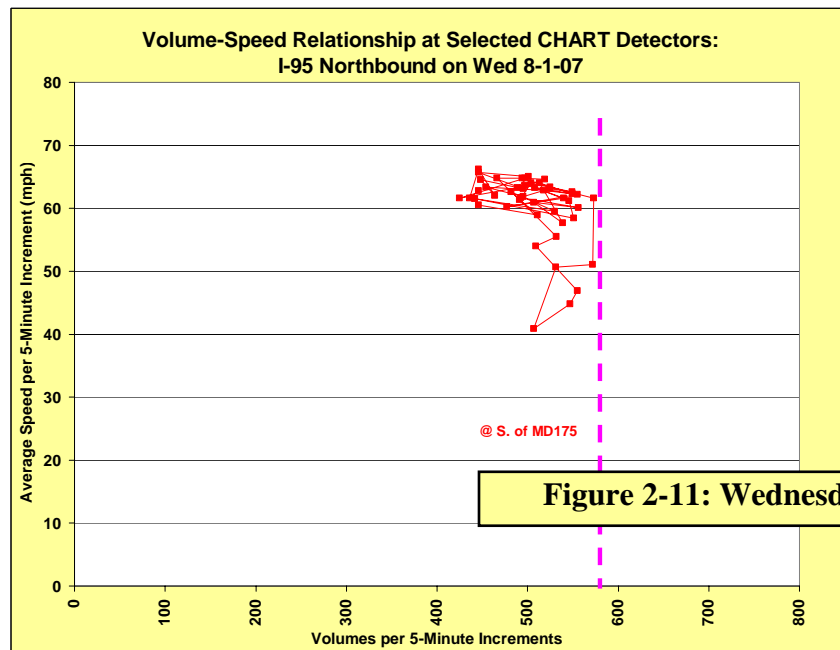


Figure 2-11: Wednesday, Aug 1, 2007

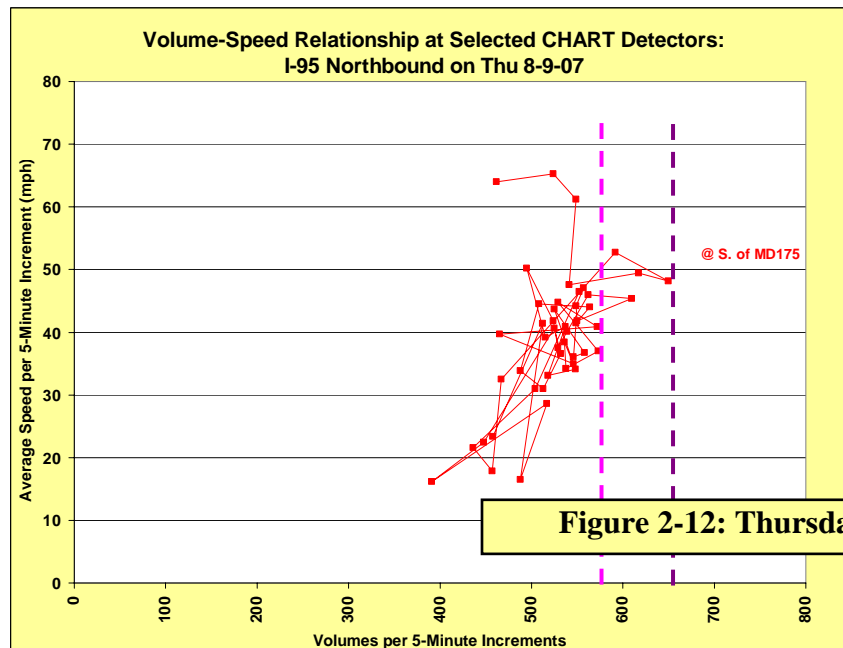


Figure 2-12: Thursday, Aug 9, 2008

- Graphs show that at the detector south of MD 175 the breakdown capacity seems to be about 575 vehicles per 5-minutes.
- While the consistency of such a capacity value on a day-to-day basis is beyond the scope of this research, the sample day of Thursday Aug 9, 2007 (Figure 2-12) indicates a higher value of about 650 vehicles per 5-minutes. That higher capacity value corresponds to an hourly maximum observed flow of about 1,950 vehicles.

I-270 Corridor

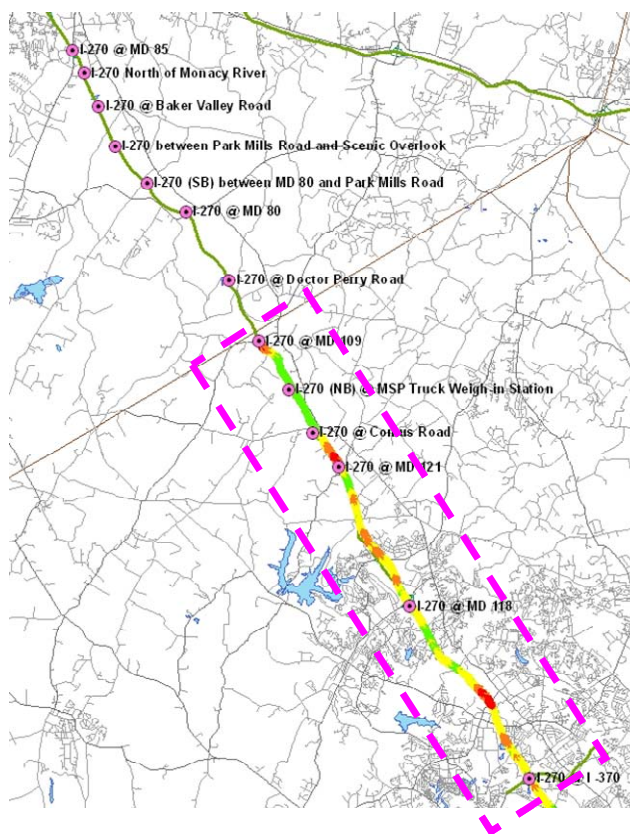
I-270 Corridor: General Locations of Detectors

Parts of the I-270 Corridor were also analyzed to evaluate and confirm many of the traffic characteristics and speed-volume relationships discussed in the previous section for parts of I-95. In a similar fashion this analysis relied on the CHART system of the Maryland DOT that operates a set of traffic flow detectors along the I-270 Corridor in Frederick and Montgomery Counties. The five-minute summaries of the volume and average speed are also archived by the Center for Advanced Transportation Technology of the University of Maryland (UMD-CATT). This analysis focuses on data from the six detectors on I-270 from I-370 north to MD 109, in Montgomery County, a distance of about 12.9 miles. The general location and names for those detectors are shown in Figure 2-13 below. Seven of the I-270 detectors located in Frederick County are shown here for informational purposes. It should be noted that the number and use of lanes for this section of I-270 changes a few times and differs for southbound and northbound travel. One of those lane changes highlighted in the analysis is the lane-drop from 3 to 2 lanes in the Northbound direction between MD 121 and Comus Road, where the concurrent-flow High Occupancy Vehicle lane also ends, which operates weekdays between 3:30 and 6:30 PM. Congested conditions are often found at and near this lane drop.

Figure 2-13

Note: the speed ranges shown reflect a PM Peak Period northbound sample of GPS Probe Data for the corridor, not any overall assessment

1 to 20 20 to 35 35 to 50 > 50 mph



Traffic Characteristics:

As part of our analysis, the Study Team examined various traffic characteristics obtained from measured variations in five-minute volumes and five-minute average speeds at each of the six detectors of the analysis section of I-270. Similar to I-95 discussed previously, this operational data is nominally collected “24 x 7 x 365” and the other features previously discussed also apply. Generally speaking there is an adequate amount of reliable data to identify various traffic characteristics including: (a) variation in volume by time of day used to define the “peak traffic volume periods”, (b) comparative speed range that can be used to define different degrees of congestion, such as free-flow/uncongested, slowing, slow, or jammed or stop-and-go conditions, and (c) section delay, the difference between the time it would take to travel the section at the observation time compared to the time it would take to travel that same distance at the speed-limit (Speed-Limit-Travel-Time, SLTT) or when traveling at free-flow. This last characteristic can have its own peaking patterns that may be similar to or differ from volume-peaks. This latter traffic characteristic of cumulative “section delay” for a typical Thursday and Friday in October, as well as a Tuesday in April are plotted and are shown in Figure 2-14 below. For this corridor the analysis uses a 5-hour peak period of 2 to 7 PM as congested section delays seems to be more prolonged in this corridor than in the I-95 Corridor. As noted above, this analysis section of I-270 is about 12.9 miles long. The speed limit there is mostly 65 mph and the travel time to travel at that speed is just under 12 minutes (11 minutes, 56 seconds, or 716 seconds). For a traveler beginning this section about before 4 PM on Friday 10-12-07, the amount of calculated section delay was about 720 seconds, or about 12 minutes more than the expected SLTT of coincidentally also about 12 minutes.

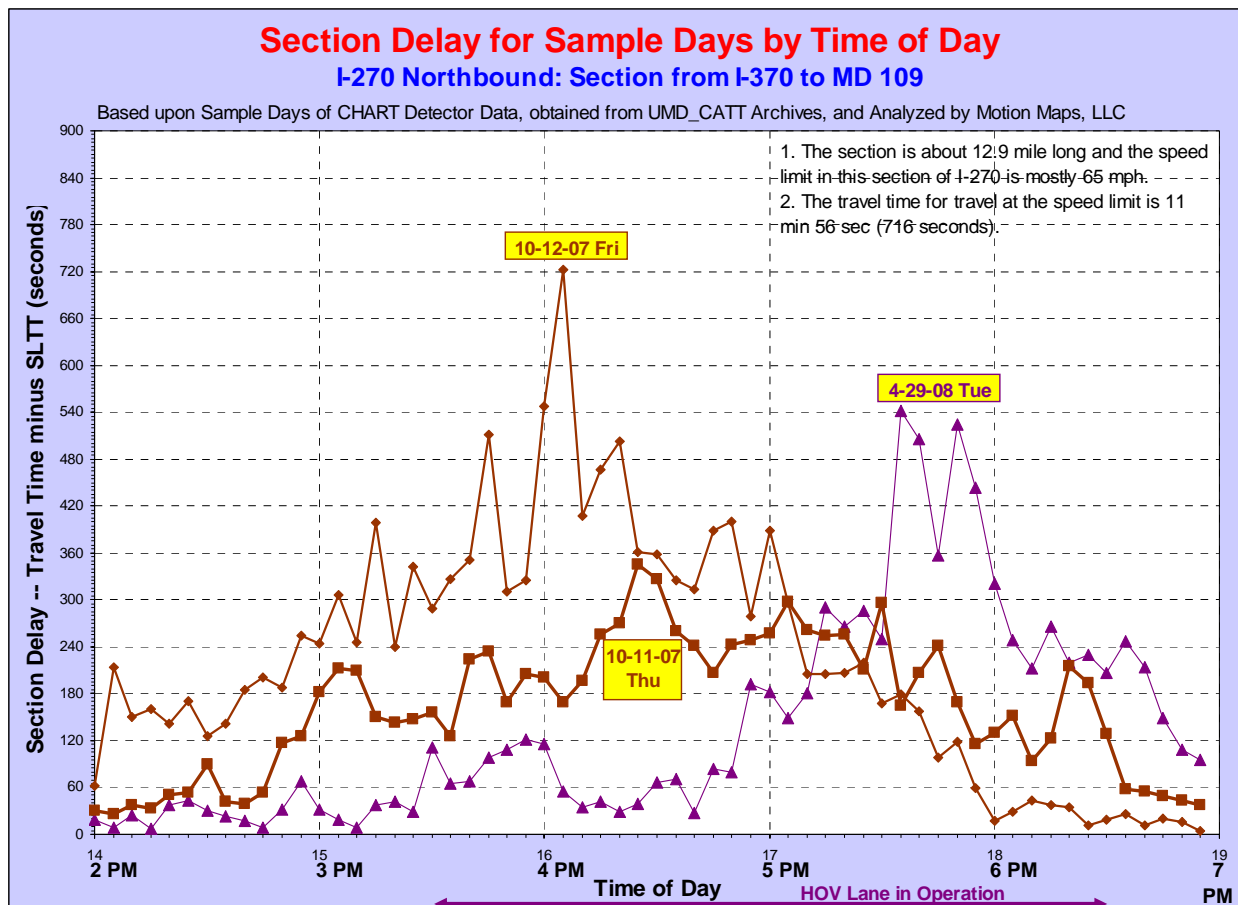


Figure 2-14: Typical Peaking of Section Delay for the Analysis Section of I-270

A good understanding of the patterns of variation in delay can better inform strategies aimed at managing that delay. For example, as shown in Figure 2-14 above, congestion on Thursdays is usually more prolonged and later in the afternoon relative to congestion on Fridays, which is usually more peaked and starts earlier. This pattern was also found in the I-95 Corridor analysis. For the Tuesday example of 4-29-08, the peak is even later in the PM. Strategies that address differences between days of the week will help the effectiveness of other strategies trying to restore freer flowing traffic.

Another characteristic considered was the length or duration of the peak period. Even during the lighter traffic days of August, the duration of the peak within the peak period is about 3 hours shown in Figure 2-15 below. Even one of the least congested summer days examined of 7-30-07 shows a peak of about 30 minutes duration at about 5:30 PM. For the typical October day of 10-11-07 Figure 2-15 shows that the duration of the peak section delay is even longer and starting before 3 PM and extending to nearly 7 PM. Thus strategies that account for seasonal as well as time-of-day patterns of travel behavior will be more effective than those that do not do so.

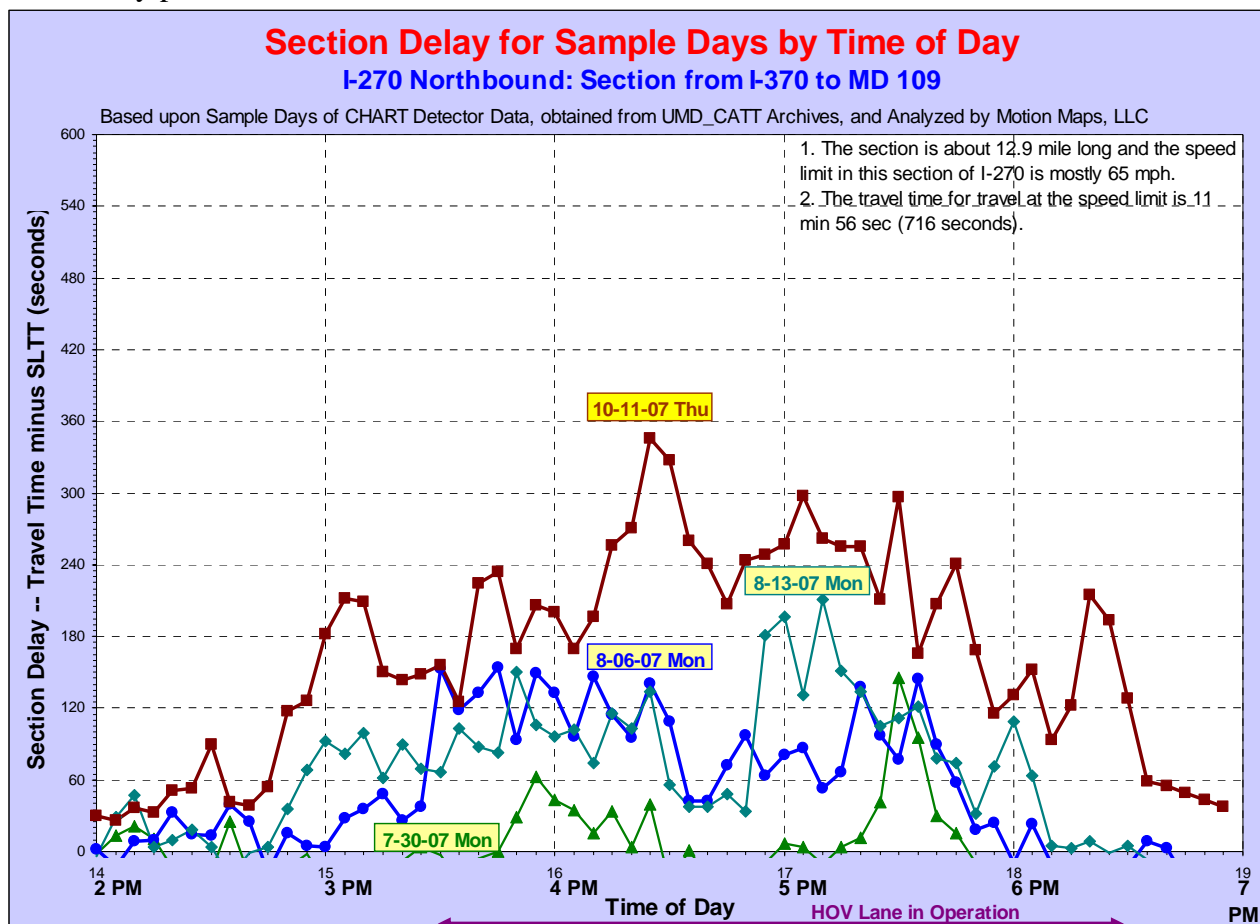


Figure 2-15: Peking of Section Delay During August-Lite Traffic Conditions

A third traffic characteristic that affects traffic volume, speed, and delay is that of trip purpose and the effects that systemic changes in trip purpose have on the temporal and spatial distribution of travel demand. An interesting illustration of this can be seen by examining the I-270 section delay characteristics for two “special days”. The first of these special days is the Columbus Day Holiday of Monday 10-8-07, which was also examined in the I-95 analysis. For the I-270 analysis even though Federal offices are closed as are some schools in the region, the schools in Montgomery County remain open for parent visitations. The section delay for Columbus Day is

seen in Figure 2-16 shows that I-270 was still congested for about 2 hours between about 4:30 and about 6:30 PM. This suggests that many people still traveled based on their usual trip purpose of a work trip heading home that afternoon, even though a significant proportion of workers (Federal employees) had the day off. Perhaps that is why during the first half of the PM peak period from about 2 to 4:30 PM the section delay was much lighter than usual for October and even lighter than an August-like day of Monday 8-6-07. In addition, many people who were off work probably attended to personal business and shopping, that is typical for that holiday. Strategies for restoring freer flowing traffic need to anticipate and address trip purpose as well.

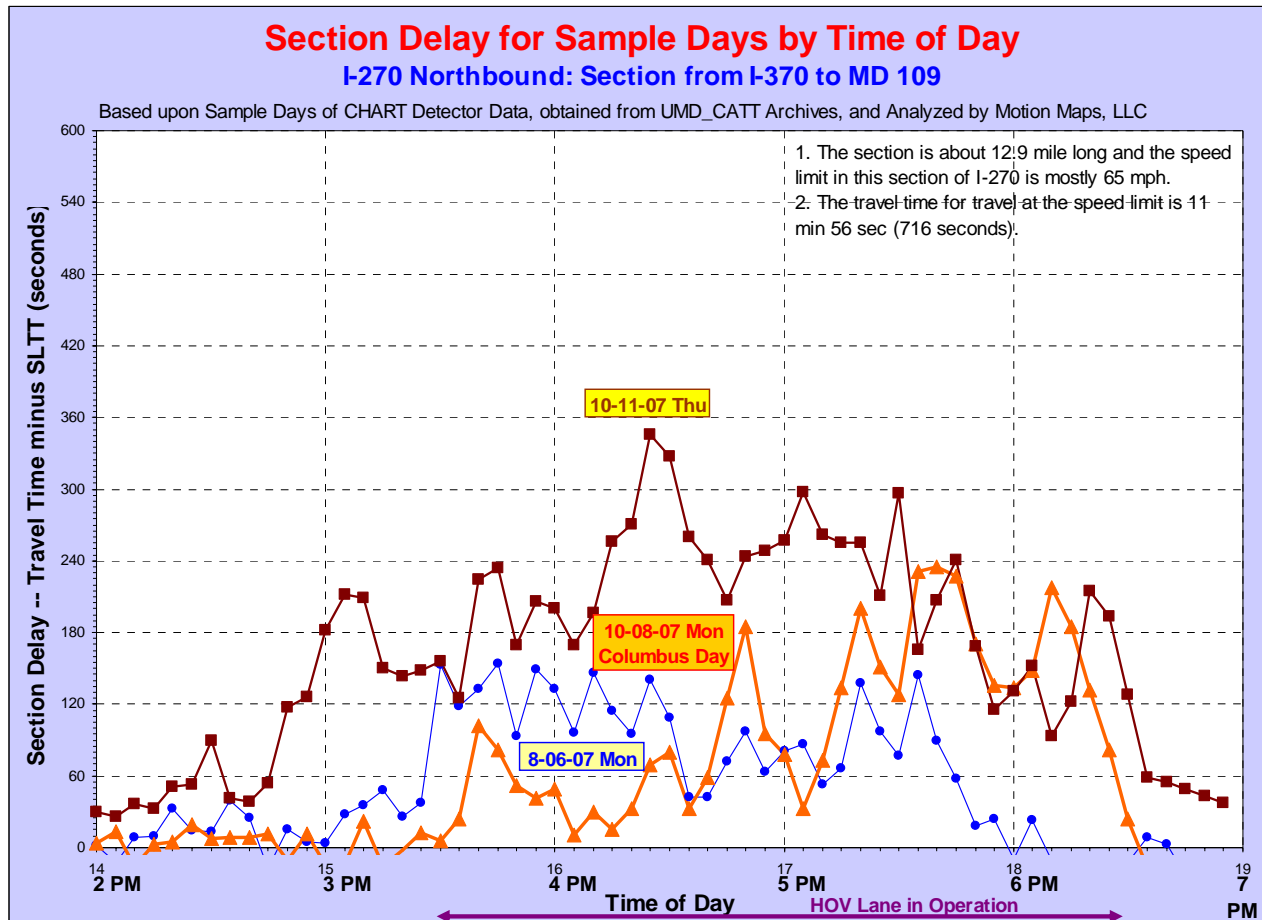


Figure 2-16: Relative Changes in Section Delay for the Columbus Day Holiday

The second of these “special days” systemically affecting travel demand is somewhat unique to Montgomery County and the analysis for this section of I-270 appears to be sensitive to those systemic changes. A relatively significant portion of residents (perhaps 10 to 15%) observe the religious holiday of Rosh Hashanah and do not go to work on that day, which was Thursday, 9-13-07 in 2007. In addition, for the past few decades if that Holiday falls on a weekday then the schools are closed county-wide. About 25 % of the households in the County have school age children and a significant proportion of the adults from those households chose not to work and remain home with their children. In addition, for many of the observers of the religious Holiday, there is a custom of visiting relatives and friends throughout the afternoon after the religious services are over resulting in higher than normal social trips and travel than normally occurs on a weekday. Figure 2-17 below shows the effects of the combination of these relatively large and systemic changes in travel demand on the section delay along I-270. The peak delay occurred between 2:30 and 4:30 PM, which probably corresponded to the extra amount of social travel

and trip making. On the other hand, during the usual commuter peak-times, there in essence was no section delay and the traffic conditions were more like those associated with weekend travel.

Because of the relatively uniformly light traffic congestion along I-270 on that religious Holiday, and the temporal and spatial changes in travel due to the shifts in trip purpose and destination, the throughput of traffic was high, which will be reviewed later in the analysis summary. Due to those high volumes of throughput and the low congestion, and because data was available at all detector locations, September 13, 2007 was selected as a “benchmark” for non-congested time periods for I-270 instead of one of the August-lite days previously examined. Appendix A in this document provides the detailed speed/volume plots for each detector site for the “August-lite” days that were considered plus discussion as to the relative merits of each day and the rationale for the September 13 selection.

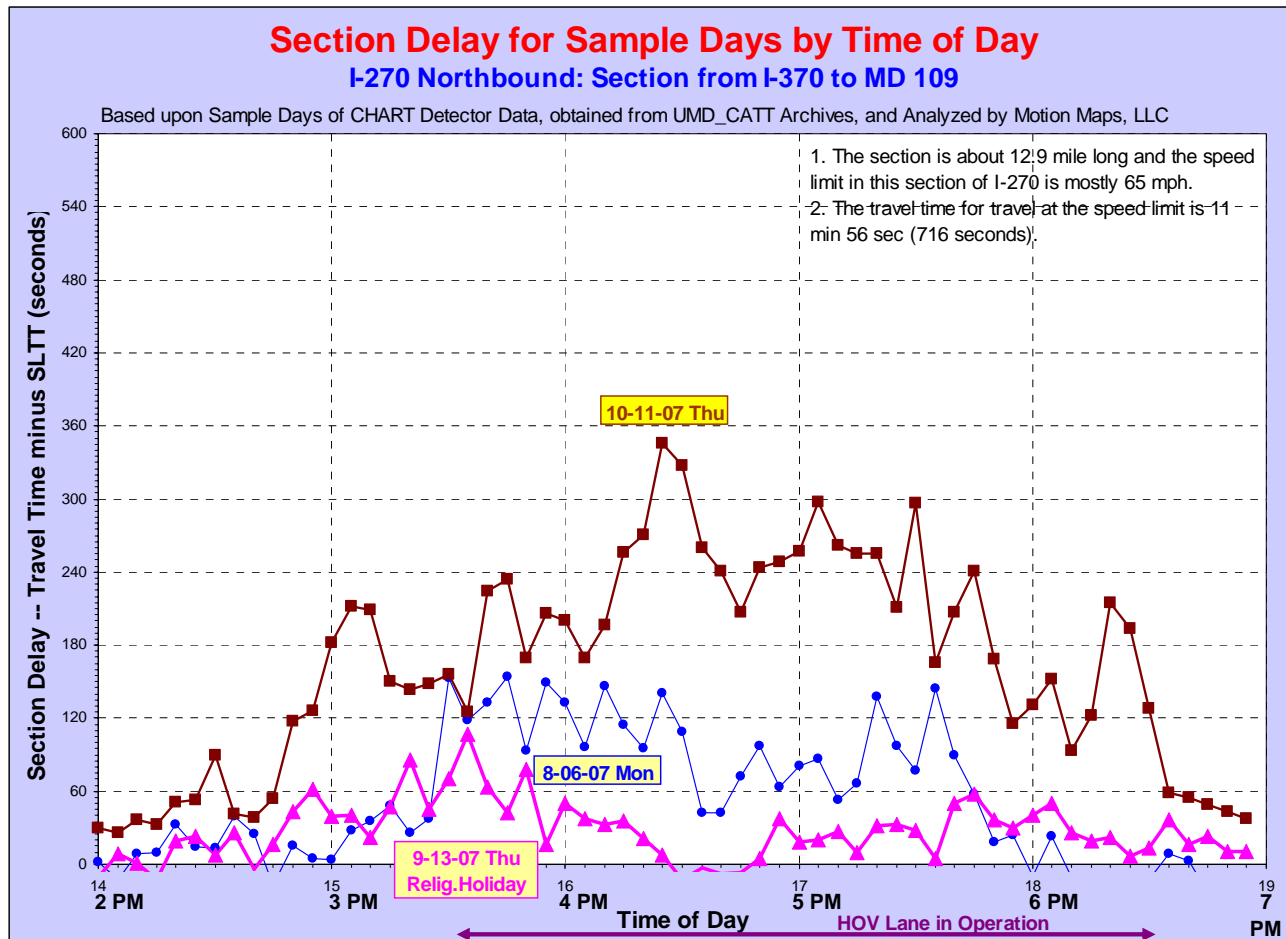


Figure 2-17: Relative Changes in Section Delay for the Religious Holiday Example

Volume-Speed-Delay Relationships

The overall data set for this section of I-270 was also analyzed in more depth to address the first research question of, how much traffic needs to be taken off freeways operating at various levels of congestion to restore free flow during rush hours?

To address that question the Study Team has taken the approach of first needing to “boil-down” the time-of-day variation in section delay to one indicator of delay. The measure of average delay per 5-minute increment over the 5-hour peak period was selected as the representative indicator of delay. Thus, the patterns of section delay from the prior four figures were reduced to

one five-hour average value. For example, the day with the most peak section delay of those shown in the prior figures was that of Friday, 10-12-07, and averaging over the entire five hours results in a value of about 280 seconds of average delay over the five-hour peak period in excess of the SLTT. That is an indicator measure for the entire analysis section of 12.9 miles.

In addition, we can measure the variation in demand along this analysis section of I-270 for that five-hour period by adding up the cumulative volumes observed at each of the six detectors. For example, about 27,500 vehicles passed the detector at MD 118 (Germantown Road) and that appears to be the location of the maximum quantity of flow along this analysis section of I-270 based upon the data from the detectors. However, since there is a long spatial gap of about 5.25 miles between the prior detector at the Express Lanes at I-370 and the one at MD 118, there may actually be a higher volume location based upon other data sources.

In Figure 2-18a the Study Team graphed the average section delay versus the total five-hour volume for each detector for the several example days being considered. The analysis results shown there have the three “August-lite” samples (7-30-07, 8-6-07, and 8-13-07) with less peak-period volume and less peak-period section delay than the three selected sample days for other times of the year (10-11-07, 10-12-07, and 4-29-08). Figure 2-18a also shows that there is a generally consistent relationship among the different detectors across the sample days – generally speaking as the volumes decline or increase there appears to be a linear relationship to the values of average delay. However, for two of the detector locations the relationship seems less strong, as discussed more next.

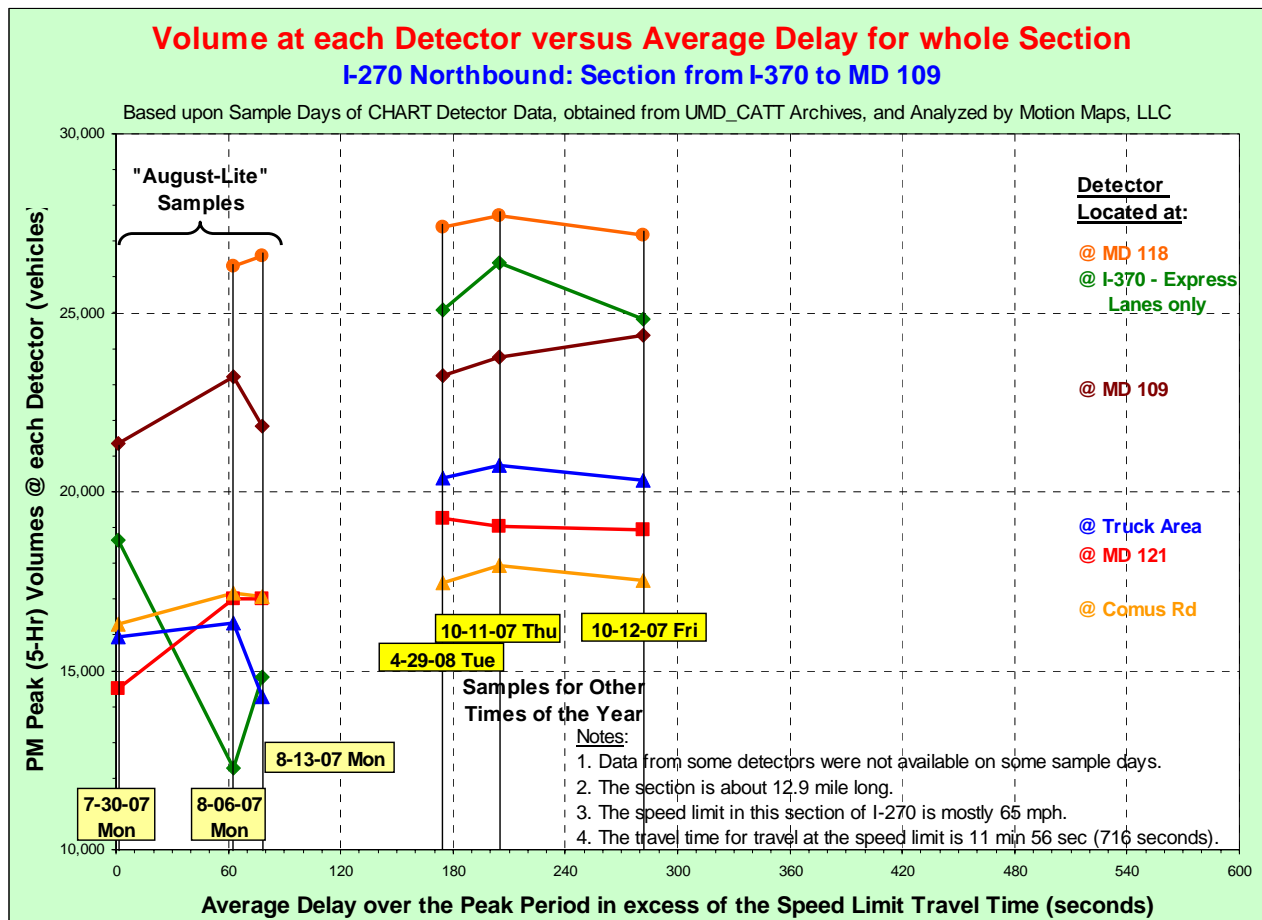


Figure 2-18a: Relationship between Total Volume and Average Section Delay for I-270

In Figure 2-18a above, for the detectors at “I-370 – Express Lanes Only”, and at the “Truck Weigh Station” there appears to be a less firm relationship between total volume average section delay in that the apparent linearity for the other four seems more independent at these two locations. For the detector at I-370, the archived data from UMD-CATT also had a set of values of 5-minute volumes and average speed for the “Local Lanes” at I-370. The study team chose to ignore that data set as we reasoned that we were interested in the variation in “mainline” volumes, speed, and delay and thus traffic flow of the local lanes represented a different set of traffic flows for our study purposes. At the truck weigh station the detector is positioned after the off ramp and before the on ramp from the weigh station. Thus traffic that turns into that area does not get counted in either the total volumes or the average speed.

For purposes of this part of the analysis, we feel comfortable with excluding the information for those two detectors in a revised version of the graph, which is termed Figure 18b given below. In addition, while Figure 2-18a tends to show the “traditional relationship” of volume versus delay – more volume – more delay, however, examination of other examples of three distinct “special days” in Figure 18b tends to indicate that when we “connect-the-dots” that the nature of the relationship between volume and average delay is perhaps richer in information and more complex.

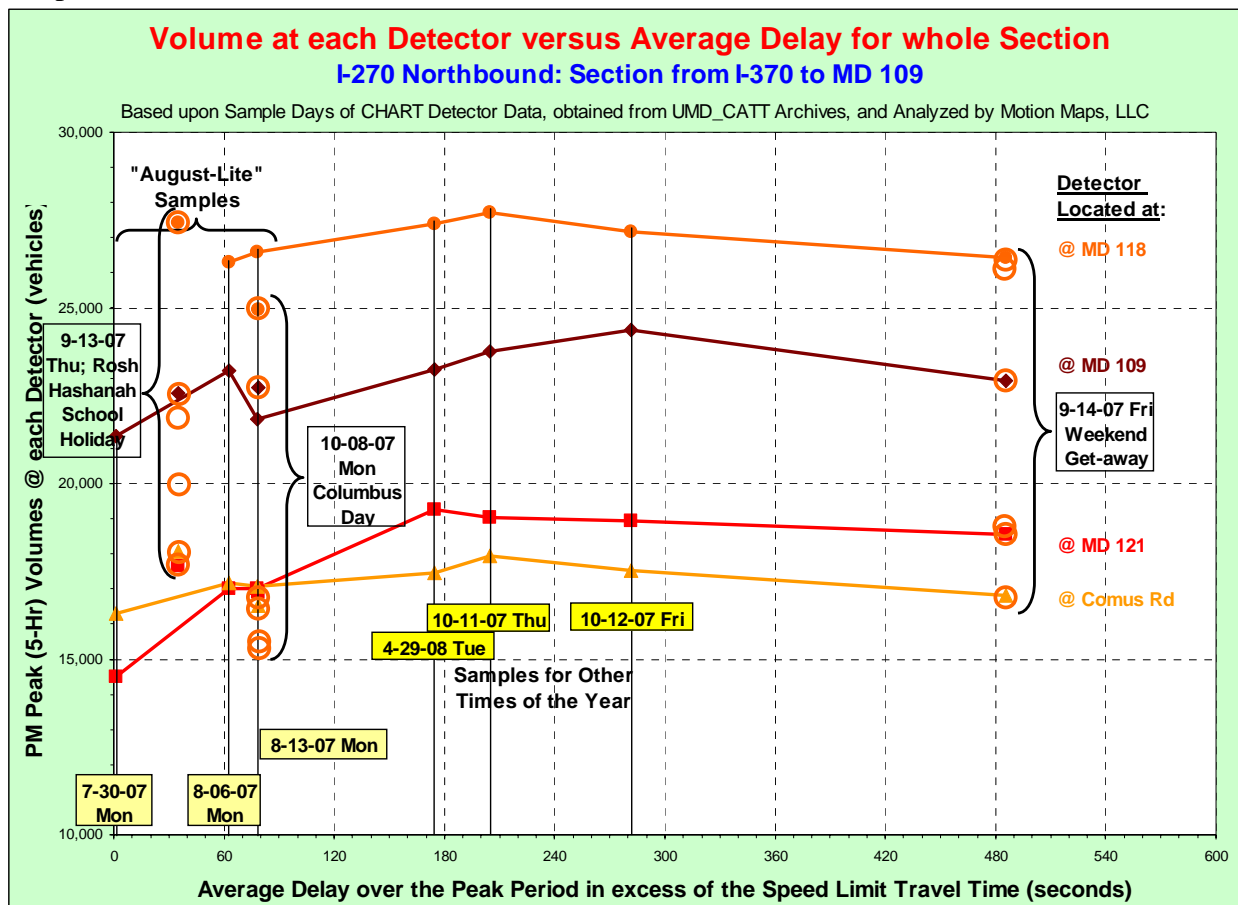


Figure 2-18b: Relationship between Total Volume and Average Section Delay for I-270 for Selected Detectors and a Range of “Special Days”

Before returning to comparing the October to August samples, we need to put the three “special days” in context. We have already identified and partially discussed two of them: Monday 10-08-07, Columbus Day, and Thursday, 9-13-07, which was a religious holiday. Both of those days had systemic changes in significant components of the overall regional travel demand so it is not

surprising that the values for total volume and average section delay do not “fall in line” with the more normal traffic days with consistent demand patterns. The third “special day” that is shown in Figure 2-18b is the day after the last one mentioned – that of Friday 9-14-07. For that day, this analysis section of I-270 experienced the most congested conditions of the samples examined for this analysis – and as shown in the Figure it had an average section delay of about 480 seconds (about 8 minutes) for over the whole 5-hour time period studied. That day is the one most to the right in Figure 2-18b. That sample tends to illustrate that more congestion can have a negative feedback and result in less throughput within a fixed time period than other less congested sample days. That pattern appears to be the case for each of the four detector locations that are shown in Figure 2-18b.

Yet, for the left side of that Figure, the relationships seen indicate that by better managing and reducing demand, there can be significant reductions in the amount of congestion and delay associated with that corridor. The particular amounts of demand reductions needed for the four locations associated with these detectors is the following going northbound in the flow direction in the PM:

- A reduction of about 4% of the volume (about 1,000 vehicles in the five-hours) is needed in the vicinity of the MD 118 Detector and may be sufficient to return traffic there to freer flowing conditions,
- At the next detector at MD 121, a reduction of traffic of about 15%, or about 2,900 vehicles over the five-hour period may be sufficient.
- In the vicinity of the next detector at Comus Road about a 5% reduction in the five-hour volume is needed, or about 800 vehicles to return traffic there to freer flowing conditions
- At the northern-most detector at MD 109 about a 7% volume reduction or about 1,700 vehicles over the five-hour period appears to be needed.

Perhaps the larger and more difficult reduction would be needed in the vicinity of the MD 121 detector because: (a) that is where the number of lanes drops from 3 to 2 which results in more traffic friction, and (b) during the 3:30 to 6:30 PM period the HOV lane ends there as well. The users of the HOV lane, who are in the left lane, do not need to merge to the right. Rather the right most traffic lane is the one that is dropped and the users of that lane need to merge with the traffic in the center lane.

Comparison of Paired-Values: The next part of the analysis examined the relationships between concurrent observations of paired-values of five-minute volume and average speed. It has been found that the data analyzed both for the system of detectors along this analysis section of I-270, as well as for each detector, generally replicate the types of patterns associated with the volume-speed-density curves of the HCQSM. However, the Study Team thinks that this analysis has a few aspects that distinguish it from the work that underlies the HCQSM. In particular, unique aspects of this analysis have included: (a) tracing this phenomenon along a series of detectors, along this 12.9 mile section, as well as (b) tying the results back to specific dates and times of generally known variations in travel demand.

In Figure 2-19 and Figure 2-20 for each detector the paired-values of volumes (x-axis) and average speed (y-axis) per each five-minute summary interval are plotted, respectively first for an identified day of little congestion of Thursday 9-13-07, given in Figure 2-19. As noted and discussed above, that day was a religious Holiday for many residents in the corridor, and many others had changed travel patterns due to the schools being closed for the day. Figure 2-20 shows the similar paired-values for a typical congested day of Thursday 10-11-07. Five hours of such

data for each day are shown in this case for each of the six detectors. The following observations are noted based upon Figure 2-19 and Figure 2-20:

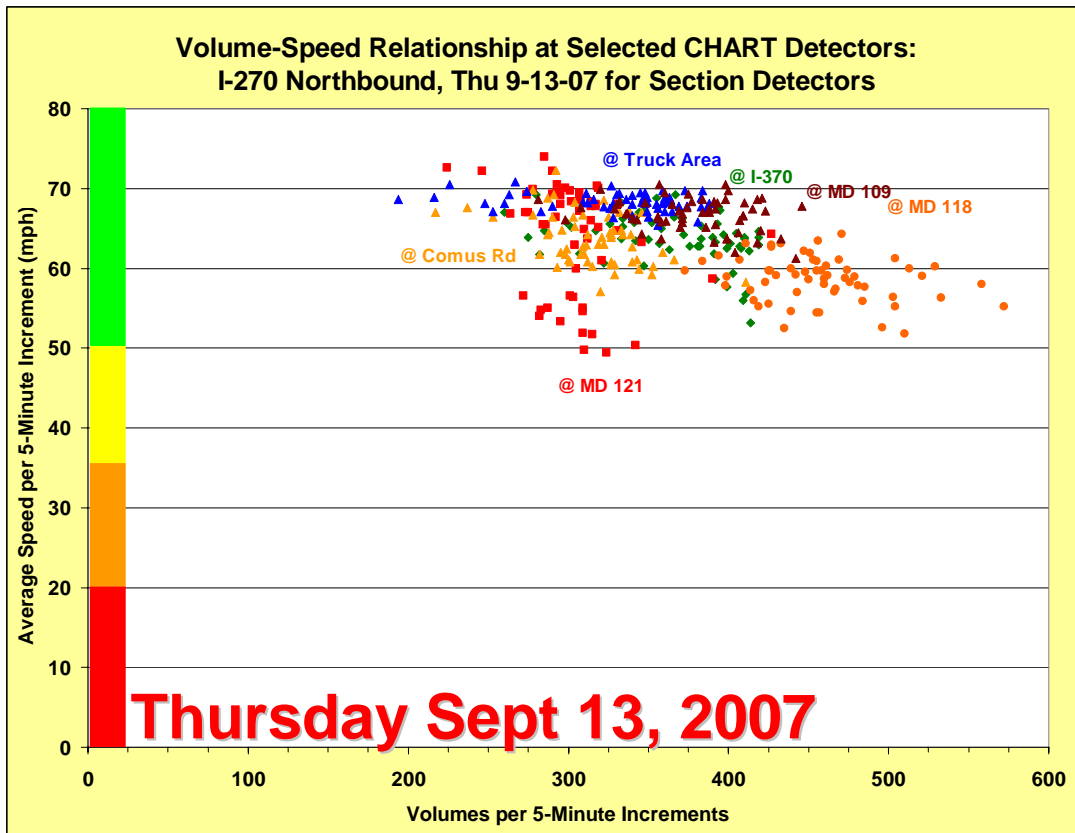


Figure 2-19: Paired-Values of Volume and Average Speed for Thursday 9-13-07

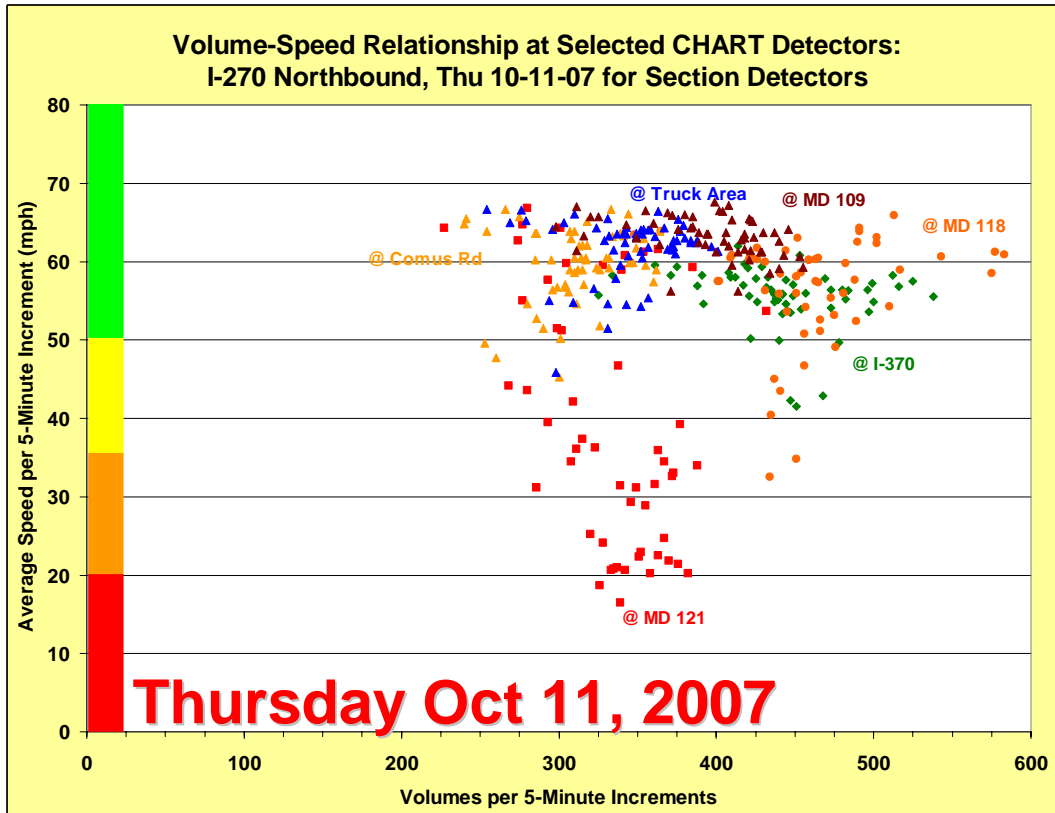
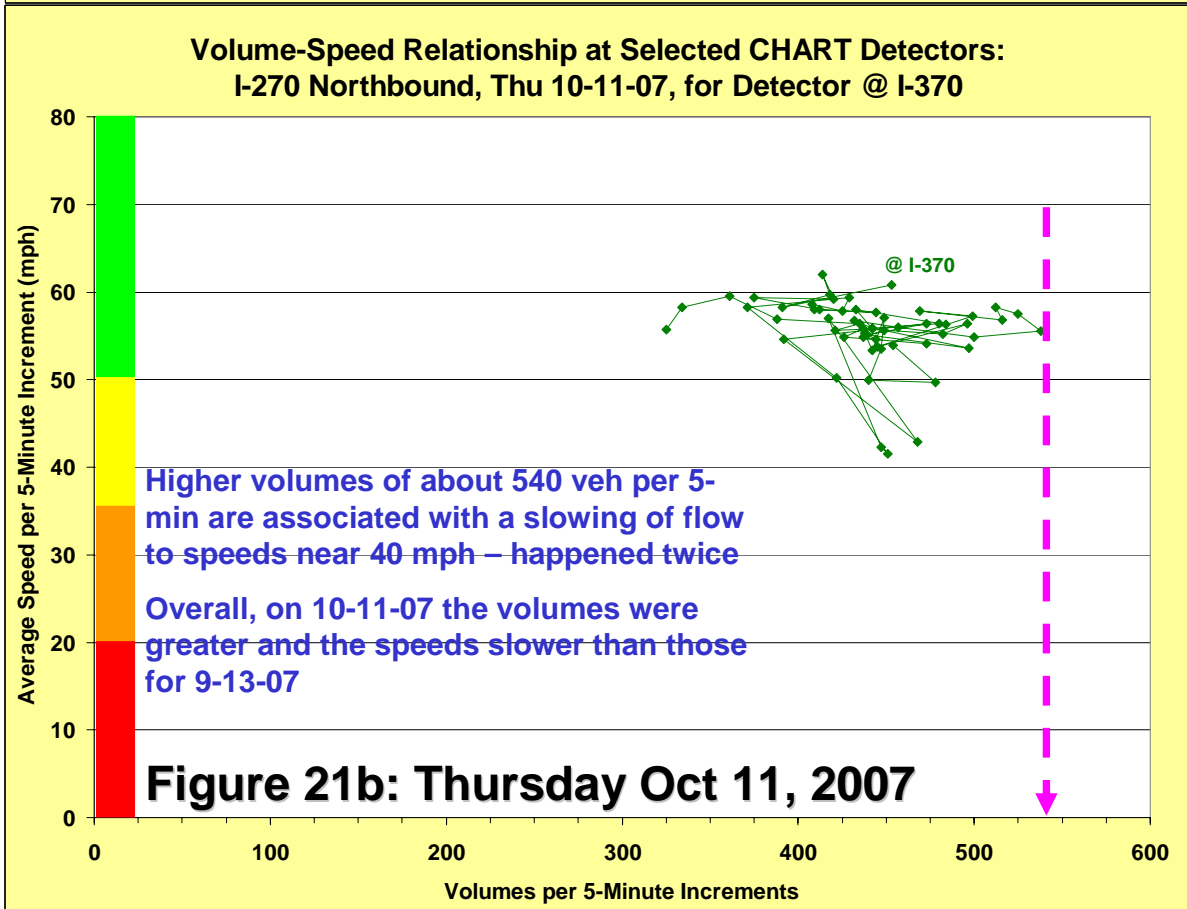
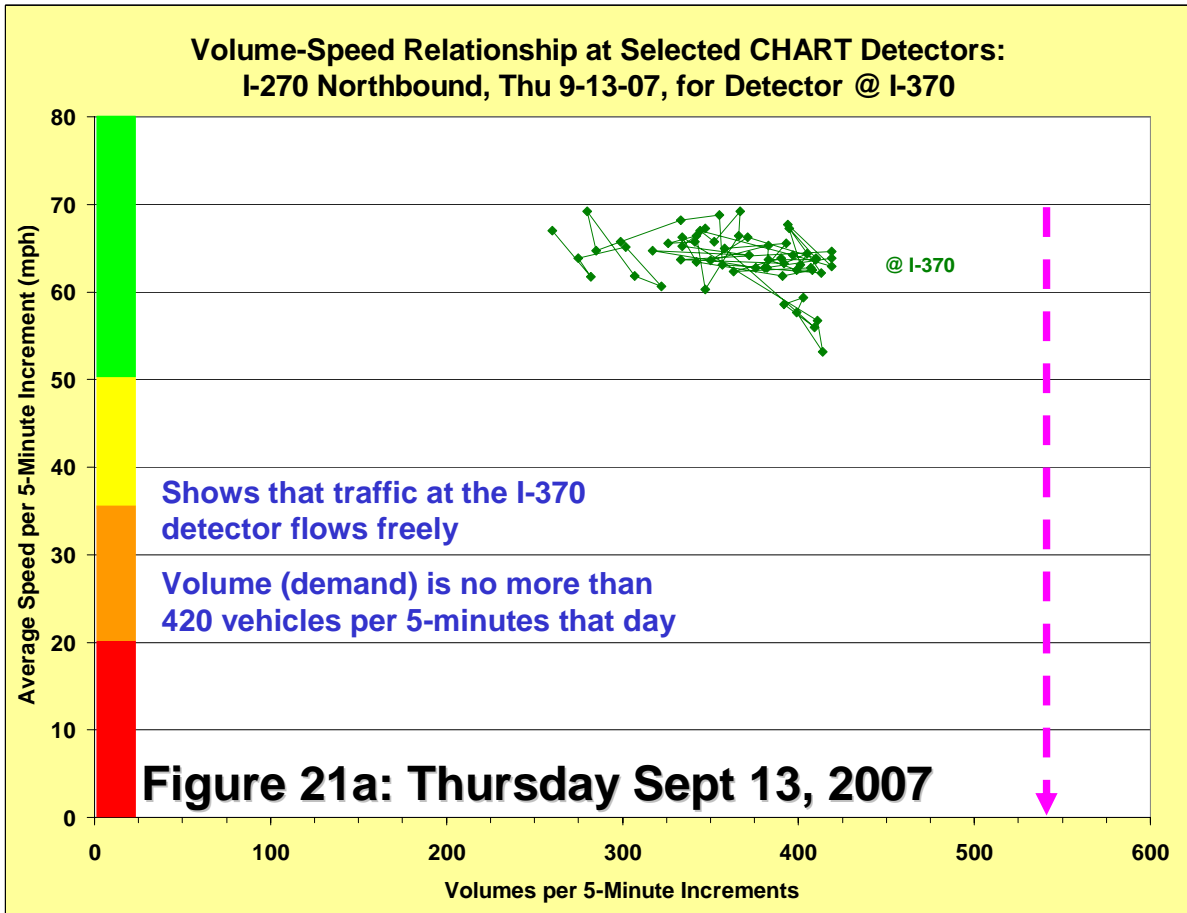


Figure 2-20: Paired-Values of Volume and Average Speed for Thursday 10-11-07

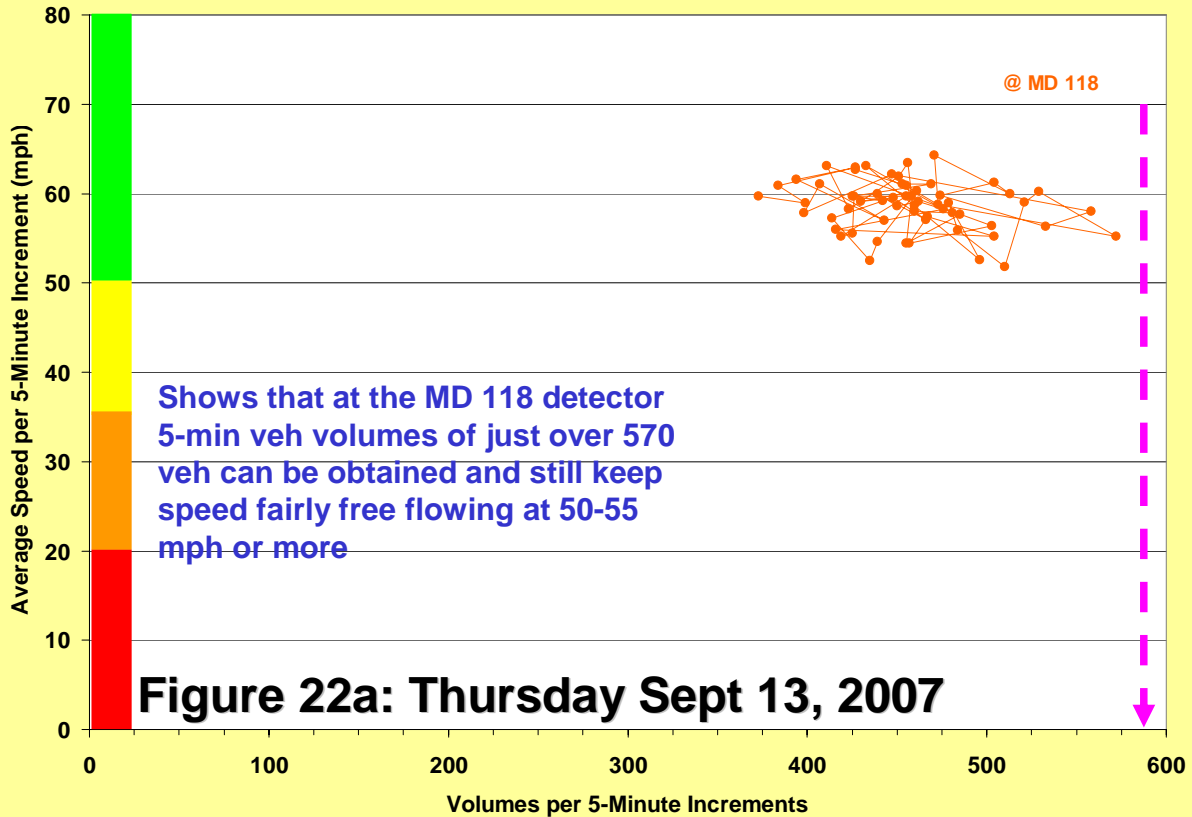
- For each detector 5-minute volumes and average speeds are plotted for a typical day in October of Thursday 10-11-07, and a lightly congested day of Thursday 9-13-07.
- The 9-13-07 sample day (Figure 2-19) shows several relatively tight clusters of points – one cluster for each detector.
- In Figure 2-19 there is a wide range of 5-minute volumes varying from about 200 to about 575 vehicles. (MD 118 detector had a peak volume of 583 vehicles per 5-minutes.)
- In Figure 2-19 there is a more narrow range of average speeds, compared to Figure 2-20, varying from about 50 to over 70 mph.
- In Figure 2-19 the vast majority of the 5-minute paired data sets have average speeds of 55 mph or faster (free-flowing) while about 15 to 20 points show “slowing” average speeds in the 50 to 55 mph range. There was no 5-minute time period that had “slow” or “very congested” average speeds.
- However, the 10-11-07 sample day (Figure 2-20) 5 of the 6 clusters of points are relatively widely dispersed with the tightest cluster being data from the detector located near MD 109, at the northern end of this analysis section.
- In Figure 2-20, the range of volumes is still just as wide compared to that of Figure 2-19 also varying from about 225 vehicles to about 575 vehicles per 5-minute interval.
- In Figure 2-20 there is a much wider range of average speeds per 5-minutes compared to those shown in Figure 2-19, with most of the paired-values being faster than the free-flowing speeds of 55 mph or more, with the remainder of the observations having slower average speeds, which are widely and somewhat evenly dispersed between about 55 mph to ones as low as 17 mph for 5-minutes.

In Figures 2-19 and 2-20 taken together there are 720 independent sets of paired-values of 5-minute volumes and average speed (5 hours, times 12 observations per hour, times 6 detectors, times 2 days). If all of those points were put on one graph and the different marker shapes and color-codes for the detectors were not shown, then the reader would find it very difficult to discern the relationships among the volumes and average speed that are there when such distinctions are accounted for. In the remainder of the analysis we do the opposite of that and highlight the similarities and differences for “paired-graphs” for the pair-values of volume and average speed for each of the six of the detectors taken one at a time and in sequence. For those paired-graphs we also “connect-the-points” sequentially in time so as to focus on the temporal as well as the spatial variations in how the paired-values of volume and average speed change over the five-hour PM peak period. Those paired-graphs demonstrate a general consistency with HCQSM findings and they are used to estimate the “tip capacity” that breaks down the flow of traffic and creates significant delays.

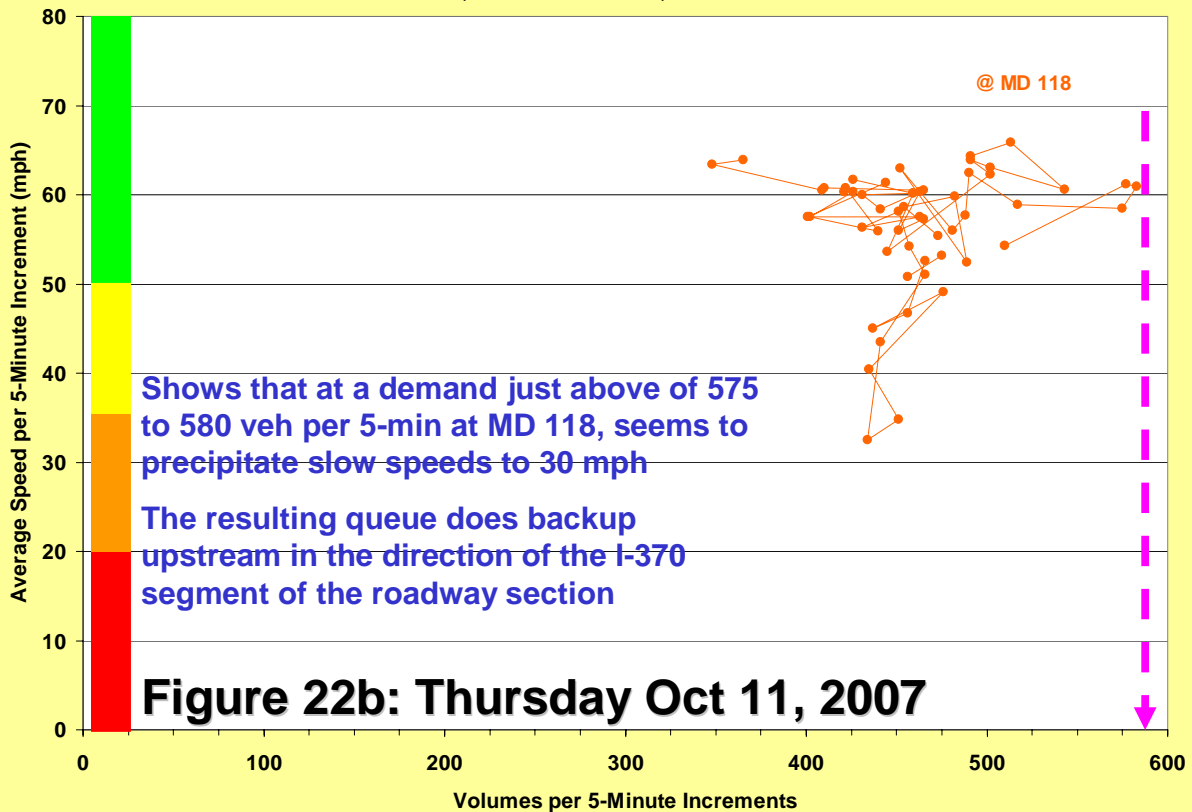
The following series of figures (Figures 21a and b through Figures 26a and b) compare the paired-values for each detector in sequence heading northbound from I-370. Text annotations are added to the figures in order to have them appear as large graphically as feasible for clarity of viewing their content. However, the pairs are kept on the same page to better enable the readers to more easily do their own comparisons between the paired-graphs and among the different paired sets, which may also help readers who may have difficulty seeing different colors. After this series of figures, Figure 27 shows six similar graphs of paired-values of five-minute volumes and average speed for Friday, 9-14-07. On that day in the afternoon and evening there was intensive “get-away congestion” along most of I-270 for many hours and each of the 6 detectors in this analysis section of I-270 operated at or near the capacity of the roadway at those locations.



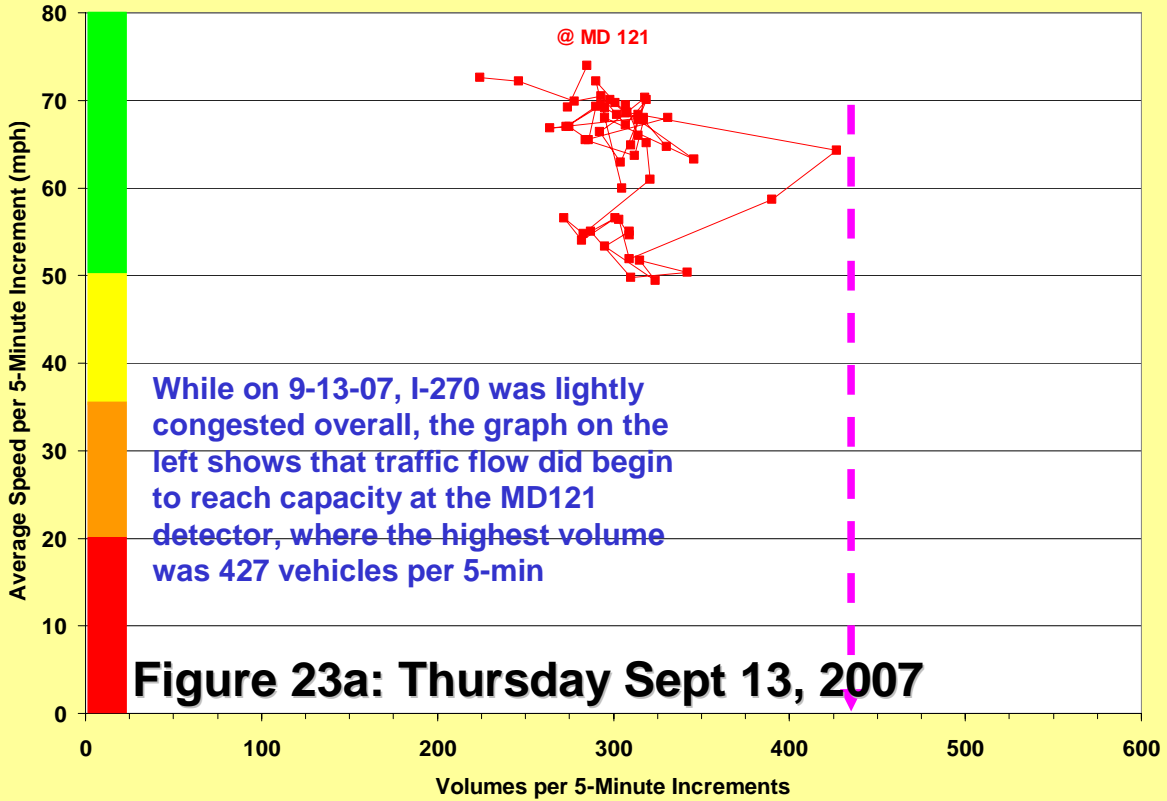
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Thu 9-13-07, for Detector @ MD118**



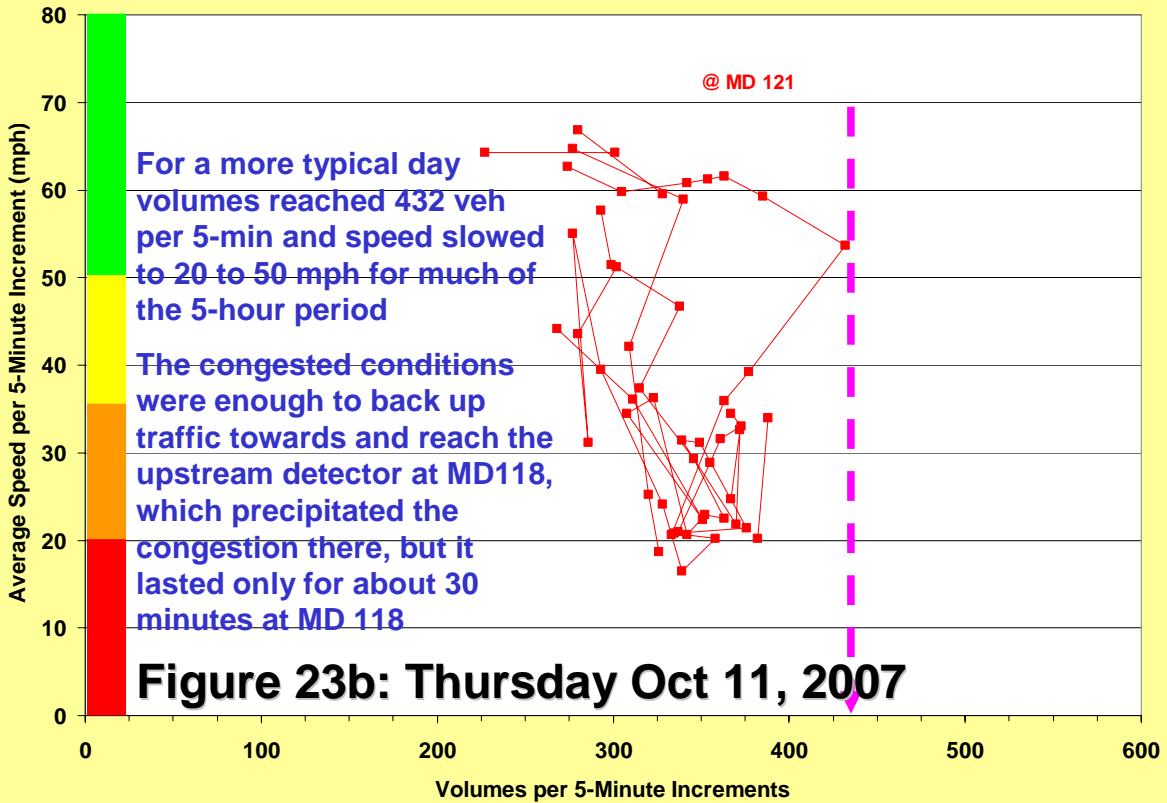
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Thu 10-11-07, for Detector @ MD118**



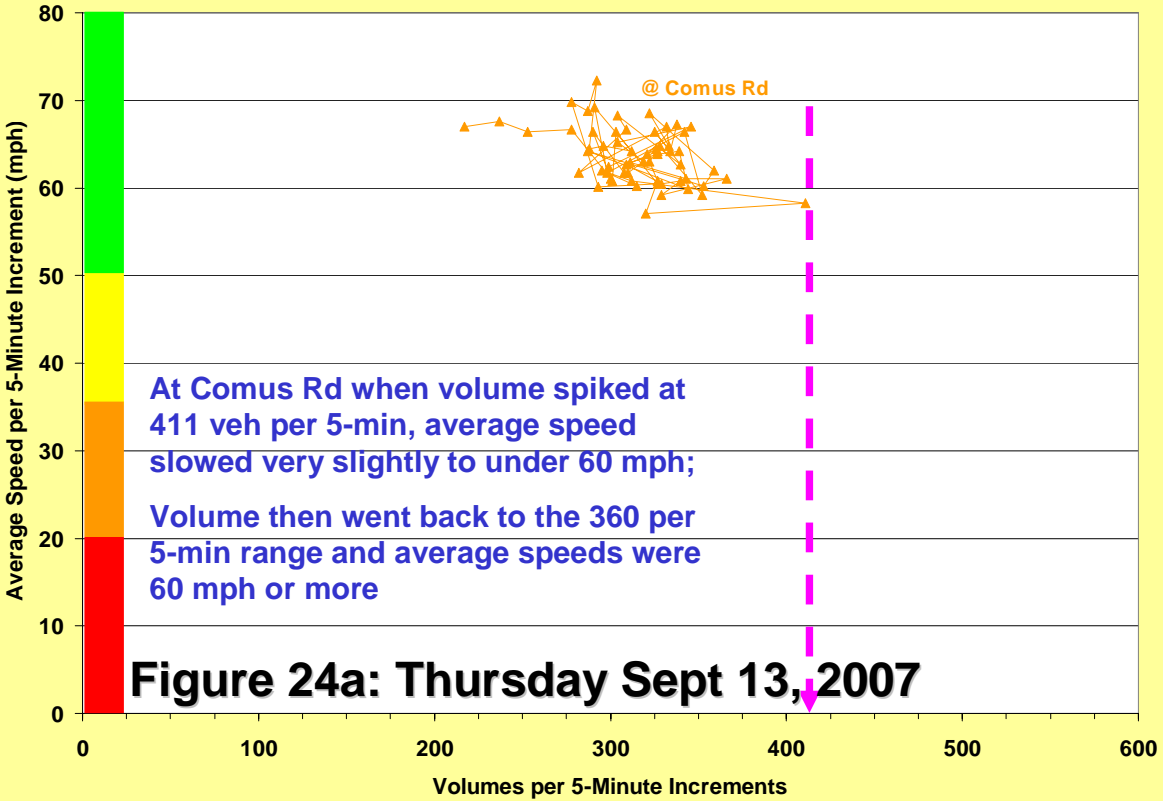
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Thu 9-13-07, for Detector @ MD121**



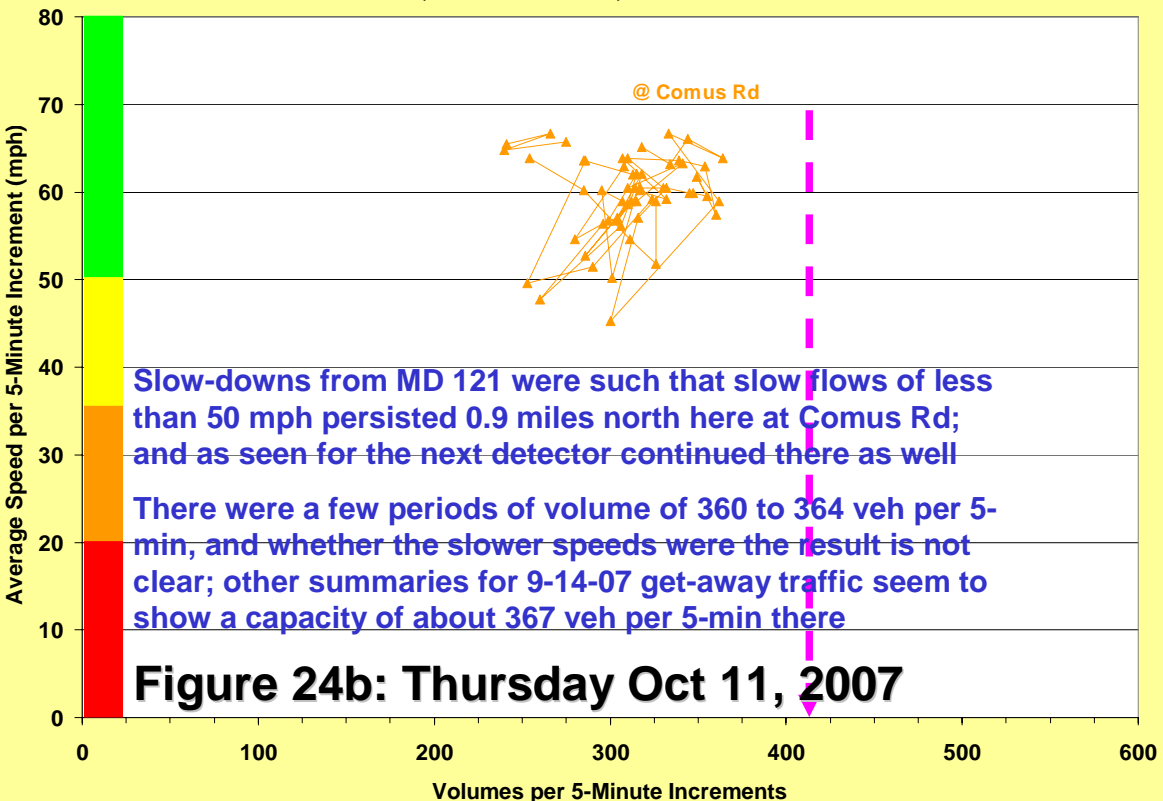
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Thu 10-11-07, for Detector @ MD121**



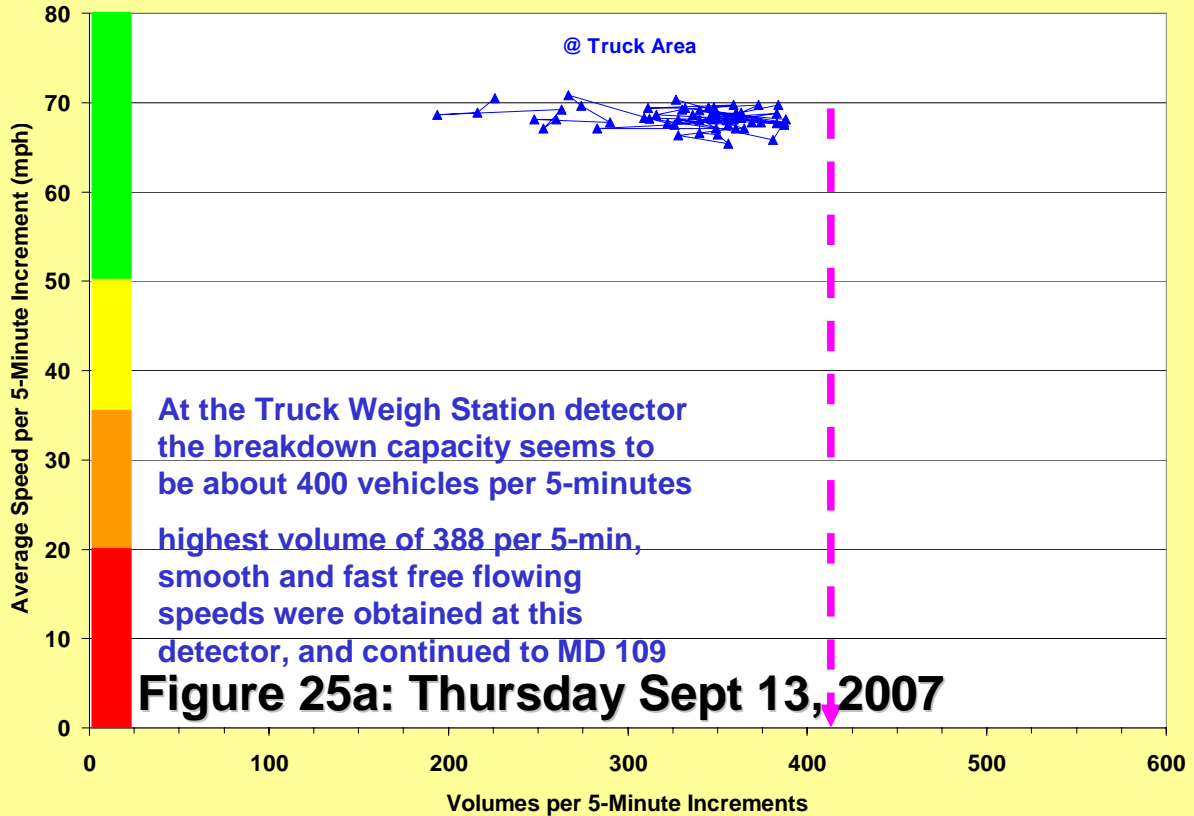
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Mon 8-06-07, for Detector @ Comus Rd**



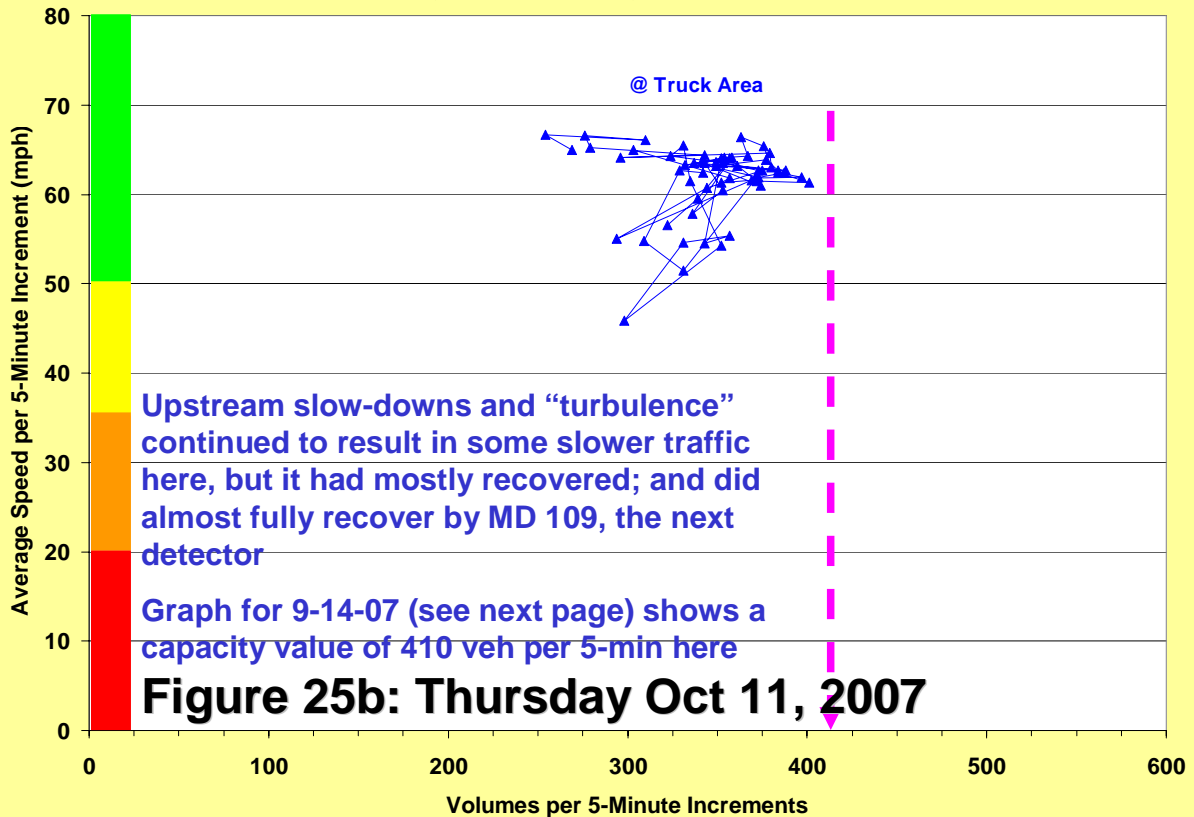
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Thu 10-11-07, for Detector @ Comus Rd**



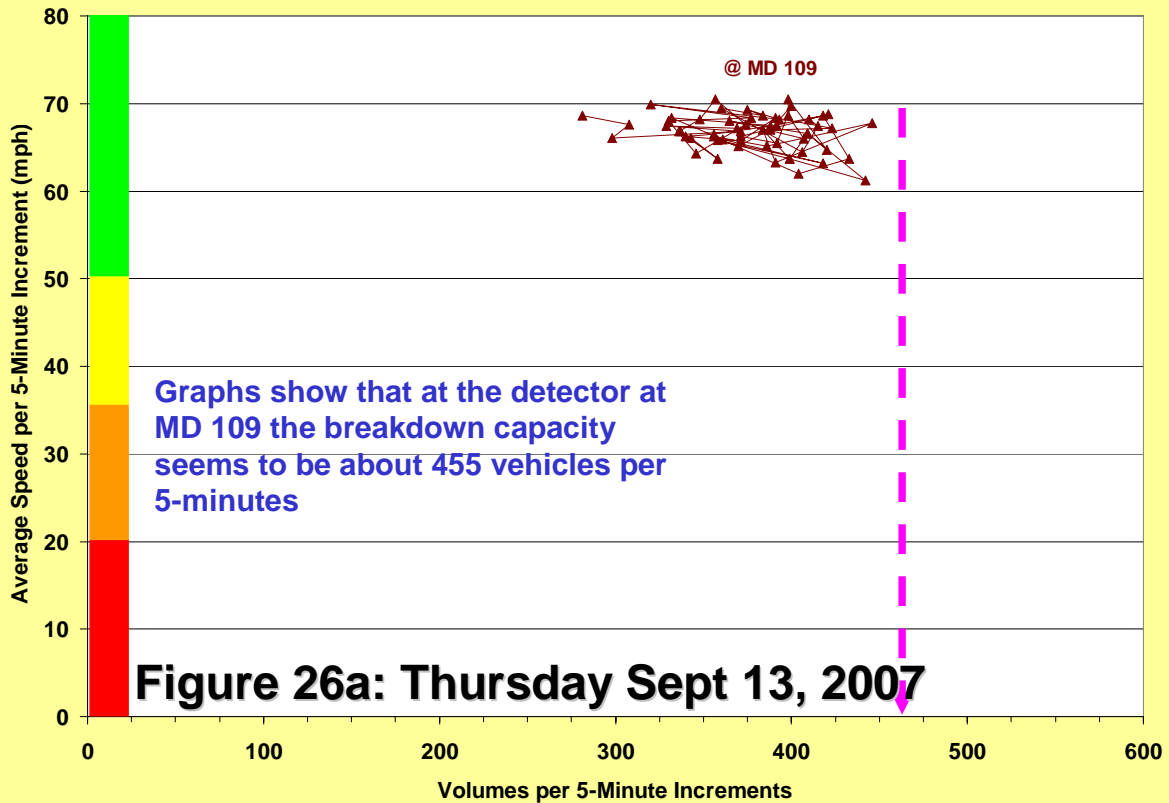
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Mon 8-06-07, for Detector @ Truck Area**



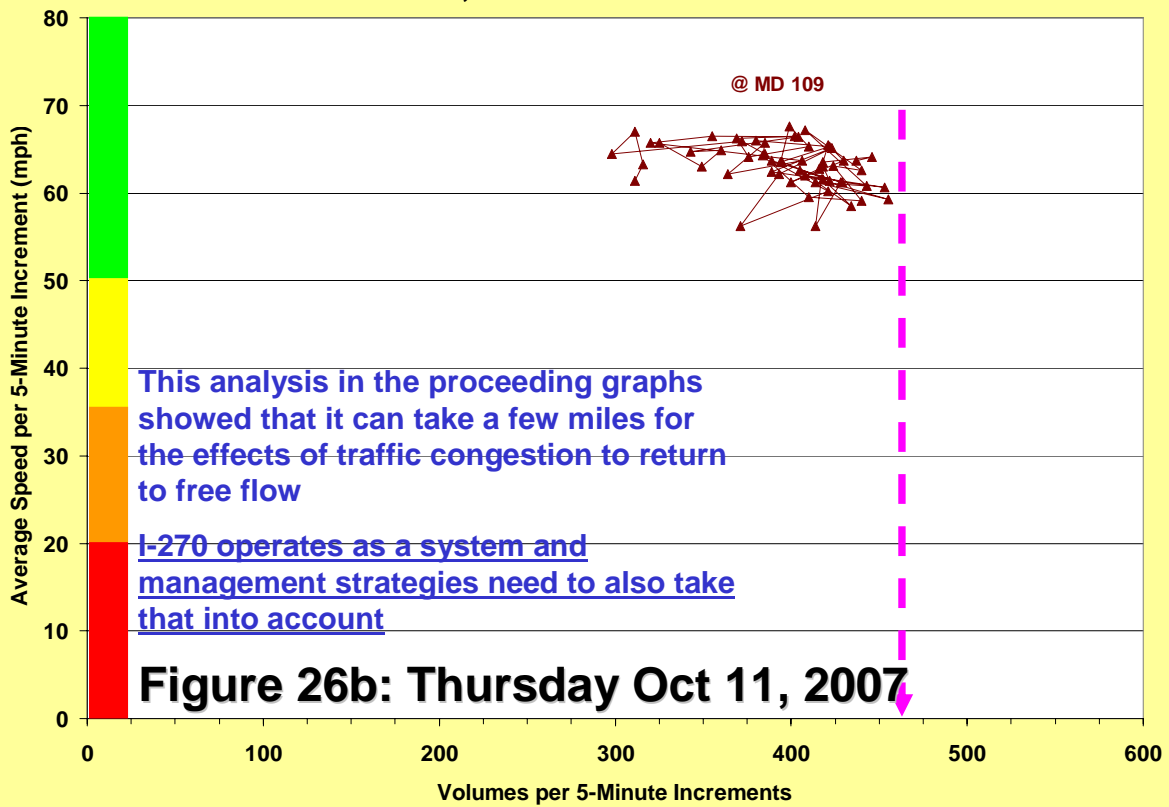
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Thu 10-11-07, for Detector @ Truck Area**



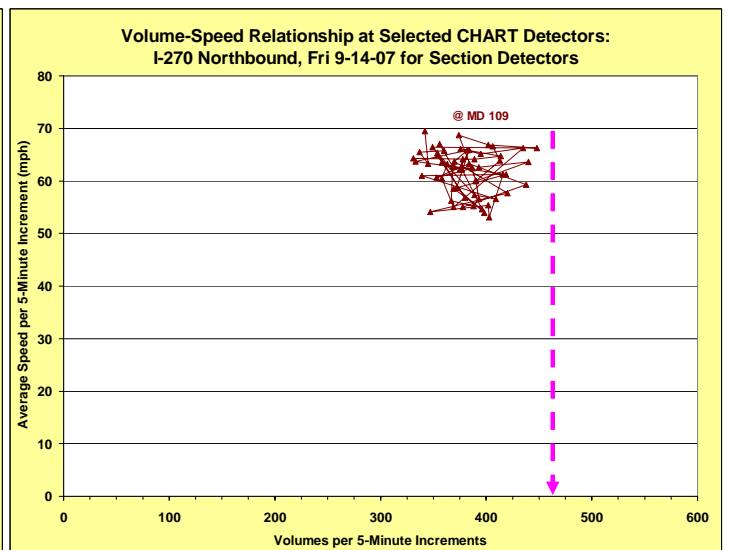
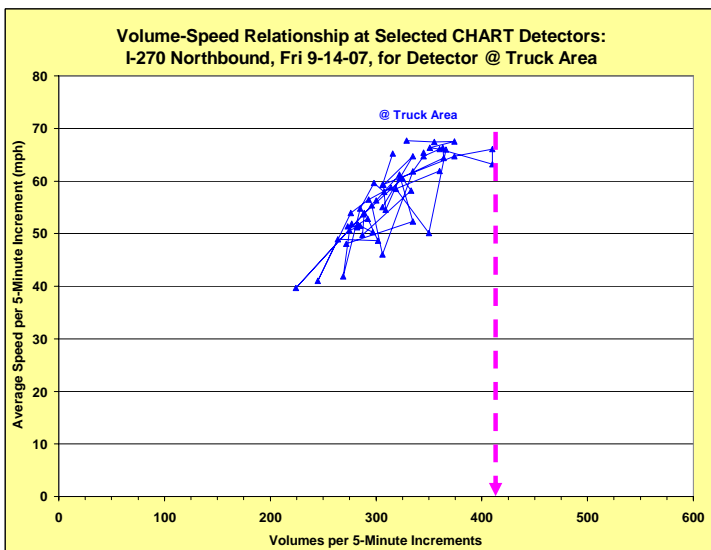
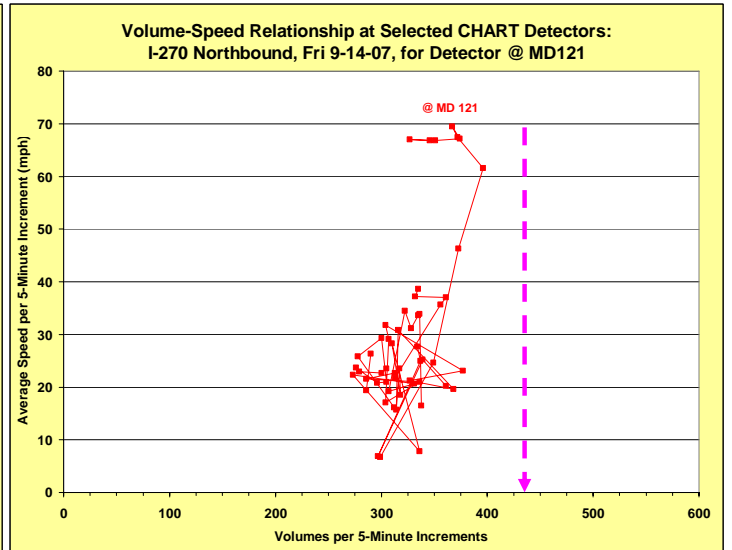
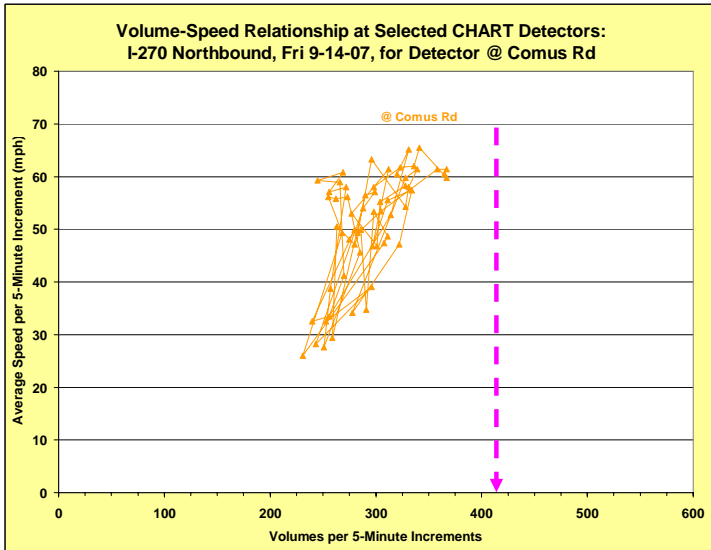
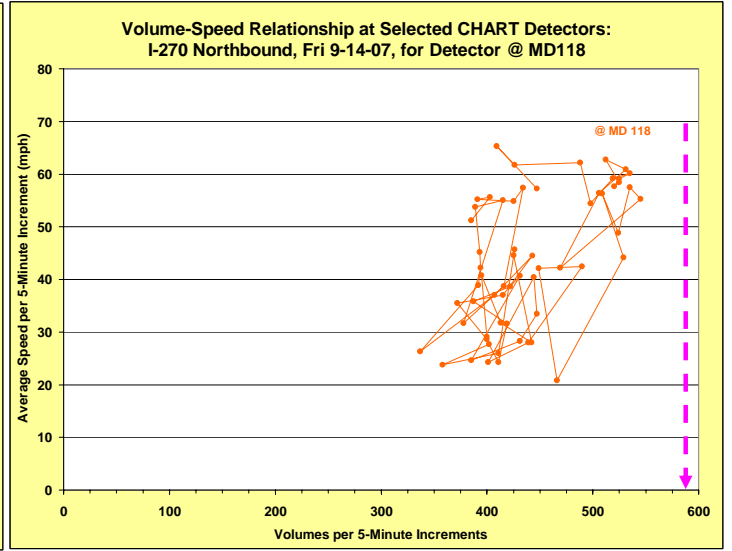
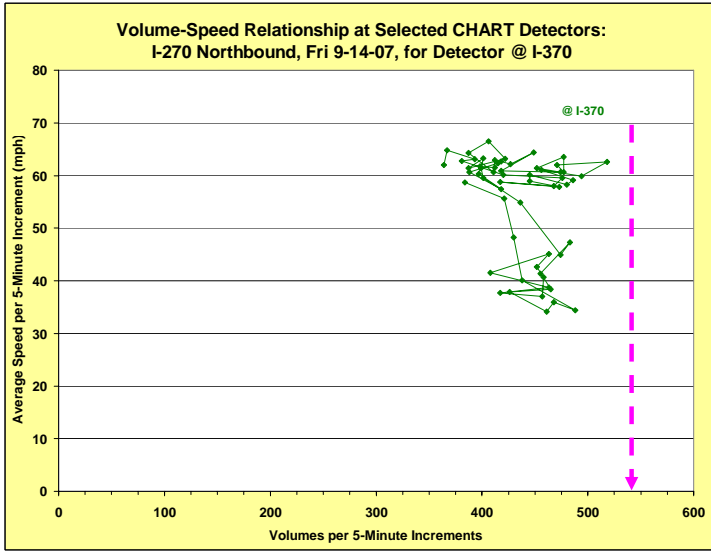
**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Thu 9-13-07 for Section Detectors**



**Volume-Speed Relationship at Selected CHART Detectors:
I-270 Northbound, Thu 10-11-07 for Section Detectors**



Figures 2-27 a thru f: Six Detector Segments at or Near Capacity on 9-14-07



- While these data sets for volume and speed pairs of six detectors of I-270 show similar patterns, from the perspective of the overall section the capacity values differ (see the set of magenta lines for specific values).
- For a demand reduction strategy, use the “weakest link” approach – which in this case is the segment near MD 121, where I-270 narrows from 3 lanes (one is a HOV) to 2 lanes.
- In summary, while it appears that the segment near MD 121 is the main capacity constraint, upstream and downstream segments also operated at or near capacity.
- Further, strategies that keep the 5-minute volumes at about 400 vehicles or less would seem to be desirable from the perspective of restoring and retaining freer flow conditions in this section of I-270.

We conclude this analysis of this section of the I-270 Corridor with a check of some of the derived capacities shown in Figure 27 (a thru f) compared to information from the HCQSM. The maximum observed flow at the MD 118 detector was about 580 vehicles, enabling the maximum flow per lane to be calculated. In that part of I-270 section there are 3 through lanes. Expanding the 5-minute volume of 580 vehicles by 12 (12 – 5 minute time periods per hour), the hourly maximum volume is about 6,960 vehicles per hour. Dividing by the 3 lanes gives a maximum volume of about 2,320 vehicles per lane per hour. This corresponds well with the HCQSM’s maximum volume of 2,400 passenger cars per lane under ideal condition. Compared to the I-95 Corridor analyzed above, the part of the I-270 data has many fewer trucks particularly during the peak period. Thus, it would be expected that the recorded maximum traffic volume is close to the theoretical HCQSM maximum flow.

The maximum observed flow at the three more northern detectors from MD 121 to MD 109 had derived capacities of about 420 to 430 vehicles per 5-minutes, enabling the maximum flow per lane to be calculated. In that part of I-270 section there are 2 through lanes. Expanding the 5-minute volume of 420 vehicles by 12 (12 – 5 minute time periods per hour), the hourly maximum volume is about 5,040 vehicles per hour. Dividing by the 2 lanes gives a maximum volume of about 2,520 vehicles per lane per hour. This is somewhat higher in value than the HCQSM’s maximum volume of 2,400 passenger cars per lane under ideal condition. However, given the relatively low percent of trucks compared to the I-95 Corridor analyzed above, particularly during the peak period and the experienced set of commuters using the roadway it may be possible that a capacity value that is about 5% higher than the theoretical HCQSM maximum flow could be found. In fact the HCQSM has reported capacities exceeding 2700 passenger cars per hour for individual lanes for short periods of time.

I-495 Corridor

I-495 Corridor: General Locations of Detectors

In addition to the I-95 and I-270 Corridors, a small part of I-495, the Capital Beltway, was also evaluated to confirm many of the traffic characteristics and speed-volume relationships discussed in the previous sections. The two previous corridors are “radials” with respect to their traffic orientation and function within the region, while I-495 serves “circumferential” traffic patterns. One question for this research is whether the radial versus circumferential orientation would result in findings and conclusion that differ from those found for the two radial corridors.

Our analysis shows that the same basic results have been found. However, the traffic demand patterns around the Beltway frequently are less continuous than those of the radial corridors, with “crisscross-flows” quickly adding or subtracting volumes. Sequential continuity of flows between adjacent detectors is not always found and as a result the detectors may not be measuring the same traffic demand composition. We think that was the case with the three detectors used here. Further, data quality issues with the volume summation for the detector at Persimmon Tree Road, resulted in it not being used as part of the analysis. Thus the analysis summarized here does differ somewhat in form and content from that presented for the prior two corridors.

The general location of the detectors used in the analysis is shown in Figure 2-28. CHART operates a limited set of traffic flow detectors along I-495 in Montgomery and Prince George’s Counties. Traffic flow detectors along the Virginia parts of the Capital Beltway have been out of service for a while and data was not available. The analysis used 5-minute summaries for total volume and average speed archived by UMD-CATT as derived from the CHART system, but only data for the flows on the “Outerloop” of I-495 are available. The southbound HOV lane of I-270 ends just prior to the merge of the I-270 Spur with the I495 Outerloop.

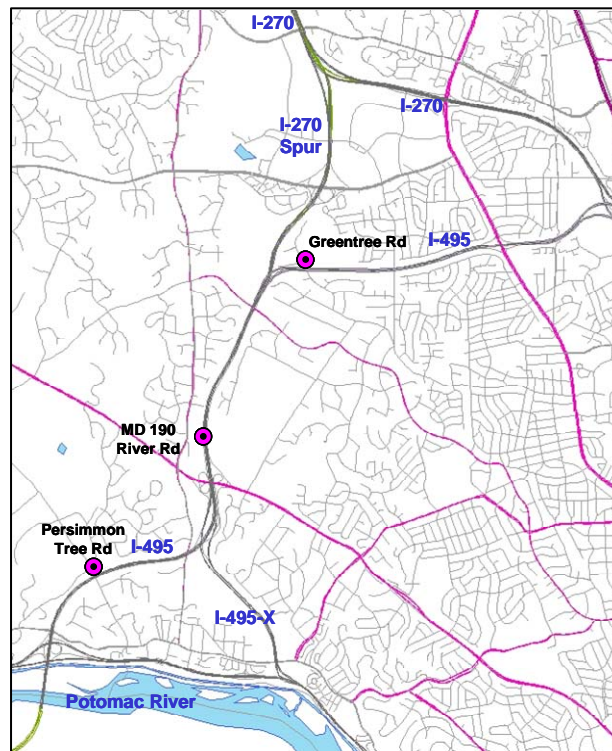


Figure 2-28: General Location of Three of the Detectors on I-495, the Capital Beltway

Traffic Characteristics

As part of the analysis, the Study Team looked at potential differences in the peaking of volume and average speed traffic flow characteristics of two detectors on the Outerloop near Greentree Rd and MD 190, River Road. Estimates of delay in the vicinity of those detectors were plotted and are shown in Figure 2-29 and 2-30, at Greentree Rd and MD 190, respectively. It should be noted that these delays were estimated in a different but similar manner to those given for the two prior corridors. Rather than estimating and using the cumulative delay for the section of the corridor as was done for the other two cases, delay for each of the two detectors was separately estimated relative to the observed free-flow average speed at each detector and assumed that speed was representative of the speed about one-half mile on either side of the detector. Thus the inverse of the average speed applied over one mile yielded an estimate of the travel time per 5-minute interval, and subtracting the free-flow travel time resulted in the delay for each 5-minute period.

One notable traffic characteristic that is different at the I-270 and I-95 locations is that of the length of the peak period. During the heavier and more normal traffic days of September and October, the duration of the peak within the peak period is about 90 minutes between about 5:30 and 7 PM, as shown in Figure 2-29. The duration of the peak within the peak period shown in Figure 2-30 is substantially longer starting about 3:30 PM and continuing until 6:30 to 7 PM. Thus strategies that account for time-of-day patterns of travel behavior will need to be prepared to function over prolonged time periods and not just be peak-hour oriented.

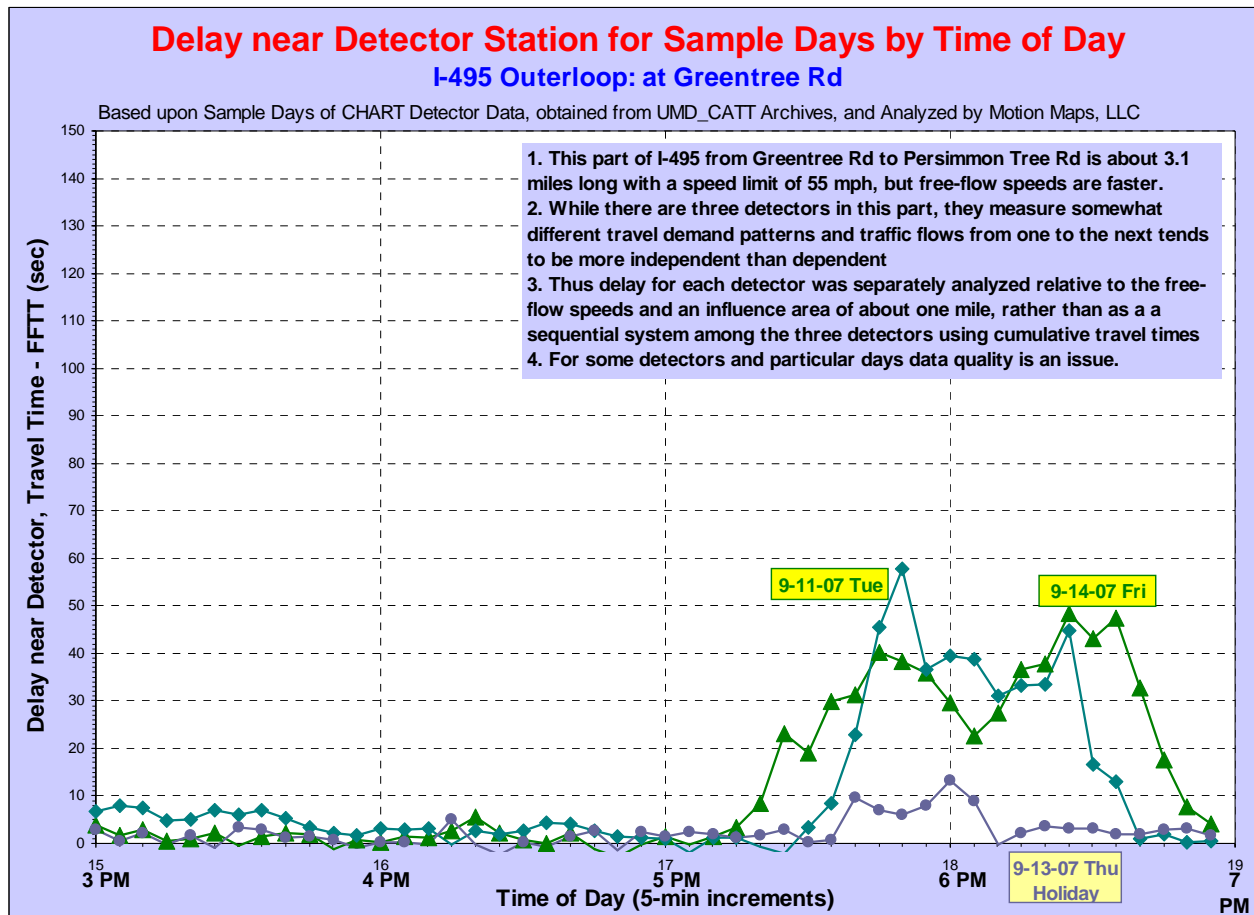


Figure 2-29: Delay by Time of Day at Greentree Rd on the Outerloop of I-495

An important aspect of these two Figures is to show that delay during the lighter traffic volume days of summer can result in the near absence of congestion and delay. The example the delay shown for Wednesday 8-8-07 given in Figure 2-30 shows that to be the case. However, for the Greentree Road detector shown in Figure 2-29, the traffic volume data at that location for the week of August 6, 2007 were questionably low and were not used. Instead one of the traffic days of mid-September, that of Thursday 9-13-07 was used as that was a day that the entire Montgomery County school system was closed due to a religious holiday resulting in a significant and systemic shift from normal traffic demands.

Indeed the two other days shown in Figure 2.29 that straddle that low-demand day, those of Tuesday 9-11-07 and Friday 9-14-07 had more normal traffic characteristics typical for that time of year. Of the days sampled for this detector in the analysis, those two other days are the ones that had the most delay at this detector. Returning to Figure 2-30, it can be seen that the delay by time-of-day for Thursday 9-13-07 was very light, being very similar to that found for Wednesday 8-8-07. Another distinguishing traffic characteristic shown in Figure 2-30 for the detector at MD 190 is that the high traffic delays for Friday 9-14-07 were not only long in duration, they were also very erratic and volatile within this time period, probably indicating that surges of different traffic flow demands were passing this location. The shape of the highest delay patterns shown in Figure 2-29 are more similar to that usually associated with a “normal distribution”, indicating that more consistent travel demands were being observed.

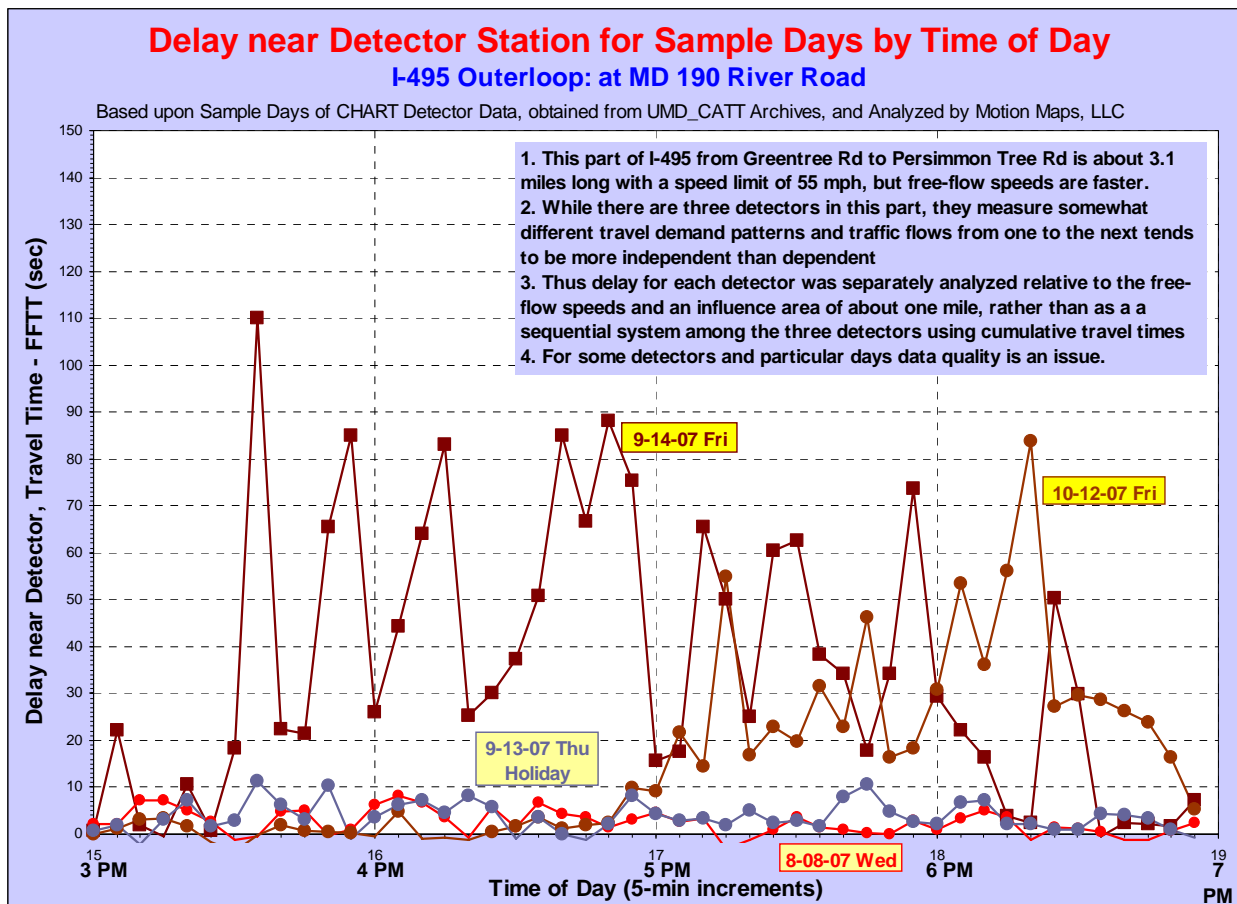


Figure 2-30: Delay by Time of Day at MD 190 (River Rd) on the Outerloop of I-495

Volume-Speed-Delay Relationships

The data set was also analyzed in detail to address the research question of:

- How much traffic needs to be taken off freeways operating at various levels of congestion to restore free flow during rush hours?

To address that question in this case the particular and similar data for other days shown in the prior two figures needed first to be “boiled-down” to one indicator of delay. The measure of average delay per 5-minute increment over the 4-hour peak period was selected as the representative indicator of delay. Thus all of the erratic and volatile ups and downs of delay for Friday 9-14-07 from Figure 2-30 above were reduced to a value of about 35 seconds of average delay per 5 minutes over the 4-hour period, as shown below in Figure 2-31. Similarly, the more normal variation of delay shown in Figure 2-29 for Friday 9-14-07 was reduced to a value of about 13 seconds of average delay over the four-hour peak period, as shown below in Figure 2-31. The other dimension of Figure 2-31 is the cumulative volume for the corresponding 4-hour peak period at each detector on the day shown.

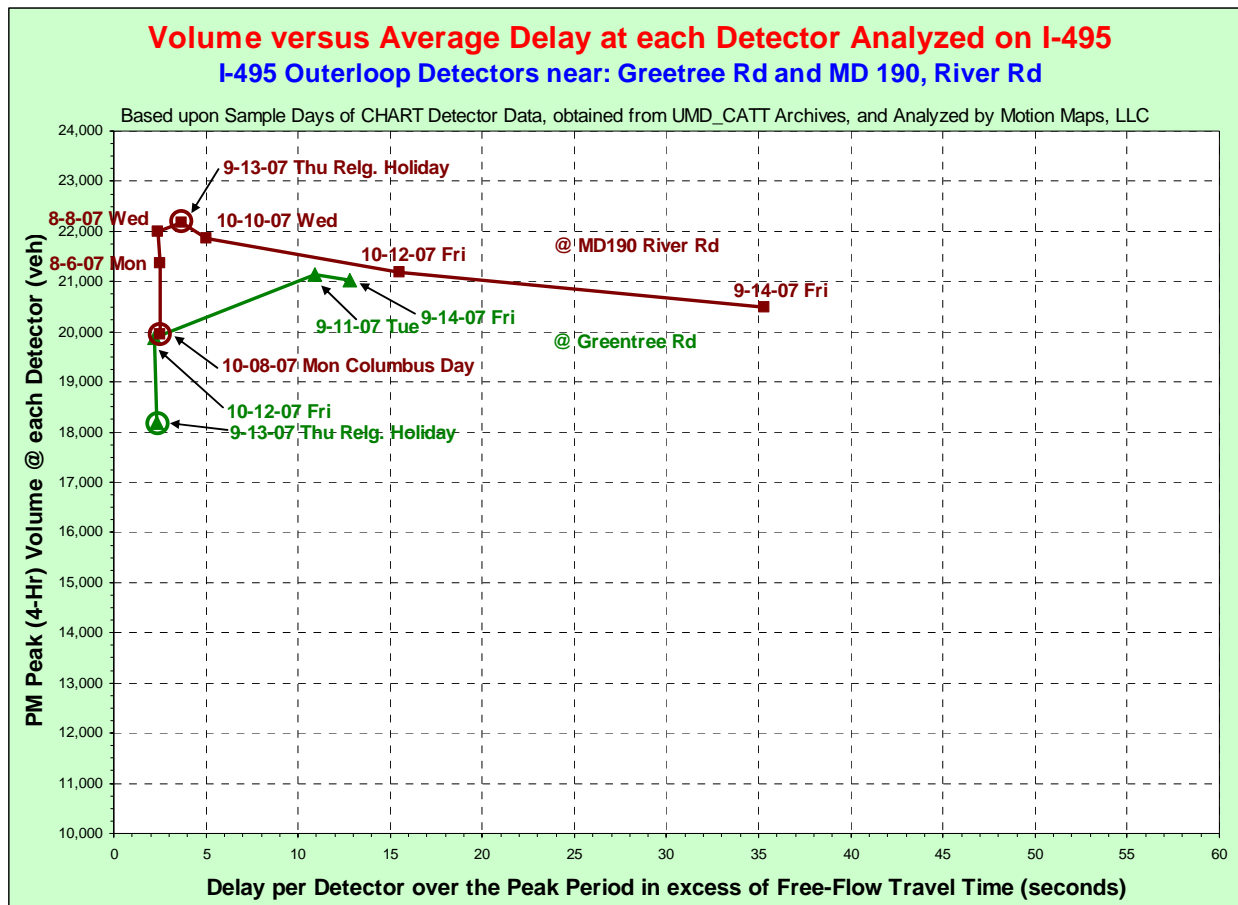


Figure 2-31: Examination of Volume – Delay Relationships for the Two I-495 Detectors

The derived information shown in Figure 2-31 indicates a similar pattern for the two detectors analyzed. Maximum flows seem to occur when the average delay is minimal – on the order of 5 to 10 seconds per 5-minute period. As the average delay increases above that range, there appears to be a reduction in total volume that is served by that part of the roadway, with reductions of about ten percent being found. However, going to the left in Figure 2-31 away from

the maximum flow, as the average delay approaches zero, there also appears to be a relatively sharp drop in total volume.

An important observation to note goes to the main premise of the research question, which assumes that the traffic volume or demand is the independent variable, while the average speed or delay is the dependent variable. That may not necessarily be the case. The findings in this and the prior two cases show that strategies that reduce demand by small, marginal amounts can result in significantly less amounts of delay or congestion. However, trying to have a goal of restoring free-flow at all times and completely reduce congestion may not be the optimum situation. Trying to manage demand so that the traffic flows are located and timed everywhere at the same time to have free-flow conditions will be extremely difficult if not near impossible from a practical sense. That is because there seems to be a feedback in the relationship between volume and delay – perhaps interdependencies.

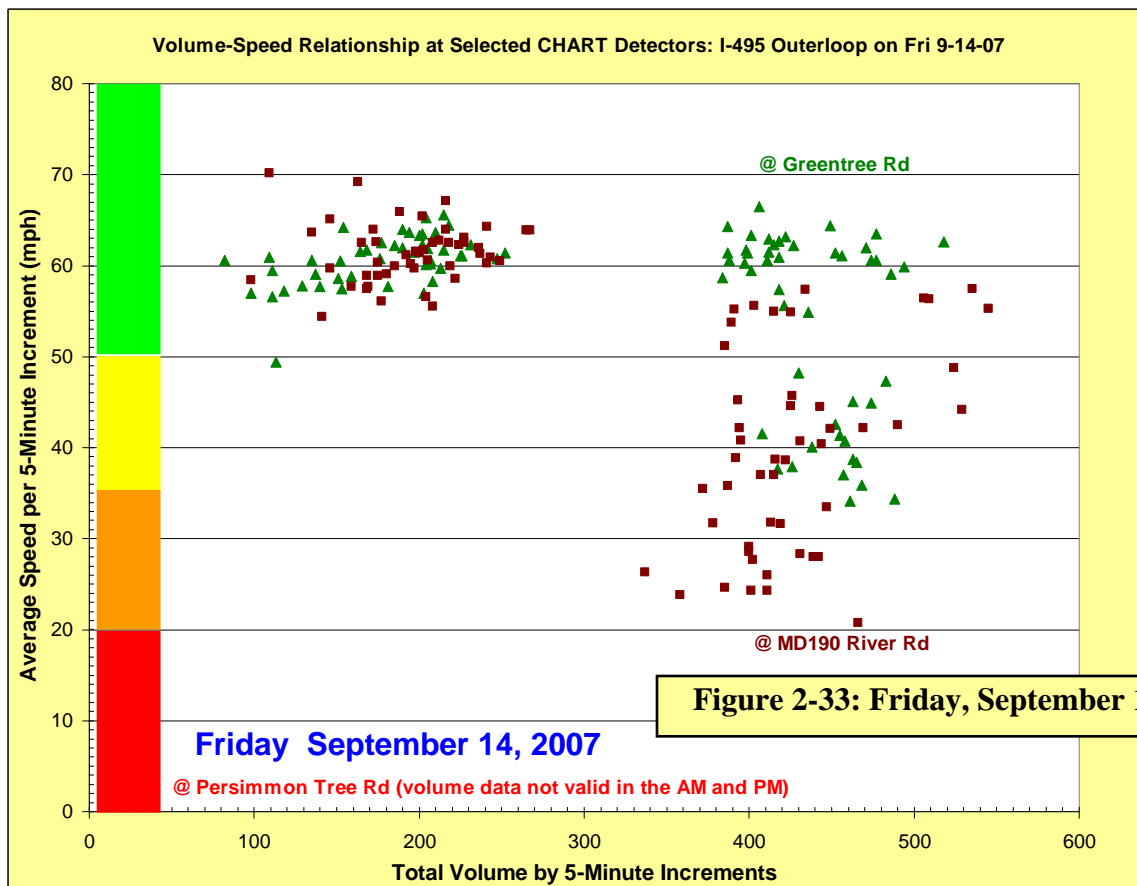
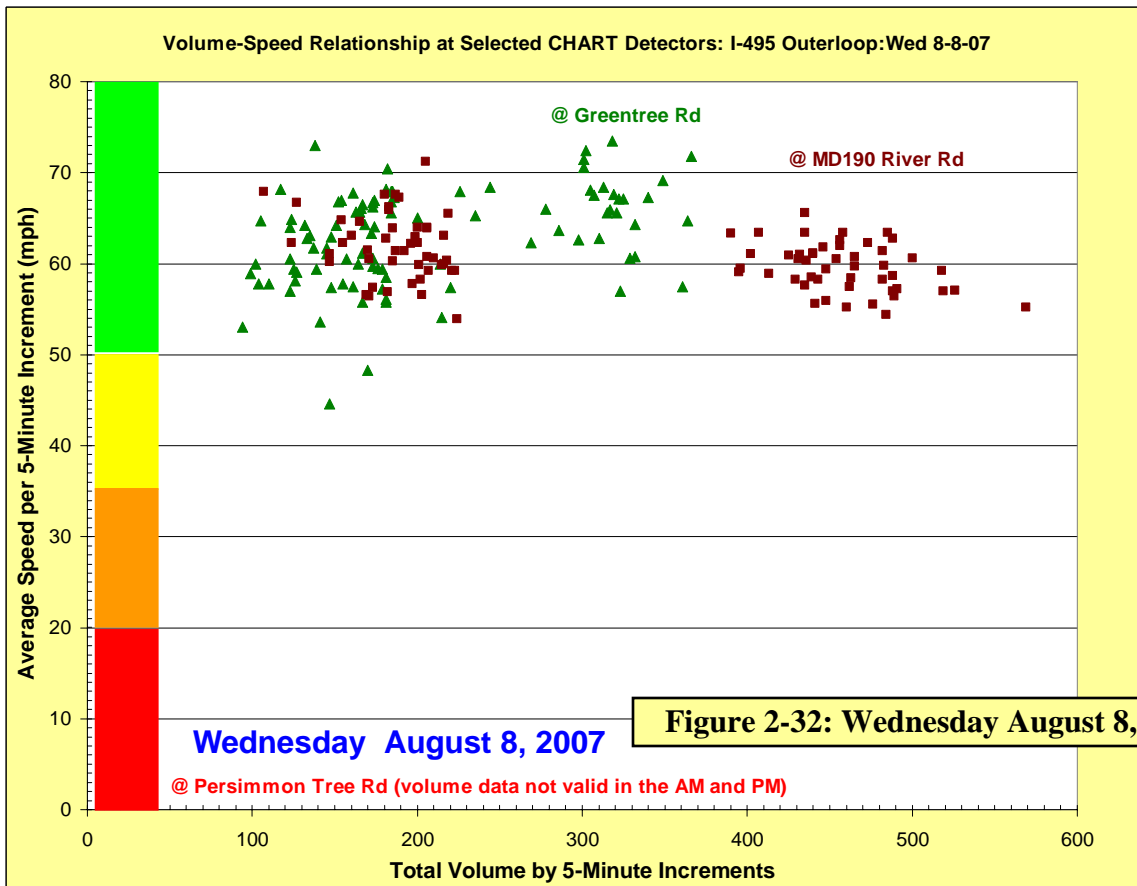
To keep flows at or near maximum during the peak of the peak requires the flow to be just upstream and ready to move onto the next part of the roadway, but without queuing or delay. However, if the managers try to avoid any delay, then being able to sustain a maximum traffic flow to pass through the next roadway segment becomes nearly impossible too – so avoidance of some minor delay will likely result in less than maximum flow or throughput of traffic. There appears to be a trade-off between minimizing delay and maximizing volume. Achieving both at the same time everywhere throughout a roadway system is truly a significant challenge. This is how we interpret the results shown in Figure 2-31.

On sample days in early August when demand is low there still tends to be some minor amount of congestion or delay, as shown in Figure 2-31 for 8-6-08 and 8-8-08 for the detector near MD 190. Even weekdays with large systemic demand reductions, the holidays of 9-13-07 and 10-08-07, still have some minor amounts of average delay. Trying to manage the demand so that the flows have no delay will likely result in under-utilized capacity – there would still be some minor amounts of delay but significant drops in throughput would likely result.

To better understand this apparent trade-off in management objectives, the next part of the analysis examined the paired-relationship between concurrent observations of volume and average speed.

In Figure 2-32 and Figure 2-33 for each Outerloop detector the paired-values of volumes (x-axis) and average speed (y-axis) per each 5-minute summary interval are plotted, respectively first for a typical day in August (8-8-07) and then for a typically congested day at another time of the year, such as in September (9-14-07). Eight hours of such data are shown in this case with the clusters of points on the left-side being for the 4-hour AM peak period of 6 to 10 AM, and the clusters in the mid and right-sides being for the 4-hour PM peak period of 3 to 7 PM. The following observations are noted based upon Figures 2-32 and 2-33:

- For the 8-8-07 sample day (Figure 2-32) the smaller volumes concurrently have typically high speeds and almost no 5-minute periods of congestion, although two observations in the AM have average speeds between 45 and 50 mph.
- For the 9-14-07 sample day (Figure 2-33) there are numerous 5-minute periods when the speeds are in the 20 to 50 mile per hour range representative of moderately congested conditions.



- For the 9-14-07 sample day (Figure 2-33) the larger values of the volume seems to have exceeded the capacities of the roadway in the vicinity of both of those detectors. Once the demand has exceeded the capacity the traffic flow breaks down; with average speeds dropping from the 55 to 60 mile per hour range to the 20-50 mile per hour range; and volume or throughput declining as well to about 350 to 500 vehicles per 5-minutes.
- The 8-8-07 Figure 2-32 does not show the breakdown in speed because the flow rates either do not exceed the capacity or they were still approaching capacity. In the subsequent steps, our analysis estimates what is the “tip capacity” that will break down the flow of traffic, create significant delays, and result in constricted flows.

So the question we need to address is: Do marginally higher volumes cause congestion? And if they do, what are the values of the higher volumes when that starts to happen?

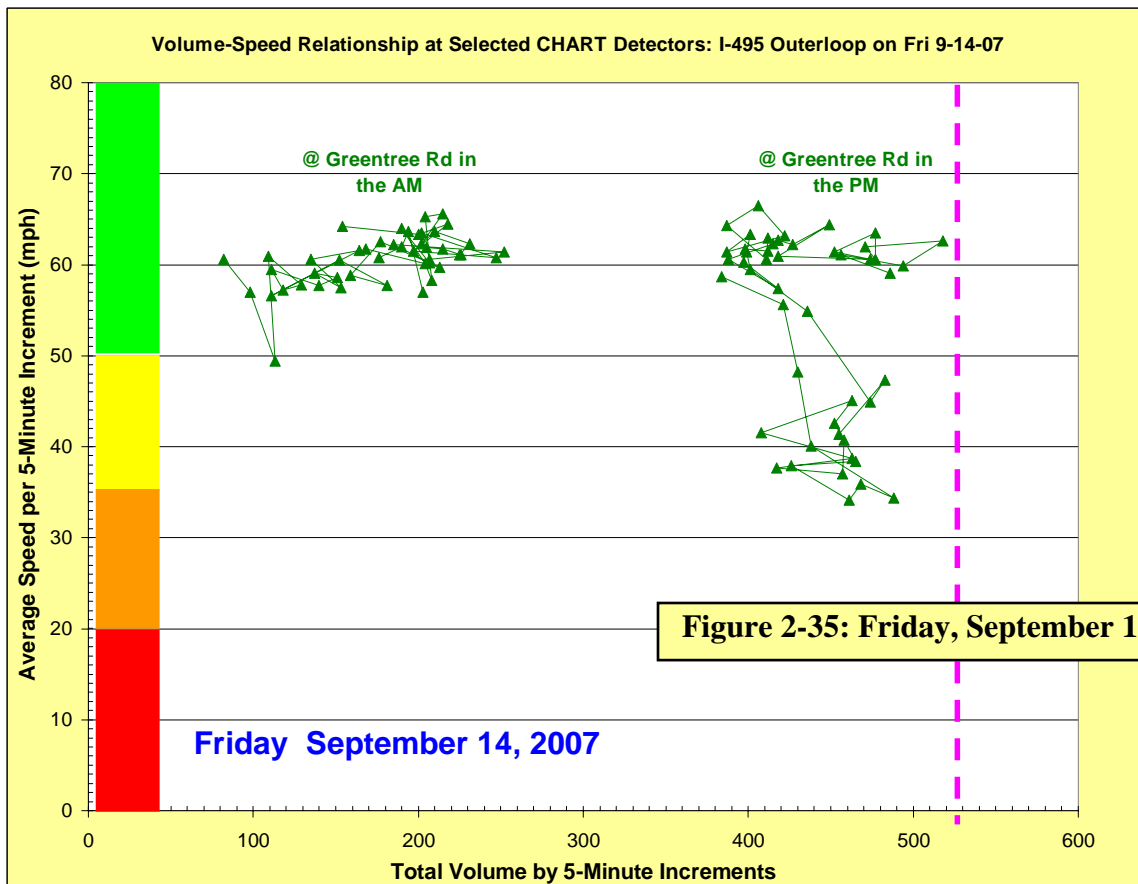
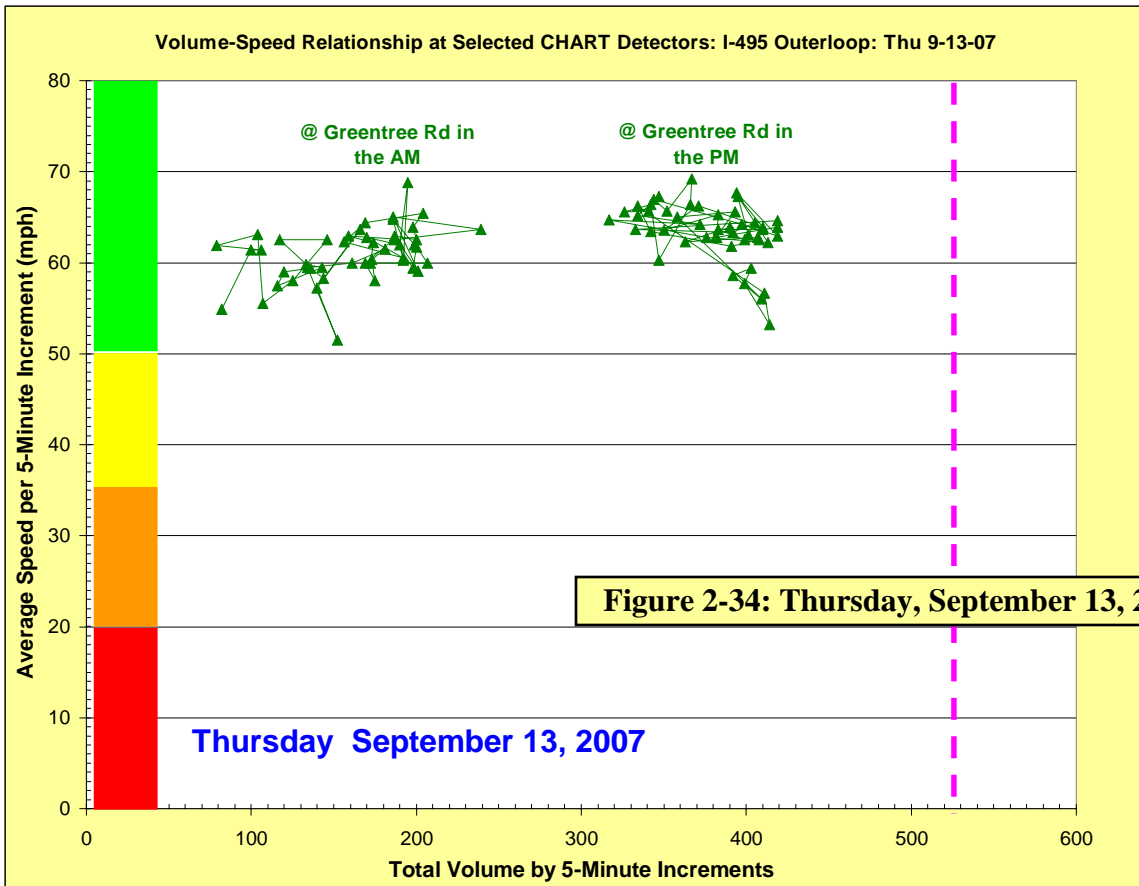
As noted in the previous Figures, higher volumes are associated with speeds beginning to slow down; and if the flow rate volumes become high enough, and begin to exceed the roadway capacity, then: (a) significantly slower speeds, congestion and delay rapidly increase at the point of observation-detection; (b) the flow rate declines significantly; and (c) queues begin to form upstream from the point of observation-detection.

In Figure 2-34 the same sets of the 5-minute volumes of I-495 for the detector near Greentree Road are plotted versus average speed with lines connecting sequential points. The low-demand weekday of 9-13-07 was used here instead of the early August sample because the PM peak period volumes for 8-8-07 were exceedingly low even for a lower volume day. (There may be some data quality issues with part of the sample for that day.) Even with using the higher demand day of 9-13-07, as shown in Figure 2-38 almost all of the paired-values had average speeds over 60 mph, five had speeds between 55 and 60 mph, and just one had a speed of about 53 mph. In essence almost the whole peak period was free-flowing.

Examining the volumes in Figure 2-34, the 5-minute volumes barely exceeded a value of 400 vehicles, which is a good deal away from the estimated 5-minute flow rate capacity of about 525 vehicles. The volumes for 9-14-07 given in Figure 2-35 have perhaps two-thirds to three-quarters of the paired-observations over the value of 400 vehicles per 5-minute period – and perhaps half of the observations having moderately congested speeds of less than 50 mph, but over 35 mph.

It is noted that in both Figures the onset of the flow breakdown seems to have begun at volumes that are closer to the value of 400 vehicles per 5-minutes. Perhaps an explanation for this apparent discrepancy stems from the roadway geometrics just downstream from the location of this detector. The roadway in the vicinity before and after the detector is on a long down-grade that about 2,000 feet past the detector enters a relatively sharp turn (for Interstate standards) after which I-495 merges with the southbound I-270 Spur. There are warning signs indicating a sharp turn ahead that can be seen from the general vicinity of the detector near Greentree Rd. Unfamiliar or overly cautious drivers may slow down even if the volumes are lighter than capacity flow rates. That could explain why at lower volumes slower speeds are seen.

Another different finding seen in Figures 2-34 and 2-35 is in both AM clusters of points where lighter volumes have slower speeds – the opposite of one of the premises of the analysis. Perhaps here too the roadway geometrics can help explain the observation if the drivers widely separated from others may actually be more observant of speed limits and warning signs.

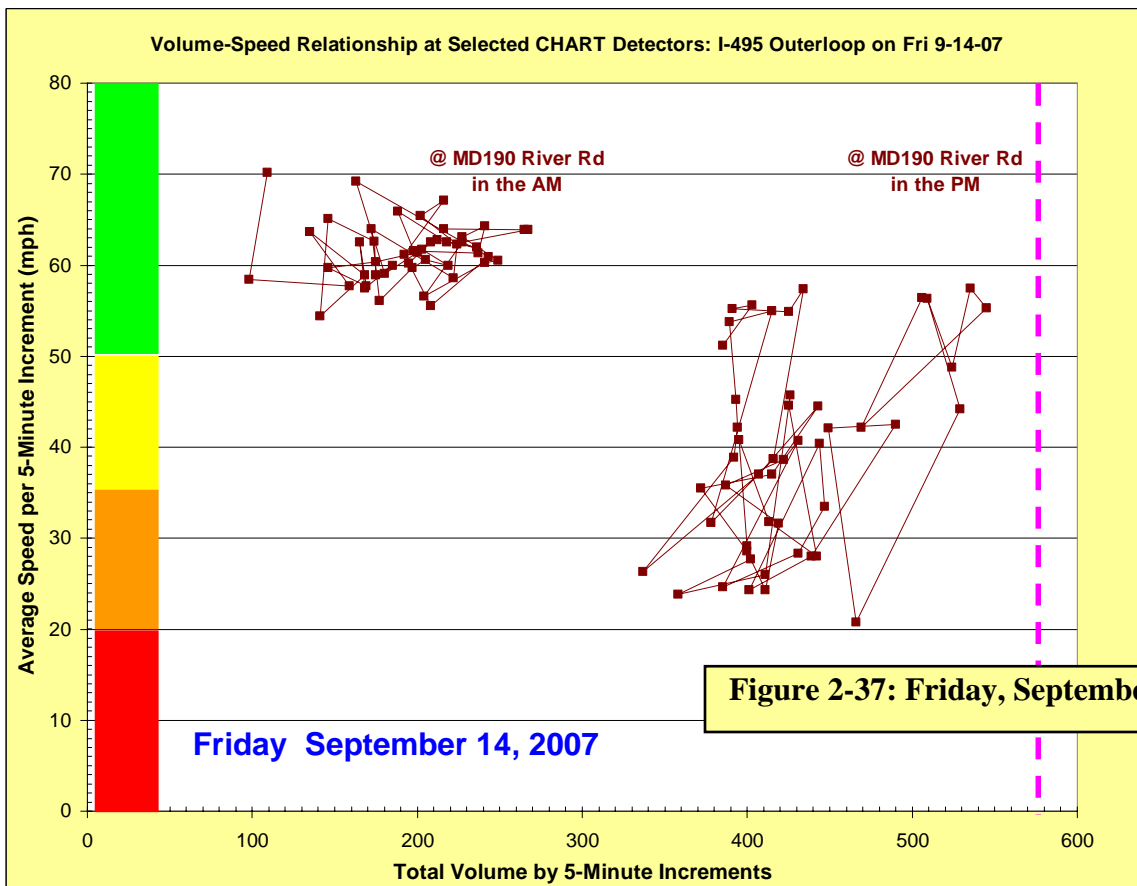
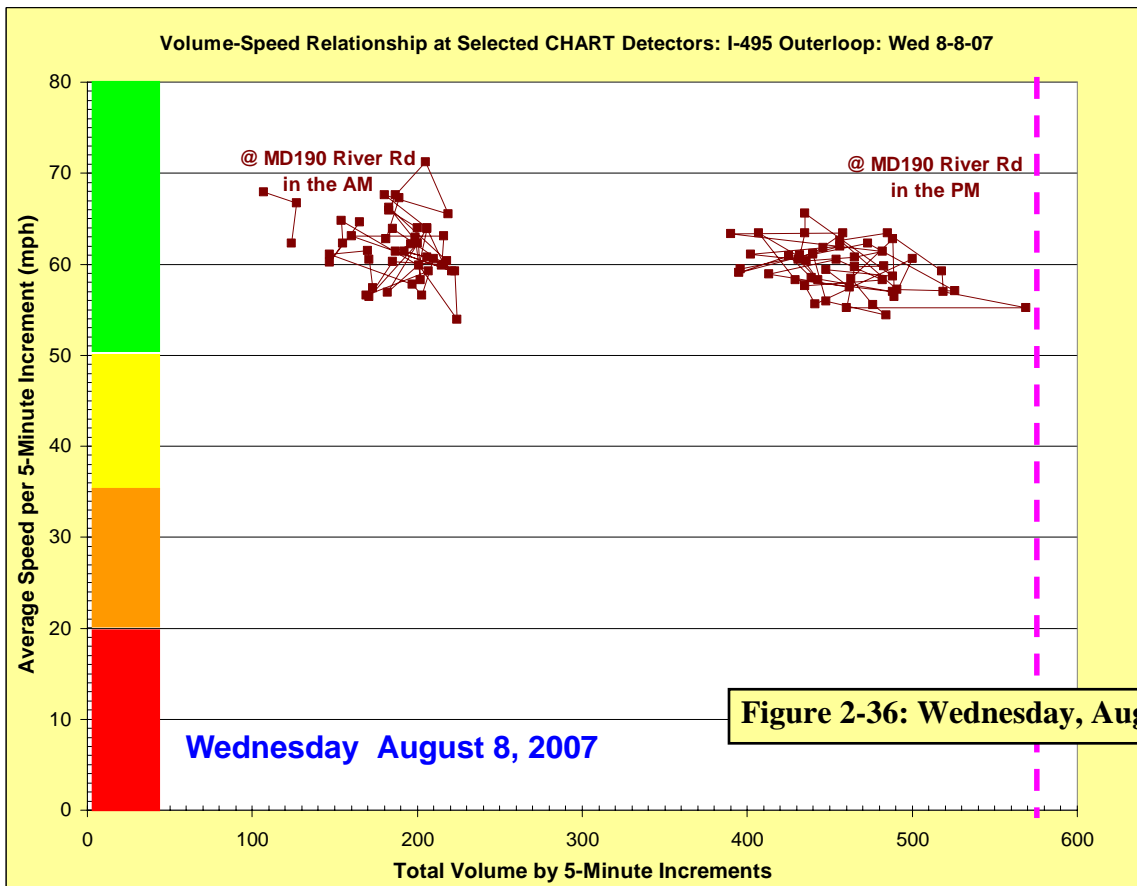


If the maximum 5-minute flow rate in the vicinity of this detector is about 525 vehicles then the maximum hourly flow per lane may be calculated. At this detector near Greentree Rd the I-495 Outerloop has 3 through lanes. Expanding the 5 minute volume of 525 vehicles by 12 (12 – 5 minute time periods per hour), the hourly maximum volume is 6,300 vehicles per hour. Dividing by 3 since there are three lanes, yields a per-lane maximum volume of 2,100 vehicles per hour. This corresponds well with the HCQSM Manual's maximum volume of 2,400 passenger cars per lane under ideal condition.

Turning the remainder of the analysis towards the other detector near MD 190, River Road, it is located just before the interchange with MD 190. Figure 2-36 shows the paired 5-minute volume and speed data for the early –August light demand conditions of the sample day of 8-8-07. Figure 2-37 shows the heavier demand sample day from other times of the year of 9-14-07. The following general observations about the volume-speed relationships at that general location are made:

- For the 8-8-07 sample day (Figure 2-36) the smaller volumes concurrently have typically high speeds with no 5-minute periods of congestion.
- For the 8-8-07 sample day (Figure 2-36) one 5-minute period has a maximum volume of about 570 vehicles, and since that demand did not persist there was not a resultant sharp drop in speeds.
- For the 9-14-07 sample day (Figure 2-37) almost the entire 4-hour PM peak period has slowing, moderately congested, and congested speeds with speeds ranging from about 20 to 55 mile per hour. Further, the wide dispersion of the points is another indicator of the erratic and volatile nature of the traffic flow that day, as was observed earlier by examining the pattern of delay by time-of-day.
- For the 9-14-07 sample day (Figure 2-37) the observed volumes fall short of the estimated capacity of about 575 vehicles per 5-minutes as the unevenness of the flow rate and speed is probably unable to sustain a ready-high-volume-flow upstream of the detector.

Regarding the capacity of the I-495 Outerloop near the MD 190 Detector, if the maximum 5-minute flow rate in the vicinity of this detector is about 575 vehicles then the maximum hourly flow per lane may be calculated. At this detector near the I-495 Outerloop effectively has three through lanes and two auxiliary lanes for traffic exiting at MD 190 and immediately after for I-495X, Clara Barton Parkway. Expanding the 5 minute volume of 575 vehicles by 12 (12 – 5 minute time periods per hour), the hourly maximum volume is 6,900 vehicles per hour. Dividing by 3 since there are effectively three lanes, yields a per-lane maximum volume of 2,300 vehicles per hour. This corresponds very well with the HCQSM Manual's maximum volume of 2,400 passenger cars per lane under ideal condition.



AM Peak Volume Analysis

Comparison of AM and PM Peak Period Volumes

The analyses presented above in the Task 2 discussion focused on evening PM peak period traffic conditions. During the review of the analysis a question was raised as to whether the seasonal reductions in volumes observed in comparing PM peak period summer-lite traffic to PM peak period traffic at other times of the year would also be the case for the AM peak period. That question was based upon the premise that is a long-standing generalization in transportation planning that, “the PM peak period tends to be much longer and more uniform in shape, while the AM peak is shorter and much more sharply peaked in its shape”.

To address this question some additional analysis, using archived detector data from RITIS at the UMD CATT Lab, was carried out that examined the volume data for one detector on I-95 at Cherry Hill Rd and one detector on I-270 at MD 118, Germantown Road. Peak direction volumes for a four-hour AM peak period of 6 AM to 10 AM and a four-hour PM peak period of 3 PM to 7 PM in the opposing direction were summarized for selected days that were used in the prior analyses. The tabulation of that information for the Cherry Hill Road detector and the MD 118, Germantown Road detector is given below in Figures 2-38a and 2-38b, respectively. The tables identify the particular days that were selected for this analysis including: their date, day-of-the-week, and whether there were special conditions.

I-95 Detector at			Cherry Hill Rd	
Date (YYMMDD)	Day-of- the-Week	Special Conditions	4-Hour Volume in the	
			AM Peak	PM Peak
070801	Wednesday		25,567	29,047
070802	Thursday		26,456	27,966
071008	Monday	Columbus Day	21,396	25,402
071011	Thursday		24,750	27,883

Figure 2-38a: AM and PM Peak Period, Peak Direction Volumes: I-95 and Cherry Hill Rd.

I-270 Detector at			MD 118 Germantown Rd	
Date (YYMMDD)	Day-of- the-Week	Special Conditions	4-Hour Volume in the	
			AM Peak	PM Peak
070806	Monday		17,882	21,374
070813	Monday		18,321	21,781
070913	Thursday	Relig. Holiday	17,293	22,188
070914	Friday		17,962	20,500
071008	Monday	Columbus Day	15,547	19,954
071011	Thursday		18,605	22,281
071012	Friday	Incident in AM	15,252	21,180

Figure 2-38b: AM and PM Peak Period, Peak Direction Volumes at I-270 and MD 118

Figure 2-39 is a graph that plots and compares the AM versus the PM data from the two previous Figures. The AM peak volume scale is on the vertical axis, with the PM peak volume scale on the horizontal axis. The blue diagonal indicates the center point where data points would lie if there were equal volumes in the AM and the PM peak. This shows that in all cases the AM peak period peak direction volumes are less than the corresponding PM peak period peak opposing direction volumes for that same day. In the graph the days that were summer-lite days are

marked with a circle around their data points, and the days that had special conditions are marked with a square around their data points. A generalization from the pattern shown in the graph for the limited number of days analyzed for these two locations is that there seems to be a relatively consistent relationship between the AM peak period peak direction volumes and the PM peak period opposing direction volumes for the same day that do not appear to differ much for: (a) the summer-lite days compared to the more normal traffic days at other times of the year, nor (b) the special days with light traffic compared to the more normal traffic days at other times of the year.

We thus conclude this additional analysis with the finding that the AM peak period peak direction volumes are about 80 to 85 percent of the PM peak period opposing direction volumes as a first approximation, although on any given day that range could be a somewhat smaller or larger percentage. That implies that the AM-oriented strategies of travel demand reductions may need shorter durations than during the afternoon peak period in order to have reduced delays. It is important to note that during the morning peak period significant congestion is experienced.⁴ The congestion however does not have as long a duration as the afternoon peak. But just as it is the case in the afternoon, a 10 to 14% drop in the morning peak volume will reduce delay. However, the reduction needed will only apply to that portion of the morning peak period that is congested.

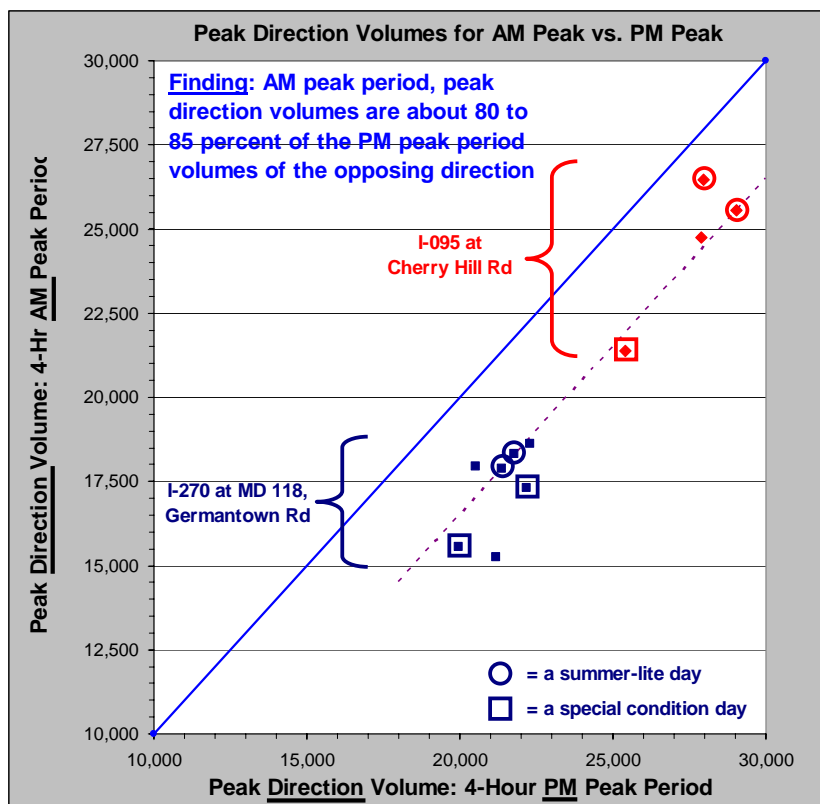


Figure 2-39: AM and PM Peak Period Peak Direction Volumes on I-95 and I-270

⁴ Although AM Peak 4-hour volumes are 15 to 20 percent lower than PM Peak volumes, drivers do experience congestion and delay in the AM Peak, although it may be more peaked or of shorter duration than congestion in the PM Peak. A full analysis of bottlenecks and series of data, comparable to that performed for the PM Peak, would be required to establish “why” and “where” there is AM Peak delay, and “how much” is there, in order to define comparable volume reduction targets for the AM Peak as for the PM Peak.

What Does This All Mean?

The analysis for these sections of I-95, I-270 and I-495 has demonstrated that there are clearly many places where the capacity of those parts of the roadways can be reached and exceeded. When that starts to happen there are relatively quick, sharp and prolonged drops in speed and a decrease in throughput of the traffic flow. It can sometimes take a considerable amount of time until the upstream volumes and demand decline enough to enable the roadway operating at reduced performance to once again have flows that can get back to freer flowing speed.

We also have seen examples in the analysis where the reduced roadway performance propagates or flows downstream from the constriction locations. We have seen that the turbulence in flow that occurs at the bottlenecks does not always clear up just after vehicles pass that point. Many drivers may still be driving cautiously while others are impatient so that in the mix of traffic there can be speed-ups and slow-downs taking place somewhat simultaneously until the vehicle density spreads out enough to absorb the fluctuations in flow. Then the cautious drivers begin to drive at freer flowing speeds and the whole flow itself tends to operate without congested conditions.

In conclusion, a main finding of this Study has been that if relatively small changes can be made in peak demand (volume) through various programs and strategies, such as congestion pricing, then two beneficial things can happen: (1) there can be relatively large decreases in congestion and delay at key choke points, and (2) there can be increased through-put along those roads during peak times of travel – thus by effectively managing the demand more travelers can be served per time period with the available fixed-supply of roadway capacity.

The analysis has shown that in many instances the amount of needed demand reduction can be on the order of five to ten percent of the peak period flow. However, there still may be a particularly difficult bottleneck in a corridor that would need reductions on the order of 15 to 20 percent. While demand reduction and operational strategies may be able go a long way in improving the flow at those locations so that capacity is exceeded less often and/or recovery is quicker, there still may need to be localized geometric or lane use changes at those locations to routinely have freer flowing traffic at those troublesome locations.

Based on our analysis we now have the information and data available to estimate the delay reduction associated with traffic reduction.

Summary Traffic Analysis

The review and evaluation of traffic data on the Washington DC Interstate System has provided a clear picture of the relationship between traffic flow, speed, and delay. All three highway sections on I-95, I-270, and I-495 showed similar traffic flow characteristics. In fact, there were no differences in the relationship between flow, speed, and delay whether the facility was a radial or circumferential freeway. And the traffic flow relationships from the field data validated both the maximum per lane capacity and the operational flow during congestion.

The recorded maximum capacities in all three sections ranged approximately between 2100 and 2400 vehicles per hour. These values compare quite well with the Highway Capacity and Quality of Service Manual (HCQSM) speed – flow curves as shown in Figure 2-40.

EXHIBIT 23-3. SPEED-FLOW CURVES AND LOS FOR BASIC FREEWAY SEGMENTS

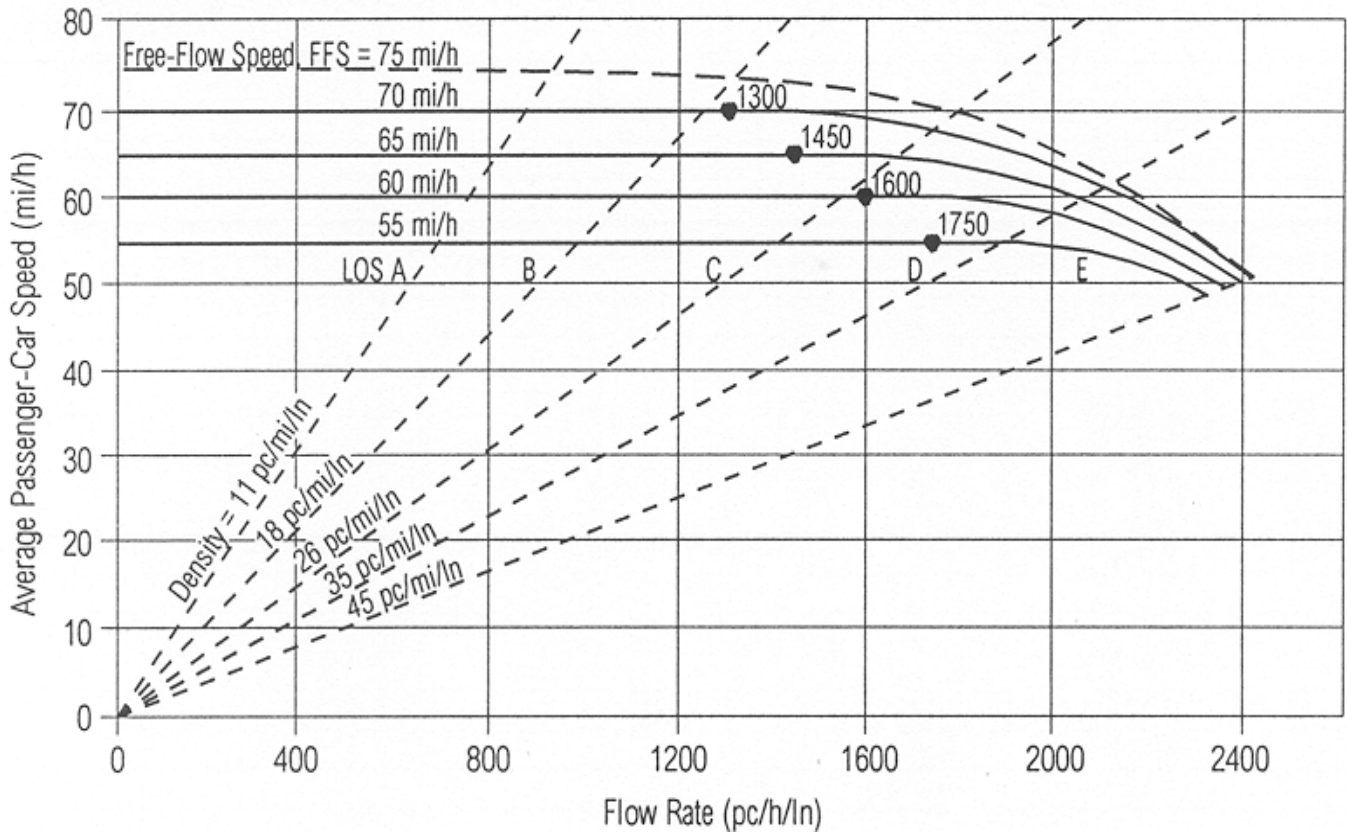


Figure 2-40: Speed Flow Density Curve from the Highway Capacity and Quality of Service Manual

In the Speed Flow Density Curve, the maximum flow rates are in passenger cars per lane per hour. The Congestion Delay Study results are in vehicles per lane per hour. If the Study's capacity results were adjusted for heavy vehicles, and geometric conditions such as interchange spacing and traffic friction at the ramps and weaving sections, the maximum capacities would be even closer to the HCQSM Speed Flow Density Curves.

It should also be noted that Figure 2-40 (HCQSM Exhibit 23-3 – Speed Flow Density Curve) is a discontinuous curve. In other words, if the demand on the freeway system exceeds the maximum capacity (in this case 2400 passenger per hour), then the flow breaks down, speeds drop to the 20 to 40 mile per hour range and the capacities are reduced to approximately 2000 passenger cars per lane per hour. Based on the field data this is exactly what occurred in all three sections that were analyzed in the study.

Having verified the speed-flow-delay relationship, the reduction in delay due to a reduction in traffic flow or the shifting of traffic from the peak period may be estimated. As part of the study,

traffic volume, speed, and delays in August and during holidays was evaluated and compared to the volume, speed, and delays in October when the traffic was heavier. Therefore the reduction in delay if modest reductions in volume occur may be estimated. What follows is an estimate of the potential delay reduction that may result if volumes are reduced.

I-95 Section Delay Analysis – I-95 Northbound from Brooklyn Bridge Road to Montgomery Road

Based on Figure 2-2 and Figure 2-3 for the 4 hour afternoon peak period that was analyzed the delay for the comparatively light travel days in August was estimated to be an average of **40** seconds per vehicle. During October, with heavier traffic flows the delay was estimated to be about **150** seconds per vehicle. As noted earlier in the report delay is calculated by taking the time difference between driving the 10.5 mile section of roadway at 65 miles an hour versus the time it would take to drive the section at the congested speed. Therefore the travel time would be:

Free flow travel time for 10.5 miles at 65 miles per hour = 570 SECONDS
 October Congested travel time for 10.5 miles at congested speed = 720 SECONDS
 August Congested travel time for 10.5 miles at congested speed = 610 SECONDS

The estimated congested travel times are the average over the 4 hour afternoon peak period. Individual afternoon peak hours will have significantly higher and lower delays.

The next step in the analysis is to estimate the vehicle hours of delay for the typical days selected in August and October.

On a typical day approximately 25,000 vehicles traverse the I-95 study section. The difference between average delay in August versus October is **110** seconds (150 – 40).

Therefore:

Vehicle Hours of Delay = $\frac{25,000 \text{ peak period vehicles} \times 110 \text{ seconds of delay}}{3,600 \text{ seconds per hour}}$
 = **764** Vehicle Hours of Delay

If the average vehicle occupancy rate for all trip purposes in the Washington, DC area is 1.2 then the person hours of delay is **920** hours. A typical driver values their time at 1/3 to 1/2 of their hourly wages. If each person values their time at \$15 per hour then the delay on this one 10.5 mile section of I-95 is costing **\$13,800** per afternoon peak period (920 X \$15/hour). If converted to a yearly cost, the delay cost would be **\$3,450,000** (\$13,800 X 250 working days).

This can also be expressed as a delay cost / vehicle mile which would be:

Delay Cost / Vehicle Mile = $\frac{\$13,800}{25,000 \text{ vehicles} \times 10.5 \text{ miles}}$ = **5.27** cents/vehicle mile

Percent Reductions in Traffic and Delay

In October it takes an extra 150 seconds to traverse the I-95 10.5 mile study section. In August during light traffic it takes an extra 40 seconds. Therefore if we reduce our traffic below the tipping point of congestion then the percentage reduction of delay would be:

Percent Delay Reduction = $\frac{150-40}{150}$ = **73 %**

In order to get this reduction in the I-95 corridor we would need a drop in the traffic from 25,000 vehicles during the afternoon peak to 22,000. This is a traffic reduction of 12% and corresponds to the average traffic difference between August and October. A **12%** traffic reduction would result in a **73%** reduction in delay.

Analysis of the Peak Hour of the Afternoon Peak Period

During the peak hour in the afternoon peak period, the traffic flow is approximately 8,000 vehicles versus 25,000 vehicles during the entire afternoon peak period. From Figure 2.1 the average delay on the I-95 study section during the peak hour is 350 seconds. With no congestion the sections travel time is 570 seconds and with peak hour congestion it is 920 seconds. By reducing the demand by 12% (typical traffic reduction for August versus October) to 7400 vehicles during the peak hour there would be a significant percent delay reduction as the following calculations will show:

$$\begin{aligned} \text{Percent Delay Reduction} &= \frac{350 \text{ Seconds}(\text{October Delay}) - 40 \text{ Seconds}(\text{August Delay})}{350 \text{ Seconds}} \\ &= \mathbf{89 \%} \text{ Delay Reduction} \end{aligned}$$

By reducing demand **12%** we can achieve a delay reduction of **89%**.

The cost savings to the individual vehicle on a per mile basis would be:

$$\begin{aligned} \text{Peak Hour Delay Savings} &= \frac{8000 \text{ Vehicles Peak Hour} \times 310 \text{ seconds Delay Reduction}}{3600 \text{ Seconds}} \\ &= \mathbf{690} \text{ Vehicle Hours of Delay Reduction} \end{aligned}$$

$$\text{Delay Savings} = 690 \text{ Vehicle Hours} \times 1.2 \text{ Vehicle Occupancy} \times \$15 \text{ VOT} = \$12,400$$

Note: VOT = Hourly Value of Time

$$\text{Delay Cost / Vehicle Mile} = \frac{\$12,400}{8000 \text{ vehicles} \times 10.5 \text{ miles}} = \mathbf{14.76} \text{ cents/vehicle mile}$$

The savings in delay during the peak hour if traffic is reduced during the peak hour by 12% would be 14.76 cents/ vehicle mile.

I-270 Delay Analysis: I-270 Northbound – Section from I-370 to MD 109

Based on Figure 2-14 and Figure 2-15 for the 5 hour afternoon peak period that was analyzed the delay for the comparatively light travel days in August was estimated to be an average of **80** seconds per vehicle. During October, with heavier traffic flows the delay was estimated to about **300** seconds per vehicle. As noted earlier in the report delay is calculated by taking the time difference between driving the 12.9 mile section of roadway at 65 miles an hour versus the time it would take to drive the section at the congested speed. Therefore the travel time would be:

$$\begin{aligned} \text{Free flow travel time for 12.9 miles at 65 miles per hour} &= 716 \text{ SECONDS} \\ \text{October Congested travel time for 12.9 miles at congested speed} &= 1016 \text{ SECONDS} \\ \text{August Congested travel time for 12.9 miles at congested speed} &= 796 \text{ SECONDS} \end{aligned}$$

The estimated congested travel times are the average over the 5 hour afternoon peak period. Individual afternoon peak hours will have significantly higher and lower delays.

The next step in the analysis is to estimate the vehicle hours of delay for the typical days selected in August and October.

On a typical day approximately 22,000 vehicles traverse the I-270 study section. The difference between average delay in August versus October is **220** seconds (300 – 80).

Therefore:

$$\begin{aligned} \text{Vehicle Hours of Delay} &= \frac{\mathbf{22,000} \text{ peak period vehicles} \times \mathbf{220} \text{ seconds of delay}}{3,600 \text{ seconds per hour}} \\ &= \mathbf{1344} \text{ Vehicle Hours of Delay} \end{aligned}$$

If the average vehicle occupancy rate for all trip purposes in the Washington, DC area is 1.2 then the person hours of delay is **1613** hours. A typical driver values their time at 1/3 to 1/2 of their hourly wages. If each person values their time at \$15 per hour then the delay on this one 10.5 mile section of I-270 is costing **\$24,195** per afternoon peak period (1613 X \$15/hour). If converted to a yearly cost, the delay cost would be **\$6,048,750** (\$24,195 X 250 working days).

This can also be expressed as a delay cost / vehicle mile which would be:

$$\text{Delay Cost / Vehicle Mile} = \frac{\$24,195}{22,000 \text{ vehicles} \times 12.9 \text{ miles}} = \mathbf{8.53} \text{ cents/vehicle mile}$$

Percent Reductions in Traffic and Delay

In October it takes an extra 300 seconds to traverse the I-270 12.9 mile study section. In August during light traffic it takes an extra 80 seconds. Therefore if we reduce our traffic below the tipping point of congestion then the percentage reduction of delay would be:

$$\text{Percent Delay Reduction} = \frac{(300-80)}{300} = \mathbf{73 \%}$$

In order to get this reduction in the I-270 corridor we would need a drop in the traffic from 22,000 vehicles during the afternoon peak to 19,000. This is a traffic reduction of 14% and corresponds to the average traffic difference between August and October. A **14%** traffic reduction would result in a **73%** reduction in delay.

Analysis of the Peak Hour of the Afternoon Peak Period

During the peak hour in the afternoon peak period, the traffic flow is approximately 6,800 vehicles versus 22,000 vehicles during the entire afternoon peak period. From Figure 2.14 the average delay on the I-270 study section during the peak hour is 420 seconds. With no congestion the sections travel time is 716 seconds and with peak hour congestion it is 1136 seconds. By reducing the demand by 14% (typical traffic reduction for August versus October) to 6000 vehicles during the peak hour there would be a significant percent delay reduction as the following calculations will show:

$$\begin{aligned} \text{Percent Delay Reduction} &= \frac{420 \text{ Seconds(October Delay)} - 80 \text{ Seconds(August Delay)}}{420 \text{ Seconds}} \\ &= \mathbf{81 \%} \text{ Delay Reduction} \end{aligned}$$

By reducing demand **14%** we can achieve a delay reduction of **81%**. This demand to delay percentage ratio is similar in scale to the delay reduction found on I-95.
The cost savings to the individual vehicle on a per mile basis would be:

$$\begin{aligned} \text{Peak Hour Delay Savings} &= \frac{6800 \text{ Vehicles Peak Hour} \times 340 \text{ seconds Delay Reduction}}{3600 \text{ Seconds}} \\ &= \mathbf{642} \text{ Vehicle Hours of Delay Reduction} \end{aligned}$$

$$\text{Delay Savings} = 642 \text{ Vehicle Hours} \times 1.2 \text{ Vehicle Occupancy} \times \$15 \text{ VOT} = \$11,560$$

Note: VOT = Hourly Value of Time

$$\text{Delay Cost / Vehicle Mile} = \frac{\$11,560}{6800 \text{ vehicles} \times 12.9 \text{ miles}} = \mathbf{13.18} \text{ cents/vehicle mile}$$

The savings in delay during the peak hour if traffic is reduced during the peak hour by **14%** would be **13.18 cents/ vehicle mile**.

In Sections 3 and 4 that follow, we address how many peak period trips can be truly deemed discretionary, and therefore may be able to shift times to reduce congestion (Section 3), and how effective congestion pricing and similar strategies have been in encouraging travel mode and travel time pattern changes (Section 4).



3. Washington, DC Household Survey Key Findings

The purpose of this section is to address the first two questions on the second objective, namely:

- ❖ What is the share of travel that is made for various purposes other than commuting on congested freeways in the Washington, DC area? and
- ❖ What share of these travelers may have some flexibility to shift their time of travel to off-peak periods?

Methodology Used to “Mine” the MWCOG 1994 Survey

The MWCOG 1994 household travel survey is a statistically valid survey for the Washington region, with a sample of 4,863 households. One drawback is that the survey is more than twelve years old. (MWCOG is in the process of conducting a new household travel survey for the region. However, data will not be available until mid-2009, well outside the timeframe for this project.) The Study Team obtained the documentation and an electronic version of the MWCOG 1994 survey in ASCII comma-delimited format from MWCOG. The structure and definitions are similar to National Household Travel Survey (NHTS). Some “data cleaning” was required.

The following data sorts, combinations and analyses were performed on the survey data, as defined below:

1. Separated trip records by peak and non-peak and created trip chains for work and non-work travel. Work trips were defined as all trips with an ultimate origin or destination of work as long as interim stops are 30 minutes or less (to overcome the problem of a work trip with a stop to pick up coffee being coded or interpreted as a shopping trip). Work trips include home to work trips (HW), work to home trips (WH), work to work trips (WW), work to other trips (WO), and other to work trips (OW). Non-work trips include home to home trips (HH), home to other (HO), other to home (OH), and other to other. The morning peak period is defined as trips beginning from 6 am to 9 am, while the evening peak period is defined as trips beginning from 3 pm to 6 pm.⁵
2. The MWCOG survey did not include questions on distance, but did include travel time records. Trip origin and destination addresses were not available, however, information on the city or county of origin was provided. (The study scope and time frame precluded a detailed analysis by Transportation Analysis Zone or TAZ). Travel times greater than twenty minutes are used as surrogates for trips that are likely to use freeways. These are referred to as longer trips; the majority of the analysis focuses on these longer trips.
3. Identified mode of travel (personal vehicle versus all other; all other meaning rail and bus transit, bike, walk, and other) to focus on longer trips using a personal vehicle as the “target universe”
4. Evaluated longer AM Peak trips with stops on the way to work, including travel time from home and purpose (e.g., stopping for daycare or coffee) and longer PM Peak trips on the way home from work.
5. Compared AM Peak and PM Peak trip purposes and patterns for longer work and non-work trips using a personal vehicle, narrowing the focus further to those trips with 0 or 1 stops.

⁵ MWCOG typically defines the PM Peak as 4 PM to 7 PM for regional modeling purposes, but it is not anticipated that the composition of travel by purpose is substantially different for this time period.

6. Analyzed longer non-work personal vehicle 0-stop or 1-stop trips to identify those discretionary trips that appear most likely to be able to shift time. The study defines discretionary trips based on trip purposes. The discretionary category includes family and personal business, social and recreational activities, shopping, and restaurant trip purpose destinations as discretionary.
7. Developed graphic representations of the data to summarize essential findings.

MWCOG Survey Findings

Note: All Findings are based on trip chains, not individual unlinked trips, so results are likely to vary from other studies. We begin with broad overviews of travel purposes and patterns, then evaluate subsets of the data to address the research questions as fully as possible.

1. Who travels in peak and off-peak periods? How many trips are for work versus non-work? How many of these trips are longer trips (greater than 20 minutes)?

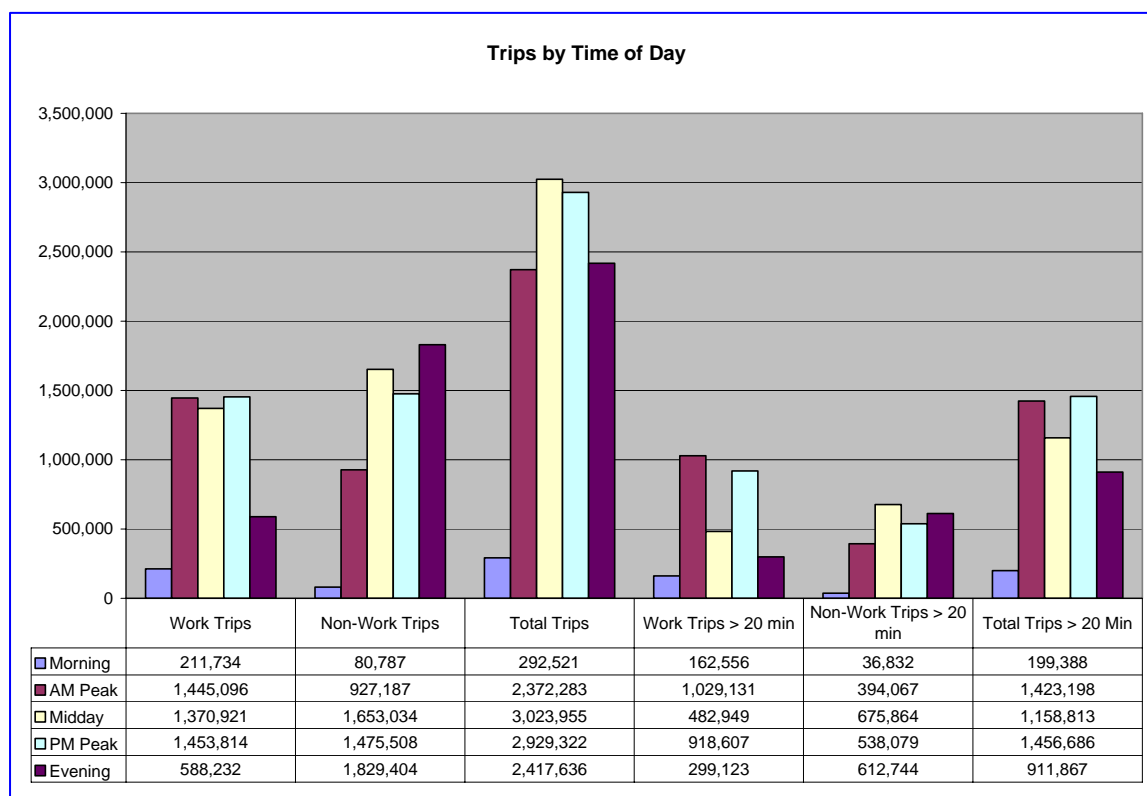


Figure 3-1: Trips by Time of Day and Overall Trip Purpose

Figure 3-1 demonstrates that there are very significant volumes of travel throughout the day and during peak periods, including large numbers of non-work trips. The three columns to the left summarize total trips during the day. Approximately 61 percent of the 2.37 million total AM Peak Trips are work trips, while slightly less than half of the PM Peak Trips are work trips.⁶ Trips that take more than 20 minutes travel time (longer trips) are depicted in the three right-hand columns, and show somewhat different patterns from the total trips. For example, in the

⁶ This analysis groups “Home – Work”, “Work – Home”, “Work – Work”, “Work – Other” and “Other –Work” to define Work Trips; and combines “Home – Other”, “Home – Home”, “Other – Home” and “Other – Other” to define non-work trips.

AM Peak, the 1.4 million longer trips comprise 60 percent of the 2.4 million total trips, while in the PM Peak the 1.5 million longer trips comprise 50 percent of the 2.9 million total trips.

Figures 3.2 and 3.3 illustrate the major differences between the AM Peak and PM Peak in terms of proportions of longer trips, and in proportions of work and non-work trips for these longer trips. The AM Peak and PM Peak total volumes of longer trips are very close to the same, at 1.42 and 1.46 million trips, but the proportions of work and non-work trips are quite different. In the

AM Peak, over 1 million (72 percent of the 1.42 million longer trips, or 43 percent of all AM Peak trips) are work trips, while less than 400,000 (28 percent of the 1.42 million, or 17 percent of all AM Peak trips) are non-work trips. In the PM Peak, over 900,000 (63 percent of the 1.46 million longer trips, or 31 percent of all trips) are work trips, with almost 540,000 (37 percent of the longer trips, 18 percent of all PM Peak trips) non-work trips.²

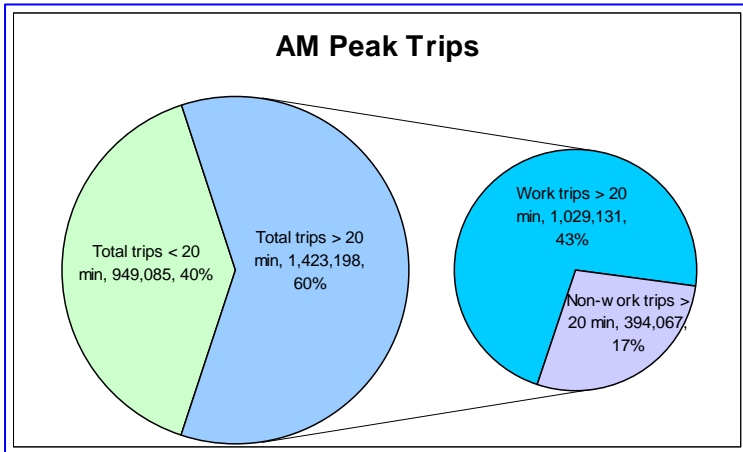


Figure 3.2 Key AM Peak Trip Characteristics

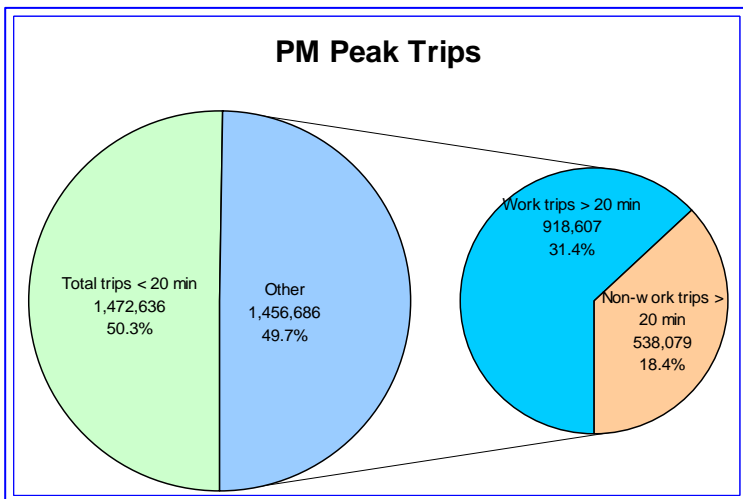


Figure 3.3 Key PM Peak Trip Characteristics

The remainder of the analysis will focus on these longer trips in the AM and PM Peak Periods, steadily narrowing the focus to identify the appropriate “universe” and our “target population” of longer peak period discretionary trips. The first step is discerning mode: private vehicle use versus other modes.

Among the universe of longer trips in the AM and PM peaks, the personal vehicle is the mode of choice for work trips and non-work trips, as shown in Figures 3.4 and 3.5.

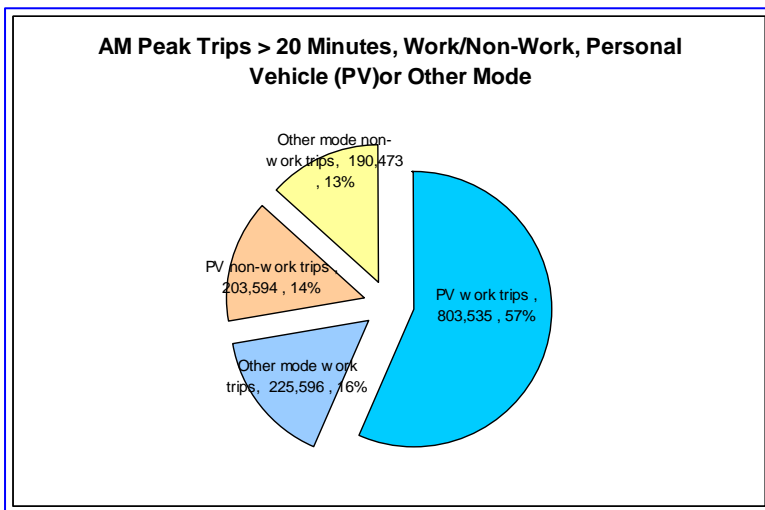


Figure 3.4 AM Peak Longer Trip Distribution by Type

Figure 3.4 demonstrates that personal vehicles account for 1.0 million trips or 71 percent of all longer trips in the AM Peak. Because the other 29 percent of the trips include walking, biking, and transit, as well as “other”, we will consider only the personal vehicles as our “universe” for traffic for the remainder of the analysis. Once we eliminate the “other mode” trips, work trips represent 80 percent of the AM Peak longer trips.

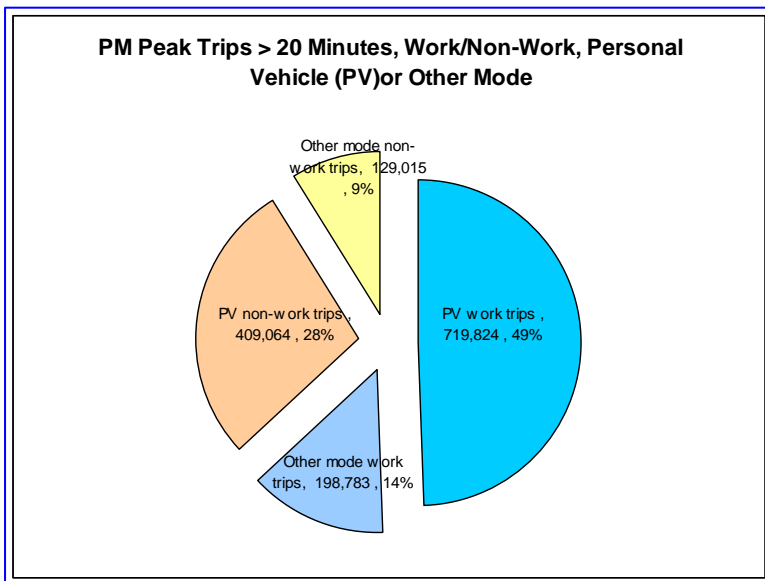


Figure 3.5 PM Peak Longer Trip Distribution by Type

Figure 3.5 shows a very different pattern for the PM Peak trips, compared with the AM Peak Trips. Personal vehicles account for 1.13 million of the longer PM Peak period trips, or 77 percent of the total. Of these 1.13 million trips, only 64 percent are work trips, with 36 percent non-work trips. It is also significant that the volumes of non-work personal vehicle trips in the PM Peak are more than double the volumes in the AM Peak.

Morning and Afternoon Peak Longer Discretionary Trips

One of the challenges for the study is to estimate the non-work trips that are using freeways during peak periods. Without a complete origin-destination matrix of trips, and without distance being part of the survey, we must make some broad assumptions about travel patterns in order to address this question. As noted in the introduction to the survey, since we do not have direct distance information, we are using time as a surrogate and assuming that many of the longer trips – more than 20 minutes each - are using freeways. For this “drilling-down” into the data, we ask the following questions:

- What are the key trip purposes for the longer non-work trips?
- Of these longer, non-work trips, which categories are commonly deemed to be discretionary and therefore capable of moving the travel to other time periods, other days, or other routes?

Many trip destination purposes are included in the survey, including Home, Work and Related, School, Child Care, Pick Up / Drop Off, Shopping, Family / Personal, Restaurant, Changing Mode, and Other. Activity Modeling analyzes work and non-work trips into three main categories: Maintenance, Subsistence, and Discretionary, as well as some trips that are generally not separately categorized in the analysis bridging trips and activities (marked as N/A – Home is self-defined).⁷ Work trips are considered in the Subsistence category. The key to the Trip Purposes delineated in the MWCOC survey for the following analysis and figures is as follows:

Abbreviation	Explanation	Category	Included as Discretionary?
Home	Non-Work-Home Trip	N/A	No
PckUpDrp	Pick up or Drop Off	N/A	No
ChngMode	Change Mode	N/A	No
Other		N/A	No
School	School	Subsistence	No
ChldCare	Child Care	Maintenance	No
Shop	Shop (for goods or services)	Maintenance	Yes
Restrant	Restaurant	Discretionary	Yes
Fam/Pers	Family Personal	Discretionary	Yes
SocRec	Social / Recreational	Discretionary	Yes

Although shopping is identified as a maintenance activity, we believe that in general it may be considered as discretionary, particularly in terms of choice of time of day or day of week for most types of shopping, in particular for the longer trips included for this analysis. We analyze AM Peak and PM Peak travel in turn. In order to err on the side of caution in our estimates of discretionary trips, we focus our attention only on non-work trips with 0 or 1 stops, to reduce or eliminate the likelihood of identifying a discretionary trip with an interim non-discretionary destination purpose. Figures 3.6 and 3.7 identify the trip purposes for AM Peak and PM Peak

⁷ “Activity Analysis Using the NHTS”; <http://nhts.ornl.gov> and “Using NHTS to Estimate Activity Patterns”, Planning Applications Conference, Powerpoint presentation courtesy of Heather Contrino, FHWA Travel Surveys Team Leader.

non-work trips, longer than 20 minutes, taken in personal vehicles. In each figure, the four pieces of the pie that are extracted represent discretionary trips, as defined for this study.

Figure 3.6 illustrates the non-work trip purpose destinations for these longer trips in the AM Peak period, using a personal vehicle. After eliminating home, school, child care, etc. we have over 77,000 longer trips that can be identified as discretionary. This represents 38 percent of the pertinent non-work trips, and a full 7.7 percent of the total personal vehicle longer trips (work and non-work).

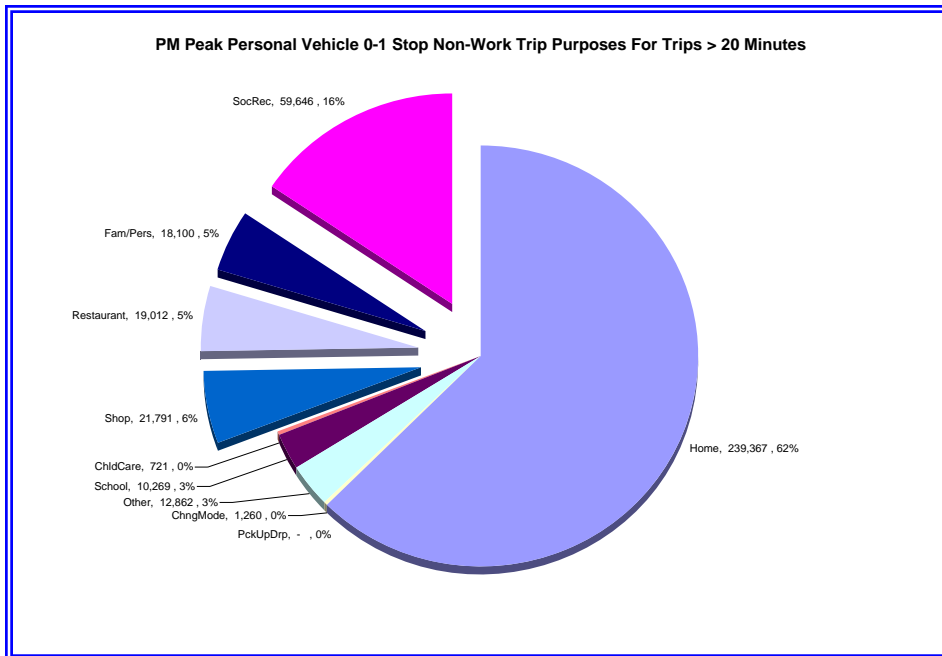


Figure 3.6 Non-Work AM Peak Trip Purposes

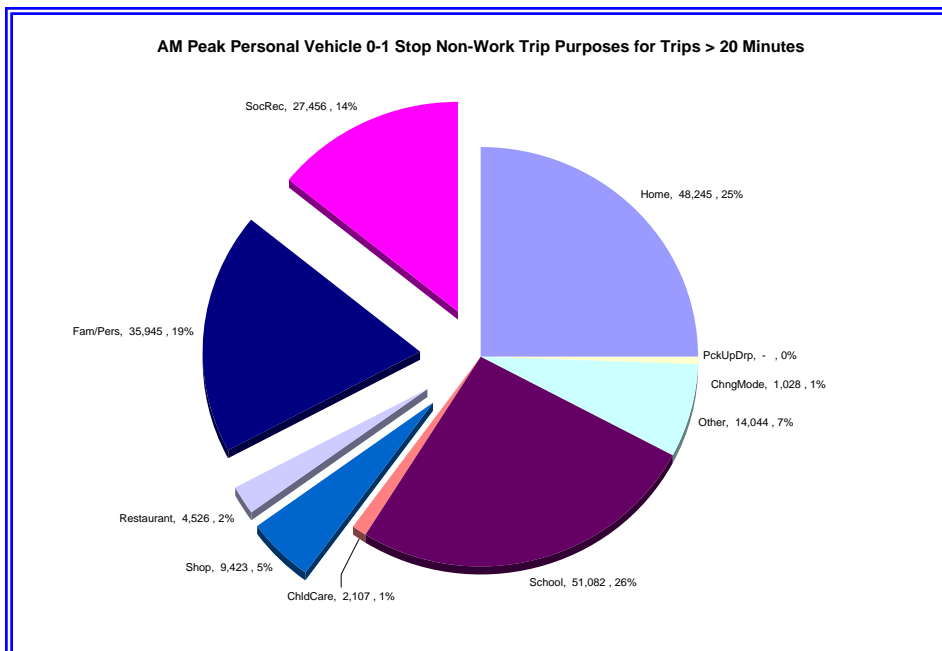


Figure 3.7 Non-Work PM Peak Trip Purposes

Figure 3.7 illustrates that, as expected, there are substantial differences in trip purpose distributions between the AM Peak and the PM Peak, as well as differences in volumes, as previously noted in relation to Figure 3.5. PM Peak discretionary trips total about 118,500, about 53 percent more than in the AM Peak. Though these discretionary trips represent only 29 percent of the PM Peak non-work trips, they account for a full 10.5 percent of all the personal vehicle longer PM Peak trips. This is due to the earlier finding, that non-work trips represent a much greater portion and volume of travel in the PM Peak compared with the AM Peak.

What Does This All Mean?

Longer discretionary trips form a substantial portion of the AM Peak and PM Peak trips. However it is not feasible to discourage or remove all discretionary trips from freeways, and even if it were, removing all such trips would not necessarily be sufficient to ensure free-flow conditions on all segments of the freeways.

Figure 3.8 illustrates how the discretionary trips, “teased out” of the non-work trips, form a notable portion (7.7 percent) of the AM Peak “universe” of personal vehicle trips. These trips have the greatest flexibility to shift time or route away from crowded freeway facilities; this shift can be encouraged through pricing and other incentives. Shifting this base of trips away from peak congested facilities would help congestion in many corridors; as noted in the traffic analysis section above, the reduction in traffic needed to restore “free-flow” conditions varies by facility, but in general will require a range of 10 percent to 14 percent to attain free-flow.

We have established that reducing traffic by 10 to 14 percent (in the PM Peak, generalizing in this case to the AM Peak) will result in a 75 to 80 percent reduction in delay, which would benefit millions of travelers every day. Achieving a 10 to 14 percent reduction in the AM Peak cannot be accomplished solely by diverting discretionary travelers. In addition to strongly encouraging AM Peak discretionary travelers to shift travel to other times or routes, it will likely

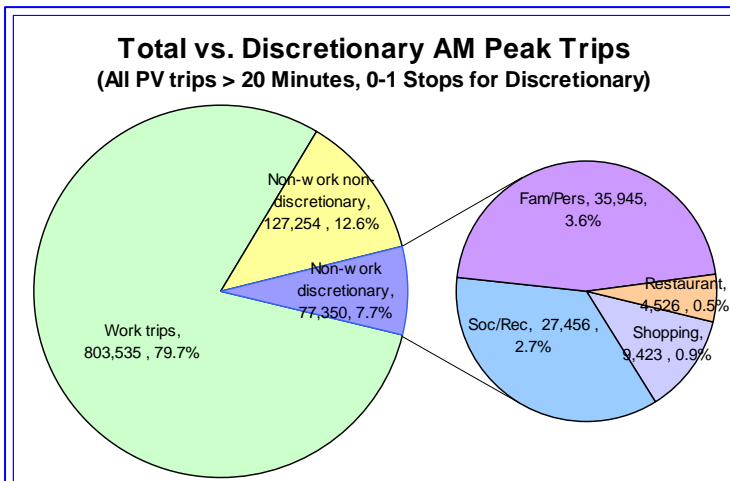


Figure 3.8 Summary AM Peak Discretionary Trip Breakdown

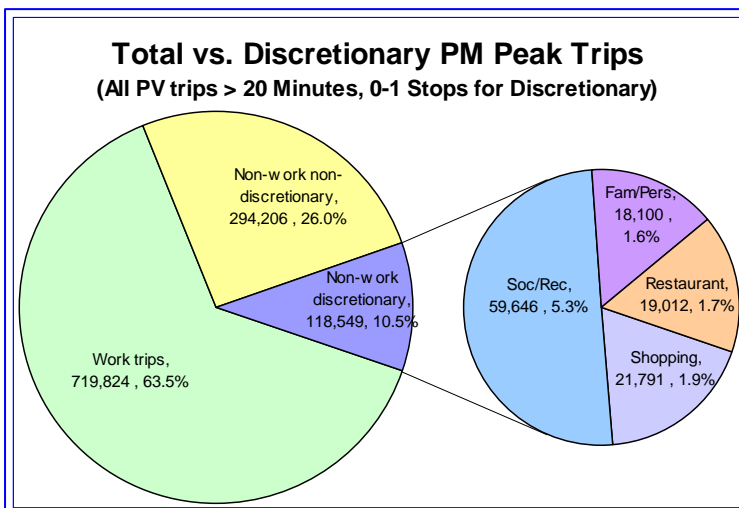


Figure 3.9 Summary PM Peak Discretionary Trip Breakdown

be necessary to encourage other travelers to shift as well. Strategies to reduce work trips in personal vehicles, such as telecommuting or transit/ carpool/ vanpool incentives and facilitation, have also proven effective in the region, as shown by the 16 percent “other modes” for AM Peak work trips in Figure 3.4. More can be done; strategies that decrease travel times for carpools, vanpools and buses increase the appeal and market share of these modes, as discussed in Section 4. Thus, shifting AM Peak discretionary trips off our congested freeways, to other times or other routes, represents a promising strategy that must be used in concert with other strategies.

Figure 3.9 summarizes the somewhat more promising potential for reducing discretionary trips in the PM Peak. Discretionary personal vehicle trips making one or no stops represent a full 10.5 percent of longer PM Peak personal vehicle trips- within the target range of the 10 percent to 14 percent reduction required to achieve a 75 to 80

percent reduction in delay. Since PM Peak trip volumes are substantially

greater than AM Peak trip volumes, and since this is largely due to the higher volumes of non-work trips, strategies that encourage discretionary trips to seek other times or other routes show great promise for reducing congestion in the PM Peak. Strategies that reduce commute trips by using pricing as a tool to promote carpools, vanpools, transit and telecommuting for work trips provide another significant “pool” of trips for reducing congestion, as discussed in Section 4.

4. Effectiveness of Congestion Pricing Strategies: Literature Review Key Findings

Is there empirical evidence that people will shift travel times and/or travel modes in response to traffic management strategies such as congestion pricing? What is the potential for other modes (e.g., transit, vanpools, carpools, etc.) to attract additional mode share, if free-flow service on all freeways were guaranteed to these modes through aggressive and active traffic management strategies such as congestion pricing?

Many studies have been conducted to answer the many facets and potential solutions to the traffic congestion question. Experience from around the world and in the United States has demonstrated that congestion pricing represents one of the most powerful tools to change driving behavior. Empirical studies of congestion pricing have been conducted in many different venues, and in many types of applications. It should be noted that other direct influences on traffic volumes and occupancy include fuel prices⁸ and parking costs (which are not addressed in detail in this review). Comprehensive approaches that include “carrots” of faster travel times, preferred parking and/or lower costs for shared rides, and “sticks” of higher costs and/or greater inconvenience or travel times for single-occupancy vehicles, appear to have the greatest potential for modifying behavior and decreasing congestion on key roadways. For example, TCRP Project B-4, “Cost Effectiveness of TDM Programs”, found the following: “The average reduction in vehicle trips among “successful” programs was 15.3%. Programs that provided enhanced alternatives, such as vanpools or shuttle buses, realized an 8.5% reduction in trips. Programs that focused on financial incentives and disincentives realized a 16.4% reduction of trips, and programs that combined enhanced alternatives with incentives/disincentives for their use, realized a 24.5% reduction in vehicle trips.” (Reference 7, below, p. 46, citing COMSIS, 1994). Subsequent studies and practical experience have validated the power of even token pricing signals to influence behavior, change traffic patterns, and reduce congestion. The effectiveness is greatly increased when coupled with transit improvements, HOV-3 lanes (including facilitation of informal carpools or “slugging”, employer ride share incentives and/or parking disincentives, and all the other tools in the travel demand management (TDM) strategies “toolbox”.

The key findings on empirical evidence for the effectiveness of congestion pricing are summarized in the tables below (reference numbers in parentheses), with brief annotated references describing each case and/or reference below the tables.

⁸ The recent US surge in fuel prices resulted in significant drops in total driving. In Maryland and Virginia, for example, prices increased by approximately 25 percent over the prior year for the months of March through June, (average prices per gasbuddy.com) and miles driven on urban arterials decreased by a little less than 3 percent over the same period, (per FHWA reports). Washington DC miles actually increased slightly. However, an increase in fuel prices or parking will not necessarily induce a shift from a congested roadway, or to a less-congested time period.

Table 1: Observed Changes in Traffic due to Congestion Pricing

	Percentage Shift	
	Person Trips	Vehicle Trips
Shift from Peak to Off-Peak	-14% (1: Seattle)	-8% (1: Seattle- varied rates) -7% (3: NY- \$1.50 fee)
Change in Peak (or all) Traffic on Tolled Facilities	+18% (4: Mn I-394)	+54% (6: I-15 CA HOV to HOT) -7% (3: NY-\$1.50 fee) -7% (6: FL- \$.25/ \$.50 discount offpk) -13% (1: Seattle - varied rates) -15% (7: NJ Tpk) -20% to 24% (6: Singapore -\$2.50) -21% to 30% (2: London -£5 then £8)
Increase in HOV Use	+ 3% (4: Mn I-394) +10% (1: Seattle - work trips)	+25% (6: I-15 CA) +33% to 40% (6: Singapore)
Increase in Transit Use	+3% (1: Seattle - work trips) +23% (4: Mn I-394) +37% (2:London - £5 then £8)	N/A

The “outlier” in the above table (the 54% increase in vehicle trips on I-15 in California) represents the successful introduction of HOT lanes to a previously under-utilized HOV lane facility. When the enforcement on illegal SOVs increased with the introduction of tolls for SOVs, HOV use increased significantly, as shown. The introduction of tolls results in traffic reductions ranging from 7% to 30%, depending on the pricing and the breadth of the strategy. The highest values, in Singapore and London, represent comprehensive central city core area pricing programs, that were introduced with concurrent increases in transit and shared-ride alternatives. Most examples use electronic tolling. It is significant that decreases in vehicle trips can result in increases in person-trips, both through improved through-put based on reduced congestion, and on improved efficiency based on the balance between SOV and HOV.

Some empirical studies have evaluated changes in traffic with corresponding changes in congestion. Results vary greatly, due to the existing conditions and the methods used to evaluate congestion. However, as demonstrated in the Section 2 Traffic Analysis above, modest changes in volumes can generate significant decreases in delay.

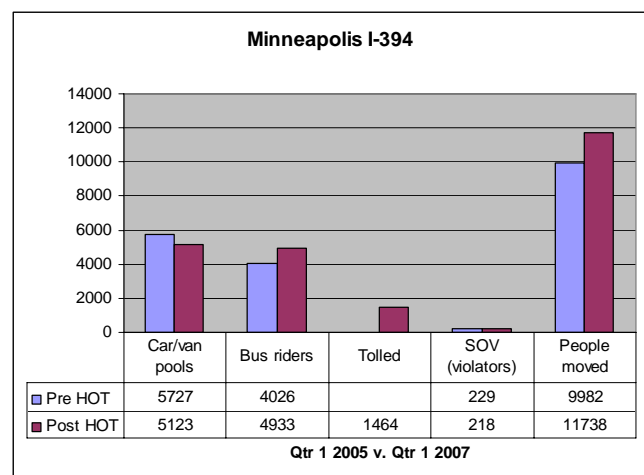
Location	Traffic Change	Congestion Change
London (2: £5 then £8)	-20%	-30% (2003-2004)
Stockholm (5: variable fee)	-15%	-50%
Singapore (6)	-20% to 24%	-30% (avg. speeds up)

- 1) Puget Sound Regional Council, “Traffic Choices Study- Summary Report”, April, 2008. Report on 18-month study of 275 individual drivers who participated in a voluntary GPS-monitored tolling study. As this was a sample, drivers did not have the option to pay a toll to drive on uncongested major roads. Reported results are from page 12 of the study, and

extrapolated from Tables 2 and 3 on page 23 of the study. <http://psrc.org/projects/trafficchoices/in-summary.pdf>

- 2) Transport for London, “Central London Congestion Charging: Impacts Monitoring - Fifth Annual Report, July 2007.” London introduced congestion pricing for its central section in 2003, along with improved bus services, and has been monitoring and adjusting the system since that time. In the first year congestion was reduced by 30% (p.35). In 2006, traffic with four or more wheels was down 21 percent from 2002, and vehicles that could potentially be charged was down 30% (p.19); nevertheless in 2006 congestion increased significantly from earlier years (but is still 8% lower than 2002), largely due to roadway construction, changes in signals and other factors (p. 48-53). This is being studied intensively to work out problems; for example, bus service times and delays increased, even though signal priority schemes for buses were in effect (p.72). <http://www.tfl.gov.uk/assets/downloads/fifth-annual-impacts-monitoring-report-2007-07-07.pdf>
- 3) Breakthrough Technologies Institute and Environmental Defense, “Changing Lanes – Linking Bus Rapid Transit and High Occupancy Toll Networks in Northern Virginia”, September, 2005. The purpose of the study is clear from its title. It included a review of previous experiences. Cited here is the example from the Port Authority of New York-New Jersey that introduced time-of-day tolls on Hudson River bridges and tunnels and Staten Island bridges (7% peak hour traffic reduction- see p. 13).
- 4) Turnbull, Katherine, “High-Occupancy Toll (HOT) Lanes and Public Transportation”, TRB 2008 Annual Meeting CD-ROM. Ms. Turnbull examines the introduction of Single-Occupant Vehicles (SOVs) paying tolls onto High-Occupancy Vehicle (HOV) lanes, examining the impacts on public transportation services and ridership levels. The three cases explore bus services operating on the HOV/HOT lanes on I-15 in San Diego, I-394 in Minneapolis, and I-25 in Denver. In San Diego, HOVs account for approximately 75 to 78 percent of total vehicle volumes, with FasTrak™ users accounting for most of the remainder. Bus riders comprise about 10 to 11 percent of daily users, mostly for reverse commutes, and taking advantage of service that was introduced and partially funded by the new tolls. Denver’s I-25 has from 68% to 72% of its lanes occupied by HOV, with 28% to 32% paying tolls. Denver instituted a performance monitoring system, using GPS to track the on-time performance of buses. They have been able to use this information to fine-tune signals near exit ramps and other potential problems on the route for buses as well as other vehicles.

The Minneapolis HOT/HOV lane deliberately improved transit services when it opened the HOV lanes as HOT lanes. Although carpool and vanpool riders declined by about 10%, bus ridership increased by over 22%, for a 3% increase in total HOV use, and an 18% increase in people moved along the corridor. Figure to right derived from study.



- 5) Replogle, Michael, “Is Congestion Pricing Ready for Prime Time?”, Planning, Vol. 74, No. 5, May 2008, pp. 6-11.

- 6) TCRP Report 95, Chapter 14, “Road Value Pricing- Traveler Response to Transportation System Changes” – This comprehensive study completed in 2003 includes detailed analysis of major road, city center, and other US and international experience in congestion pricing strategies, including Singapore’s ALS experience beginning in 1975 and the United Kingdom’s experience in Durham (beginning in 2000) and London (beginning in 2003). Florida reference page 14-16. I-15 California reference p. 14-56, Table 14-13, Oct. 1996 v. Oct. 1999. Singapore reference p. 14-10 and 14-53, extrapolating between mode shares from Table 14-2 and the traffic volumes shown on page 14-53. Pre-ALS volume is estimated at 308,500 based on the statement on p. 14-10 that inbound traffic during restricted hours has been capped at below 70% of 1975 pre-ALS volumes.
- 7) FHWA, “Mitigating Traffic Congestion: The Role of Demand-Side Strategies, 2004, www.ops.fhwa.gov. This study provides a few examples of congestion pricing, and is also an accessible and valuable reference with “fast facts” and case studies on a wide range of Transportation Demand Management (TDM) strategies that will enhance the effectiveness of congestion pricing efforts. NJ Reference p. 22 “Fast Facts”.

What Does This All Mean?

Traffic congestion and delay have become an endemic component of commuting life in the Washington DC region. To many, the unpredictability of travel time is even more annoying- one day a 10 mile trip may require 20 minutes, and the next day 45 minutes. Because the system is so near capacity, and exceeding capacity in some areas, a minor incident or a rainstorm causes major breakdowns and systemic delays. In this paper we have shown that there is a way to restore reliability and predictability to our highway system, without spending billions on new lanes of traffic.

In Section 2 we established that a 10 to 14 percent decrease in traffic on congested freeways will reduce delay by approximately 75 to 80 percent. In Section 3 we established that from 7 to 9 percent of the longer trips in personal vehicles during peak periods are discretionary. In Section 4 we have established that modest pricing signals for private vehicles can reduce traffic enough to significantly reduce congestion and save time for all drivers, while at the same time increasing the “people-carrying capacity” of the roadway, by increasing the use of carpools, vanpools and transit. It therefore appears feasible to restore and maintain free-flow on the freeways in the Metropolitan Washington area, without adding capacity, by applying congestion pricing to the major facilities, and at the same time increasing transit, carpool and vanpool programs. The combination of diverting most discretionary trips to other times and diverting an additional five to ten percent of personal vehicle work trips to HOV modes should achieve the needed 10 to 14 percent overall decrease in traffic needed to achieve major reductions in delay.⁹

Tolls are typically set to match the value of the reduction in delay. Some of the most effective programs vary the tolls by as little as 15 minute increments based on volumes and demand, in order to keep the facility operating smoothly. Others have a fixed rate for the “peak of the peak” (usually the peak hour), with a discount for the “shoulders” of the peak, and no charge in off-

⁹ Caution must be used in developing the program and publicizing and enforcing the HOV restrictions. In many cases discretionary trips, such as social and recreational trips, involve multiple people traveling together, who may consider themselves “HOV”. Thus it must be made clear that the HOV refers to registered carpools or vanpools for work trips, to avoid the unintended consequence of facilitating discretionary group travel.

peak hours. Most systems use transponders (similar to the E-Z Pass in use throughout much of the East Coast) with cameras to identify violators, designed to collect information at high speeds.

Going forward with such a system would require political will, as well as phased implementation and experimentation to identify workable technologies and appropriate rates to achieve the desired result. However, based on the cited examples, it could be expected that a charge of approximately \$.15 per mile (or \$1.50 for the 10 mile freeway segments in the analysis) would be a reasonable starting point, comparable to the value of time saved. It is expected that registered car pools (HOV 3 or more, preferably), vanpools and transit would not be charged. Rates could be adjusted up or down, to ensure the roadway is used to near-maximum capacity, without exceeding capacity to the point of breaking down and failing. Revenues collected could be used to improve HOV alternatives as well as maintain the roadways, address choke points and bottlenecks, and improve alternate routes. Finally, travelers in the region would travel in confidence, knowing that they can reliably predict their travel time on a daily basis.

Appendix A: Detailed Traffic Analysis for I-270 Corridor

The following graphics and text summarize the rationale for the selection of September 13, 2007 as the “benchmark” non-congested day for I-270.

Paired Volume – Speed for “Summer-lite” Days

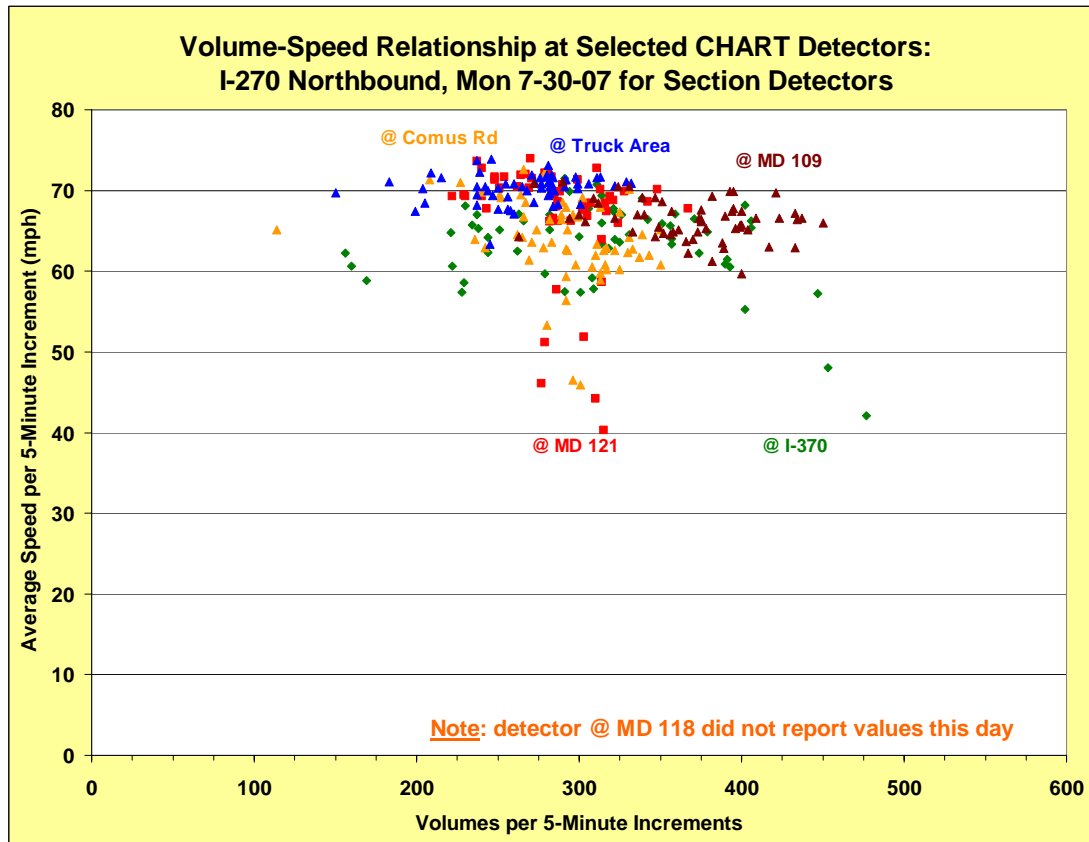


Figure A-1: Volume-Speed relationship for 7-30-07

- Shows generally tight clusters of points – one cluster for each detector
- 5-minute volumes go from about 100 to 475 veh
- Each cluster has mostly high speeds of 60-75 mph; some speeds drop to 40 to 60 mph range
- The points are consistent with HCQSM findings
- Although this was a lightly congested day, the absence of data for MD 118 makes this day less useful for comparison to congested days

Paired Volume – Speed for “Summer-lite” Days

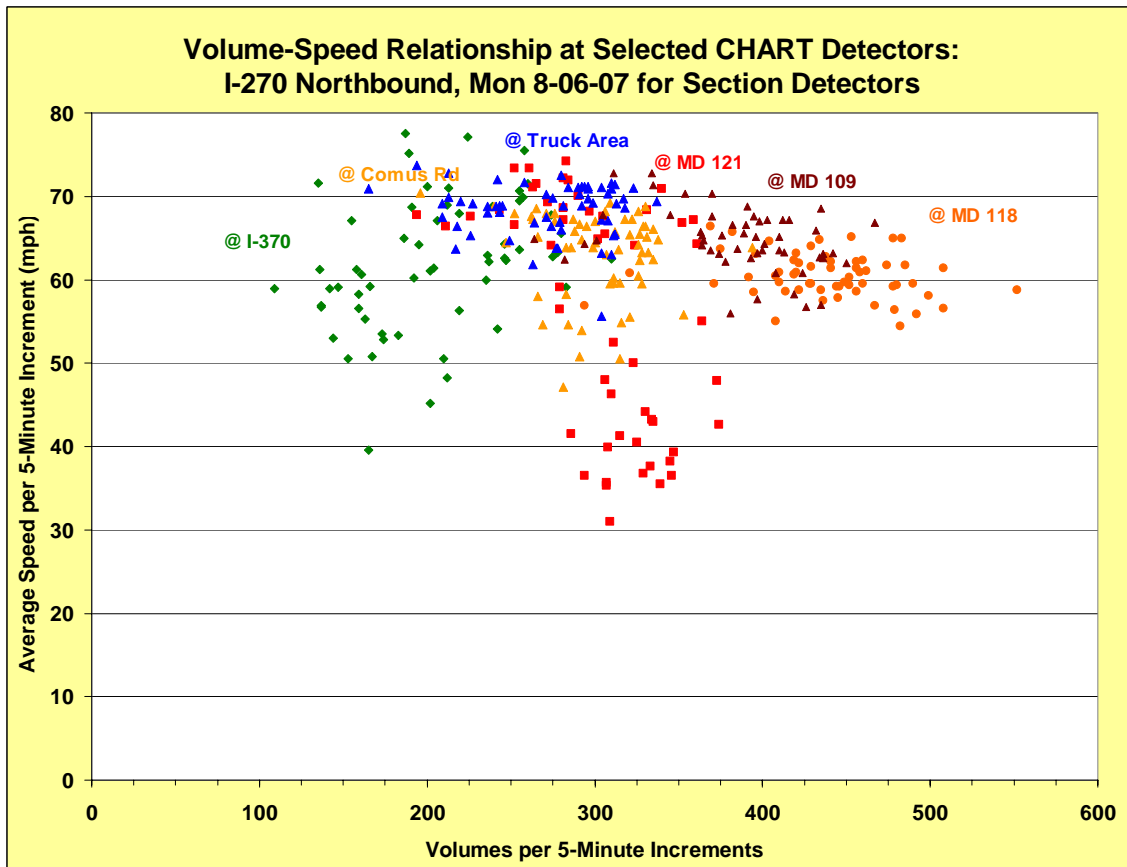


Figure A-2: Volume-Speed relationship for 8-6-07:

- Also shows generally tight but more dispersed clusters of points – one cluster for each detector.
- 5-minute volumes go from about 100 to 550 veh.
- Each cluster has mostly high speeds of 50-75 mph; some speeds drop to 30 to 50 mph range.
- The points are consistent with HCQSM findings.
- Presence of data for MD 118 makes this day more useful, but minor congested conditions at three detectors makes this day less useful.

Volume – Speed for a Summer & a “Special” Day

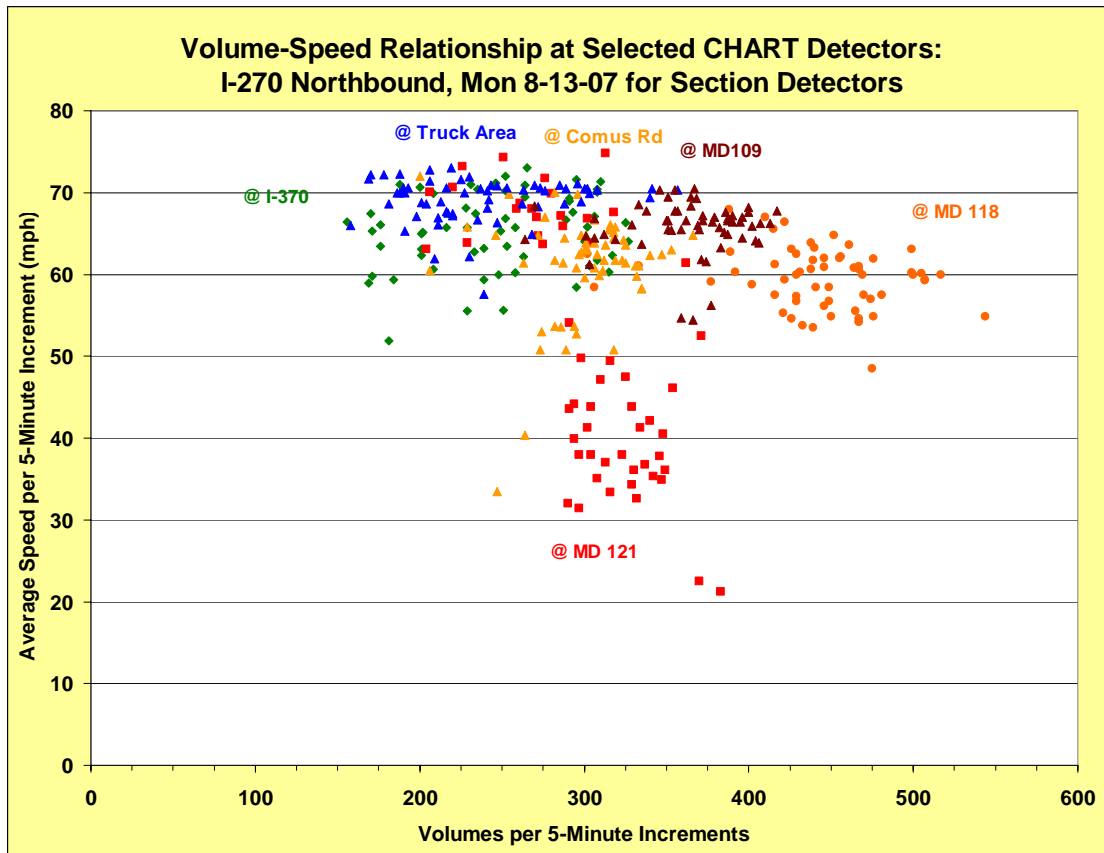


Figure A-3: Volume-Speed relationship for 8-13-07:

- Specific clusters of points are more dispersed
- 5-minute volumes go from about 150 to 550 veh
- Most speeds of 50-75 mph, but speed drops at:
 - MD121: many speeds of 20 to 50 mph
 - Comus Rd: some speeds of 30 to 50 mph
- The points are consistent with HCQSM findings
- Presence of congested conditions makes this day less useful for comparison purposes

Volume – Speed for a Summer & a “Special” Day

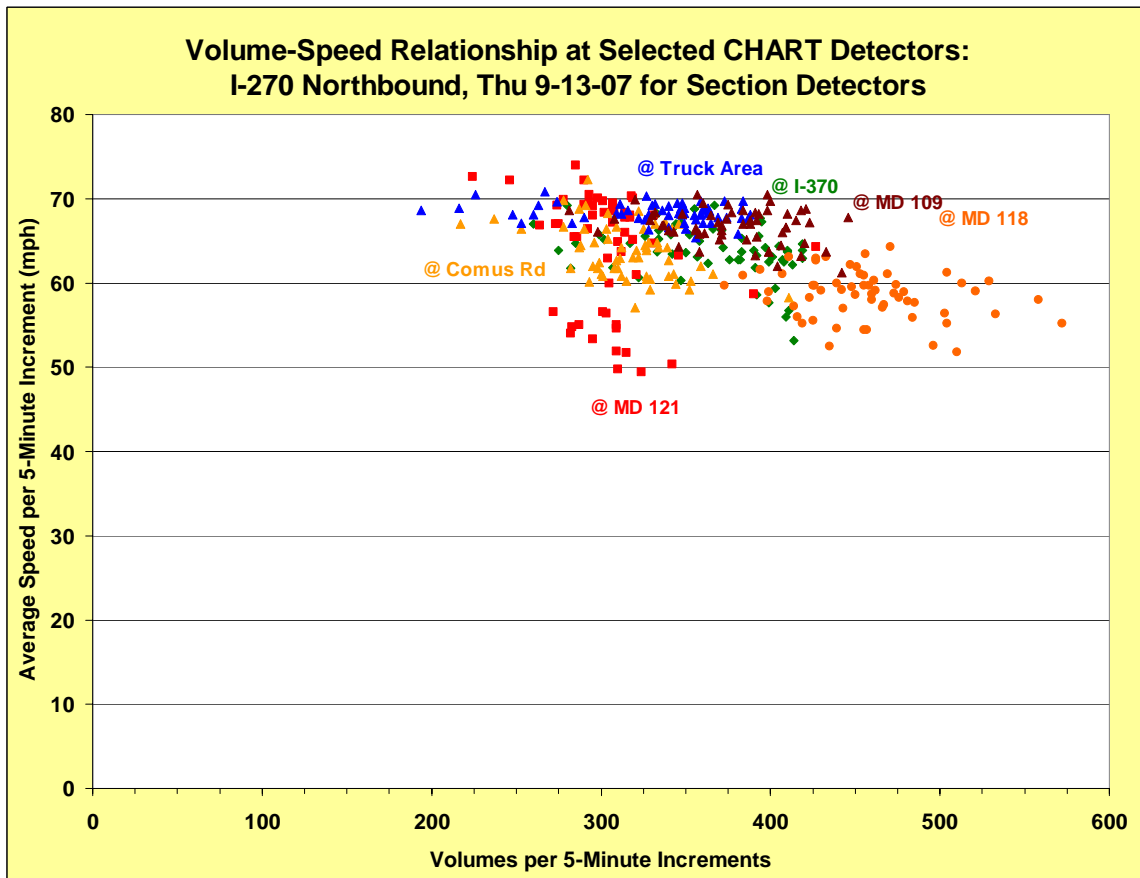
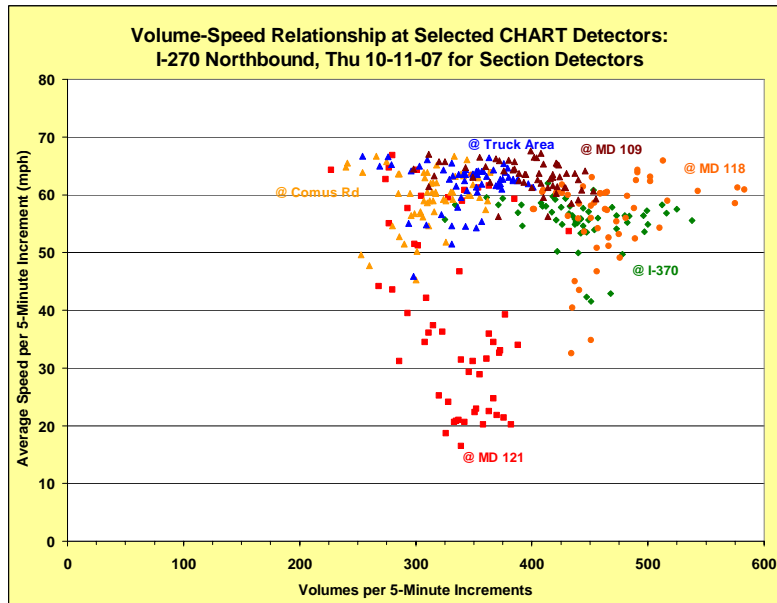
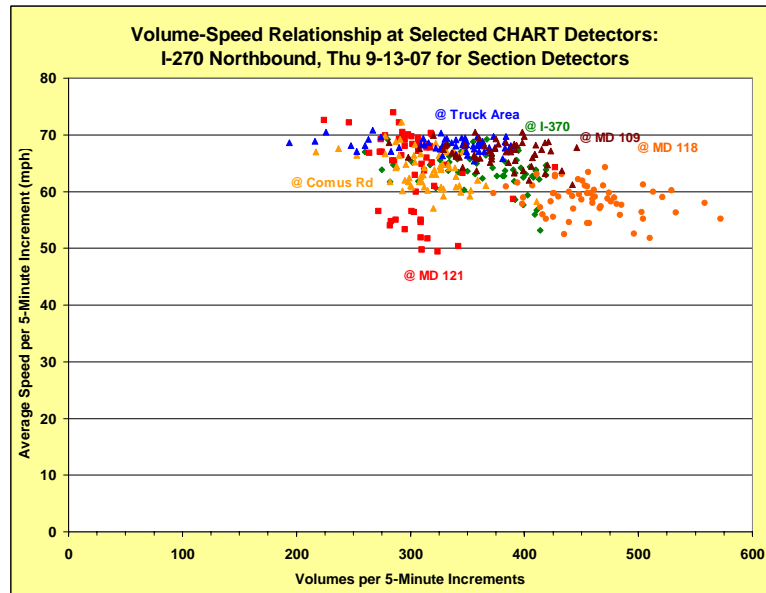


Figure A-4: Volume-Speed relationship for 9-13-07:

- Specific clusters of points are fairly tight.
- 5-minute volumes go from about 200 to 575 veh.
- Each cluster has mostly high speeds of 60-70 mph; some speeds 50 to 60; few over 70; only two 5-minutes intervals just under 50 mph
- The points are consistent with HCQSM findings.
- Although not in “August”, combination of high volumes, light congestion, and systemic demand reductions makes this day good for comparison.

Comparison of an Uncongested to a Congested Day



Figures A-5 and A-6

- The 10-11-07 graph directly above, for a typical congested day shows:
 - Volumes vary from 225 to 575 vehicles (MD 118 had peak volume of 583 veh)
 - Five of the six detectors have speeds below 50 mph
 - At MD 121 many speeds less than 30 mph (slowest average speed of 17 mph)

Again, the points for both graphs are consistent with HCQSM findings.



**Examining the Speed-Flow-Delay Paradox in the Washington, DC Region:
Potential Impacts of Reduced Traffic on Congestion Delay and Potential for
Reductions in Discretionary Travel during Peak Periods**

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