Maryland Transportation Authority

EXPERIMENTAL TRAFFIC CONTROL DEVICE TESTING AT MARYLAND TOLL PLAZAS

FHWA Experimentation #3-181 (Ex) -Purple Dot Markings for E-ZPass® Lanes

June, 2012

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KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING/PLANNING

MOVING**FORWARD**THINKING™

Final Report

Purple Dots Phase II

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Executive Summary

On behalf of the Maryland Transportation Authority (MDTA), Kittelson & Associates, Inc. (KAI) is conducting an evaluation of an experimental traffic control device at a Maryland toll plaza. This report summarizes our findings for the evaluation of the purple dot pavement marking treatment. The purple dots were installed on the northbound Fort McHenry Toll Plaza approach in Baltimore, Maryland in June 2011. They were installed for three dedicated *E-ZPass*® lanes (Lanes 3, 6, and 10) as shown in Figure 4 in the main section of this report. The goal of applying the purple dots is to improve toll plaza operations and safety between the tunnel mouth and toll plaza by reducing conflicts created by lane changes and weaving just prior to the plaza. Additionally, the purple dots are intended to improve wayfinding for *E-ZPass*® customers

This is the second time purple dots have been installed on the northbound Fort McHenry Toll Plaza approach. Under the Phase I experiment, purple dots were installed in November 2005, and removed several years later when a portion of the toll plaza was rebuilt and the roadway was resurfaced. The results of the Phase I experiment are documented in an MDTA Report prepared by KAI dated May 11, 2007 (Ref. 1). In Phase I, the purple dots were generally found to reduce lane changing and increase utilization of the *E-ZPass*®ONLY lanes on the right side of the toll plaza.

This report provides the results of the current, Phase II experiment, as well as analysis of Phase I crash data not available at the time the Phase I report was prepared. The Phase II experiment was conducted in response to the Federal Highway Administration's (FHWA) comments on the Phase I experiment. At this time, the Phase II purple dots remain in place at the Fort McHenry Toll Plaza. FHWA granted approval for experimental use of the dots through July 1, 2012.

EVALUATION AND RESULTS

Six operational measures of effectiveness (MOEs) are identified in this report (consistent with the 2007 Phase I report) and are evaluated to determine if the purple dots improve wayfinding for *E-ZPass*® customers. Additionally, the report includes a review of crash data at the toll plaza.

For the six operational MOEs, data are analyzed for an *after* period (August/September 2011) and compared to *before* data collected prior to the Phase II installation of the purple dots. Data was aggregated by time of day and week, resulting in a number of before/after comparisons for each MOE.

A statistical analysis test, called the "test of proportions", is used to evaluate each MOE and determine if changes in results are statistically significant. Statistical significance indicates that the purple dots had a true effect on the performance measure when comparing the before and after data. In this experiment, statistical significance means there is a 95-percent probability that if the same experiment were repeated, the same result would occur.

Safety was assessed using a small sample of enhanced crash data collected during the Phase II experiment and more complete historical crash data from the years of the Phase I experiment. The enhanced Phase II crash data consisted of reports voluntarily submitted by members of the public who were involved in minor property damage crashes for which police reports are generally not filed. The Phase I crash data consisted of records from the state's crash database.

Table 1 summarizes our findings, and Figure 1 illustrates lane assignment at the toll plaza.

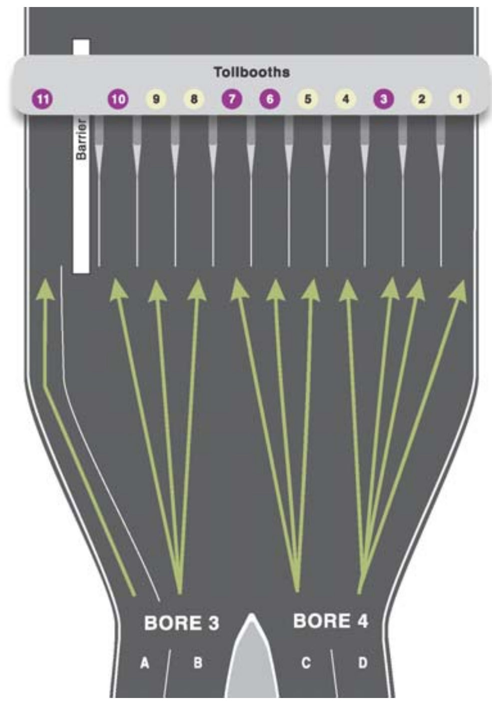
Table 1 - Measures of Effectiveness Summary

MOE #	Description	Findings
1	Lane changes from cash-accepted Lanes 5 and 8 to dedicated *E-ZPass®* Lanes 6 and 7	Before/after tests indicate that that the purple dots generally decreased lane changing by *E-ZPass®* customers, and the results were statistically significant. This is a desirable outcome.
2	Lane changes from dedicated *E-ZPass®* Lanes 6 and 7 to cash-accepted Lanes 5 and 8	Before/after tests indicate that the purple dots generally increased lane changing by cash customers, and the results were statistically significant. This is an undesirable outcome.
3	Percent lane changes from Approach Lane C to Toll Lanes 10 and 11	Before/after tests indicate that the purple dots generally increased this lane change maneuver, although not at a statistically significant level. An increase in this lane change maneuver would be considered an undesirable outcome.
4	Toll plaza lane volume utilization for *E-ZPass®* drivers	This MOE is listed for consistency with the Phase I report, but based upon changes to the toll plaza since that time it is no longer considered relevant.
5	Approach lane versus toll lane distribution for all traffic	The difference between approach lane and toll lane volumes changed at a statistically significant level in all cases. However, approximately half of the changes were desirable and half were undesirable.
6	Toll violations	Violations increased with the purple dots in the place, with most of the increase occurring in *E-ZPass®* ONLY lanes. The increases were generally statistically significant.
Safety Performance		Comprehensive safety data from the Phase 1 installation (2005-2008) that is now available indicates a 32% reduction in crashes prior to the toll plaza with the purple dots in place. This reduction is statistically significant with 93% confidence. The safety performance of the Phase II installation is unclear because of the long timeframe associated with police crash reports getting entered into the state's crash database.

The results of the MOE #1 suggest that the purple dots are beneficial to the largest group of toll plaza customers – *E-ZPass*® users. With the dots in place, lane changing by *E-ZPass*® customers decreased. The impact of the purple dots on cash customer operational performance is mixed. Lane changing by cash customers generally increased, and toll violations generally increased, particularly in *E-ZPass*®ONLY lanes. Cash customers may be taking advantage of the improved operational performance of the *E-ZPass*®ONLY lanes to avoid congestion in cash lanes.

A reduction in crashes occurred prior to the toll plaza with the Phase I purple dots in place (2005-2008). The reduction was statistically significant with 93% confidence, indicating that the purple dots likely improved safety.

Figure 1 – Lane Assignment at Toll Plaza Area



Note: Toll lanes 3, 6, 7, 10, and 11 (numbered in purple) are usually *E-ZPass*®ONLY lanes

Introduction

MDTA is interested in reducing lane-changing, and improving wayfinding and safety at the Fort McHenry Toll Plaza. A 2005 to 2007 test (referred to as Phase I in this report) evaluated the effectiveness of an experimental traffic control device and the degree to which these goals were accomplished. The experimental device was a series of purple dot pavement markings leading to *E-ZPass*®ONLY lanes. At that time, MDTA submitted a formal request to the Federal Highway Administration (FHWA) for permission to implement and test the purple dots. The purple dots were considered an experimental traffic control device because they were not identified in the Manual on Uniform Traffic Control Devices (MUTCD) (Ref. 2). The results of the Phase I experiment are documented in an MDTA Report prepared by KAI dated May 11, 2007 (Ref. 1). In Phase I, the purple dots were generally found to reduce lane changing and increase utilization of the *E-ZPass*®ONLY lanes on the right side of the toll plaza.

However, in a letter dated November 20, 2008, FHWA requested MDTA no longer maintain the dots for two reasons:

- The experiment was only conducted at one site
- The experiment did not include analysis of before and after crash data

The Phase I purple dots were later removed when resurfacing and other construction activities occurred at the toll plaza.

Based on FHWA's comments on the Phase I experiment, the purple dots were not included in the 2009 MUTCD and remain an experimental control device. However, based upon the benefits identified in the Phase I study, MDTA remained interested in installing the purple dots. In a letter to FHWA dated February 28, 2011, MDTA sought permission to conduct a second phase of the purple dots experiment. In a letter to MDTA dated April 4, 2011, FHWA granted their approval to re-install the purple dots. Approval was granted through July 1, 2012 under the same conditions as the Phase I experiment. All correspondence with FHWA is included in Appendix A.

The Phase II experiment used the same six operational measures of effectiveness (MOEs) as the Phase I experiment, as well as additional safety MOEs. The operational MOEs analyze the experimental control device with before and after field data. The goal of the data collection and analysis effort is to determine if the purple dots improve wayfinding for "confused" or "lost" motorists, particularly those attempting to locate a dedicated *E-ZPass*® lane. The purple dots are not expected to alter the behavior of aggressive drivers, such as motorists without an *E-ZPass*® who intentionally drive in the dedicated *E-ZPass*® lanes in an attempt to bypass the cash-paying queue, or motorists who traverse multiple lanes in a toll plaza searching for the lane with the shortest queue. In addition, the Phase II experiment included a review of crash data in an effort to address one of FHWA's comments on the Phase I report. Unlike the Phase I experiment, the Phase II experiment did not include a customer survey, as FHWA indicated such a survey would not play a major role in determining if the purple dots will be included in a future edition of the MUTCD.

This report presents the data collection methodology, and analysis findings and results for Phase II of the purple dots experiment.

Experimental Location and Treatment

Field observations indicate that some motorists have a difficult time locating dedicated *E-ZPass*® lanes placed at the center and right-hand side of mixed-use toll plazas. Northbound at the Fort McHenry Tunnel toll plaza, this issue is compounded by the horizontal curvature of the roadway, the uphill grade, and the emergence from the tunnel. Figure 3 shows a site vicinity map which highlights the location of the FMT Toll Plaza. The northbound Fort McHenry Tunnel (FMT) Toll Plaza was used as the Phase I testing site for the purple dots. It was chosen again for Phase II testing to build upon the results of the first experiment.

This photo highlights the horizontal and vertical curvature on the approach to the northbound Fort McHenry toll plaza.

The northbound Fort McHenry Tunnel Toll Plaza has four approach lanes that exit from two tunnel bores in the northbound direction. Figure 4 shows the lane configuration and numbering system for the toll lanes and the approach lanes. For the purpose of this study, the four approach lanes are referred to (from left to right) as A, B, C, and D. The four approach lanes widen and feed into a total of eleven toll lanes (numbered from right to left) at the toll barrier. The leftmost tunnel lane feeds into only one toll lane: Lane 11. This is a 30 MPH, *E-ZPass*®ONLY dedicated lane without a toll booth. The remaining three tunnel lanes each feed into three or four toll lanes, at least one of which is an *E-ZPass*®ONLY lane. All of these lanes still have a toll booth and vehicles are required to slow to 5-10 mph (if paying *E-ZPass*®) or stop (if paying with cash) when paying the toll. Toll Lanes 3, 6, 7, 10, and 11 generally operate as dedicated *E-ZPass*® lanes, although some are equipped with changeable lane control signs and can be converted to cash-accepting lanes. Likewise, some lanes that usually accept cash can be converted to E-ZPass®ONLY lanes; this change is made most frequently with Lane 4. Heavy vehicles (trucks with a gross vehicle weight greater than 5 tons) are required to use the four right-most lanes of the toll plaza.

Emergence from the tunnel, horizontal curvature, an uphill grade, and vehicle queues can make wayfinding between the tunnel and toll plaza challenging for drivers.

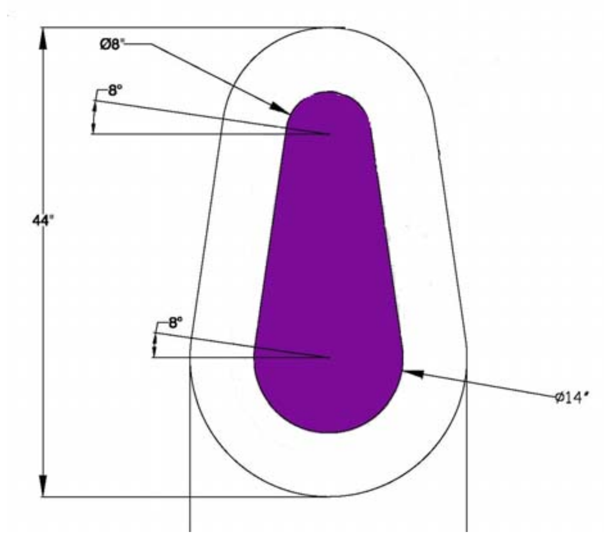
Example of the "*E-ZPass*®ONLY" pavement markings and solid white stripe (toll lane 11, approach lane D).

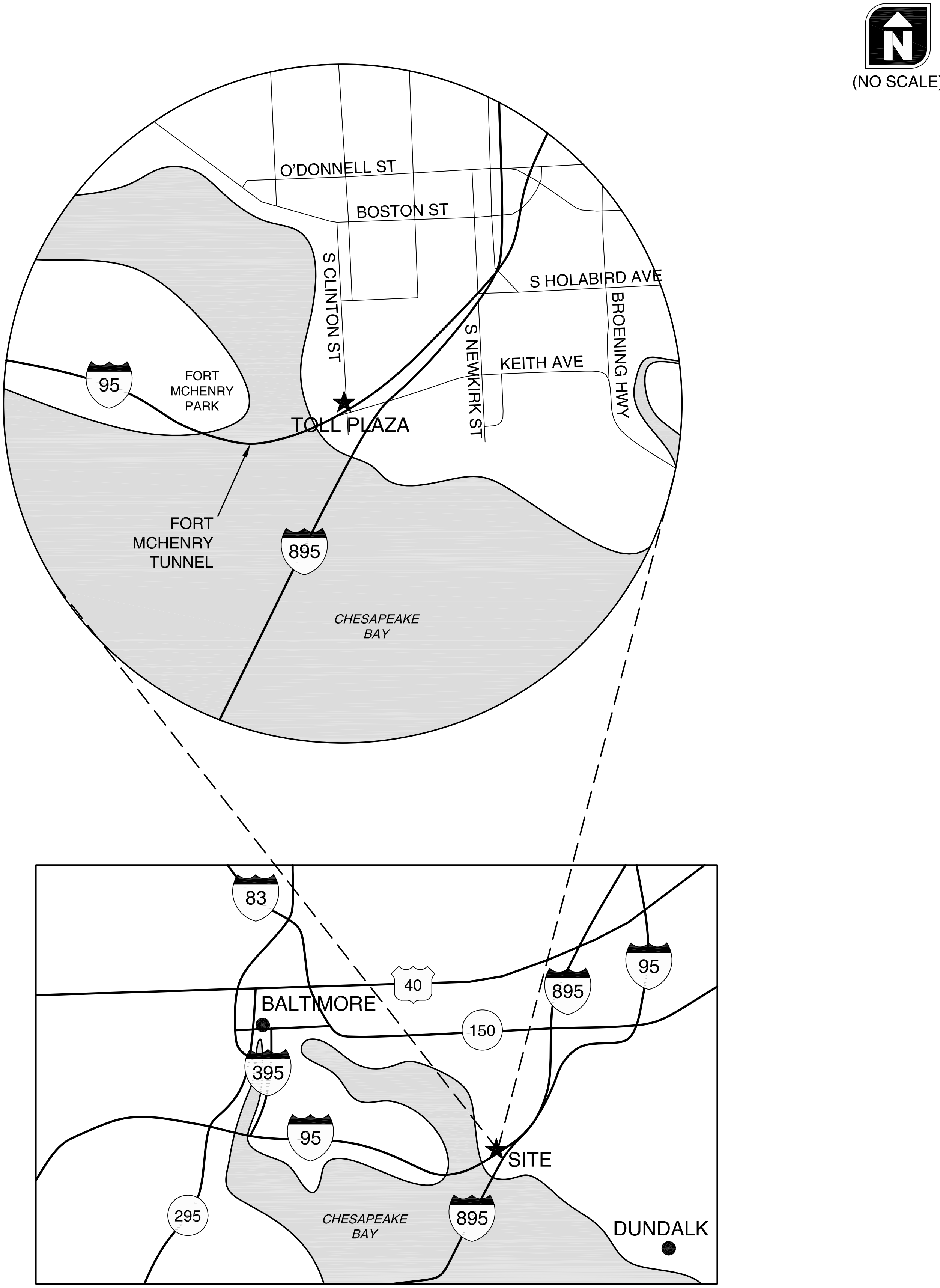
The goal of the experimental testing is to determine if purple dots improve wayfinding for *E-ZPass®* customers, compared to a condition with no purple dots. The purple dots are a guiding, non-restrictive traffic control device allowing drivers to change lanes as needed. The comparison between the existing traffic control devices and the experimental treatment is relative in nature. The 2005-2007 Phase I experiment at the same site found that the purple dots reduced the number of lane changes and provided a high level of customer satisfaction.

The purple dots are made from skid resistant thermoplastic material. The purple dot is 14 inches wide by 32 inches long. The dots are surrounded by a white ring to increase their visibility. Figure 2 shows the dimension of a purple dot.

Plans for the dots called for them to begin near the overhead sign bridge just north of the tunnel exit and are spaced at 50 feet for the first 550 feet, 40 feet for the following 160 feet, and 30 feet for the final 90 feet prior to the toll barrier. The design and layout of the dots was determined based on the Phase I experiment. Figure 5 illustrates the designed dot layout at the northbound FMT Toll Plaza.

Figure 2 – Purple Dot Design





H:\projfile\8157 - MdTA Traffic Engineering Open End\Tasks\Task 5 - Purple DOTS II\dwgs\figs\8157-5 fig 3 site map from 6065.dwg Jun 12, 2012 - 9:57am - pjenior Layout Tab: FIG 01

SITE VICINITY MAP
BALTIMORE, MARYLAND

FIGURE
3

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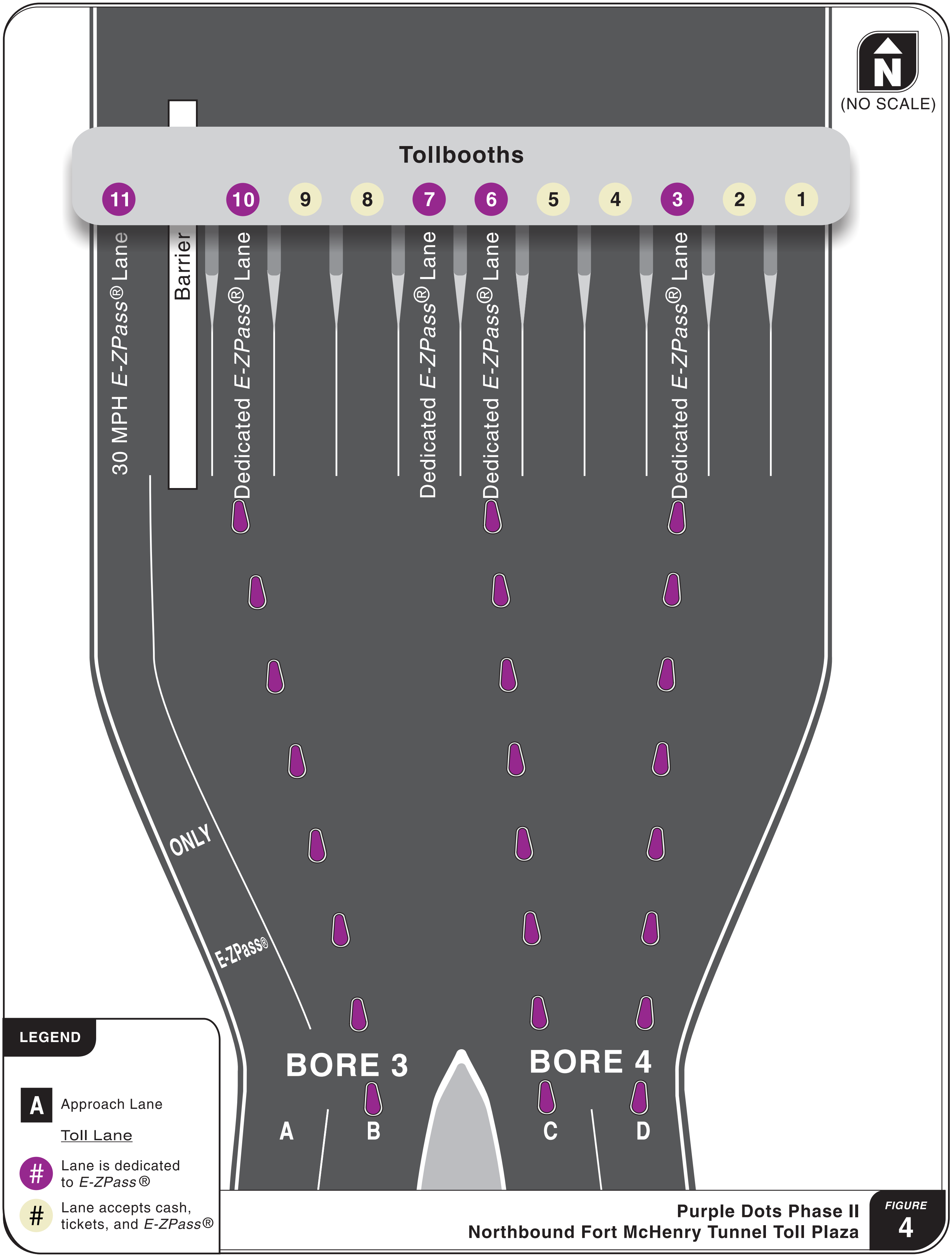
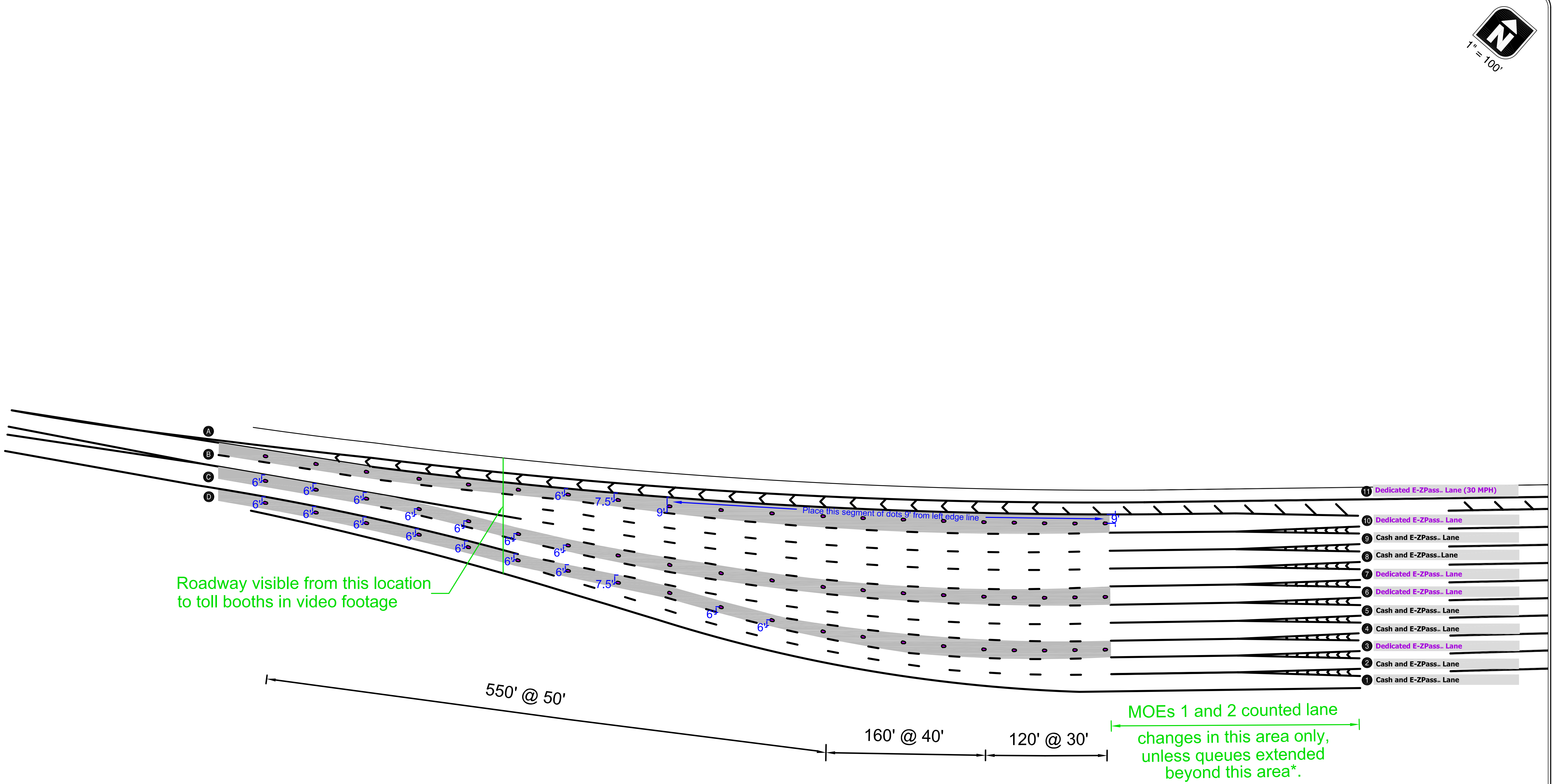


Purple Dots Phase II
Northbound Fort McHenry Tunnel Toll Plaza

FIGURE 4



NOTE: Center dots within shaded lane unless noted

* When queues extended beyond this area, lane changes by vehicles in queue were also counted.

SCALE
0 100 200

PURPLE DOTS LAYOUT
FORT MCHENRY TUNNEL TOLL PLAZA NORTHBOUND

FIGURE 5

Traffic Operations Data Collection Methodology and Measures of Effectiveness

Before data was collected over a period of three weeks in May 2011. Data collection occurred sporadically during this time due to issues with the video camera recording system. After data collection occurred in three one-week periods in August and September 2011. The purple dots were installed for two months prior to the start of the data collection. The three weeks of after data collection were intended to capture three distinct groups of drivers:

- After week 1: August 16 – 18 and 27. This week was during the summertime and schools were not in session. The traffic mix during this week presumably consisted primarily of commuters and some tourists.
- After week 2: August 30 – September 1, and September 3. This was the week leading up to Labor Day. A major auto race (Baltimore Grand Prix) was held in downtown Baltimore over Labor Day weekend and attracted many out-of-town spectators. The traffic mix during this week presumably contained a greater than normal percentage of drivers unfamiliar with the toll plaza and the purple dots
- After week 3: September 13 – 15, 17. School was in session during this week. The traffic mix during this week presumably consisted primarily of work and school-related commuters. Of the three after weeks, the traffic mix this week was likely most similar to the mix during before data collection in May.

The Measures of Effectiveness (MOEs) described in this section are intended to capture the safety and operational effects of the purple dots. The six specific MOEs evaluated are:

- MOE #1: Lane changes by E-ZPass® customers
- MOE #2: Lane changes by cash paying customers
- MOE #3: Distribution of traffic from Approach Lane C
- MOE #4: Percent utilization of dedicated E-ZPass® Lanes
- MOE #5: Distribution of traffic at the toll plaza approach and the toll barrier
- MOE #6: Toll violations

MOE #4 was included for consistency with the 2007 Phase I report. However, changes at the toll plaza (discussed in the MOE #4 section of this report) have reduced the relevance of this measure, and therefore, only limited analysis was conducted.

Table 2 summarizes the dates, days of the week, and times that the video data was collected and reduced. Video data was collected with a camera, which had been set up in a window of the MDTA Police Detachment overlooking the FMT Toll Plaza. The camera was capable of recording 80 hours of video on one set of memory cards, allowing the camera to be left unattended for several days at a time. Footage captured outside of the set time periods of the experiment was discarded.

Table 2 - Dates and Times of Data Collection

Time		7am-9am	11am-1pm	4pm-6pm
Before: May 2011				
May 3	Tue	X	X	X
May 4	Wed			X
May 5	Thur			X
May 7	*Sat*		X	
May 10	Tue	X	X	
May 11	Wed			
May 12	Thur		X	
May 14	*Sat*		X	
May 17	Tue			
May 18	Wed		X	
After: August 16 – 18, 27				
Aug 16	Tue	X	X	X
Aug 17	Wed	X	X	X
Aug 18	Thur	X	X	X
Aug 27	*Sat*		X	
After: August 30 – September 1, September 3				
Aug 30	Tue	X	X	X
Aug 31	Wed	X	X	X
Sept 1	Thur	X	X	X
Sept 3	*Sat*		X	
After: September 13 – 15, 17				
Sept 13	Tue	X	X	X
Sept 14	Wed	X	X	X
Sept 15	Thur	X	X	X
Sept 17	*Sat*		X	

X – video data recorded and reduced during these times

Differences in the before and after sample sizes are due to problems with the video camera that occurred during before data collection. The camera frequently stopped recording much earlier than anticipated and, as previously shown in Table 2, the before dataset is smaller than the after dataset and contains a different number of observations from each time period. The before dataset consists of two weekday a.m. periods, four weekday midday periods, three weekday p.m. periods, and two Saturday midday periods. The after dataset consists of nine weekday a.m., midday, and p.m. periods, and three Saturday midday periods.

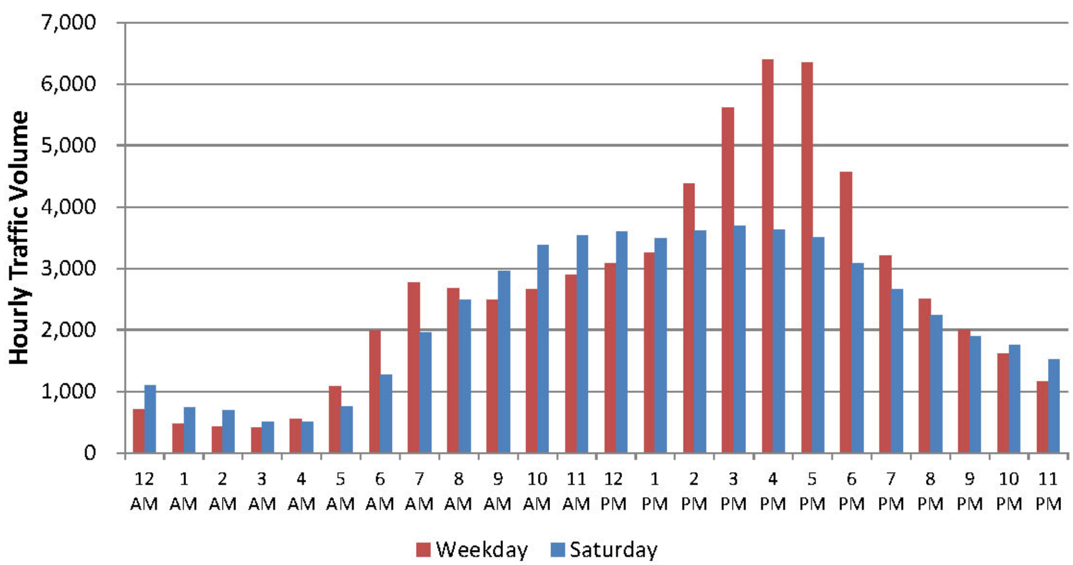
Before data was aggregated by time of day (weekday a.m., midday, and p.m., and Saturday midday) and compared to after data aggregated by these same four time of day periods. After data was also aggregated by week and compared to an aggregation of all before data. Each week of after data was analyzed separately to assess variation in potential driver population. Before data was not aggregated by week in the manner that after data was for two reasons.

First, during the period in which the data was collected (May 3 – 18), there was presumably little variation in driver population. Second, due to the issues with the video camera, some time of day periods would have been greatly over- or under-represented in an aggregation by week.

Traffic Volume Summary

Figure 6 compares the hourly traffic volumes for a typical weekday and Saturday during February through May 2011. The purpose of this chart is to illustrate the typical peaking patterns throughout the day during the before condition. Sunday is excluded because no data was collected on Sundays.

Figure 6 - Northbound Fort McHenry Toll Plaza



Weekday volumes peak from 4 p.m. to 6 p.m. Traffic volumes on Saturday are relatively constant throughout the day, and do not peak as significantly as they do during weekdays.

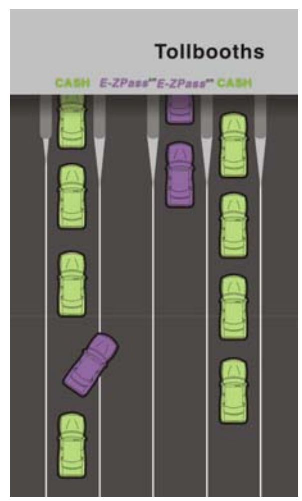
MOE Evaluation

The following sections describe the data collection methodology, analysis results, and findings for each measure of effectiveness (MOE) for the before and after conditions.

Descriptive observations and statistical analyses were used to evaluate and summarize the effectiveness of each MOE and ultimately the overall effectiveness of the purple dots. Initially, a statistical test of proportions was used for each MOE to determine if the differences between the before and after conditions are statistically significant. Due to the wide variation within the data, a regression analysis was performed for some MOEs to assess the impacts of traffic volume and other factors (besides the presence of the purple dots) which may have impacted before and after results. However, the regression analysis was ultimately abandoned because it did not provide additional insights into the variation in the data.

Statistical significance implies that an intervention (i.e., purple dots) has a true effect when comparing the before and after data. A statistically significant change indicates that the observed difference in the before and after data is not likely due to chance, as determined by a statistical test. In this experiment, statistical significance means there is a 95 percent probability that if the same experiment was repeated, the same result would occur. Appendix B explains the methodology and contains the proportional statistical analysis calculations for each MOE.

MOE #1: PERCENT OF LANE CHANGES BY *E-ZPASS* ® CUSTOMERS



This measure is defined as the percent of *E-ZPass*® customers who change lanes into a dedicated *E-ZPass*® lane from a cash-accepted lane. The percent is calculated based on the number of *E-ZPass*® customers who travel through the dedicated *E-ZPass*® lane being studied. This evaluation focused on lane changes occurring in dedicated *E-ZPass*® Lanes 6 and 7. A lane change was recorded when a vehicle changed lanes from a queue in a cash-accepted lane to a dedicated *E-ZPass*® lane. When queues in the cash-accepted lanes were not present, lane changes were recorded if a vehicle crossed the solid white line near the toll barrier. Lane changes into dedicated *E-ZPass*® Lanes 6 and 7 were assumed to be made by *E-ZPass*® customers; therefore, MOE #1 does not consider toll violations.

Data for this MOE were recorded using the camcorder set up by the project team in the police station window in the FMT East Vent Building. Video data was played back and manually reduced.

Data reduction for MOE #1 focused on the typical weekday (Tuesday, Wednesday, or Thursday) a.m., midday, and p.m. peak periods, as well as the Saturday peak period. This was intended to capture the effects the purple dots had on commuter and non-commuter traffic during peak and off-peak periods.

MOE #1 Data Reduction Summary

Table 3 summarizes the number and percent of lane change maneuvers made by *E-ZPass*® customers out of cash paying queues into dedicated *E-ZPass*® Lanes 6 and 7. Changes into Lane 6 come from Lane 5, and changes into Lane 7 come from Lane 8. Statistically significant decreases in lane changing (positive impact) are indicated with green shading, and statistically significant increases in lane changing (negative impact) are indicated with red shading. After conditions that were not statistically different compared to before conditions are indicated with gray shading. The percent values in the table were also used to compute a "lane change modification factor", appearing in the column labeled "LCMF*". The LCMF is computed by dividing the after lane changing percent by the before lane changing percent, similar to how crash modification factors are computed. The LCMF is the factor by which lane changing increased or decreased with the purple dots in place. For Lane 6 weekday a.m., for example, there were 1.22 times as many lane changes with the purple dots as there were without them.

In Table 3, before data is aggregated by time of day and further aggregated into a single before value ("Total"). Before data aggregated by time of day is compared to after data aggregated by time of day, and the total before values are compared to after data aggregated by week. For example, the 6.6% lane change (into lane 6) value from the weekday a.m. before period was compared to the 8.0% lane change value from the weekday a.m. after period to determine that the before/after change (8.0% vs. 6.6%) was not significant and that the LCMF was 1.22. Likewise, the 10.2% lane change (into lane 6) value from the total before period was compared to the 5.4% lane change value from the week 1 after period to determine that the before/after change (5.4% vs. 10.2%) was a statistically significant positive result.

Table 3 – MOE #1 – Percent of Lane Changes by *E-ZPass*® Customers

Time Period (Hours of Data)		Dedicated *E-ZPass*® Lane 6				Dedicated *E-ZPass*® Lane 7			
		Lane Changes Into Lane 6	Lane 6 Volume	Percent	LCMF*	Lane Changes Into Lane 7	Lane 7 Volume	Percent	LCMF*
Before	Weekday AM (4)	57	865	6.6%	-	141	768	18.4%	-
	Weekday MD (8)	449	1579	28.4%	-	157	1709	9.2%	-
	Weekday PM (6)	307	5464	5.6%	-	284	3853	7.4%	-
	Saturday MD (4)	81	891	9.1%	-	157	737	21.3%	-
	Total (22)	*894*	*8799*	*10.2%*	-	*739*	*7067*	*10.5%*	-
After – by time of day	Weekday AM (18)	322	4006	8.0%	1.22	261	3384	7.7%	0.42
	Weekday MD (18)	467	5013	9.3%	0.33	462	3456	13.4%	1.46
	Weekday PM (18)	668	10887	6.1%	1.09	872	11472	7.6%	1.03
	Saturday MD (6)	49	670	7.3%	0.72	50	622	8.0%	0.38
After – by week	Week 1 total (20)	420	7727	5.4%	0.53	479	5860	8.2%	0.78
	Week 2 total (20)	502	6419	7.8%	0.76	544	6322	8.6%	0.82
	Week 3 total (20)	584	6430	9.1%	0.89	622	6752	9.2%	0.88

*LCMF = Lane Change Modification Factor. Analogous to Crash Modification Factor.

Green shading indicates a positive impact that was statistically significant

Red shading indicates a negative impact that was statistically significant

Gray shading indicates change with no statistical significance.

MOE #1 Data Analysis Findings

DESCRIPTIVE OBSERVATIONS

- Aggregating by week, the before data is approximately 10% for the occurrence of lane changes by *E-ZPass®* customers into Lane 6 and Lane 7 and the after data ranges from 5.4% to 9.2%.
- Aggregating by time of day, the before data varies greatly with a range of 5.6% to 28.4% for the occurrence of lane changes by *E-ZPass®* customers into Lane 6 and Lane 7. The after data varies less, ranging from 6.1% to 13.4%.

RESULTS OF STATISTICAL ANALYSIS

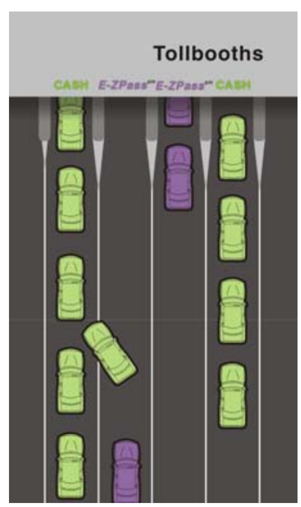
- Aggregating by time of day, a statistically significant reduction in the percent of lane changes into Lane 6 occurred in one of four periods – the weekday midday.
- Aggregating by time of day, a statistically significant reduction in the percent of lane changes into Lane 7 occurred in two of four periods – the weekday a.m. and the Saturday midday.
- Aggregating by week, the reduction in the percent of lane changes occurring into Lane 6 and Lane 7 for all three weeks is statistically significant.

MOE #1 Analysis Summary

The purple dots have generally reduced the number of lane changes occurring close to the toll booths in Lanes 6 and 7. The reduction in lane change maneuvers corresponds to a reduction in vehicle conflicts close to the toll booths. Aggregated by time of day, the percentage of lane changes decreased between half of the before and after observation periods. Aggregated by weeks, the percentage of lane changes has decreased between all of the before and after observation periods. The results of this MOE indicate that the purple dots had a positive impact.

MOE #2: PERCENT OF LANE CHANGES BY CASH-PAYING CUSTOMERS

This MOE refers to cash-paying customers who mistakenly find themselves in a dedicated *E-ZPass®* lane. It is defined as the percent of cash paying customers who change lanes out of a dedicated *E-ZPass®* lane into a cash-accepted lane near the toll barrier. The percent is determined based on the total number of cash paying motorists who travel through the cash-accepted lanes adjacent to the dedicated *E-ZPass®* lane being studied. This evaluation focused on cash-accepted Lanes 5 and 8, which are adjacent to dedicated *E-ZPass®* Lanes 6 and 7.



Data for this MOE were recorded using the camcorder set up by the project team in the police station window in the FMT East Vent Building. Video data was played back and manually reduced.

Data reduction for MOE #2 focused on the typical weekday (Tuesday, Wednesday, or Thursday) a.m., midday, and p.m. peak periods, as well as the Saturday peak period. This was intended to capture the effects the purple dots had on commuter and non-commuter traffic during peak and off-peak periods.

MOE #2 Data Reduction Summary

Table 4 summarizes the number and percent of lane change maneuvers made by cash paying customers out of dedicated *E-ZPass*® Lanes 6 and 7. Lane changes out of Lane 6 go to Lane 5, and lane changes out of Lane 7 go to Lane 8. Statistically significant decreases in lane changing (positive impact) are indicated with green shading, and statistically significant increases in lane changing (negative impact) are indicated with red shading. After conditions that were not statistically different than before conditions are indicated with gray shading.

Table 4
Measure of Effectiveness #2 – Data Reduction Summary

Time Period (Hours of Data)		Cash Accepting Lane 5				Cash Accepting Lane 8			
		Lane Changes Out of Lane 6	Lane 5 Volume	Percent	LCMF*	Lane Changes Out of Lane 7	Lane 8 Volume	Percent	LCMF*
Before	Weekday AM (4)	54	727	7.4%	-	24	691	3.5%	-
	Weekday MD (8)	194	1759	11.0%	-	133	1886	7.1%	-
	Weekday PM (6)	307	1415	21.7%	-	293	1478	19.8%	-
	Saturday MD (4)	617	1333	46.3%	-	184	1389	13.2%	-
	Total (22)	*1172*	*5234*	*22.4%*	-	*634*	*5444*	*11.6%*	-
After – by time of day	Weekday AM (18)	692	3210	21.6%	2.92	614	3369	18.2%	5.20
	Weekday MD (18)	871	4290	20.3%	1.85	521	4243	12.3%	1.73
	Weekday PM (18)	1115	4532	24.6%	1.13	825	4536	18.2%	0.92
	Saturday MD (6)	182	955	19.1%	0.41	68	951	7.2%	0.62
After – by week	Week 1 total (20)	517	4128	12.5%	0.56	516	4293	12.0%	1.03
	Week 2 total (20)	1276	4634	27.5%	1.23	738	4349	17.0%	1.47
	Week 3 total (20)	1067	4225	25.3%	1.13	774	4457	17.4%	1.50

*LCMF = Lane Change Modification Factor. Analogous to Crash Modification Factor.

Green shading indicates a positive impact that was statistically significant

Red shading indicates a negative impact that was statistically significant

Gray shading indicates change with no statistical significance.

MOE #2 Data Analysis Findings

DESCRIPTIVE OBSERVATIONS

- Aggregating by week, the before data is 22.4% for the occurrence of lane changes by cash customers out of Lane 6 (into Lane 5) and 11.6% for the occurrence of lane changes by cash customers out of Lane 7 (into Lane 8). The after data ranges from 12.5% to 27.5% for Lane 6 and 12.0% to 17.4% for Lane 7.
- For each aggregated before time period, the percentage of lane changes out of Lane 6 was greater than the percentage of lane changes out of Lane 7.
- For the Saturday before period, nearly half of vehicles in Lane 5 were initially in Lane 6 and changed lanes.
- The percent of lane changes generally *increased* in the after periods.

RESULTS OF STATISTICAL ANALYSIS

- Aggregating by either time of day or week, the *increases* in lane changes were generally statistically significant.
- A statistically significant decrease in the percent of lane changes out of Lane 6 and Lane 7 occurred between the Saturday midday before and after periods.
- A statistically significant decrease in the percent of lane changes out of Lane 6 occurred between the before and after week 1 periods.

This MOE is intended to assess wayfinding by cash customers, who may mistakenly end up in *E-ZPass®ONLY* lanes. However, some cash customers may intentionally position themselves in *E-ZPass®ONLY* lanes to avoid queues in cash lanes, and then change into cash lanes just prior to the toll plaza. This action does not represent driver confusion and is undesirable only if it creates a safety hazard. A sample of the before/after data was reduced to identify potentially hazardous lane changes. A lane change was considered potentially hazardous if any of the follow occurred:

- A driver forced their way between vehicles that were stopped in queue
- A driver cut off another vehicle and appeared to force the vehicle to slow or brake

Within the reviewed sample of data, about 20% of the lane changes from Lane 6 to Lane 5 were found to be potentially hazardous both before and after the purple dots.

Within the reviewed sample of data, over half of the lane changes from Lane 7 to Lane 8 were found to be potentially hazardous before the purple dots and about 35% were found to be potentially hazardous after the purple dots. However, there was an increased in the percentage of vehicles (lane changers or not) making a potentially hazard lane change from Lane 7 to Lane 8, just as there was an increase in the percentage of vehicles making a lane change (potentially hazardous or not)

MOE #2 Analysis Summary

More lane changes are being made by cash-paying customers in Lanes 5 and 8 following the installation of purple dots. It is unclear why this is occurring. Lane changes that may be potentially hazardous also increased, but not to the extent that overall lane changing did. The very high percentage of lane changes from Lane 6 to Lane 5 that occurred in the Saturday midday before period decreased in the after period.

MOE #3: PERCENT OF VEHICLES EMERGING FROM APPROACH LANE C AND CHANGING LANES INTO TOLL LANES 10 OR 11

This measure of effectiveness divides the number of vehicles emerging from Approach Lane C that changed lanes and used Toll Lane 10 or 11 by the total volume of traffic that used Approach Lane C. This maneuver may affect safety because to complete it a motorist must cross four to six lanes of traffic. Ideally, vehicles would choose the dedicated *E-ZPass®* lane that the approach lane feeds into. The purple dots are intended to encourage *E-ZPass®* motorists traveling in Approach Lanes B, C, and D to use dedicated *E-ZPass®* lanes, specifically:

- Vehicles in Approach Lane B are encouraged to use dedicated *E-ZPass®* Lane 10
- Vehicles in Approach Lane C are encouraged to use dedicated *E-ZPass®* Lanes 7 or 6

- Vehicles in Approach Lane D are encouraged to use dedicated *E-ZPass*® Lane 3

Data for this MOE were recorded using the camcorder set up by the project team in the police station window in the FMT East Vent Building. Video data was played back and manually reduced.

Data reduction for MOE #3 focused on the typical weekday (Tuesday, Wednesday, or Thursday) a.m., midday, and p.m. peak periods, as well as the Saturday peak period. This was intended to capture the effects the purple dots had on commuter and non-commuter traffic during peak and off-peak periods.

MOE #3 Data Reduction Summary

Table 5 shows the number of vehicles during the before and after data collection periods that emerged from Approach Lane C and used Toll Lane 10 or 11. Statistically significant decreases in lane changing (positive impact) are indicated with green shading, and statistically significant increases in lane changing (negative impact) are indicated with red shading. After conditions that were not statistically different than before conditions are indicated with gray shading.

Table 5 - Lane Changes From Approach Lane C to Toll Lane 10 or 11

Time Period (Hours of Data)		Lane Change Volume	Total Volume for Approach Lane C	Percent	LCMF*
Before	Weekday AM (4)	18	1,326	1.4	-
	Weekday MD (8)	33	5,428	0.6	-
	Weekday PM (6)	3	4,791	0.1	-
	Saturday MD (4)	11	1,639	0.7	-
	Total (22)	*65*	*13,184*	*0.5*	-
After – by time of day	Weekday AM (18)	205	12,184	1.7	1.2
	Weekday MD (18)	135	13,046	1.0	1.7
	Weekday PM (18)	197	27,836	0.7	7.0
	Saturday MD (6)	12	2,651	0.5	0.7
After – by week	Week 1 total (20)	219	19,503	1.1	2.2
	Week 2 total (20)	84	19,136	0.4	0.8
	Week 3 total (20)	250	21,401	1.2	2.4

*LCMF = Lane Change Modification Factor. Analogous to Crash Modification Factor.

Green shading indicates a positive impact that was statistically significant

Red shading indicates a negative impact that was statistically significant

Gray shading indicates change with no statistical significance.

MOE #3 Data Analysis Findings

DESCRIPTIVE OBSERVATIONS

- A lane change from Approach Lane C to Toll Plaza Lane 10 or 11 is a relatively rare event. In the before period, only 0.5% of vehicles in Approach Lane C made this maneuver.
- Aggregated by either time of day or week, the percent of lane changes generally increased in the after period.

- The percent of lane changes was lowest during the weekday p.m. peak (when volumes were highest) and Saturday midday (when volumes were similar to the weekday a.m. and weekday midday peaks).

RESULTS OF STATISTICAL ANALYSIS

- Aggregated by week, the purple dots did not create a statistically significant change in the percent of drivers who travel from Approach Lane C to Toll Lanes 10 or 11.
- Aggregated by time of day, the purple dots created a statistically significant *increase* in the percent of drivers who travel from Approach Lane C to Toll Lanes 10 or 11 for two time periods: weekday midday and weekday p.m. It is noted that the weekday p.m. period before period had a very low lane change rate, and virtually any increase would be statistically significant.

MOE #3 Analysis Summary

The purple dots have minimal influence on the behavior of drivers emerging from Approach Lane C and traveling across the toll plaza to use Toll Lane 10 or 11. However, the percent of lane changes did *increase* by a statistically significant amount in some after periods. The driver population that make this maneuver may represent aggressive and/or commuter drivers who are accustomed to traveling through the FMT Toll Plaza and likely intentionally make this maneuver in an attempt to reduce their perceived travel time through the toll plaza.

MOE #4: TOLL LANE VOLUME UTILIZATION FOR ETC MOTORISTS

Changes to the toll plaza between the Phase I and Phase II experiments have reduced the relevance of MOE #4. A goal of the purple dots at the time of the Phase I experiment was to create a more uniform distribution of *E-ZPass*® traffic across the toll plaza. This goal is not necessarily applicable under Phase II conditions for two reasons:

- Under Phase I conditions (with and without purple dots), *E-ZPass*® customers utilized the two left-most lanes of the toll plaza (both of which were *E-ZPass*®ONLY) more than other *E-ZPass*®ONLY lanes). At that time, the 30 mph *E-ZPass*®ONLY lane did not exist and the capacity of all *E-ZPass*®ONLY lanes was the same. Now, with the 30 mph *E-ZPass*®ONLY lane in place, it is desirable that more drivers use the leftmost *E-ZPass*®ONLY lane than other *E-ZPass*®ONLY lanes
- Under Phase II conditions, striping connects Tunnel Lane C with two *E-ZPass*®ONLY lanes (6 and 7) whereas Tunnel Lanes A, B, and D are only connected to one *E-ZPass*®ONLY lane (See Figure 9). Therefore, regardless of how well the purple dots improve wayfinding, it is expected that the percent of *E-ZPass*® customers using Lane 6 and Lane 7 will be lower than the percent of customers using the *E-ZPass*®ONLY lanes associated with Tunnel Lanes B and D.

For these two reasons, MOE #4 is no longer considered a relevant performance measure for the purple dots. Data related to MOE #4 is presented in Figures 7 through 10 for consistency with the May 2007 Phase I report. However, this data/MOE was not considered when evaluating the purple dots and no statistical analysis was performed.

The Authority provided toll lane utilization reports for the relevant months. The toll lane utilization reports identify the number of vehicles using each toll lane within each hour of each day of the month. Utilization reports were obtained for cash and *E-ZPass*® traffic traveling through the northbound Fort McHenry Toll Plaza. The utilization of tolls lanes during the before and after data collection periods was then compared.

MOE #4 Data Reduction Summary

Figures 7 through 10 illustrate the toll lane utilization for *E-ZPass*® customers traveling through the northbound Fort McHenry Toll Plaza. Figures 7 and 8 show the percent of the total number of *E-ZPass*® customers that use each toll lane on a midweek day and the total traffic volume in each toll lane on a midweek day, respectively. Figures 9 and 10 each consist of the four bar charts. The charts display utilization data similar to Figures 7 and 8, but for certain hours within the day rather than an entire day.

Figure 7

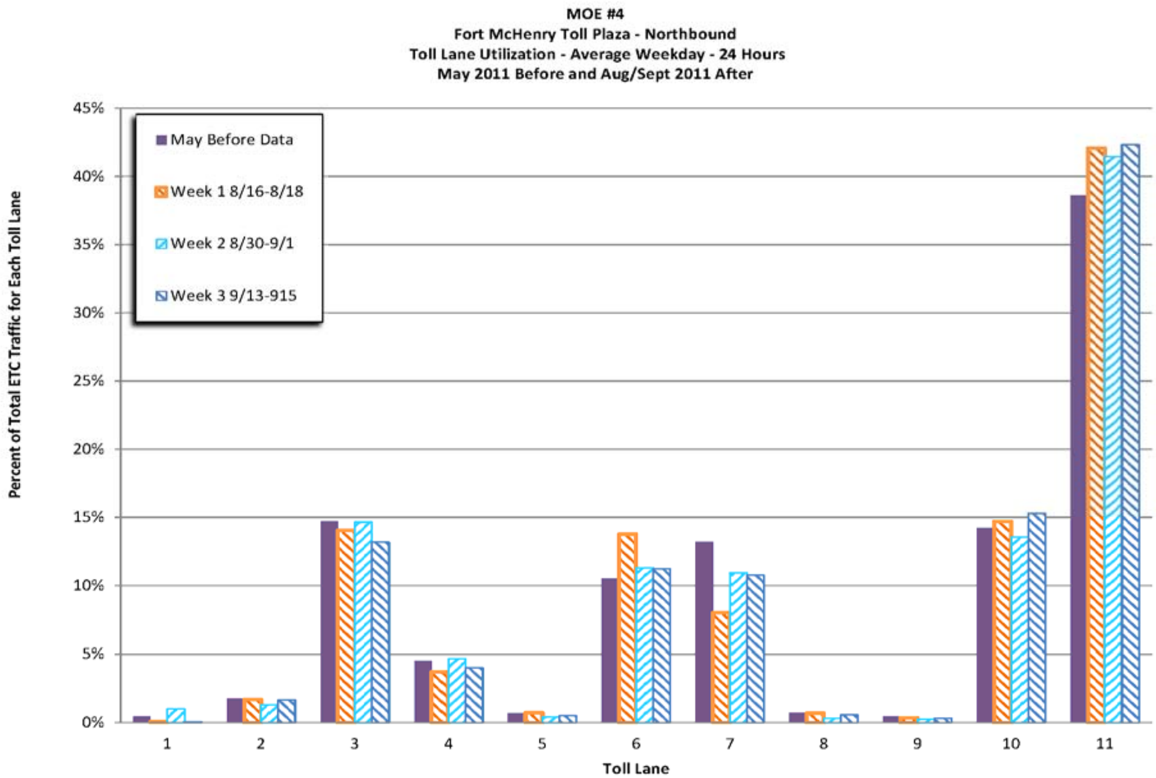


Figure 8

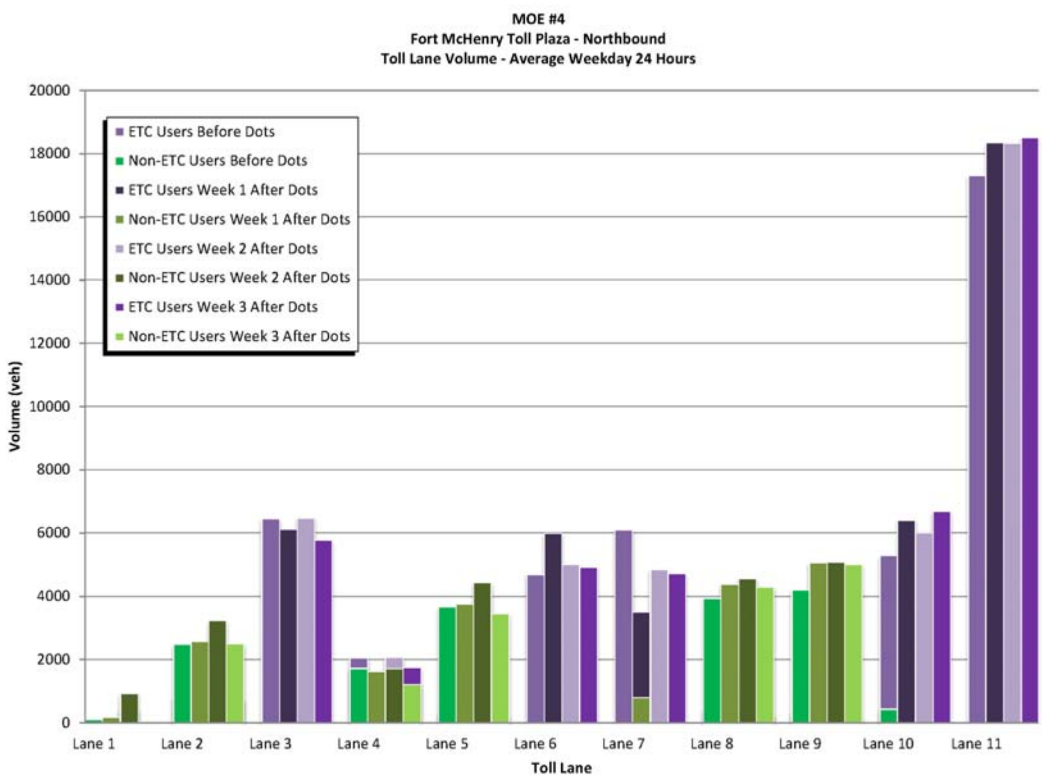
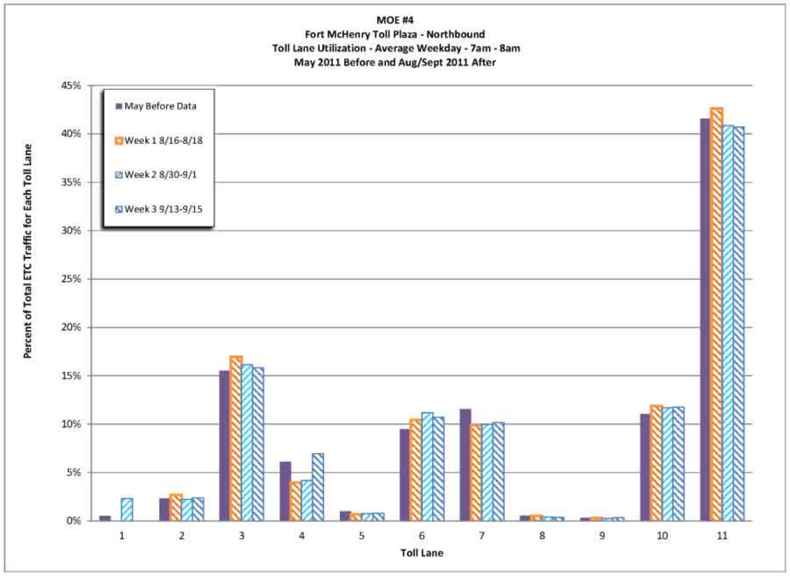
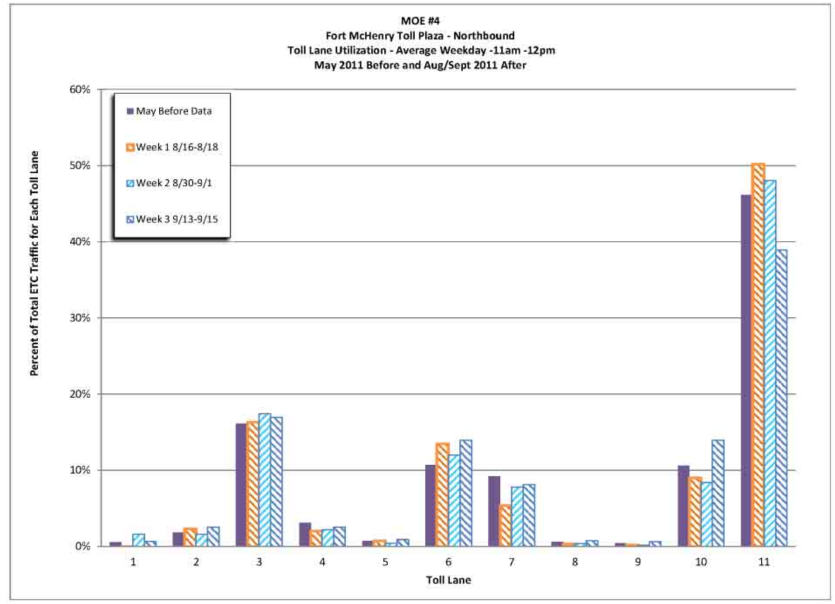
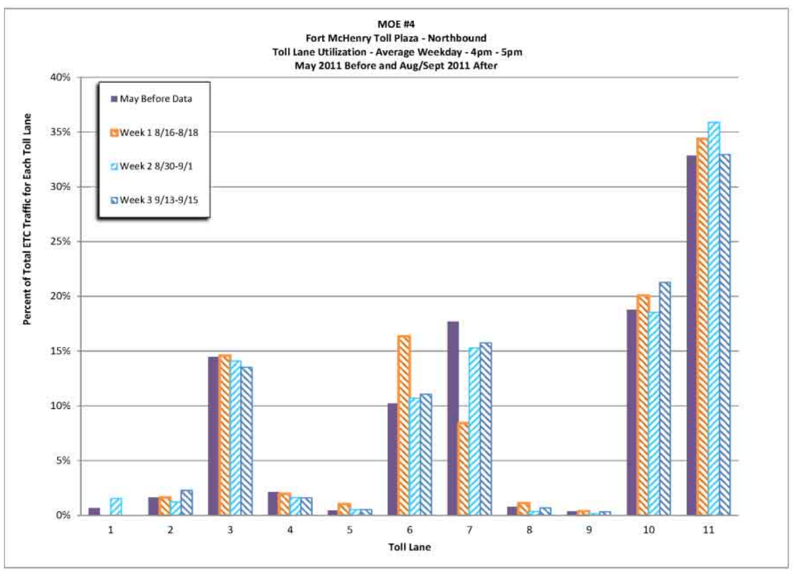


Figure 9


MOE #4
Fort McHenry Toll Plaza - Northbound
Toll Lane Utilization - Average Weekday - 7am - 8am
May 2011 Before and Aug/Sept 2011 After
May Before Data
Week 1 8/16-8/18
Week 2 8/30-9/1
Week 3 9/13-9/15
Percent of Total ETC Traffic for Each Toll Lane
Toll Lane


MOE #4
Fort McHenry Toll Plaza - Northbound
Toll Lane Utilization - Average Weekday -11am -12pm
May 2011 Before and Aug/Sept 2011 After
May Before Data
Week 1 8/16-8/18
Week 2 8/30-9/1
Week 3 9/13-9/15
Percent of Total ETC Traffic for Each Toll Lane
Toll Lane


MOE #4
Fort McHenry Toll Plaza - Northbound
Toll Lane Utilization - Average Weekday - 4pm - 5pm
May 2011 Before and Aug/Sept 2011 After
May Before Data
Week 1 8/16-8/18
Week 2 8/30-9/1
Week 3 9/13-9/15
Percent of Total ETC Traffic for Each Toll Lane
Toll Lane

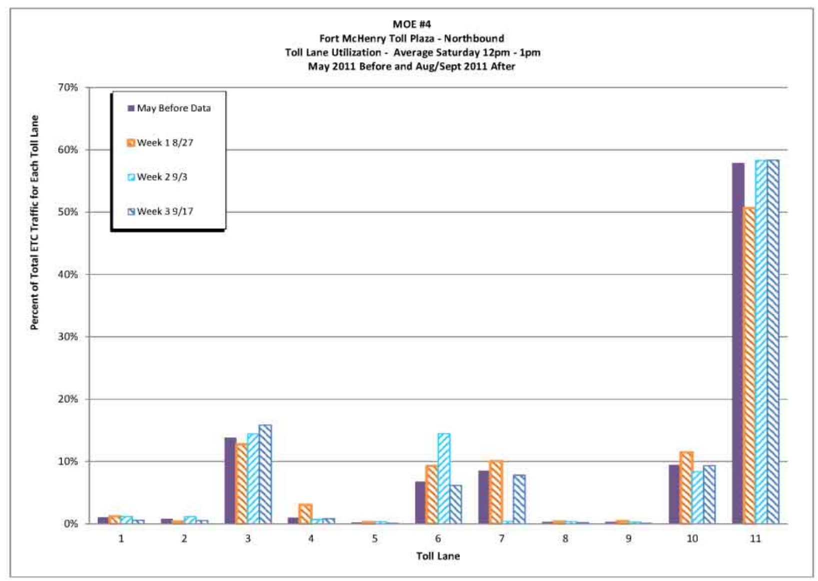
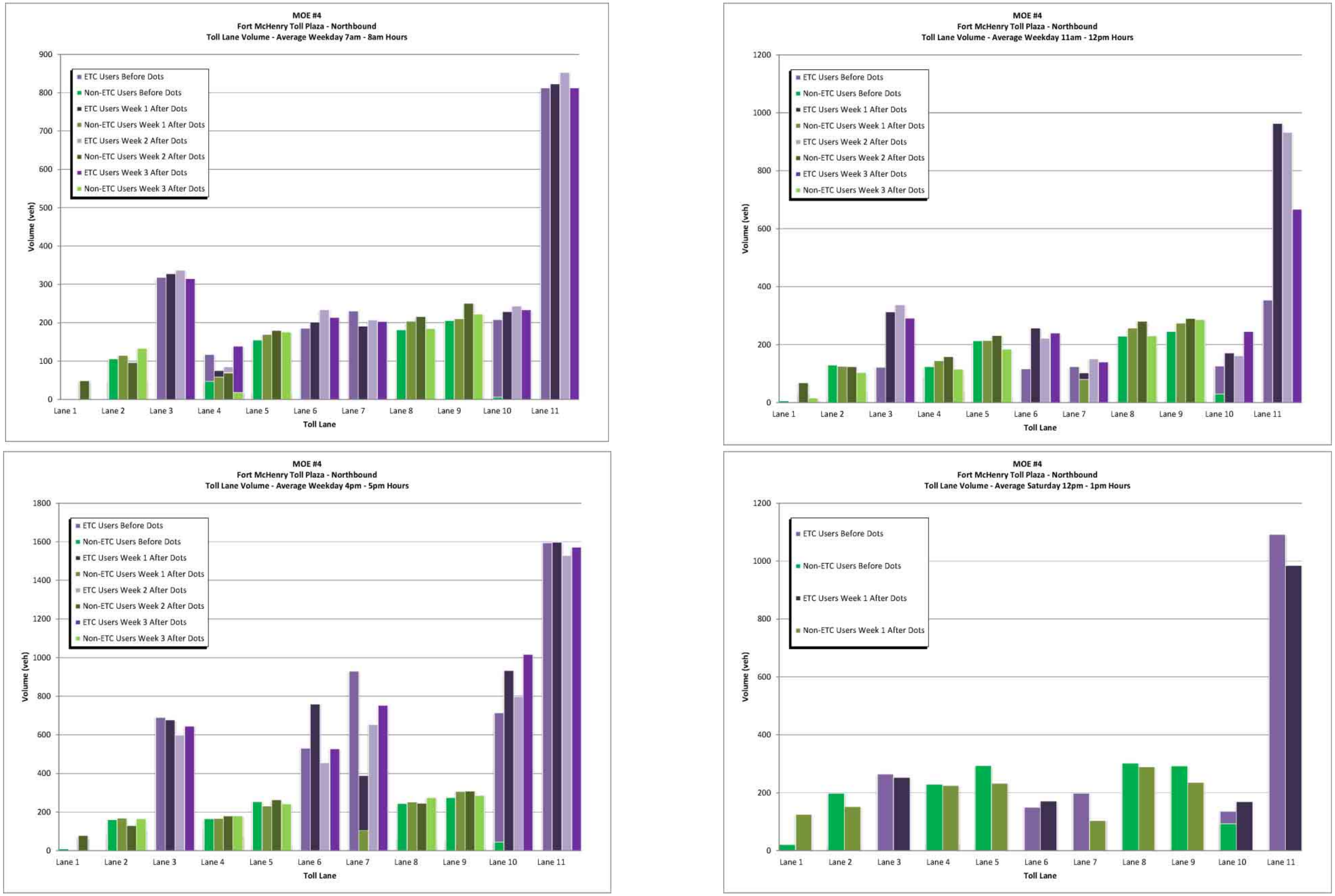

MOE #4
Fort McHenry Toll Plaza - Northbound
Toll Lane Utilization - Average Saturday 12pm - 1pm
May 2011 Before and Aug/Sept 2011 After
May Before Data
Week 1 8/27
Week 2 9/3
Week 3 9/17
Percent of Total ETC Traffic for Each Toll Lane
Toll Lane

Figure 10


MOE #4
Fort McHenry Toll Plaza - Northbound
Toll Lane Volume - Average Weekday 7am - 8am Hours
ETC Users Before Dots
Non-ETC Users Before Dots
ETC Users Week 1 After Dots
Non-ETC Users Week 1 After Dots
ETC Users Week 2 After Dots
Non-ETC Users Week 2 After Dots
ETC Users Week 3 After Dots
Non-ETC Users Week 3 After Dots
Volume (veh)
Toll Lane
MOE #4
Fort McHenry Toll Plaza - Northbound
Toll Lane Volume - Average Weekday 11am - 12pm Hours
MOE #4
Fort McHenry Toll Plaza - Northbound
Toll Lane Volume - Average Weekday 4pm - 5pm Hours
MOE #4
Fort McHenry Toll Plaza - Northbound
Toll Lane Volume - Average Saturday 12pm - 1pm Hours
Lane 1
Lane 2
Lane 3
Lane 4
Lane 5
Lane 6
Lane 7
Lane 8
Lane 9
Lane 10
Lane 11

MOE #4 Summary

As expected, the 30 mph *E-ZPass*®ONLY lane is used by a greater proportion of *E-ZPass*® customers than other *E-ZPass*®ONLY lanes. Also as expected, *E-ZPass*®ONLY lanes 6 and 7, which are fed by the same tunnel lane, have a slightly smaller proportion of *E-ZPass*® customers than other *E-ZPass*®ONLY lanes over a full day and during most hourly periods. Figure 7 through 10 also indicate higher utilization of Lane 4 compared to other cash-accepting lanes. This is due to the fact that Lane 4 is sometimes converted to an *E-ZPass*®ONLY lane. These conditions were found both with and without the purple dots.

MOE #5: APPROACH LANE VERSUS TOLL LANE UTILIZATION

The volume of traffic in each approach lane leaving the tunnel was compared to lane volumes at the toll plaza lanes associated with each tunnel lane to determine if, and to what degree, the lane utilization is balanced and consistent between the approach lanes and the toll lanes. This MOE is an indicator of the number and severity of lane changes taking place between the approach lanes and toll lanes, and whether the purple dots improve the distribution of traffic across tunnel and toll plaza lanes.

Traffic volumes for the four lanes leaving the tunnel were recorded using the camcorder set up by the project team in the police station window in the FMT East Vent Building. Video data was played back and manually reduced. Traffic volumes for the eleven lanes at the toll plaza were obtained from reports produced by the Maryland Transportation Authority (HOST reports). MOE #5 analysis is reflective of all traffic – not just ETC motorists.

The objective of the dots being assessed with this MOE is to reduce the variation in the percent distribution of traffic between each approach lane and its corresponding set of toll lanes.

MOE #5 Data Reduction Summary

The analysis compares the percentage of traffic using:

- Approach Lane A versus Toll Lane 11.
- Approach Lane B versus Toll Lanes 8, 9 and 10.
- Approach Lane C versus Toll Lanes 5, 6, and 7.
- Approach Lane D versus Toll Lanes 1, 2, 3, and 4.

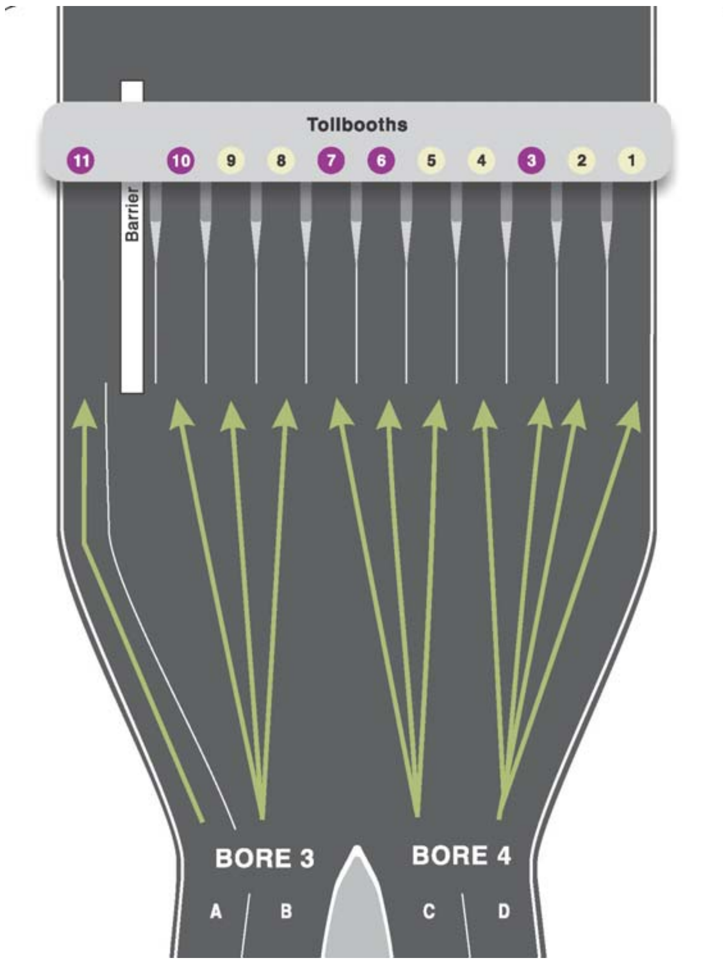
This grouping is consistent with pavement markings at the site. Striping (previously shown in Figure 5) connects each approach lane with the toll lanes grouped with it above; this is also illustrated in Figure 11. The grouping of approach lanes and toll lanes was different at the time of the Phase 1 experiment. At that time, there were twelve toll lanes and each approach lane was grouped with three toll lanes.

Table 6 compares the approach lane distribution to the toll lane utilization during the before data collection period and the after data collection period. A more balanced distribution of traffic between the approach lanes and toll lanes would be indicated by a decrease in the absolute percent difference of traffic from the before condition to the after condition.

The percent values in the table were also used to compute a “volume difference modification factor”, appearing the column labeled VDMF*. Similar to LCMF for MOE #1 - 3, the

VDMF is computed by dividing the after volume difference percent by the before volume difference percent.

Figure 11
Grouping of Tunnel Lanes and Toll Plaza Lanes



Notes:
Lane numbers shown in purple are *E-ZPass®ONLY* lanes.
Lane 4 is sometimes changed to *E-ZPass®ONLY* operation.
Trucks are restricted to Toll Lanes 1 - 4

Table 6 – Approach Lane and Toll Lane Utilization

		Tunnel Lane A/ Toll Lane 11	Tunnel Lane B/ Toll Lanes 8, 9, and 10	Tunnel Lane C/ Toll Lanes 5, 6, and 7	Tunnel Lane D/ Toll Lanes 1, 2, 3, and 4
Before	Tunnel Lane	30.3%	25.1%	24.5%	20.1%
	Toll Lanes	29.1%	25.1%	23.2%	22.6%
	Difference	1.7%	0.0%	1.3%	2.5%
After – Week 1	Tunnel Lane	29.5%	24.5%	24.2%	21.8%
	Toll Lanes	27.4%	23.6%	22.0%	20.2%
	Difference	2.1%	0.9%	2.1%	1.6%
	VDMF*	1.2	>>1	1.6	0.6
After – Week 2	Tunnel Lane	28.9%	24.4%	24.1%	22.7%
	Toll Lanes	28.5%	24.4%	23.1%	23.2%
	Difference	0.4%	0.0%	1.0%	0.6%
	VDMF*	0.2	0	0.8	0.2
After – Week 3	Tunnel Lane	28.0%	25.8%	24.5%	21.6%
	Toll Lanes	27.1%	26.1%	22.9%	21.7%
	Difference	0.9%	0.3%	1.6%	0.0%
	VDMF*	0.5	>>1	1.2	0

*VDMF = Volume Difference Modification Factor. Analogous to Crash Modification Factor.

Values in table are the percent of total tunnel traffic using a given tunnel lane or the percent of total toll plaza traffic using a given toll plaza lane group.

Green shading indicates a positive impact that was statistically significant

Red shading indicates a negative impact that was statistically significant

Gray shading indicates change with no statistical significance.

MOE #5 Data Analysis Findings

DESCRIPTIVE OBSERVATIONS

- Tunnel Lane A and Toll Lane 11 consistently have a higher proportion of the total traffic volume than any other tunnel lane or toll lane group. Toll Lane 11 is a 30 mph *E-ZPass*®ONLY lane.
- Before and after, Tunnel Lane A generally has a greater proportion of traffic than Toll Plaza Lane 11. This indicates that some drivers are using the left-hand lane of the tunnel and then shifting to the right portion of the toll plaza, potentially to pay with cash.
- Before and after, Tunnel Lane D and Toll Plaza lanes 1, 2, 3, and 4 are the least utilized.
- The difference between the percent of traffic in a tunnel lane and the corresponding toll plaza lanes is 2.5% or less of the total volume in the tunnel/toll plaza in all cases.

RESULTS OF STATISTICAL ANALYSIS

- All changes were statistically significant.
- In After Week 2, the difference between the percent of traffic in a tunnel lane and the corresponding toll plaza lanes was reduced at a statistically significant level for all approach lanes. In After Weeks 1 and 3, results were mixed.

MOE #5 Analysis Summary

The purple dots appear to have slightly improved the balance between the approach lanes and the toll lane volumes. The improved balance is a small numerical shift in the percent of the total traffic. The percentage of motorists using Tunnel Lane A/Toll Plaza Lane 11 has decreased slightly since dots were put in place.

MOE #6: TOLL VIOLATIONS

Violations in dedicated *E-ZPass*® lanes were identified from reports produced by the Authority. A toll violation is when a vehicle goes through the toll plaza and no toll is paid with either cash or electronic transaction. Toll violations are the result of confused, aggressive, and/or negligent drivers.

MOE #6 Data Reduction Summary

Figure 12 compares the percent of toll violations in each lane before the installation of the purple dots (months of August 2010, September 2010, and May 2011) and after the installation of the purple dots (months of August and September 2011). Table 7 displays statistical analysis results of this MOE. Unlike MOEs 1, 2, 3, and 5, MOE #6 is not dependent upon video data, providing greater flexibility when choosing analysis periods. August and September 2010 were chosen as before months to eliminate potential seasonal variation. May 2011 is shown as a before month for consistency with previous MOEs, although no analysis was conducted with this data.

Figure 12
Toll Plaza Violations

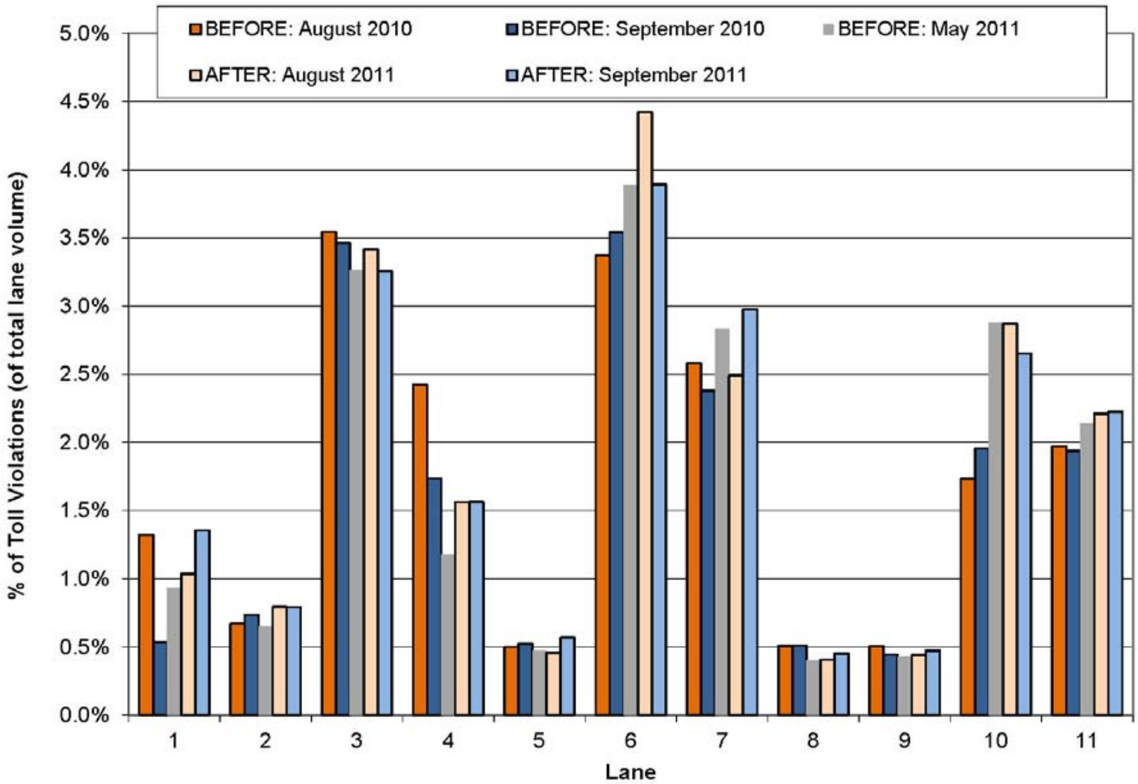


Table 7 – Statistical Significance of Before/After Violation Rate Changes

Lane	August	September
1	[green]	[red]
2	[red]	[gray]
3	[green]	[green]
4	[green]	[green]
5	[green]	[gray]
6	[red]	[red]
7	[gray]	[red]
8	[green]	[green]
9	[green]	[gray]
10	[red]	[red]
11	[red]	[red]

Refer to Figure 12 for before/after violation rates. This table uses color to indicate trends.
Green shading indicates a positive impact that was statistically significant
Red shading indicates a negative impact that was statistically significant
Gray shading indicates change with no statistical significance.

MOE #6 Data Analysis Findings

- For both August and September, there was an overall increase in the violation rate of 0.20% – 0.25%
- With the exception of Lane 3, *E-ZPass*®ONLY lanes generally showed an increase in violations.

- Most lanes with a decrease in violations were cash lanes.

MOE #6 Analysis Summary

The overall percentage of toll violations occurring at the northbound FMT Toll Plaza increased after the purple dots were installed. Much of the increase occurred at *E-ZPass®* ONLY lanes. Cash customers may be intentionally using *E-ZPass®* ONLY lanes to avoid queues in cash lanes.

Crash Data Analysis

Two approaches were used to investigate the safety performance of the purple dots:

- Data from the state's crash database before and after the *Phase I* experiment was analyzed.
- A custom crash form was developed and given to MDTA Police. The Police were asked to record all crashes that occurred on I-95 northbound between the tunnel mouth and toll plaza, including minor crashes that would normally not be entered into the state's crash database.

A before and after crash analysis of the *Phase II* purple dots using the state's crash database was not feasible. Crash data for a given year is generally not available until the latter half of the following year. Additionally, the number of crashes recorded would likely have been too small for conducting meaningful analysis due to the short timeframe of the study (less than a year for the before and after condition) and the fact that minor property damage crashes are not entered into the database.

CRASH DATA FROM PHASE I PERIOD

The Phase I purple dots were installed in November 2005, and their safety performance was assessed with crash data from November 2002 to October 2005 (before) and November 2005 to October 2008 (after). Table 8 summarizes this crash data between the tunnel mouth (Log Mile 6.03) and just prior to the toll plaza (Log Mile 6.42).

Table 8 – Phase I Crash Summary

Location	Before	After	Percent Change	Notes
Northbound – between tunnel and toll plaza	28	19	-32%	Focus of Analysis
Southbound – between tunnel and Toll Plaza	56	59	+5%	Purple Dots not installed here; included for comparative purposes only
Unknown direction – between tunnel and toll plaza	5	1	-80%	Some of these crashes likely occurred in the northbound direction

As shown in Table 8, a 32 percent reduction in crashes occurred in the study area (before the toll plaza in the northbound direction) when the purple dots were in place. Assuming that some of the five before crashes of an unknown direction were northbound crashes, the reduction with the purple dots in place was actually slightly greater than 32 percent.

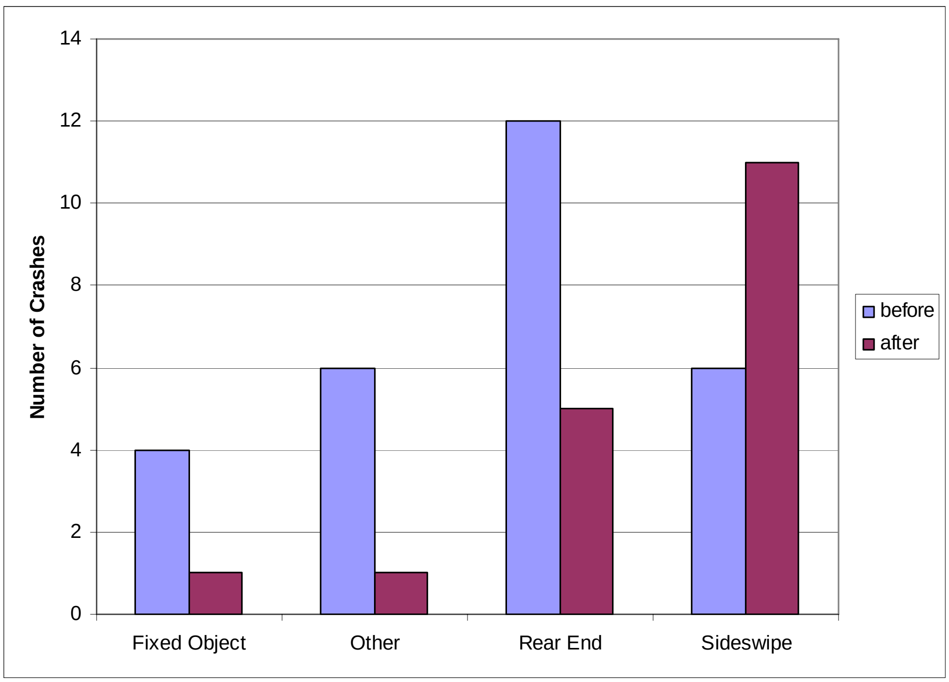
A naïve before/after analysis was conducted to determine if the change in crash frequency was statistically significant. Calculations are provided in Appendix C. This analysis assumes that all factors at the site except the purple dots were the same in the before and after periods, and was conducted with the manner described in Hauer's *Observational Before-After Studies in Road Safety* (Ref. 3). The analysis determined that the reduction in crash frequency was statistically significant at a 93% level of confidence.

It is noted that, in general, it would be preferable to conduct a before/after crash analysis by comparing the study site's safety performance with the safety performance of similar locations. Techniques for doing this type of analysis are provided in the *Highway Safety Manual* (Ref. 4). However, this approach is not possible due to the unique attributes of the site, which is a road segment between a tunnel and a toll plaza with horizontal and vertical curvature.

Crashes on the same road segment in the opposite direction (southbound) increased following the installation of the purple dots in the northbound direction; this provides an indication that the entire toll plaza area did not merely experience a decrease in crashes during the same period in which the purple dots were in place.

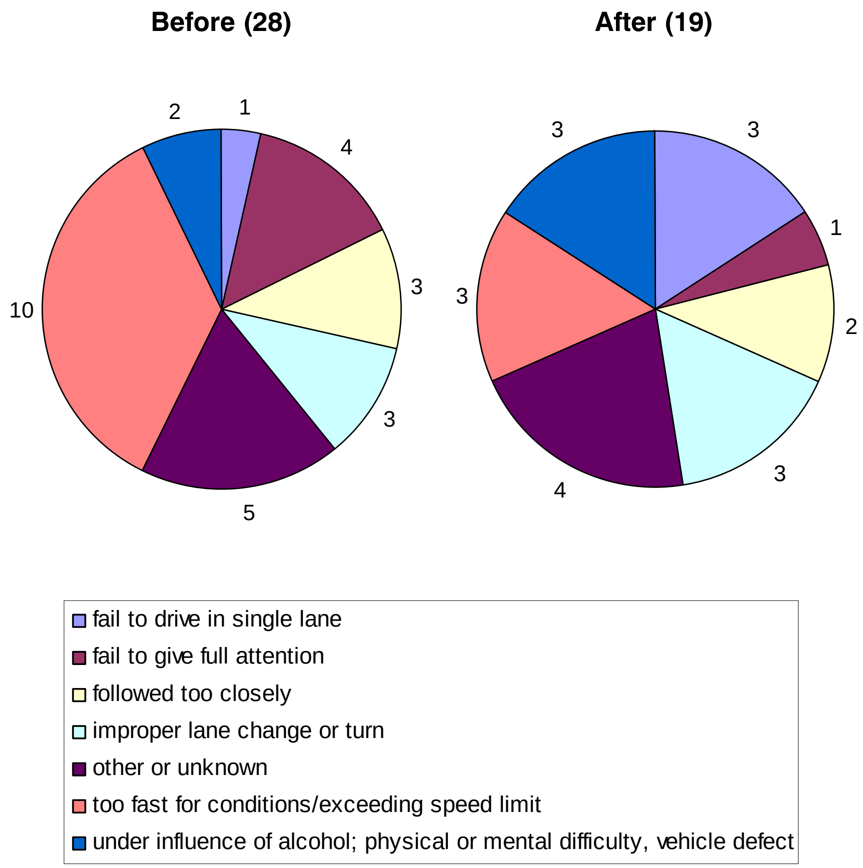
To further explore the decrease in crashes, safety data was analyzed by crash severity, crash type, time of day, and probable cause (all for the northbound direction only). There was no change in crash severity; 21% of all crashes were injury crashes both before and after the dots were installed. Crashes by type are shown in Figure 13.

Figure 13
Phase I Crashes by Type



As shown in Figure 13, sideswipe crashes increased after the purple dots were installed and all other types of crashes decreased. The increase in sideswipe crashes is unexpected, as the purple dots are intended to reduce lane changing. Figure 14 presents the probable cause of crashes, as reported by police.

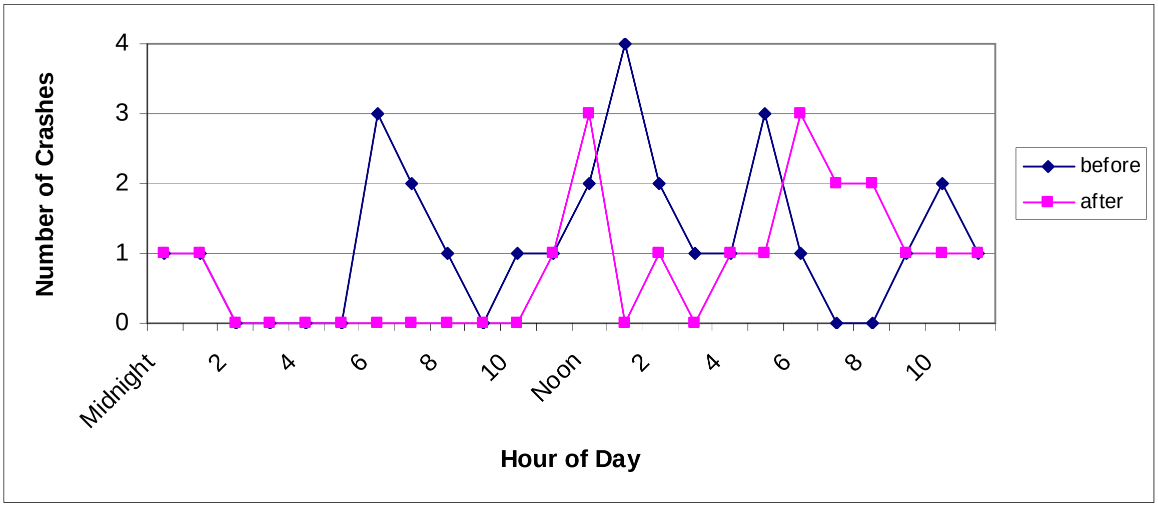
Figure 14
Phase I Crashes by Probable Cause



As shown in Figure 14, the purple dots primarily decreased crashes in which the probable cause was identified as too fast for conditions, exceeding speed limit, improper lane change, or improper turn.

Finally, crashes were analyzed by light conditions and time of day. There were 21 crashes in daylight and 7 crashes at nighttime before the purple dots, and there where were 11 crashes in daylight and 8 crashes at nighttime after the purple dots. Figure 15 presents the number of crashes that occurred in each hour of the day.

Figure 15
Phase I Crashes by Time of Day



As shown in Figure 15, crashes generally decreased in the morning and mid-afternoon with the purple dots in place.

Crashes occurring at the toll booths or 100 feet prior to the toll booths (Log Miles 6.43-6.44) were not included in Table 8 or any of the analysis in this section. The purple dots are not intended to improve operations or safety in this area, as drivers have already selected a lane by this point. This segment of roadway had 32 northbound crashes in the before period and 34 northbound crashes in the after period. Additionally, there were 5 crashes of an unknown direction in the before period and zero crash of an unknown direction in the after period. Assuming some of the crashes coded with an unknown direction occurred in the northbound direction, it appears that, with the purple dots in place, crash frequency at the toll plaza stayed approximately the same.

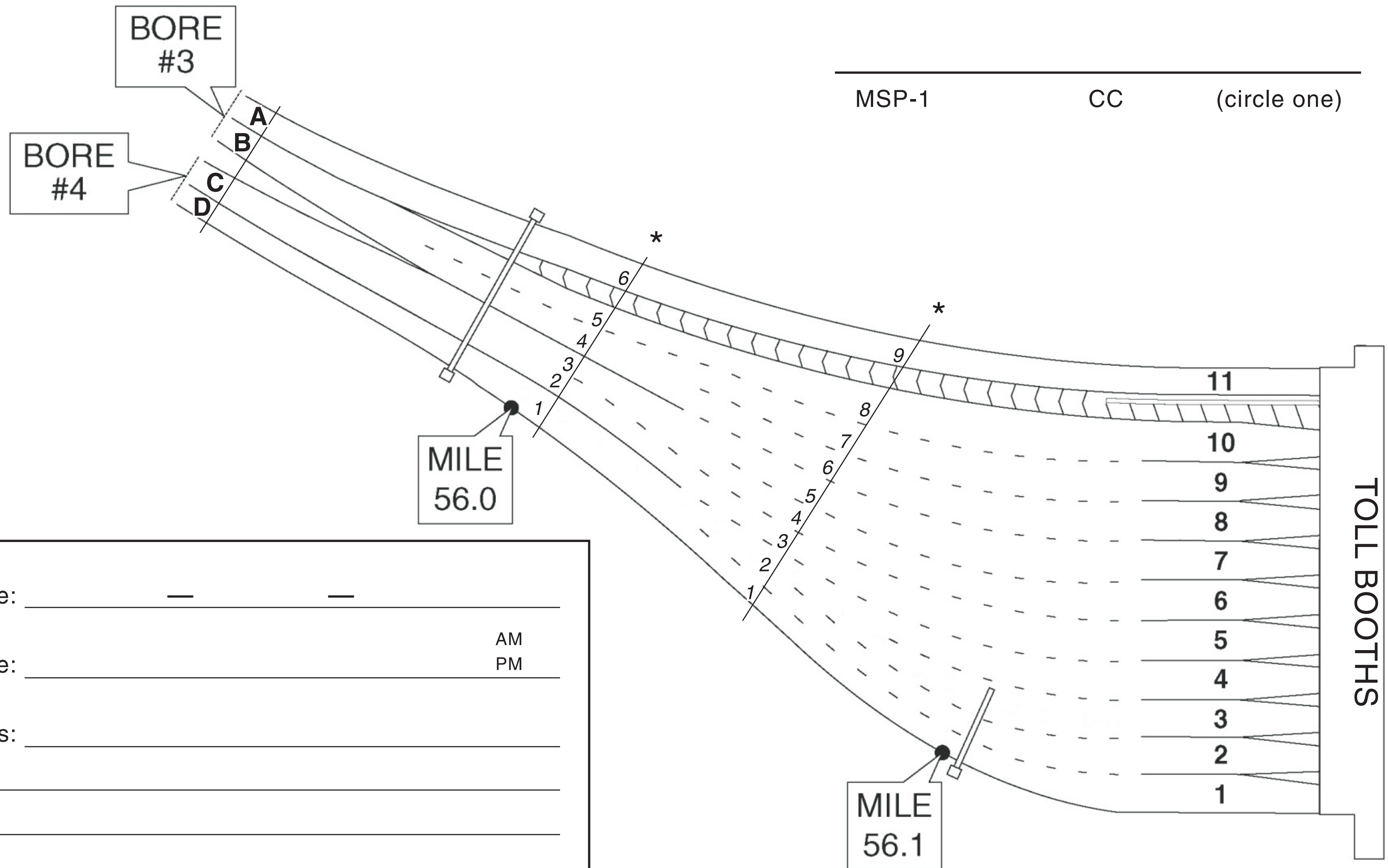
In summary, crashes prior to the toll plaza declined at a statistically significant level (93% confidence) with the purple dots in place, thus indicating an improvement in safety.

CUSTOM CRASH FORM REPORTING

At the start of the Phase II experiment in Fall 2010, a custom crash form for the study area was developed and given to MDTA Police. This form is shown in Figure 16. The forms were intended to capture all crashes occurring in the study area, including minor property damage crashes. The form also contains a diagram of the toll plaza area including lanes. Beginning in October 2010, MDTA Police were asked to fill out the form for all crashes occurring on I-95 northbound between the tunnel mouth and toll plaza, and to indicate the location of the crash on the form.

Ultimately, the custom crash forms were not consistently completed in both the before and after periods of the study. The completed crash forms do not constitute a complete set of crashes that occurred during any particular period of time, and thus no before/after crash rate could be computed. However, the crashes that were captured can be compared to investigate

MSP-1 CC (circle one)



Date: ______ — ______ — ______

Time: ______________________ AM PM

Notes: ______________________

* For informational purposes only lane number

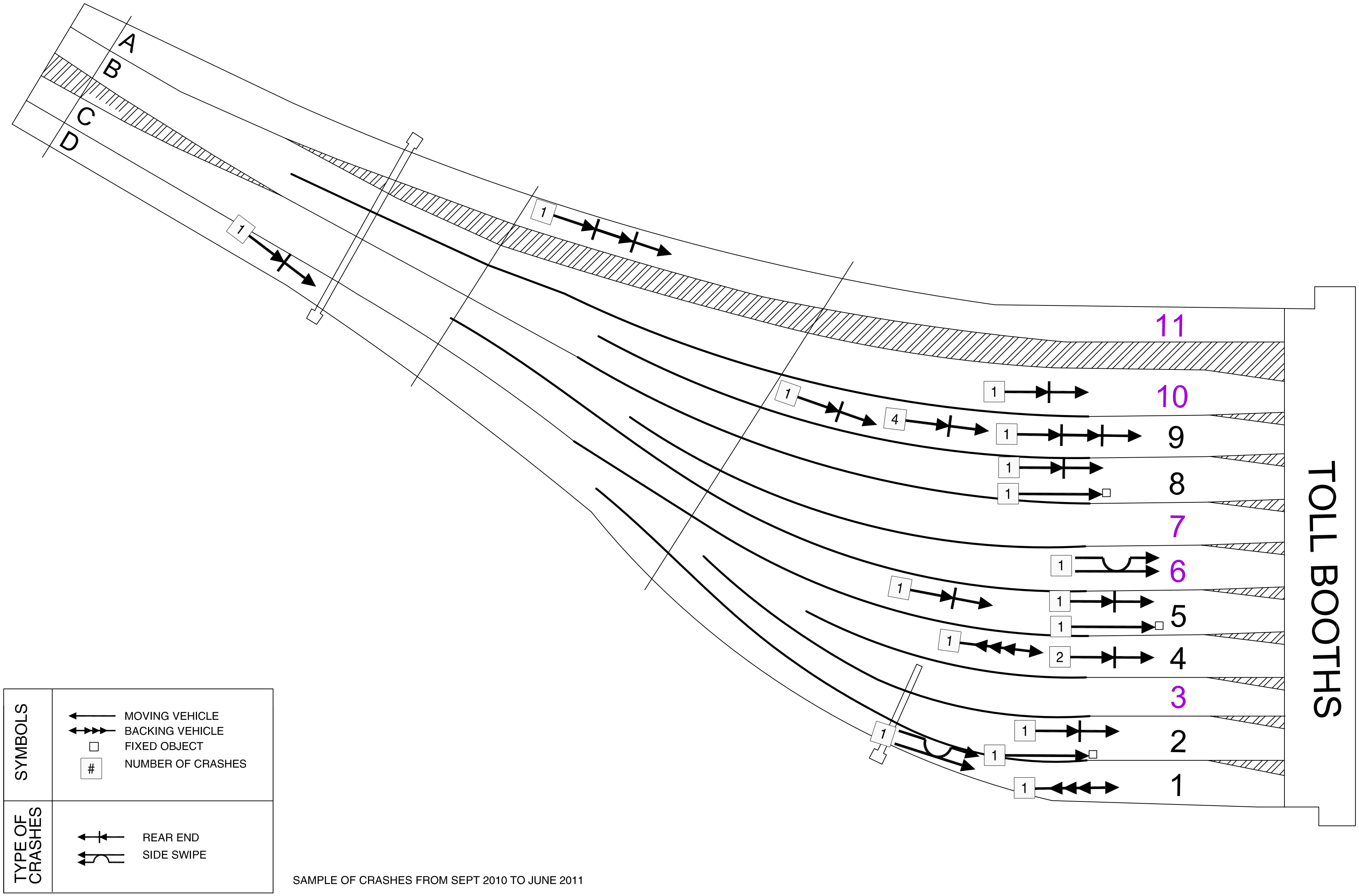
CUSTOM CRASH FORM
PURPLE DOTS BEFORE/AFTER STUDY
BALTIMORE, MARYLAND

FIGURE 16

changes in type and location before and after the purple dots were implemented.

Before and after crash diagrams are shown in Figures 17 and 18. As shown in these figures, the majority of crashes before and after the purple dots were rear-end collisions. In the before condition, crashes were relatively evenly distributed across the toll plaza. In the after condition, the vast majority of crashes were on the right side of the plaza. In both conditions, cash-accepting lanes had more crashes than *E-ZPass*®ONLY lanes. As previously noted, the difference in the *number* of crashes before and after the installation of the dots is not representative of a change in safety performance.

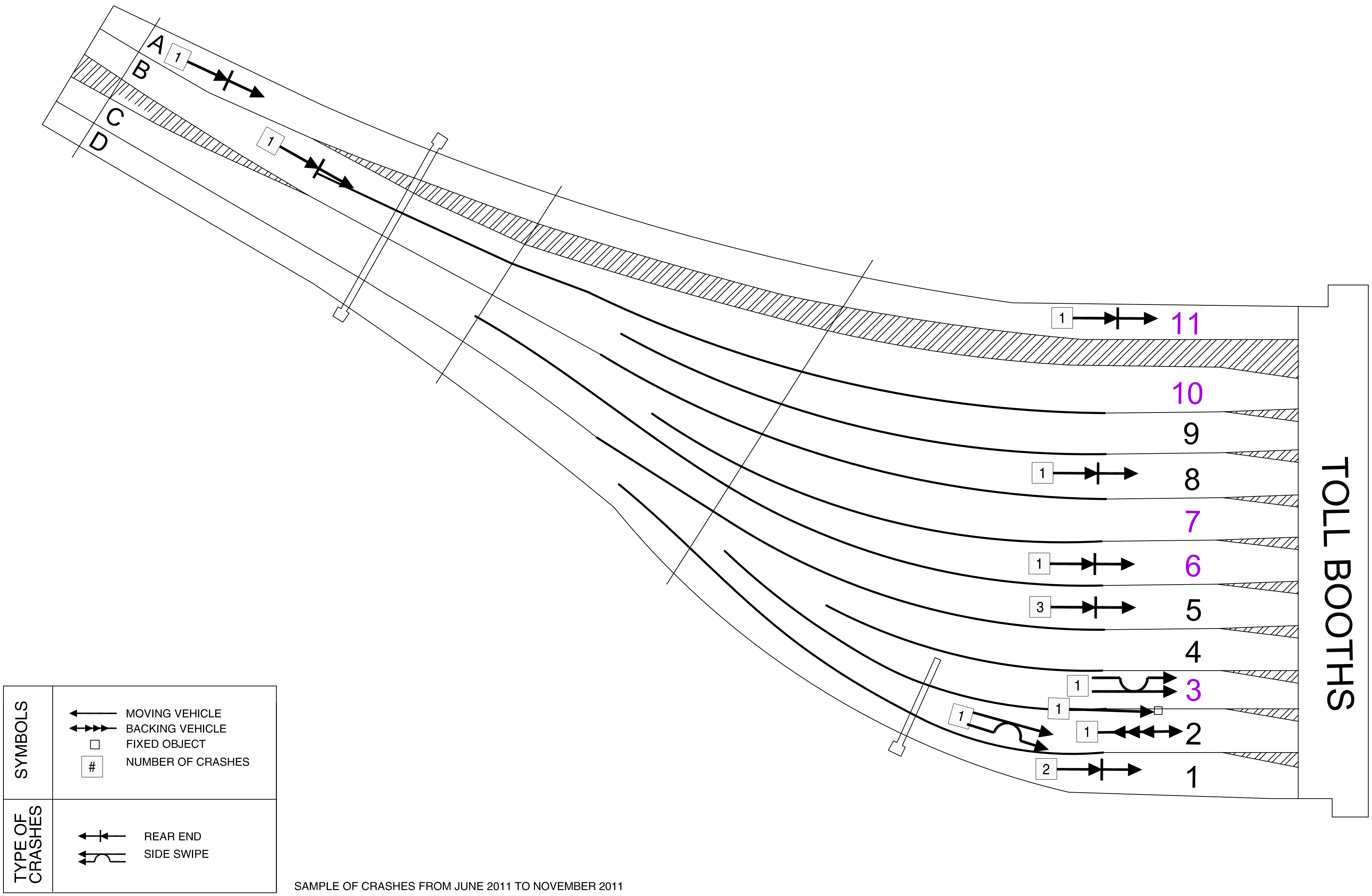
H:\projfile\8157 - MdTA Traffic Engineering Open End\Tasks\Task 5 - Purple DOTS II\dwgs\figs\8157-5 Crash Diagram.dwg Jun 12, 2012 - 11:13am - pjenior Layout Tab: Before Smaller



SAMPLE OF CRASHES FROM SEPT 2010 TO JUNE 2011

CRASH DIAGRAM
BEFORE THE PURPLE DOTS
BALTIMORE, MARYLAND

FIGURE
17



SAMPLE OF CRASHES FROM JUNE 2011 TO NOVEMBER 2011

CRASH DIAGRAM
AFTER THE PURPLE DOTS
BALTIMORE, MARYLAND

FIGURE 18

Findings and Recommendations

The analysis of operations and safety data indicates that the purple dots have statistically improved driver behavior and safety at the toll plaza in the following respects:

- Lane changes by E-ZPass® customers from Lanes 5 and 8 (both cash-accepting) to Lanes 6 and 7 (both E-ZPass®ONLY) decreased with the purple dots in place.
- Using newly-available crash data from the time period of the Phase I study, a reduction in crashes that is statistically significant with 93% confidence occurred between the tunnel exit and toll plaza.

The results of this experiment indicate that the purple dots reduced lane changing by E-ZPass® customers. E-ZPass® customers constitute the greatest percentage of toll plaza users (approximately 70% and growing) and are the group of drivers which the purple dots are intended to assist. Additionally, the purple dots appear to improve safety by reducing crashes on the approach to the toll plaza.

The results of some operational MOEs were mixed. Toll violation rates increased in some lanes and decreased in others, both at statistically significant levels. Likewise, the difference between approach lane volumes and toll lane volumes was desirable in about half the cases and undesirable in about half the cases, all at statistically significant levels. Lane changes by cash customers from Lanes 6 and 7 to Lanes 5 and 8 increased.

The purple dots are applicable for center and right-hand side dedicated *E-ZPass*®ONLY lanes that are difficult for drivers to locate because of site-specific elements such as horizontal or vertical curvature.

References

1. Maryland Transportation Authority. *Experimental Traffic Control Device Testing at Maryland Toll Plazas: FHWA Experimentation #3-181 (Ex) – Purple Dot Markings for E-ZPass[SM] Lanes at Tollbooth (MD)*. Prepared by Kittelson & Associates, Inc. May 11, 2007.

2. Federal Highway Administration. Manual of Uniform Traffic Control Devices. Washington, DC. 2009.

3. Hauer, E. *Observational Before-after Studies in Road Safety*. Oxford: Pergamon, 1998.

4. American Association of State Highway and Transportation Officials. *Highway Safety Manual*. Washington, DC. 2009.

Appendices

Appendix A – FHWA Correspondence

Appendix B – Statistical Analysis of Operational Measures of Effectiveness

Appendix C – Statistical Analysis of Before/After Safety Data

Appendix A – FHWA Correspondence

Mr. Roger Wentz, ATSSA

U.S. Department
of Transportation

**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

November 15, 2005

Refer to: HOTO-1

Mr. Trent M. Kittleman
Executive Secretary
Maryland Transportation Authority
300 Authority Drive
Baltimore, MD 21222

Dear Mr. Kittleman:

Thank you for your October 11 request for approval to experiment with purple pavement marking "dots" (and accompanying explanatory signs) to guide E-Z Pass transponder holders into the dedicated transponder lanes at certain tollbooth plazas in Maryland. The Maryland State Highway Administration forwarded your request and supporting information to us along with their endorsement.

Your evaluation plan will measure the effects of the dots versus the existing conditions, rather than in comparison to other potential standard pavement markings such as dotted white lane line extensions and/or word message pavement marking legends. We understand that, due to the particular geometrics of the approaches to the toll plazas, adding such standard markings was found to be infeasible and that is the reason for the request to experiment with the purple dots. Your request described the dots as the first phase, with potential additional phases involving different, non-standard lane control signal colors and displays. We approve your experimentation with the purple "dots" and the accompanying explanatory signs, for a period not to exceed 2 years. For future reference purposes, we have assigned the following official experimentation number and title to your request: "3-181(Ex)—Purple Dot Markings for EZ Pass Lanes at Tollbooth (MD)." Please refer to this number in future correspondence.

This approval is subject to the following additional conditions:

- The site of the experiment must be restored to a condition that complies with the provisions of the Manual on Uniform Traffic Control Devices (MUTCD) within 3 months following the end of the time period of the experiment. If, as a result of the experimentation, a request is made that the MUTCD be changed to include the device or application being experimented with, the device or application will be permitted to remain in place until an official rulemaking action has occurred.
- The experimentation must be terminated at any time that you determine significant safety concerns are directly or indirectly attributable to the experimentation. The Office of Transportation Operations also has the right to terminate approval of the experimentation at any time if there is an indication of safety concerns.

- Semiannual progress reports must be provided to the Office of Transportation Operations for the duration of the experimentation, as well as a copy of the final results of the experimentation within 3 months following completion of the experimentation.

We understand from Ms. Roxane Y. Mukai of your staff that the Maryland Transportation Authority is not ready at this time to proceed with the lane control signal portion of your proposed experimentation. Additionally, we are not ready to approve that portion at this time. We have concerns about the color purple as a signal display, in terms of conspicuity and visibility distance, ability of road users to distinguish it from other signal colors under day and night conditions, and impacts on road users with color vision deficiencies. We recommend that you investigate these issues and obtain more information from available previous research and/or from a laboratory study, before you submit a separate request for experimentation with purple signal devices at tollbooths.

Thank you for your interest in improving traffic safety through the use of innovative traffic control devices. We look forward to receiving your semiannual progress reports and final report. If we can be of further assistance on this matter, please contact Mr. Scott Wainwright at 202-366-0857 or via email at **scott.wainwright@fhwa.dot.gov**.

Sincerely yours,

Regina S. McElroy
Director, Office of Transportation Operations

cc: Mr. Roger Wentz, ATSSA

FHWA:HOTO-1:SWainwright:ds:60857:11-9-05
cc: HOTO-1 HOTO-1(SWainwright/HKalla)
Mr. Pat Hasson, HRC-MW Mr. Martin Knopp, HRC-MW
HDA-MD(2) Mr. Roger Wentz, ATSSA Mr. Jim Baron, ATSSA
Mr. Thomas Hicks, MD State Highway Administration
Mr. Carl Andersen, HRD T-301
Chron 3408 Reader 3408

DF(3-181(Ex)—Purple Dot Markings for EZ Pass Lanes at Tollbooth (MD))
M:\MUTCD\EXPERIME\3-181(EX) Purple Dots EZ Pass Lanes at Tollbooth (MD).doc

U.S. Department
of Transportation
Federal Highway
Administration

1200 New Jersey Avenue, SE.
Washington, DC 20590

November 20, 2008

In Reply Refer To: HOTO-1

Mr. Ronald L. Freeland
Executive Secretary
Maryland Transportation Authority
300 Authority Drive
Baltimore, MD 21222-2200

EXECUTIVE SECRETARY
DEC [illegible] 2008

Dear Mr. Freeland:

Thank you for your July 10 letter to Nelson J. Castellanos, Division Administrator of the Maryland Division of the Federal Highway Administration (FHWA), forwarding your May 11, 2007, Final Report on the evaluation of your experiment number 3-181(Ex) with purple pavement marking "dots" to guide E-Z Pass transponder holders into the dedicated transponder lanes at the Fort McHenry Tunnel toll plaza on I-95 in Maryland. Mr. Castellanos forwarded your letter and report to my office for reply.

We are pleased that your evaluation has found that the experimental purple dot markings have provided documented operational benefits at the Fort McHenry Tunnel toll plaza. The reduction in lane changes with the dots in place indicates a potential for safety benefits, although the duration of your experiment was too short to document actual crash reductions, if any. The high level of customer satisfaction with the markings is also of value.

Your letter requests permission to expand the use of the purple dot markings by installing them at other suitable toll plaza sites in Maryland, such as those listed on page 35 of the 2007 evaluation report. In our November 15, 2005, letter approving your experimentation, we noted that:

> The site of the experiment must be restored to a condition that complies with the provisions of the Manual on Uniform Traffic Control Devices (MUTCD) within 3 months following the end of the time period of the experiment. If, as a result of the experimentation, a request is made that the MUTCD be changed to include the device or application being experimented with, the device or application will be permitted to remain in place until an official rulemaking action has occurred.

As noted previously, your experimentation to date has provided some data that is very promising in terms of the benefits of these markings. However, we do not believe that there is sufficient data at this time, from a sufficient number of sites that are geographically dispersed (not just in Maryland but around the U.S.), to justify consideration of including these markings in the MUTCD. We believe it would be beneficial for your agency to expand your experimentation with these markings by collecting, analyzing, and reporting on the before-and-after crash data at the Fort McHenry toll plaza and by adding the markings at other toll plazas in Maryland that may have different types of conditions present. However, it must be recognized that the experimentation process is not to be considered a carte blanche approval for widespread use of experimental devices on a system-wide basis. Thus, we would entertain a request from the Maryland Transportation Authority to expand the current experiment to include crash data at the Fort McHenry Tunnel site and to add purple dot markings at some specific selected additional toll plazas, with comparable data collection, analysis, and reporting.

If you wish to expand your experiment under these terms, please send us a letter so indicating, and we will consider granting approval. Otherwise, the existing purple dot markings should be allowed to deteriorate and not be maintained or replaced, and the explanatory signs should be removed.

Thank you for your interest in improving traffic safety through the use of innovative traffic control devices. If we can be of further assistance on this matter, please contact Mr. Scott Wainwright via e-mail at **scott.wainwright@dot.gov** or by telephone at 202-366-0857.

Sincerely yours,

Hari Kalla
Acting Director, Office of Transportation
Operations

March 3, 2011

Mr. Hassan Raza
Acting Division Administrator
Federal Highway Administration
City Crescent Building, Suite 2450
10 South Howard Street
Baltimore, MD 21201

Re: FHWA Experimentation No. 3-181(EX)
Experimental Traffic Control Device Testing at Maryland Toll Plazas

Dear Mr. Castellanos:

The Maryland Transportation Authority received a letter regarding the above referenced experimentation; from Mr. Hari Kalla, Acting Director of the Office of Transportation Operations; dated November 20, 2008. This letter stated that "it would be beneficial for your agency to expand your experimentation with these markings by collecting, analyzing and reporting on the before-and-after crash data at the Fort McHenry toll plaza and by adding the markings at other toll plazas in Maryland that may have different types of conditions present…Thus, we would entertain a request from the Maryland Transportation Authority to expand the current experimentation to include crash data at the Fort McHenry Tunnel site and to add purple dot markings at some specific selected additional toll plazas, with comparable data collection, analysis and reporting." We have secured grant funding to continue the experimentation at the Fort McHenry Tunnel toll plaza and request your concurrence with a continuation of the experiment 3-181(EX) with the reinstallation of purple dots at the Fort McHenry Tunnel toll plaza. Additionally, we are researching the applicability for installing purple dots at the John F. Kennedy Memorial Highway (I-95) toll plaza in Cecil County and at the William Preston Lane Memorial Bridge (US 50/301) toll plaza in Anne Arundel County.

The Fort McHenry Tunnel toll plaza has been reconstructed since the original experimentation. Lane (toll payment) assignments have been changed, the purple dots were removed and additional (dashed) lane line markings have been added to assist drivers in maintaining their lane placement as the four lane approach expands to the 11 toll payment lanes available on the toll plaza. Additionally, one of the four approach lanes is signed and marked for ETC Only use and directed into a 30 mph dedicated Electronic Toll Collection (ETC) express lane at the toll plaza.

The original goal of the experimentation was to provide drivers with guidance from the approach highway lanes into the dedicated ETC toll payment lanes without restricting lane changing options. A review of the 2009 Manual on Uniform Traffic Control Devices identified two pavement markings intended to identify dedicated ETC lanes on toll plazas. The identified options were the “ETC ONLY” word markings and a solid white lane line outlined with a purple edging. The “ONLY” wording would imply that drivers without ETC transponders should not be in or crossing the ETC dedicated lanes so identified and the solid white line marking would imply that drivers should not enter or exit the ETC dedicated lanes once they are so marked. Both of these options would restrict lane changing and impact traffic operations within the toll plaza area. A sketch of the proposed Ft. McHenry Tunnel purple dot reinstallation is shown on the attached Figure 1.

A revised form for more intensive crash data collection is shown on the attached Figure 2. Upon completion of standard crash reporting forms, the affected Police unit is already attempting to document the additional crash data when possible. Collection of this “before” crash data began in September 2010 and will continue until the Purple Dots are installed. Collection of “after” crash data will begin after installation of the Purple Dots and will continue for 6 months after the installation.

The purpose of continuing this experiment at this time would be to secure the requested before-after crash data collection, analysis and report as requested in the November 20, 2008 letter. We thank you for your continued support of this study effort. Please let us know if we can respond to any questions, the contact for this study is Ms. Roxane Y. Mukai, Traffic Manager at 410-537-7848.

Sincerely,

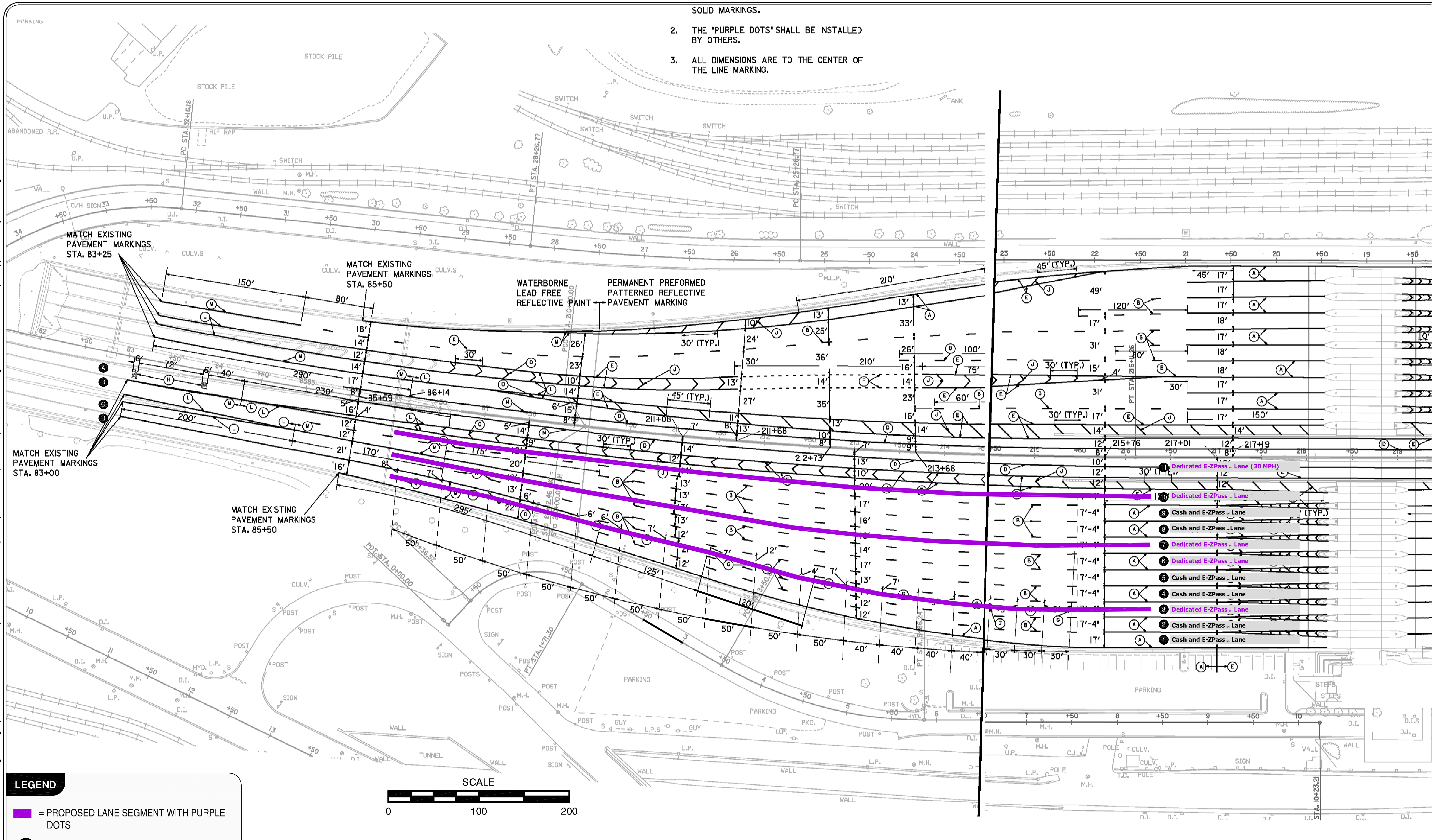
Harold M. Bartlett
Executive Secretary

Attachments

C: Mr. Breck Jeffers, FHWA
Mr. Scott Wainwright, FHWA (w/attachment)
Mr. Thomas Hicks, SHA (w/attachment)
Ms. Roxane Y. Mukai, MDTA

BC:

Mr. Randolph P. Brown, MDTA
Mr. Gordon Garretson, WPL, MDTA
Ms. Martara Hannah, FMT, MDTA
Mr. Douglas Hutcheson, MDTA
Mr. John Lohmeyer, JFK, MDTA
Mr. Dilip Patel, OOTS, SHA
Mr. Eric Tabacek, OOTS, SHA



LEGEND

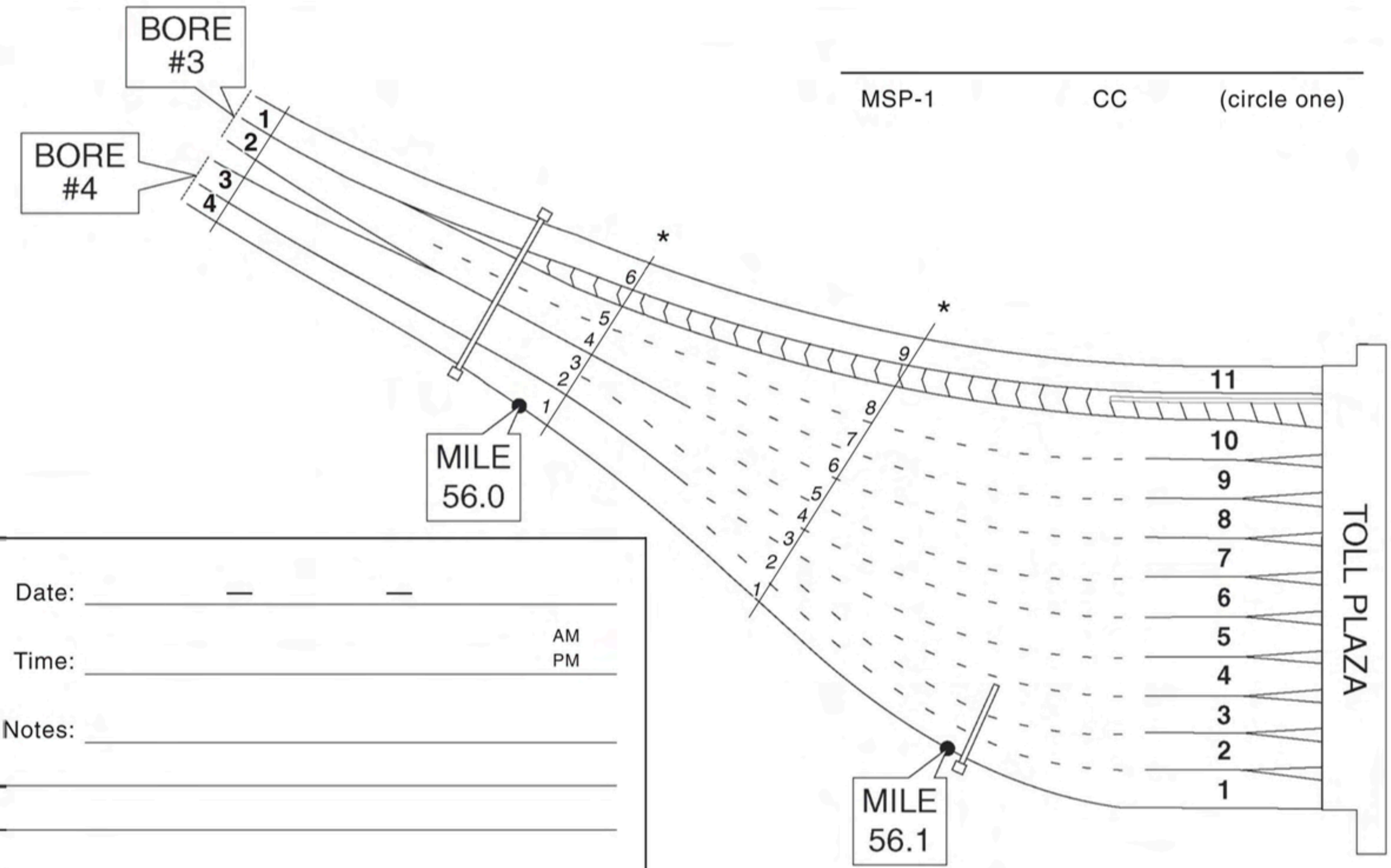
= PROPOSED LANE SEGMENT WITH PURPLE DOTS

1 = LANE IDENTIFICATION

PROPOSED LANES FOR PURPLE DOT MARKINGS
BALTIMORE, MARYLAND

FIGURE 1

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING / PLANNING



Date: ____ — ____ — ____

Time: ________ AM PM

Notes: ________

* For informational purposes only lane number

Sample Crash Reporting Form for Fort McHenry Tunnel

FIGURE **2**

U.S. Department
of Transportation
Federal Highway
Administration

APR - 4 2011

1200 New Jersey Ave., SE
Washington, D.C. 20590

In Reply Refer To:
HOTO-1

Mr. Harold M. Bartlett
Acting Executive Secretary
Maryland Transportation Authority
2310 Broening Highway, Suite 150
Baltimore, MD 21224

Dear Mr. Bartlett:

Thank you for your letter of March 3 to Hassan Raza, Acting Division Administrator of the DelMar Division of the Federal Highway Administration (FHWA), requesting extension and modification of your experiment number 3-181(Ex) with purple pavement marking "dots" to guide E-Z Pass transponder holders into the dedicated transponder lanes at the Fort McHenry Tunnel toll plaza on I-95 in Maryland. Your letter has been forwarded to the Office of Transportation Operations for reply.

We have reviewed your request and agree that it would be beneficial to extend the approval of this experiment to enable collection and analysis of crash data at the Fort McHenry Tunnel site. Based on the information supplied by your consultant, we agree that Empirical-Bayes analysis of the crash data is not possible for this evaluation. Accordingly, we are granting an extension for this experiment until July 1, 2012, under the same conditions as the original approval.

Your letter mentioned that toll plazas at two other locations in Maryland are under consideration for potential application of the experimental purple dot markings. Should you decide to pursue the use of this device at these additional locations, please submit a separate request to add such locations to the experiment, including site details and proposed evaluation plans.

Thank you for your interest in improving traffic safety through the use of innovative traffic control devices. If we can be of further assistance on this matter, please contact Mr. Scott Wainwright via e-mail at **scott.wainwright@dot.gov** or by telephone at 202-366-0857.

Sincerely yours,

Mark R. Kehrli
Director, Office Transportation
Operation

Appendix B – Statistical Analysis of Operational Measures of Effectiveness

BACKGROUND

The following measures of effectiveness (MOEs) were collected and reported for the follow-up subject field study:

1. Percent of lane change by E-ZPass customers;
2. Percent of lane changes by cash-paying customers;
3. Percent of vehicles emerging from approach lane C and changing lanes into toll lanes #10 or #11;
4. Toll lane volume utilization;
5. Approach lane distribution versus toll lane utilization; and,
6. Toll violations.

Before data was collected during May 2010 and after data was collected during the months of August and September 2010. A z-test was used to compare the difference in proportions from before and after (broke down into 3 different weeks for MOEs # 1, 2 and #5 and into 2 different months, August and September for MOE #6). A five percent significance level ($\alpha = 0.05$) was considered the Z-statistic, P-value and the 95% Confidence Interval is presented in the statistical analysis for all MOEs.

ANALYSIS AND INTERPRETATION

This section contains a tabular summary of the data analysis for all MOE's noted above. Each table provide a before and after statistical analysis with the following statistics: proportion difference between before and after scenarios (*p_before – p-after*); *z-statistic*, *p-value, and 95% Confidence Interval.* Interpretation of the results is also described in this section.

MOE #1: Percent of Lane Changes by E-ZPass Customers

Table 1 shows the total number of before and after period (week 1, week 2 and week 3) lane changes, total lane volume, confidence interval, and p-value for the lane #6, lane #7, and pooled test of proportions (lane #6 and lane #7 combined).

The analysis results indicate that the purple dots did reduce the number of lane changes in lane #6 only, lane # 7 only, and lanes #6 and #7 combined. The magnitude of this change was a reduction in the change in proportions by 1.08 to 4.72 percent. All results were statistically significant when comparing the before period to the second after period suggesting that the long-term effects of the purple dots are positive. This interpretation is denoted by the following: *z-statistic* higher than 1.96; *p-value* lower than 0.05 and zero difference outside the lower and upper limits of the 95% confidence interval.

Table 1 -

All Data - Excluding Late Night							
Lane_6_Before_ Changes	Lane_6_Before _Volume	p_lane6_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
894	8799	**10.2%**	NA	NA	NA	NA	NA
Lane_6_After_ Wk1_Changes	Lane_6_After_ Wk1_Volume	p_lane6_wk1					
420	7727	**5.4%**	4.72%	11.451	**0.000**	0.039	0.055
Lane_6_After_ Wk2_Changes	Lane_6_After_ Wk2_Volume	p_lane6_wk2					
502	6419	**7.8%**	2.34%	5.034	**0.000**	0.014	0.033
Lane_6_After_ Wk3_Changes	Lane_6_After_ Wk3_Volume	p_lane6_wk3					
584	6430	**9.1%**	1.08%	2.237	**0.013**	0.001	0.020
Lane_7_Before_ Changes	Lane_7_Before _Volume	p_lane7_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
739	7067	**10.5%**	NA	NA	NA	NA	NA
Lane_7_After_ Wk1_Changes	Lane_7_After_ Wk1_Volume	p_lane7_wk1					
479	5860	**8.2%**	2.28%	4.472	**0.000**	0.013	0.033
Lane_7_After_ Wk2_Changes	Lane_7_After_ Wk2_Volume	p_lane7_wk2					
544	6322	**8.6%**	1.85%	3.654	**0.000**	0.009	0.028
Lane_7_After_ Wk3_Changes	Lane_7_After_ Wk3_Volume	p_lane7_wk3					
622	6752	**9.2%**	1.24%	2.459	**0.007**	0.003	0.022
Lane_6&7_Befo re_Changes	Lane_6&7_Bef ore_Volume	p_lane6&7_bef ore	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
1633	15866	**10.3%**	NA	NA	NA	NA	NA
Lane_6&7_Afte r_Wk1_Changes	Lane_6&7_Afte r_Wk1_Volume	p_lane6&7_wk1					
899	13587	**6.6%**	3.68%	11.416	**0.000**	0.030	0.043
Lane_6&7_Afte r_Wk2_Changes	Lane_6&7_Afte r_Wk2_Volume	p_lane6&7_wk2					
1046	12741	**8.2%**	2.08%	6.080	**0.000**	0.014	0.028
Lane_6&7_Afte r_Wk3_Changes	Lane_6&7_Afte r_Wk3_Volume	p_lane6&7_wk3					
1206	13182	**9.1%**	1.14%	3.284	**0.001**	0.005	0.018

Table 2 breaks down MOE #1 analysis into four different periods: AM, Midday, PM and Saturday. During the AM time period, no difference on lane changes was observed for lane 6 only. This can be interpreted by the following: *z-statistic* lower than 1.96; *p-value* higher than

0.05 and zero difference within the lower and upper limits of the 95% confidence interval. For lane 7 only and lane 6 and 7 combined, a significant reduction in lane changes was observed.

Table 2 also shows that at midday, a significant reduction was observed for lane 6 only, lane 7 only and lane 6 and 7 combined. During the PM time period, the opposite was observed: no significant reduction was perceived for lane 6 only, lane 7 only and lane 6 and 7 combined. This can be associated to a saturated traffic flow condition, which would limit the ability of roadway users to change lanes.

Lastly, lane 7 only and lane 6 and 7 combined did present an significant reduction ranging from 21.3 to 8 percent and from 14.6 to 7.7 percent.

Table 2 -

AM							
Lane_6_Before_Changes	Lane_6_Before_Volume	p_lane6_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
57	865	**6.6%**	NA	NA	NA	NA	NA
Lane_6_After_Changes	Lane_6_After_Volume	p_lane6_after					
322	4006	**8.0%**	-1.45%	-1.530	**0.063**	-0.033	0.004
Lane_7_Before_Changes	Lane_7_Before_Volume	p_lane7_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
141	768	**18.4%**	NA	NA	NA	NA	NA
Lane_7_After_Changes	Lane_7_After_Volume	p_lane7_after					
261	3384	**7.7%**	10.65%	7.241	**0.000**	0.078	0.135
Lane_6&7_Before_Changes	Lane_6&7_Before_Volume	p_lane6&7_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
198	1633	**12.1%**	NA	NA	NA	NA	NA
Lane_6&7_After_Changes	Lane_6&7_After_Volume	p_lane6&7_after					
583	7390	**7.9%**	4.24%	4.889	**0.000**	0.025	0.059

Midday							
Lane_6_Before_Changes	Lane_6_Before_Volume	p_lane6_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
449	1579	**28.4%**	NA	NA	NA	NA	NA
Lane_6_After_Changes	Lane_6_After_Volume	p_lane6_after					
467	5013	**9.3%**	19.12%	15.838	**0.000**	0.168	0.215
Lane_7_Before_Changes	Lane_7_Before_Volume	p_lane7_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
157	1709	**9.2%**	NA	NA	NA	NA	NA
Lane_7_After_Changes	Lane_7_After_Volume	p_lane7_after					
462	3456	**13.4%**	-4.18%	-4.608	**0.000**	-0.060	-0.024
Lane_6&7_Before_Changes	Lane_6&7_Before_Volume	p_lane6&7_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
606	3288	**18.4%**	NA	NA	NA	NA	NA
Lane_6&7_After_Changes	Lane_6&7_After_Volume	p_lane6&7_after					
929	8469	**11.0%**	7.46%	9.861	**0.000**	0.060	0.089

PM							
Lane_6_Before_Changes	Lane_6_Before_Volume	p_lane6_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
307	5464	**5.6%**	NA	NA	NA	NA	NA
Lane_6_After_Changes	Lane_6_After_Volume	p_lane6_after					
668	10887	**6.1%**	-0.52%	-1.336	**0.091**	-0.013	0.002
Lane_7_Before_Changes	Lane_7_Before_Volume	p_lane7_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
284	3853	**7.4%**	NA	NA	NA	NA	NA
Lane_7_After_Changes	Lane_7_After_Volume	p_lane7_after					
872	11472	**7.6%**	-0.23%	-0.472	**0.319**	-0.012	0.007
Lane_6&7_Before_Changes	Lane_6&7_Before_Volume	p_lane6&7_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
591	9317	**6.3%**	NA	NA	NA	NA	NA
Lane_6&7_After_Changes	Lane_6&7_After_Volume	p_lane6&7_after					
1540	22359	**6.9%**	-0.54%	-1.790	**0.037**	-0.011	0.001

Saturday							
Lane_6_Before_Changes	Lane_6_Before_Volume	p_lane6_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
81	891	**9.1%**	NA	NA	NA	NA	NA
Lane_6_After_Changes	Lane_6_After_Volume	p_lane6_after					
49	670	**7.3%**	1.78%	1.276	**0.101**	-0.010	0.045
Lane_7_Before_Changes	Lane_7_Before_Volume	p_lane7_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
157	737	**21.3%**	NA	NA	NA	NA	NA
Lane_7_After_Changes	Lane_7_After_Volume	p_lane7_after					
50	622	**8.0%**	13.26%	7.127	**0.000**	0.096	0.169
Lane_6&7_Before_Changes	Lane_6&7_Before_Volume	p_lane6&7_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
238	1628	**14.6%**	NA	NA	NA	NA	NA
Lane_6&7_After_Changes	Lane_6&7_After_Volume	p_lane6&7_after					
99	1292	**7.7%**	6.96%	6.068	**0.000**	0.047	0.092

MOE #2: Percent of Lane Changes by Cash-paying Customer

Table 3 shows the total number of before and after period (week 1, week 2 and week 3) lane changes, total lane volume, confidence interval, and p-value for for the lane #5, lane #8, and pooled test of proportions (lane #5 and lane #8 combined).

The overall analysis results indicate that the purple dots did not reduce the number of lane changes in lane #5 only, lane #8 only, and lanes #5 and #8 combined. Indeed, a significant increase in lane changes was observed in week 2 and week 3 after periods, with week 2 showing the worst results overall. The increase difference ranged from 2.86 to.5.72%. Conversely, week 1 showed a significant reduction for lane # 5 and lane 5# and 8# combined.

Table 3 -

All Data - Excluding Late Night							
Lane_5_Before_Changes	Lane_5_Before_Volume	p_lane5_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
1172	5234	**22.4%**	NA	NA	NA	NA	NA
Lane_5_After_Wk1_Changes	Lane_5_After_Wk1_Volume	p_lane5_wk1					
517	4128	**12.5%**	9.87%	12.767	**0.000**	0.084	0.114
Lane_5_After_Wk2_Changes	Lane_5_After_Wk2_Volume	p_lane5_wk2					
1276	4634	**27.5%**	-5.14%	-5.890	**0.000**	-0.069	-0.034
Lane_5_After_Wk3_Changes	Lane_5_After_Wk3_Volume	p_lane5_wk3					
1067	4225	**25.3%**	-2.86%	-3.244	**0.001**	-0.046	-0.011
Lane_8_Before_Changes	Lane_8_Before_Volume	p_lane8_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
634	5444	**11.6%**	NA	NA	NA	NA	NA
Lane_8_After_Wk1_Changes	Lane_8_After_Wk1_Volume	p_lane8_wk1					
516	4293	**12.0%**	-0.37%	-0.566	**0.286**	-0.017	0.009
Lane_8_After_Wk2_Changes	Lane_8_After_Wk2_Volume	p_lane8_wk2					
738	4349	**17.0%**	-5.32%	-7.433	**0.000**	-0.067	-0.039
Lane_8_After_Wk3_Changes	Lane_8_After_Wk3_Volume	p_lane8_wk3					
774	4457	**17.4%**	-5.72%	-8.002	**0.000**	-0.071	-0.043
Lane_5&8_Before_Changes	Lane_5&8_Before_Volume	p_lane7&8_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
1806	10678	**16.9%**	NA	NA	NA	NA	NA
Lane_5&8_After_Wk1_Changes	Lane_5&8_After_Wk1_Volume	p_lane7&8_wk1					
1033	8421	**12.3%**	4.65%	9.123	**0.000**	0.036	0.056
Lane_5&8_After_Wk2_Changes	Lane_5&8_After_Wk2_Volume	p_lane7&8_wk2					
2014	8983	**22.4%**	-5.51%	-9.656	**0.000**	-0.066	-0.044
Lane_5&8_After_Wk3_Changes	Lane_5&8_After_Wk3_Volume	p_lane7&8_wk3					
1841	8682	**21.2%**	-4.29%	-7.539	**0.000**	-0.054	-0.032

Table 4 breaks down MOE #2 analysis into four different periods: AM, Midday, PM and Saturday. A significant increase on lane changes for lane #5, lane # 8 and lane #5 and # 8 combined was observed during AM, midday and PM periods. The significant increase difference ranged from 2.91 to 14.13 percent. It should be pointed out that the lower differences were observed during the PM period. This can associated to the saturated traffic flow conditions where roadway users have less opportunity to perform lane changes.

Table 4 -

AM							
Lane_5_Before_Changes	Lane_5_Before_Volume	p_lane5_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
54	727	**7.4%**	NA	NA	NA	NA	NA
Lane_5_After_Changes	Lane_5_After_Volume	p_lane5_after					
692	3210	**21.6%**	-14.13%	-11.644	**0.000**	-0.165	-0.118
Lane_8_Before_Changes	Lane_8_Before_Volume	p_lane8_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
24	691	**3.5%**	NA	NA	NA	NA	NA
Lane_8_After_Changes	Lane_8_After_Volume	p_lane8_after					
614	3369	**18.2%**	-14.75%	-15.317	**0.000**	-0.166	-0.129
Lane_5&8_Before_Changes	Lane_5&8_Before_Volume	p_lane5&8_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
78	1418	**5.5%**	NA	NA	NA	NA	NA
Lane_5&8_After_Changes	Lane_5&8_After_Volume	p_lane5&8_after					
1306	6579	**19.9%**	-14.35%	-18.398	**0.000**	-0.159	-0.128

Midday								
Lane_5_Before_Changes	Lane_5_Before_Volume	p_lane5_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**		
194	1759	**11.0%**	NA	NA	NA	NA	NA	
Lane_5_After_Changes	Lane_5_After_Volume	p_lane5_after						
871	4290	**20.3%**	-9.27%	-9.591	**0.000**	-0.112	-0.074	
Lane_8_Before_Changes	Lane_8_Before_Volume	p_lane8_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**		
133	1886	**7.1%**	NA	NA	NA	NA	NA	
Lane_8_After_Changes	Lane_8_After_Volume	p_lane8_after						
521	4243	**12.3%**	-5.23%	-6.740	**0.000**	-0.067	-0.037	
Lane_5&8_Before_Changes	Lane_5&8_Before_Volume	p_lane5&8_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**		
327	3645	**9.0%**	NA	NA	NA	NA	NA	
Lane_5&8_After_Changes	Lane_5&8_After_Volume	p_lane5&8_after						
1392	8533	**16.3%**	-7.34%	-11.847	**0.000**	-0.086	-0.061	

PM								
Lane_5_Before_Changes	Lane_5_Before_Volume	p_lane5_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**		
307	1415	**21.7%**	NA	NA	NA	NA	NA	
Lane_5_After_Changes	Lane_5_After_Volume	p_lane5_after						
1115	4532	**24.6%**	-2.91%	-2.291	**0.011**	-0.054	-0.004	
Lane_8_Before_Changes	Lane_8_Before_Volume	p_lane8_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**		
293	1478	**19.8%**	NA	NA	NA	NA	NA	
Lane_8_After_Changes	Lane_8_After_Volume	p_lane8_after						
825	4536	**18.2%**	1.64%	1.381	**0.084**	-0.007	0.040	
Lane_5&8_Before_Changes	Lane_5&8_Before_Volume	p_lane5&8_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**		
600	2893	**20.7%**	NA	NA	NA	NA	NA	
Lane_5&8_After_Changes	Lane_5&8_After_Volume	p_lane5&8_after						
1940	9068	**21.4%**	-0.65%	-0.754	**0.226**	-0.024	0.010	

Saturday							
Lane_6_Before_Changes	Lane_6_Before_Volume	p_lane5_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
617	1333	**46.3%**	NA	NA	NA	NA	NA
Lane_5_After_Changes	Lane_5_After_Volume	p_lane5_after					
182	955	**19.1%**	27.23%	14.595	**0.000**	0.236	0.309
Lane_7_Before_Changes	Lane_7_Before_Volume	p_lane8_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
184	1389	**13.2%**	NA	NA	NA	NA	NA
Lane_8_After_Changes	Lane_8_After_Volume	p_lane8_after					
68	951	**7.2%**	6.10%	4.936	**0.000**	0.037	0.085
Lane_5&8_Before_Changes	Lane_5&8_Before_Volume	p_lane5&8_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
801	2722	**29.4%**	NA	NA	NA	NA	NA
Lane_5&8_After_Changes	Lane_5&8_After_Volume	p_lane5&8_after					
250	1906	**13.1%**	16.31%	13.982	**0.000**	0.140	0.186

MOE #3: Percent of Vehicles Emerging from Approach Lane C and Changing Lanes into Toll Lanes #10 or #11

Table 5 shows the total number of before and after period (week 1, week 2 and week 3) lane changes, total lane volume, confidence interval, and p-value for approach lane C.

The analysis results indicate that the purple dots increased the proportion of lane changes from approach lane C to toll lane #10 or #11 or as evidenced by the negative change in proportion from the before and week 1 and week 3 after periods. The change was statistically significant, with an increase of the proportion of lane changes increased by 0.63 and 0.68 percent in week 1 and week 3 respectively. No changes were observed in week 2. Despite the statistical significance, the magnitude of changes was marginal (less than 1%). This can be explained by the small variance due to the large sample size of before and after total volume.

Table 5 -

All Data - Excluding Late Night							
Lane_C_Before_Changes	Lane_C_Before_Volume	p_laneC_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
65	13184	**0.5%**	NA	NA	NA	NA	NA
Lane_C_After_Wk1_Changes	Lane_C_After_Wk1_Volume	p_laneC_wk1					
219	19503	**1.1%**	-0.63%	-6.492	**0.000**	-0.008	-0.004
Lane_C_After_Wk2_Changes	Lane_C_After_Wk2_Volume	p_laneC_wk2					
84	19136	**0.4%**	0.05%	0.698	**0.243**	-0.001	0.002
Lane_C_After_Wk3_Changes	Lane_C_After_Wk3_Volume	p_laneC_wk3					
250	21401	**1.2%**	-0.68%	-7.071	**0.000**	-0.009	-0.005

Table 6 breaks down MOE #3 analysis into four different periods: AM, Midday, PM and Saturday. A significant increase on approach lane C changes was observed during midday and PM periods. The significant increase difference ranged from 0.43 to 0.63 percent. No significant changes were observed during AM and Saturday analysis periods.

Table 6 -

AM							
Lane_C_Before_Changes	Lane_C_Before_Volume	p_laneC_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
18	1326	**1.4%**	NA	NA	NA	NA	NA
Lane_C_After_Changes	Lane_C_After_Volume	p_laneC_after					
205	12184	**1.7%**	-0.33%	-0.960	**0.168**	-0.010	0.003

Midday							
Lane_C_Before_Changes	Lane_C_Before_Volume	p_laneC_before	p_Before - p_After	Z Statistic	P-Value	95% CI	
33	5428	**0.6%**	NA	NA	NA	NA	NA
Lane_C_After_Changes	Lane_C_After_Volume	p_laneC_after					
135	13046	**1.0%**	-0.43%	-3.098	**0.001**	-0.007	-0.002

PM							
Lane_C_Before_Changes	Lane_C_Before_Volume	p_laneC_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
3	4791	**0.1%**	NA	NA	NA	NA	NA
Lane_C_After_Changes	Lane_C_After_Volume	p_laneC_after					
197	27836	**0.7%**	-0.65%	-10.423	**0.000**	-0.008	-0.005

Saturday							
Lane_C_Before_Changes	Lane_C_Before_Volume	p_laneC_before	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
11	1639	**0.7%**	NA	NA	NA	NA	NA
Lane_C_After_Changes	Lane_C_After_Volume	p_laneC_after					
12	2651	**0.5%**	0.22%	0.910	**0.181**	-0.003	0.007

MOE #4: Toll Lane Volume Utilization

The toll lane volume utilization analysis uses a test of proportions to compare the percentage of traffic using each lane in the before and after time periods. Traffic volume counts were available for 24-hour periods, AM and PM peak periods as shown in Tables 7, 8 and 9 respectively.

Table 7 shows that there was a statistically significant increase in the proportion of traffic utilizing each lane changed from the before to after time period in lanes 1, 6, and 10 for the 24-hour analysis. A significant decrease in lane utilization occurred in lanes 2, 4, 5, 7, 8 and 9 for the same period.

Table 7 -

24hr

	Total ETC Volume_Before (Feb-May)	Lane ETC Volume_Before (Feb-May)	%_Before	Total ETC Volume_After (August-September)	Lane ETC Volume_After (August-September)	%_After	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
Lane 1	43840	66	**0.1%**	43557	253	**0.6%**	-0.43%	-10.576	**0.000**	-0.005	-0.004
Lane 2		785	**1.8%**		571	**1.3%**	0.48%	5.744	**0.000**	0.003	0.006
Lane 3		6455	**14.7%**		6325	**14.5%**	0.20%	0.846	**0.199**	-0.003	0.007
Lane 4		2059	**4.7%**		1883	**4.3%**	0.37%	2.664	**0.004**	0.001	0.006
Lane 5		318	**0.7%**		264	**0.6%**	0.12%	2.181	**0.015**	0.000	0.002
Lane 6		4699	**10.7%**		5409	**12.4%**	-1.70%	-7.855	**0.000**	-0.021	-0.013
Lane 7		6111	**13.9%**		4671	**10.7%**	3.22%	14.477	**0.000**	0.028	0.037
Lane 8		413	**0.9%**		304	**0.7%**	0.24%	4.004	**0.000**	0.001	0.004
Lane 9		347	**0.8%**		159	**0.4%**	0.43%	8.329	**0.000**	0.003	0.005
Lane 10		5279	**12.0%**		6349	**14.6%**	-2.54%	-11.040	**0.000**	-0.030	-0.021
Lane 11		17310	**39.5%**		17370	**39.9%**	-0.40%	-1.196	**0.116**	-0.010	0.003

Table 8 shows that there was a statistically significant increase in the proportion of traffic utilizing each lane changed from the before to after time period in lanes 1 only for the AM analysis. A significant decrease in lane utilization occurred in lanes 2, and 7.

Table 8 –

AM (7-9)

	Total ETC Volume_Before (Feb-May)	Lane ETC Volume_Before (Feb-May)	%_Before	Total ETC Volume_After (August-September)	Lane ETC Volume_After (August-September)	%_After	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
Lane 1	3809	7	**0.2%**	3841	39	**1.0%**	-0.85%	-4.829	**0.000**	-0.012	-0.005
Lane 2		108	**2.8%**		82	**2.1%**	0.69%	1.940	**0.026**	0.000	0.014
Lane 3		674	**17.7%**		691	**18.0%**	-0.30%	-0.345	**0.365**	-0.020	0.014
Lane 4		199	**5.2%**		174	**4.5%**	0.71%	1.434	**0.076**	-0.003	0.017
Lane 5		42	**1.1%**		33	**0.8%**	0.24%	1.084	**0.139**	-0.002	0.007
Lane 6		368	**9.7%**		416	**10.8%**	-1.16%	-1.672	**0.047**	-0.025	0.002
Lane 7		419	**11.0%**		357	**9.3%**	1.69%	2.443	**0.007**	0.003	0.030
Lane 8		23	**0.6%**		16	**0.4%**	0.18%	1.082	**0.140**	-0.001	0.005
Lane 9		15	**0.4%**		12	**0.3%**	0.09%	0.689	**0.245**	-0.002	0.004
Lane 10		387	**10.1%**		436	**11.4%**	-1.21%	-1.712	**0.043**	-0.026	0.002
Lane 11		1569	**41.2%**		1585	**41.3%**	-0.08%	-0.068	**0.473**	-0.023	0.021

Table 9 shows that there was a statistically significant increase in the proportion of traffic utilizing each lane changed from the before to after time period in lanes 1, 6, and 10 for the PM analysis. A significant decrease in lane utilization occurred in lanes 2, 4, 7, 8 and 9.

Table 9 -

PM (4-6)

	Total ETC Volume_Before (Feb-May)	Lane ETC Volume_Before (Feb-May)	%_Before	Total ETC Volume_After (August-September)	Lane ETC Volume_After (August-September)	%_After	**p_Before - p_After**	**Z Statistic**	**P-Value**	**95% CI**	
Lane 1	9693	16	**0.2%**	9303	44	**0.5%**	-0.31%	-3.796	**0.000**	-0.005	-0.001
Lane 2		177	**1.8%**		135	**1.5%**	0.37%	2.002	**0.023**	-0.001	0.009
Lane 3		1458	**15.0%**		1414	**15.2%**	-0.17%	-0.320	**0.374**	-0.015	0.012
Lane 4		298	**3.1%**		199	**2.1%**	0.94%	4.069	**0.000**	0.004	0.016
Lane 5		63	**0.6%**		50	**0.5%**	0.11%	0.961	**0.168**	-0.002	0.004
Lane 6		1050	**10.8%**		1107	**11.9%**	-1.06%	-2.311	**0.010**	-0.023	0.001
Lane 7		1823	**18.8%**		1318	**14.2%**	4.64%	8.646	**0.000**	0.033	0.061
Lane 8		138	**1.4%**		56	**0.6%**	0.83%	5.737	**0.000**	0.005	0.012
Lane 9		99	**1.0%**		25	**0.3%**	0.76%	6.583	**0.000**	0.005	0.011
Lane 10		1398	**14.4%**		1822	**19.6%**	-5.17%	-9.491	**0.000**	-0.066	-0.038
Lane 11		3174	**32.7%**		3133	**33.7%**	-0.93%	-1.363	**0.086**	-0.027	0.008

24hr

	Lane ETC Volume_Before (Feb-May)	Lane 3,6,7 and 10 ETC Volume_Before (Feb-May)	Lane 3, 6, 7 and 10 % Split_Before	Lane ETC Volume_After (August-September)	Lane 3,6,7 and 10 ETC Volume_After (August-Sept)	Lane 3, 6, 7 and 10 % Split_After	p_Before -p_After	Z Statistic	P-Value	95% CI	
Lane 1	66			253							
Lane 2	785			571							
Lane 3	6455		**28.6%**	6325		**27.8%**	0.83%	1.973	**0.024**	0.000	0.017
Lane 4	2059			1883							
Lane 5	318			264							
Lane 6	4699	**22543**	**20.8%**	5409	**22754**	**23.8%**	-2.93%	-7.487	**0.000**	-0.037	-0.022
Lane 7	6111		**27.1%**	4671		**20.5%**	6.58%	16.484	**0.000**	0.058	0.074
Lane 8	413			304							
Lane 9	347			159							
Lane 10	5279		**23.4%**	6349		**27.9%**	-4.49%	-10.950	**0.000**	-0.053	-0.037
Lane 11	17310			17370							

AM (7-9)

	Lane ETC Volume_Before (Feb-May)	Lane 3,6,7 and 10 ETC Volume_Before (Feb-May)	Lane 3, 6, 7 and 10 % Split_Before	Lane ETC Volume_After (August-September)	Lane 3,6,7 and 10 ETC Volume_After (August-Sept)	Lane 3, 6, 7 and 10 % Split_After	p_Before -p_After	Z Statistic	P-Value	95% CI	
Lane 1	7			39							
Lane 2	108			82							
Lane 3	674		**36.5%**	691		**36.3%**	0.12%	0.075	**0.470**	-0.030	0.032
Lane 4	199			174							
Lane 5	42			33							
Lane 6	368	**1847**	**19.9%**	416	**1900**	**21.9%**	-1.95%	-1.465	**0.072**	-0.045	0.007
Lane 7	419		**22.7%**	357		**18.8%**	3.86%	2.917	**0.002**	0.013	0.065
Lane 8	23			16							
Lane 9	15			12							
Lane 10	387		**20.9%**	436		**23.0%**	-2.03%	-1.504	**0.066**	-0.047	0.006
Lane 11	1569			1585							

PM (4-6)

	Lane ETC Volume_Before (Feb-May)	Lane 3,6,7 and 10 ETC Volume_Before (Feb-May)	Lane 3, 6, 7 and 10 % Split_Before	Lane ETC Volume_After (August-September)	Lane 3,6,7 and 10 ETC Volume_After (August-Sept)	Lane 3, 6, 7 and 10 % Split_After	p_Before -p_After	Z Statistic	P-Value	95% CI	
Lane 1	16			44							
Lane 2	177			135							
Lane 3	1458		**25.4%**	1414		**25.0%**	0.46%	0.567	**0.285**	-0.011	0.021
Lane 4	298			199							
Lane 5	63			50							
Lane 6	1050	**5728**	**18.3%**	1107	**5662**	**19.5%**	-1.22%	-1.662	**0.048**	-0.027	0.002
Lane 7	1823		**31.8%**	1318		**23.3%**	8.55%	10.258	**0.000**	0.069	0.102
Lane 8	138			56							
Lane 9	99			25							
Lane 10	1398		**24.4%**	1822		**32.2%**	-7.79%	-9.260	**0.000**	-0.094	-0.061
Lane 11	3174			3133							

MOE #5: Approach Lane Distribution vs. Toll Lane Distribution

Lanes A through D are the approach lanes from left to right that come out of the tunnel – the traffic volumes for these lanes are referred to as the approach lane distribution. Approach lane groups 1 through 4 represent the toll lane utilization. Approach lane group 1 corresponds to toll lanes 10 and 11. Traffic volumes on these lanes are expected to match the Approach Lane A volume. Approach lane group 2 corresponds to toll lanes 7, 8, and 9. Traffic volumes on these lanes are expected to match the Approach Lane B volume. Approach lane group 3 corresponds to toll lanes 4, 5, and 6. Traffic volumes on these lanes are expected to match the Approach Lane C volume. Approach lane group 4 corresponds to toll lanes 1, 2, and 3. Traffic volumes on these lanes are expected to match the Approach Lane D volume. The statistical analyses was conducted by evaluating changes on the differences from Approach Lanes and Group Lanes from before and the week 1, 2 and 3 after periods. Table 10 summarizes the statistics.

Based on the results shown in Table 10, the change in approach lane distributions versus toll lane utilization is statistically significant for all approach lanes. This difference is positive (showing a difference reduction between approach lane and group lanes during the after scenario) for all approach lane and lane groups during after week 2.

The difference in proportions is negative for the approach lane A, B, C and group lanes 1, 2 and 3 during after week 1. In addition, the difference in proportions is negative for the approach lane B, C and group lanes 2 and 3 during after week 3, which showed an increased lane imbalance for the mentioned approach lanes.

Approach Lane D showed an improvement on lane balance, with positive difference between before and after proportions for all 3 weeks. Because the difference in volume proportions between approach lanes A, B, C and D and lane groups 1, 2, 3 and 4 is positive during after week 2, lane utilization is becoming more balanced after installing the purple wayfinding dots. The balance between the approach lane A, B, C volume and corresponding lane groups worsened slightly in the week 1 and week 3 after time period as evidenced by the negative change in proportions.

In summary, the purple wayfinding dots seem to be effective in balancing the approach lane A, B and C volumes with the toll lane utilization.

Table 10 -

	Before_Volume	Week 1_Volume	Week 2_Volume	Week 3_Volume
Lane A	12,886	11,780	11,102	10,780
Group1	12,390	10,942	10,969	10,421
Lane A %	30.3%	29.5%	28.9%	28.0%
Group1 %	29.1%	27.4%	28.5%	27.1%
abs difference	496	838	133	359
Lane A - Group 1% difference (p)	1.17%	2.10%	0.35%	0.93%
p_Before - p_After	NA	-0.93%	0.82%	0.23%
Z Statistic	NA	-10.53	13.65	3.26
P- Value	NA	**0.000**	**0.000**	**0.001**
95% CI	NA	-0.011	0.007	0.001
	NA	-0.008	0.009	0.004

	Before_Volume	Week 1_Volume	Week 2_Volume	Week 3_Volume
Lane B	10,683	9,791	9,371	9,938
Group2	10,673	9,420	9,369	10,044
Lane B %	25.1%	24.5%	24.4%	25.8%
Group2 %	25.1%	23.6%	24.4%	26.1%
abs difference	10	371	2	-106
Lane B - Group 2% difference (p)	0.02%	0.93%	0.01%	0.28%
p_Before - p_After	NA	-0.91%	0.02%	-0.25%
Z Statistic	NA	-18.64	2.21	-9.09
P- Value	NA	**0.000**	**0.014**	**0.000**
95% CI	NA	-0.010	0.000	-0.003
	NA	-0.008	0.000	-0.002

	Before_Volume	Week 1_Volume	Week 2_Volume	Week 3_Volume
Lane C	10,431	9,641	9,251	9,438
Group3	9,871	8,790	8,873	8,807
Lane C %	24.5%	24.2%	24.1%	24.5%
GroupC %	23.2%	22.0%	23.1%	22.9%
abs difference	560	851	378	631
Lane C - Group 3% difference (p)	1.32%	2.13%	0.98%	1.64%
p_Before - p_After	NA	-0.82%	0.33%	-0.32%
Z Statistic	NA	-8.97	4.45	-3.80
P- Value	NA	**0.000**	**0.000**	**0.000**
95% CI	NA	-0.010	0.002	-0.005
	NA	-0.006	0.005	-0.002

	Before_Volume	Week 1_Volume	Week 2_Volume	Week 3_Volume
Lane D	8,546	8,700	8,704	8,327
Group4	9,601	8,070	8,926	8,332
Lane D %	20.1%	21.8%	22.7%	21.6%
Group4 %	22.6%	20.2%	23.2%	21.7%
abs difference	-1,055	630	-222	-5
Lane D - Group 4% difference (p)	2.48%	1.58%	0.56%	0.01%
p_Before - p_After	NA	0.90%	1.92%	2.47%
Z Statistic	NA	9.21	22.79	32.63
P- Value	NA	**0.000**	**0.000**	**0.000**
95% CI	NA	0.007	0.018	0.023
	NA	0.011	0.021	0.026

Total Volume (Lanes A through D)	**42,546**	**39,912**	**38,428**	**38,483**

MOE #6: Percent of Toll Violations

Tables 11 and 12 provide a statistical comparison on toll violations during before and after (broke down into August and September for 2010 and 2011) time periods. Furthermore, Table 13 combines August and September for 2010 and 2011. Like all previous MOE's, the percent of toll violations occurring during the before and subsequent after treatment periods was evaluated using a statistical test of proportions. Table 11 shows that there is a statistically significant decrease in the proportion of toll violations on lanes 1, 3, 4, 5, 8, and 9 between August 2010 and August 2011.Tabel 11 also shows that there is a statistically significant increase in the proportion of toll violations on lanes 2, 6, 10 and 11 for the same period. No significant changes were observed on lane 7.

Table 11

	Violations_Before August 2010	Voulme_Before August 2010	%_Before	Violations_After August 2011	Volume_After August 2011	%_After 1	**p_Before -p_After**	**Z Statistic**	**P-Value**	**95% CI**	
Lane 1	672	50,852	**1.32%**	499	48,216	**1.03%**	0.29%	4.185	**0.000**	0.002	0.004
Lane 2	790	117,778	**0.67%**	549	69,048	**0.80%**	-0.12%	-3.009	**0.001**	-0.002	0.000
Lane 3	4,874	137,517	**3.54%**	5,907	172,972	**3.42%**	0.13%	1.951	**0.026**	0.000	0.003
Lane 4	3,042	125,370	**2.43%**	1,745	111,761	**1.56%**	0.87%	15.142	**0.000**	0.008	0.010
Lane 5	729	145,591	**0.50%**	631	138,135	**0.46%**	0.04%	1.695	**0.045**	0.000	0.001
Lane 6	3,961	117,399	**3.37%**	5,567	125,937	**4.42%**	-1.05%	-13.364	**0.000**	-0.012	-0.009
Lane 7	4,302	166,627	**2.58%**	3,418	137,196	**2.49%**	0.09%	1.580	**0.057**	0.000	0.002
Lane 8	828	163,322	**0.51%**	619	151,898	**0.41%**	0.10%	4.144	**0.000**	0.001	0.001
Lane 9	863	170,398	**0.51%**	678	153,898	**0.44%**	0.07%	2.735	**0.003**	0.000	0.001
Lane 10	2,468	142,487	**1.73%**	4,788	166,796	**2.87%**	-1.14%	-21.266	**0.000**	-0.012	-0.010
Lane 11	11,789	597,666	**1.97%**	12,105	547,339	**2.21%**	-0.24%	-8.919	**0.000**	-0.003	-0.002
Total	34,318	1,935,007	**1.77%**	36,506	1,823,196	**2.00%**					

Table 12 shows that there is a statistically significant decrease in the proportion of toll violations on lanes 3, 4, and 8 between September 2010 and September 2011. Additionally, Table 12 also shows a statistically significant increase in the proportion of toll violations on lanes 1, 6, 7, 10 and 11 for the same period. No significant changes were observed on lanes 2, 5 and 9.

Table 12

	Violations_Before Septmeber 2010	Voulme_Before September 2010	%_Before	Violations_After September 2011	Volume_After September 2011	%_After 2	p_Before -p_After	Z Statistic	P-Value	95% CI	
Lane 1	87	16,213	**0.54%**	201	14,828	**1.36%**	-0.82%	-7.381	**0.000**	-0.010	-0.006
Lane 2	747	101,520	**0.74%**	809	102,072	**0.79%**	-0.06%	-1.471	**0.071**	-0.001	0.000
Lane 3	5,163	149,126	**3.46%**	5,299	162,772	**3.26%**	0.21%	3.199	**0.001**	0.001	0.003
Lane 4	1,958	112,780	**1.74%**	1,660	106,172	**1.56%**	0.17%	3.172	**0.001**	0.001	0.003
Lane 5	687	131,410	**0.52%**	724	127,406	**0.57%**	-0.05%	-1.570	**0.058**	-0.001	0.000
Lane 6	4,084	115,301	**3.54%**	4,946	127,116	**3.89%**	-0.35%	-4.540	**0.000**	-0.005	-0.002
Lane 7	3,567	149,884	**2.38%**	3,745	125,843	**2.98%**	-0.60%	-9.614	**0.000**	-0.007	-0.005
Lane 8	709	138,952	**0.51%**	629	138,713	**0.45%**	0.06%	2.161	**0.015**	0.000	0.001
Lane 9	673	151,674	**0.44%**	681	143,866	**0.47%**	-0.03%	-1.192	**0.117**	-0.001	0.000
Lane 10	2,704	138,232	**1.96%**	4,273	161,029	**2.65%**	-0.70%	-12.751	**0.000**	-0.008	-0.006
Lane 11	10,324	532,525	**1.94%**	11,037	495,720	**2.23%**	-0.29%	-10.199	**0.000**	-0.003	-0.002
Total	30,703	1,737,617	**1.77%**	34,004	1,705,537	**1.99%**					

Lastly, Table 13 shows that there is a statistically significant decrease in the proportion of toll violations on lanes 3, 4, and 8 between the combined periods of August and September 2010 and August and September 2011. Table 13 also shows a statistically significant increase in the proportion of toll violations on lanes 2, 6, 7, 10 and 11 for the same period. No significant changes were observed on lanes 1, 5 and 9.

Table 13

	Violations_Before Aug + Sept 2010	Voulme_Before August +Sept 2010	%_Before	Violations_After Aug + Sept 2011	Volume_After Aug + Sept 2011	%_After3	p_Before -p_After	Z Statistic	P-Value	95% CI	
Lane 1	759	67,065	**1.13%**	700	63,044	**1.1%**	0.02%	0.367	**0.357**	-0.001	0.001
Lane 2	1,537	219,298	**0.70%**	1,358	171,120	**0.8%**	-0.09%	-3.325	**0.000**	-0.001	0.000
Lane 3	10,037	286,643	**3.50%**	11,206	335,744	**3.3%**	0.16%	3.543	**0.000**	0.001	0.003
Lane 4	5,000	238,150	**2.10%**	3,405	217,933	**1.6%**	0.54%	13.561	**0.000**	0.005	0.006
Lane 5	1,416	277,001	**0.51%**	1,355	265,541	**0.5%**	0.00%	0.047	**0.481**	0.000	0.000
Lane 6	8,045	232,700	**3.46%**	10,513	253,053	**4.2%**	-0.70%	-12.713	**0.000**	-0.008	-0.006
Lane 7	7,869	316,511	**2.49%**	7,163	263,039	**2.7%**	-0.24%	-5.628	**0.000**	-0.003	-0.002
Lane 8	1,537	302,274	**0.51%**	1,248	290,611	**0.4%**	0.08%	4.457	**0.000**	0.000	0.001
Lane 9	1,536	322,072	**0.48%**	1,359	297,764	**0.5%**	0.02%	1.184	**0.118**	0.000	0.001
Lane 10	5,172	280,719	**1.84%**	9,061	327,825	**2.8%**	-0.92%	-24.085	**0.000**	-0.010	-0.008
Lane 11	22,113	1,130,191	**1.96%**	23,142	1,043,059	**2.2%**	-0.26%	-13.486	**0.000**	-0.003	-0.002
Total	65,021	3,672,624	**1.77%**	70,510	3,528,733	**2.0%**					

Appendix C – Statistical Analysis of Before/After Safety Data

Statistical Analysis of Phase I Crash Data

Crash Data

π = estimate of the number of crashes that would have occurred without purple dots in place = 28

28 crashes occurred in the three years before the purple dots were installed. Assume that 28 crashes would have occurred in the three years after the purple dots were installed.

λ = estimate of the number of crashes that occurred with the purple dots in place = 19

Note: The before and after period were both three years

Observed Change in Crash Frequency

θ = ratio of crash frequency with purple dots to crash frequency without purple dots ("index of effectiveness").

$$\theta^* = \text{unbiased estimator of } \theta = \frac{\lambda / \pi}{1 + \frac{VAR\{\pi\}}{\pi^2}} = \frac{19 / 28}{1 + \frac{28}{28^2}} = 0.655$$

Note: Assume crashes are Poisson distributed. Var(x) ~ x

The number of crashes with the purple dots in place was 65.5% of the number of crashes which would have been expected without the purple dots in place. Conversely, there was a 100 – 65.5 = 34.5% observed reduction in crashes.

Confidence of Observed Change

$$\text{Var}\{\theta\} = \frac{\theta^2(\frac{VAR\{\lambda\}}{\lambda^2} + \frac{VAR\{\pi\}}{\pi^2})}{(1+\frac{VAR\{\pi\}}{\pi^2})^2} \sim \frac{0.655^2(\frac{19}{19^2}+\frac{28}{28^2})}{(1+\frac{1}{28})^2} = 0.0353$$

Standard deviation{θ} = √Var{θ} = √0.0353 = 0.188 = 18.8%

A reduction in crashes was observed. Iterate and complete the table below to determine the level of confidence in the finding that crashes decreased (versus staying the same or increasing)

Confidence Level	p-value	z-statistic	Confidence Interval		Interpretation
65%	0.35	~1	18.8	34.5% ± 18.8%	With 65% confidence, conditions in the after period deceased crashed by 15.7% to 53.3%
70%	0.30	1.036	19.5	34.5% ± 19.5%	Similar to above
80%	0.20	1.282	24.1	34.5% ± 24.1%	
90%	0.10	1.645	30.9	34.5% ± 30.9%	
93%	0.07	1.811	34.0	34.5% ± 34.0%	This is the approximate maximum confidence level.