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TECHNICAL MEMORANDUM

DATE: January 19, 2018

TO: Andy Oberlander, P.E., Texas Department of Transportation

FROM: Rajat Rajbhandari, P.E.
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SUBJECT: SH 161 Peak-Hour Lanes Before/After Assessment

SUMMARY

The Texas Department of Transportation (TxDOT) opened peak-hour lanes (PHLs) on SH 161 in both directions in September 2016 as a way to relieve congestion on an approximately three-mile section of four-lane, divided access controlled highway connecting two segments of six-lane, divided toll lanes of President George Bush Turnpike (PGBT.) TxDOT allocated $3.7 million to install new infrastructure including dynamic message signs, new pavement markers, static signs, illumination, and emergency pull offs. The North Central Texas Council of Governments (NCTCOG) supplemented the physical improvements to assist in the operation of the PHLs by contracting with a towing company to provide for visual inspection of the PHLs before each opening and incident clearance on all lanes during the PHLs operating hours.

TxDOT requested the Texas A&M Transportation Institute (TTI) analyze the Before/After performance of the PHL segments and the impacts on traffic operations such as speeds, vehicle volumes, queue jumping, crashes and PHL violations. This technical memorandum summarizes the results of the study, which showed significant improvements in speeds, vehicle volumes and queue jump reduction after the PHLs were implemented. The technical memorandum also discusses capital and operational costs associated with implementing the PHLs, as well as the day-to-day operational needs to maintain a safe roadway system.

BACKGROUND

Project Description

SH 161 is an approximately 3.7-mile section linking President George Bush Turnpike (PGBT) just north of SH 114 to PGBT Western Extension (generally south of SH 183). The project area is shown in Figure 1. SH 161 is a Texas Department of Transportation (TxDOT) facility connecting two turnpike sections owned, operated and maintained by the North Texas Tollway Authority (NTTA). PGBT and the PGBT Western Extension are full toll roads with static pricing based on vehicle axles.

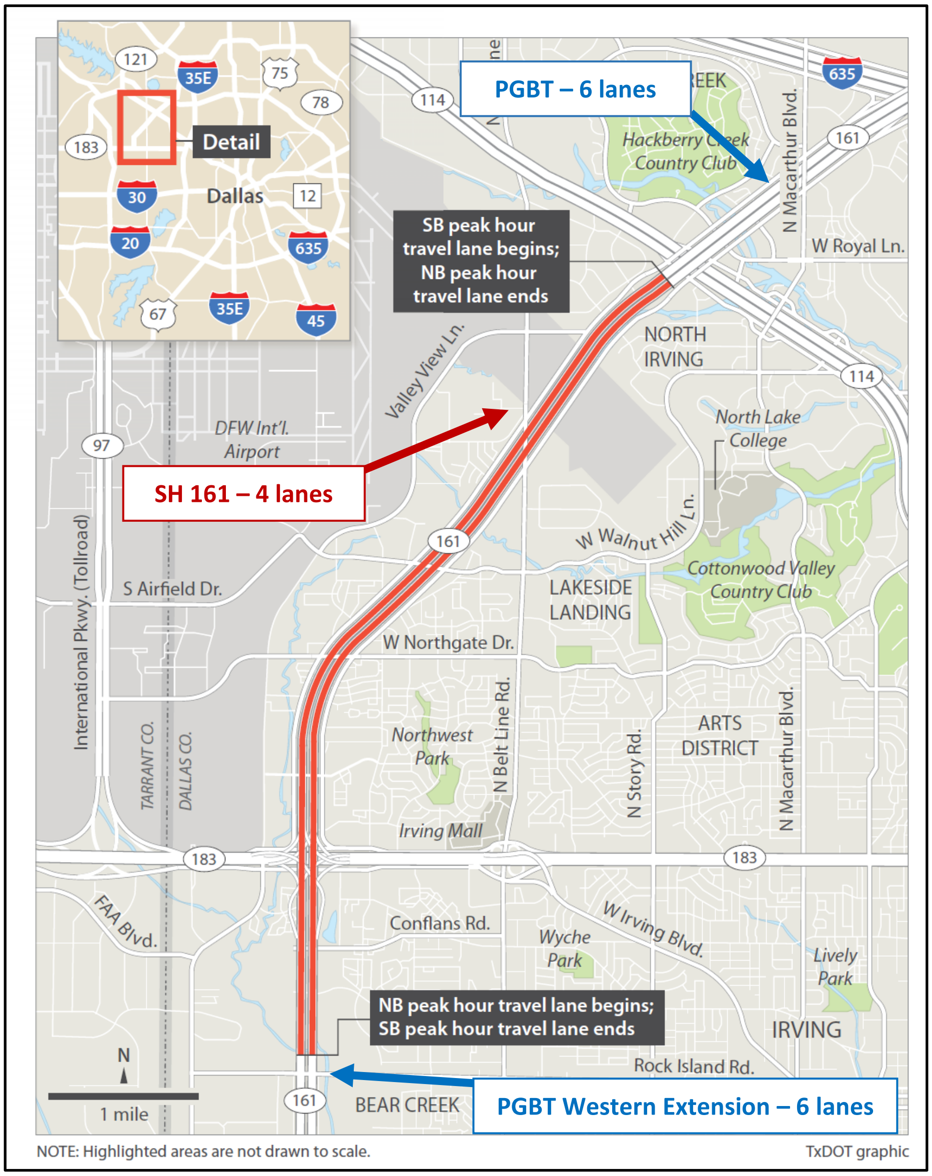


Figure 1. Project Area Map

SH 161 is a four-lane divided highway while both PGBT and PGBT Western Extension are six-lane divided highways as shown in Figure 1. During peak hours, there was a clear capacity bottleneck when transitioning from three-lanes to two-lanes and back to three-lanes in each direction of travel.

To address this bottleneck concern, TxDOT, NTTA, and North Central Texas Council of Governments (NCTCOG) partnered to convert the SH 161 left, inside shoulder to a temporary travel lane in each direction of travel during the weekday peak periods to provide proper lane balancing and continuity through the SH 161 section from and to its connecting facilities.

Texas Department of Transportation named the part-time, converted shoulder as a peak-hour lane (PHL) to best convey its purpose and operation to the public. The peak-hour lanes are 11-feet wide with a 6-inch solid yellow stripe for the left edge and an 8-inch solid white stripe adjacent to the off-peak, inside lane. The peak-hour lanes are accessed from Lane 1 in the PGBT sections with a left entering area.

One advance dynamic message sign (DMS) in each direction displayed in the peak, operational hours informs motorists that the lane is open and accessible from the left. In the off-peak hours, the DMS displays the daily operating hours. Ground-mounted signs with operational hours were initially installed ahead of the section and at points after entrance ramps would merge into the general-purpose lanes. These ground-mounted signs have since been removed to provide flexibility for the lanes operation outside of the initially established hours to support special event traffic that commonly uses the corridor.

The lanes are controlled by the use of an overhead static sign with a single line DMS and a lane control signal to display a GREEN ARROW (PHL open) or a RED X (PHL closed). One emergency stopping area is provided for each direction of travel. The emergency stopping areas provide an additional 10-foot shoulder, when the PHLs are closed. A 300-foot tangent section is used with 300-foot tapers on either end of the PHL for a total of 900-feet for transitioning into and out of the PHLs.

The peak operating hours are 6 a.m. to 10 a.m. and 2 p.m. to 7 p.m. These operational hours were initially set after a review of corridor hourly traffic volumes and were meant to open the peak-hour lane before congestion was on-set in the section.

This technical memorandum describes operational impacts on SH 161 and connecting segments before and after the inside lanes were converted to part time running lanes.

LITERATURE REVIEW

The Federal Highway Administration defines active traffic management (ATM) as “the ability to dynamically manage recurrent and non-recurrent congestion based on prevailing and predicted traffic conditions.” One congestion mitigation technique is part-time running lanes (PRL). This technique uses the roadway shoulder as a travel lane(s) to provide additional roadway capacity and accommodate increased traffic demands during peak periods and in response to incidents or other conditions as warranted during non-peak periods.

Deployment of PRLs to increase capacity falls under two categories – static and dynamic (*2*). Static PRLs are implemented during peak periods by allowing all vehicle types to use the shoulder during fixed periods of the day. Static signs are used to notify motorists about the predetermined hours of operation. Dynamic signs may be used to reinforce restrictions or occasionally change operation during special events. In dynamic PRL implementations, traffic conditions are continuously monitored to determine the need for using a shoulder lane as a regular or special purpose travel lane. Dynamic message signs or arrows are then activated to inform motorists when the shoulder is open for use.

PRL use can be effective by providing additional capacity when it is needed most during peak periods, incidents, and special events, while preserving the use of a shoulder during the majority of the day. PRL is a common practice in some European countries due to benefits in reduction of travel time and capacity increase (*3*).

In Germany, PRL has been in use since 1990 and has resulted in 20 percent increase in rush-hour capacity along Munich area freeways (*3*). The Netherlands started using PRL since 2003. They experienced overall capacity increase of seven to 22 percent by decreasing trip travel times and increasing traffic volumes throughput. Italy operates PRLs on 78-mile stretch of highway as part of managed lane strategy using extensive deployment of intelligent transportation systems (ITS) to monitor traffic conditions (*4*). They experienced significant decrease in congestion. PRLs have been gaining interest in the U.S. There are currently over 30 shoulder use installations in operation across the country covering 14 states (*2*).

Even though benefits of PRLs are obvious, its use is slowly gaining traction in the U.S. Reasons for slow traction are following:

- FHWA's Evaluation of Operational and Safety Characteristics of Shoulders Used for Part-Time Travel Lanes (FHWA-HOP-12-008) found that the functional capacity of most shoulder lanes to be approximately one-half that of a normal general-purpose lane (*5*). This may be due in part to the geometric deficiencies and the fact that motorists may feel uncomfortable using the shoulder as a temporary travel lane.
- PRLs may have potentially negative effect on incident response because first responders use the shoulder as a way to reach incident locations (*5*).
- Operation of PRLs incur continuous cost in order to monitor traffic, remove debris from shoulder lanes, pavement maintenance, dynamic signs etc. (*2*)

Typically, left and right shoulders are narrower than regular lanes. Motorists may find it uncomfortable to use them due to safety reasons (*4*). Hence, it is recommended that lower speed limits during shoulder operation, restrictions on the type of vehicles allowed into the shoulder, and restrictions on overtaking are to be enforced. In situations where PRL ends at a major interchange or an exit ramp, it may have a negative effect on the overall flow there while capacity increase is achieved upstream.

The main legal issue discussed in the United Kingdom deployment is the issue of keeping motorists from traveling in the hard shoulder beyond the specified time period (*4*). The study in Germany recommended that opening hard shoulders to regular traffic should be considered as a temporary measure, unless speed limits can be enforced and refuge areas can be provided.

FHWA also recommends assessment of the safety impacts of PRL, if there is an intent to operate it for longer term (*2*). In that case, it recommends review of three or more years of historical crash data. The review should consider the crash type, temporal factors (e.g., time of day, day of week), and location. Congestion-related crashes, such as rear-ends occurring during times the shoulder would be open, may potentially be reduced with part-time shoulder uses if congestion is reduced. Crashes related to erratic driver behavior or suboptimal geometry, such as run-off-road, fixed-object, or sideswipe crashes, may increase with part-time shoulder use. Crashes related to right-side ramp-freeway junctions may increase with right part-time shoulder use.

Empirical studies mentioned in the FHWA report (*2*) suggest mix results when it comes to safety. In Europe, overall number of crashes were mostly reduced. In Colorado and Virginia, crash increased slightly. Mixed results may be because these deployments are all unique in their own way. In Europe, PRLs were deployed as part of overall advanced traffic management along with other strategies such as speed harmonization, changes in geometries of auxiliary lanes close to exits and interchanges. Hence, it is difficult to conclude that PRLs will increase or decrease number of crashes on a corridor.

The cost of implementing PRL is also not clear since previous deployments were subset of larger ATM deployments. In a 2001 feasibility study conducted by Colorado Department of Transportation, cost of implementing a PRL on 9-mile roadway was estimated to be approximately $18.0 million (*6*) However, it includes repaving shoulder lanes, adding fiber for ITS etc. It also did not include cost of operating the PRL.

DEPLOYMENT OF PHL ON SH 161

TxDOT began construction of PHLs in May 2014 and the lanes were open to the public in September 2015. It included installation of traffic cameras, dynamic message signs, static signs, illumination, paving lanes, and emergency areas. Approximate cost of project was $3.7 million.

Figures 2 through 9 shows various assets deployed as part of the SH 161 PHL project.

Figure 2. Physical Features within Peak-Hour Lane Section.

Figure 3. Initial Static Signing (Removed in 2017) for Peak-Hour Lane Operational Hours.

Figure 4. Overhead Static Signing with Lane Control Signal and Single Line DMS.

Figure 5. Advance Signing for Emergency Parking in Peak-Hour Lane Section.

Figure 6. Emergency Parking Static Sign within Peak-Hour Lane Section.

Figure 7. Dynamic Message Sign Message Leading into Peak-Hour Lane Section.

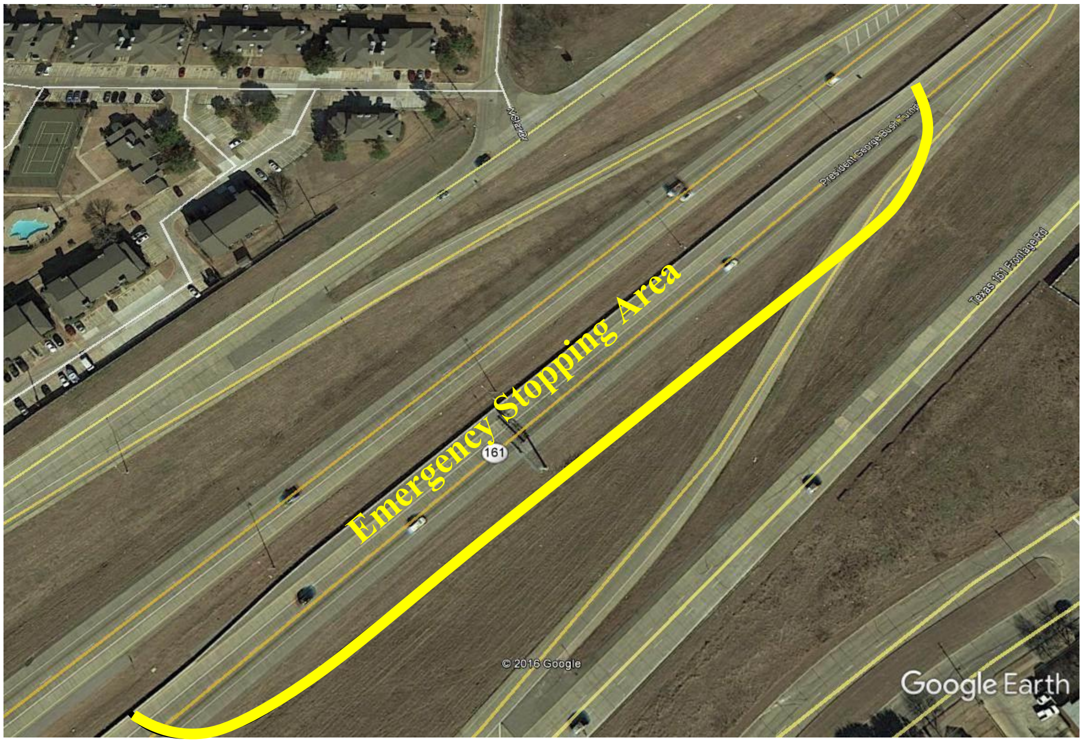


Figure 8. NB SH 161 Emergency Shoulder Area within Peak-Hour Lane Section.

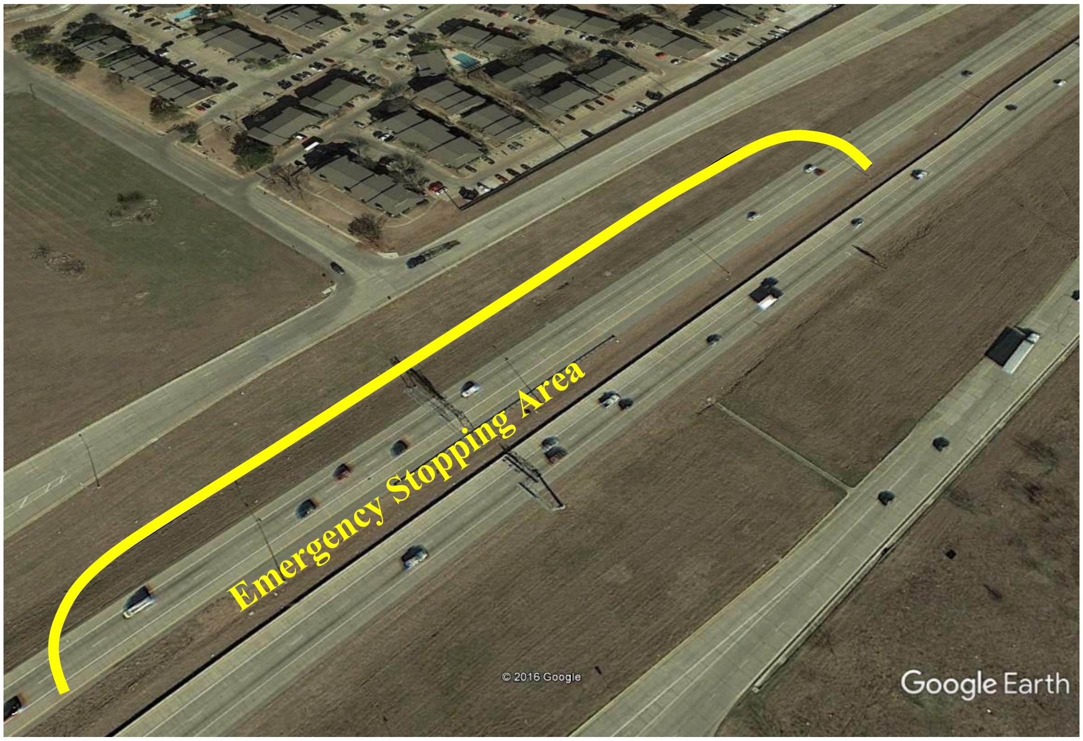


Figure 9. SB SH 161 Emergency Shoulder Area within Peak-Hour Lane Section.

BEFORE/AFTER ANALYSIS RESULTS

The Texas A&M Transportation Institute (TTI) conducted a Before/After study to analyze the operational impacts of deploying PHLs on SH 161. The before data collection period was October 27-November 13, 2013. The project was under construction between May 2014 and September 2015. The PHLs were open to the public on September 14, 2015. The after data collection period was in May 2016.

TTI collected and analyzed traffic volumes, travel speeds, queue jumping volumes and origin/destination data before and after the PHLs were implemented. Traffic volume was collected at several points along SH 161 in both directions using video feed from the traffic management center (DalTrans) and roadway axle tube counters. Travel speeds were collected using traditional "floating car" technique, Inrix data, and Bluetooth technology. Queue jumping volumes were collected using manual volume counts from recorded video at various locations on exit and entrance ramps as well as frontage roads. Origin/Destination information throughout the corridor and locations just outside of SH 161 was collected using the Bluetooth technology.

Additionally, Before/After crash data was analyzed to determine any safety concerns related to the implementation of the PHLs. Finally, transaction data from the NTTA toll plaza north of Beltline Road was used to determine by-lane volumes and PHL violations as this data was available in a by-lane format for the general-purpose lanes.

Comparison of Hourly Volumes

Because PHLs were open during peak morning and evening hours, it was expected that PHLs would attract more vehicles to the general-purpose lanes from the frontage road and arterial roads due to the added capacity to the general-purpose lanes.

Figure 10 shows the lane-by-lane and total volume by travel direction on SH 161 at the Belt Line Toll Plaza. The top horizontal arrow marks indicate one week before and three weeks after the PHLs were opened to motorists. The second set of horizontal arrow marks indicate the four weeks in May 2016 when after data were collected. In both directions, vehicle volume significantly increased on the general-purpose lanes. PHLs vehicle volume are shown as red bars in southbound and yellow bars in northbound directions, respectively. Two distinct red and yellow spikes show motorists using PHLs mostly during the morning and evening periods, when they are open to public.

As seen in Figure 10, the first weekend after opening, there were no detectable PHL violations at this location. However, the following weekend, PHL violations can be observed on both Saturday, September 26, and Sunday, September 27, in a southbound then northbound pattern roughly 4 to 5 hours between violation flows. Coincidently, on each of these dates a major sporting event was held in Arlington, Texas with a typical duration of 3 hours. Researchers infer that most of these violations represent traffic traveling to and from the special events.

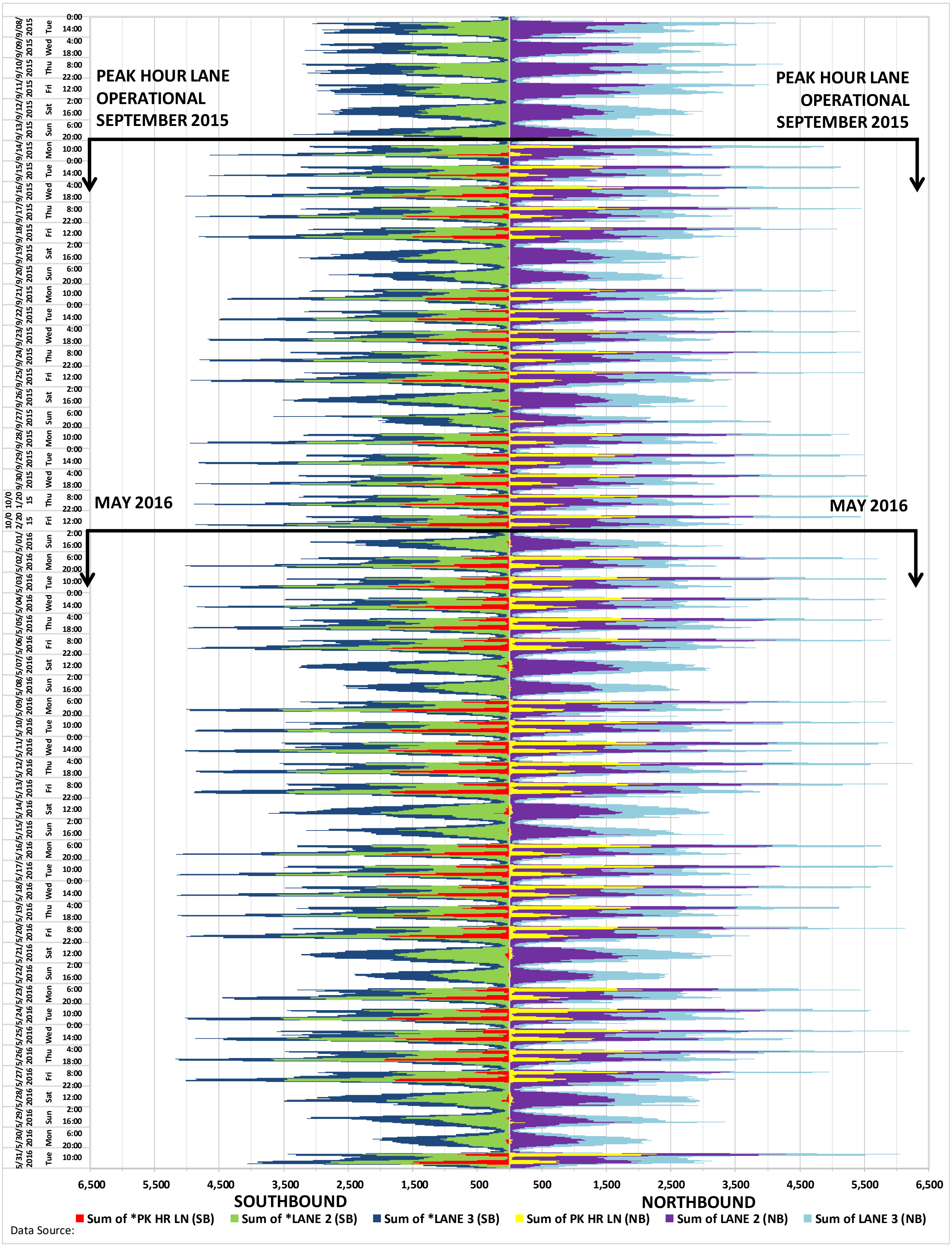


Figure 10. SH 161 at Beltline Road Toll Plaza Directional Hourly By-lane Traffic Volume.

The figure also shows that PHL use almost doubled from the initial opening week (~1,000 vehicles per hour in the lane) to the second week (~2,000 vehicles per hour in the lane). As expected from the typical peak-flow direction, the northbound PHL has approximately 2-3 times the lane demand in the morning versus the southbound lane demand in the morning, and a counter effect in the evening southbound.

Vehicle volume data was collected throughout the corridor on exit and entrance ramps, general-purpose lanes, frontage roads and direct connector ramps using automatic tube counters and counts from video. The data was summarized for PHL operational periods and peak hours of the day, by direction. Furthermore, the data was summarized for general-purpose lanes and frontage roads separately. For reporting purposes in this memorandum, only the peak direction during the peak hours (northbound for morning peak hour and southbound for evening peak hour) for the general-purpose lane volumes are be reported and discussed.

Figure 11 and Figure 12 show Before/After volumes at entrance and exit ramps as well as on the general-purpose lanes during the morning and evening peak hours, respectively. Red boxes represent volumes at general-purpose lane locations, green boxes represent volumes at entrance ramp locations, and blue boxes represent volumes at exit ramp locations. Each box location contains a before and after volume separated by "/."

Both figures show that vehicle volumes at general-purpose lane locations throughout the study limits increased after the implementation of the PHLs. Researchers infer that volumes increased due to the removal of "bottleneck" locations, as well as, some vehicles may have shifted from the frontage road lanes and/or arterial routes as the general-purpose lanes became less congested and more attractive for motorists to move into the general-purpose lanes. Northbound general-purpose lane volumes increased in the project area between 300 and 1,400 vehicles in the morning peak hour. Southbound general-purpose lane volumes increased in the project area between 1,300 and 1,700 vehicles in the afternoon peak hour.

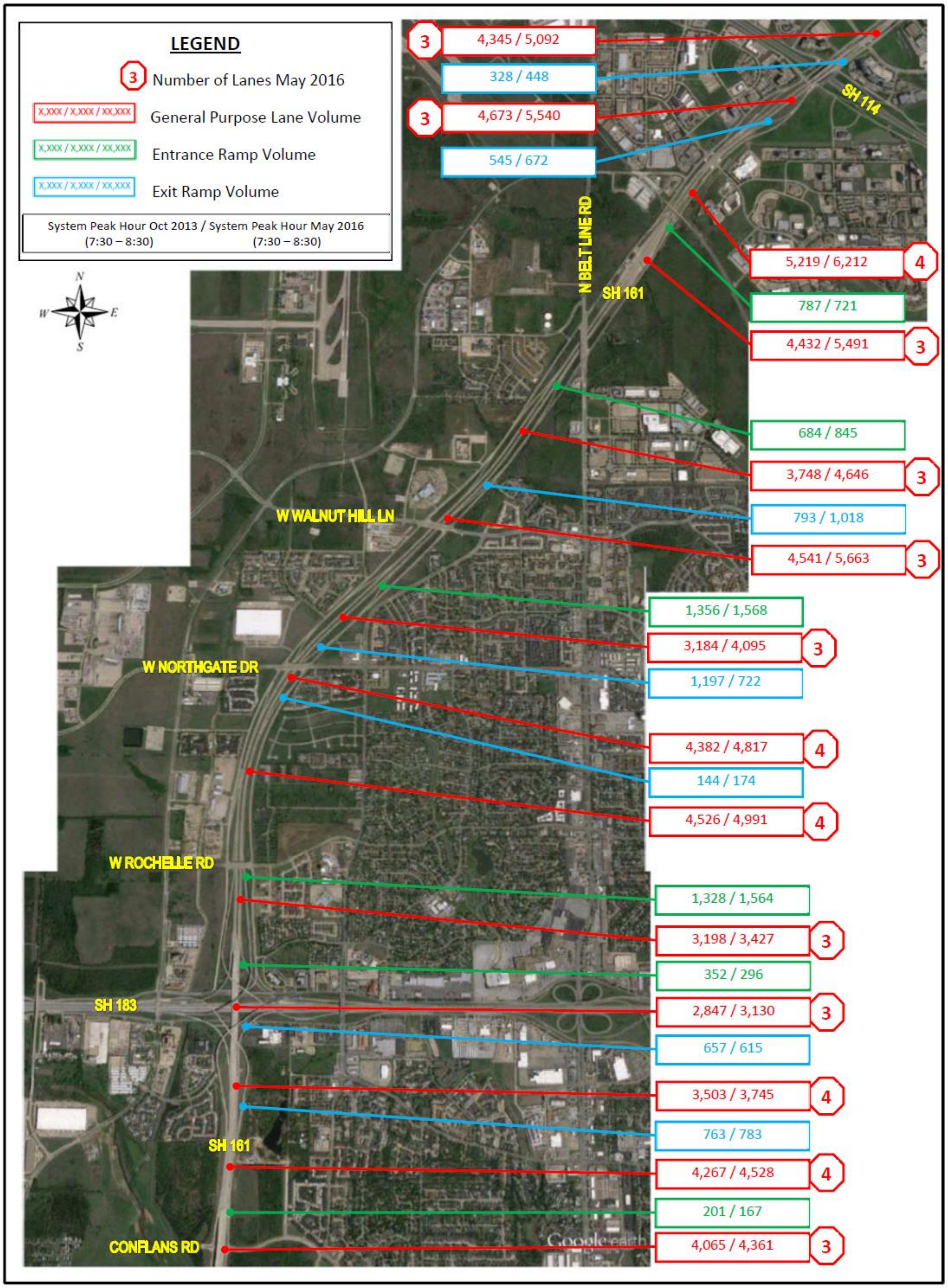


Figure 11. Comparison of "Before" and "After" Traffic Volume During Morning Peak Hour.

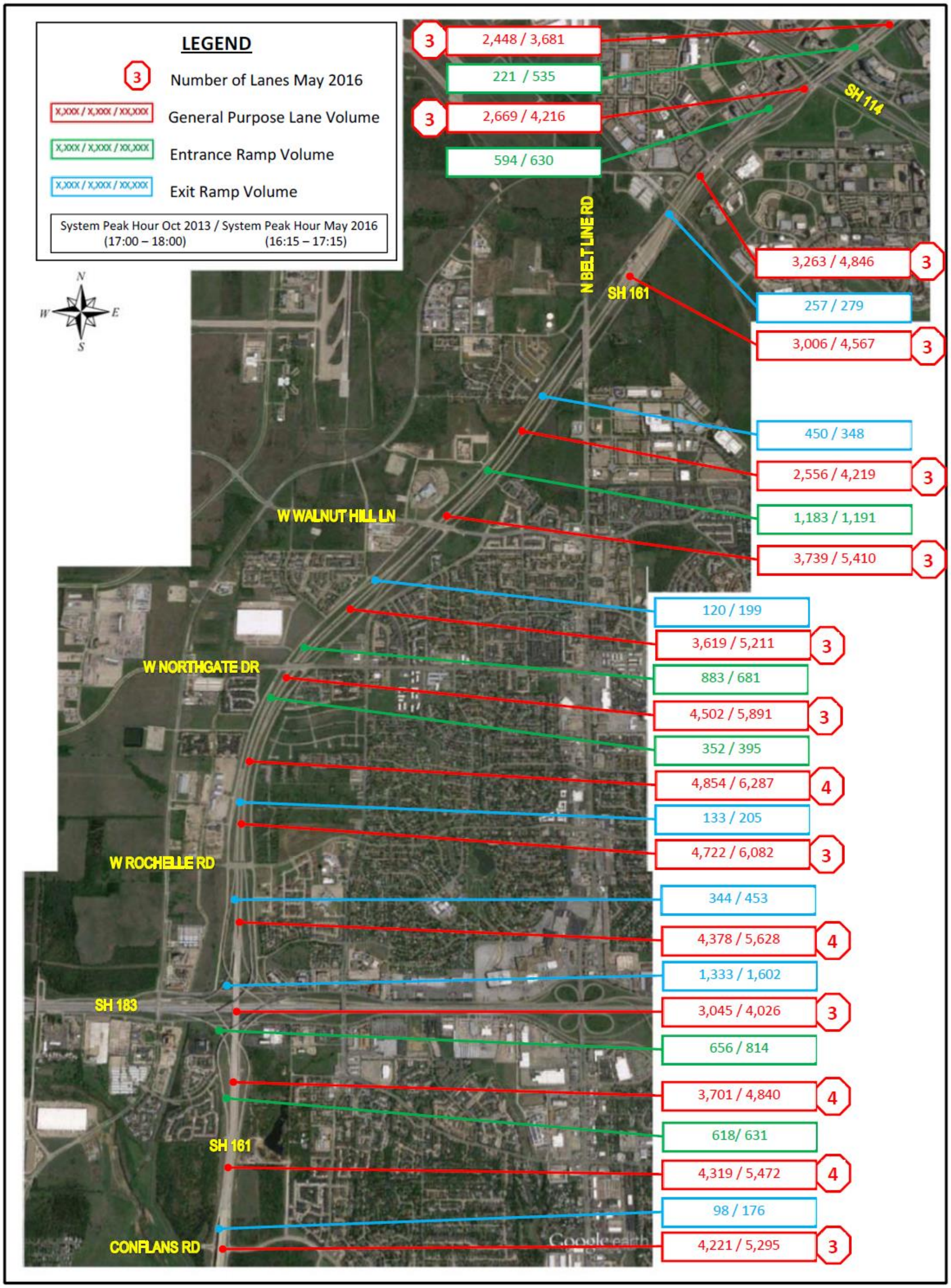


Figure 12. Comparison of "Before" and "After" Traffic Volume During Evening Peak Hour.

Comparison of Inrix Segment Speeds

TTI obtained from Inrix hourly average speed data for five segments on SH 161. Inrix uses connected vehicle technology to estimate traffic data information. Figure 13 and Figure 14 show comparison of average speed of vehicles during the northbound morning periods and the southbound evening periods, respectively. In Figure 13, the top chart shows Before/After comparison of speeds for the northbound peak directional period of 6 a.m. to 9 a.m. The bottom chart shows Before/After comparison of speeds during the hours 7:00 a.m. to 9:00 a.m. when there was congestion observed in the before conditions prior to PHL implementation. The top chart shows that average speed increased from 46 mph to 67 mph during 6 a.m. to 9 a.m. period, a 46 percent increase in speeds over the study limits. During the northbound morning congested hours from 7 a.m. to 9 a.m., a 34 percent increase in speeds over the study limits was observed. This increase in speed is mostly attributed to a decrease in congestion at two segments (Northgate Drive and Walnut Hill Lane) due to the implementation of the PHL.

In Figure 14, the top chart shows “before” and “after” comparison of speeds for the southbound peak direction period from 3 p.m. to 7 p.m. The bottom chart shows Before/After comparison of speeds during the hours of 4 p.m. to 7 p.m. when there was congestion observed in the before conditions prior to PHL implementation. The top chart shows speed increased from 45 mph to 56 mph during the 3 p.m. to 7 p.m. period, a 25 percent increase in speeds over the study limits. During the southbound evening congested hours from 4 p.m. to 7 p.m., a 32 percent increase in speeds over the study limits was observed. This increase in speed appears to be attributed, again, to a decrease in congestion due to the implementation of the PHL.

AM OPERATIONAL PERIOD (6:00-9:00 A.M.) BY HOUR

road	TX-161
TTI ROADTYPE	(Multiple Items)
direction	NORTHBOUND

MILES	Average of speed	Column Labels							
		2013			2013 Total	2015			2015 Total
	Row Labels	6 am	7 am	8 am		6 am	7 am	8 am	
1.27	NORTHGATE DR	55	23	23	34	67	65	64	66
0.24	WALNUT HILL LN	62	44	39	48	67	63	63	65
1.02	BELT LINE RD	69	62	49	60	70	69	67	69
0.41	MAINLINE TOLL PLAZA 10	69	64	54	62	70	68	66	68
0.27	END OF FREEWAY	69	67	63	66	69	68	66	68
3.21	**Grand Total**	**64**	**48**	**43**	**52**	**69**	**66**	**65**	**67**
	Weighted Speed				**46**				**67**
						Percent Change			**46.4%**

AM "PEAK" PERIOD (7:00-9:00 A.M.)

road	TX-161
TTI ROADTYPE	(Multiple Items)
direction	NORTHBOUND

MILES	Average of speed	Column Labels					
		2013		2013 Total	2015		2015 Total
	Row Labels	7 am	8 am		7 am	8 am	
1.27	NORTHGATE DR	23	23	23	65	64	65
0.24	WALNUT HILL LN	44	39	42	63	63	63
1.02	BELT LINE RD	62	49	55	69	67	68
0.41	MAINLINE TOLL PLAZA 10	64	54	59	68	66	67
0.27	END OF FREEWAY	67	63	65	68	66	67
3.21	**Grand Total**	**48**	**43**	**46**	**66**	**65**	**66**
	Weighted Speed			**36**			**66**
				Percent Change			**84.3%**

Figure 13. Comparison of "Before" and "After" Northbound Speed During Morning Period.

PM OPERATIONAL PERIOD (3:00-7:00 P.M.) BY HOUR

road	TX-161
TTI ROADTYPE	(Multiple Items)
direction	SOUTHBOUND

	Average of speed	Column Labels									
		2013				2013 Total	2015				2015 Total
MILES	Row Labels	3 pm	4 pm	5 pm	6 pm		3 pm	4 pm	5 pm	6 pm	
0.29	MAINLINE TOLL PLAZA 10	63	34	27	42	42	62	59	52	59	58
0.4	BELT LINE RD	64	38	32	45	45	63	59	52	60	58
1.05	WALNUT HILL LN	58	29	23	35	36	62	52	41	55	52
1.16	NORTHGATE DR	63	48	42	52	51	66	59	47	57	57
0.34	TX-183	67	63	60	64	64	65	63	48	55	58
3.24	Grand Total	63	41	35	46	46	63	58	47	57	56
	Weighted Speed					45					56
								Percent Change			25.1%

PM "PEAK" PERIOD (4:00-7:00 P.M.)

road	TX-161
TTI ROADTYPE	(Multiple Items)
direction	SOUTHBOUND

	Average of speed	Column Labels						
		2013			2013 Total	2015			2015 Total
MILES	Row Labels	4 pm	5 pm	6 pm		4 pm	5 pm	6 pm	
0.29	MAINLINE TOLL PLAZA 10	34	27	42	35	59	52	59	57
0.4	BELT LINE RD	38	32	45	38	59	52	60	57
1.05	WALNUT HILL LN	29	23	35	29	52	41	55	49
1.16	NORTHGATE DR	48	42	52	47	59	47	57	54
0.34	TX-183	63	60	64	62	63	48	55	56
3.24	Grand Total	41	35	46	41	58	47	57	54
	Weighted Distance Speed				38				53
						Percent Change			32.4%

Figure 14. Comparison of "Before" and "After" Speed During Evening Peak Periods in Southbound Direction.

Inrix Heat Map Speed Comparison

Using the Inrix data to examine hourly speeds across multiple days over the study limits on SH 161 between SH 183 to North of Beltline Road Toll Plaza, a “heat map” comparison was prepared displaying the weekday “before” conditions on September 16, 2013 through October 3, 2013, and “after” conditions on September 14, 2015 through October 2, 2015, respectively.

Figure 15 shows a comparison of northbound vehicle speeds where the top portion of the image shows weekday “before” conditions, and the bottom portion shows the weekday “after” conditions. The bottom portion shows that there were much more instances of high average speed (as represented by mostly green boxes) during the “after” conditions than in the top portion “before” conditions where there were more instances of low speed (as represented by yellow, orange and red boxes). Hence, the image shows that there was a significant decrease in lower speed instances during the 6:00-9:00 a.m. northbound peak periods after the implementation of the PHL.

Figure 16 shows the comparison of southbound speed improvements during the 3:00-7:00 p.m. southbound peak periods, where again, there is a reduction of yellow, orange and red boxes shown in the “after” conditions. The density of congested hours in the evening peak period of the after condition is substantially reduced when compared to the before condition. However, some congestion still remains in the southbound evening hours even with the implementation of the PHL.

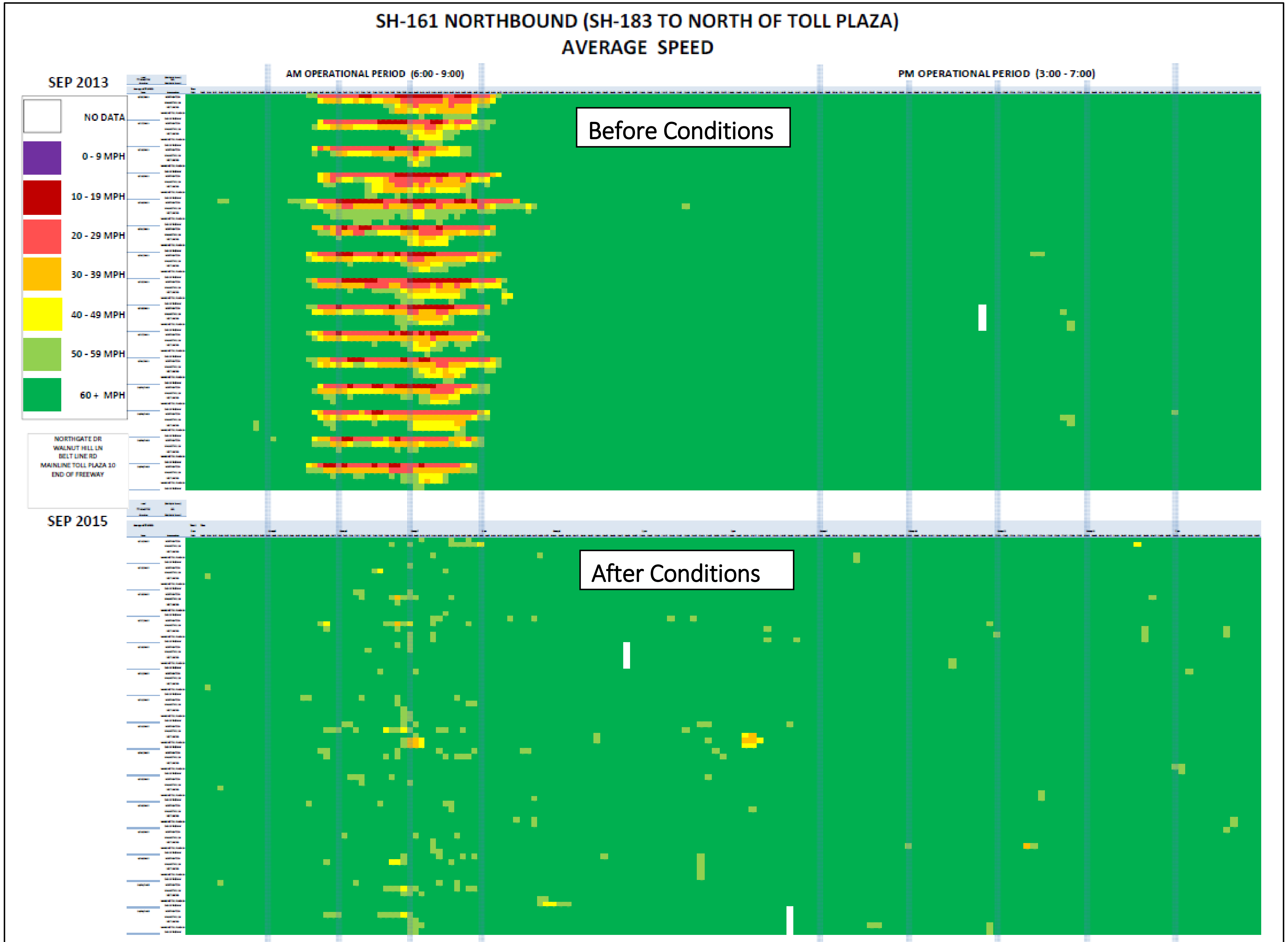


Figure 15. Comparison of "Before" and "After" Daily Average Speed Northbound.

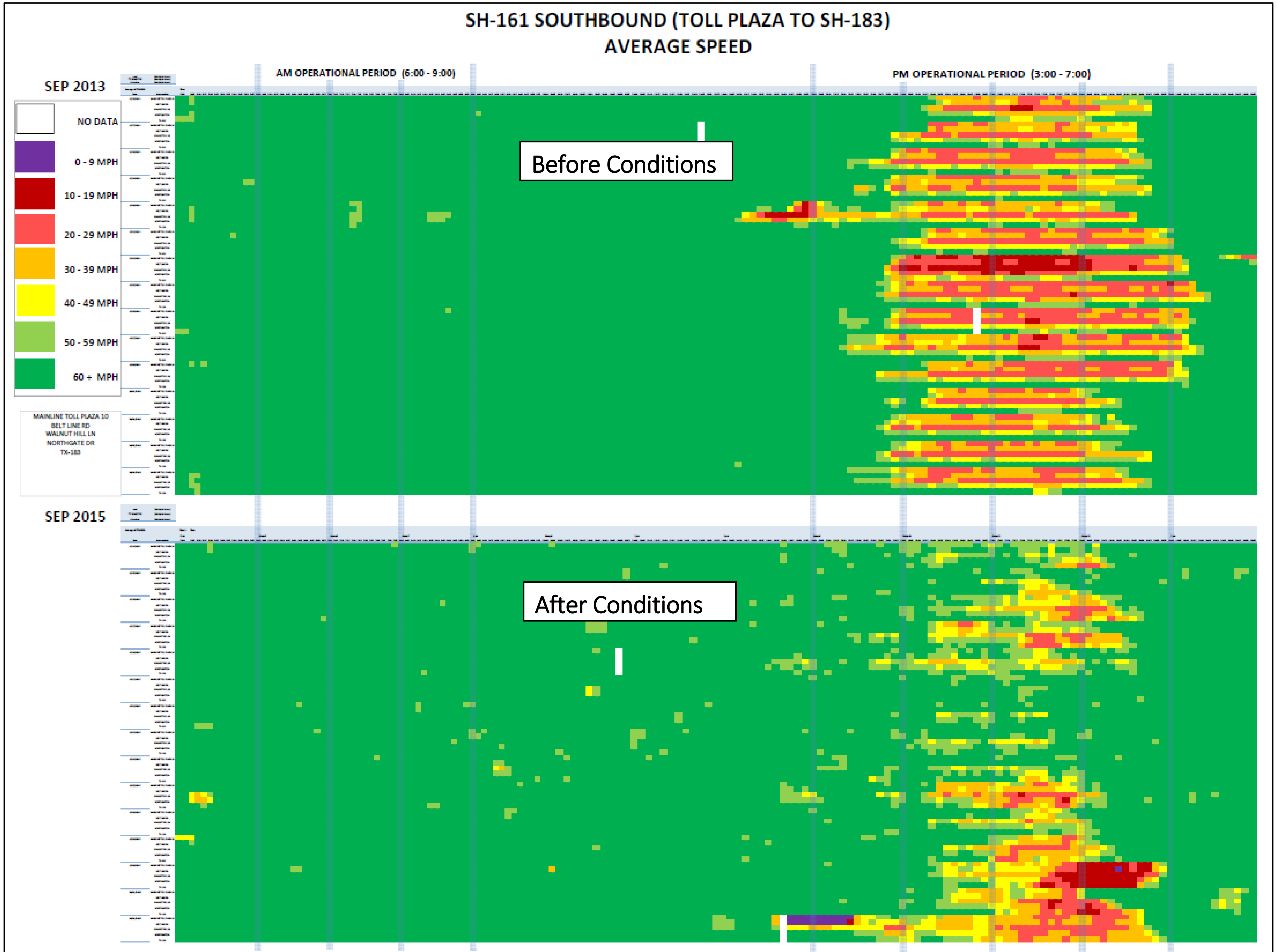


Figure 16. Comparison of "Before" and "After" Daily Average Speed Southbound.

Comparison of Vehicle Speeds

TTI installed Bluetooth readers at 30 locations (both directions) to measure speeds of vehicles and compared them "before" and "after" opening of the PHLs. Bluetooth technology identifies Media Access Control (MAC) identifications of either a mobile devices of motorists in vehicles or the vehicle themselves. Using multiple Bluetooth sensors, MAC IDs are matched and speeds on segments are determined. TTI measured vehicle speeds on eleven segments in both the northbound and southbound directions during morning and evening peak periods. Figure 17 displays the functionality of a typical Bluetooth monitoring setup.

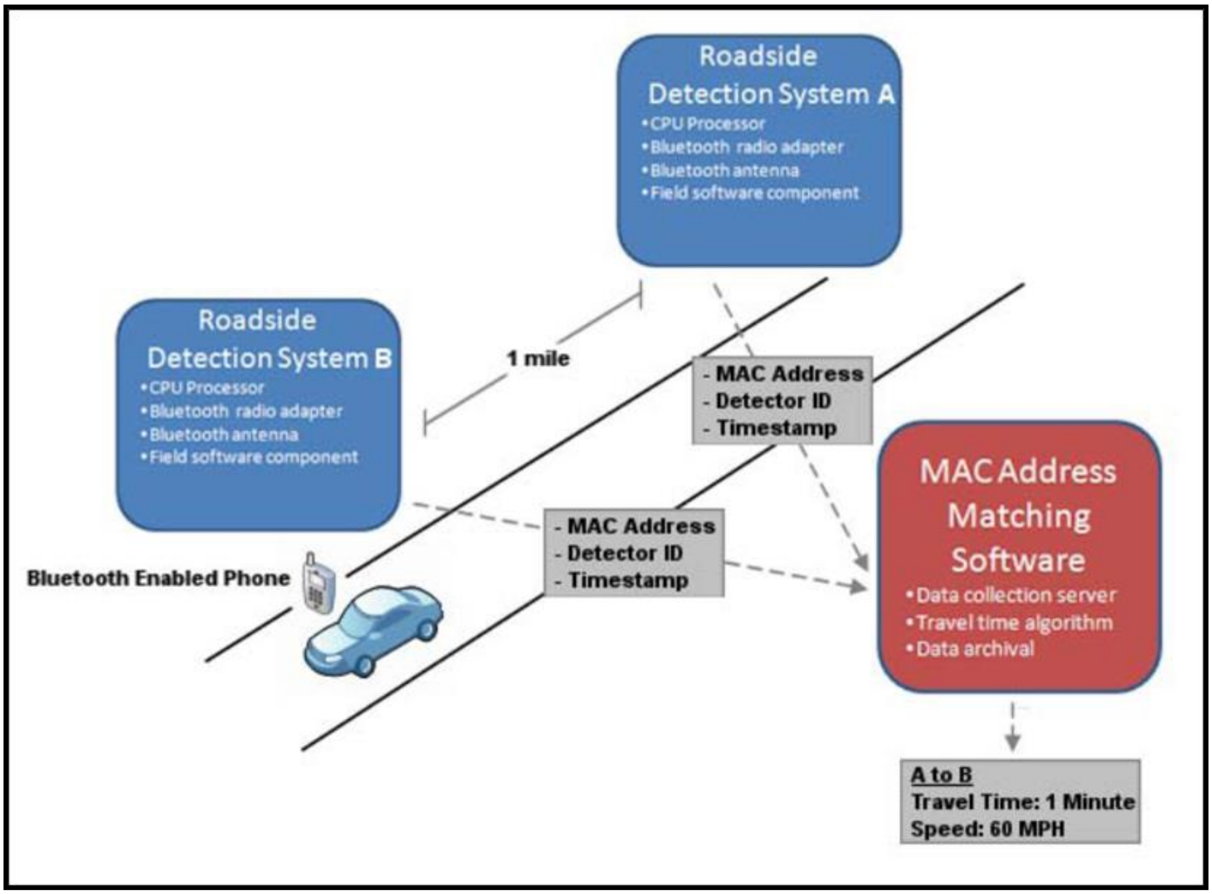


Figure 17. Typical Bluetooth Monitoring Setup.

Figure 18 and 19 show a comparison of vehicle speeds for all lanes for the southbound morning (top portion) and southbound evening (bottom portion) operational periods and peak hours, respectively, before and after the PHLs opened. The data was collected on the following dates:

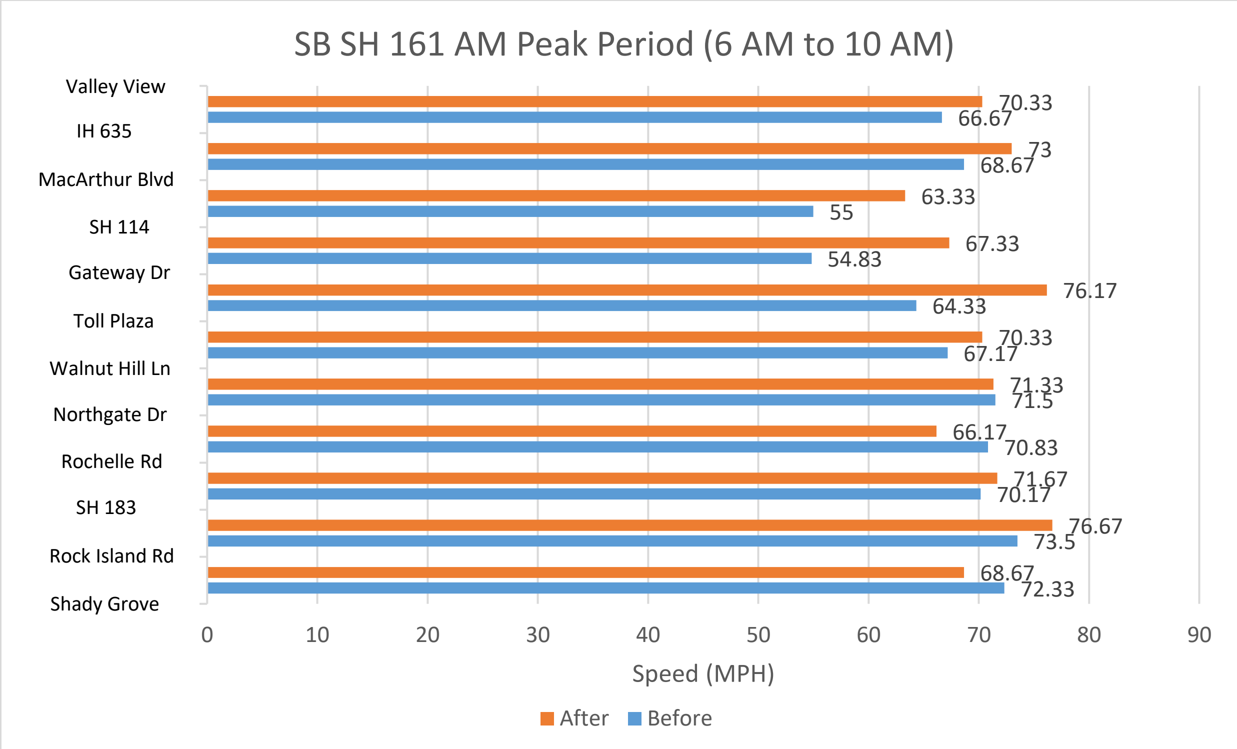
- Before Data: 10/29/2013 through 10/31/2013 (Tuesday through Thursday) and 11/05/2013 through 11/07/2013 (Tuesday through Thursday)
- After Data: 04/26/2016 through 04/28/2016 (Tuesday through Thursday) and 05/03/2016 through 05/05/2016 (Tuesday through Thursday)

"Before" speeds are represented by blue bars and "After" speeds are represented by orange bars. The segment limits are defined in Table 1. Figures 18 and 19 show that southbound morning speeds remained free-flow throughout the segment limits from a before/after comparison, as expected, since this is the off-peak direction of travel in the morning. In the southbound evening period, the before speed shows a disruptive flow pattern when compared to the after speeds.

While some after speeds in the southbound evening period are slower in some of the segments when compared to before speeds, the after speeds are more constant and steady throughout the segment limits when compared to the before speeds. Researchers suspect the southbound evening after speed impacts may be a result of both the queueing effects from the PGBT Western Extension capacity reduction at I-30 that is extending back to the SH183 interchange and also additional weaving for traffic accessing the SH183 direct connector ramps to SH183. Table 1 provides the peak period percentage change in speed at the 11 southbound study segments before and after PHLs went into operation.

Table 1. Percent Change in Vehicle Speeds in Southbound Direction.

Segments	Morning Peak Period			Evening Peak Period		
	"Before" Speed	"After" Speed	Percent Change	"Before" Speed	"After" Speed	Percent Change
Seg 1: North of IH 635 to North of MacArthur Blvd	66.7	68.7	+3%	65.2	52.5	-19%
Seg 2: North of MacArthur Blvd to South of MacArthur Blvd	68.7	73.0	+6%	68.5	42.8	-37%
Seg 3: South of MacArthur Blvd to North of SH 114	55.0	63.3	+15%	49.3	38.3	-22%
Seg 4: North of SH 114 to South of SH 114	54.8	67.3	+23%	26.7	37.5	+41%
Seg 5: South of SH 114 to Toll Plaza	64.3	76.2	+18%	36.2	42.8	+18%
Seg 6: Toll Plaza to North of Walnut Hill	67.2	70.3	+5%	38.8	46.8	+21%
Seg 7: North of Walnut Hill to North of Northgate	71.5	71.3	0%	39.3	45.3	+15%
Seg 8: North of Northgate to North of Rochelle	70.8	66.2	-7%	59.0	53.2	-10%
Seg 9: North of Rochelle to South of SH 183	70.2	71.7	+2%	65.0	44.7	-31%
Seg 10: South of SH 183 to North of Shady Grove	73.5	76.7	+4%	71.3	49.7	-30%
Seg 11: North of Shady Grove to End (South of Shady Grove)	72.3	68.7	-5%	67.7	49.2	-27%



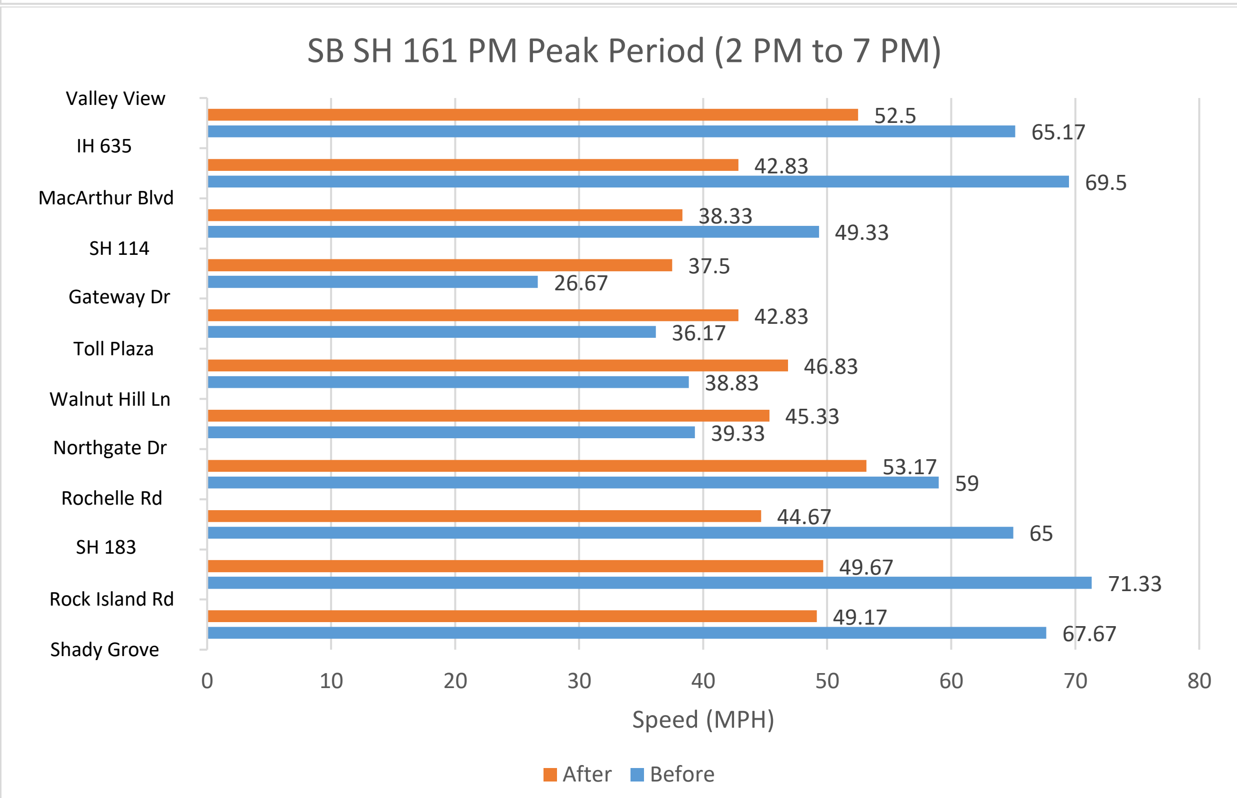
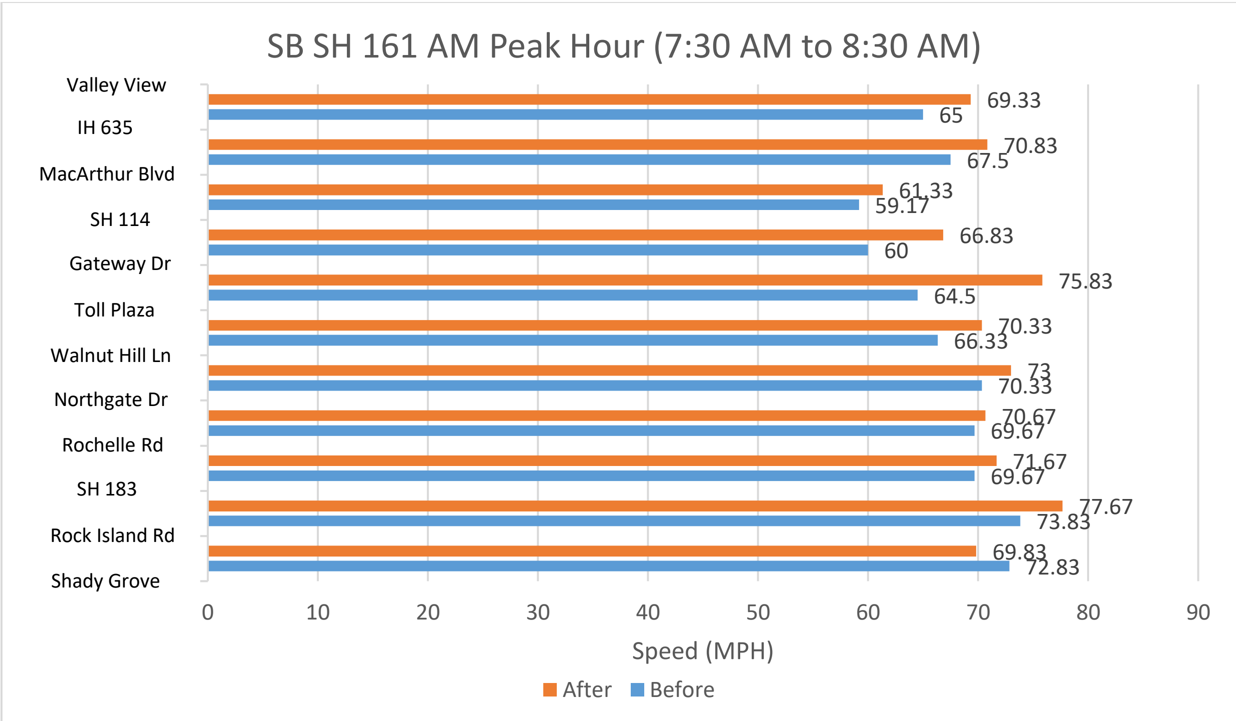


Figure 18. Comparison of Southbound Vehicle Speeds During Operational Periods.



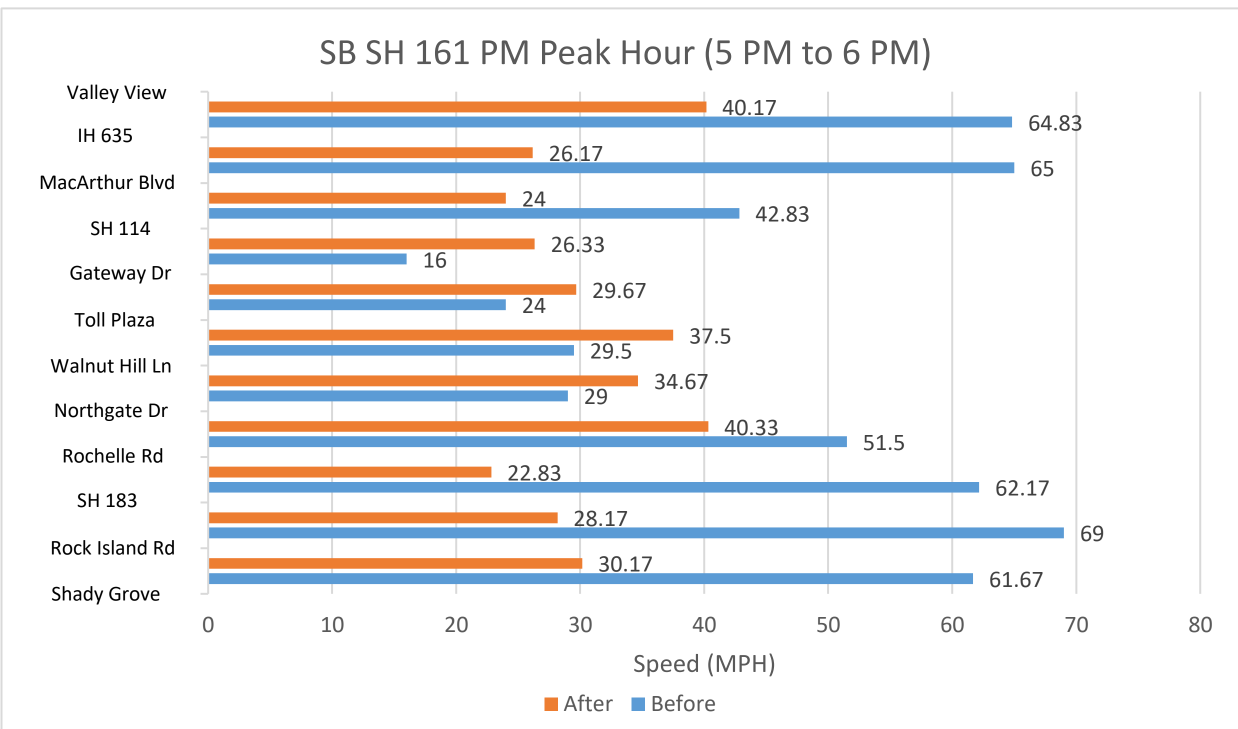
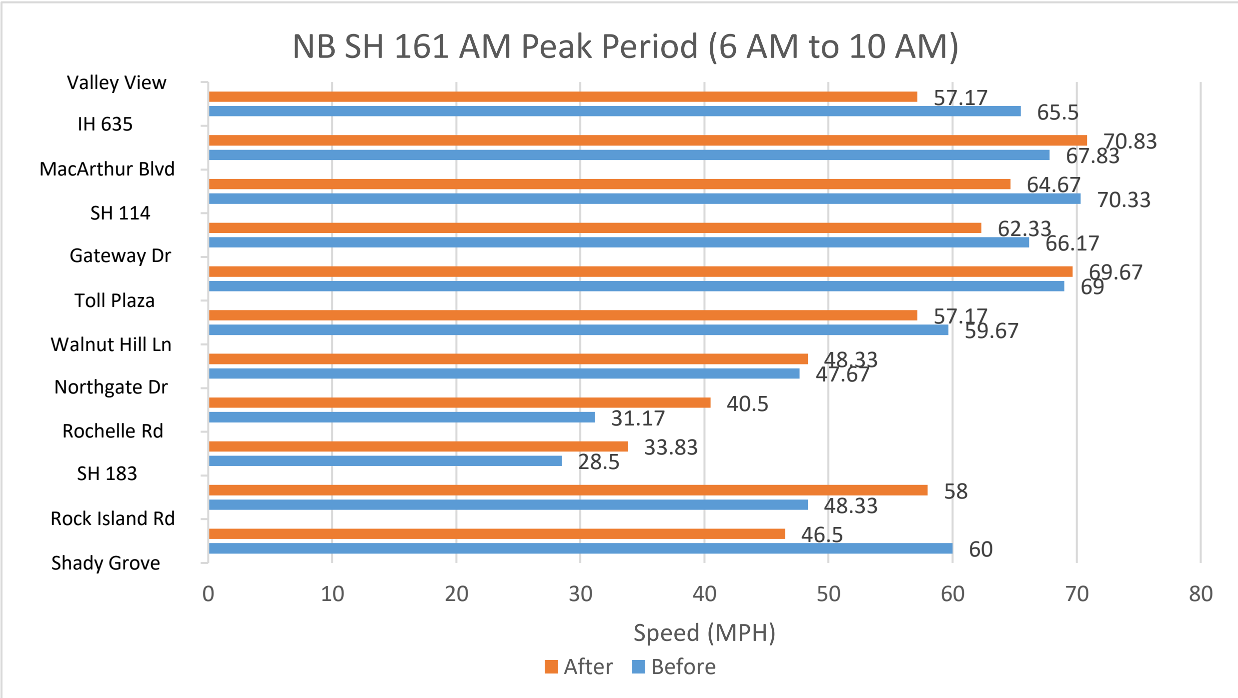


Figure 19. Comparison of Southbound Vehicle Speeds During Peak Hours.

Figure 20 and 21 show a comparison of vehicle speeds for all lanes for the northbound morning (top portion) and evening (bottom portion) operational periods and peak hours, respectively, before and after PHLs opened. Again, “before” speeds are represented by blue bars and “after” speeds are represented by orange bars. The segment limits have been defined in Table 2. The figures show variable and inconsistent increase in speed along the entire northbound segment during both the morning and evening peak periods. Table 2 provides the percentage change in speed at the 11 northbound study segments before and after PHLs went into operation.

Table 2. Percent Change in Vehicle Speeds in Northbound Direction.

Segment	Morning Peak Period			Evening Peak Period		
	“Before” Speed	**“After” Speed**	**Percent Change**	**“Before” Speed**	**“After” Speed**	**Percent Change**
Seg 1: South of Shady Grove to North of Shady Grove	60.0	46.5	-23%	75.5	65.8	-13%
Seg 2: North of Shady Grove to South of SH 183	48.3	58.0	+20%	75.7	77.5	+2%
Seg 3: South of SH 183 to North of Rochelle	28.5	33.8	+19%	68.0	68.2	0%
Seg 4: North of Rochelle to North of Northgate	31.2	40.5	+30%	66.0	73.8	+12%
Seg 5: North of Northgate to North of Walnut Hill	47.7	48.3	+1%	72.3	71.7	-1%
Seg 6: North of Walnut Hill to Toll Plaza	59.7	51.2	-14%	69.3	72.3	+4%
Seg 7: Toll Plaza to South of SH 114	69.0	69.7	+1%	71.2	77.7	+9%
Seg 8: South of SH 114 to North of SH 114	66.2	62.3	-6%	66.3	67.8	+2%
Seg 9: North of SH 114 to South of MacArthur Blvd	70.3	64.7	-8%	67.3	64.3	-4%
Seg 10: South of MacArthur Blvd to North of MacArthur Blvd	67.8	70.8	+4%	60.8	64.7	+6%
Seg 11: North of MacArthur Blvd to North of IH 635	65.5	57.2	-13%	47.0	33.7	-28%



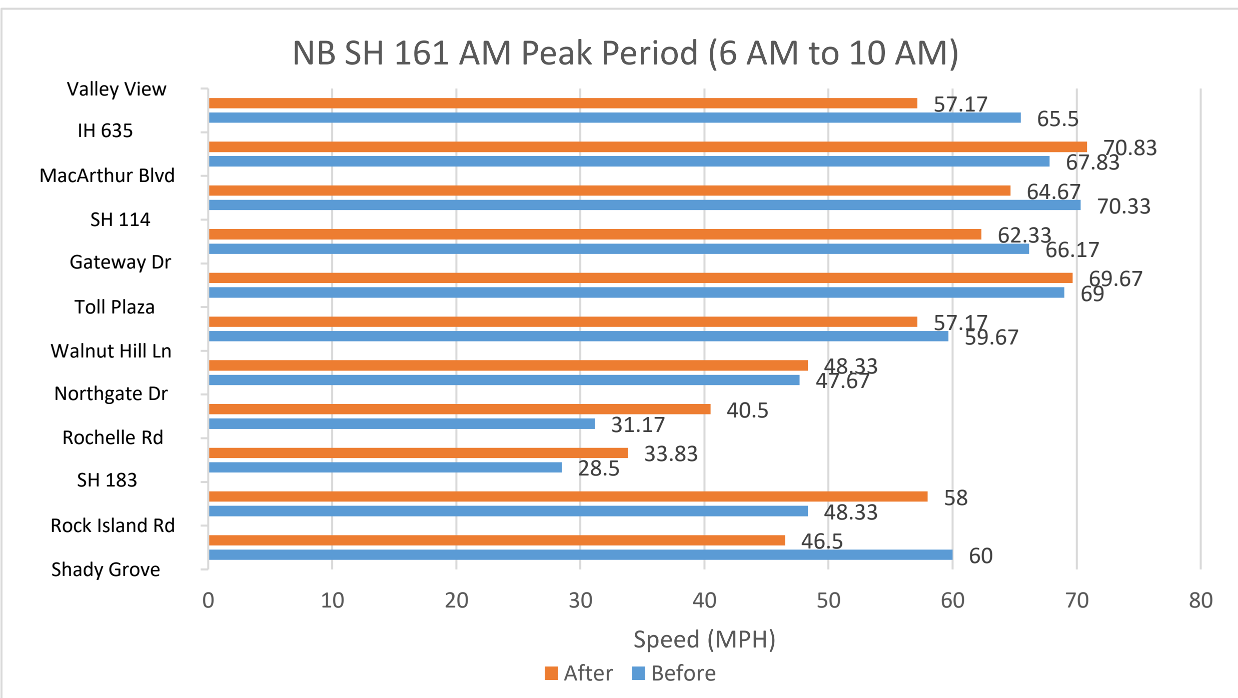
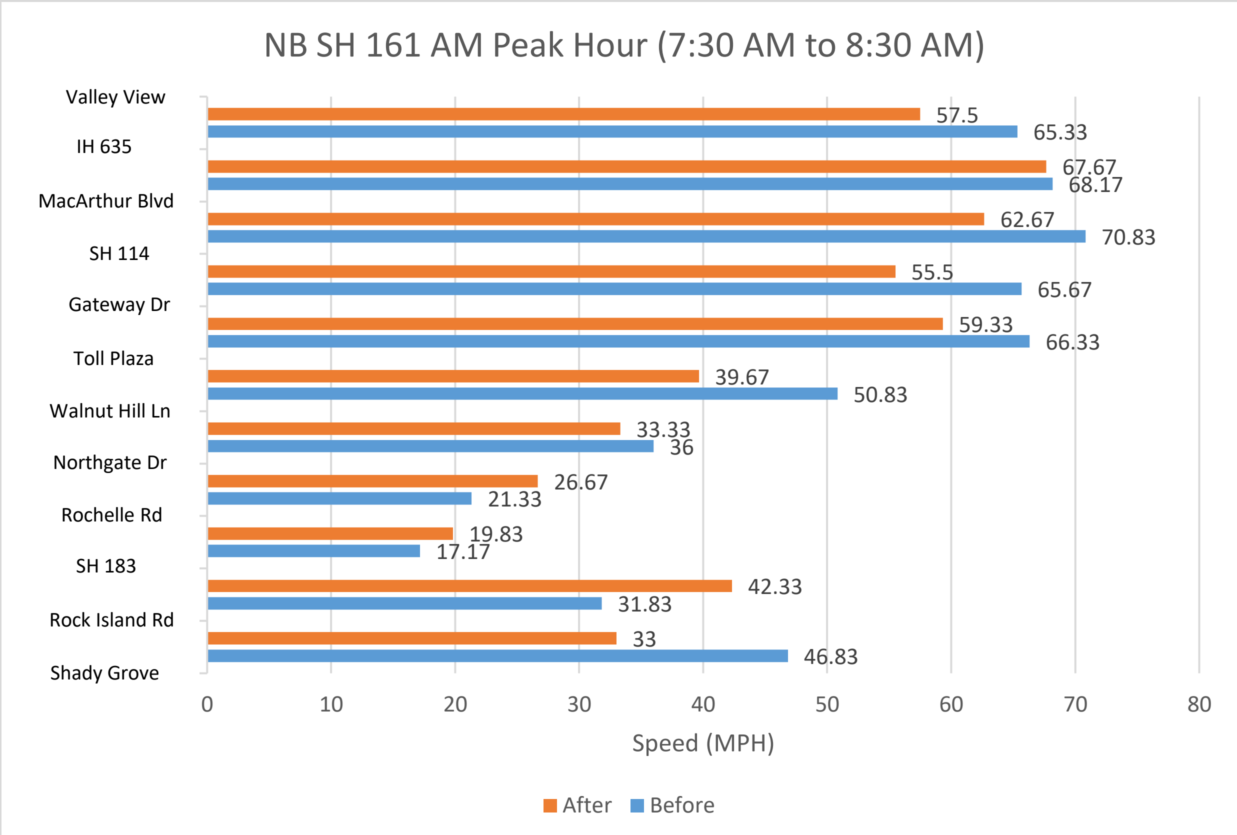


Figure 20. Comparison of Northbound Vehicle Speeds During Operational Periods.



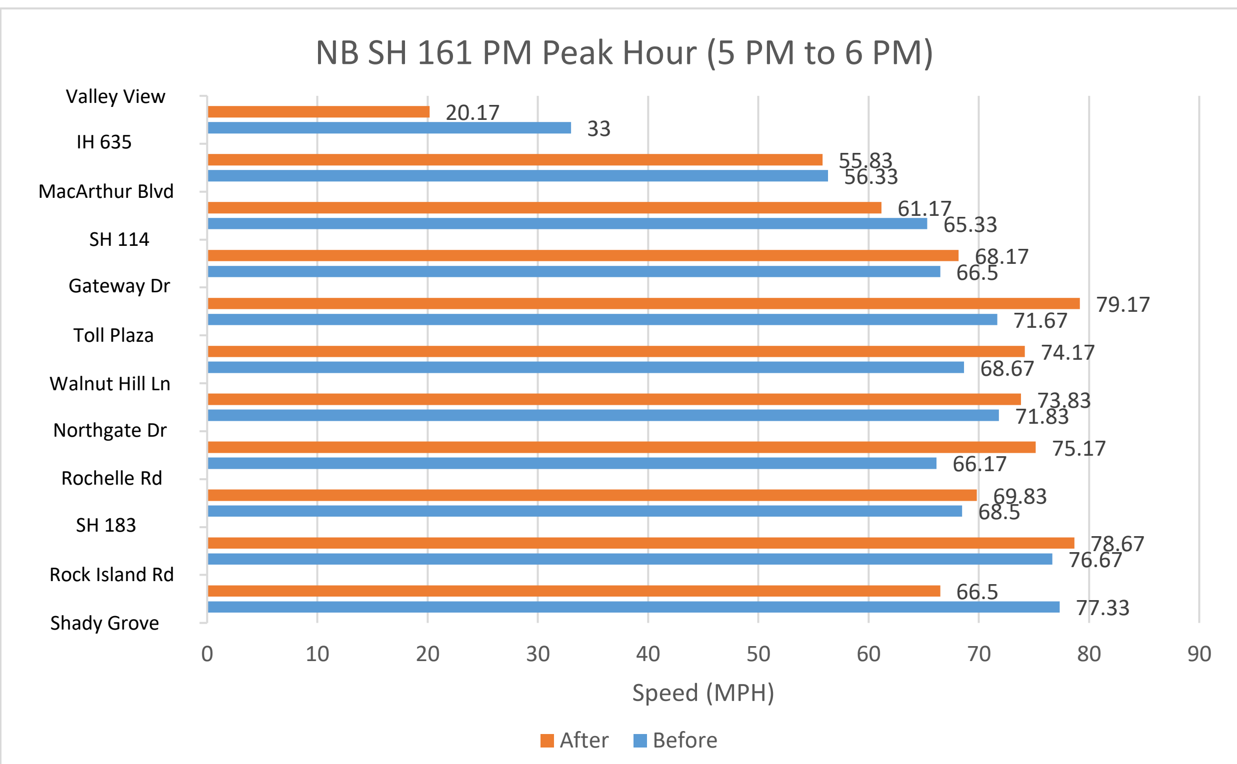


Figure 21. Comparison of Northbound Vehicle Speeds During Peak Hours.

TTI Speed Comparison

TTI collected speed data utilizing the floating car method on SH 161 before and after the PHL implementation. This method utilizes probe vehicles to collect travel time on SH 161 general-purpose lanes during the morning and evening peak periods. Two probe vehicles traveled the SH 161 main lanes beginning from Shady Grove Road (south of SH 183) to Valley View Lane (north of IH 635).

Figure 22 and 23 show a plot of each northbound travel time run during the morning period before and after PHL implementation, respectively. It can be seen in the before data that significant congestion was consistently experienced between Conflans Road north to near Walnut Hill Lane during the morning peak period with average speeds typically concentrated in this section between 5 mph and 25 mph. In the after data, it can be seen that congestion was less experienced between Conflans Road north to near Walnut Hill Lane during the morning peak period with average speeds that were less concentrated when compared to the before data and typically ranging from between 5 mph and 45 mph. This same pattern of before/after speeds in the northbound morning period tends to replicate what was shown in both the Inrix and Bluetooth speed data previously discussed.

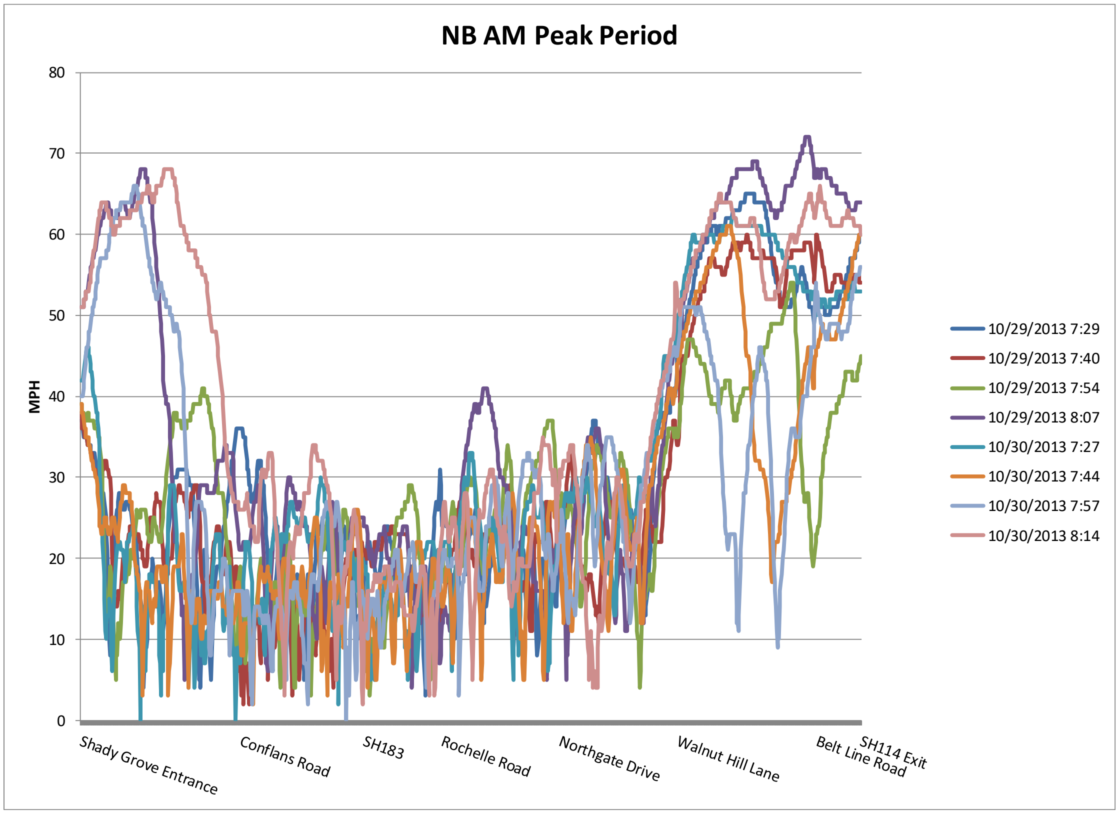


Figure 22. Morning Northbound Vehicle Speeds Before PHL.

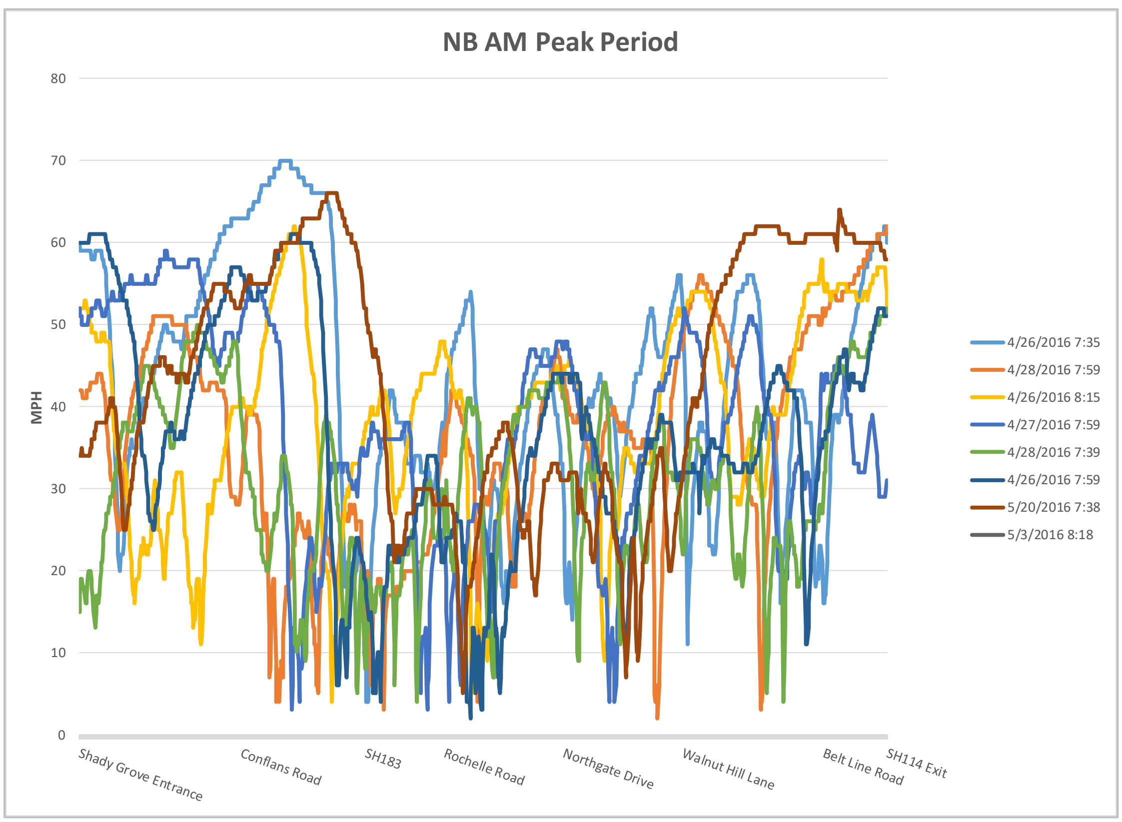


Figure 23. Morning Northbound Vehicle Speeds After PHL.

Figure 24 and 25 show a plot of each southbound travel time run during the evening period before and after PHL implementation, respectively. It can be seen in the before data that significant congestion was consistently experienced between SH 114 south to near Walnut Hill Lane during the evening peak period with average speeds typically concentrated in this section from less than 5 mph to near 30 mph. In the after data, it can be seen that congestion was less experienced between SH114 south to near Walnut Hill Lane during the evening peak period with average speeds that were less concentrated when compared to the before data and typically ranging from between 15 mph and 55 mph.

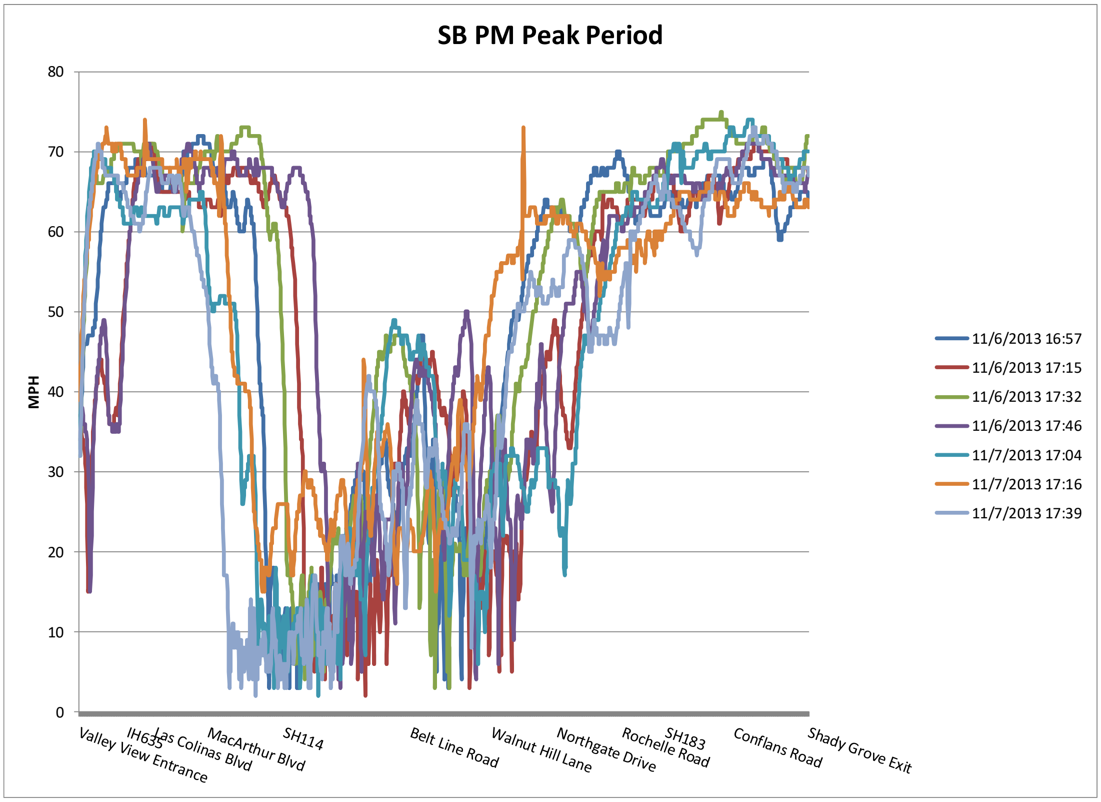


Figure 24. Evening Southbound Vehicle Speeds Before PHL.

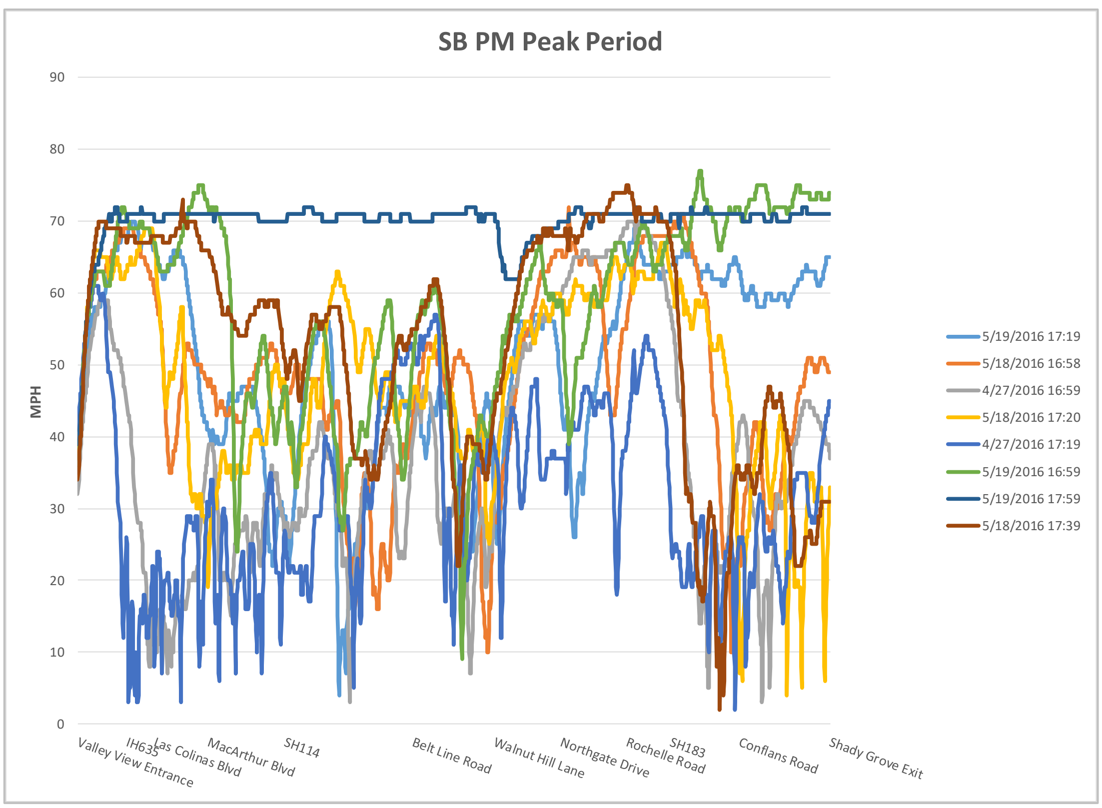


Figure 25. Evening Southbound Vehicle Speeds After PHL.

Queue Jumping

Queue jumping is the term used to define the action of motorist who by-pass a queued section of roadway by utilizing an exit ramp to entrance ramp maneuver. This maneuver can cause severe congestion when the entrance ramp being used for said purpose is a merge operation which then perpetuates the congestion upstream of the entrance ramp. TTI staff used a video trailer to video record at three locations in the SH 161 corridor before and after the PHLs were implemented to determine the percentage of vehicles that were exploiting the queue jump maneuver. Additionally, the percentage of vehicles which were already on the frontage road but chose to stay on the frontage road versus using an entrance ramp were also determined at the same locations.

In Figure 26, 27 and 28, the left figure shows a comparison of vehicles exiting a ramp and by-passing queueing traffic on the general-purpose lanes and are represented by a RED arrow in the figures. The top number represents the before data collected in 2013 and the bottom number represents the after data collected in 2016. In Figure 26 (left side), queue jumping between Walnut Hill Lane and Northgate Drive northbound in 2013 showed 77 percent of vehicles exited the ramp and returned via the entrance ramp to by-pass the queue on the general-purpose lanes during the morning period. After PHLs were implemented, that percentage decreased to 42 percent.

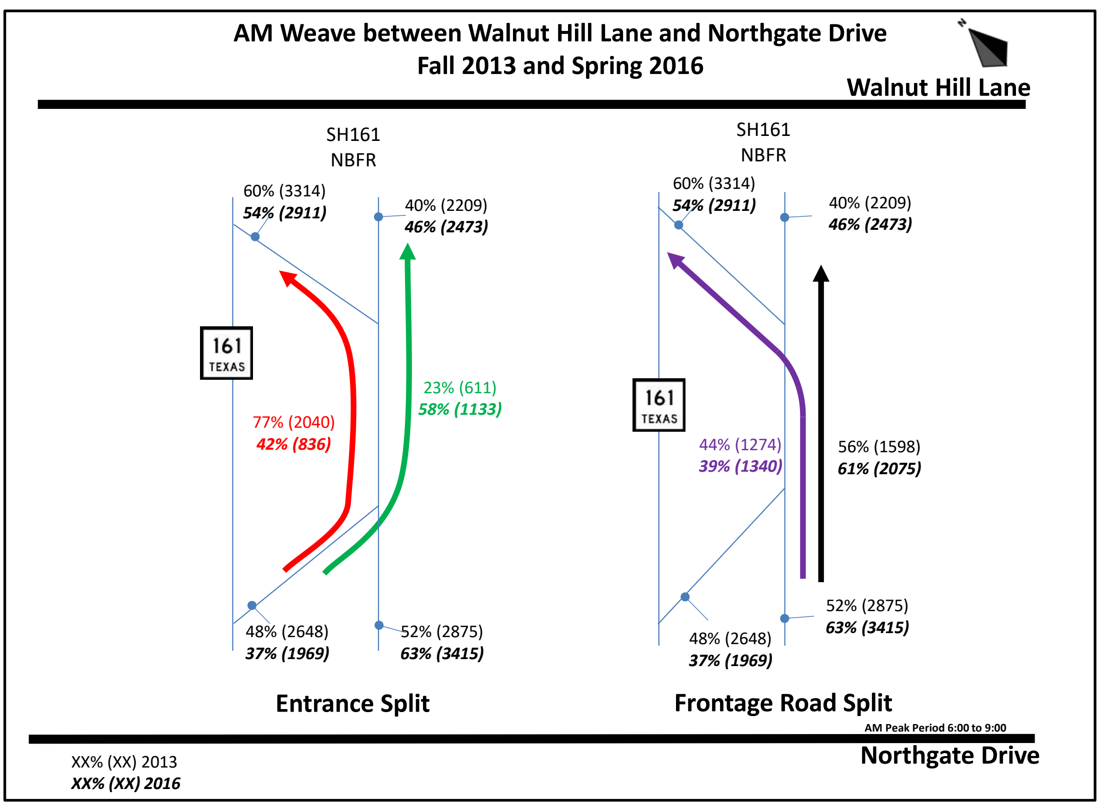


Figure 26. Before/After Comparison of Northbound Queue Jumpers During Morning Peak at Walnut Hill.

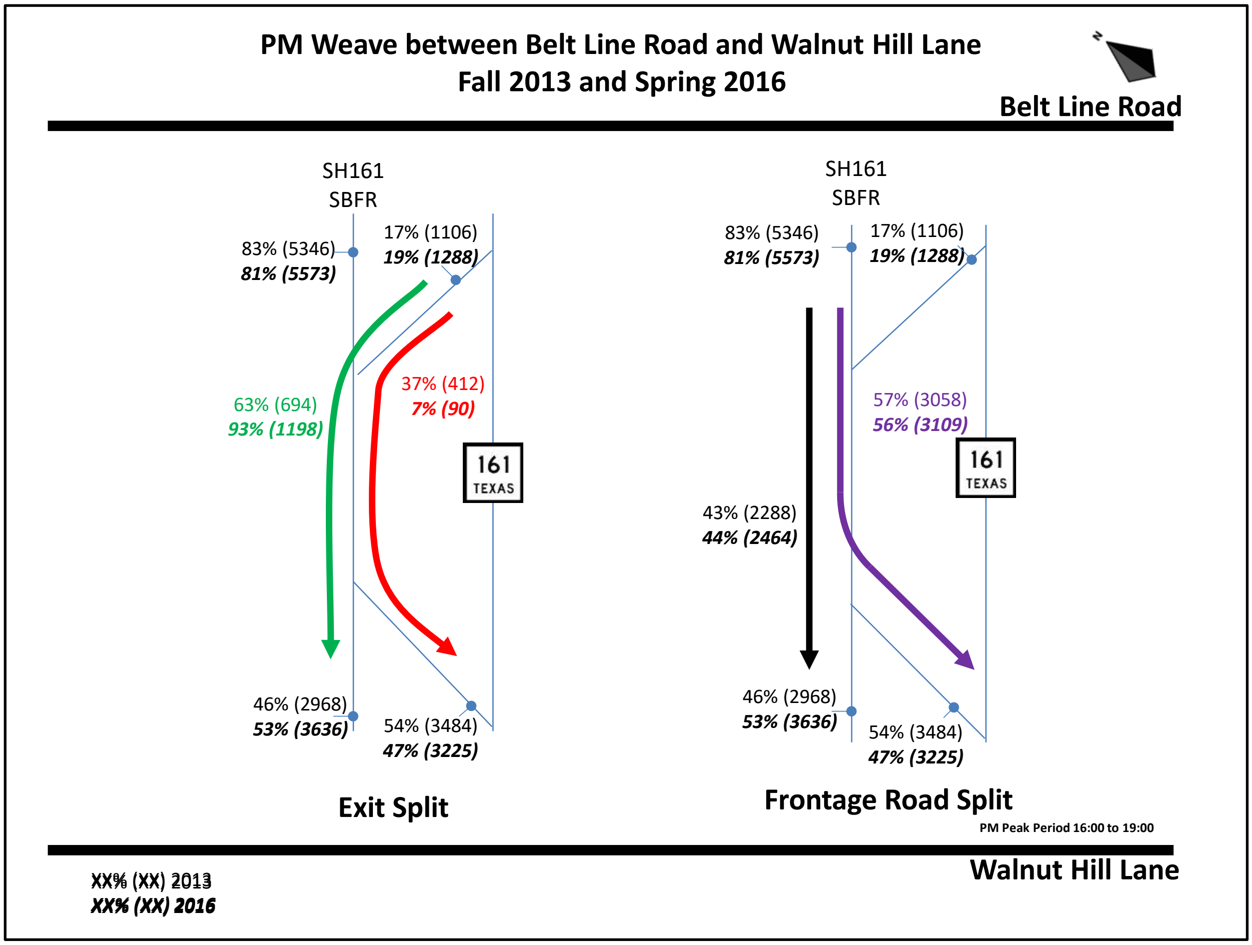


Figure 27. Before/After Comparison of Southbound Queue Jumpers During Evening Peak at Beltline Road.

Similarly, Figure 7 (left side) shows queue jumping between Beltline Road and Walnut Hill Lane southbound in 2013 with 37 percent of vehicles exiting the ramp and returning via the entrance ramp to by-pass the queue on the general-purpose lanes during the evening period. After PHLs were implemented, that percentage decreased to 7 percent.

Finally, Figure 28 (left side) shows minimal queue jumping between Walnut Hill Lane and Northgate Drive southbound in 2013 with 1 percent of vehicles exiting the ramp and returning via the entrance ramp to by-pass the queue on the general-purpose lanes during the evening period. After PHLs were implemented, that percentage remained at 1 percent.

It is interesting to note that at each of the queue jump locations, the volumes that used the exit ramp and remained on the frontage road showed significant increases at all of the locations. Researchers suspect that this is due to local traffic returning to the SH 161 corridor after the implementation of the PHLs.

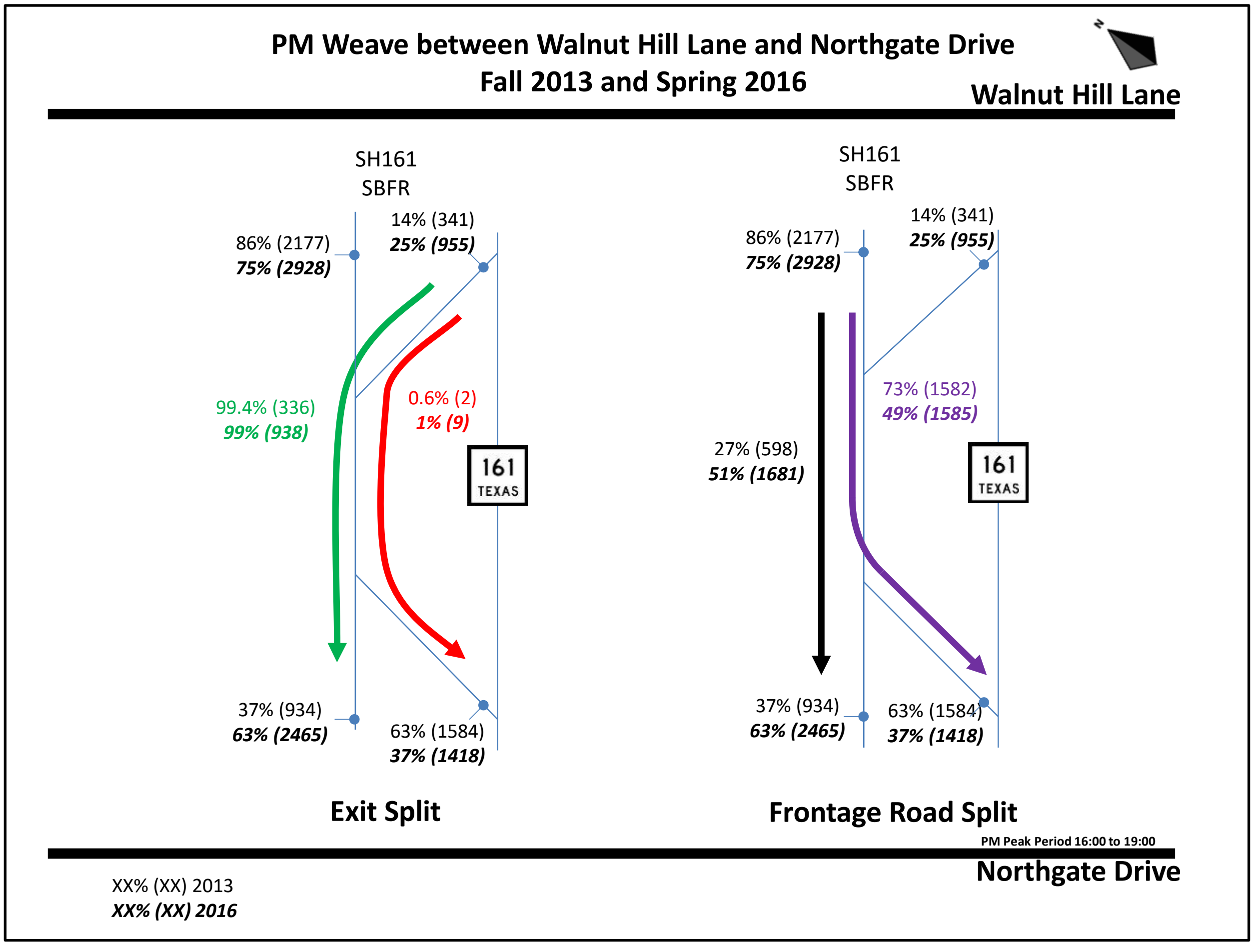


Figure 28. Before/After Comparison of Southbound Queue Jumpers During Evening Peak at Walnut Hill Lane.

Origin/Destination Analysis

Origin and destination patterns were derived from the use of Bluetooth technology. As previously stated, Bluetooth technology identifies Media Access Control (MAC) identifications of either a mobile device of motorists in vehicles or the vehicle themselves. Using multiple Bluetooth sensors, MAC IDs are matched at various locations throughout the study limits to determine where vehicles have traveled from (origins) and where vehicles are traveling to (destinations). Bluetooth sensors were placed on major freeway sections as well as on arterial routes within the SH 161 corridor. The Origin/Destination analysis included looking at data for each operational period and peak hour for each direction of travel on SH 161. For this memorandum, only the peak direction of travel during the peak hour (northbound in the morning and southbound in the evening) will be reported and discussed.

Morning Northbound

Travel patterns during the morning northbound SH 161 corridor were derived from origins beginning on SH 161 south of SH 183 and traveling northward to destinations either to SH 183, SH 114, IH 635, arterials along the SH 161 corridor or through the corridor beyond IH 635 on the north end of the study limits. Figure 29 provides the percent of origin/destination traffic before and after implementation of the PHLs for the morning peak hour from 7:30 a.m. to 8:30 a.m. Some of the more notable changes in traffic patterns after the implementation of the PHLs for the morning northbound traffic include:

- Decrease in percent of traffic going to eastbound SH 183
    - Possibly due to the decrease in congestion on SH 161 north of SH 183

- Increase in percent of traffic going to westbound SH 183
    - Possibly due to the decrease in congestion on SH 161 south of SH 183 allowing better access to the direct connect ramps

- Increase in percent of traffic going to northbound Beltline Road
    - Possibly due to the decrease in congestion on SH 161 north of SH 183

- Increase in percent of traffic going to eastbound IH 635
    - Possibly due to the decrease in congestion on SH 161 and greater usage of IH 635 and LBJ Express

- Decrease in percent of traffic continuing on to PGBT north of IH 635
    - Possibly due to the congestion on PGBT to the north and greater usage of IH 635 and LBJ Express

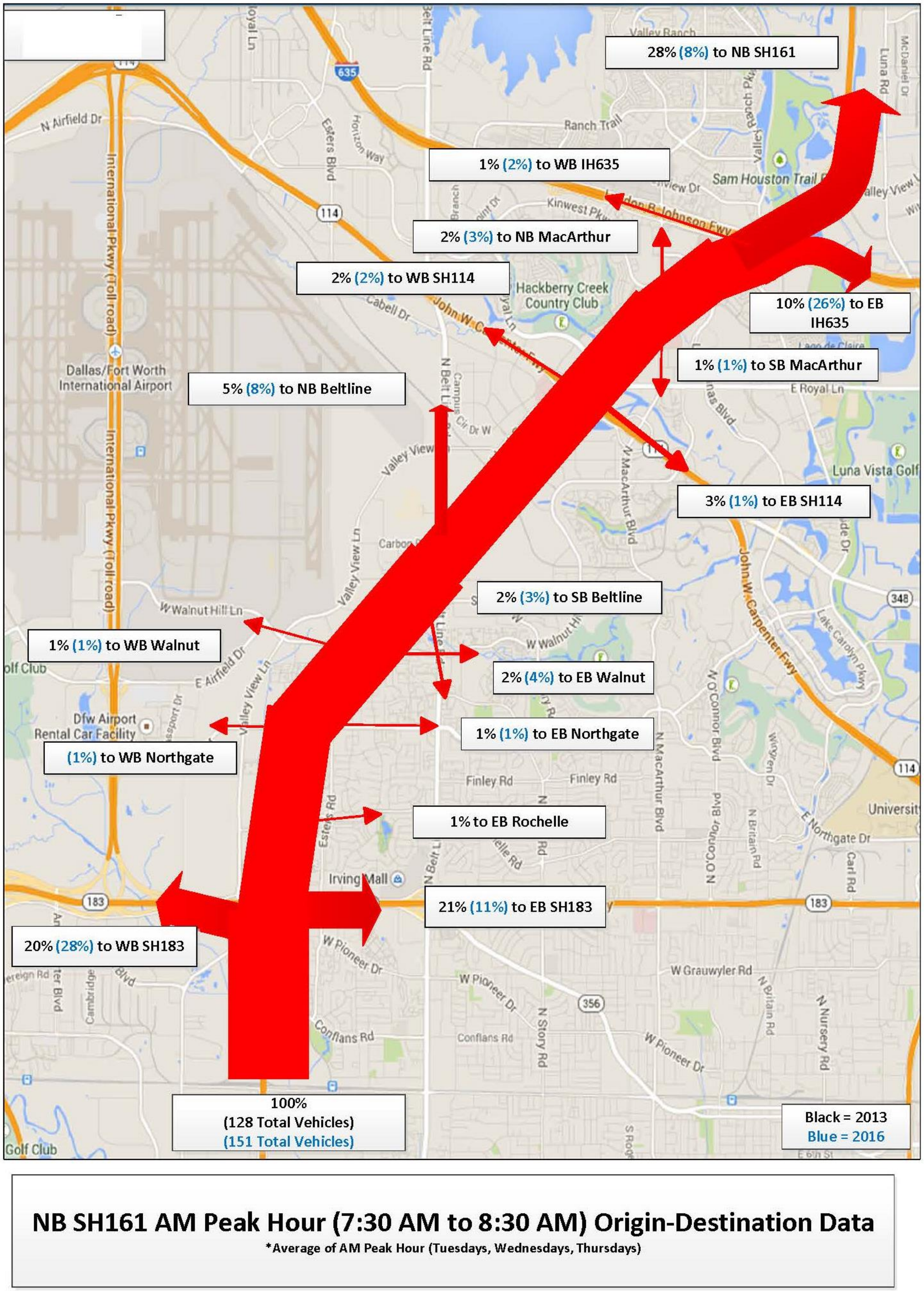


Figure 29. Before/After Comparison of Origin/Destination Data in Northbound Direction During Morning Peak Hour.

Evening Southbound

Travel patterns during the evening southbound SH 161 corridor were derived from origins beginning on SH 161 north of IH 635 and traveling southward to destinations either to IH 635, SH 114, SH 183, arterials along the SH 161 corridor or through the corridor beyond SH 183 on the south end of the study limits. Figure 30 provides the percent of origin/destination traffic before and after implementation of the PHLs for the evening peak hour from 5:00 p.m. to 6:00 p.m. Some of the more notable changes in traffic patterns after the implementation of the PHLs for the evening southbound traffic include:

- Decrease in percent of traffic going to westbound IH 635
  - Possibly due to the greater usage of IH 635 and LBJ Express

- Increase in percent of traffic going to southbound Beltline Road
  - Possibly due to the decrease in congestion on SH 161 south of SH 114

- Increase in percent of traffic going to westbound SH 183
  - Possibly due to the decrease in congestion on SH 161

- No change in percent of traffic continuing on to PGBT Western Extension south of SH 183

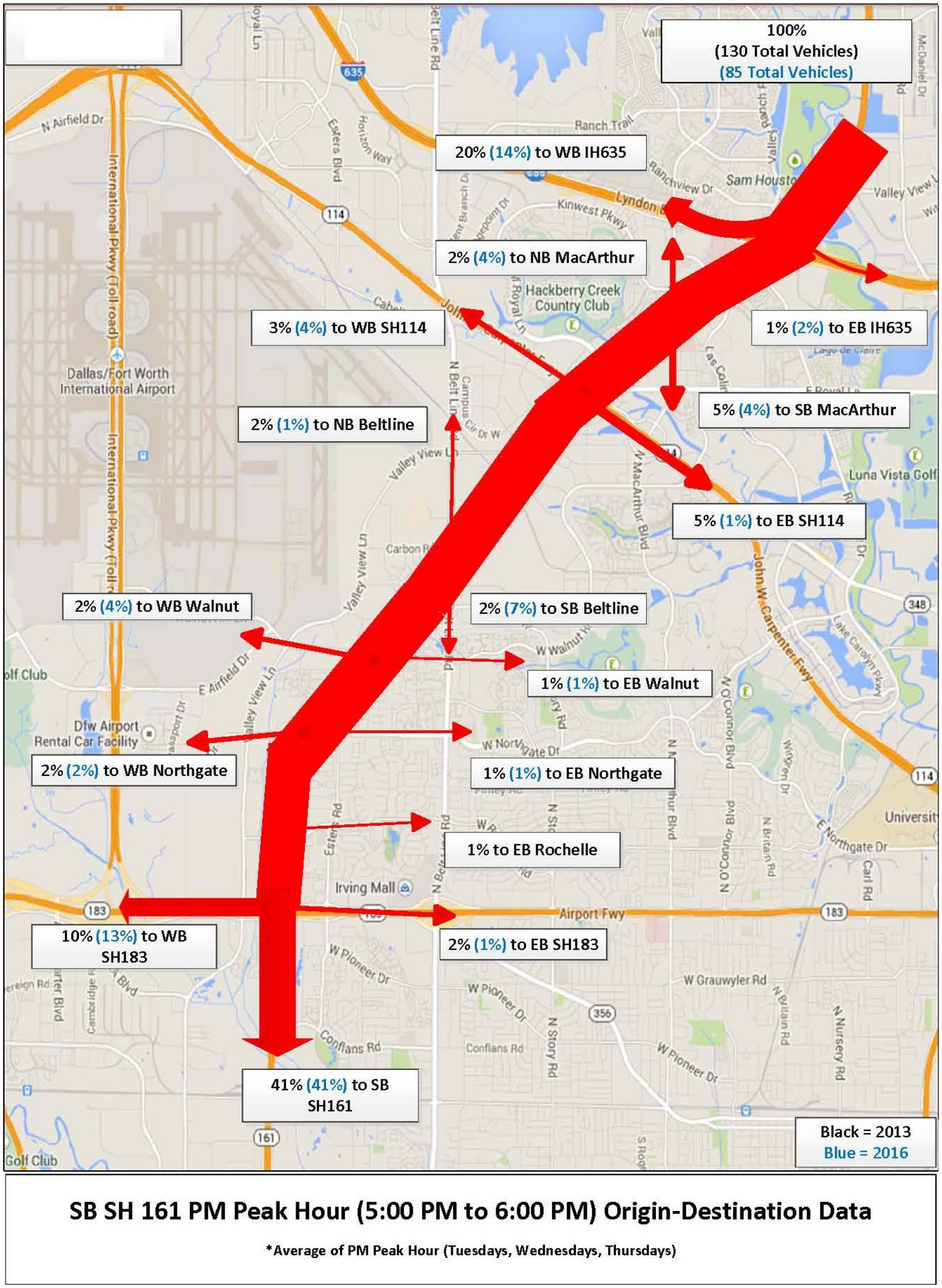


Figure 30. Before/After Comparison of Origin/Destination Data in Southbound Direction During Evening Peak Hour.

Comparison of Crashes

Crash data was extracted February 28, 2017 for the period from January 1, 2012, through January 14, 2017. Figure 31, through Figure 33 represent SH 161 crash data located in the City of Irving from Conflans Road to Gateway Drive on the general-purpose lanes, exit ramps, entrance ramps and connectors (excludes arterial, service road and other). Cross street crash locations were determined by taking the half-way point between adjacent cross streets. Crash data analysis included looking at crash frequency as is related to various factors such as time of day, day of week, location, crash rates, severity, manner of collision and contributing factors. For purposes of this memorandum, the following discussion was determined to be the important findings as they relate to crash information.

Figure 31 shows the crash frequency for both directions of travel on SH 161 by location by year. The peak-hour lane became operational September 14, 2015, therefore for analysis purposes, the annual crash data was determined for each year from September 14 to September 13 for years 2013-2016. Figure 31 shows crash frequency increasing on an annual basis at Beltline Road while other locations remain relatively constant across time.

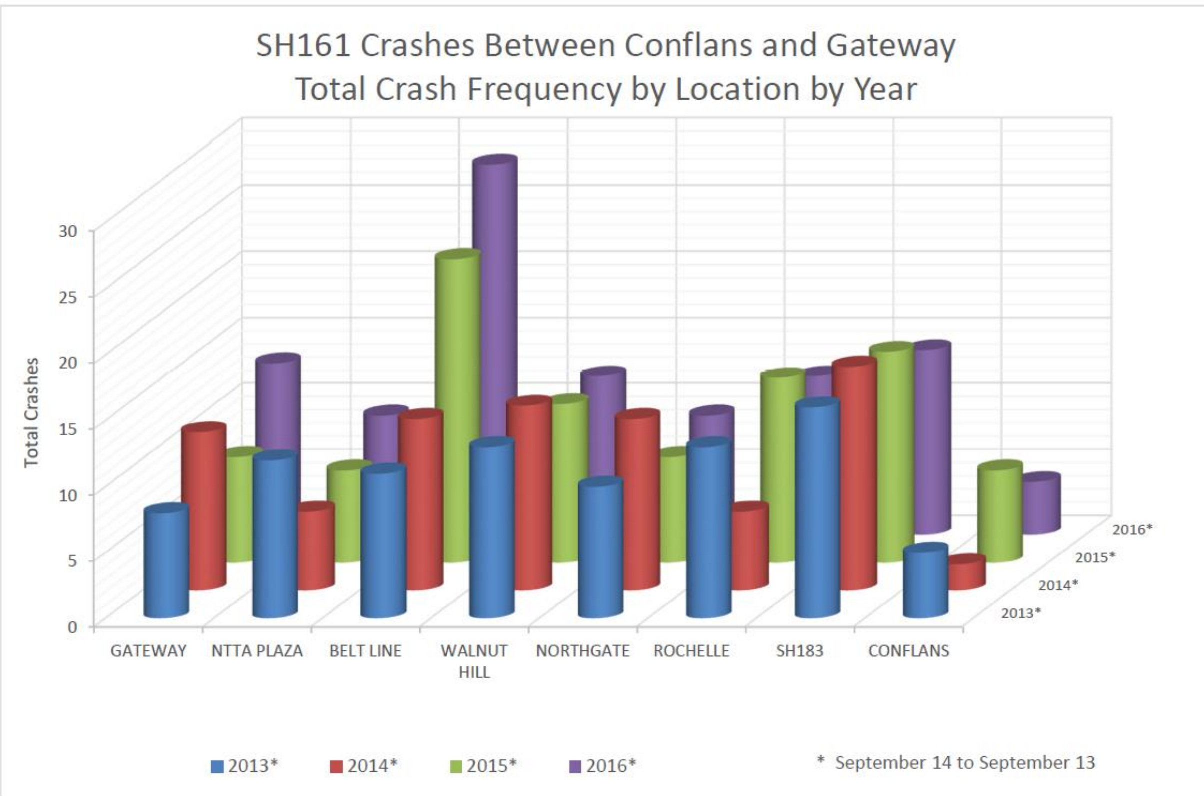


Figure 31. Before/After Comparison of Total Crashes at Various Locations.

Figure 32 displays the crash frequency on SH 161 by operational period by direction by year. This figure shows the crash frequency typically decreasing each year in the northbound morning operational time period and a converse trend in the southbound evening operational time period where crashes typically increased each year throughout the limits of the PHL.

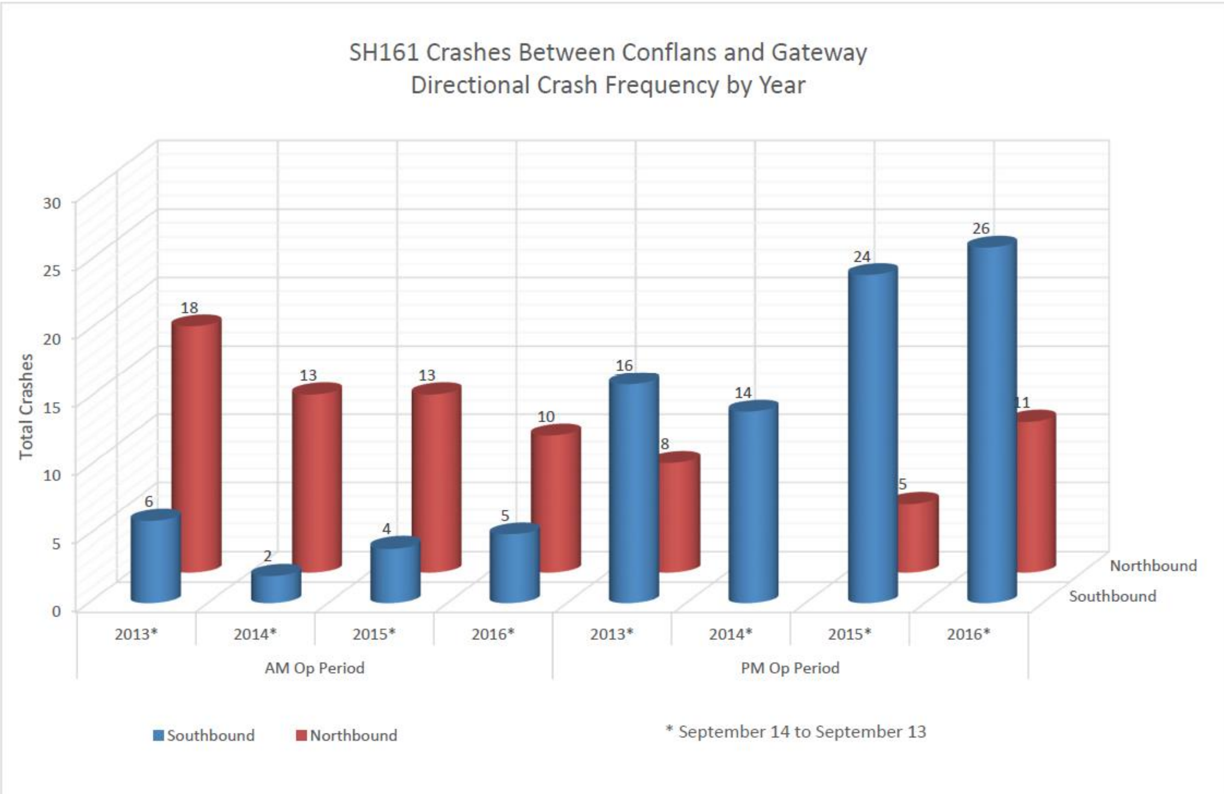


Figure 32. Before/After Comparison of Total Crashes Between Conflans and Gateway.

Figure 33 shows the injury crash rate calculation on SH 161 between Walnut Hill Lane and Beltline Road by year. Again, the PHLs became operational September 14, 2015, and therefore annual injury crash data was determined for each year from September 14 to September 13 for years 2013-2016. Annual average daily traffic (AADT) data was derived for years 2012 through 2015 and extrapolated to year 2016. The crash rate change revealed an overall crash rate increase from 18 crashes per 100M VMT in 2013, to 23 crashes per 100M VMT in 2016. The net change is +5 crashes per 100M VMT, or a 28 percent increase. It should be noted that crash data is more statistically valid when more after data is available, typically three years of after data.

Injury crash rate calculation (KABC)

Year	Crashes	VMT	100Mil VMT	Crash Rate
2013	36	204138113	2.04138113	18
2014	40	208121248	2.08121248	19
2015	49	218716505	2.18716505	22
2016	51	221215879	2.21215879	23

Year	AADT	
2012	105000	
2013	105525	
2014	107584	
2015	113061	
2016	114353	forecast

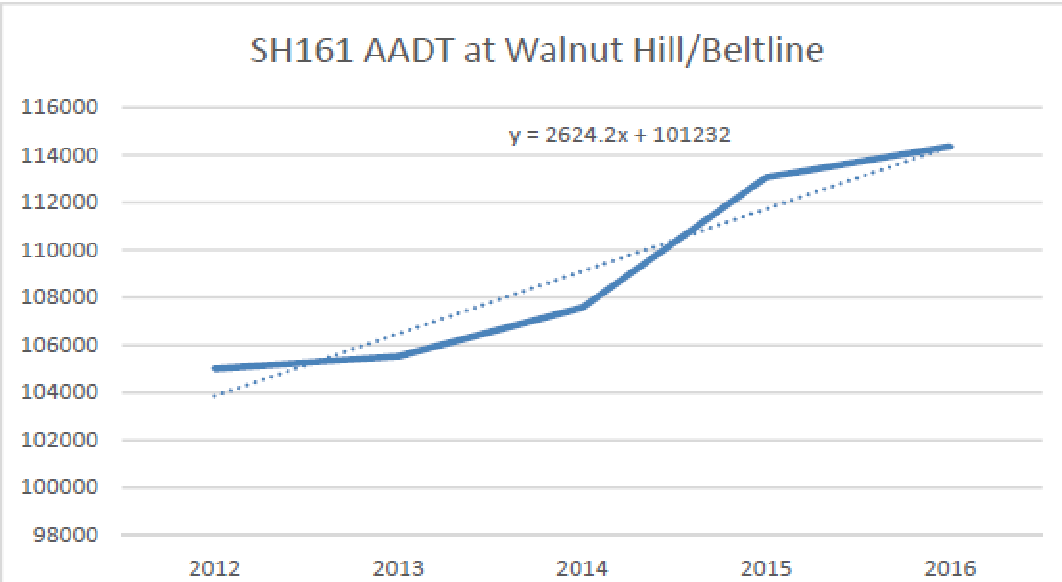


Figure 33. Before/After Crash Rates and AADT Between Walnut Hill Lane and Beltline Road.

Vehicle Violations

TTI staff conducted a study of the number of violations at different times of day after PHLs went into operation. Using NTTA transaction data, TTI staff were able to determine how many vehicles used PHLs when they were in fact closed and advertised closed during weekday times and weekends.

Figure 34**Error! Reference source not found.** shows patterns of the number of violations between September 4, 2015 to October 2, 2015 and between May 1, 2016 to May 31, 2016. In September 2015 when the PHLs first opened, violations were minimal except during weekend special events on September 26 and 27, as indicated by two spikes in each direction. However, after six months of operations, PHL violations are more prevalent. In fact, violations occur throughout the day on Saturdays and Sundays, and on the holiday of Memorial Day (May 30, 2016).

During weekdays, the violations rates ranged from 50 to 100 violations per hour in the northbound direction with a peak violation rate of 400 vehicles per hour on Wednesday, May 18, 2016, possibly due to an incident in the general-purpose lanes. Southbound violations on weekdays typically range from 100 to 150 violations per hour with a peak violation rate of 350 vehicles per hour on Tuesday, May 31, 2016. The peak violation rates for both directions tend to occur just prior to the opening times of the PHLs and just after the closing times of the PHLs.

Figure 35 shows the distribution of violations between the morning and evening PHL operational periods at different segments as measured in May 2016. The number of violations are higher at 10 a.m. time period, again, probably from spillover of morning rush hour traffic. Violations then subside in the mid-day. Violations start to increase as the evening PHL operational period is about to begin. These spikes are right before PHLs open or right after they close. Typically, the PHLs are closed Saturdays and Sundays. However, violations occur on Saturdays and Sundays especially because of special events at nearby high capacity venues.

Researchers traveling the SH161 PHL corridor during mid-day hours have not seen a law enforcement presence enforcing the PHLs. Due to absence of active enforcement, violations during off peak periods and weekends is anticipated to remain a common occurrence.

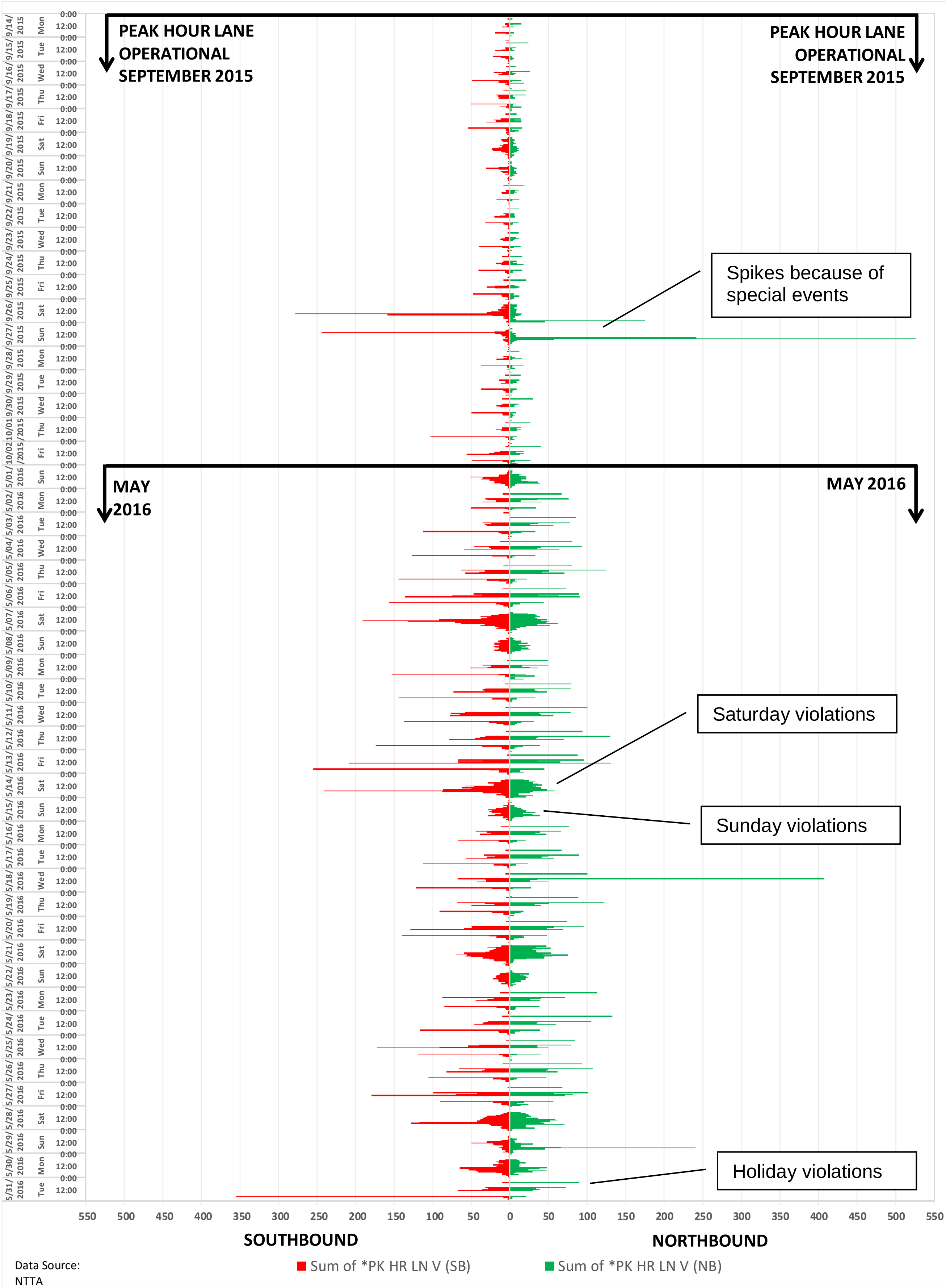
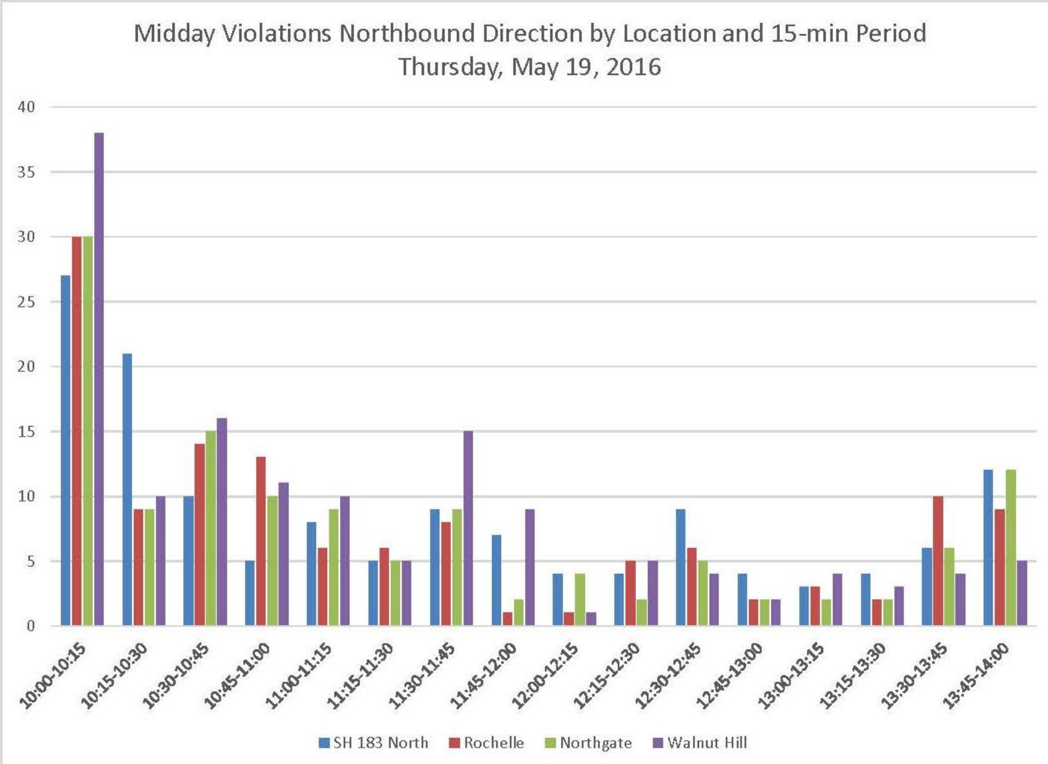


Figure 34. SH 161 at Beltline Road Toll Plaza Directional By-Hour PHL Violations.



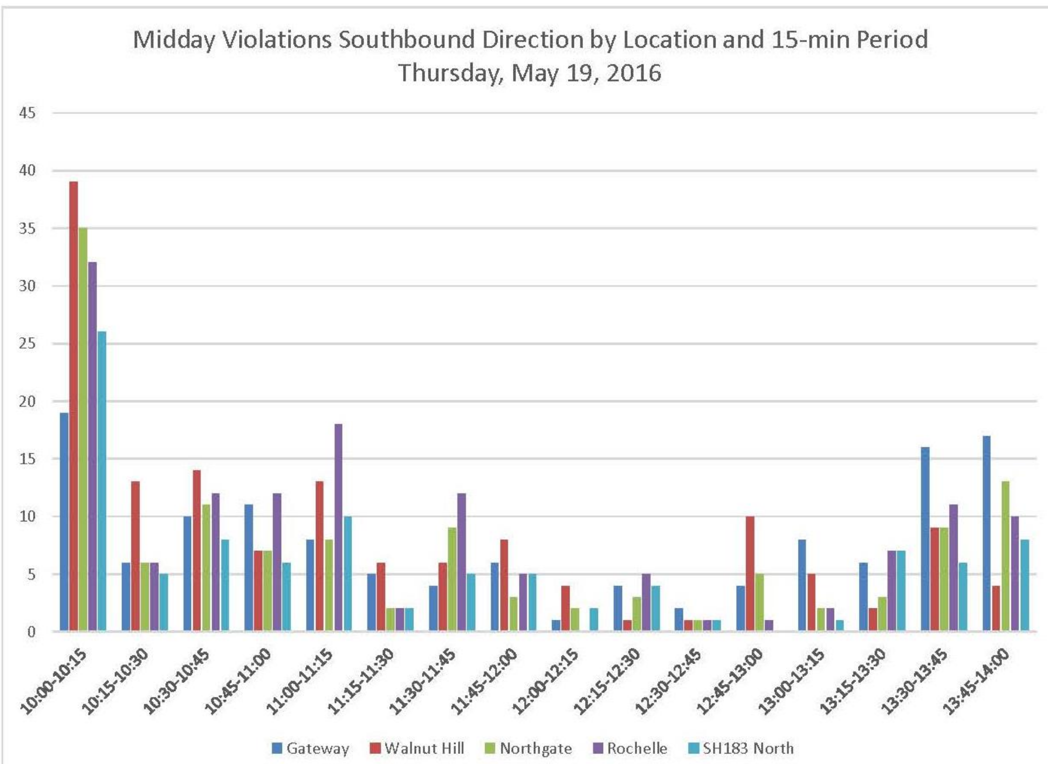


Figure 35. Distribution of Weekday PHL Violations Between Morning and Evening Operational Periods.

DAILY OPERATION OF PHL

This section describes tasks undertaken by different agencies to ensure the PHLs are ready to open for traffic every day and the associated costs to implement and operate PHLs.

Legislation

Texas Administrative Code Section 545.058(b)(2) allows a motor vehicle operator "to drive on an improved shoulder to the left of the main traveled portion of a divided or limited-access or controlled-access highway if that operation may be done safely," and is "permitted or required by an official traffic-control device". The code can be accessed at the following web site:

http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.545.htm

Motorist Assistance

NCTCOG acquired the services of a towing company to quickly remove abandoned vehicles and debris from PHLs. The towing company visually inspects the PHLs prior to each period the lanes are opened, typically twice per weekday, and then the towing vehicles are on standby within the corridor to respond to incidents for the remainder when the PHLs are operational. The towing company works closely with the TxDOT traffic management center operators to notify when the lanes have been visually inspected prior to opening and when there is any debris or abandoned vehicles that need to be removed.

Daily Sweep

TxDOT uses traffic cameras to visually "sweep" the PHLs in various locations to ensure there are no debris and abandoned vehicles while the PHLs are operational. The towing company also performs daily physical sweep of PHLs prior to each morning and evening openings to remove debris and/or abandoned vehicles, and to report to the traffic management center (Daltrans) that the PHL operational signals may indicate that the lane is open by changing to the GREEN ARROW.

Capital and Operational Costs

TxDOT acquired services of a contractor to install additional traffic cameras close to entrances and exits of PHLs, dynamic and static message signs, additional illumination, towing company, pavement markings, and emergency pull off locations. Bid cost for the project was $3.7 million.

Additionally, NCTCOG retained services of a towing company at the rate of $15,000 per month to sweep daily PHLs before they open and strategically place towing vehicles in case abandoned or disabled vehicles have to be moved from PHLs.

Furthermore, operators at DalTrans perform visual sweep of PHLs and closely monitor the PHLs around opening and closing times. They work together with the towing company to report abandoned and disabled vehicles as well as debris. Estimated cost of DalTrans staff time is

$37,100 per month. DalTrans staff reported that $9,804.00 was spent on ITS maintenance on this section between September 2015 and June 2016.

CONCLUSIONS

This segment of SH 161 is a two-lane access controlled highway surrounded on both sides by three-lane accessed controlled tolled lanes. Before peak-hour lanes (PHLs) were implemented in this corridor, there were significant bottlenecks where segments transitioned from three-lanes to two-lanes causing severe congestion during the peak hours of the weekday. Upon implementing the PHLs, the entire SH 161 corridor became a continuous three-lane section during the peak hours of the day which eliminated the bottleneck locations resulting in increased speeds, increased vehicle volumes and other traffic improvements.

Before–after analysis of traffic operations on SH 161 showed improvement on the segment after PHLs were introduced. There was clear evidence of improvements related to speed during the peak hours of the weekday when PHLs are operational in both directions of travel, as well as, increases in vehicle volumes throughout the corridor during the peak hours of the weekday. Crash analysis comparison over several years leading up to the PHL implementation and several years after the PHL implementation showed no significant increase in crash rates on this section of the SH 161 corridor. Additionally, locations where vehicles were queue jumping to avoid congestion on freeway segments prior to the implementation of the PHLs saw significantly lower occurrences of queue jumping due to better speed conditions and lower congestion levels on the general-purpose lanes after to the implementation of the PHL.

However, day-to-day operations of PHLs is not trivial. Before motorists are allowed to use PHLs, the lanes have to be “swept” or visually verified for any debris and abandoned vehicles that may need removal prior to opening the PHLs. This occurs twice each weekday by an in-the-field assistance patrol vehicle. As well, roadside cameras assist in performing the visual “sweep” during operational hours at locations where the cameras are able to view. Subsequently, there are costs associated with hiring a company to perform the “sweep” and to remove vehicles from PHLs for as long as the PHLs are to be in operation. Furthermore, there is an additional cost for the man-hours that are required at the traffic management center to coordinate with the sweep/removal company on a daily basis, as well as a cost associated with the upkeep of ITS field devices utilized by the PHLs.

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