I-10, 35TH AVE TO SKY HARBOR BLVD PHOENIX CORRIDOR SAFETY STUDY

FINAL REPORT

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EXECUTIVE SUMMARY

The downtown Phoenix corridor section of I-10 between 35th Ave and Sky Harbor Blvd is one of the most heavily traveled freeways in the region and state, carrying up to 280,000 vehicles-per-day (vpd) on a typical weekday. As might be expected given the high traffic volume, this freeway section experiences a high number of crashes each year. The crash rate for the 3-year period from 2011-2013 was 3.10 crashes per million vehicle miles travelled (crashes/mvm), compared with an average rate of 1.47 crashes/mvm on other freeways throughout the region. Given these conditions, improving the safety of this section of I-10 is a priority for ADOT. The I-10 Phoenix Corridor Safety Study is an initial step in achieving this objective.

METHODOLOGY

This study conducted a safety performance evaluation of the I-10 Phoenix corridor section following the urban freeway safety evaluation methodologies described in the AASHTO Highway Safety Manual (HSM). A rigorous process was conducted to calibrate the HSM freeway crash prediction models to accurately reflect conditions on Phoenix area freeways. Using these calibrated models, the study quantified the safety performance of the I-10 study section relative to other freeways in the Phoenix area, identified the primary factors contributing to the high crash frequency in the section, identified opportunities for reducing crashes, and evaluated potential countermeasures to improve safety. Figure ES- 1 summarizes the study process.

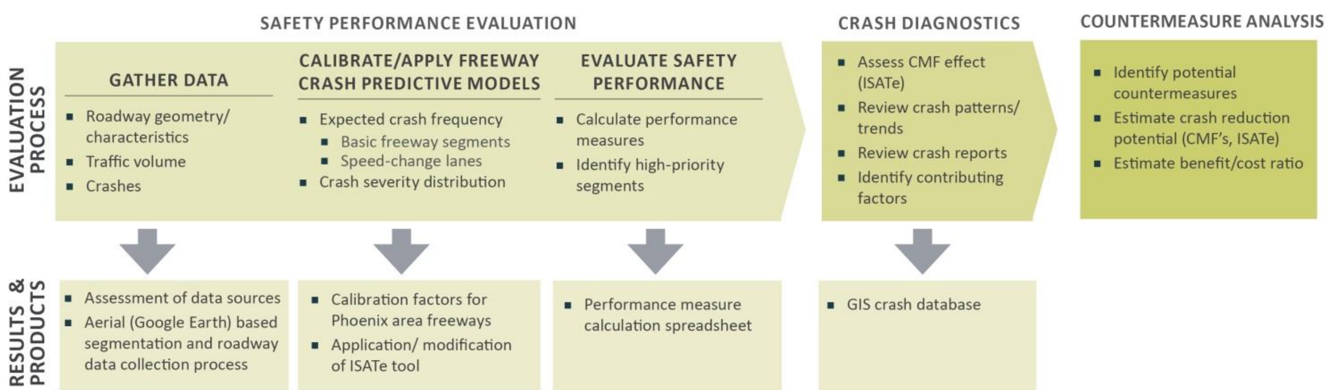


Figure ES- 1. I-10 Safety Study Process

The safety evaluation tools developed from the study can be applied and expanded by ADOT to conduct quantitative safety performance evaluations of urban and rural freeway sections across the state. The application of the HSM methods and these evaluation tools provide ADOT with a quantitative and reliable approach to identify and prioritize freeway safety improvement needs and evaluate safety improvements to achieve the greatest benefit to the public. In addition, the evaluation methods and tools can be applied to assess the safety performance of freeway and interchange improvement alternatives while in the project development process.

SAFETY PERFORMANCE RESULTS

Several metrics that describe safety performance were calculated for each freeway segment in the study section. Evaluating the performance of the section by segment, including basic segments and speed-change lanes, is necessary to pinpoint physical and operational factors that are contributing to high crash frequency and which can then potentially be addressed with roadway and operational improvements. The safety performance of the I-10 study section can best be described using two metrics: expected crash frequency per mile and level of service of safety (LOSS).

The expected crash frequency per mile describes the magnitude of the safety performance of a segment relative to other segments in the study section and to other freeways in the Phoenix area. The expected crash frequencies per mile for the study section are graphically presented in Figure ES- **2**. The red line represents the average expected crash frequency per mile on other Phoenix area freeways. Clearly, the results show many high crash locations within the study section. In the Deck Park Tunnel and the segment to the west, expected crashes per year per mile exceed 400. Other segments, essentially between 19th Ave and the L202/SR 51 TI also have high expected crash frequencies.

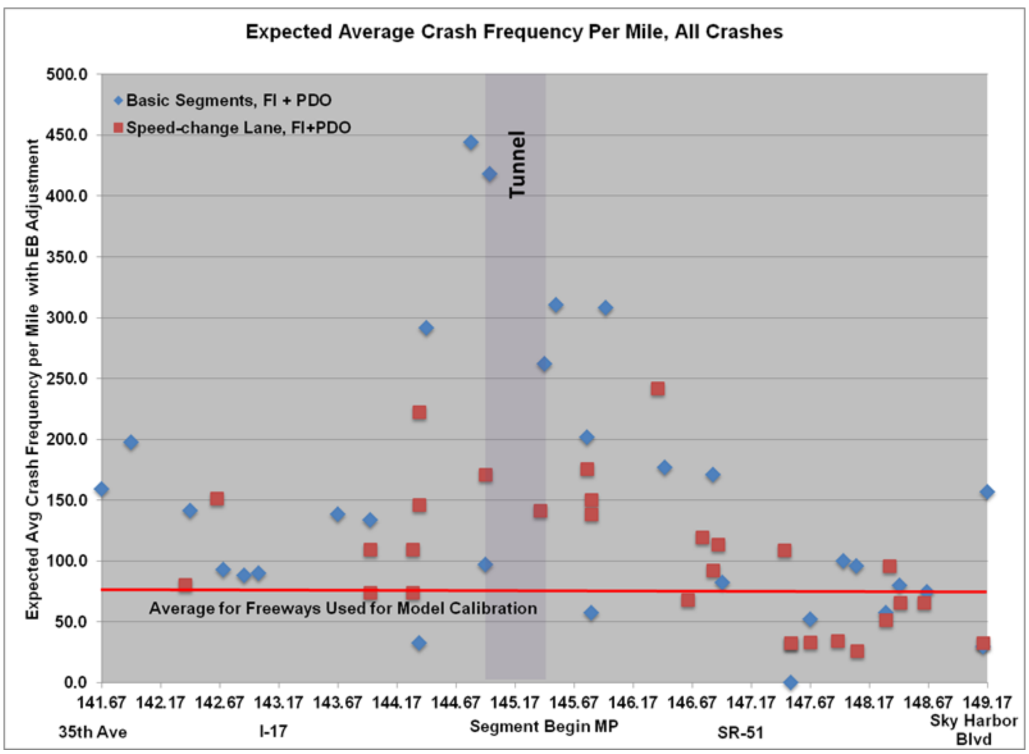


Figure ES- 2. Safety Performance of Study Section Segments

Level of service of safety describes the potential to reduce crash frequency with the application of appropriate countermeasures. The LOSS results presented in Figure ES- 3 show that nearly all of the segments have a moderate (III) to high (IV) potential to find safety improvement opportunities.

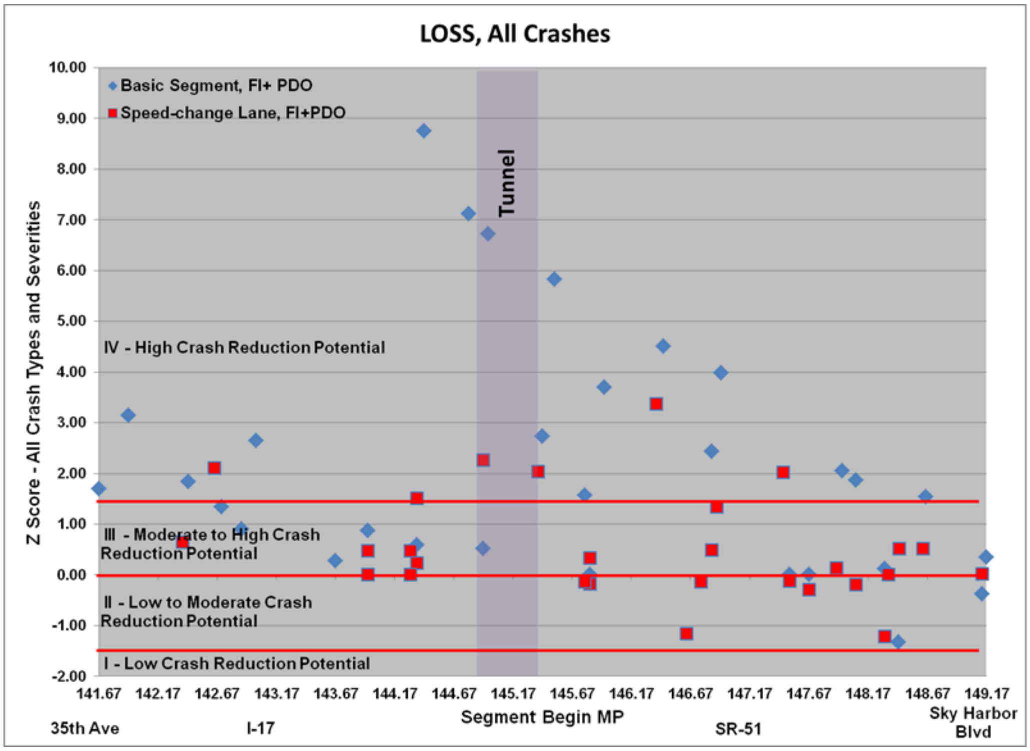


Figure ES- 3. Potential to Reduce Crashes with Improvement

Table ES-1 provides the average number of crashes, by severity, expected to occur each year in this 7.6 mile stretch of I-10 without safety improvement. When considering the overall safety performance, it is clear that the I-10 study section is a strong candidate for implementing appropriate crash reduction countermeasures.

Table ES- 1. Annual Crashes Expected on I-10 Study Section

Total	Fatal	Incapacitating Injury	Non-incapacitating Injury	Possible Injury	Property Damage Only
1718.4	11.5	27.6	190.8	257.3	1231.3

KEY FINDINGS

The safety performance evaluation not only identified the magnitude of the safety problem within the study section, but also identified high priority areas to focus further attention to determine factors contributing to high crash rates. A detailed diagnosis of two years (2012-2013) of crash data produced the following findings.

- 6 fatal and 40 incapacitating injury crashes occurred.
- Rear-end crashes are the predominant crash type.
- Speed and congestion are contributing factors in approximately 57% of the crashes. Of the 40 incapacitating injury crashes, half noted congested conditions and speed as factors.
- Congestion is a primary contributing factor, with 70% of the crashes occurring during congested periods.
- Large speed differentials due to congestion are associated with a notably high number of crashes. During peak periods, crashes associated with high speed vehicles encountering slowed or stopped vehicles is common, particularly with crashes in the HOV lanes.
- The number of reported crashes associated with left-side HOV entry ramps (3 locations) was low.
- A combination of several factors likely contributes to the exceptionally high crash frequency in the Deck Park Tunnel. These factors include:
    - the illumination levels at the tunnel threshold zones are lower than the original design, likely due to the effect of age and environment on the luminaires;
    - the difference between the day-time ambient illumination level outside of the tunnel and the illumination level at the tunnel portals which can affect drivers vision as their eyes adjust when they enter/exit the tunnel,
    - lane changing within the tunnel associated with the eastbound and westbound weaving sections between 7th St and 7th Ave,
    - the horizontal curve within the tunnel, and
    - congestion occurring within the tunnel and just outside the exit portals.
- Heavy lane changing associated with the major weaving sections at the I-17 and L202/SR51 system interchanges creates congestion at the exit ramps, resulting in rear-end and sideswipe crashes.
- Mainline right-side lane drops at two locations, WB at 7th Ave and EB at 7th St are a factor in observed crashes. The lane drops contribute to congestion and produce forced lane changes. In contrast, the EB lane drop at Washington St. does not appear to be contributing to an increased number of crashes.

STUDY RECOMMENDATIONS

Countermeasures to mitigate the contributing factors and reduce crashes were identified and analyzed. Based on the results of benefit/cost analysis, the following countermeasures are recommended for consideration and evaluation.

Lower Speed Limit: Lowering the speed limit (65 mph to 55 mph) along the I-10 Phoenix study corridor, in conjunction with heightened and continued enforcement is expected to lower the average operating speed on the freeway, potentially reducing crash frequency substantially at a high benefit/cost. The limits of the reduced speed zone could extend further to the east and west on I-10. ADOT and DPS should evaluate this countermeasure further.

Variable Speed Limit: VSL systems are effective in lowering primary and secondary crashes, and increasing capacity and throughput on high speed access controlled roadways. Installing a variable speed limit system that operates primarily during weekday peak traffic periods to lower operating speeds on I-10 is estimated to result in potentially 100 fewer total crashes and 30 fatal and injury crashes each year. ADOT should consider developing a VSL system design concept to define system limits, operations, system requirements, and construction, operating, and added enforcement costs.

Upgrade Deck Park Tunnel Lighting: It is not possible to definitively quantify the effect of existing illumination levels on the high expected crash frequency within the tunnel, particularly since there are other contributing factors (weaving sections, horizontal curve, and congestion). However, the high crash frequency within the tunnel section supports the need for safety improvement. It is understood that ADOT is evaluating a possible upgrade to tunnel lighting to reduce energy costs. If implemented, a study of the effect of tunnel illumination improvements on crash frequency should be conducted.

Meter EB 7th Ave and WB 7th St Entry Ramps: Lane changing is contributing to the high crash frequency in the tunnel. It is recommended that ADOT evaluate installing ramp meters on these two ramps. The evaluation should include study of the effect of ramp metering on traffic operations on the freeway mainline, the ramp terminal intersections, and cross streets.

High Friction Surface Treatment: Since rear end-crashes are predominant, application of HFST may prove to be an effective countermeasure for this crash type. ADOT should assess the survivability and service life of this treatment for application on the I-10 study section and consider applying HFST on a test segment. If installed, the safety benefit of this treatment should be evaluated.

Other Countermeasures Recommended for Consideration:

- Install freeway lane markings in advance of the I-17 and SR 51/SR 202 interchanges where two or more lanes exit I-10. The intent of this low cost countermeasure is to reduce last minute lane changing.
- Turn-on the ramp meter on the westbound Sky Harbor Blvd on-ramp during morning and evening peak hours to reduce the impact of merging traffic on the congested mainline. This countermeasure should be evaluated to confirm potential impacts on traffic operations within Sky Harbor airport.
- Implement enforcement and education countermeasures intended to reduce speed and increase driver awareness during peak traffic periods. Potential countermeasures include:
    - Heightened and visible DPS presence within the corridor.
    - Using existing dynamic message signs, provide messages reminding drivers to be prepared for upcoming congestion and to drive at a safe speed.
    - Develop and implement a public outreach campaign designating this section of I-10 as a “safety corridor”. The campaign would inform the public of the need to improve safety on this freeway section, steps being taken by ADOT and DPS to do so, and actions that the public can take to reduce crash potential.
    - Regional and statewide efforts to reduce distracted driving.

Other Countermeasures Evaluated:

- Eliminate Lane Drops at 7th Ave and 7^{th}. This countermeasure is not recommended due to the low estimated benefit/cost based on lowered crash frequency.
- Restrict HOV Lane Access Points. Based on the limited information available, it is unclear if this countermeasure will reduce crashes.
- Automated Speed Enforcement. Studies of this technology have shown it lowers average operating speeds, resulting in reduced crashes.

The I-10 study has provided a solid foundation for conducting safety performance evaluations on Arizona freeways using the HSM predictive methods. In order to expand the predictive models to cover all freeways throughout the state, it is recommended that the following additional model calibration be conducted.

- Develop calibration factors for urban freeways without HOV lanes and without ramp metering.
- Develop calibrated crash predictive models for 4 and 6-lane rural freeways.
- Evaluate the need for calibration factors for urban freeway with posted speeds of 55 mph.
- Evaluate the applicability of calibration factors based strictly on MAG region data to other urban areas in the state.

INTRODUCTION

This report documents the safety performance study conducted for the section of I-10 from 35th Ave to Sky Harbor Blvd. The safety performance evaluation was conducted following the urban freeway safety evaluation methodologies described in the AASHTO Highway Safety Manual (HSM). The study results quantify the safety performance of the I-10 study section relative to other freeways in the Phoenix area, identify the primary factors contributing to the crash frequency in the section and opportunities for reducing crashes, and present potential countermeasures to improve safety. The safety evaluation tools developed from the study can be applied and expanded by ADOT to conduct quantitative safety performance evaluations of urban and rural freeway sections across the state. The application of the HSM methods and these evaluation tools provide ADOT with a quantitative and statistically sound approach to identify and prioritize freeway safety improvement needs and evaluate safety improvements to achieve the greatest benefit to the public. In addition, the evaluation methods and tools can be applied to assess the safety performance of freeway and interchange improvement alternatives while in the project development process.

STUDY OBJECTIVES

The following objectives and goals were achieved in this study:

Expand ADOT's capacity to apply state-of-the art safety evaluation methods.

- HSM crash prediction models for urban freeways were calibrated to reflect local conditions so that the models will more accurately assess the safety performance of freeways in the Phoenix metropolitan area. The calibration process applied in this study can be used by ADOT for calibration of predictive models for other freeway facility types in the Phoenix area or around the state.
- The availability and quality of existing ADOT databases relative to the needs of the HSM crash predictive methods for safety performance evaluation was assessed. Efficient methods for collecting accurate data, not available from existing databases, were demonstrated.
- ADOT staff received training in data collection methods, application of the predictive models, and the HSM safety performance evaluation methods and process.

Apply the predictive and diagnostic HSM methodologies to evaluate the safety performance of the I-10 study section.

- Using the calibrated crash prediction models, the safety performance of the I-10 study section was evaluated based on a range of performance measures. High crash locations were identified for more detailed evaluation.
- A detailed diagnostic review of high crash locations within the study section was conducted following the methods prescribed in the HSM. Roadway, traffic, and operational factors contributing to high crash frequencies were identified through the diagnostic process.

Identify and assess countermeasures intended to reduce crash frequency at high crash locations.

- Countermeasures intended to improve safety at high crash locations were identified and evaluated to determine the potential benefit in reducing crashes, as well as cost effectiveness.

STUDY TEAM

The study was conducted by the consultant team led by Kittelson & Associates, including support from Lee Engineering, Works Consulting, and DiExSys,LLC, managed by ADOT MPD under the direction of the ADOT Traffic Engineering Group. Study technical oversight and support was provided by a Core Team comprised of representatives from the following ADOT organizations and other agencies.

- ADOT
    - Traffic Operations
    - Traffic Safety
    - Phoenix Regional Traffic Engineering
    - MPD – HPMS
    - Budget
    - Traffic Records
    - State Traffic Engineering
    - Urban Project Management
    - Traffic Design
    - Roadway Engineering
    - Information Technology Group
- Maricopa Association of Governments – ITS and Safety
- FHWA

As part of the study, two workshops were conducted with the intent of disseminating information on study progress and results as well as the value of implementing the HSM safety performance evaluation methods into ADOT's safety management program and project development process. A workshop to provide ADOT Safety Section staff with training on the application of the freeway crash prediction methodology and tools was also held.

STUDY LIMITS

The study limits are shown in Figure 1, extending from 35th Ave (MP 141.67) to Sky Harbor Blvd (MP 149.30).

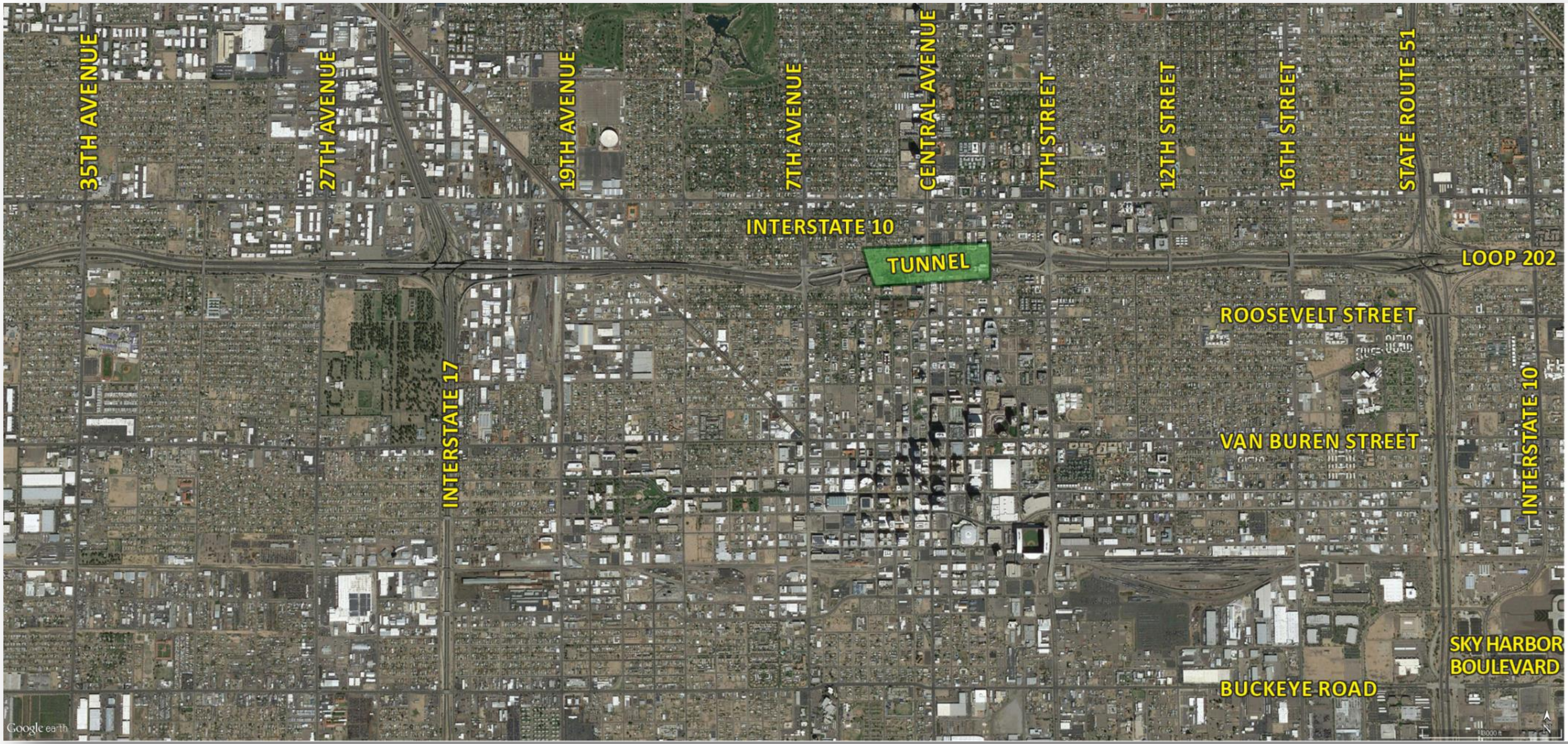


Figure 1. I-10 Study Section Map

OVERVIEW OF THE FREEWAY SAFETY EVALUATION METHODOLOGY

The HSM provides a methodology, tools, and guidance for evaluating the safety performance of a freeway network, facility, section, and interchange. This methodology is used to identify and prioritize freeway segments where improvements have a high potential to reduce crashes, diagnose safety issues, assess future safety conditions, and evaluate the impact of design alternatives on crash frequency and severity. The methodology includes detailed models for predicting crashes by type and severity. These models provide several important advantages:

- they reflect the effects of roadway geometry, physical features, and traffic volume on crash frequency and severity,
- they allow for a thorough understanding of safety performance and opportunity to improve performance,
- they can quantify the benefits of crash countermeasures, and the use of the predictive models in the screening process will more reliably identify segments with potential for safety improvement.

The freeway predictive models were developed for the HSM through a research project funded by the Transportation Research Board's National Cooperative Highway Research Program (NCHRP 17-45)(Ref. 4). Crash predictive models are available for rural and urban freeway segments, speed-change lanes, and ramps. The models applied in this safety study are listed in Table 1.

Table 1. Freeway Crash Prediction Models

Urban Freeway Segments	Urban Freeway Speed-change Lanes
▪ Multiple vehicle crashes – FI ▪ Multiple vehicle crashes – PDO ▪ Single vehicle crashes – FI ▪ Single vehicle crashes - PDO	▪ Multiple vehicle crashes – FI ▪ Multiple vehicle crashes – PDO ▪ Single vehicle crashes – FI ▪ Single vehicle crashes - PDO

Each model predicts average crash frequency using Safety Performance Functions (SPFs), Crash Modification Factors (CMFs), and a local calibration factor (C). The general form of the predictive model is as follows:

$$N_p = N_{spf} \text{ x } (CMF_1 \text{ x } CMF_2 \text{ x } CMF_3 \text{ x } \ldots\text{x } CMF_n) \text{ x } C$$

Specific SPFs are available for predicting multiple vehicle and single vehicle crashes on basic freeway segments and speed-change lanes. The SPF predicts the average crash frequency for base conditions. For example, the base conditions for the SPF used to predict multiple vehicle crashes on a freeway segment are:

- Length of horizontal curve - 0.0 mi (curve not present)
- Lane width – 12 ft.
- Inside paved shoulder width – 6 ft.
- Median width – 60 ft.
- Length of median barrier – 0.0 mi (barrier not present)
- Number of hours where traffic volume exceeds 1000 veh/ln/hr – none
- Distance to nearest upstream entry ramp - > 0.5 mi
- Distance to nearest downstream exit ramp - >0.5 mi
- Length of Type B weaving section – 0.0 mi (weaving section not present)

The CMFs are applied to adjust the average number of crashes predicted by the SPF to account for differences from the base conditions. For example, the CMF for paved shoulder width would increase the average number of predicted crashes if the width was less than 6 ft. If the width was greater than 6 ft, the predicted average number of crashes may decrease. A calibration factor (C) is also applied to adjust the average number of crashes predicted by the SPF to reflect local conditions and factors that are not covered by the CMFs, but which may affect crash frequency. Development of the calibration factors for Phoenix freeways is described in the following section.

The average number of predicted crashes, adjusted for variations from base conditions and for the effect of local conditions are then distributed by severity – fatal (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), and non-injury (O or PDO). This distribution is performed using Severity Distribution Functions (SDFs). The SDF distributes crashes by severity based on a number of factors, including presence of median barrier and shoulder barrier, level of congestion, presence of rumble strips, lane width, area type, and horizontal curvature of the roadway. Similar to the SPF, the SDF is also calibrated to local conditions.

APPLICATION OF THE FREEWAY PREDICTIVE MODELS FOR THIS STUDY

The HSM freeway predictive models were developed using field data from freeways in three states – Maine, Washington, and California. These data were used to calibrate and validate the base models. The sites selected for urban freeway model development covered a range of physical conditions that are reflected in the model factors. Conditions which are not explicitly reflected in the base models include:

- urban freeway sections with 11 or more through lanes
- HOV or managed lanes
- ramp metering
- use of shoulders as travel lanes
- toll plazas
- reversible lanes

Three of these conditions are present within the I-10 Study Section and/or on other Phoenix freeways. Most notably, nearly all of the freeway sections within the Phoenix urban core include HOV lanes and ramp metering. Freeway sections with 11 or more through lanes are also present. While further research on the effect of each of these conditions is needed to refine the freeway crash prediction models, their presence does not preclude the use of the current models for the purpose of evaluating freeway safety performance. The models can be applied with reliable results as long as the conditions are consistent between the freeways used to develop local calibration factors and the I-10 freeway section being evaluated. The effect of HOV lanes and ramp metering is then reflected in the local calibration factor and not as a separate CMF.

The presence of HOV lanes was given careful consideration, since HOV lane access control can have a marked impact on traffic operations. Since all of the HOV lanes on the Phoenix freeways have continuous access (no access control) and use of the HOV lanes by general traffic is allowed for much of the day during the week and on weekends, it is reasonable to treat these lanes as general through lanes within the model. While the calibrated Phoenix freeway models will not be able to assess modifications to changes in HOV lane access control, the models will be valid for evaluating freeway safety performance and screening freeway segments to prioritize those with the highest potential for crash reduction.

MODEL CALIBRATION

The eight urban freeway crash prediction models listed in Table 1 were used to evaluate the safety performance of the I-10 study section. Since crash frequencies can vary significantly from one area of the country to another, calibration of these models to conditions on Phoenix urban freeways was necessary so that crash predictions reflect actual Phoenix crash experience. Calibration accounts for differences in climate, driver population, driver behavior (aggressiveness), speed limit, enforcement, crash reporting practices, driving laws, and other unknown differences.

The model calibration process involved the following steps:

1. Identify Phoenix urban freeway sections that represent a normal range of physical and operational conditions. Develop criteria for selecting appropriate calibration segments.
2. Segment these freeway sections into homogeneous segments.
3. Randomly select 30 to 50 segments for use in calibration. Avoid segments that are atypical of the Phoenix freeway system, such as one that includes a left-hand entry or exit ramp, or tunnel.
4. Gather and check data for each segment, developing a calibration database. The data required includes detailed roadway geometry and physical characteristics, mainline and ramp traffic volumes (AADT), level of mainline congestion, and crash history.
5. Calculate model calibration factors using the calibration database and the Enhanced Interchange Safety Analysis Tool (ISATe), developed in conjunction with the HSM urban freeway crash prediction methodologies and used to evaluate freeway and interchange safety.

CALIBRATION SEGMENTS

Freeway calibration segments were selected from freeways in the Phoenix area with generally similar operational characteristics as exists on the I-10 study section. Two particularly key features include ramp metering and HOV lanes. Since both are common on Phoenix freeways and are present in the study section, they must also be present in the segments used to calibrate the crash prediction model. The following summarizes the criteria used to identify freeway sections that would provide appropriate calibration segments.

- Terrain - Level or rolling terrain such that individual grades of significant length are 4 percent or less.
- Freeway AADT - AADT data should be available for two or more of the years of the crash period being evaluated in the study section (2011-2013).
- Ramp AADT - AADT data should be available for each ramp for two or more of the years of the crash period being evaluated in the study section (2011-2013).
- Freeway crash data - An electronic record should be available of every reported crash occurring on the freeway section during each year of the crash period (2011-2013). Each record should specify the crash severity using the KABCO scale (or be convertible to this scale), the crash type category (i.e., single-vehicle or multiple-vehicle), direction of travel of each involved vehicle, and crash location by roadbed and milepost (or geo-coordinates). Crash location should be specified to the nearest 0.1 mile or less (or its equivalent using geo-coordinates).
    - Speed limit - The speed limit should be 60, 65, or 70 mi/h.
    - Shoulder use - No section should allow shoulder use as a travel lane at any time.
    - Reversible lanes - No section should include travel lanes that are reversed by time of day.
- Work zone presence - Desirably, no section would have any long-term (i.e., 4 or more days) work zones present during the crash period (2011-2013). It is acceptable to retain a section if it had only a few long-term work zones during the crash period provided that their start and end dates can be identified (so the crash data for these periods can be omitted and the calibration factor adjusted for partial year data).
- HOV Lanes – Freeway sections should have HOV lanes separated by a single white stripe or white stripe buffer, with no control of where vehicles can enter or exit.
- Through Lanes – If possible, the selected calibration segments should have an equal number of 6/7, 8/9, and 10/11- lane cross sections. HOV lanes were not counted as through lanes, however were included in each calibration segment.
- Ramp meters – The selected calibration segments should have ramp metering.

Based on these criteria, the freeway sections listed in Table 2 were determined to be appropriate from which to select segments to be used to calibrate the crash prediction models. These freeway sections were clear of long-term construction during the calibration timeframe (2011-2013) as determined from the ADOT construction log, included ramp meters, included HOV lanes, included 6 to 11 through lanes, excluded 55 mph posted speed limits, and had AADT and crash data available for the study period (2011-2013).

Table 2 Candidate Freeway Calibration Sections

Facility	BMP	EMP	Length (miles)	Comments
I-10 (91st Ave to 35th Ave)	134.68	141.66	6.98	Long-term construction west of section, study area east of section
I-10 (Buckeye Rd to Ray Rd)	148.93	159.78	10.85	HOV lanes end south of section
I-17 (Cactus Rd to Union Hills Blvd)	209.96	213.98	4.02	South of section posted 55 mph, long-term construction north of section
SR-101 (Shea Blvd to Warner Rd)	41.06	58.60	17.54	West/north valley 101 due to long-term construction
SR-202 (24th St to McClintock Dr)	0.74	8.80	8.06	Long-term construction east of section
US-60 (Mill Ave to Sossaman Rd)	173.68	189.70	16.02	HOV lanes end east of section

BMP – Begin Mile Post, EMP – End Mile Post.

SEGMENTATION

Each of the freeway sections was segmented according to the following guidelines:

- Segments must be essentially homogeneous for the entire length. This requirement includes number of lanes, lane width, shoulder width, median width, and clear zone.
- Segments should be longer than 0.1 mile. This requirement minimizes the potential of crash location error.
- New segments should begin where:
  - Number-of-lanes change
  - Lane width changes by 0.5 ft. or more
  - Shoulder width changes by 1 ft. or more
  - A ramp is present (the gore point defines start of the segment)
  - Clear zone width changes by 5 ft. or more
  - Median width changes by 10 ft. or more if the width is ≤ 90 ft.; if more than 90 ft., changes in median width are not considered
- The presence of a horizontal curve or roadside barrier does not define a segment. The research that developed the freeway crash prediction models concluded that these elements are so common that their consideration as segmentation criteria would result in too many small segments. As a result, their presence is incorporated directly into the models.

Approximately 2-4 miles of each freeway section, listed in Table 2 was fully segmented. The segmented sections are listed in Table 3. Segmentation of each freeway section was conducted using Google Earth. The aerial imagery for the Phoenix metro area is high quality and current (2014). Figure 2 provides an image of a section of freeway segmented. The yellow push-pins represent the beginning of each segment. The exact milepost location of each pin was determined using ADOT's linear referencing system.

Table 3. Segmented Freeway Sections

Facility	BMP	EMP	Length (miles)
I-10 (67th Ave to 43rd Ave)	137.36	140.93	3.57
I-10 (Sky Harbor Blvd to 40th St)	149.15	152.04	2.89
I-17 (Cactus Rd to Bell Rd)	210.24	212.71	2.47
SR-101 (Shea Blvd to Indian Bend Rd)	41.06	44.77	3.71
SR-202 (Van Buren St to McClintock Dr)	4.84	6.48	1.64
US-60 (McQueen Rd to Val Vista Dr)	180.41	184.40	3.99

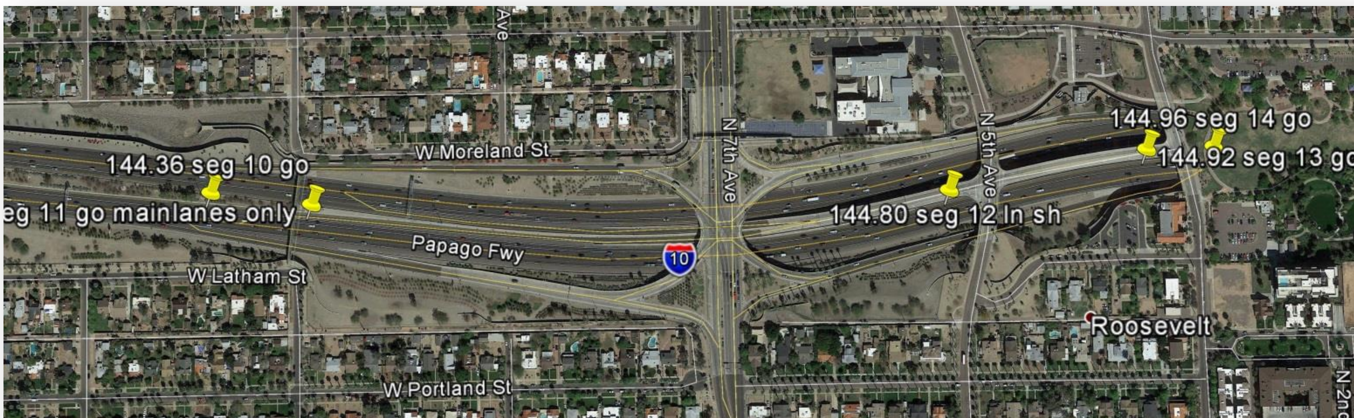


Figure 2. Example of Segmentation

Some 18 miles of freeway segments are listed in Table 4. The minimum segment length is 0.04 miles. The range of each cross section element included in these segments is as follows:

- Number of through lanes, 6 to11
- Lane width, 11.4 to 12.4 ft.,
- Outside shoulder width, 7.3 to 14 ft.
- Inside shoulder width, 6.1 to 11.9 ft.,
- Median width, 19.2 to 79.2 ft.,
- Clear zone width, 23.6 to 30 ft.

Table 4. Calibration Segments

Facility	BMP	EMP	Controlling Attribute
SR 101	41.070	41.370	Ramp
	41.370	41.430	Ramp
	41.430	41.980	Ramp
	41.980	42.055	Ramp
	42.055	42.675	Ramp
	42.675	43.040	Ramp
	43.040	43.085	Ramp
	43.085	43.695	Ramp
	43.695	44.140	Ramp
	44.140	44.745	Ramp
US 60	180.405	180.695	Ramp
	180.695	181.135	Ramp
	181.135	181.675	Ramp
	181.675	182.130	Ramp
	182.130	182.685	Ramp
	182.685	183.720	Ramp
	183.720	184.095	Lane Add
	184.095	184.400	Ramp
SR 202	4.840	4.890	Ramp
	4.890	5.035	Ramp
	5.035	5.190	Outside Shoulder Width
	5.190	5.365	Ramp
	5.365	5.690	Ramp
	5.690	5.860	Ramp
	5.860	6.225	Median Width
	6.225	6.650	Ramp
	6.650	6.735	Ramp
	6.735	7.392	Ramp
	7.392	7.495	Ramp
	7.495	7.690	Inside Shoulder Width
	7.690	8.005	Lane Drop
	8.005	8.050	Ramp
	8.050	8.300	Ramp
	8.300	8.430	Ramp
	8.430	8.650	Ramp
I 17	210.240	210.695	Ramp
	210.695	210.920	Ramp
	210.920	211.180	Outside Shoulder Width
	211.180	211.230	Ramp
	211.230	211.655	Ramp
	211.655	212.260	Ramp
	212.260	212.390	Ramp
	212.390	212.450	Ramp
	212.450	212.560	Ramp
	212.560	212.710	Clear Zone Width
I 10 W	137.362	138.002	Ramp
	138.002	138.323	Ramp
	138.323	138.843	Ramp
	138.843	138.954	Inside Shoulder Width
	138.954	139.375	Ramp
	139.375	139.923	Ramp
	139.923	140.398	Ramp
	140.398	140.926	Ramp
I 10 E	149.152	149.287	Ramp
	149.287	149.380	Ramp
	149.380	149.461	Ramp
	149.461	149.512	Median Width
	149.512	149.582	Median Width
	149.582	149.646	Median Width
	149.646	149.818	Median Width
	149.818	149.971	Ramp
	149.971	150.178	Ramp
	150.178	150.246	Ramp
	150.246	151.223	Ramp
	151.223	151.349	Ramp
	151.349	151.775	Lane Drop
	151.775	151.920	Ramp
	151.920	151.982	Ramp
	151.982	152.041	Ramp

In addition to segmenting the freeway sections to be used for calibration, the I-10 study section was also segmented. The resulting 30 study section segments are listed in Table 5.

Table 5. I-10 Study Section Segments

Facility	BMP	EMP	Controlling Attribute
I 10	141.670	141.920	Project Begin
	141.920	141.425	Ramp
	141.425	142.705	Ramp
	142.705	142.880	Ramp
	142.880	143.000	Ramp
	143.000	143.670	Outside Shoulder Width
	143.670	143.945	Ramp
	143.945	144.360	Ramp
	144.360	144.420	Ramp
	144.420	144.800	Ramp
	144.800	144.920	Outside Shoulder Width
	144.920	144.960	Ramp
	144.960	145.420	Ramp
	145.420	145.520	Ramp
	145.520	145.780	Outside Shoulder Width
	145.780	145.820	Ramp
	145.820	145.940	Ramp
	145.940	146.440	Ramp
	146.440	146.850	Ramp
	146.850	146.930	Ramp
	146.930	147.510	Ramp
	147.510	147.670	Ramp
	147.670	147.955	Ramp
	147.955	148.065	Ramp
	148.065	148.310	Ramp
	148.310	148.430	Ramp
	148.430	148.660	Ramp
	148.660	149.135	Ramp
	149.135	149.170	Ramp
	149.170	149.300	Ramp

Of the segments listed in Table 4, 31 (those highlighted) were randomly selected to be used for model calibration. An additional 9 segments were selected from the I-10 study section and added to the calibration database. These nine segments are highlighted in Table 5. The resulting distribution of calibration segments by freeway and by physical features is summarized in Table 6.

Table 6. Distribution of Calibration Database

Calibration Segment Characteristics		Freeway Facility	
6-7 Thru Lanes	20	I-10	20
8-9 Thru Lanes	12	I-17	4
10-11 Thru Lanes	8	SR 101	9
Weave	15	SR 202	2
HOV Lanes	40	US 60	5
Ramp Meter	40		
Curve	14		
Freeway Segments	40	Total	40
Speed-Change Segments	7 Entry 17 Exit		
ADT High	240,000		
ADT Low	129,000		

DATABASE DEVELOPMENT

Databases were developed for both the calibration segments and the I-10 study section segments. The data collection process is described below.

Roadway Geometry and Characteristics

The required data included:

- number of through lanes,
- length of freeway segments and speed-change lanes,
- presence of horizontal curve in one or both direction of travel, including length of curve, radius of curve, and length of curve within a segment,
- width of lanes, outside shoulders, inside shoulder, and median,
- length of rumble strips on the inside or outside shoulders,
- length and offset median and shoulder barriers,
- width of continuous median barrier, if present,
- presence and length of a Type B weaving section,
- distance to nearest upstream entry and downstream exit ramps in each travel direction, and
- clear zone width.

In order to efficiently and accurately gather roadway geometry and characteristic data for 31 calibration segments, totaling 10 miles, and 30 study section segments, totaling 7.6 miles, the following data collection process was used.

A comparison of roadway geometry and characteristics data obtained from the ADOT Roadway Characteristic Inventory Database (RCID) and extracted from Google Earth aerials was conducted to determine the accuracy of each method. The results indicated that lane width, shoulder width, and median width information, as well as the horizontal curve data (curvature and length) from the RCID compared well with that data collected from the aerials. However, information on barrier location and offset, clear zone, presence of continuous median barrier, presence of a Type B weaving section was not readily available from the RCID. Therefore, data from both the RCID and collected using Google Earth were used.

A process to partially automate the extraction of roadway geometry and characteristic data from Google Earth imagery was developed to support application of the urban freeway crash prediction methodology. The process involves pinning the location of key cross section points using the Google Earth software. The points located in this manner include: edge of clear zone, edge of shoulder, edge of travel lanes, edge of median, location of barrier, begin/end points of weaving lanes, speed-change lane tapers, and roadway curvature. An example of a pinned segment is presented in Figure 3. Each pin is coded by latitude and longitude. These points were digitized and imported into an in-house, Excel-based software tool (Earth Tools) that generates the cross section and roadway characteristic data for each segment. The resulting data was reviewed and potential errors identified and checked. Since data for the tunnel segment of I-10 cannot be collected using aerials, field measurements were collected by ADOT staff during a schedule tunnel maintenance closure in January 2014.

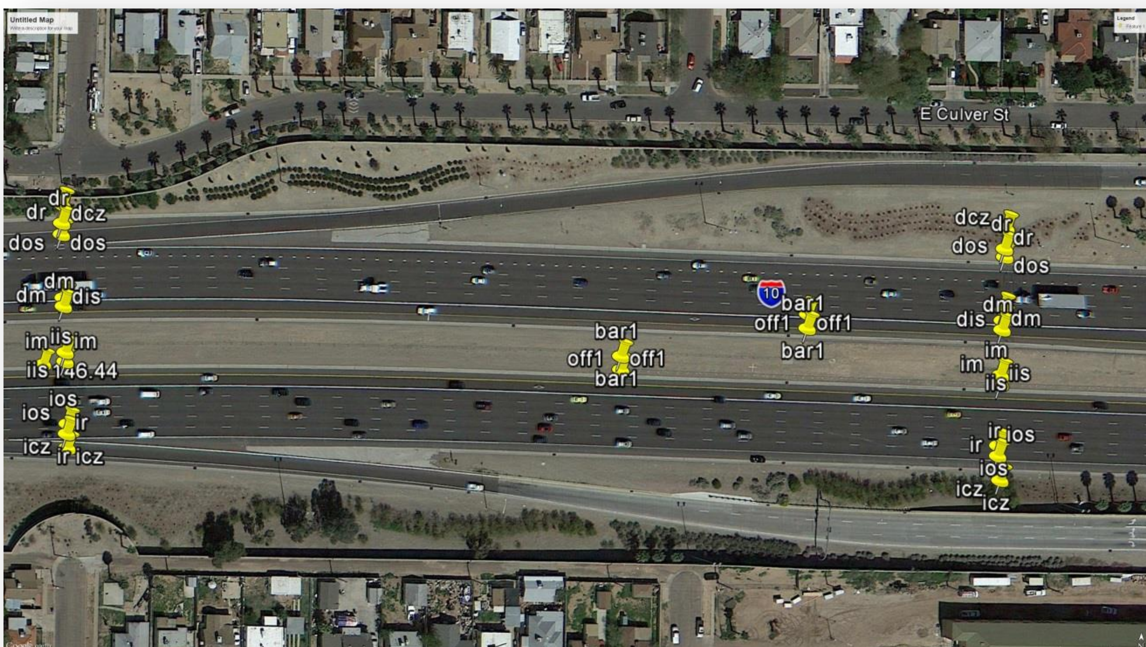


Figure 3. Example of Pinning to Collect Physical Features Data

Traffic Volume Data

Traffic volume data required for calibration and evaluation of safety performance on the I-10 study section included mainline and ramp AADTs for the years 2011-2013 and level of mainline congestion.

Mainline AADTs – Two sources of mainline AADTs were available – the ADOT Traffic Data Management System (TDMS) website and the traffic count data collected by the ADOT Freeway

Management System. The FMS counts are the basis for the TDMS AADTs. Comparison of the AADTs from each source indicated potential inconsistencies in the 2011 and 2012 data. At the locations reviewed, there were in some cases, substantial differences between the FMS counts and the AADTs for 2011 and 2012. However, the FMS counts compared well with the AADTs in 2013. It appears that this difference is likely due to missing data. For example, at one count site, 251 days of FMS data were available in 2011, 305 in 2012, and 342 in 2013. The reported AADTs likely represent an adjusted FMS volume to account for the missing data. Since it was not possible to verify the accuracy of the adjusted AADT's, it was decided that only the 2013 AADTs should be used for the evaluation. The AADT's for 2011 and 2012 were assumed to be reasonably close to the 2013 values.

AADT's for each calibration and I-10 study section segment were calculated based on the AADT from the nearest TDMS mainline count station, adjusted to reflect traffic entering or exiting from adjacent ramps.

Ramp AADTs – ADOT collects volume data at most freeway entrance and exit ramps on a bi-annual basis in the form of a 48-hour tube count. The most recent count was in 2012 and that data was assumed to be equivalent to the 2013 analysis year for the purposes of crash prediction and calibration.

Level of Congestion – Level of congestion is described as the proportion of high volume hours occurring during a typical day. Specifically, this input is the proportion of freeway AADT volume that occurs during hours where the lane volume exceeds 1,000 vehicles per hour per lane (vphpl). The proportion was calculated by first summing the volume during each hour where the average lane volume exceeds 1,000 vphpl and then dividing this sum by the AADT. Using Microsoft Access, 2013 FMS data was queried to determine the average annual proportion of high volume hours for each calibration and I-10 study segment. Volume data that occurred during lane or ramp closures was eliminated from the calculation as it would impact the high volume proportion, particularly on high volume facilities. Traffic volume in HOV lanes was included in the calculation. The hourly lane volume was computed by dividing the hourly volume by the number of through lanes, where the number of through lanes included all general purpose lanes (excluding auxiliary lanes) and HOV lanes.

Crash Data

Crash data for the freeway sections containing the calibration segments and the I-10 study section were obtained from ADOT for 2011, 2012, and 2013. These data were subsequently assigned to the individual freeway segments. The reported crashes for each segment are listed in Table 7 and Table 8.

The crash records were reviewed to confirm that there were no duplicate records. However, it was noted that about 2 percent of the crashes occurred at the same time and location. An additional 1 percent of the crashes occurred within five minutes and within 500 ft. of one another. These crashes were assumed to be secondary crashes that resulted partly from the initial crash. They were retained in the database.

In about 1 percent of the crash records, the RoadCondition attribute indicated that a work zone may have been present. These crashes were removed from the database.

The crash records were screened to include only crashes that were located on either "two-way divided roadway without median barrier" or "two-way divided with median barrier." In about 1 percent of the crash records, the TrafficWayType variable indicated that the crash occurred on a "one-way roadways (including ramps)." Since these crashes may have occurred on a ramp or frontage road and not the mainline, they were removed from the database.

In about 1 percent of the crash records, the JunctionRelation attribute indicated that the crash was located on a ramp or frontage road. These crashes were removed from the database.

Finally, it was noted that the crash milepost location was less precise for 2011 than for either 2012 or 2013. Crashes in 2011 were more frequently assigned to an even milepost (e.g., 279.00) than they were to locations identified to the tenth or hundredth of a mile (e.g., 279.9 or 279.95). In general, the count of crashes at "full mile" locations in 2011 is twice as large as that for 2012 or 2013. This trend is true for all freeway sections represented in the calibration database. It suggests that using milepost location to determine the number of 2011 crashes associated with a particular segment may not lead to an accurate count of crashes for segments less than one mile in length. The more frequent even milepost grouping of the 2011 crashes may be a result of the new GPS-based Traffic and Citation (TraCS) crash reporting system not being fully implemented in that year.

Even though there is crash location uncertainty in the 2011 data, it was concluded that data for all three years could be used to quantify the calibration factors. This conclusion recognizes that the calibration factors are based on the total count of crashes for all segments combined. That is, the aforementioned crash location bias would tend to "average out" when considering the total number of crashes for the collective set of segments.

However, due to location uncertainty, it was concluded that only data for 2012 and 2013 can be used to evaluate safety performance for the individual segments on the I-10 study section. Crash location uncertainty would be problematic for the evaluation of an individual segment for several reasons (e.g., the evaluation would require an accurate count of crashes occurring on that segment). Evidence of this uncertainty can be seen by comparing the crash rates for adjacent segments in Table 7 and Table 8. The rates often vary widely from segment to segment.

Table 7. Calibration Segments Crash Summary

Location	Segment Begin Milepost	Segment Length, mi	Exposure, mvm/3years[1]	Crash Count, crashes/3 years	Crash Rate, crashes/mvm
I-10	138.002	0.321	81.0	87	1.07
	138.954	0.421	80.8	112	1.39
	139.375	0.548	90.3	137	1.52
	139.923	0.475	109.1	126	1.15
	141.67	0.25	61.1	127	2.08
	141.92	0.505	132.5	325	2.45
	142.425	0.28	67.6	171	2.53
	142.705	0.175	29.3	50	1.71
	143.67	0.275	62.3	105	1.69
	143.945	0.415	97.5	269	2.76
	147.51	0.16	25.2	24	0.95

Location	Segment Begin Milepost	Segment Length, mi	Exposure, mvm/3years[1]	Crash Count, crashes/3 years	Crash Rate, crashes/mvm
	147.67	0.285	44.6	46	1.03
	148.43	0.23	45.0	48	1.07
	149.287	0.093	15.7	23	1.47
	149.512	0.07	9.9	10	1.01
	149.646	0.172	24.3	32	1.32
	149.818	0.153	30.0	49	1.63
	151.223	0.126	28.9	31	1.07
	151.775	0.145	34.4	22	0.64
	151.92	0.062	15.2	17	1.12
I-17	210.24	0.455	83.6	106	1.27
	211.18	0.05	8.4	18	2.16
	211.655	0.605	92.9	101	1.09
	212.56	0.15	24.5	18	0.74
L 101	41.37	0.06	9.4	12	1.28
	41.43	0.55	93.7	109	1.16
	41.98	0.075	12.3	30	2.43
	42.055	0.62	95.7	97	1.01
	42.675	0.365	65.8	62	0.94
	43.04	0.045	7.8	7	0.89
	43.085	0.61	103.1	139	1.35
	43.695	0.445	81.5	101	1.24
	44.14	0.605	102.2	106	1.04
L 202	5.19	0.175	25.5	33	1.29
	6.735	0.657	113.0	242	2.14
U.S. 60	180.695	0.44	105.2	196	1.86
	181.675	0.455	105.1	194	1.85
	182.13	0.555	102.4	117	1.14
	183.72	0.375	76.9	82	1.07
	184.095	0.565	95.3	77	0.81
Total:		13.018	2489	3658	1.47

Note: 1 - mvm/3 years: million-vehicle-miles (= segment length x AADT x 365 x 3 / 1,000,000).

Table 8. I-10 Study Section Segments Crash Summary

Location	Segment Begin Milepost[2]	Segment Length, mi	Exposure, mvm/3years[1]	Crash Count, crashes/3 years	Crash Rate, crashes/mvm
I-10	141.67	0.25	61.1	127	2.08
	141.92	0.505	132.5	325	2.45
	142.425	0.28	67.6	171	2.53
	142.705	0.175	29.3	50	1.71
	142.88	0.12	17.8	32	1.80
	143.00	0.67	99.2	201	2.03
	143.67	0.275	62.3	105	1.69
	143.945	0.415	97.5	269	2.76
	144.36	0.06	12.7	71	5.61
	144.42	0.38	79.6	422	5.30
	144.80	0.12	25.5	198	7.76
	144.92	0.04	9.1	44	4.85
	144.96	0.46	112.9	672	5.95
	145.42	0.10	22.8	96	4.21
	145.52	0.26	60.0	276	4.60
	145.78	0.04	9.5	51	5.36
	145.82	0.12	29.8	80	2.68
	145.94	0.50	150.3	575	3.83
	146.44	0.41	119.3	370	3.10
	146.85	0.08	20.8	78	3.75
	146.93	0.58	64.3	243	3.78
	147.51	0.16	25.2	24	0.95
	147.67	0.285	44.6	46	1.03
	147.955	0.11	15.7	48	3.06
	148.065	0.245	40.7	70	1.72
	148.31	0.12	21.7	39	1.80
	148.43	0.23	45.0	48	1.07
	148.66	0.475	76.9	114	1.48
	149.135	0.035	5.8	6	1.04
	149.17	0.13	21.9	49	2.24
Total:		7.63	1581	4900	3.10

Notes:
1 - mvm/3 years: million-vehicle-miles (= segment length x AADT x 365 x 3 / 1,000,000).
2 – Highlighted segments are also included in the set of calibration segments.

GENERAL DISCUSSION OF OBSERVED CRASH RATES

The overall average crash rate for the calibration segments and the I-10 study section is provided in the last row of Table 7 and Table 8, respectively. The rate for the I-10 study section is roughly twice that for the calibration segments. This finding confirms the basis for this safety study regarding the significant potential for safety improvement in the I-10 study section.

The overall average crash rates identified in the last row of Table 7 and Table 8 were compared to the crash rates for urban freeways in other states and metropolitan areas, including the three states (Washington, Maine, California) used to develop the HCS urban freeway crash prediction methodology. The objective of the comparison is to understand the extent to which crash rate can vary among jurisdictions and to develop some expectation about the likely magnitude of the calibration factors for Phoenix urban freeways.

The crash rates for several jurisdictions are listed in Table 9. The source of the data is indicated in the first column. The total crash rate varies from 0.63 to 1.48 crashes per million vehicle miles (cr/mvm). There are many possible reasons for this variation in rates. These reasons relate to differences among jurisdiction in reporting threshold and process, the manner by which a secondary crash is defined, HOV lane presence/mileage, speed limit, level of enforcement, and so on. The crash rate for "Washington, Maine, and California combined" describes the data used to calibrate the base safety prediction models included in the HSM urban freeway crash prediction methodology. The total crash rate for these three states combined is 0.76 cr/mvm. A comparison of this rate with that for the Phoenix calibration segments suggests that the typical calibration required to yield accurate estimates of the predicted crash frequency for Phoenix urban freeway segments will be in the range of 1.47/0.76 = 1.90, although the magnitude of the factor varied among the eight crash prediction models calibrated.

The crash severity distribution for the Phoenix segments can also be compared with the corresponding distributions for several other jurisdictions. The objective of the comparison is to understand the extent to which the crash severity distribution can vary among jurisdictions and to develop some expectation about the likely magnitude of the calibration factor of the severity distribution function (SDF) for Phoenix urban freeways.

The crash severity distributions for several jurisdictions are listed in Table 10. The proportion of property damage only (PDO) crashes tends to range from 0.67 to 0.73. The proportion of PDO crashes for the Phoenix calibration segments (i.e., 0.68) is near the low end of this range. It is equal to that for the "Washington, Maine, and California combined" data that were used to develop the SDF for the HSM urban freeway crash prediction methodology

Table 9. Comparative Urban Freeway Crash Frequency and Rate

Location (Reference)	Exposure, mvm[1]	Fatal (K) and Injury (A,B,C)		Total (K,A,B,C,PDO)	
		Crash Count, cr	Crash Rate, cr/mvm	Crash Count, cr	Crash Rate, cr/mvm
Maine DOT (*1*)	536	113	0.21	340	0.63
Utah DOT (*1*)	3005	1015	0.34	3103	1.03
Illinois DOT (*1*)	10,213	4698	0.46	15,156	1.48
Minnesota DOT (*1*)	6919	2054	0.30	7732	1.12
Oregon DOT (*2*)	5778	not available	not available	3694	0.64
Dallas-Ft. Worth (*3*)	27,226	not available	not available	20,530	0.75
Washington, Maine, California combined (*4*)	21,224	5112	0.24	16,205	0.76
Phoenix metro. calibration segments	2489 (13.0 mi, 3 yrs.)	1167 (3 years)	0.47	3658 (3 years)	1.47
Phoenix I-10 study section	1581 (7.6 mi, 3 yrs.)	1427 (3 years)	0.90	4900 (3 years)	3.10

Note:
1 - mvm: million-vehicle-miles (= segment length x AADT x 365 / 1,000,000).

Table 10. Comparative Urban Freeway Crash Severity Distribution

Location (Reference)	Crash Severity Distribution1				
	Property Damage Only, PDO	Possible Injury, C	Non-incapacitating Injury, B	Incapacitating Injury, A	Fatal, K
Maine DOT (1)	0.67	0.16	0.13	0.04	0.012
Utah DOT (1)	0.67	0.16	0.09	0.07	0.005
Illinois DOT (1)	0.69	0.16	0.08	0.07	0.005
Minnesota DOT (1)	0.73	0.17	0.08	0.01	0.002
Washington, Maine, California combined (1)	0.68	0.21	0.09	0.01	0.005
Phoenix metro. calibration segments	0.68	0.17	0.13	0.02	0.002
Phoenix I-10 study section	0.71	0.16	0.11	0.01	0.002

The proportion of possible injury (C) crashes ranges from 0.16 to 0.21. The proportion of C-type crashes for the Phoenix calibration segments (0.17) and the I-10 study section (0.16.) are essentially the same as the other urban areas. In contrast, that for the "Washington, Maine, and California combined" data is 0.21. The proportion of non-incapacitating injury (B) and incapacitating injury (A) crashes on Phoenix urban freeways are higher than the combined data for these three states. These differences may be due to differences in severity definition, severity reporting, operating speed, and so on among jurisdictions. The severity distribution function (SDF) calibration factor will be used to account for these differences so that the crash severity distribution predicted for the Phoenix urban freeways accurately represents what is observed in the crash data. The calibration factor is based on calculations using the non-PDO proportions for the Phoenix calibration segments and those for the "Washington, Maine, and California combined" data. The SDF calibration process is described in the final report by Bonneson et al.(Ref 4).

ASSIGNMENT OF CRASHES TO SEGMENTS

Forty segments located on five representative freeways in the Phoenix metropolitan area were used for model calibration. The safety prediction procedure explicitly evaluates both speed-change lanes and basic segments, therefore requiring calibration factors for each. To support this type of evaluation and calibration of the underlying models, reported crashes must be appropriately assigned to speed-change lanes and the basic segments. The definitions of "speed-change lane" and "basis segment" are provided in this section to describe how crashes are assigned to each entity.

Crashes assigned to a speed-change lane are identified as the crashes occurring on the roadbed served by the speed-change lane, between the taper and gore points. The region defined by these points is shown in grey in Figure 4.

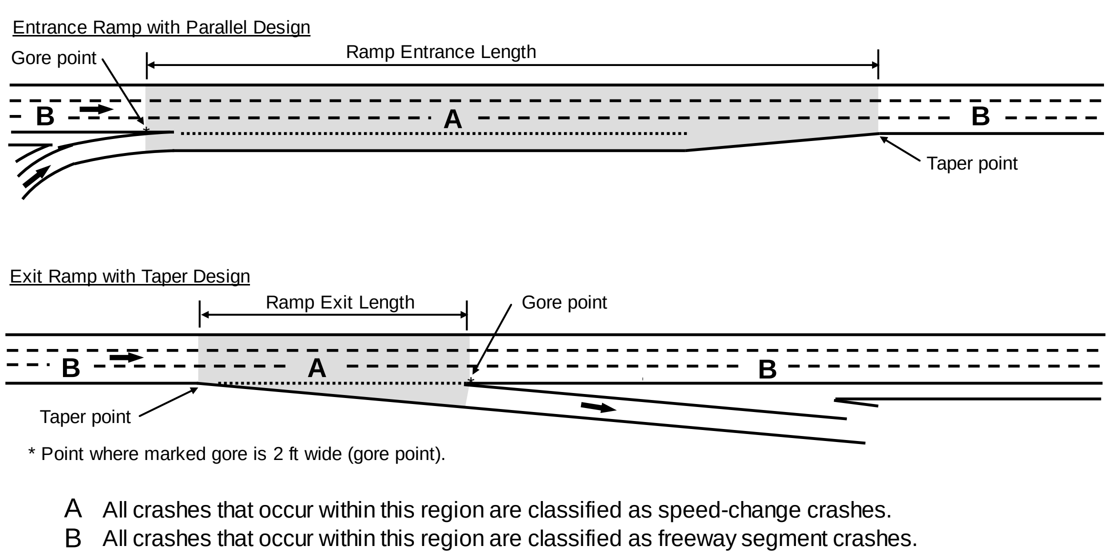


Figure 4. Region Defining Speed-Change Related Crashes

Crashes that are not assigned to a speed-change lane were assigned to a basic segment. The sum of the speed-change-related crashes and the basic-segment crashes represents the total number of crashes reported between the begin- and end-mileposts associated with a given segment. That is, all reported crashes occurring between a segment's begin- and end-mileposts must be assigned to either a speed-change lane or a basic segment (but not both).

CALIBRATION FACTORS

Calculation of calibration factors involved assessing the degree to which each calibration segment is reasonably representative of typical Phoenix-area freeways. Atypical segments were considered for removal from the calibration database based on their influence on the calculated calibration factors. Model calibration factors were then calculated from the screened database.

Screening Calibration Segments

The screening process compared the reported fatal and injury crashes within a segment for the years 2011, 2012 and 2013 with average number of crashes occurring in the same period based on the a typical crash rate observed in the data used to develop the HSM freeway crash prediction models (0.24 fatal-and-injury crashes per million vehicle miles (cr/mvm). The assessment focused on fatal-and-injury crashes because property-damage-only crashes can be less consistently reported depending upon the level of damage.

Screening of the 40 basic segments is summarized in Table 11. Column 3 lists an estimate of the average number of fatal-and-injury crashes occurring in a three-year period based on a typical crash rate of 0.24 crashes per million vehicle-miles. Column 4 lists the reported fatal-and-injury crashes for the basic segment. The segment beginning at MP147.51 consists of two speed-change lanes, which means that a basic segment does not exist at this location.

A "z-score" shown in the last column of Table 11 is computed to identify basic segments where the reported crash frequency is much higher than typical. The z-score is calculated by:

z-score = (computed – reported crashes)/(reported crashes)$^{0.5}$

A typical segment would have a z-score near 0.0. A segment with a large positive z-score would have many more crashes than a typical segment with similar volume and length. The basic segment on I-10 beginning at MP 143.95 is noted to have the largest z-score. It has left- and right-side ramps adjacent to one another on the same roadbed which makes this segment unusual. For this reason, it is considered an outlier and was removed from the calibration database.

Table 11. Screening of Basic Segments (excluding speed-change lanes)

Location	Segment Begin Milepost	Fatal-and-Injury Crash Frequency, cr/3 years		z-score[2, 3]
		Computed[1]	Reported	
I-10	138.00	19.4	28	1.9
	138.95	19.4	26	1.5
	139.38	21.7	47	5.4
	139.92	26.2	39	2.5
	141.67	14.7	29	3.7

Location	Segment Begin	Fatal-and-Injury Crash Frequency, cr/3 years		z-score[2, 3]
	141.92	30.4	89	10.6
	142.43	14.5	47	8.5
	142.71	7.0	18	4.1
	143.67	14.9	38	6.0
	143.95	16.8	64	11.5
	147.51	0.0	0	includes two speed-change lanes
	147.67	8.9	15	2.1
	148.43	9.3	11	0.6
	149.29	2.6	5	1.5
	149.51	2.4	3	0.4
	149.65	5.8	8	0.9
	149.82	3.6	2	-0.8
	151.22	6.6	8	0.6
	151.78	7.0	5	-0.7
	151.92	3.6	4	0.2
I-17	210.24	20.1	38	4.0
	211.18	2.0	5	2.1
	211.66	22.3	32	2.1
	212.56	4.2	7	1.3
L 101	41.37	2.2	3	0.5
	41.43	21.5	39	3.8
	41.98	2.2	3	0.5
	42.06	23.0	30	1.5
	42.68	15.8	14	-0.5
	43.04	1.9	1	-0.6
	43.09	24.8	46	4.3
	43.70	19.6	29	2.1
	44.14	24.5	34	1.9
L 202	5.19	5.6	10	1.8
	6.74	21.6	67	9.8
U.S. 60	180.69	25.2	69	8.7
	181.67	23.7	60	7.5
	182.13	24.6	24	-0.1
	183.72	9.5	16	2.1
	184.09	22.9	35	2.5
Total:		552.0	1048	not applicable

Notes:
1 – Based on typical urban freeway crash rate of 0.24 fatal-and-injury crashes per million vehicle miles (cr/mvm).
2 - z-score computed as (Computed - Reported)/(Reported)$^{0.5}$.
3 - Segments determined to be outliers are identified by highlighted Z-score.

Screening of the twenty four speed-change lanes in the calibration database is listed in Table 12. The z-score for one of the speed-change lanes on the I-10 segment beginning at MP 143.95 has a high score. The corresponding basic segment was identified in Table 11 as an outlier so all three speed-change lanes associated with this segment were considered outliers and were removed.

The z-score for the L202 segment beginning MP 6.74 was also found to have a high score. This speed-change lane occurs partly on a horizontal curve. It is also the first speed-change lane encountered by drivers (traveling in the decreasing milepost direction) for several miles. The upstream interchange traffic is served by auxiliary lanes (as opposed to speed-change lanes) such that the subject speed-change lane may be somewhat unexpected by drivers. For these reasons, the speed-change lanes and associated basic segment are considered outlier and were removed from the database.

Calculation of Calibration Factors

The ISATe spreadsheet was used to compute the predicted crash frequency for each of the basic calibration segments. The predicted values are summarized in. Also shown in the table is the reported crash frequency for each basic segment. These values are summed for all segments and the results are shown in the second-to-last row of the table. These sums are used to compute the calibration factors for the safety performance functions (SPFs) in ISATe. Specifically, each factor is computed as the ratio of the reported crash frequency to the predicted crash frequency. A similar process was used to compute the calibration factors for speed-change lanes. The data used and the resulting factors are shown in.

Table 12. Screening of Speed-Change Lanes

Location	Segment Begin Milepost	Speed-Change Lane		Fatal-and-Injury Crash Frequency, cr/3 years		z-score[2, 3]
		Type	Travel Direction	Computed[1]	Reported	
I-17	212.56	Exit	Increasing	1.6	0	-1.3
I-10	151.77	Exit	Decreasing	1.3	3	1.5
	151.22	Exit	Increasing	0.4	0	-0.6
	149.82	Entrance	Increasing	3.6	11	3.9
	149.29	Exit	Increasing	1.2	2	0.7
	148.43	Exit	Increasing	0.5	0	-0.7
	148.43	Exit	Decreasing	0.9	1	0.1
	147.67	Entrance	Increasing	1.0	3	2.1
	147.67	Exit	Increasing	0.9	0	-0.9
	147.51	Entrance	Increasing	3.0	1	-1.2
	147.51	Entrance	Decreasing	3.0	6	1.7
	143.95	Entrance	Increasing	4.5	24	9.3
	143.95	Exit	Increasing	1.2	4	2.6
	143.95	Exit	Decreasing	0.9	2	1.1

Location	Segment Begin	Speed-Change Lane		Fatal-and-Injury Crash Frequency, cr/3 years		z-score[2, 3]
	142.45	Exit	Increasing	1.7	4	1.7
	141.92	Exit	Increasing	1.4	3	1.3
L 202	6.74	Entrance	Decreasing	4.5	27	10.6
	6.74	Exit	Decreasing	1.0	3	2.0
	5.19	Exit	Increasing	0.5	0	-0.7
L 101	41.98	Exit	Increasing	0.7	4	3.9
	41.43	Exit	Decreasing	1.0	2	1.0
U.S. 60	183.72	Exit	Increasing	1.6	0	-1.3
	183.72	Entrance	Decreasing	7.4	15	2.8
	181.68	Exit	Increasing	1.6	4	2.0
Total:				45.4	119	

Notes:
1 – Based on typical urban freeway crash rate of 0.24 fatal-and-injury crashes per million vehicle miles (cr/mvm) .
2 - z-score computed as (Computed - Reported)/(Reported)$^{0.5}$.
3 - Segments determined to be outliers are identified by highlighted Z-score .

Table 13. SPF Calibration for Basic Freeway Segments (excl. speed-change lanes).

Location	Segment Begin Milepost	Predicted Crash Frequency, crashes/3years[1]				Reported Crash Frequency, crashes/3 years			
		Single-Vehicle		Multiple-Vehicle		Single-Vehicle		Multiple-Vehicle	
		PDO	FI	PDO	FI	PDO	FI	PDO	FI
I-10	138.002	7.5	3.6	50.9	19.0	13	3	46	25
	138.954	11.3	5.1	33.6	13.8	26	4	60	22
	139.375	12.3	5.7	28.4	12.4	18	7	72	40
	139.923	12.2	6.5	60.1	23.5	17	8	70	31
	141.67	7.8	4.0	32.2	11.7	12	3	86	26
	141.92	14.2	8.1	71.0	29.1	24	8	202	81
	142.425	7.1	3.0	30.3	12.5	11	6	83	41
	142.705	3.7	1.5	12.4	5.4	2	1	30	17
	143.67	11.0	4.4	44.2	17.5	8	5	59	33
	143.945	outlier							
	147.51	0	0.0	0.0	0.0	0	0	0	0
	147.67	6.4	2.3	16.9	7.3	2	0	21	15
	148.43	4.8	2.2	45.9	21.9	2	0	25	11
	149.287	1.6	0.6	7.3	3.4	2	1	8	4
	149.512	4.2	1.9	7.6	2.3	3	1	4	2
	149.646	5.4	2.1	11.7	4.1	2	2	22	6

Location	Segment Begin Milepost	Predicted Crash Frequency, crashes/3years[1]				Reported Crash Frequency, crashes/3 years			
		Single-Vehicle		Multiple-Vehicle		Single-Vehicle		Multiple-Vehicle	
		PDO	FI	PDO	FI	PDO	FI	PDO	FI
	149.818	1.5	0.7	8.4	3.2	0	0	14	2
	151.223	2.7	1.4	15.1	5.7	4	0	18	8
	151.775	3.6	1.8	28.4	12.6	2	0	11	5
	151.92	1.9	0.7	20.0	8.5	4	0	9	4
I-17	210.24	11.8	5.2	59.0	20.7	13	9	55	29
	211.18	1.1	0.5	5.2	1.9	0	0	13	5
	211.655	14.1	6.3	47.2	17.7	14	6	55	26
	212.56	2.5	1.1	13.9	5.7	2	3	9	4
L 101	41.37	1.2	0.7	6.0	2.4	3	1	6	2
	41.43	14.7	7.9	73.0	28.1	16	11	51	28
	41.98	2.2	1.1	8.7	3.0	3	0	18	3
	42.055	17.4	8.8	61.3	21.1	9	9	58	21
	42.675	9.6	4.8	50.2	17.5	14	2	34	12
	43.04	1.2	0.6	6.0	2.1	3	1	3	0
	43.085	14.8	7.0	62.8	22.3	10	3	83	43
	43.695	9.6	4.6	55.9	20.2	16	3	56	26
	44.14	13.1	5.7	55.9	20.6	18	4	54	30
L 202	5.19	5.7	2.4	13.5	5.2	7	4	15	6
	6.735	outlier							
U.S. 60	180.695	16.9	7.4	57.3	21.6	24	9	103	60
	181.675	14.2	6.7	55.6	22.9	10	6	113	54
	182.13	17.3	7.3	34.7	14.2	13	6	80	18
	183.72	6.0	2.9	13.7	5.8	9	3	12	13
	184.095	16.1	6.7	29.0	12.3	10	6	32	29
Total:		308.7	143.3	1232.9	479.2	346	135	1690	782
Calibration Factor:						1.12	0.94	1.37	1.63

Note:
1 - Based on safety prediction models developed for NCHRP Project 17-45 (and in ISATe).

Table 14. SPF Calibration for Speed-Change Lanes.

Location	Segment Begin Milepost	Predicted Crash Frequency, crashes/3years[1]				Reported Crash Frequency, crashes/3 years			
		Entrance Ramp		Exit Ramp		Entrance Ramp		Exit Ramp	
		PDO	FI	PDO	FI	PDO	FI	PDO	FI
I-17	212.56	--	--	3.8	1.6	--	--	0	0
I-10	151.77	--	--	2.9	1.3	--	--	1	3
	151.223	--	--	0.9	0.4	--	--	1	0
	149.818	8.2	5.3	--	--	22	11	--	--
	149.287	--	--	2.1	0.9	--	--	6	2
	148.43	--	--	1.5	0.8	--	--	5	0
	148.43	--	--	1.5	0.8	--	--	4	1
	147.67	1.7	1.1	--	--	1	3	--	--
	147.67	--	--	1.5	0.7	--	--	4	0
	147.51	4.7	2.5	--	--	9	1	--	--
	147.51	4.7	2.5	--	--	8	6	--	--
	143.945	outlier							
	143.945	outlier							
	143.945	outlier							
	142.425	--	--	3.3	1.5	--	--	26	4
	141.92	--	--	2.5	1.2	--	--	7	3
L 202	6.735	outlier							
	6.735	outlier							
	5.19	--	--	1.2	0.6	--	--	1	0
L 101	41.98	--	--	2.2	1.0	--	--	2	4
	41.43	--	--	2.5	1.1	--	--	1	2
U.S. 60	183.72	--	--	3.0	1.3	--	--	3	0
	183.72	10.0	4.6	--	--	27	15	--	--
	181.675	--	--	3.1	1.4	--	--	7	4
Total:		29.3	15.9	31.8	14.5	67	36	68	23
Calibration Factor:						2.29	2.27	2.14	1.58

Note:
1 - Based on safety prediction models developed for NCHRP Project 17-45 (and in ISATe).

The severity distribution function (SDF) is calibrated using the crash data for the injury and fatal crashes. The procedure for quantifying this calibration factor is described in the final report for NCHRP Project 17-45. This factor adjusts the SDF in ISATe such that the predicted frequency of K, A-injury, B-injury, and C-injury crashes matches more closely to that for the local conditions (e.g., the Phoenix calibration sites).

The data used to compute the SDF calibration factor is shown in Table 15. An examination of these data indicates that the proportion of reported K-fatal, A-injury, and B-injury crashes is 0.14. However, this same proportion for the predicted crashes is 0.082. Thus, the uncalibrated SDF is under-predicting the proportion of K, A, and B crashes. The calibration factor shown in the last row of the table will remove this bias such that the SDF model predictions will more reliably reflect the distribution of K, A, and B crashes on the Phoenix metro area freeways. This factor is used for both the basic segment SPFs and the speed-change lane SPFs.

Table 15. SDF Calibration for Basic Segments and Speed-Change Lanes Combined.

Severity Category	Predicted Crash Frequency, crashes/3years[1]	Reported Crash Frequency, crashes/3 years
K - fatal	8.5	8
A - incapacitating injury	22.4	57
B - non-incapacitating injury	153.8	382
C - possible injury	458.2	529
Total KAB	184.7	447
Total KABC	652.9	976
Ratio KAB/KABC	0.283	0.458
Calibration Factor:		2.14

Note:
1 - Calibration factor = Reported Ratio / (1.0 - Reported Ratio) x (1.0 - Predicted Ratio) / Predicted Ratio.

Application of the Calibrated Model

The eight calibrated SPFs and calibrated SDF provide a crash prediction model that accurately reflects safety performance for Phoenix freeways. The model can be used to effectively evaluate the safety performance of freeway sections with physical and operational characteristics similar to the calibration freeway sections. The ISATe spreadsheet tool is now available to ADOT for use in applying the model on future safety performance studies. The model can also be used to accurately assess freeway design alternatives relative to crash frequency, and evaluate crash mitigation measures. Since the model calibration segments included continuous access HOV lanes and ramp meters, the model should not be applied to freeway sections without HOV lanes or with access controlled HOV lanes, as well as freeways without ramp metering. Care should be used in applying the model to freeway sections with posted speed limits below 65 mph, in which case the free-flow speed should be approximately 65 mph.

The geometry, traffic, and crash data for the I-10 study section were entered into the ISATe software. The error-checking routines were used to verify that the data were entered correctly. The calibration factors were also entered into the ISATe software. The expected crash frequency (by type and severity) was then computed for each speed-change lane and basic segment using the Empirical Bayes Method, described in the HSM. The ISATe output is provided in Appendix B. Other performance measures were also computed and are described in the next section. These performance measures were computed for a study period that was coincident with the crash period (2011 - 2013). The safety performance for future or prior years was not estimated, but the software will support the safety evaluation of other years if the traffic volumes for these years can be estimated.

The two segments having left-side (HOV) and right-side ramps on the same roadbed could not be evaluated directly due to limitations of the predictive method. The technique used to overcome this limitation was to disaggregate the two "left+right" segments that could be evaluated with the method. Specifically, each of the two "left+right" segments was entered into ISATe as three simplified segments whose results could be combined to represent the safety of a "left+right" segment. One simplified segment (i.e., segment 1) described the segment geometry, ramp traffic, and crash as if there were no ramps. A second simplified segment (i.e., segment 2) described the segment as if there were only left-side ramps. The third simplified segment (i.e., segment 3) described the segment as if there were only right-side ramps. The crash estimate for the "left+right" segment was then computed as equal to the safety estimate for Segment 2 plus that for Segment 3 minus that for Segment 1.

EVALUATION OF THE SAFETY PERFORMANCE OF THE I-10 STUDY SECTION

Based on the calculated performance measures, the segments were ranked to help identify those segments which have the greatest potential for crash reduction and were the focus of the detailed crash diagnostic process.

PERFORMANCE MEASURES

Figure 5 lists the 13 HSM performance measures that were considered for evaluation of the I-10 study section. Moving down the list, the potential for bias that occurs when safety evaluations are based on short term crash histories (e.g. 2 to 3 years) decreases. This bias, known as regression-to-the-mean (RTM), reflects the potential that the short term crash frequency observed at a site may represent either an abnormally high or low crash frequency relative to the long term crash frequency at the site. Reducing or eliminating the RTM bias provides greater

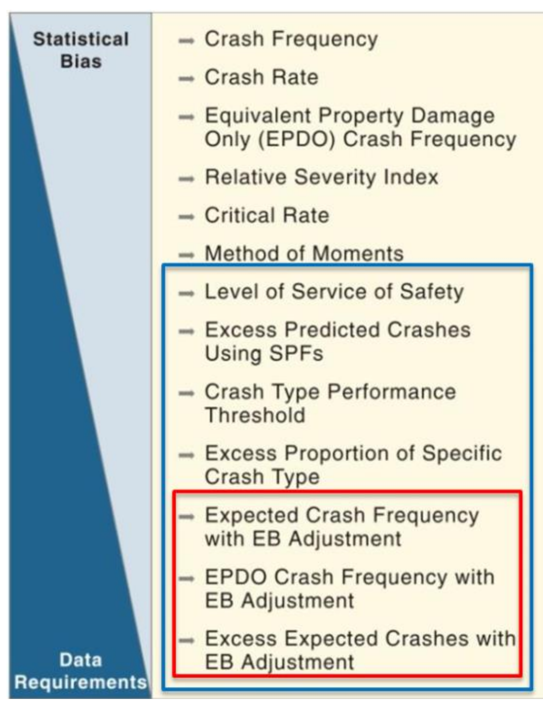


Figure 5. Alternative Safety Performance Measures

accuracy in identifying sites that have the highest potential for crash reduction. Given the intent of this study, only performance measures that account for RTM bias were used to evaluate safety performance on the I-10 study section segments.

The following six performance measures were calculated for each of the basic segments and speed-change lanes in the I-10 study section. Each of these performance measures either is not affected by RTM bias or accounts for the bias through an adjustment using the Empirical Bayse (EB) methodology.

1. Probability of specific crash types exceeding threshold proportion (Crash Type Performance Threshold)
2. Excess proportion of specific crash type
3. Expected average crash frequency with EB adjustment
4. Equivalent PDO average crash frequency with EB adjustment
5. Excess expected average crash frequency with EB adjustment
6. Modified level of service of safety (LOSS)

Discussion of each performance measure, including their strengths and weaknesses in evaluating safety performance, and results relative to the I-10 study section are provided in Appendix A. The six performance measures describe the magnitude of the safety problem within the I-10 study section in essentially two dimensions: (a) relative to other segments in the I-10 study section (the ranks do this); and (b) relative to other freeways relative to other similar freeway segments in the Phoenix region.

In addition to describing the safety performance within the study segment, these measures were used to identify those segments with high potential to reduce crashes. The two primary ranking measures used were the z-score calculated to define the level of service of safety (LOSS) and the expected average crash frequency with EB adjustment (EACFEB).

The z-score indicates whether a site has potential for improvement beyond that potential already identified by the CMF values calculated for each segment. For example, the segment with the 90-degree horizontal curve through the L202/SR51 interchange has a combined CMF value of 1.67 and a relatively high z-score of 4.18. The combined CMF value indicates that 67% of the expected crashes in this segment result from the physical characteristics of the roadway (horizontal curve, shoulder width, presence of ramps, etc.). In this particular segment, the horizontal curve is the primary contributing physical characteristic affecting safety performance. While flattening out the curve is not a reasonable solution, other treatments for curvature may be appropriate such as enhanced signing or delineation. Therefore, when using CMF corrected crash predictions, it is important to screen for locations with high composite CMFs and locations with high expected excess values.

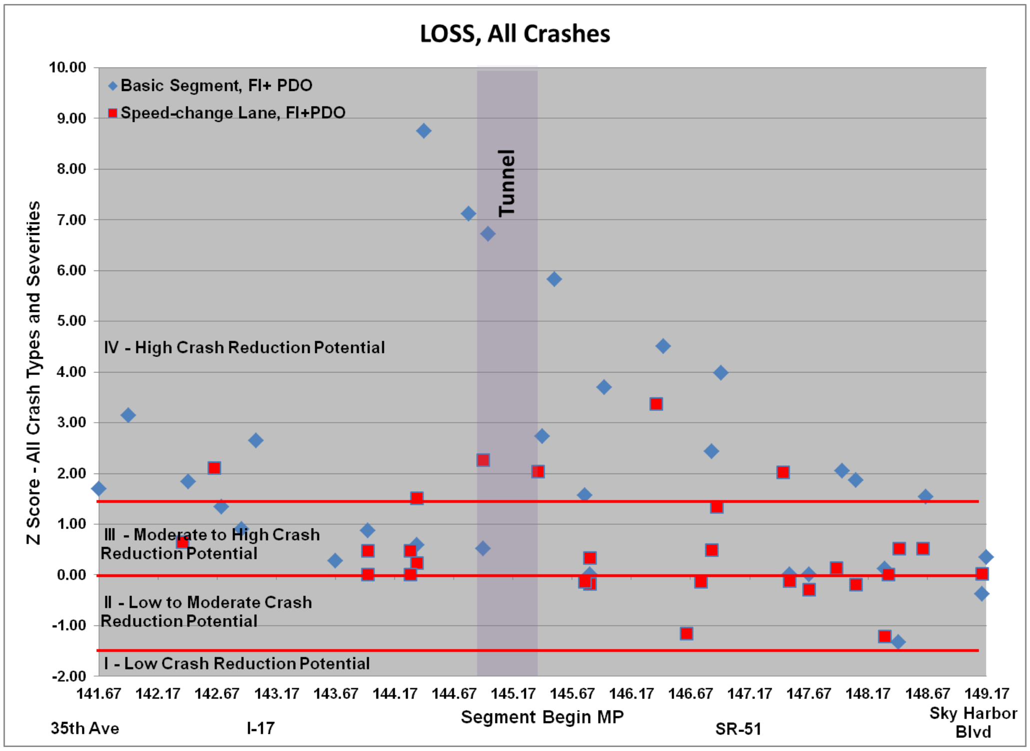
Still, the high z-score for this segment indicates that there are other factors beyond the physical characteristics described by the calculated CMF values that are contributing to the expected crashes in the segment. Determining these other factors and identifying potential countermeasures requires diagnosis involving a detailed review of site conditions, crash trends, and crash reports.

The LOSS results presented in Figure 6 indicate that nearly all of the basic segments and a majority of the speed-change lanes in the study section, either considering all crashes or just fatal and injury crashes, have a moderate to high potential to find safety improvement opportunities through diagnosis of site conditions and a review of crash history. These results also suggest that there may be common factors within the entire study section contributing to the crashes occurring. The red lines in each graph delineate the potential (low, moderate, or high) of identifying opportunities to reduce crashes.

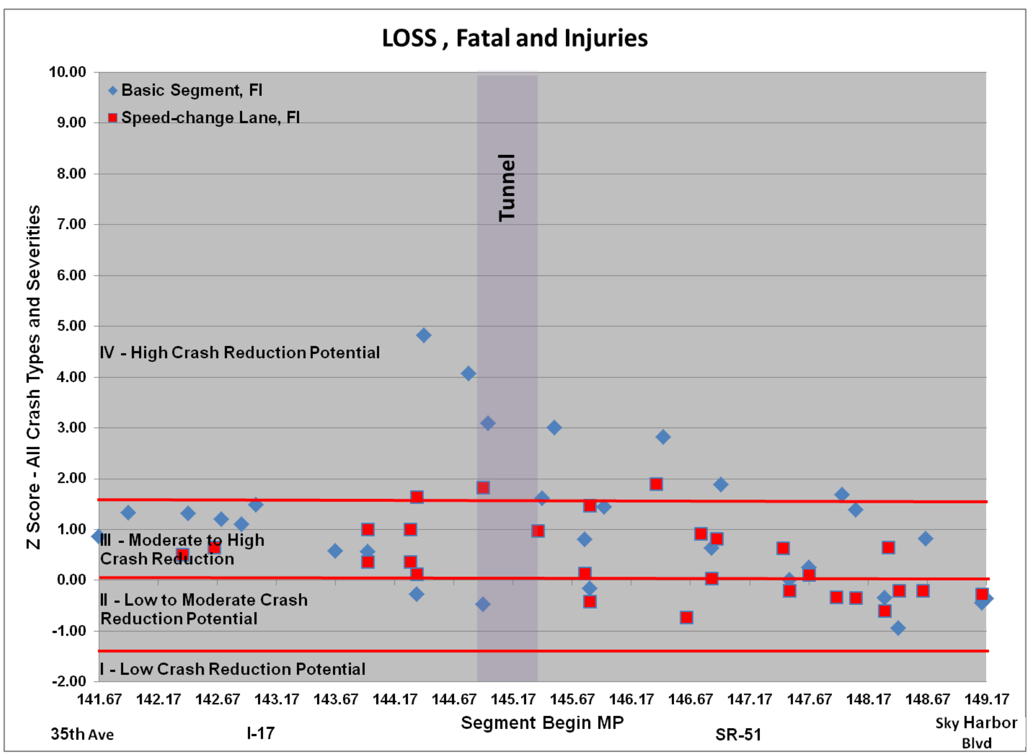
Figure 7 presents the expected average crash frequencies per mile for each study section segment. The red line in each graph is the expected average crash frequency for the 40 Phoenix area freeway segments used to calibrate the crash prediction models. These calibration values included segments on 1-10, I-17, L101, L202, and US60, which are similar to those segments found within the I-10 study section. Therefore, while it may not be fully accurate to call these values “typical” for Phoenix freeways, they are fairly representative of urban freeways throughout the area and therefore offer a solid reference to assess the performance of the I-10 study section and priority for safety improvement. These results show that approximately half of the segments in the I-10 study section have crash frequencies that are substantially higher than other similar Phoenix urban freeways. The results confirm the intent of this study to focus on identifying potential countermeasures to reduce the high crash frequency within this section of I-10.

Considering these two performance measures, LOSS and EACFEB, the safety performance evaluation indicates that not only can this freeway section be considered a priority, but there is a high potential to reduce crash frequency with the application of appropriate countermeasures.

The numerical LOSS and EACFEB results for the basic freeway segments and speed-change lanes are provided in Appendix C.

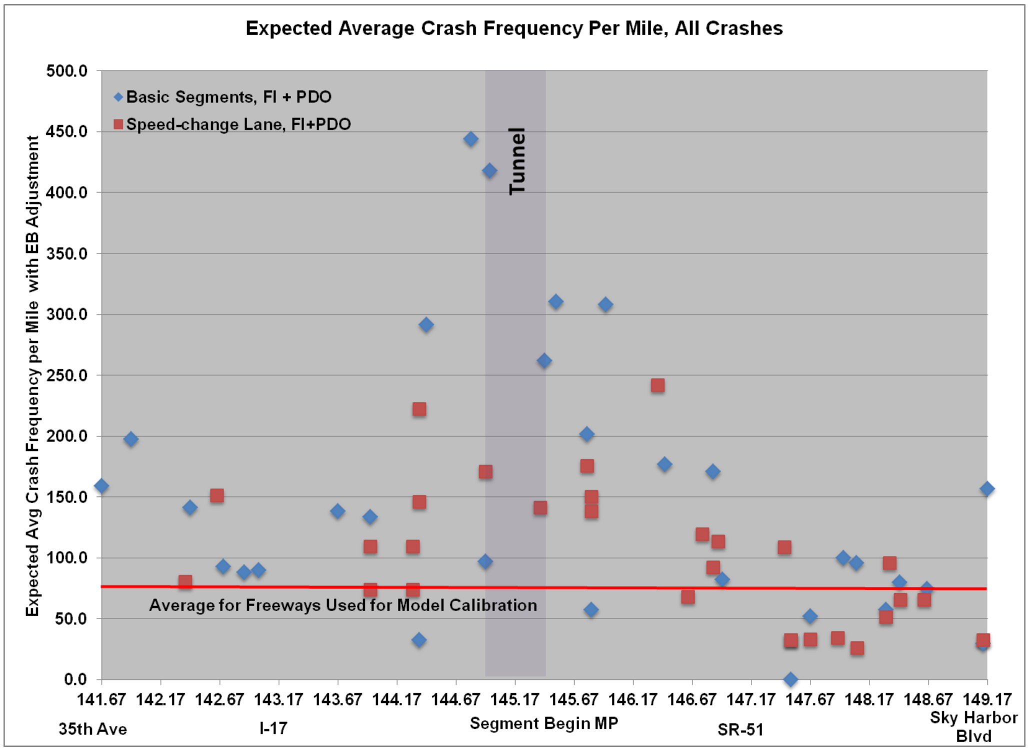


a. All Crashes (Fatal, Injury, and PDO)

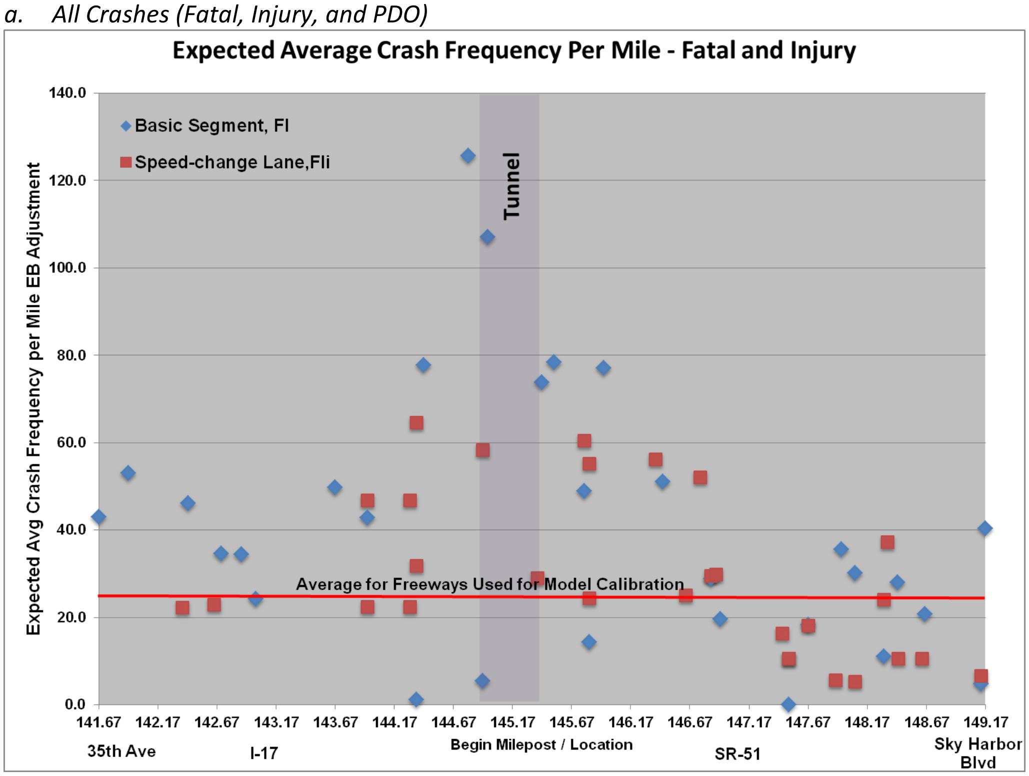


b. Fatal and Injury Crashes only

Figure 6. Level of Service of Safety (z-score) for Study Section Basic Segments.



a. All Crashes (Fatal, Injury, and PDO)



b. Fatal and Injury Crashes Only

Figure 7. Expected Average Crash Frequency per Mile

CRASH DIAGNOSTIC PROCESS

DEVELOPMENT OF GIS BASED CRASH DATABASE

The ADOT crash database for the years 2012 and 2013 was imported into a GIS environment. Initially, crashes were located along the center line of the freeway mainline for each direction of travel utilizing latitude and longitude and an appropriate coordinate system. The distribution of the 2-years of crashes within the entire study section is provided in Figure 8. Each blue dot represents a crash. Figure 9 shows the crash locations on one segment of the study area.

Using the GIS crash database, the distribution of different crash attributes including severity, manner of collision, first harmful event, lighting condition, and weather condition were reviewed. Figure 10 shows the crash distribution for a segment by severity type. FMS and HPMS counting stations were added to the database so that traffic volume and operations information can be included in the review of crash trends.

ANALYSIS OF CRASH PATTERNS AND FREEWAY OPERATIONAL CHARACTERISTICS

An investigative analysis on the crash data and freeway operational data was conducted in an attempt to identify a direct correlation between operational characteristics and crash patterns. Crash distribution by time of day, collision manner, and drivers' maneuvering action were analyzed for each study section segment. FMS traffic operational data was used to develop speed and congestion profiles for the study area for a typical weekday. These data indicate that the I-10 eastbound direction is typically congested in the morning peak hours from 35th Avenue to 19th Avenue, and the eastbound section from 19th Avenue to 16th Street is congested in both morning peak and afternoon peak hours. For the I-10 westbound direction, the section from 16th Street to 35th Avenue is congested during afternoon peak hours.

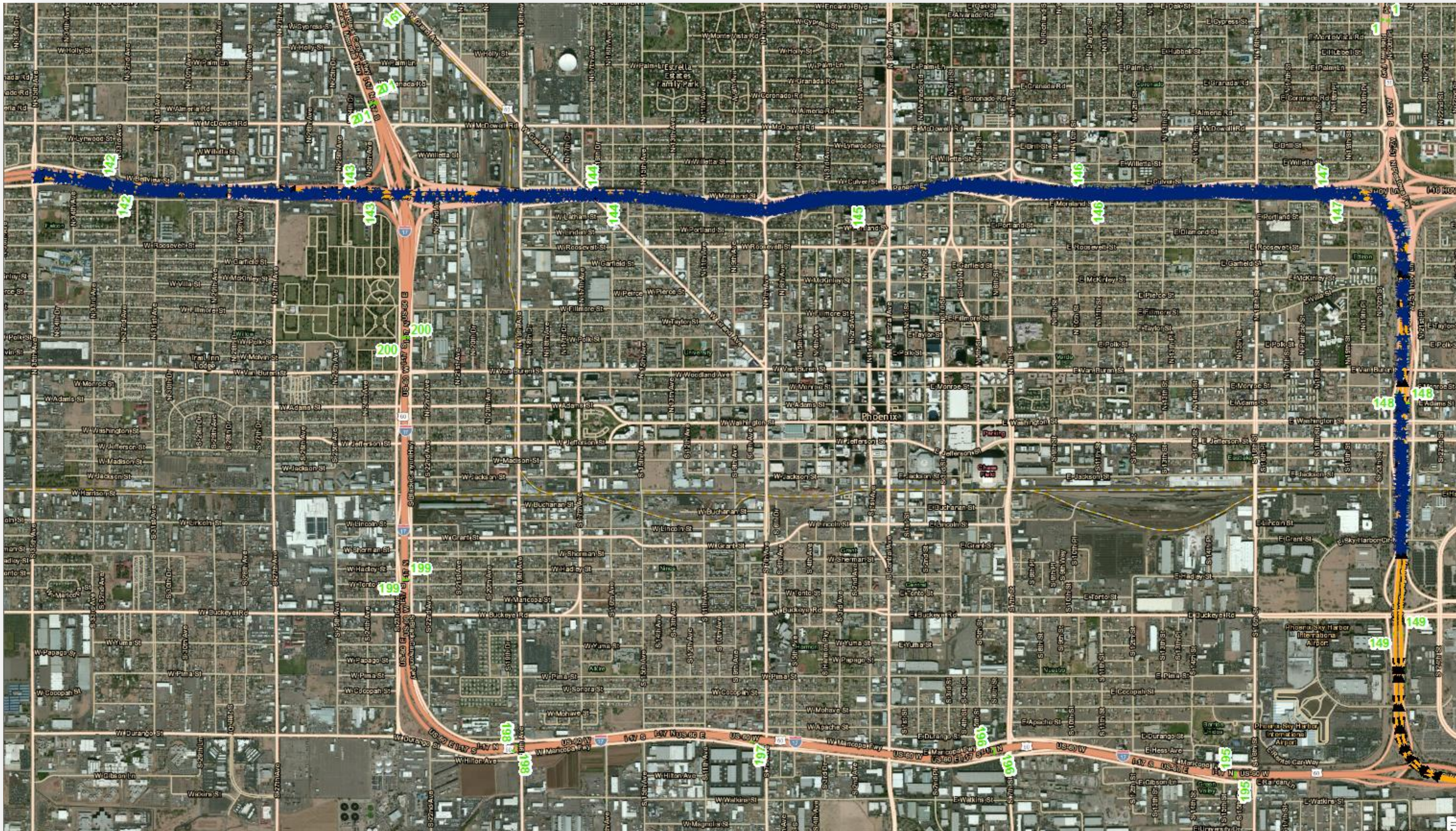


Figure 8. Two-year (2012-2013) Crashes within the I-10 Study Section

Figure 9. Crash locations on one segment (Deck Park Tunnel to 7th St)

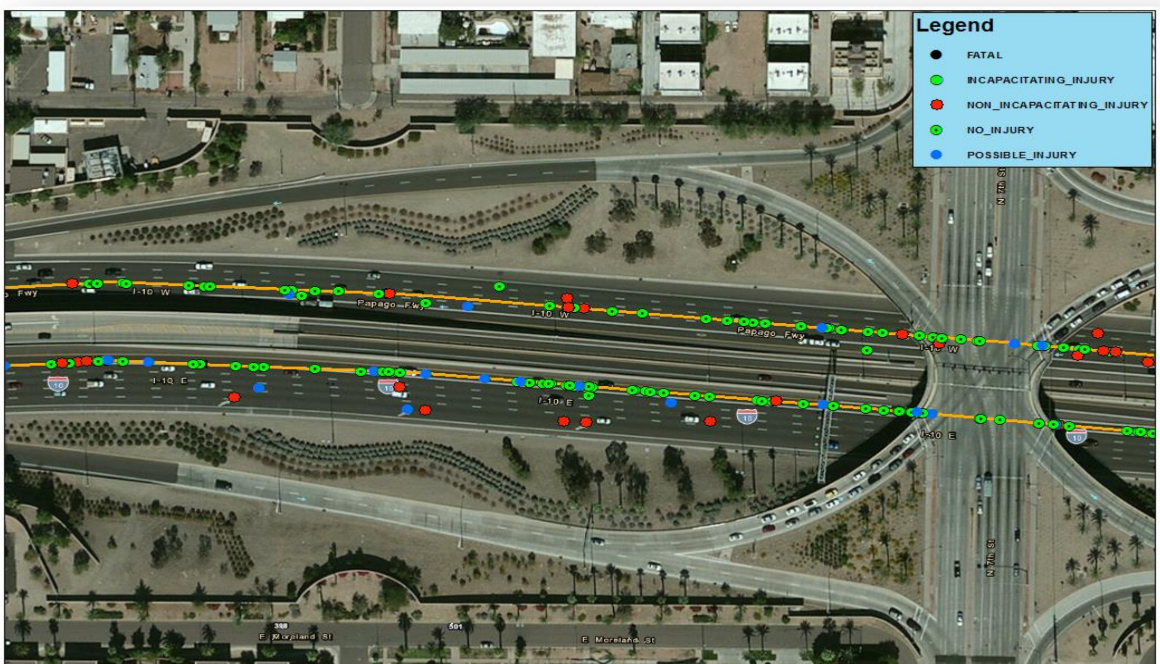


Figure 10. Distribution of Crashes by Severity (Deck Park Tunnel to 7th St)

The crash distribution for the entire study section by time of day provided in Table 16 shows that approximately 70% of observed crashes in 2012 and 2013 occurred during the peak traffic hours. Analysis of individual study section segments provided insight into crash patterns. For example, Table 17 presents the time-of-day crash distribution for the segment from the 3rd St HOV on-ramp to the 7th St on-ramp, Figure 11 and Figure 12 show the speed and congestion profile of two adjacent FMS count stations for this segment. These data support the hypothesis that most crashes are related to congestion and high traffic volumes.

Further analysis shows that most crashes that occurred in this segment were rear-end crashes and that prior to the crash both drivers were either slowing or were stopped in the traffic way. Table 18 and Table 20 show crash distribution by type of collision and drivers' maneuvering action, respectively. Time of day distribution for the crashes associated with stopped and/or slowing traffic,

Table 16. Crash Distribution by Time-of-Day for Study Section

Time of Day	Frequency	Percent
0:00	23	0.7%
1:00	10	0.3%
2:00	20	0.6%
3:00	9	0.3%
4:00	31	0.9%
5:00	73	2.2%
6:00	139	4.2%
7:00	169	5.1%
8:00	172	5.2%
9:00	75	2.2%
10:00	65	1.9%
11:00	57	1.7%
12:00	86	2.6%
13:00	110	3.3%
14:00	199	6.0%
15:00	448	13.4%
16:00	536	16.1%
17:00	542	16.2%
18:00	341	10.2%
19:00	80	2.4%
20:00	46	1.4%
21:00	47	1.4%
22:00	40	1.2%
23:00	20	0.6%
Total	3,338	100.0%

Table 17. Crash Distribution by Time-of-Day 3rd St HOV Ramp to 7th St Ramp

Time of Day	Frequency	Percent
0:00	0	0.00%
1:00	0	0.00%
2:00	0	0.00%
3:00	0	0.00%
4:00	0	0.00%
5:00	0	0.00%
6:00	1	4.55%
7:00	2	9.09%
8:00	1	4.55%
9:00	1	4.55%
10:00	1	4.55%
11:00	0	0.00%
12:00	0	0.00%
13:00	2	9.09%
14:00	1	4.55%
15:00	2	9.09%
16:00	3	13.64%
17:00	5	22.73%
18:00	3	13.64%
19:00	0	0.00%
20:00	0	0.00%
21:00	0	0.00%
22:00	0	0.00%
23:00	0	0.00%
Total	22	100.00%

Table 19 shows that the crashes are directly correlated to the congestion and speed reduction on the freeway. Appendix D includes the statistics for the westbound direction for this segment. Figure 13 and Figure 14 show the direct correlation between the speed reduction and the crashes that occurred in both westbound and eastbound directions in this segment due to vehicles stopped and/or slowing in traffic.

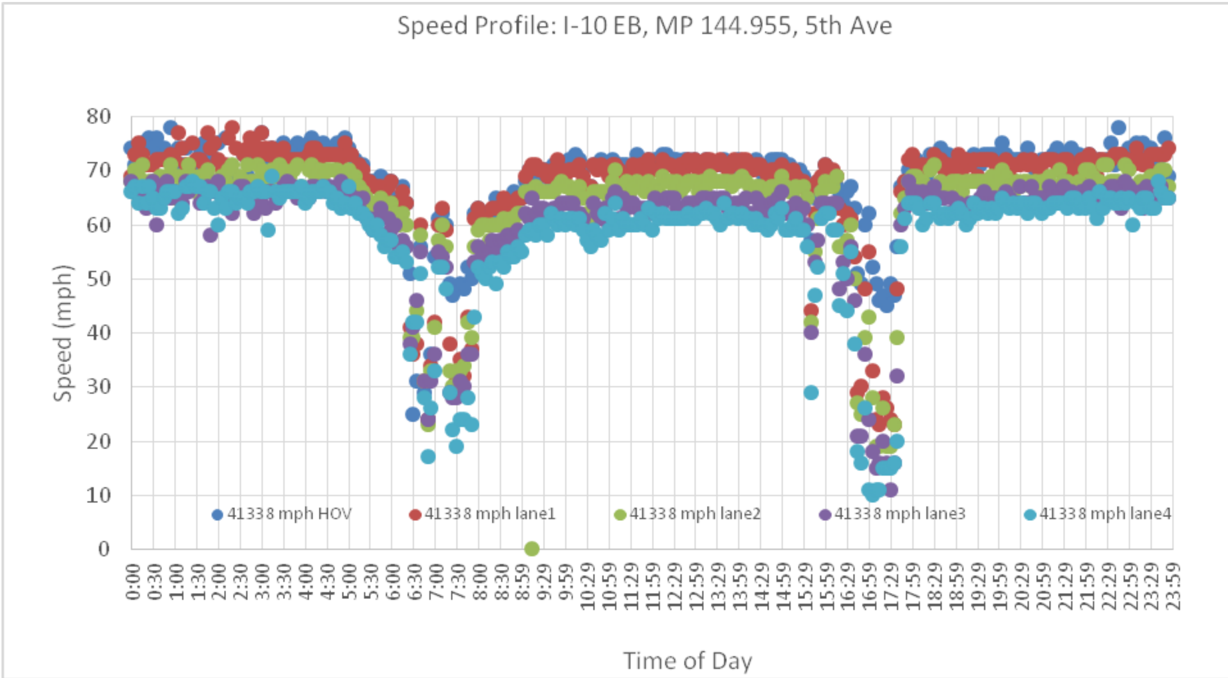


Figure 11. Speed profile for eastbound I-10, MP 146.96

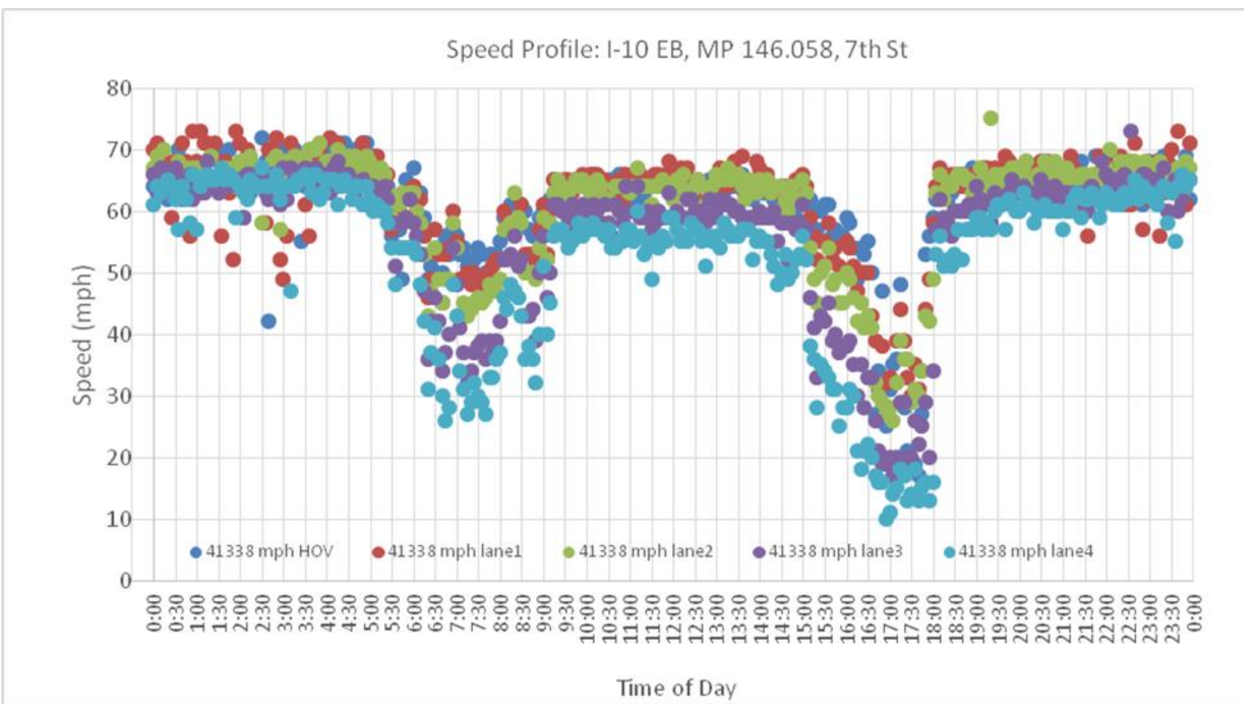


Figure 12. Speed profile for eastbound I-10, MP 146.06

Table 18. Collision Type Distribution (Segment – I-10 EB, MP 145.78)

Collision Type	Frequency	Percent
REAR_END	18	81.82%
SIDESWIPE_OPPOSITE_DIRECTION	1	4.55%
SIDESWIPE_SAME_DIRECTION	2	9.09%
SINGLE VEHICLE	1	4.55%
Total	22	100.00%

Table 20. Drivers' Maneuvering/Action (Segment – I-10 EB, MP 145.78)

Drivers Action	Frequency	Percent
CHANGING_LANES	4	8.70%
GOING_STRAIGHT_AHEAD	17	36.96%
SLOWING_IN_TRAFFICWAY	14	30.43%
STOPPED_IN_TRAFFICWAY	7	15.22%
UNKNOWN	4	8.70%
Total	46	100.00%

Table 19. Distribution of Slowing/Stopped in the Traffic Way by Time of Day (Segment – I-10 EB, MP 145.78)

Time of Day	Frequency	Percent
0:00	0	0.00%
1:00	0	0.00%
2:00	0	0.00%
3:00	0	0.00%
4:00	0	0.00%
5:00	0	0.00%
6:00	2	9.52%
7:00	2	9.52%
8:00	0	0.00%
9:00	0	0.00%
10:00	0	0.00%
11:00	0	0.00%
12:00	0	0.00%
13:00	1	4.76%
14:00	1	4.76%
15:00	3	14.29%
16:00	2	9.52%
17:00	7	33.33%
18:00	3	14.29%
19:00	0	0.00%
20:00	0	0.00%
21:00	0	0.00%
22:00	0	0.00%
23:00	0	0.00%
Total	21	100.00 %

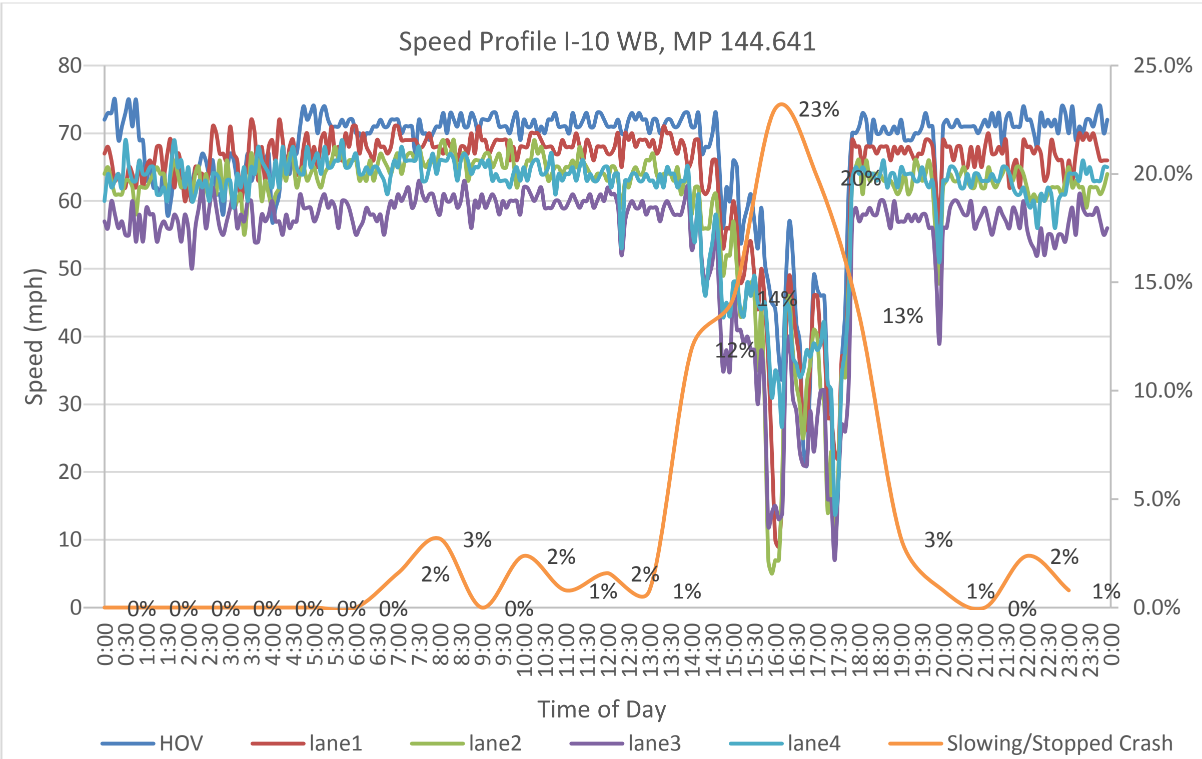


Figure 13. Correlation between Speed and Crashes due to Slowing/Stopped Maneuvering (Segment I-10 WB, MP 144.42)

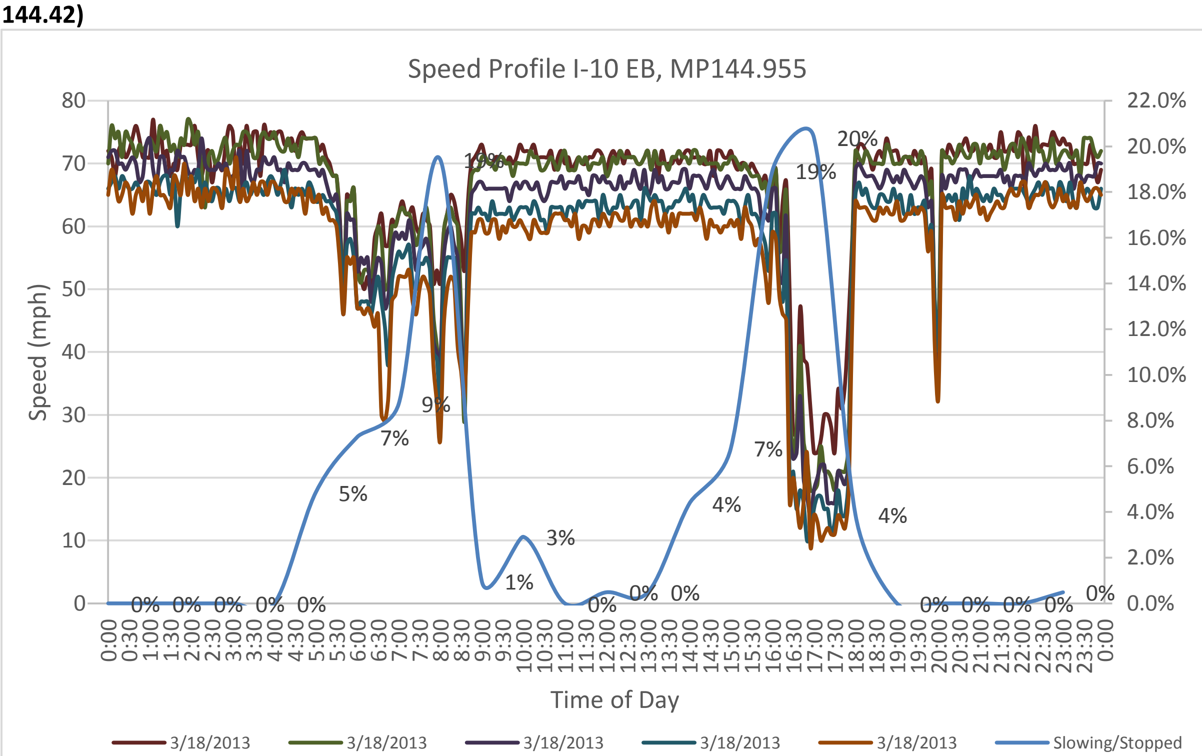


Figure 14. Correlation between Speed and Crashes due to Slowing/Stopped Maneuvering (Segment I-10 EB, MP 144.42)

CRASH DIAGNOSTIC ANALYSIS OF STUDY SECTION SEGMENTS

A detailed diagnostic analysis was conducted in an attempt to determine the primary contributing factors to observed crashes. As a part of this analysis 756 crash reports of 3,255 crashes (23%) occurring in the study section in 2011 and 2013 were reviewed. The crash reports were selected based on the review of the crash data to identify trends or areas of interest within each segment. The diagnostic analysis was conducted in three phases. First, a subset of study section segments which exhibited high crash frequencies per mile when compared with the average for the broader set of Phoenix freeway segments used for the predictive model calibration and/or in which existing roadway characteristics are contributing substantially to observed crashes was selected for review. The criteria used to select this subset were the estimated z-score and the cumulative effect of crash modification factors (CMFs) for each segment.

The z-score compares the expected crashes of a study segment with the average expected crashes for the 40 Phoenix freeway segments used to calibrate the crash prediction models. High z-scores reflect segments where there is high potential for crash reduction as a result of factors not explained by the models.

The cumulative CMF of a segment reflects the level at which roadway and traffic characteristics included in the model contribute to the expected crash frequency. High potential for achieving crash reduction in a segment is indicated by a high z-score, a high combined CMF, or both

Based on the z-scores and combined CMFs, eleven segments were selected for the Phase 1 diagnostic analysis. The selected segments are listed in Table 21. Figure 15 displays the z-scores and cumulative CMF values for all of the study segments, with those selected for further analysis highlighted.

Table 21. List of Selected Segments for Phase 1 Detail Crash Report Review

Segment	Begin MP	End MP	Speed Change Lane	Combined CMF	z-score
I-17 to 19th Ave	142.30	143.67		1.44	2.69
7th Ave Exit Ramp to 5th Ave HOV Exit Ramp	144.36	-	Exit	3.15	1.54
5th Ave HOV Exit Ramp to WB Lane Drop West of 7th Ave	144.42	144.80		1.19	9.22
WB Lane Drop West of 7th Ave to 7th Ave Entry	144.80	144.92		1.33	7.61
7th Ave Entry to 7th St Exit (Deck Park Tunnel)	144.96	145.38		2.26	6.78
Lane Drop East of 7th St to 3rd St HOV Entry	145.52	145.78		1.40	5.97
3rd St HOV Entry to 7th St Entry	145.78	145.82		1.82	1.59
7th St Entry to 16th St Exit	145.94	146.38		1.74	3.72
16th St Exit to SR 51 HOV Lane Exit	146.44	146.64		1.41	4.59
L202/SR51 Exit to L202/SR51 Entry	146.93	147.45		1.67	4.18
SR 202 HOV Lanes to Jefferson St Entry	148.31	-	Ent.	5.04	-1.21

The second phase of the diagnostic review focused on known geometric or operational features within the study section that were expected to be primary contributing factors in observed crashes. These features primarily included the left-hand HOV entry/exit ramps, lane drops, weaving sections, tunnel lighting, and HOV lane access. Based on these features, 19 additional segments were reviewed.

Finally, diagnostic review of all fatal, and serious injury crashes (total of 46 crashes) was conducted. Though the proportion of fatal and serious injury crashes (1.4%, 46 fatal and serious injury crashes out of 3,255 total crashes) is small, and recognizing the importance of more severe crashes, the fatal and serious injury crash reports were reviewed to investigate whether or not they show any specific pattern or causal factors.

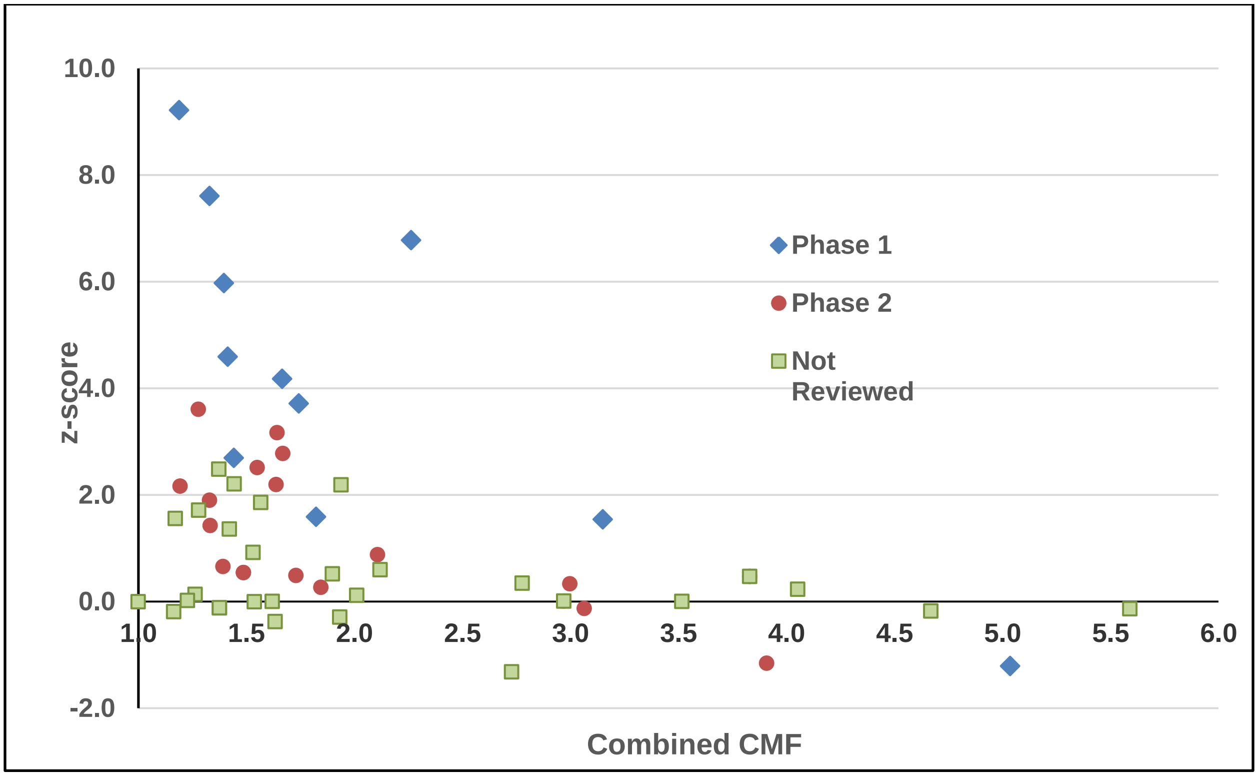


Figure 15. Distribution of z-score and Cumulative CMF of the I-10 Corridor Study Segments

Phase I Analysis – High z-Score and Combined CMF Segments

In the Phase 1 analysis, 323 crash reports out of 1,687 crashes that occurred in 2012 and 2013 were reviewed. Approximately 15 collision reports for crashes that occurred during the periods of congestion for each direction of travel were randomly selected for each segment. For each detailed crash report, a short summary was generated. The effort also included identifying the exact position of the vehicles on the roadway including the lane number during the crash, manner of collision, lighting conditions, vehicular conditions, driver behavior, vehicular speed, traffic conditions, and any influencing factors. Based on the information extracted from the crash reports, FMS speed profile, and features of the roadway segment, a brief summary (per direction of travel) was developed for each segment. Then the information was imported into the GIS database.

A collision diagram for each crash was also drawn based on the information contained in the crash report. These collision diagrams were not intended to duplicate or replace existing techniques adopted by ADOT, but were used only for analysis by the study team. A library in GIS environment was developed for the collision diagrams to represent the exact crash location on the roadway which helped the study team to visually identify traffic issues in the roadway, potential contributing factors, and what could be done to resolve the issues. Table 22 provides an example of the crash report review summary for one of the segments. Figure 16 shows a sample collision diagram identifying the exact location of each crash within a segment.

Phase I Findings

The following section provides the diagnostic summary and discusses the contributing factors for the Phase I analysis and crash report review.

Eastbound, I-17 (MP143.00) to 19th Ave (MP143.66): In this segment, a total of 86 crashes occurred during 2012 and 2013, and 15 crash reports were reviewed. Ramp traffic from both northbound and southbound I-17 merge with I-10 eastbound traffic just east of this segment. Eastbound I-10 traffic west of I-17 travels at a high speed and suddenly encounters slowing and/or stopped traffic. Congestion, speed, and merging traffic were contributing factors to the crashes in this segment.

Eastbound, 7th Ave Exit Ramp (MP144.36) to 5th Ave HOV Exit Ramp (MP144.42): In this segment, a total of 32 crashes (533 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. There is a left-side HOV exit to 5th Avenue in this segment. Higher speed approaching traffic rear-ending stopped traffic on this downgrade, mainly in lane 1 (median lane),is a common crash type. Speed and congestion are the main contributing factors for these crashes.

Eastbound, 5th Ave HOV Exit Ramp (MP144.42) to WB Lane Drop West of 7th Ave (MP144.80): In this segment, a total of 178 crashes (468 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. This segment is a downgrade and is located west of the tunnel. Higher speed approaching traffic encounters congestion, resulting in rear end crashes. Congestion and speed are contributing factors in this segment.

Eastbound, WB Lane Drop West of 7th Ave (MP144.80) to 7th Ave Entry (MP144.92): In this segment, a total of 54 crashes (450 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. This segment is the west end of the tunnel. Higher speed approaching traffic encounters congestion, often resulting in rear-end crashes. There is merging of heavy, unmetered traffic from the 7th Ave entry ramp that contributes to congestion. Congestion, speed, and merging, were contributing factors for these crashes.

Eastbound, 7th Ave Entry (MP144.96) to 7th St Exit (MP145.42)(Deck Park Tunnel): In this segment, a total of 202 crashes (439 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. This is a majority of the tunnel segment. Traffic is congested, and higher speed traffic encounters slowing and/or stopped traffic and a change in lighting conditions. The 7th Street exit starts at the east end of the tunnel segment. Congestion, speed, lighting conditions, tunnel effects, and horizontal curve are the contributing factors in this segment.

Westbound, 5th Ave HOV Entry Ramp (MP144.42) to 7th Ave Entry Ramp (MP144.36): In this segment, a total of 17 crashes (283 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. Traffic entering from 7th Avenue merges just west of this segment. There is also a left-side HOV entrance from 5th Avenue. There is a significant amount of lane changing resulting in slowing traffic which leads to sideswipe or rear-end crashes. Congestion from downstream bottlenecks can extend into this segment. Congestion and lane changing are the primary contributing factors in this segment.

Westbound, Lane Drop West of 7th Ave (MP144.80) to 5th Ave HOV Entry Ramp (MP144.42) : In this segment, a total of 118 crashes (311 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. This segment contains the merge area from a right-side lane drop. After leaving the tunnel traffic starts accelerating, but then often encounters slowed or stopped traffic. Merging from the lane drop, often late and forced, contributes to congestion. Congestion, speed, and merging associated with the lane drop are contributing factors in this segment.

Westbound, 7th Ave Exit Ramp (MP144.92) to Lane Drop West of 7th Ave (MP144.80): In this segment, a total of 70 crashes (583 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. This segment is at the west end of the tunnel (including the 7th Avenue exit ramp). Westbound motorists exiting the tunnel on a downgrade and on a curve, often accelerating, typically encounter slowed or stopped traffic during peak hours. Rear end crashes are predominant. Several crash reports noted glare from the setting sun as a factor. The effect of the transition from the tunnel illumination conditions to much brighter ambient conditions, particularly in the afternoon, is also a factor. Congestion, speed, differential illumination levels, sun glare, and roadway geometry (downgrade and horizontal curve) are contributing factors in this segment.

Westbound, 7th St Entry Ramp (MP145.42 to 7th Ave Exit Ramp (MP144.96)(Deck Park Tunnel)): In this segment, the Deck Park Tunnel, a total of 214 crashes (465 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. Traffic in the tunnel is very congested during peak traffic periods. The 7th Street entry ramp (lane add) and 7th Avenue exit ramp create a Type B weaving section. Heavy, unmetered, traffic enters the westbound tunnel from 7th Street, weaving with traffic destined for the 7th Avenue exit. The illumination levels in the tunnel likely compound the effect of the horizontal curve and grade, downgrade in the westbound direction, and make weaving maneuvers more challenging. Several crash reports noted that the vehicle drifting out of its lane, suggesting the motorists are having trouble tracking the lane lines. Congestion, speed, tunnel illumination, weaving traffic, roadway geometry (horizontal curve, grade), and overall tunnel effects, are the contributing factors.

Westbound, 1st St HOV Exit (MP145.78) to Lane Drop East of 7th St Exit (MP145.52): In this segment, a total of 85 crashes (304 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. High speed traffic encounters congestion of either slowing or stopped traffic approaching the tunnel. Motorists attempting to change lanes to avoid congested lanes are often involved in crashes. Congestion, speed, and lane changing were contributing factors.

Table 22. Sample Crash Summary for Segment I-17 (MP142.99) to 19th Ave (MP143.66)

Segment_StartingMP	Direction	IncidentID	IncidentLevelSummary	SegmentLevelSummary	CollisionDiagramTypeGIS	LaneNumber	V1Speed	V2Speed
142.993	EB	2590818	1 UNIT, 1 INJURY, V1 LOST CONTROL WHILE TRYING TO AVOID COLLISOIN WITH ANOTHER LANE-CHANGING VEHICLE, AND HIT CONCRETE BA	RAMP TRAFFIC FROM BOTH I-17 NORTHBOUND AND SOUTHBOUND MERGE WITH I-10 EASTBOIUND TRAFFIC JUST EAST OF THIS SEGMENT. I-10 EASTBOUND TRAFFIC FROM WEST OF I-17 COMES WITH HIGH SPEED AND SUDDENLY ENCOUNTERS THE SLOWING AND/OR STOPPED TRAFFIC.	1VLostHitInjury	0	65	-
142.993	EB	2609980	2 UNITS, 3 INJURIES, V2 WAS STOPPED IN TRAFFIC IN LANE 3, D1 COULDN'T STOP AND STRUCK V2		2VRearEndInjury	3	20	0
142.993	EB	2610027	2 UNITS, 2 INJURIES, V2 STOPPED IN TRAFFIC IN LANE 3, V1 COULDN'T STOP AND STRUCK V2		2VRearEndInjury	3	65	0
142.993	EB	2657193	2 UNITS, 1 INJURY, V2 GOT SIDE SWIPED BY V1 WHILE CHANGING LANE IN LANE 4 AND THEN HIT CONCRETE BARRIER		2VSideLostHit	4	60	45
142.993	EB	2660923	2 UNITS, 1 INJURY, V2 WAS STOPPED IN CONGESTION IN LANE 5 AND GOT STRUCK BY V1		2VRearEndInjury	5	25	0
142.993	EB	2666489	3 UNITS, 1 INJURY		3VSideRearInjury	0	45	55
142.993	EB	2669555	3 UNITS, 2 INJURIES		3VRearEndInjury	0	30	15
142.993	EB	2672342	3 UNITS, 1 INJURY, V2 WAS SLOWING IN TRAFFIC IN LANE 1, D1 WAS DISTRACTED BY ANOTHER LANE-CHANGING VEHICLE, COULDN'T STOP,		3VRearEndInjury	1	20	0
142.993	EB	2683829	2 UNITS, 1 INJURY		2VRearEndInjury	0	5	0
142.993	EB	2683899	2 UNITS, 1 INJURY, V2 WAS SLOWING IN TRAFFIC IN LANE 1, D1 COULDN'T STOP AND STRUCK V2		2VRearEndInjury	1	-	-
142.993	EB	2689469	3 UNITS, 1 INJURY		3VRearEndInjury	0	30	0
142.993	EB	2689482	2 UNITS, 1 INJURY, V2 AND V1 WERE SLOWING DOWN IN TRAFFIC, V1 STRUCK V2 IN LANE 3		2VRearEndInjury	3	40	30
142.993	EB	2715241	2 UNITS, 1 INJURY, V1 APPLIED BRAKE TO AVOID REAR END WITH ANOTHER VEHICLE IN LANE 1, SWERVED INTO HOV LANE AND SIDE SWIPED		2VSideSwipInjury	1	50	60
142.993	EB	2748649	4 UNITS, 2 INJURIES, V2 WAS SLOWING DOWN IN TRAFFIC, D1 APPLIED HARD BRAKE, COULDN'T STOP, STRUCK V2, PUSHED V2 INTO V3 IN LA		4VRearLostRearInjury	2	35	65
142.993	EB	2770525	3 UNITS, 1 INJURY, V2 WAS SLOWING IN TRAFFIC, V1 STRUCK V2 AND PUSHED V2 INTO V3		3VRearEndInjury	0	40	0
142.993	WB	2575594	2 UNITS, 1 INJURY, V2 STOPPED IN TRAFFIC, D1 FELL ASLEEP AND STRUCK V2	RAMP TRAFFIC FROM I-17 NORTHBOUND AND I-17 SOUTHBOUND MERGE WITH I-10 WESTBOUND TRAFFIC JUST WEST OF THIS SEGMENT. I-10 WESTBOUND TRAFFIC THINKS CONGESTION IS GONE, STARTS ACCELRALERATING AND ENCOUNTERS THE SLOWED AND/OR STOPPED TARAFFIC.	2VRearEndInjury	0	-	-
142.993	WB	2592959	1 UNIT, 1 INJURY		1VLostHitNonInjury	0	65	-
142.993	WB	2619478	2 UNITS, 0 INJURIES, V2 WAS SLOWING IN TRAFFIC AND V1 STRUCK V2 IN LANE 3		2VRearEndNonInjury	3	3	0
142.993	WB	2640973	3 UNITS, 1 INJURY, V2 WAS SLOWING IN CONGESTION AND STRUCK BY V1, V1 WAS THEN STRUCK BY V3 IN LANE 1		2VRearEndInjury	1	15	0
142.993	WB	2645526	2 UNITS, 1 INJURY, TRAFFIC CAME TO AN ABRUPT STOP AND V1 STRUCK V2 IN LANE 1		2VRearEndInjury	1	35	0
142.993	WB	2666766	2 UNITS, 1 INJURY, V2 WAS STOPPED IN CONGESTION IN LANE 1, D1 WAS GOING FAST, COULDN'T STOP AND STRUCK V2		2VRearEndInjury	1	50	0
142.993	WB	2673916	3 UNITS, 2 INJURIES, V2 WAS SLOWIG IN CONGESTION IN LANE 3, D1 WAS GOING FAST, COULDN'T STOP, STRUCK V2 AND PUSHED V2 INTO V		3VRearEndInjury	3	65	15
142.993	WB	2700719	2 UNITS, 1 INJURY, V2 AND V1 WERE SLOWING DOWN IN TRAFFIC, V1 STRUCK V2 IN LANE 1		2VRearEndInjury	1	60	45
142.993	WB	2711949	2 UNITS, 2 INJURIES, V2 STOPPED IN CONGESTION AND GOT STRUCK BY V1 IN LANE 5		2VRearEndInjury	5	60	0
142.993	WB	2730434	2 UNITS, 0 INJURIES, TRAFFIC WAS IN STOP AND GO CONDITION, V1 STRUCK V2 IN LANE 1		2VRearEndNonInjury	1	5	0
142.993	WB	2734105	2 UNITS, 1 INJURY, TRAFFIC WAS STOP AND GO CONIDTION, V1 STARTED ACCELERATION, THEN APPLIED BARKE, AND STRUCK V2 IN LANE 1		2VRearEndInjury	1	-	45
142.993	WB	2753561	2 UNITS, 1 INJURY		2VRearLost2nd	0	65	65
142.993	WB	2762626	2 UNITS, 0 INJURIES, V2 WAS SLOWING DOWN IN LANE 2 AND GOT STRUCK BY V1		2VRearEndNonInjury	2	5	0

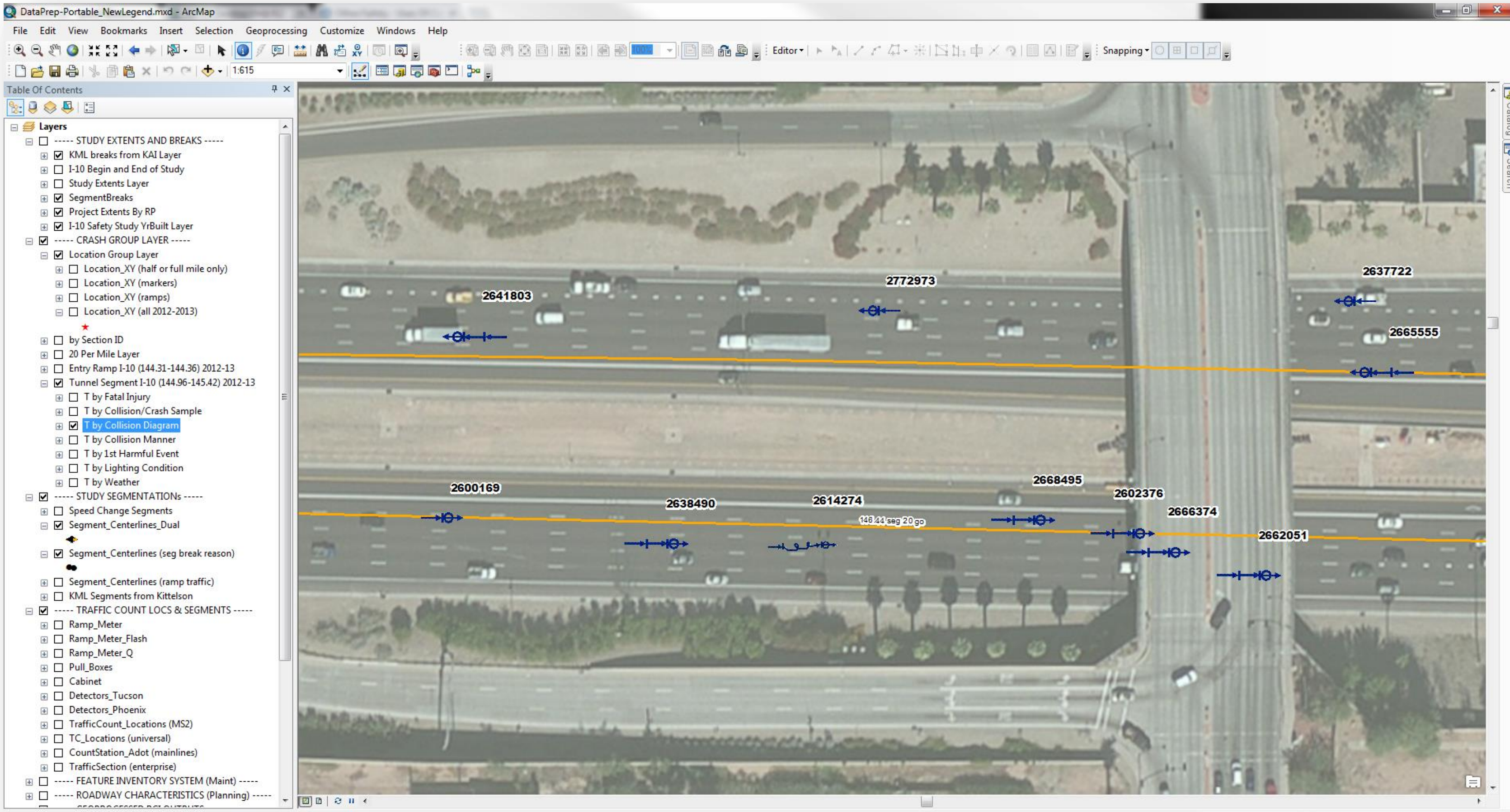


Figure 16. Sample Collision Diagram for a Segment (7th St to 16th St) on a GIS Platform

Westbound, 7th St Exit (MP145.84) to 1st St HOV Exit (MP145.78): In this segment, a total of 22 crashes (367 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. Higher speed traffic encounters slowing/stopped traffic approaching the tunnel. The left-side HOV exit does not appear to be a factor. Congestion and speed are the contributing factors.

Westbound, 16th St Entry (MP146.44) to 7th St Exit (MP145.9): In this segment, a total of 151 crashes (280 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. This segment contains a one-lane on-ramp from 16th Street and a two-lane off-ramp to 7th Street. The weaving in this segment, particularly in the morning, is heavy between traffic entering from L202/SR51 and 16th Street, and traffic destined for 7th Street. In the evening peak period, higher speed traffic often encounters congestion. Rear-end and sideswipe crashes are predominant. Congestion, weaving, and speed are contributing factors.

Westbound, L202/SR51 Entry (MP146.93) to 16th St Entry (MP146.44): In this segment, a total of 75 crashes (188 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. Traffic from southbound SR-51, westbound Loop 202, westbound I-10, and an additional left-side HOV lane from Loop 202 merge together. Higher speed traffic encounters a significant amount of lane changing and slowed traffic and often fails to stop in time. Congestion, speed, and lane changing are contributing factors.

Westbound, L202/SR51 Exit (MP147.52) to L202/SR51 Entry (MP146.93): In this segment, a total of 88 crashes (149 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. The segment includes the 90-degree curve which accommodates high-speeds. High speed traffic exiting the curve often encounter slowed or stopped traffic created by downstream bottlenecks. Congestion and speed are contributing factors. Twenty sideswipe collisions caused by lane changing or vehicles drifting outside their lanes occurred within the curve.

Westbound, Jefferson St Exit (MP148.44) to L202 HOV Lanes (MP148.33): In this segment, a total of 17 crashes (142 crashes per mile) occurred during 2012 and 2013, and 15 crash reports were reviewed. In this segment there is a left-side HOV diverging ramp to northbound L202/SR-51. The right-side diverging ramp to northbound SR-51 and eastbound Loop 202 is just north of this segment (one lane must exit and a second lane is an optional exit). Relatively high speed traffic often encounters slowed and/or stopped traffic. Congestion, speed, and lane changing are contributing factors.

Phase II Analysis – Known Operational Issues/Hot Spots

The segments included in the Phase II analysis are listed in Table 23. The z-scores and cumulative CMFs for these segments are included in Figure 15. Segments included in the Phase II analysis included several Phase I segments, as well as 19 additional segments (highlighted in Table 23). Note that several segments are listed multiple times depending upon the feature that was reviewed. In all, 387 crash reports were reviewed in the Phase II analysis.

Phase II Findings

HOV Lanes; Westbound 5th Ave HOV Entrance and Eastbound 3rd St HOV Entrance, and Loop 202 HOV Entrance: In these segments, a total of 314 crashes occurred during 2012 and 2013, and 84 of them were reviewed. Crash types included the following: Rear-end crashes due to motorists making a sudden lane change from lane 1 to the HOV lane while trying to avoid congestion (18 crashes). The crashes attributed to the left side HOV entry ramps at the 5th Avenue and 3rd Street entrance were lower than anticipated and primarily involved rear-end crashes within the merge areas (5 crashes). Higher speed vehicles encountering slowed and/or stopped vehicles were reported in 41 crashes reviewed. Contributing crash factors appear to include: open access to HOV lanes, congestion, and speed differential.

Table 23. Segments in the Phase II Crash Analysis

Features/Issues	Begin MP	End MP	Crash Reports of Interest
5th Ave HOV Entrance	144.42	144.80	Weekday morning and evening peak period
3rd St HOV Entrance	145.78	145.82	Weekday morning and evening peak period
HOV lane access to/from through lanes I-17 to 7th St	143.67	143.95	Weekday morning and evening peak period If possible, screen crash reports for only crashes occurring in lane 1 or HOV lane.
	143.95	143.30	
	144.30	144.31	
	144.31	144.36	
	144.36	144.42	
	144.42	144.80	
	144.80	144.92	
	144.92	144.96	
	144.96	145.38	
Tunnel lighting, Light level differential at tunnel entries/exits	144.92	144.96	Weekday off-peak; 10:00 AM to 3:00 PM
	144.96	145.38	
	145.38	145.42	
WB Lane Drop West of 7th Ave Exit	144.42	144.80	Weekday morning and evening peak period
	144.80	144.92	
EB Lane Drop, East of 7th St Exit	145.42	144.52	Weekday morning and evening peak period
	145.52	145.78	
EB Lane Drop at Washington St	147.96	148.07	Weekday morning and evening peak period
	148.07	148.31	
WB Sky Harbor Blvd to Washington St	148.43	148.64	Weekday morning and evening peak period
	148.64	148.66	
WB, 16th St Entrance to 7th St Exit	145.82	145.94	Weekday morning peak period
	145.94	146.38	
	146.38	146.44	
	146.44	146.64	
EB 16th St to L202/SR-51	146.44	146.64	Weekday evening peak period
	146.64	147.76	
	146.76	146.85	
	146.85	146.89	
	146.89	146.93	
EB 35th Ave Entrance to 27th Ave Exit	141.92	142.42	Weekday morning peak period
WB 27th Ave Entrance to 35th Ave Exit	142.42	141.92	Weekday evening peak period

Tunnel Lighting (MP144.92 to MP145.52): In this segment, a total of 479 crashes occurred during 2012 and 2013, and 60 crash reports were reviewed. Several of the crash reports reviewed noted that sun glare (3 crashes) and lighting conditions (5 crashes) contributed to the crash. The noted lighting effect, combined with the horizontal roadway curvature, caused drivers to “drift” into an adjacent lane. Crashes caused by lane changing within the tunnel were noted on 38 crashes reports. Contributing crash factors appear to include: congestion, speed differential, lane changing, tunnel lighting, sun glare, and roadway horizontal curvature.

Westbound Lane Drop West of 7th Ave Exit, (MP144.42 to MP144.92): In this segment, a total of 188 crashes occurred during 2012 and 2013, and 18 crash reports were reviewed. This segment begins at the lane drop and ends at the left-side 5th Ave HOV entry ramp. The lane changing at the lane drop was noted for 6 crashes. Further investigation found that 22 out of 38 crashes occurred in lanes 4 and 5 (closest to the shoulder) in the lane drop influence area (200 feet upstream to 100 feet downstream of lane drop point), suggesting that the forced merge created by the lane drop contributed to 22 crashes. Congestion, speed differential, and the lane drop were contributing factors for these crashes.

Eastbound Lane Drop, East of 7th St Exit, (145.42 to MP145.78): In this segment, a total of 146 crashes occurred during 2012 and 2013, and 15 crash reports were reviewed. This segment begins at the lane drop starting 400 feet east of the tunnel and contains the merge area, and ends at the left-side 3rd St HOV on-ramp. In four crashes, traffic in lane 4 and lane 5 were involved in rear-end crashes attributed to congestion caused by merging traffic. Further analysis revealed that 14 out of 32 crashes occurred in lanes 4 and 5 in the lane drop influence area (200 feet upstream to 100 feet downstream of lane drop). Congestion, speed differential, and lane changing were contributing factors for these crashes. The forced merge at the lane drop is likely a contributing factor, particularly during high traffic periods.

Eastbound Lane Drop at Washington St, (MP147.97 to MP148.31): In this segment, a total of 37 crashes occurred during 2012 and 2013, and 21 crash reports were reviewed. The lane drop and congestion downstream were noted in four rear end crashes. Last minute merging vehicles at the lane drop were noted in three sideswipe crashes. Thirteen of the 21 crashes occurred in the right two lanes. Contributing crash factors appear to include: congestion, speed differential, and the lane drop.

Westbound, Sky Harbor Blvd to Washington St, (MP148.43 to MP148.66): In this segment, a total of 73 crashes occurred during 2012 and 2013, and 30 crash reports were reviewed. Lane changing was noted as the primary cause in 10 crashes and slowed/stopped traffic was noted as a contributing factor in 20 crashes. Sideswipe and rear end crashes were predominant. Of the 30 crashes, 20 occurred in the right two lanes. Contributing crash factors appear to include: speed differential, lane changing, and congestion.

Westbound, 16th St Entrance to 7th St Exit, (MP145.82 to MP146.64): In this weaving segment, a total of 261 crashes occurred during 2012 and 2013, and 40 crash reports were reviewed. There is an auxiliary lane from the 16th Street on-ramp that terminates at the 7th Street exit. Two lanes must exit at 7th Street. Higher speed traffic encountering slowed traffic was noted in 26 crashes. In 12 crashes, lane changing due to congestion resulted in rear-end and sideswipe collisions. Lane changing, congestion, and speed differential were contributing factors for the crashes.

Eastbound, 16th St to L202/SR-51, (MP146.44to MP146.93): In this weaving section, a total of 172 crashes occurred during 2012 and 2013, and 42 crash reports were reviewed. This segment contains a left-side HOV exit and right-side advance exit lanes for Loop 202 (two lanes) and one optional exit lane for SR-51. In 33 crashes reviewed, higher speed vehicles encounter slowing traffic and stop-and-go traffic which resulted in a rear-end crash. Weaving and lane changing was noted as a factor in 7 crashes. Congestion, speed differential, weaving, and lane changing were contributing factors for these crashes.

Eastbound 35th Ave Entrance to 27th Ave Exit, (MP141.92 to MP142.42): In this Type B weaving segment, a total of 189 crashes occurred during 2012 and 2013, and 28 crash reports were reviewed. Ten rear-end collisions noted stop-and-go conditions as a primary factor. Ten sideswipe crashes were attributed to lane changing in the weaving section. Contributing crash factors appear to include: congestion, speed differential, and lane changing.

Westbound 27th Ave Entrance to 35th Ave Exit (MP142.42 to MP141.92): In this Type A weaving segment with auxiliary lane, a total of 126 crashes occurred during 2012 and 2013, and 49 crash reports were reviewed. There is an additional lane drop just west of the WB 35th Avenue exit. Traffic entering I-10 from I-17 were noted in 8 rear-end and sideswipe crashes due to lane changing and congestion. Higher speed traffic encountering slowed traffic was noted in 39 crashes reviewed. Congestion, speed differential, lane changing, and merging traffic were contributing factors for these crashes.

Phase III Analysis – Fatal and Serious Injury Crashes

All reported fatal and serious injury crashes from 2012 to 2013 were reviewed as a part of this analysis. A detailed review of each fatal and serious injury crash is shown in Appendix F. Table 24 and Table 25 summarize the fatal and serious injury crashes. The crash reports provided for the analysis contain a very limited amount of information (no supplemental reports were provided for review); therefore, the possible contributing factors presented were based on information available coupled with engineering judgment and knowledge of the crash location.

Phase III Findings

The following section provides the diagnostic summary and a discussion on the contributing factors for fatal and serious injury crash reports reviewed.

Fatal crashes: No specific patterns or roadway geometry features were identified from the analysis of fatal crashes. Two out of six fatal crashes involved pedestrians, however due to a lack of information provided (no supplemental reports were provided) it was not possible to determine why the pedestrians were walking along or across the freeway. One fatal crash was related to a vehicle malfunction (wheel), two other fatal crashes involved single vehicles and one was a rear-end crash. Not including the two pedestrian fatalities, excessive speed, and potentially other driver related factors (e.g. older driver) were the primary contributing factors. Congestion and high speed contributed to one fatality.

Serious Injury (Type A) crashes: A total of 40 serious injury crashes occurred within the entire study section. Approximately half were related to congestion in combination with excessive speed. Twenty were rear end crashes, 9 were single vehicle crashes, 3 were sideswipe crashes, and 8 were angle/other/or unknown crashes. The remaining serious injury crashes occurred under uncongested conditions. The study segment with the highest number of serious injury crashes was westbound I-10 MP143.94 to MP 144.36 (between the 7th Ave on-ramp and the 19th Ave off-ramp). Some 18% of all serious injury crashes involved motorcyclists, with speed being a contributing factor. Two of the nine reported motorcycle serious injuries crashes occurred along the sweeping 90-degree curve. Approximately 20% of all serious injury crashes were single-vehicle crashes.

Table 24. Fatal crash information

Direction and Segment	Summary	Contributing Factors
Eastbound MP141.67 to MP141.92	Crash #2660116: Tractor-Trailer wheel failure	Vehicle: Yes Driver : No Roadway: No Environmental: No
Eastbound MP142.43 to M 142.71	Crash #2735405: Unknown. Single vehicle	Vehicle: No Driver: Unknown Roadway: No Environmental: No
Westbound MP144.42 to MP144.80	Crash #2595077: Pedestrian walking against traffic	Vehicle: No Pedestrian: Yes Roadway: No Environmental: No
Westbound MP145.94 to MP146.44	Crash # 2676135: Pedestrian crossing road. Alcohol involved	Vehicle: No Pedestrian: Yes Roadway: No Environmental: No
Westbound MP146.93 to MP147.52	Crash #2689544: Single vehicle, negotiating curve at 70 mph during rain, wet surface condition	Vehicle: No Driver: Yes Roadway: Yes Environmental: Yes
Westbound MP148.07 to MP148.31	Crash #2599442: Driver DOB: 1927. Rear-end crash. Speed too fast for conditions. Congestion present	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes

Table 25. Incapacitating injury (Type A) crash information

Direction and Segment	Summary	Contributing Factors
Eastbound MP141.94 to MP142.42	Total crashes occurred: 3 (2585023, 2622201, 2752470), Crash reports reviewed: 3. Rear-end crash, speed too fast for conditions, congestion. Rear-end crash, speed too fast for conditions, congestion. Object avoidance crash, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: No Environmental: NO Congestion: Yes
Eastbound MP142.42 to MP142.43	Total crashes occurred: 1 (2744192), Crash reports reviewed: 1. Rear-end, speed too fast for conditions, congestion.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Westbound MP142.42 to MP142.43	Total crashes occurred: 1 (2596917), Crash reports reviewed: 1. Single vehicle, motorcycle, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: No Environmental: No
Eastbound MP142.70 to MP142.71	Total crashes occurred: 2 (2595374, 2595773), Crash reports reviewed: 2. Rear-end, lane change, motorcyclist following too close, congestion, speed too fast for conditions. Rear-end, congestion, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Eastbound MP142.87 to MP142.99	Total crashes occurred: 1 (2579668), Crash reports reviewed: 1. Crash information unknown	Vehicle: No Driver: Unknown Roadway: No Environmental: Unknown
Westbound MP142.99 to MP143.67	Total crashes occurred: 1 (2715241), Crash reports reviewed: 1. Sideswipe. V1 entered HOV lane from lane 1. Speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: No Environmental: No
Eastbound MP143.67 to MP143.94	Total crash occurred: 1 (2585064), Crash reports reviewed - 1. Rear-end, speed too fast for conditions, congestion.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Westbound MP143.67 to MP143.94	Total crashes occurred: 1 (2596216), Crash reports reviewed - 1. Rear-end, speed too fast for conditions, congestion.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Westbound MP143.94 to MP144.36	Total crashes occurred: 6 (2583826, 2671728, 2689512, 2719871, 2757122, 2778115), Crash reports reviewed: 6. Rear-end, speed too fast for conditions, congestion. Single vehicle, alcohol. Single vehicle, fatigue/fell asleep. Motorcycle, speed too fast for conditions, congestion. Rear-end, driver distracted by police vehicle, congestion. Single vehicle (speed 85 mph).	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes

Direction and Segment	Summary	Contributing Factors
Eastbound MP144.42 to MP144.80	Total crashes occurred: 3 (2593799, 2648100, 2696715), Crash reports reviewed: 3. Sideswipe, unsafe passing. Angle, lane change from lane 1 into HOV, speed too fast for conditions, congestion. Single vehicle, motorcycle, speed too fast for conditions	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Westbound MP144.42 to MP144.80	Total crashes occurred: 1 (2665932), Crash reports reviewed: 1. Single Vehicle	Vehicle: No Driver: Yes Roadway: No Environmental: No
Eastbound MP144.80 to MP144.92	Total crashes occurred: 2 (2752349, 2762880), Crash reports reviewed: 2. Rear-end, congestion, speed too fast for conditions. Driver tried to avoid object, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Westbound MP144.80 to MP144.92	Total crashes occurred: 1 (2651125), Crash reports reviewed: 1. Rear-end, congestion, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Eastbound MP144.96 to MP145.42	Total crashes occurred: 2 (2624458, 2788793), Crash reports reviewed: 2. Rear-end, speed too fast for conditions, congestion. Rear-end, speed too fast for conditions, failed to remain in proper lane.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Westbound MP144.96 to MP145.42	Total crashes occurred: 2 (2585385, 2738892), Crash reports reviewed: 2. Rear-end, lane change, speed too fast for conditions. Rear-end, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Eastbound MP145.52 to MP145.78	Total crashes occurred: 1 (2768280), Crash reports reviewed: 1. Angle, avoiding object, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: No Environmental: No
Westbound MP145.84 to MP145.94	Total crashes occurred: 1 (2661954), Crash reports reviewed - 1. Rear-end, motorcycle, speed too fast for condition, congestion.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Eastbound MP146.44 to MP146.84	Total crashes occurred: 1 (2662051), Crash reports reviewed: 1. Rear-end, driver applied brake as well as gas, congestion.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes

Direction and Segment	Summary	Contributing Factors
Eastbound MP146.93 to MP147.52	Total crashes occurred: 2 (2595789, 2642347), Crash reports reviewed: 2. Rear-end, congestion, speed too fast for conditions. Single vehicle, motorcycle, negotiating curve, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: Yes Environmental: No Congestion: Yes
Westbound MP146.93 to MP147.52	Total crashes occurred: 1 (2638496), Crash reports reviewed: 1. Single vehicle, motorcycle, speed too fast for conditions (75 mph), negotiating curve.	Vehicle: No Driver: Yes Roadway: Yes Environmental: No
Westbound MP148.05 to MP148.31	Total crashes occurred: 1 (2638496), Crash reports reviewed: 1. Rear-end, congestion.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Eastbound MP148.42 to MP148.64	Total crashes occurred: 1 (2665404), Crash reports reviewed: 1. Sideswipe, rear-end, motorcycle, speed too fast for conditions, congestion.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Eastbound MP148.64 to MP149.14	Total crashes occurred: 1 (2665404), Crash reports reviewed: 1. Rear-end, speed too fast for conditions, congestion.	Vehicle: No Driver: Yes Roadway: No Environmental: No Congestion: Yes
Westbound MP148.64 to MP149.14	Total crashes occurred: 2 (2706271, 2719776), Crash reports reviewed: 2. Rear-end, congestion, speed too fast for conditions, right lane ends, congestion. Single vehicle, motorcycle, speed too fast for conditions.	Vehicle: No Driver: Yes Roadway: Yes Environmental: No Congestion: Yes

POTENTIAL COUNTERMEASURES

Based on the detailed review and analysis of observed crashes within the study section, potential countermeasures were identified. Considering that speed and congestion were contributing factors in approximately 57% of all crashes occurring within the study section in 2012 and 2013, half of the serious injury crashes, and were noted on the majority of crash reports reviewed, countermeasures intended to address these factors were primarily considered. Countermeasures to address crash issues at specific hotspots, including lane drops, weaving areas, and HOV access were also identified and evaluated. Detailed evaluations of potential countermeasures to estimate their potential effect on reducing crashes, and their benefit/cost were conducted. The countermeasure evaluation results are discussed below.

CRASH REDUCTION BENEFIT

The benefit, or reduced crash costs associated with each countermeasure was estimated for the expected crashes over a 20 year period. The expected crashes occurring in each study section segment were calculated using the calibrated freeway crash prediction models, based on 20-year traffic volume projections provided from the MAG regional traffic forecasting model. Crashes by severity type (K, A, B, C, PDO) were calculated using the crash severity distribution factor calibrated for Phoenix freeways. However, in reviewing the expected number of fatal (K) crashes relative to the crashes observed in 2012 and 2013, there was concern that the expected number of fatal crashes was potentially high when considering the effect of a fatal crash in the benefit/cost analysis. In the observed 2012-2013 crashes, six fatal crashes occurred (Table 24), two of which were pedestrians and one was a vehicle mechanical failure in which a wheel broke free from a truck and caused the fatal crash.

Since only three of the observed fatal crashes could realistically be affected by the range of countermeasures considered, it was determined that the proportion of fatal crashes in the expected crashes should be reduced. The adjusted crash severity distribution applied for the cost benefit analysis is provided in Table 26. The number of expected fatal crashes per year was reduced from 11.5 to 4, while the number of incapacitating injury crashes (A) and non-incapacitating injury crashes (B) were increased so that the total number of crashes remained unchanged.

Crash benefit costs were calculated using the cost factors provided in the ADOT HSIP manual and in Table 27. Note the these cost factors only account for costs associated with the crash itself and do not reflect the additional cost benefit that may be incurred due to reduction in secondary crashes and in congestion caused by crashes.

Table 26. Crash Severity Distribution Used for Benefit/Cost Analysis

	Expected Crashes Per Year based on Calibrated Crash Severity Distribution					
	K	**A**	**B**	**C**	**PDO**	**Total**
Number of Crashes	11.5	27.6	140.8	257.3	1231.3	1718.4
Proportion	0.0067	0.0161	0.0819	0.1497	0.7165	1.0000
Number of Crashes -Adjusted	4.0	30.1	145.0	257.3	1231.3	1718.4
Proportion - Adjusted	0.0023	0.0175	0.0844	0.1497	0.7165	1.0000

Table 27. ADOT Crash Cost Factors

Crash Severity	Comprehensive Cost (2)
K, Fatal	$5,800,000
A, Incapacitating Injury	$400,000
B, Non-incapacitating injury	$80,000
C, Possible injury	$42,000
PDO	$4,000

LOWER SPEED LIMIT

Description

Lower the speed limit on I-10 from 65 to 55 mph. The reduced speed limit zone could include just the study section, 35th Ave to Sky Harbor Blvd, or might extend further east and west. Continual speed enforcement emphasis will be an integral part of this countermeasure to produce the desired reduction in operating speeds. This section of I-10 could be designated as a "Safety Corridor", with enhanced focus by ADOT and DPS.

Potential Crash Reduction

The Highway Safety Manual (Chapter 3, Table 3E-2) provides CMFs for changes in average operating speed. Crash reduction varies depending upon the initial average operating speed and the speed reduction achieved, ranging from -1 to -5 mph. Separate CMFs are provided for fatal crashes and injury crashes. No CMFs are provided for property damage only crashes. Since the effect of reducing the speed limit from 65 to 55 mph on lowering operating speed can vary, the crash reduction analysis performed for this study considered a range, from -2 to -4 mph.

The speed data collected for this study indicates the average operating speed on I-10 under uncongested conditions is essentially at the 65 mph posted speed limit. The 85th percentile speed is closer to 70 mph. Therefore, based on a 65 mph average operating speed, the expected reductions in fatal and injury crashes using the CMFs provided in the HSM are listed in Table 28.

Table 28. Crash Modification Factors for Reduction in Operating Speed [1,2]

Reduction in Average Operating Speed	Fatal Crashes		Injury Crashes	
	CMF	CRF	CMF	CRF
-4 mph	0.70	-0.30	0.81	-0.19
-3 mph	0.77	-0.23	0.86	-0.14
-2 mph	0.84	-0.16	0.90	-0.10

Source: Highway Safety Manuel, Chapter 3, Table 3E-2.
CMFs for 65 mph interpolated from 60 mph and 70 mph factors.

Applying the crash reduction factors from Table 28 to the expected fatal and injury crashes over a 20 year period on the entire I-10 study section produces estimated crash reductions listed in Table 29.

Table 29 . Estimated Reduced Crashes over 20 years on I-10 Study Section Resulting from Lowered Speed Limit

Effect of Lowered Speed Limit on Average Operating Speed	Fatal Crashes (K)		Serious Injury Crashes (A)		Non-serious Injury Crashes (B)		Possible Injury Crashes (C)		PDO Crashes	
	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced
-4 mph	88.4	26.5	667.3	126.8	4340.8	824.7	5702.6	1083.5	28087.4	-
-3 mph	88.4	20.3	667.3	93.4	4340.8	607.7	5702.6	798.4	28087.4	-
-2 mph	88.4	14.1	667.3	66.7	4340.8	434.1	5702.6	570.3	28087.4	-

Potential Crash Reduction Benefit/Cost

The estimated benefit value of the reduction in K, A,and B crashes is presented in Table 30. Note that higher benefit is expected if possible injury and PDO crashes are also considered.

Estimating the cost of achieving a lower average operating speed is difficult as the greatest proportion of the cost will be in added enforcement. The cost of changing the speed limit signing is negligible, however the cost of additional DPS officers and equipment can be substantial. Assuming enforcement costs of $1 million/yr, Table 31 presents the B/C ratios. Two scenarios are included in the analysis, the first considering crashes occurring during both congested and non-congested periods, and the second assuming that lowered operating speeds would only be achieved during non-congested conditions.

Table 30. Estimated 20-yr Benefit Value of Reduced K, A, & B Crashes Resulting from Lowered Speed Limit

Effect of Lowered Speed Limit on Average Operating Speed	Fatal Crashes (K)	Serious Injury Crashes (A)	Non-serious Injury Crashes (B)	Total	
				K+A+B	K+A
-4 mph	$153,786,714	$50,712,994	$65,979,942	$270,479,650	$204,499,708
-3 mph	$117,903,148	$37,367,470	$48,616,800	$203,887,418	$155,270,618
-2 mph	$82,019,580	$26,691,050	$34,726,286	$143,436,916	$108,710,630

Crash cost factors from ADOT Highway Safety Improvement Program Manual, March 2010

Based on the distribution of observed crashes by time-of-day, it is estimated that 30% of expected crashes within the study section occur during non-congested conditions. The results show that even when considering only non-congested periods, reducing the operating speed will be a cost effective crash countermeasure.

Table 31. 20-yr B/C Analysis of Lowered Speed Limit

Reduced Operating Speed	Total Const. Cost	Annual Const. Cost (CRF x Total Const Cost) (1)	Change in Annual O & M Cost	Total Annual Cost	Annual Benefit		B/C	
					K+A+B	K+A	K+A+B	K+A
All Expected Crashes								
-4 mph	$50,000	$5,095	$1,000,000	$1,005,095	$13,523,983	$10,224,985	13.46	10.17
-3 mph	$50,000	$5,095	$1,000,000	$1,005,095	$10,194,371	$7,763,531	10.14	7.72
-2 mph	$50,000	$5,095	$1,000,000	$1,005,095	$7,171,846	$5,435,532	7.14	5.41
Expected Crashes Occurring During Non-congested Periods Only								
-4 mph	$50,000	$5,095	$1,000,000	$1,005,095	$4,057,195	$3,067,496	4.04	3.05
-3 mph	$50,000	$5,095	$1,000,000	$1,005,095	$3,058,311	$2,329,059	3.04	2.32
-2 mph	$50,000	$5,095	$1,000,000	$1,005,095	$2,151,554	$1,630,659	2.14	1.62

CRF =0.1019; 20 yrs at 8% interest; ADOT HSIP Manual, 2010

VARIABLE SPEED LIMIT SYSTEM

Description

Variable speed limit (VSL) systems have been widely used around the world to improve safety and operational efficiency on congested highways. The principle behind VSL systems is to post a speed limit that is appropriate for current conditions considering time dependent freeway traffic demand, speed profile and/or special conditions like adverse weather and incidents. This provides an opportunity to warn drivers of downstream conditions, reduce speed, decrease headways and encourage more uniform flow. VSL has the capability of increasing safety by reducing both primary and secondary crashes. It can also reduce congestion, travel time, and emissions. VSL systems have been one of the most heavily researched Active Traffic Management (ATM) techniques, and deployments have occurred in the U.S. and internationally. Recently several state DOTs in the United States including Florida DOT, Caltrans, Washington DOT, Minnesota DOT, Virginia DOT, Missouri DOT, Utah DOT, and Colorado DOT have implemented VSL systems. A literature review of VSL systems around the world was conducted and a summary is provided in Appendix G.

Figure 17. VSL System in Seattle, WA

Relative to the I-10 Study Section, the application of VSL would primarily be intended to reduce operating speeds during peak traffic periods when high traffic volumes produce congestion and when the majority (70%) of crashes occur. In addition to reducing primary and secondary crashes, an ancillary effect would be improved traffic flow with stop-and-go conditions occurring less frequently. Similar to reducing the posted speed limit, the success of a VSL system will also require emphasis on speed enforcement. However, heightened enforcement would only be required during peak traffic periods. As such, the potential application of automated enforcement or some hybrid of automated detection with manual enforcement during these periods within a limited section of I-10 might be an effective alternative.

Potential Crash Reduction

A recent (2008) application and evaluation of a VSL system installed on an interstate freeway in Missouri (Ref. 7) produced a high quality (four star) CMF included in the FHWA CMF Clearinghouse. The evaluation found that while the VSL is not providing the desired improvement in overall mobility along the freeway corridor, noticeable benefits have been seen with respect to reduction in the number of crashes. The evaluation determined that all crashes decreased 8% with the VSL system in operation.

Evaluations of other systems installed internationally and in the U.S. have provided additional information relative to the potential benefit of a VSL system. The following benefits have been reported in different published research documents:

- Increase in average congested period throughput – 3% to 7%
- Increase in overall capacity – 3% to 22%
- Decrease in primary incidents – 3% to 30%
- Decrease in secondary incidents – 40% to 50%

Applying the CMF from the CMF Clearinghouse to the expected crashes (all crash types) over a 20 year period on the entire I-10 study section produces estimated crash reductions listed in Table 32. The CMF was applied to all crashes and to those crashes occurring during peak traffic periods (6:00 – 10:00 a.m. and 3:00 to 7:00 pm) when approximately 70% of observed crashes occurred.

Potential Crash Reduction Benefit/Cost

The estimated benefit value of the reduction in all crashes and in fatal and serious injury crashes only is presented in Table 33.

Table 32. Estimated Reduced Crashes over 20 years on I-10 Study Section Resulting from a VSL System

	Fatal Crashes (K)		Serious Injury Crashes (A)		Non-serious Injury Crashes (B)		Possible Injury Crashes (C)		PDO Crashes	
	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced
All Crashes	88.4	7.1	667.3	53.4	4340.8	347.3	5702.6	456.2	28087.4	2247.0
Peak Traffic Period Crashes	61.9	4.9	467.1	37.4	3038.5	243.1	3991.8	319.3	19661.2	1572.9

Table 33. Estimated 20-yr Benefit Value of Reduced Crashes Resulting from a VSL System

	Fatal Crashes (K)	Serious Injury Crashes (A)	Non-serious Injury Crashes (B)	Possible Injury Crashes (C)	PDO Crashes	Total	
						All Crash Severities	K+A
All Crashes	$41,009,790	$21,352,840	$27,781,028	$19,160,756	$8,987,966	$118,292,380	$62,362,630
Peak Traffic Period Crashes	$28,706,854	$14,946,988	$19,446,720	$13,412,530	$6,291,576	$82,804,668	$43,653,842

Crash cost factors from ADOT Highway Safety Improvement Program Manual, March 2010

A planning level cost estimate for implementing a VSL system within the I-10 study section was prepared. This estimate represents implementation of a VSL system from just east of the I-17 TI to the L202/SR51 TI. However, a broader application of a VSL system, potentially from 35th Ave to Sky Harbor Blvd can be considered. It may also be appropriate to extend a VSL system east on L202 and north on SR51 as well. Five-year (2009-2013) crash data reviewed for the I-10/I-17 Master Plan (Spine Study) indicate high crash rates on segments in the vicinity of system interchanges, which is observed in this I-10 safety study.

The detailed cost estimate, provided in Appendix H reflects a VSL that includes 12 VSL sign structures and necessary control and communications equipment to operate the system as part of the regional FMS. The estimated implementation cost of the system is roughly $8.2 million or $2.7 million/mile. The electrical cost for the VSL was estimated at $12,500/yr in the update to the tunnel lighting study (3). Assuming an annual maintenance costs of $20,000/yr and $500,000 of annual enforcement costs, the B/C analysis is summarized in Table 34.

Table 34. 20-yr B/C Analysis of VSL System

	Total Const. Cost	Annual Const. Cost (CRF x Total Const Cost) (1)	Change in Annual O & M Cost	Total Annual Cost	Annual Benefit		B/C	
					All Crash Severities	K+A	All Crash Severities	K+A
All Crashes	$8,200,000	$835,580	$532,500	$1,368,080	$4,507,183	$3,118,132	3.29	2.28
Peak Traffic Period Crashes	$8,200,000	$835,580	$532,500	$1,368,080	$3,155,028	$2,182,692	2.31	1.60

CRF =0.1019; 20 yrs at 8% interest; ADOT HSIP Manual, 2010

AUTOMATED SPEED ENFORCEMENT

Description

Automated speed enforcement has been shown to be an effective safety countermeasure on roadways of all types. While public perception of the use of these systems is often negative for several reasons, including the increased number of citations that result, they are viewed as revenue generators, and since in the United States, they are typically installed and operated by private companies, their application on selected roadway segments, such as the I-10 Study section, where it is highly desirable to lower operating speed to reduce crashes could prove more acceptable. Automated enforcement could be installed in conjunction with a variable speed limit system to produce greater compliance during peak traffic periods when crash potential is highest.

Potential Crash Reduction

The Highway Safety Manual (Chapter 17, Table 17-5) provides a very high quality CMF for the potential crash effect of automated speed enforcement. The CMF is 0.83 with a standard error of 0.01. The CMF reflects the effect on fatal and injury crashes only. Applying the Highway Safety Manual CMF to the expected fatal and injury crashes over a 10 year period on the entire I-10 study section produces estimated crash reductions listed in Table 35. The CMF used was 0.83, or a 17% reduction in crashes.

Table 35. Estimated Reduced Crashes over 20 years on I-10 Study Section Resulting from an Automated Speed Enforcement System

	Fatal Crashes (K)		Serious Injury Crashes (A)		Non-serious Injury Crashes (B)		Possible Injury Crashes (C)		PDO Crashes	
	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced
All Crashes	88.4	15.0	667.3	113.4	4340.8	737.9	5702.6	969.4	28087.4	-

Potential Crash Reduction Benefit/Cost

The estimated benefit value of the reduction in all injury crashes is presented in Table 36. As the cost of installing, operating, and maintaining an automated speed enforcement system within the study section is unknown, a B/C analysis was not prepared.

Table 36. Estimated 20-yr Benefit Value of Reduced Crashes Resulting from an Automated Speed Enforcement System

	Fatal Crashes (K)	Serious Injury Crashes (A)	Non-serious Injury Crashes (B)	Possible Injury Crashes (C)	PDO Crashes	Total	
						All Injury Crashes K+A+B	K+A
All Crashes	$87,145,804	$45,374,784	$59,034,686	$40,716,608	-	$191,555,274	$132,520,588

Crash cost factors from ADOT Highway Safety Improvement Program Manual, March 2010

UPGRADE TUNNEL LIGHTING

Description

Based on an evaluation of crash frequency within the Deck Park Tunnel relative to adjacent segments and information provided by the crash reports reviewed, several conditions within the tunnel segment appear to be contributing factors to the high crash frequency observed in the 2012 and 2013 crash data. The data suggests that two lighting issues are occurring. First, the difference between the day-time ambient illumination level outside of the tunnel and the illumination level at the tunnel portals, or threshold zones, is affecting drivers vision as their eyes adjust. Second, as noted in the Deck Park Tunnel Energy Efficiency Study (Ref. 9) the illumination levels within the tunnel do not meet current IES recommendations for tunnel lighting. At the tunnel threshold zones (entrances), the measured illumination levels are below the original design levels. The effects of age and environment on the

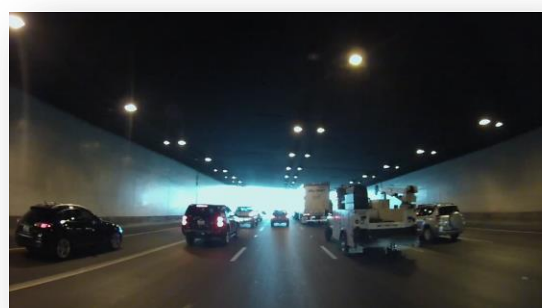


Figure 18. Westbound Tunnel in the Afternoon

luminaires reduce lumen output and resulting illumination levels achieved. To reduce the safety effects of these two issues, the tunnel lighting system will need to be upgraded. A range of options exist, however the primary improvement would be to upgrade the existing system to meet current IES recommended practice for tunnel lighting levels.

The upgrade would replace the current HPS fixtures with fixtures that provide greater lumen output, either HPS or LED. The LED option offers greater efficiency (i.e. more lumens per watt) and the ability to dim the lighting in the tunnel transition areas depending on the ambient illumination levels. With LED, the lighting could also be efficiently dimmed based on changes in daytime ambient light levels and variable speed. The IES standard changes based on posted speed limit.

Several traffic issues within the tunnel are also likely contributing to the high expected crash frequency. These include lane changing associated with the 7th St and 7th Ave entry and exit ramps in close proximity to the tunnel portals and unexpected queueing that typically occurs within the tunnel during peak periods. Reducing the lane changing activity during peak traffic periods could be achieved by metering the eastbound 7th Ave and westbound 7th St entry ramps. The potential benefit of metering is described as a separate countermeasure.

Finally, the horizontal curve within the tunnel is likely also contributing to the crash frequency. A potential countermeasure for this geometric condition is to reduce vehicle operating speeds through the tunnel. The benefit of reduced operating speed was previously discussed.

Potential Crash Reduction

CMFs for tunnel lighting are not available and no studies were identified that might provide information to estimate the potential crash reduction associated with tunnel lighting. To quantify the potential effect of tunnel presence (with the existing illumination design) on safety performance, the expected crash frequency within the tunnel was compared with the frequency in the adjacent freeway segments. As these segments have essentially the same roadway characteristics (lane and shoulder width, HOV lanes, median and shoulder barrier, roadway curvature, grade) and traffic conditions, a significant difference in crash frequency could be attributed to the five issues previously identified. However, rather than simply compare the expected crash frequencies, the“Excess”expected crash frequencies within these segments were compared. When the expected crash frequency exceeds the predicted crash frequency, the difference is called excess expected crashes. These excess crashes reflect the effect of unknown factors or a combination of factors that are not included in the predictive methodology.

The tunnel and adjacent segments all exhibit high excess expected crash values. A comparison of the “Excess” statistics for the segments before and after the tunnel exhibit shows a similar large number of excess crashes. The high excess values extending from MP 144.42 to 145.82 are provided in Table 37. Note that the lower crash rate in the segment beginning at MP 144.92 is likely a crash reporting error, with crashes incorrectly located in the adjacent segment beginning at MP 144.80.

Table 37. Excess Expected Average Crashes in Tunnel and Adjacent Segments

	Segment Begin MP						
	144.42	144.80	144.92	144.96 (tunnel)	145.42	145.52	145.78
Excess Expected Average Crashes per mile per year	219.9	368.4	36.8	269.2	161.6	215.5	136.9

The average excess for the segments adjacent to the tunnel is 220 total crashes/mile (excluding the tunnel segment). The tunnel has an excess of 269 total crashes/mile. Thus, the tunnel segment has about 22% (= 100 [269/220 -1], more excess crashes than the average segment in this area. This data infers that the tunnel with the existing illumination design may be contributing to a 22% increase in crashes, relative to the neighboring segments. This amounts to nearly 49 crashes per year or 38 crashes if only daytime crashes are considered.

Table 38 lists the crash reduction that could potentially occur over 20 years with upgraded tunnel lighting.

Table 38. Estimated Reduced Crashes over 20 years on I-10 Study Section Resulting from Upgraded Tunnel Lighting

	Fatal Crashes (K)		Serious Injury Crashes (A)		Non-serious Injury Crashes (B)		Possible Injury Crashes (C)		PDO Crashes	
	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced
All Excess Tunnel Crashes (49/yr)	21.7	1.9	52.2	14.2	374.4	96.0	676.8	169.4	3400.6	850.9
Daylight Excess Tunnel Crashes (38/yr)	21.7	1.4	52.2	10.8	374.4	73.0	676.8	128.7	3400.6	646.7

Potential Crash Reduction Benefit/Cost

The estimated benefit value of the reduction in all crashes and in fatal and serious injury crashes only is presented in Table 39. Note that these values assume that all of the excess expected crashes will be affected by improved tunnel lighting. Practically, it is more likely that some portion of the excess expected crashes would be eliminated.

The Deck Park Tunnel Energy Efficiency Study offered several lighting upgrade options, however the LED option is preferred. Several LED lighting design alternatives can be considered, including designing for a constant speed limit (55, 60, 65 mph) or for a variable speed limit. Since it is unknown if the crash reduction effects of the upgrade tunnel lighting and the VSL system can be combined, only the tunnel lighting upgrade to was included in the B/C analysis. The lighting upgrade was assumed to provide illumination levels required for a 65 mph posted speed limit and will have dimming capabilities.

Table 39. Estimated 20-yr Benefit Value of Reduced Crashes Resulting from Upgraded Tunnel Lighting

	Fatal Crashes (K)	Serious Injury Crashes (A)	Non-serious Injury Crashes (B)	Possible Injury Crashes (C)	PDO Crashes	Total	
						All Crash Severities	K+A
All Excess Tunnel Crashes (49/yr)	$10,957,418	$5,699,100	$7,682,524	$7,112,876	$3,403,571	$34,855,489	$16,656,518
Daylight Excess Tunnel Crashes (38/yr)	$8,327,638	$4,331,316	$5,838,718	$5,405,786	$2,586,714	$26,490,172	$12,658,954

Crash cost factors from ADOT Highway Safety Improvement Program Manual, March 2010

The tunnel energy efficiency study estimated the construction cost for an LED upgrade at $20,055,000. Annual maintenance costs are estimated at $43,000 and electrical costs are estimated to be $327,000, approximately $8,000 lower than current electrical costs with the HPS system. Table 40 presents the benefit/cost ratios for the tunnel lighting upgrade. Note that the annual electrical savings is included as a benefit with the value of the crash reduction benefit.

Table 40. 20-yr B/C Analysis of Upgraded Tunnel Lighting

Crash Redcuction	Total Const. Cost	Annual Const. Cost (CRF x Total Const Cost) (1)	Change in Annual O & M Cost	Total Annual Cost	Annual Benefit		B/C	
					All Crashes	K+A	All Crashes	K+A
All Excess Tunnel Crashes (49/yr)	$20,055,840	$2,043,690	$35,298	$2,078,988	$1,742,774	$832,826	0.84	0.40
Daylight Excess Tunnel Crashes (38/yr)	$20,055,840	$2,043,690	$35,298	$2,078,988	$1,324,509	$632,948	0.64	0.30

1. *CRF =0.1019; 20 yrs at 8% interest; ADOT HSIP Manual, 2010*

ELIMINATE LANE DROPS

Description

There are three lane drops within the study section, EB at 7^{th} St, WB at 7^{th} Ave, and EB at Washington St. Review of the crash data and sample reports for each segment indicated that the lane drops at 7^{th} St and 7^{th} Ave contribute to the observed crash frequency, particularly during peak traffic periods. In the 7^{th} St lane drop segment, 146 EB crashes occurred in 2012 and 2013, while 188 WB crashes occurred in the 7^{th} Ave lane drop segment. In the Washington St lane drop segment, 37 crashes occurred over

Figure 19. Westbound Lane Drop West of 7th Ave Exit; Note queuing in right two lanes

this 2-year period. In addition to contributing to crashes due to added lane changing, the lane drops also contribute to congestion which is a primary factor in crashes occurring within the study section. The estimated expected crash frequencies in both the 7th St and 7th Ave lane drop segments are well above the value for a typical urban freeway segment in Phoenix and corresponding high Z-scores indicate that there is substantial potential to reduce crashes in these segments. The potential for crash reduction in the Washington St lane drop section is much lower.

Eliminating the 7th St and 7th Ave lane drops can be achieved by either extending the lane to the downstream entry ramp or dropping the lane at the upstream exit ramp. In both cases, extending the lane will change a lane add configuration into a merge configuration with a speed-change lane at the downstream entry ramp. An important advantage of extending the lane over dropping it at the upstream exit is that this improvement would provide additional through lane capacity in addition to eliminating a forced merge. The potential capacity impacts associated with changing the downstream lane add to a merge will need to be evaluated for each location.

Potential Crash Reduction

A CMF for eliminating a lane drop is not available. The potential crash reduction of eliminating the 7th St and 7th Ave lane drops was estimated using the crash prediction methodology and the ISATe analysis tool developed for the study. Extending each lane will affect three conditions that influence crash potential and which can be analyzed using the predictive methodology: 1) eliminate the forced merge, 2) change the downstream lane add to a speed-change lane, and 3) add a through lane to the downstream segment. Forcing the lane off at the upstream exit can also be evaluated using the predictive method. While both options can be evaluated using the predictive method the potential effect that either option will have on reducing congestion related crashes is not readily captured Table 41 summarizes the estimated potential effect on crashes of each lane drop option. Note that at 7th Ave, dropping the lane at the upstream exit will potentially result in higher expected crashes (a negative reduction in crashes). However, at 7th St, the lane drop option produces a higher reduction in crashes than extending the lane.

Potential Crash Reduction Benefit/Cost

Table 42 provides the estimated benefit value of eliminating the 7th St and 7th Ave lane drops. For 7th St, both options are provided. The benefit/cost analysis is summarized in Table 43. Detailed cost estimates to extend the lanes to the downstream on-ramp are included in Appendix H. These estimates assume that the roadway will need to be widened to extend the lanes and convert the lane add configuration at the downstream ramp to a speed-change lane.

Table 41. Estimated Reduced Crashes over 20 years on I-10 Study Section Resulting from Eliminating Lane Drops

	Fatal Crashes (K)		Serious Injury Crashes (A)		Non-serious Injury Crashes (B)		Possible Injury Crashes (C)		PDO Crashes	
	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced
Extend Lane to Downstream Entry Ramp										
WB Lane Drop at 7th Ave	6.9	0.2	48.2	1.5	305.4	9.5	298.0	7.6	1871.3	46.5
EB Lane Drop at 7th St	3.5	0.1	25.8	0.8	166.9	4.9	257.9	7.6	1390.5	29.8
Drop Lane at Upstream Exit Ramp										
WB Lane Drop at 7th Ave	6.9	0.0	48.2	-0.6	305.4	-4.3	298.0	-1.8	1871.3	-7.2
EB Lane Drop at 7th St	3.5	0.2	25.8	1.2	166.9	8.1	257.9	14.8	1390.5	28.0

Restriping of the mainline to utilize existing inside and outside shoulders to add the lane would be a substantially lower cost and would produce higher B/C ratios, however it is not preferred since it would significantly reduce the shoulder width and impact the left-side HOV ramp merge gore areas. Reducing the shoulder width will increase crash potential since there is a continuous median barrier and would eliminate shoulder width used by disabled vehicles and enforcement. The estimated construction cost for dropping the 7th St lane at the upstream exit is roughly assumed to be $500,000, although it could be lower. While the benefit/cost results based on estimated crash reduction do not necessarily support this countermeasure, it is again important to note that additional crash reduction will likely be achieved due to reduced congestion.

Table 42. Estimated 20-yr Benefit Value of Reduced Crashes Resulting from Eliminating Lane Drops

	Fatal Crashes (K)	Serious Injury Crashes (A)	Non-serious Injury Crashes (B)	Possible Injury Crashes (C)	PDO Crashes	Total	
						All Crash Severities	K+A
Extend Lane to Downstream On-Ramp							
WB Lane Drop at 7th Ave	$1,227,888	$596,748	$759,458	$320,220	$185,800	$3,090,114	$1,824,636
EB Lane Drop at 7th St	$576,606	$302,318	$390,286	$320,220	$119,284	$1,708,714	$878,924
Drop Lane at Upstream Exit Ramp							
EB Lane Drop at 7th St	$899,654	$470,628	$648,014	$621,262	$111,974	$2,751,532	$1,370,282

Crash cost factors from ADOT Highway Safety Improvement Program Manual, March 2010

Table 43. 20-yr B/C Analysis of Eliminating Lane Drops

	Total Const. Cost	Annual Const. Cost (CRF x Total Const Cost) (1)	Change in Annual O & M Cost	Total Annual Cost	Annual Benefit		B/C	
					All Crash Severities	K+A	All Crash Severities	K+A
Extend Lane to Downstream On-Ramp								
WB Lane Drop at 7th Ave	$1,500,000	$152,850	$1,000	$153,850	$158,067	$91,232	1.03	0.59
EB Lane Drop at 7th St	$1,400,000	$142,660	$1,000	$143,660	$85,436	$43,946	0.59	0.31
Drop Lane at Upstream Exit Ramp								
EB Lane Drop at 7th St	$500,000	$50,950	$1,000	$51,950	$137,577	$68,514	2.65	1.32

1. *CRF =0.1019; 20 yrs at 8% interest; ADOT HSIP Manual, 2010*

Meter EB 7th Ave and WB 7th Street Entry Ramps

Description

The EB 7th Ave and WB 7th St entry ramps are unmetered. Although auxiliary lanes are in place, heavy traffic volumes entering the tunnel from these ramps creates substantial lane changing within the weaving section in the Deck Park Tunnel which has a fairly high observed and expected crash frequency relative to typical freeway segments in the urban Phoenix area. Based on 2012 and 2013 crash data, 116 crashes/yr occurred in the eastbound direction and 123 crashes/yr in the westbound direction within the tunnel. Metering of the heavy on-ramp traffic during peak periods could reduce crashes within the tunnel.

Potential Crash Reduction

A CMF of moderate quality is available from the FHWA Clearinghouse. The CMF is based on a study conducted in 2013 which looked at the effect of installing ramp metering on 19 ramps in Northern California (Ref.8). The study found that freeway collisions in the vicinity of the ramp speed-change lane were 36% lower with ramp metering in place. The study noted that PDO crashes were primarily affected.

The results of the safety performance evaluation conducted for this study using the calibrated crash prediction model and diagnostic analysis indicates that lane changing is a primary factor contributing to the observed and expected crash frequency within the tunnel. The calculated CMF that reflects the effect of lane changing on crash frequency within the tunnel is nearly 1.7 for fatal and injury crashes and 1.5 for PDO crashes, indicating a substantial effect.

While we are unable to estimate the specific effect that metering of these two ramps will have on crash reduction, it is reasonable to consider modest reductions in crashes (i.e. 5 to 15%) in order to assess the potential benefit. Based on current observations 56% of crashes within the tunnel occur during the morning (7:00 to 9:00 am)and evening (3:00 – 6:00 pm) peak periods during which metering would operate. The estimated reduction in expected peak period crashes over 20 yrs with metering of these two ramps is presented in Table 44 for several scenarios.

Table 44. Estimated Reduced Crashes over 20 years Resulting from Metering the EB 7th Ave and WB 7th St On-ramps

Peak Period Crash Reduction (1)	Fatal Crashes (K)		Serious Injury Crashes (A)		Non-serious Injury Crashes (B)		Possible Injury Crashes (C)		PDO Crashes	
	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced	Total	Reduced
5%	4.2	0.2	31.9	1.6	214.9	10.7	379.0	19.0	1904.3	95.2
10%	4.2	0.4	31.9	3.2	214.9	21.5	379.0	37.9	1904.3	190.4
15%	4.2	0.6	31.9	4.8	214.9	32.2	379.0	56.9	1904.3	285.6

1. *Based on 56% of crashes occurring during peak periods when metering typically operates.*

The estimated benefit value of the reduction in all crashes and in fatal and serious injury crashes only is presented in Table 45. Table 46 presents the benefit/cost ratios for metering these ramps. The construction cost for adding meters is estimated at $250,000 per ramp, which does not include improvements that might be required at the cross street ramp terminals to add storage for additional queueing.

Table 45. Estimated 20-yr Benefit Value of Reduced Crashes Resulting from Metering the EB 7th Ave and WB 7th St On-ramps

Peak Period Crash Reduction (1)	Fatal Crashes (K)	Serious Injury Crashes (A)	Non-serious Injury Crashes (B)	Possible Injury Crashes (C)	PDO Crashes	Total	
						All Crash Severities	K+A
5%	$1,226,158	$637,740	$859,690	$795,946	$380,866	$3,900,400	$1,863,898
10%	$2,452,316	$1,275,482	$1,719,380	$1,591,892	$761,734	$7,800,804	$3,727,798
15%	$3,678,474	$1,913,222	$2,579,070	$2,387,836	$1,142,600	$11,701,202	$5,591,696

1. *Based on 56% of crashes occurring during peak periods when metering typically operates.*
2. *Crash cost factors from ADOT Highway Safety Improvement Program Manual, March 2010*

Table 46. 20-yr B/C Analysis of Metering the EB 7th Ave and WB 7th St On-ramps

Peak Period Crash Reduction (1)	Total Const(2). Cost	Annual Const. Cost (CRF x Total Const Cost) (1)	Change in Annual O & M Cost	Total Annual Cost	Annual Benefit		B/C	
					All Crash Severities	K+A	All Crash Severities	K+A
5%	$500,000	$50,950	$1,000	$51,950	$195,020	$93,195	3.75	1.79
10%	$500,000	$50,950	$1,000	$51,950	$390,040	$186,390	7.51	3.59
15%	$500,000	$50,950	$1,000	$51,950	$585,060	$279,585	11.26	5.38

1. *CRF =0.1019; 20 yrs at 8% interest; ADOT HSIP Manual, 2010*
2. *Construction cost reflects the cost for installing two ramp meters with connection to the FMS. It does not include costs for improvements to the cross streets that may be needed to provide queue storage.*

RESTRICT HOV LANE ACCESS

Description

The crash analysis revealed that approximately 60% of the crashes that occurred between lane 1 and the HOV lane in 2012 and 2013 involved single occupancy vehicles entered the HOV lane, typically when the general purpose lanes were congested. Crashes in the HOV lanes typically involved higher speed vehicles traveling in the HOV lanes colliding with lower speed vehicles entering the HOV lane. Several countermeasures to address crashes occurring between the interaction of the HOV lane and Lane 1 can be considered.

Increased enforcement of the HOV lanes, particularly during peak traffic periods would reduce the potential of single occupant vehicles jumping into the HOV lane to avoid congestion. The increased enforcement could be achieved using additional DPS patrols within the corridor during peak traffic periods. Increased fines for HOV violations with appropriate signing placed along the HOV lanes may also lower violations.

Restricting HOV lane access to all vehicles using striping (double yellow lines) and signing, as is done in California, may also reduce HOV related crashes. The restrictions could be placed on a limited section of the HOV lanes within the study section, between 7th St and 7th Ave for example, where the highest crash frequencies were observed in the 2012-2013 data and are expected based on the safety performance evaluation of the study section.

Potential Crash Reduction

The potential crash reduction associated with increased enforcement and fines is unknown. Limited restriction of HOV lane access will have to be carefully assessed, as research conducted in California (Ref. 11) suggests that access restrictions may actually result in higher crash frequency than with unrestricted access control.

HIGH FRICTION SURFACE TREATMENT

Description

High-Friction Surface Treatment (HFST) is a specialty pavement treatment used specifically to enhance friction. It is commonly used as a safety treatment on curves, at intersections, on ramps, and on steep grades to reduce stopping distance and the potential of skidding off the road, particularly under wet conditions. HFST is comprised of a thin a resin binder sprayed over the pavement surface followed by broadcasting of abrasion and polish-resistant aggregate. A recent study conducted by the FHWA that evaluated pavement safety performance (Ref.12) reported that while initial evaluation of applications on curves and ramps around the U.S. indicates potentially significant crash reduction benefits, additional research is needed to develop a CMF that can be provided to practitioners.

Since rear-end crashes comprise the highest proportion of crashes on the I-10 study section, HFST may be an effective countermeasure for this crash type, particularly in instances when higher speed vehicles encounter stopped or slowed traffic. Testing HFST on a segment of the I-10 study section would be an appropriate application. A possible candidate segment would be in the westbound direction of the Deck Park Tunnel. This segment includes a downgrade and horizontal curve. Westbound traffic entering the tunnels often encounter slowed or stopped traffic, either within the tunnel or at the tunnel exit.

Since the application of HFST has primarily been on lower volume highways and freeways, its survivability and service life on a high volume, high speed freeway is unknown and will need to be assessed. The New Mexico DOT recently installed HFST on a bridge deck on I-10 in Albuquerque with a 65 mph posted speed limit. This site may provide information on the service life of the treatment. Manufacturers' have suggested a 7 to 10 year service life for the I-10 study section traffic conditions. The potential effect of HFST on traffic generated noise levels will also need to be considered. The cost of applying HSFT is $21 to $26/sq yd. For the westbound direction of the tunnel segment, the estimated installation cost, excluding traffic control, would be in the range of $550,000.

OTHER POTENTIAL COUNTERMEASURES TO CONSIDER

As noted in the diagnostic review, congestion and high speed during peak traffic periods are primary factors associated with the high observed and expected crash frequncy within the study section. Lane changing associated with merging and weaving are also contributing factors. As such, improvements that will reduce these conditions can be considered. Several additional cost effective countermeasures for consideration include the following:

- Install freeway lane markings in advance of the I-17 and SR 51/SR 202 interchanges where two or more lanes exit I-10.
- Turn-on the ramp meter on the westbound Sky Harbor Blvd on-ramp during morning and evening peak hours to reduce the impact of merging traffic on the congested mainline.

- Install a high friction pavement surface treatment to reduce rear end crashes, which are the primary crash type within the study section. Additional information on the potential benefit and cost of this countermeasure is needed.
- Non-engineering countermeasures intended to reduce speed and increase driver awareness during peak traffic periods can also be considered. Potential countermeasures could include:
  - Heightened and visible DPS presence within the corridor. For example, station DPS vehicles at highly visible locations, such as at the entrances to the tunnel.
  - Provide messages using existing dynamic message signs reminding drivers to be prepared for upcoming congestion and to drive at a safe speed. These messages can be alternated with the current travel time information being provided.
  - Develop and implement a public outreach campaign designating this section of I-10 as a "safety corridor". The campaign would inform the public of the need to improve safety on this freeway section, steps being taken by ADOT and DPS to do so, and actions that the public can take to reduce crash potential.
  - Regional and statewide efforts to reduce distracted driving.

Study Results and Recommendations

I-10 STUDY SECTION SAFETY PERFORMANCE

The safety performance of I-10, between 35th Ave and Sky Harbor Blvd was evaluated using the predictive methods prescribed in the Highway Safety Manual. Thirty basic freeway segments and 29 speed change lane segments within the study section were evaluated. Several performance measures were applied to determine the magnitude of the safety problem within each segment and identify segments with high potential for reducing crash frequency and severity.

Safety performance on the I-10 study section is described as follows:

- 4900 reported crashes occurred on the I-10 study section over the 3-year period (2011 to 2013).
- The crash rate in the I-10 study section from 2011 to 2013 was 3.10 crashes per million vehicle miles compared to 1.47 crashes per million vehicle miles on a representative sample of other Phoenix area freeways.
- Referring to Figure 7, 18 of the study section segments have expected crash frequencies exceeding 150 crashes per mile per year. Six segments have crash frequencies exceeding 250 crashes per mile per year. The average for 40 other Phoenix area freeway segments is 82 crashes/mile per year, considering all crashes. When considering only fatal and injury crashes, 22 segments have a crash frequency of 40 crashes per mile per year compared to an average of 25 crashes per mile per year for the other Phoenix freeways. These results indicate that the I-10 study section is a priority in the region for safety improvement.

- 6 fatal crashes (0.2%) and 40 incapacitating injury crashes (1.2%) occurred over the 2-year period 2012 to 2013.
- Rear-end crashes are the predominant crash type.
- Referring to Figure 6, the level of service of safety (LOSS) results for all crashes, or only considering fatal and injury crashes, indicates moderate to high potential to reduce crash frequency on a large majority of the study segments.
- When considering the expected crash frequency and LOSS results, it is clear that the I-10 study section is a strong candidate for implementing appropriate crash reduction countermeasures.

CONTRIBUTING FACTORS

- Focusing on the high crash locations identified from the safety performance evaluation, detailed crash diagnosis was conducted to identify roadway, operations, and traffic factors that are contributing to the high expected crash frequencies. The diagnosis included assessment of crash trends and patterns, review of 756 crash reports of 3,255 crashes reported in 2012 and 2013, and field reviews. The crash diagnosis produced the following results:Speed and congestion were contributing factors in approximately 57% of all crashes occurring within the study section in 2012 and 2013.
- Congestion is a primary contributing factor, with 70% of the reported crashes occurring during the morning peak period (6:00 to 9:00) and afternoon peak period (3:00 to 7:00).
- Speed is also a primary factor. The average speed appears to range from 65 to 70 mph during off peak periods. During peak periods, crashes associated with high speed vehicles encountering slowed or stopped vehicles is common. Of the 40 incapacitating injury crashes, half noted congested conditions and speed as factors. During peak periods, differential speeds between stop-and-go traffic in the general lanes and vehicles in the HOV lanes is a factor.
- Crashes associated with vehicles entering/exiting the HOV lanes in combination with the noted speed differential during peak periods is a factor.
- The number of reported crashes at the left-side HOV entry ramps (3 locations) are low. As such this roadway condition is not a contributing factor.
- A combination of several factors contribute to the exceptionally high crash frequency in the Deck Park Tunnel. These factors include:
    - the illumination levels at the tunnel threshold zones are lower than the original design, likely due to the effect of age and environment on the luminaires,
    - the difference between the day-time ambient illumination level outside of the tunnel and the illumination level at the tunnel portals which can affect drivers as their eyes adjust when they enter/exit the tunnel,
    - lane changing within the tunnel associated with the eastbound and westbound weaving sections between 7th St and 7th Ave,
    - the horizontal curve within the tunnel, and
    - congestion occurring within the tunnel and just outside the exit portals.

- Heavy lane changing associated with the major weaving sections at the I-17 and L202/SR51 system interchanges creates congestion at the exit ramps, resulting in rear-end and sideswipe crashes.
- Mainline right-side lane drops at two locations, WB at 7th Ave and EB at 7th St are a factor in observed crashes. The lane drops contribute to congestion and produced forced lane changes. The EB lane drop at Washington St, is not as much a factor in crash frequency as at the other two lane drop locations.

POTENTIAL CRASH COUNTERMEASURES

Countermeasures to mitigate the contributing factors identified in the diagnostics process, resulting in reduced crash frequency within the study section were identified and analyzed. The analysis estimated the potential reduction in crashes using crash modification factors available from the HSM and the FHWA CMF Clearinghouse, and estimated using the ISATe crash prediction modeling tool. When possible, a benefit/cost analysis of each countermeasure was prepared following the guidelines from the ADOT HSIP manual. The following summarizes the results of the countermeasure evaluation and recommendations for potential implementation.

Lower Speed Limit: Lowering the speed limit in conjunction with heightened and continued enforcement is expected to lower the average operating speed on the freeway, potentially reducing crash frequency substantially at a high benefit/cost. Lowering the speed limit from 65 to 55 mph with focused enforcement is expected to lower average operating speeds from 2 to 4 mph. A 2 mph reduction in operating speed is estimated to result in 54 fewer fatal and injury crashes per year, producing an annual benefit/cost of 2.14 to 7.14 when considering K+A+B crashes and 1.62 to 5.41 for K+A crashes only. The benefit/cost range reflects the varying effect that a lowered speed limit will have on crashes during peak periods when congestion is present. PDO crash frequency would also drop, however there is no CMF available for estimating the amount. Lowering the operating speed by 3 or 4 mph would produce substantially higher safety benefits. **Recommendation: ADOT and DPS should evaluate this countermeasure for implementation.**

Variable Speed Limit: VSL systems are effective in lowering primary and secondary crashes, and increasing capacity and throughput on high speed access controlled roadways. VSL systems are typically part of an active traffic management system that may also include advance warning of congestion, crashes, and lane closures. Installing a variable speed limit system that operates primarily during weekday peak traffic periods to lower operating speeds on I-10 is estimated to result in potentially 100 fewer total crashes and 30 fatal and injury crashes each year. The estimated benefit/cost, based on a system implementation cost of $8.2 million and additional enforcement is 2.3 for all crashes and 1.6 for K+A crashes only. **Recommendation: Prepare a VSL system design concept to define system limits, operations, system requirements, and construction, operating, and enforcement methods and costs.**

Upgrade Deck Park Tunnel Lighting: It is not possible to definitively quantify the effect of existing illumination levels on the high expected crash frequency within the tunnel, particularly since there are other contributing factors (weaving sections, horizontal curve, and congestion). However, based on the review of crash reports and field review, and the results of the illumination study conducted as part of the Deck Park Tunnel Energy Efficiency Study, it is reasonable to conclude that upgrading the tunnel illumination to meet current IES recommendations and to reduce the blinding effect of the daytime ambient light level at the tunnel portals will reduce crashes. Considering the high cost of a lighting upgrade ($20 million) and the uncertainty of the improvement on reducing crash frequency, developing a reasonably sound benefit/cost based is not possible. **Recommendation: It is understood that ADOT is moving forward on a possible upgrade to tunnel lighting to reduce energy costs. If implemented, a study of the effect of tunnel illumination improvements on crash frequency should be conducted.**

Eliminate Lane Drops: Although the right-side lane drops at 7th Ave and 7th St are a factor in crash frequency at these locations, analysis of the benefit of extending the lanes indicates a fairly low reduction in crashes and low benefit/cost. The option of dropping each lane at the upstream exit results in similar low reduction in crashes for the 7th St lane drop, but higher crash frequency at the 7th Ave lane drop. **Recommendation: Countermeasure not recommended for implementation**

Meter EB 7th Ave and WB 7th St Entry Ramps: Lane changing is contributing to the high crash frequency in the tunnel. During peak periods, heavy ramp volumes are entering each weaving section in the tunnel, often at higher speed than the mainline traffic. Although studies on the effect of ramp metering on safety limited and high quality CMFs are not available, a nominal 5% crash reduction during peak periods is estimated to produce a benefit/cost of 3.75 for all crashes and 1.8 for K + A crashes. **Recommendation: Conduct further study of the effect of ramp metering on traffic operations on the mainline, at the ramp terminal intersections, and on the cross streets. Consider metering both ramps.**

Restrict HOV Lane Access: Review of crash records indicates that vehicles, often single occupant, jumping from the congested mainline lanes to the HOV lane are causing crashes due to the higher speeds of vehicles traveling in the HOV lanes. Based on a recent California study, it is unlikely that restricting continuous HOV lane access, as currently is the case on Phoenix area freeways, will reduce HOV lane related crashes. Reducing the speed differential between congested mainline lanes and HOV lanes, could be achieved from a VSL system. **Recommendation: Restricting HOV lane access is not recommended.**

High Friction Surface Treatment: Since rear end-crashes are predominant, application of HFST may prove to be an effective countermeasure for this crash type. Although a crash modification factor is not available, a recent FHWA study concludes that this treatment potentially offers a significant crash reduction benefit. **Recommendation: Evaluate the service life of this treatment for application on the I-10 study section. Consider applying HFST on a high crash segment to test it's effectiveness, possibly westbound I-10 within the Deck Park Tunnel. If installed, evaluate the safety benefit of this treatment.**

Automated Speed Enforcement: The Highway Safety Manual identifies automated speed enforcement as an effective method of lowering average operating speeds, potentially lowering crashes by as much as 17%. **Recommendation: This enforcement method could be considered with lowering the speed limit or a variable speed limit system.**

Other Recommended Countermeasures

- Install freeway lane markings in advance of the I-17 and SR 51/SR 202 interchanges where two or more lanes exit I-10.
- Turn-on the ramp meter on the westbound Sky Harbor Blvd on-ramp during morning and evening peak hours to reduce the impact of merging traffic on the congested mainline.
- Implement non-engineering countermeasures intended to reduce speed and increase driver awareness during peak traffic periods. Potential countermeasures could include:
    - Heightened and visible DPS presence within the corridor. For example, station DPS vehicles at highly visible locations, such as at the entrances to the tunnel.
    - Provide messages using existing dynamic message signs reminding drivers to be prepared for upcoming congestion and to drive at a safe speed. These messages can be alternated with the current travel time information being provided.
    - Develop and implement a public outreach campaign designating this section of I-10 as a "safety corridor". The campaign would inform the public of the need to improve safety on this freeway section, steps being taken by ADOT and DPS to do so, and actions that the public can take to reduce crash potential.
    - Regional and statewide efforts to reduce distracted driving.

APPLICATION OF STUDY RESULTS AND TOOLS FOR FUTURE SAFETY EVALUATIONS

Not only has the I-10 safety study successfully demonstrated the application of the HSM quantitative safety performance process, but the results and tools produced can directly be applied to safety evaluations of other urban freeway sections in the Phoenix area, as well as for evaluating the safety performance of projects intended to add freeway capacity or improve operations and safety. The training provided to ADOT staff as part of the study, which included segmentation of a freeway section, gathering roadway condition data using Google Earth, and application of the ISATe evaluation tool will support future safety evaluations. Application of the study results and tools, as well as limitations on their use, is described below.

CALIBRATED CRASH PREDICTION MODELS

Eight freeway crash prediction models, listed in Table 47 were calibrated to reflect local conditions so that the models will more accurately assess the safety performance on freeways in the Phoenix metropolitan area.

Table 47. Freeway Predictive Models Calibrated for Phoenix Urban Area

Urban Basic Freeway Segments	Urban Freeway Speed-change Lanes
▪ Multiple vehicle crashes – FI ▪ Multiple vehicle crashes – PDO ▪ Single vehicle crashes – FI ▪ Single vehicle crashes – PDO	▪ Multiple vehicle crashes – FI ▪ Multiple vehicle crashes – PDO ▪ Single vehicle crashes – FI ▪ Single vehicle crashes - PDO

Each model predicts average crash frequency using Safety Performance Functions (SPFs), Crash Modification Factors (CMFs), and a local calibration factor (C).

The **calibration factors** provided in Table 48 were developed using randomly selected Phoenix urban freeway segments with generally similar operational characteristics as exists on the I-10 study section. Included in the calibration database were segments with 6, 7, 8, 9, 10, and 11 through lanes, all with a posted speed limit of 65 mph. Two particularly key features included in all of the calibration segments are ramp metering and HOV lanes. Since both are common on Phoenix freeways and are present in the study section, the effect of these features are represented in the calibration factors.

Table 48. Predictive Model Calibration Factors for Phoenix Area Urban Freeways

Model	Location	F+I Calibration Factor, C	PDO Calibration Factor, C
Multiple vehicle	Freeway Segment	1.63	1.37
Single vehicle	Freeway Segment	0.94	1.12
Multiple vehicle	Speed-change lane	2.27	2.29
Single vehicle	Speed-change lane	1.58	2.14

The **crash severity distribution function (SDF)**, which is used to predict the proportion of fatal and injury crashes by severity, (K, A, B, and C), was also calibrated. The procedure for quantifying this calibration factor is described in the Highway Safety Manual First Edition Supplement (Ref 6). This factor adjusts the SDF such that the predicted frequency of K-fatal, A-incapacitating injury, B- non-incapacitating injury, and C-possible injury crashes matches more closely to that for the Phoenix metro area. The calculated SDF calibration factor is **2.14** and applies to the predictive models for both basic freeway segments and speed-change lanes.

The eight calibrated crash prediction models for basic freeway segments and speed-change lanes can be used to evaluate safety on Phoenix urban freeways with the following limitations. First, since the model calibration sections included continuous access HOV lanes and ramp meters, the model should not be applied to freeway sections without HOV lanes as well as freeways without ramp metering, without additional calibration for these conditions. Second, care should be used in applying the model to freeway sections with posted speed limits below 65 mph, in which case the free-flow speed should be approximately 65 mph. Again, additional calibration for segments with posted speeds less than 65 mph may be desirable, depending on the operating speeds on the segments under study.

SAFETY PERFORMANCE EVALUATION TOOLS

ISATe

The ISATe tool, with calibrated models for Phoenix urban freeways is available. The calibrated tools can also be used to evaluate safety performance on existing freeways, assess freeway design alternatives, aide in crash diagnostics, evaluate crash mitigation measures, and analyze design exceptions/variances.

IHSDM Design Support Software

The Interactive Highway Safety Design Model (IHSDM) was developed by FHWA as a suite of software analysis tools used to evaluate operational effects of geometric design decisions on highways. The IHSDM was originally designed to provide “decision-support” in the highway design process – comparing existing or proposed roadway designs against relevant design and operations policy values. A crash prediction module, which incorporates the HSM methodology was added to estimate the safety impacts of design decisions.

One advantage that the IHSDM software has over ISATe is the ability to import CAD files which can substantially simplify both segmenting of the freeway section being evaluating and gathering the necessary roadway geometry data. However, if CAD files are not available, manual segmentation and gathering of roadway geometry is required.

Performance Measure Spreadsheet

The spreadsheet developed for the study to calculate safety performance measures can be used by ADOT for other safety studies. The spreadsheet is linked to the ISATe segment output data, automating the calculation of performance measures.

GIS Crash Analysis Tool:

The GIS-based crash analysis tool developed for the I-10 study section provides an efficient means of performing crash diagnostics. A similar tool can be created for other freeway sections to be studied.

DATA COLLECTION SOURCES AND METHODS

Roadway Geometry and Physical Characteristics

The study results have provided valuable information regarding the availability and quality of data on roadway geometry and characteristics, traffic volume data, and crash data. Roadway geometry data provided in the ADOT RCID is appropriate for use in safety studies. Additional roadway characteristic data will need to be collected manually, preferably using recent aerial photographs. Use of EarthTools in conjunction with Google Earth offers an accurate and efficient method of extracting the roadway condition information. Given the relatively good correlation between the RCID data and the data collected manually, as noted in Table 49, it would be more expedient on future safety studies to use the RCID data for these data elements and use the manual method to fill the gaps.

Table 49. Recommended Data Sources for Safety Performance Evaluations

Feature	ADOT RCID	Manual Method (1)	Feature	ADOT RCID	Manual Method (1)
Basic segment length		✓	Barrier length		✓
Speed-change lane length		✓	Barrier offset		✓
No. through lanes	✓	✓	Continuous median barrier width	✓	✓
Width of lanes, shoulders, median	✓	✓	Clear zone width		✓
Horizontal curve radius	✓	✓	Type B weaving section		✓
Horizontal curve length	✓	✓	Distance to upstream ramp		✓
Rumble strips; inside & outside shoulders		✓	Distance to downstream ramp		✓

1. *Roadway condition data can be extracted manually from aerial photos, design drawings, as-built plans, and using Google Earth.*

Traffic Volume Data

Mainline AADT data is available from both the ADOT Traffic Data Management System (TDMS) and the FMS. It is recommended that the TDMS data be used to determine mainline segment volumes for freeway segments. Segment volumes can be calculated based on the AADT from the nearest TDMS mainline count station, adjusted to reflect traffic entering or exiting from adjacent ramps. Ramp AADT's are available from the biannual traffic count conducted by ADOT.

Level of congestion, described as the proportion of high volume hours occurring during a typical day can be determined from hourly volume data available from the FMS. Using Microsoft Access, the FMS database can be queried to determine the average annual proportion of high volume hours for each segment. A high volume hour is defined as when the average lane volume exceeds 1,000 vphpl. The proportion is calculated by summing the volume during each hour where the average lane volume exceeds 1,000 vphpl and then dividing this sum by the AADT.

Crash Data

Multiple years, typically 3 to 5, of crash data should be used to evaluate freeway safety performance. Review of the crash data provided from the ADOT Safety Data Mart for calibration of the crash prediction models and evaluation of safety performance on the I-10 study section provided several important results. First, the new GPS-based Traffic and Citation (TraCS) crash reporting system implemented by the Arizona Department of Public Safety in 2010 and 2011 provides more accurate crash location data, certainly to the tenth of a mile and possibly to the hundredth of a mile. This improved level of accuracy was observed consistently beginning with the 2012 crash data. Crash records from earlier years show a substantial proportion of crashes located at the mile or half-mile. Therefore, it is recommend that safety evaluations only use crash data beginning in 2012.

Second, crash data needs to be screened to remove duplicate crash records, crashes that occurred during mainline or ramp construction or during an unusual event (i.e. freeway flooding or dust storm), and crashes that may have been incorrectly coded to the mainline, ramp, or frontage road. Periods when work zones were present or a freeway closure was in effect can be identified using the ADOT Highway Condition Reporting System (HCRS) database. Crash data during these periods would be removed from the safety study database. In addition, the RoadCondition attribute in each crash record can indicate the presence of a work zone.

Several attributes in each crash record can be reviewed to confirm the freeway facility where the crash occurred. TrafficWayType identifies the type of roadway on which the crash occurred and JunctionRelation indicates if a crash was located on a ramp or frontage road.

EXPANSION OF ARIZONA FREEWAY CRASH PREDICTION MODELS

The I-10 study has provided a solid foundation for conducting safety performance evaluations on Arizona freeways using the HSM predictive methods. In order to expand the predictive models to cover all freeways throughout the state, it is recommended that the following additional model calibration be conducted.

- Develop calibration factors for urban freeways without HOV lanes and without ramp metering.
- Develop calibrated crash predictive models for 4 and 6-lane rural freeways.
- Evaluate the need for calibration factors for urban freeway with posted speeds of 55 mph.
- Evaluate the applicability of calibration factors based strictly on MAG region data to other urban areas in the state.

Should ADOT desire to expand the predictive models to cover ramps and ramp terminals to support the evaluation of interchange safety performance, calibration factors for these facilities can also be developed. FHWA should also consider conducting research on the following issues that were identified in the I-10 safety study.

The effects of HOV lanes with unlimited access and ramp metering on crash frequency is unknown. These effects are reflected in the calibration factors and not as a separate CMF. Closer examination of HOV lane crashes in the diagnostics phase of the study found a notable trend in crashes associated with vehicles entering or exiting the HOV lane. Quantifying this effect on Arizona's HOV lanes in comparison to other HOV facilities in the U.S. which do not restrict access location, will enhance the crash prediction models, provide information on ways to mitigate these crashes, and better inform future design of HOV facilities.

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APPENDIX A – DISCUSSION OF SAFETY PERFORMANCE MEASURES

PROBABILITY OF SPECIFIC CRASH TYPES EXCEEDING THRESHOLD PROPORTIONS

Description: The purpose of this performance measure is to identify segments with a higher proportion of a specific crash type or severity that is of interest to an agency. For example, an agency may want to focus on roadway departure crashes or fatal and incapacitating injury crashes. The agency would establish a threshold proportion of the specific crash type or severity that is considered "acceptable". The threshold could be the average proportion across similar sites or a percentile proportion (e.g., 85th percentile), or a targeted desired proportion (e.g., goal of less than 15% of speed related crashes). For each roadway segment, the probability that the long-term predicted proportion of crashes at the site is greater than the threshold proportion is calculated. Segments where the long-term prediction proportion is greater than the threshold proportion are identified.

Strengths: Considers variance in data; not affected by RTM bias; can also be used as a diagnostic tool.

Limitations: Does not account for traffic volume; segments may be flagged for review due to unusually low frequency of non-target crash types.

Application: For the initial application of this performance measure to the I-10 study, the evaluation focused on severe crashes (K, fatal; A, incapacitating injury; B, non-incapacitating injury). The threshold proportions applied were 0.144 (or14.4 % of total crashes) for basic segments and 0.108 for speed-change lanes. Note that these proportions represent what was found in the freeway segments used for the safety prediction model calibration. Therefore, the intent of this evaluation is to identify segments in the I-10 study section where the predicted long term proportion of severe crashes is greater than the proportions observed on typical Phoenix freeways.

Results: Each of the six calculated performance measures is listed in Table 50 and Table 51 for basic segments and speed-change lanes, respectively. Column 3 lists the probability that the proportion of severe (KAB) crashes within each segment of the I-10 study section will exceed the typical proportion on similar Phoenix freeways. Based on the rankings provided in Column 4, the top 10 basic segments and speed change lanes are fairly well spread out within the I-10 study section. It is worth noting that all of the top 10 speed-change lanes have a probability 70% or higher, while only two basic segments have a probability above this section. This suggests that focusing improvements on the speed change lanes may provide the greatest potential for crash reduction. It also suggests that the severity of crashes on the basic segments in the study section are not more severe relative to typical Phoenix freeways. However, crash severity may be worse on the speed-change lanes

.

Table 50. Calculated Performance Measures and Ranking - Basic Segments

	1	2	3	4	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
			1. Probability of Specific Crash Type Exceeding Threshold Proportion		2. Excess Proportion of Specific Crash Type		3. Expected Average Crash Frequency with EB Adjustment				4. Equivalent PDO Average Crash Frequency with EB Adjustment				5. Excess Expected Crash Frequency with EB Adjustment						6. Modified Level of Service of Safety (MLOSS)								
	Basic Segments																					LOSS	Crash Reduction Potential						
			Crash Severity:		Crash Severity:		Avg. Crash Frequency for Calibraion				Avg EPDO for Calibration Sites:											I		Low					
			Severe (KAB)		Severe (KAB)		Sites:	FI = 51.2	FI+PDO = 164.8		Economic: 551		Comp.: 885									II		Low to Moderate					
			Threshold Proportion:		Threshold Proportion:						EPDO CRASHES PER MILE / 2 YEARS											III		Moderate to High					
			p* =	0.144	p* =	0.144					Basic Segments + Speed-Change Lanes											IV		High					
	Begin						Expected Crashes per mile/2yr				EPDO		EPDO		Excess Crashes per mile/1yr			Rank			SV PDO		SV FI		MV PDO		MV FI		Rank
	Milepost		Probaility	Rank	p - p*	Rank	FI	Rank	FI+PDO	Rank	Economic	Rank	Compreh	Rank	PDO	FI	PDO+FI	PDO	FI	PDO+FI	Z	LOSS	Z	LOSS	Z	LOSS	Z	LOSS	
35th Ave	141.67		0.02	27	-0.08	25	85.9	12	318.4	11	1227	17	2284	17	49.2	12.6	58.4	12	16	11	0.80	III	0.15	III	3.12	IV	1.57	IV	11
	141.92		0.18	24	-0.02	16	106.0	7	394.6	8	1482	14	2698	14	71.3	16.7	86.3	10	11	10	0.66	III	-0.01	II	6.14	IV	2.62	IV	8
	142.43		0.88	1	0.07	2	92.1	11	282.4	13	1304	15	2375	15	36.8	18.5	54.7	15	10	12	0.20	III	0.34	III	3.03	IV	2.27	IV	10
	142.71		0.83	2	0.13	1	69.2	16	186.2	19	816	22	1508	22	17.4	15.3	33.6	21	13	17	-0.33	II	0.03	III	1.73	IV	1.80	IV	17
	142.88		0.53	7	0.06	3	68.9	17	176.7	21	804	23	1495	23	12.8	16.3	27.5	23	12	20	0.32	III	-0.40	II	0.79	III	1.64	IV	20
I-17	143.00		0.02	28	-0.06	22	48.3	21	179.9	20	638	26	1146	26	25.5	7.8	32.5	17	20	18	0.41	III	0.47	III	4.03	IV	2.25	IV	9
19th Ave	143.67		0.65	3	0.04	5	99.7	9	276.8	14	1257	16	2365	16	-2.1	10.3	10.5	26	17	24	-0.66	II	0.07	III	0.23	III	1.23	III	22
	143.95		0.36	12	0.00	13	85.8	13	267.3	15	1930	11	3648	11	18.5	8.5	28.3	20	18	19	-0.65	II	0.20	III	2.18	IV	1.30	III	18
	144.36		0.24	17	-0.14	27	2.5	29	64.7	28	2455	4	4503	4	20.5	-3.2	18.1	19	24	23	-0.56	II	-0.16	II	1.41	III	-1.77	I	23
	144.42		0.29	15	-0.01	15	155.6	4	583.3	5	2346	5	4445	5	167.2	56.0	219.9	3	3	3	1.04	III	1.30	III	10.12	IV	5.89	IV	1
7th Ave	144.80		0.62	4	0.02	7	251.2	1	887.5	1	3615	1	6823	1	263.3	102.8	368.4	1	1	1	-0.50	II	-0.05	II	7.59	IV	4.74	IV	5
Deck Park Tunnel	144.92		0.18	22	-0.14	27	10.9	27	194.1	17	2023	9	3805	8	52.6	-12.9	36.8	11	27	16	0.31	III	-0.32	II	1.51	IV	-2.81	I	25
	144.96		0.00	29	-0.05	21	214.2	2	835.9	2	2783	2	4874	2	214.4	57.8	269.2	2	2	2	0.94	III	-0.32	II	11.80	IV	5.76	IV	2
	145.42		0.53	6	0.03	6	147.5	6	524.4	6	2019	10	3741	10	116.0	42.9	161.6	6	5	5	-0.67	II	-0.63	II	4.14	IV	2.50	IV	12
	145.52		0.34	14	0.00	14	156.7	3	620.2	3	2098	7	3759	9	166.5	49.4	215.5	4	4	4	0.14	III	0.79	III	8.18	IV	4.29	IV	3
7th St	145.78		0.36	11	0.01	9	97.9	10	402.6	7	2592	3	4538	3	104.6	30.0	136.9	8	7	7	-0.73	II	0.74	III	2.56	IV	1.17	III	16
	145.82		0.22	19	-0.07	23	28.7	25	114.9	25	1649	13	2995	12	1.7	-3.0	0.2	25	23	26	-0.97	II	-0.28	II	0.38	III	-0.42	II	24
	145.94		0.05	26	-0.03	19	154.3	5	616.3	4	2320	6	4194	6	124.8	25.9	149.8	5	8	6	0.39	III	-1.14	II	8.44	IV	3.33	IV	6
	146.44		0.38	10	0.00	12	102.0	8	353.2	9	2093	8	3889	7	81.5	30.9	110.6	9	6	9	0.93	III	0.39	III	6.63	IV	4.21	IV	4
	146.85		0.06	25	-0.11	26	57.6	19	341.4	10	1687	12	2953	13	112.8	13.1	122.1	7	15	8	0.72	III	-0.38	II	3.68	IV	1.13	III	13
SR 51	146.93		0.21	21	-0.02	17	39.1	23	164.6	22	653	25	1201	25	37.5	7.8	40.9	14	19	14	1.60	IV	0.94	III	4.85	IV	2.39	IV	7
	147.51		NA	NA	-0.14	27	NA	NA	NA	NA	551	29	1024	29	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	.	
	147.67		0.35	13	0.00	11	36.7	24	103.6	27	588	27	1115	27	-6.1	2.0	0.0	28	22	27	-2.63	I	-0.57	II	0.34	III	0.54	III	27
	147.96		0.54	5	0.06	4	71.0	15	199.4	16	955	19	1830	19	32.1	22.5	54.5	16	9	13	0.00	III	0.56	III	2.19	IV	2.01	IV	14
Van Buren St	148.07		0.40	9	0.01	10	60.4	18	191.3	18	863	21	1630	21	21.0	13.5	39.4	18	14	15	-2.71	I	0.21	III	2.95	IV	2.03	IV	19
	148.31		0.22	19	-0.07	23	22.1	26	114.9	26	923	20	1656	20	8.0	-5.3	4.3	24	25	25	-1.01	II	-0.27	II	0.88	III	-0.96	II	26
	148.43		0.40	8	0.02	8	56.0	20	159.1	23	694	24	1214	24	-49.0	-26.8	-74.2	29	29	29	-0.69	II	-0.61	II	-5.01	I	-4.01	I	29
	148.66		0.18	23	-0.03	20	41.5	22	149.0	24	561	28	1026	28	16.1	4.8	20.8	22	21	22	0.06	III	0.08	III	2.52	IV	1.33	III	15
Sky Harbor Blvd	149.14		0.27	16	-0.14	27	9.6	28	59.6	29	337	30	571	30	-4.2	-15.3	-24.0	27	28	28	0.51	III	-0.16	II	-0.98	II	-3.16	I	28
	149.17		0.23	18	-0.03	18	80.7	14	313.3	12	1050	18	1857	18	40.6	-12.8	21.3	13	26	21	1.06	III	0.05	III	1.47	III	-1.20	II	21

Table 51. Calculated Performance Measures and Ranking - Speed Change Lanes

	1	2	3	4	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
			1. Probability of Specific Crash Type Exceeding Threshold Proportion		2. Excess Proportion of Specific Crash Type		3. Expected Average Crash Frequency with EB Adjustment				4. Equivalent PDO Average Crash Frequency with EB Adjustment				5. Excess Expected Crash Frequency with EB Adjustment						6. Modified Level of Service of Safety (MLOSS)								
	Speed-Change Lanes																					LOSS	Crash Reduction Potential						
			Crash Severity:		Crash Severity:		Avg. Crash Frequency for Calibraion															I		Low					
			Severe (KAB)		Severe (KAB)		Sites: FI = 2.1 FI+PDO = 6.8															II		Low to Moderate					
			Threshold Proportion:		Threshold Proportion:																	III		Moderate to High					
			p* =	0.108	p* =	0.108									Excess Crashes per mile/1yr				Rank			IV		High					
							Expected Crashes per mile/2yr								EN	EN	EX	EX	EN/EX	EN/EX	Entry PDO		Entry FI		Exit PDO		Exit FI		Rank
		Type	Probaility	Rank	p - p*	Rank	FI	Rank	FI+PDO	Rank					PDO	FI	PDO	FI	PDO	FI	Z	LOSS	Z	LOSS	Z	LOSS	Z	LOSS	
	142.38	ex	0.53	18	0.00	17	2.0	21	7.3	22					.	.	0.1	-0.1	16	22					0.20	III	-0.52	II	20
I-17	142.65	ex	0.40	22	-0.02	20	2.7	18	18.2	7					.	.	0.7	-0.1	11	20					0.90	III	-0.36	II	14
	143.95	ex	0.89	6	0.29	2	2.9	15	9.5	16					.	.	0.7	-0.1	11	20					0.90	III	-0.36	II	14
	143.95	en	0.73	9	0.03	12	10.0	3	23.5	4					-6.9	-1.5	.	.	28	28	-7.83	I	-1.92	I				.	29
	144.30	en	1.00	1	0.56	1	10.0	3	23.5	4					.	.	-0.6	0.6	24	10					-0.62	II	0.88	III	18
	144.31	ex	0.62	13	0.03	13	2.9	15	9.5	16					.	.	-0.1	-0.1	19	24					-0.17	II	-0.68	II	25
	144.36	en	0.53	17	0.00	17	3.8	11	17.6	8					-0.5	0.1	.	.	23	18	-1.18	II	0.18	III				.	26
	144.36	ex	0.56	16	0.01	16	5.9	7	20.5	6					.	.	0.3	-0.1	15	23					0.39	III	-0.62	II	19
Deck Park	144.92	ex	0.99	2	0.20	5	4.7	9	13.7	11					0.0	-0.2	.	.	17	25	-0.04	II	-0.34	II				.	22
Tunnel	145.38	ex	0.50	19	0.00	19	2.7	19	13.3	12					0.0	-0.2	.	.	17	25	-0.04	II	-0.34	II				.	22
7th St	145.78	en	0.64	12	0.03	11	4.8	8	14.0	10					3.8	0.4	.	.	3	12	2.48	IV	0.81	III				.	6
	145.82	en	0.56	14	0.02	14	1.4	24	8.4	20					1.2	0.1	.	.	8	19	1.03	III	0.08	III				.	12
	145.82	ex	0.90	4	0.09	7	11.4	2	28.5	3					.	.	1.7	0.5	7	11					1.53	IV	1.01	III	7
	146.38	ex	0.04	29	-0.08	21	6.8	6	29.5	2					-15.4	-5.8	.	.	29	29	-5.90	I	-3.01	I				.	28
	146.64	en	0.88	7	0.07	8	17.7	1	48.0	1					.	.	-2.6	1.8	27	7					-1.80	I	1.43	III	21
	146.76	ex	0.89	5	0.11	6	7.4	5	17.0	9					.	.	8.7	2.5	1	2					3.80	IV	2.18	IV	1
	146.85	en	0.19	28	-0.11	22	3.0	14	9.2	18					-0.2	-0.7	.	.	20	27	-0.13	II	-1.48	II				.	27
SR 51	146.89	ex	0.70	10	0.06	9	2.1	20	8.2	21					.	.	-0.7	3.4	25	1					-0.37	II	2.17	IV	10
	147.45	en	0.56	15	0.01	15	1.8	23	12.2	13					-1.2	0.3	.	.	26	16	-0.82	II	0.32	III				.	24
	147.51	en	0.27	27	-0.11	22	3.4	12	10.4	14					.	.	3.6	0.8	4	8					2.39	IV	1.19	III	5
	147.51	en	0.67	11	0.05	10	3.4	12	10.4	14					.	.	2.9	1.8	6	6					2.13	IV	1.98	IV	2
	147.67	en	0.40	23	-0.11	22	1.9	22	3.4	26					1.0	0.2	.	.	9	17	0.59	III	0.24	III				.	13
	147.91	ex	0.40	23	-0.11	22	0.5	28	3.1	27					.	.	3.5	2.1	5	5					1.94	IV	1.93	IV	3
Van Buren St	148.07	ex	0.44	20	-0.11	22	0.5	27	2.7	28					0.4	2.5	.	.	13	3	0.23	III	1.70	IV				.	8
	148.31	en	0.87	8	0.23	4	3.9	10	8.5	19					0.4	2.5	.	.	13	3	0.23	III	1.70	IV				.	8
	148.34	ex	0.94	3	0.27	3	2.8	17	7.1	23					.	.	-0.3	0.4	21	13					-0.30	II	0.57	III	16
	148.43	ex	0.33	26	-0.11	22	0.7	25	4.1	24					.	.	-0.3	0.4	21	13					-0.30	II	0.57	III	16
	148.64	ex	0.36	25	-0.11	22	0.7	25	4.1	24					.	.	5.3	0.6	2	9					2.86	IV	0.88	III	4
Sky Harbor	149.14	ex	0.44	20	-0.11	22	0.5	29	2.3	29					.	.	0.8	0.4	10	15					0.84	III	0.70	III	11

EXCESS PROPORTIONS OF SPECIFIC CRASH TYPES

Description: The purpose of this performance measure is to identify segments with an over-representation of a specific crash type of interest relative to other crash types. This measure overlaps with the previous measure (probability of specific crash types exceeding threshold proportions), identifying the degree that the proportion of a specific crash type exceeds the threshold proportion established by an agency and aiding in the ranking of segments relative to potential for crash reduction.

Strengths: Considers variance in data; not affected by RTM bias; can also be used as a diagnostic tool.

Limitations: Does not account for traffic volume; segments may be flagged for review due to unusually low frequency of non-target crash types.

Application: For the initial application of this performance measure to the I-10 study, the evaluation focused on severe crashes (K, fatal; A, incapacitating injury; B, non-incapacitating injury). The threshold proportions applied were 0.144 for basic segments and 0.108 for speed-change lanes, representing what was found in the freeway segments used for the safety prediction model calibration.

Results: Column 6 in Table 50 and Table 51 lists the excess proportion of severe crashes within the I-10 section that exceeds the typical proportion on similar Phoenix freeways. A large positive value indicates greater potential for improvement of crashes associated with the subject crash type. As would be expected, the top 10 basic segments and speed-change lanes are nearly identical to those produced by the probability performance measure. With the exception of several speed change lanes, the excess proportion values for both basic segments and speed-change lanes are fairly low when compared with the threshold proportion that represents typical Phoenix freeways. The highest excess proportion value for the basic segments is only 0.13 higher than the threshold, while the value on five speed-change lanes range from 0.20 to 0.56 above the threshold. While these results suggest that speed-change lanes offer the greatest potential for crash reduction, they also suggest that the safety performance, based on severe crashes, on much of the I-10 section is not much worse, or perhaps better than on similar Phoenix freeways. The crashes are not really more severe—just much more frequent.

EXPECTED AVERAGE CRASH FREQUENCY WITH EB ADJUSTMENT

Description: This performance measure estimates the EB adjusted expected average crash frequency for each segment, applying the calibrated safety performance functions and observed crash data to calculate expected crash frequency for each segment. The measure can be calculated for specific crash types or severity categories, if desired. Segments can then be ranked based on expected long-term average crashes to compare relative safety performance and prioritize segments.

Strengths: Accounts for RTM bias; accounts for influence of traffic volume; accounts for influence of roadway geometry and characteristics.

Limitations: Requires SPFs calibrated to local conditions (not a limitation for this study).

Application: EB adjusted expected average crash frequencies are calculated directly from the ISATe spreadsheet. Expected average FI crash frequencies were calculated for both basic segments and speed change lanes. Total (FI + PDO) crash frequencies were also calculated for basic segments. Expected crash frequencies for basic segments were calculated on a “per mile” basis to normalize the segments to allow for more meaningful comparison and ranking among segments.

Results: The performance measure was calculated for FI and FI+PDO crashes. The results are provided in Columns 8 and 10 in Table 50 and Table 51. A large positive value indicates greater potential for improvement. The expected average crash frequencies per mile for the calibration segments are also shown in each table. These calibration segment crash frequencies can be considered as reference values, representing similar Phoenix freeways. Comparing performance measure values, the expected crash frequencies per mile on a majority of the basic segments and speed-change lanes within the I-10 study section exceed the reference values, often substantially. This finding is consistent with that found in the examination of crash rates (as shown in Table 7. Calibration Segments Crash Summary and**).** An examination of the top 10 basic segments and speed-change lanes indicates that the greatest potential for crash reduction is on the section of I-10 between I-17 and SR 51.

EQUIVALENT PDO AVERAGE CRASH FREQUENCY WITH EB ADJUSTMENT

Description: This performance measure weights crashes by severity to produce a single combined frequency and severity score for each segment. The measure incorporates calibrated SPFs and EB to address random fluctuations in crashes. The weighting factors are calculated relative to PDO crashes and are based on societal costs each crash severity. This measure allows segment ranking, highest to lowest score, based on expected long-term average crash frequency and severity.

Strengths: Accounts for RTM bias; accounts for influence of traffic volume; accounts for influence of roadway geometry and characteristics; provides a single ranking that considers crash frequency and severity.

Limitations: Requires SPFs calibrated to local conditions (not a limitation for this study).

Application: EB adjusted expected average crash frequencies are calculated directly from the ISATe spreadsheet. Equivalent PDO crash frequencies for basic segments were calculated per mile. The total segment equivalent PDO crash frequency, including basic segments and speed change lanes were calculated and ranked. PDO weighting factors were determined using two types of crash costs: economic and comprehensive. The economic costs include medical costs, lost wages, and property damage. Comprehensive costs include economic costs PLUS cost associated with lost quality of life and productivity. The crash costs and PDO weighting factors are provided in Table 52.

Table 52. Crash Cost Factors and PDO Weighting Factors

Crash Severity	Economic Cost (1)	PDO Weighting Factor	Comprehensive Cost (2)	PDO Weighting Factor
K, Fatal	$1,804,479	241.4	$5,800,000	1450.0
A, Incapacitating Injury	$205,862	61.78	$400,000	100.0
B, Non-incapacitating injury	$40,570	12.18	$80,000	20.0
C, Possible injury	$24,922	7.48	$42,000	10.5
PDO	$3,332	1.00	$4,000	1.00

Source: Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Categories. FHWA-HRT-05-051, October 2005

Source: ADOT Highway Safety Improvement Program Manual, March 2010

Results: The equivalent PDO performance measure results are provided in Columns 12 and 14 in Table 50 and Table 51. A large positive value indicates greater potential for improvement. The rankings produced using economic cost and comprehensive cost weighting factors are nearly identical. The ranking of the top 10 segments suggests that the focus for safety improvements should focus on the section inclusive of the 7th Ave interchange to the 7th St interchange.

EXCESS EXPECTED AVERAGE CRASH FREQUENCY WITH EB ADJUSTMENT

Description: This performance measure identifies segments where the expected average crash frequency is higher than the predicted average crash frequency for a segment. The predicted crash frequency is calculated using calibrated SPFs (without the EB adjustment). Thus, the predicted crash frequency represents the long-run crash frequency for typical segment having the same geometry and traffic volume as the subject segment. The expected crash frequency is calculated by weighting the predicted crashes with observed crash data for the subject segment. Thus, the expected crash frequency represents the long-run crash frequency for the subject segment. The difference between predicted and expected crashes is called “Excess Expected Crashes”. It represents the amount by which the safety of the subject segment deviates from that of the typical segment, given the same geometry and traffic volume. Segments are then ranked based on the highest excess expected crashes.

Strengths: Accounts for RTM bias; accounts for influence of traffic volume; accounts for influence of roadway geometry and characteristics; provides a single ranking that considers crash frequency and severity.

Limitations: Requires SPFs calibrated to local conditions (not a limitation for this study).

Application: Excess expected crashes were calculated for the following categories:

- Basic segment, single-vehicle crash, PDO
- Basic segment, single-vehicle crash, FI
- Basic segment, multiple-vehicle crash, PDO
- Basic segment, multiple-vehicle crash, FI
- Basic segment, FI+PDO
- Entrance speed-change lane, PDO
- Entrance speed-change lane, FI
- Exit speed-change lane, PDO
- Exit speed-change lane, FI

For basic segments, “excess expected crash frequency” was calculated on a “per mile” basis to normalize the segments to allow for more meaningful comparison and ranking among segments.

Results: The excess average crash frequency performance measure results are provided in Columns 16 thru 18 in Table 50 and Table 51. The top 10 basic segments identified using this performance measure are consistent with those produced by two other EB adjusted performance measures. However, the same results are not observed with the speed-change lanes, where there is greater spread.

MODIFIED LEVEL OF SERVICE OF SAFETY (MLOSS)

Description: The Level of Service of Safety (LOSS) has been effectively used to qualitatively describe the safety performance of a roadway and identify segments with greater potential for crash reduction. The methodology ranks segments by comparing their average crash frequency to the predicted average crash frequency for all of the segments being evaluated. The degree of standard deviation from the predicted average crash frequency defines the LOSS levels, I, II, III, and IV. The higher the level, the poorer the LOSS. One weakness in the original methodology is that it does not control for RTM bias, however this is in the process of being remedied by the developers. For the purposes of this study, a modified version of the LOSS method was applied to add an EB adjustment to account for RTM bias. Specifically, the MLOSS is based on the expected average crash frequency whereas the LOSS is based on the observed crash frequency. The LOSS categories are defined as follows:

LOSS	Potential for Crash Reduction
I	Low
II	Low to Moderate
III	Moderate to High
IV	High

Strengths: Performance measure is normalized by the variance in the crash data allowing for meaningful comparison of segments; accounts for volume; establishes a threshold for measuring crash frequency.

Limitations: Requires SPFs calibrated to local conditions (not a limitation for this study); 3-5 years of crash data are recommended.

Application: EB-based expected average crash frequency was substituted for the observed crash frequency when computing the LOSS using the criteria provided in the HSM (Table 4-11). LOSS for FI and PDO crashes was computed for basic segments and speed-change lanes. The basis for determining the LOSS was the z-score (z-score = (predicted - reported)/(reported)$^{0.5}$). This measure is a "relative measure". It "normalizes" the difference between the expected and predicted crash frequencies (where this difference relates the subject segment to the typical segment, in a manner similar to the preceding "excess expected average crash frequency with EB adjustment" measure). The z-score conveys the magnitude of the difference.

Results: The LOSS values, listed in Columns 22 thru 29 in Table 50 and Table 51, indicate that the crash reduction potential on nearly all of the basic segments and nearly all of the speed-change lanes within the I-10 study section is either moderate to high (LOSS III) or High (LOSS IV), relative to typical Phoenix freeways. Multi-vehicle PDO crashes (e.g. rear-ends) offer the highest potential for reduction, followed by multi-vehicle FI crashes. While LOSS levels don’t necessarily aide in focusing further investigation on specific segments, they may suggest that there may be a system-wide factor that is contributing to the relatively high crash frequencies. Potential system-wide factors could include high speed, or perhaps the continuous access HOV lanes. These factors will be investigated further in subsequent project tasks.

While the LOSS levels themselves do not differentiate the segments within the study section, the z-scores do. These values are also provided in Table 50 and Table 51. Segments were ranked based on summing all z-scores. The top 10 basic segments are very similar to the rankings using the excess expected average crash frequency with EB performance measure. The segments of highest potential for crash reduction are between 7th Ave and SR 51, although several segments east of 35th Ave are also of interest. The top 10 speed-change lanes are also very similar, with the speed-change lanes of highest accident potential located between 7th St and Sky Harbor Blvd.

APPENDIX B – ISATE OUTPUT

Output Summary

General Information

Project description:	I-10 Study Section - 35th Ave to Sky Harbor Blvd				
Analyst:	0	Date:	4/3/2015	Area type:	Urban
First year of analysis:	2012				
Last year of analysis:	2013				

Crash Data Description

Freeway segments	Segment crash data available?	Yes	First year of crash data:	2012
	Project-level crash data available?	No	Last year of crash data:	2013
Ramp segments	Segment crash data available?	No	First year of crash data:	
	Project-level crash data available?	No	Last year of crash data:	
Ramp terminals	Segment crash data available?	No	First year of crash data:	
	Project-level crash data available?	No	Last year of crash data:	

Estimated Crash Statistics

Crashes for Entire Facility	Total	K	A	B	C	PDO
Estimated number of crashes during Study Period, crashes:	2450.2	16.2	38.9	269.0	360.9	1765.3
Estimated average crash freq. during Study Period, crashes/yr:	1225.1	8.1	19.4	134.5	180.5	882.6

Crashes by Facility Component	Nbr. Sites	Total	K	A	B	C	PDO
Freeway segments, crashes:	20	2450.2	16.2	38.9	269.0	360.9	1765.3
Ramp segments, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0
Crossroad ramp terminals, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0

Crashes for Entire Facility by Year	Year	Total	K	A	B	C	PDO
Estimated number of crashes during	2012	1225.1	8.1	19.4	134.5	180.5	882.6
the Study Period, crashes:	2013	1225.1	8.1	19.4	134.5	180.5	882.6
	2014						
	2015						
	2016						
	2017						
	2018						
	2019						
	2020						
	2021						
	2022						
	2023						
	2024						
	2025						
	2026						
	2027						
	2028						
	2029						
	2030						
	2031						
	2032						
	2033						
	2034						
	2035						

Distribution of Crashes for Entire Facility

Crash Type	Crash Type Category	Estimated Number of Crashes During the Study Period					
		Total	K	A	B	C	PDO
Multiple vehicle	Head-on crashes:	8.1	0.1	0.3	1.9	2.6	3.2
	Right-angle crashes:	47.5	0.4	1.1	7.3	9.8	28.9
	Rear-end crashes:	1577.8	10.9	26.3	181.9	244.9	1113.8
	Sideswipe crashes:	536.0	2.7	6.4	44.1	59.4	423.5
	Other multiple-vehicle crashes:	56.9	0.4	1.1	7.3	9.9	38.2
	Total multiple-vehicle crashes:	2226.3	14.6	35.0	242.6	326.6	1607.5
Single vehicle	Crashes with animal:	3.7	0.0	0.0	0.1	0.1	3.5
	Crashes with fixed object:	162.2	1.1	2.8	19.1	24.8	114.4
	Crashes with other object:	25.4	0.1	0.2	1.4	1.9	21.7
	Crashes with parked vehicle:	2.9	0.0	0.0	0.3	0.4	2.1
	Other single-vehicle crashes	29.8	0.3	0.8	5.5	7.1	16.1
	Total single-vehicle crashes:	223.9	1.6	3.8	26.4	34.3	157.8
	Total crashes:	2450.2	16.2	38.9	269.0	360.9	1765.3

Output Summary

General Information

Project description:	I-10 Study Section - 35th Ave to Sky Harbor Blvd				
Analyst:	0	Date:	4/3/2015	Area type:	Urban
First year of analysis:	2012				
Last year of analysis:	2013				

Crash Data Description

Freeway segments	Segment crash data available?	Yes	First year of crash data:	2012
	Project-level crash data available?	No	Last year of crash data:	2013
Ramp segments	Segment crash data available?	No	First year of crash data:	
	Project-level crash data available?	No	Last year of crash data:	
Ramp terminals	Segment crash data available?	No	First year of crash data:	
	Project-level crash data available?	No	Last year of crash data:	

Estimated Crash Statistics

Crashes for Entire Facility	Total	K	A	B	C	PDO
Estimated number of crashes during Study Period, crashes:	986.6	6.8	16.4	112.6	153.5	697.3
Estimated average crash freq. during Study Period, crashes/yr:	493.3	3.4	8.2	56.3	76.8	348.7

Crashes by Facility Component	Nbr. Sites	Total	K	A	B	C	PDO
Freeway segments, crashes:	14	986.6	6.8	16.4	112.6	153.5	697.3
Ramp segments, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0
Crossroad ramp terminals, crashes:	0	0.0	0.0	0.0	0.0	0.0	0.0

Crashes for Entire Facility by Year	Year	Total	K	A	B	C	PDO
Estimated number of crashes during the Study Period, crashes:	2012	493.3	3.4	8.2	56.3	76.8	348.7
	2013	493.3	3.4	8.2	56.3	76.8	348.7
	2014						
	2015						
	2016						
	2017						
	2018						
	2019						
	2020						
	2021						
	2022						
	2023						
	2024						
	2025						
	2026						
	2027						
	2028						
	2029						
	2030						
	2031						
	2032						
	2033						
	2034						
	2035						

Distribution of Crashes for Entire Facility

Crash Type	Crash Type Category	Estimated Number of Crashes During the Study Period					
		Total	K	A	B	C	PDO
Multiple vehicle	Head-on crashes:	3.1	0.0	0.1	0.8	1.0	1.2
	Right-angle crashes:	18.6	0.2	0.4	2.9	4.0	11.1
	Rear-end crashes:	613.0	4.4	10.7	73.5	100.7	423.8
	Sideswipe crashes:	209.8	1.1	2.6	17.8	24.4	163.9
	Other multiple-vehicle crashes:	21.9	0.2	0.4	2.9	4.0	14.4
	Total multiple-vehicle crashes:	866.6	5.9	14.2	97.9	134.1	614.4
Single vehicle	Crashes with animal:	1.8	0.0	0.0	0.0	0.0	1.7
	Crashes with fixed object:	86.1	0.6	1.5	10.5	13.8	59.6
	Crashes with other object:	14.1	0.0	0.1	0.8	1.1	12.0
	Crashes with parked vehicle:	1.7	0.0	0.0	0.2	0.3	1.2
	Other single-vehicle crashes	16.3	0.2	0.5	3.1	4.1	8.4
	Total single-vehicle crashes:	120.0	0.9	2.1	14.7	19.4	82.9
	Total crashes:	986.6	6.8	16.4	112.6	153.5	697.3

APPENDIX C – SEGMENT PERFORMANCE MEASURES

I-10 Study Segments - Safety Performance

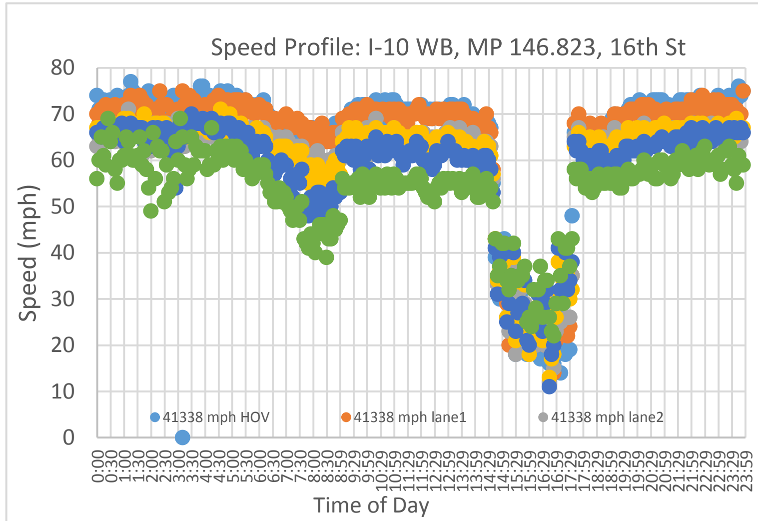
Begin MP		Observed Crashes 2012/13	Combined CMF	EACFM FI + PDO	Z-Score FI + PDO	Z-Score FI	Diagnostic Review
141.67		87	1.28	318	1.71	0.87	
141.92		215	1.64	395	3.17	1.33	x
142.38	ex	9	1.39	161	0.66	0.54	x
142.43		87	1.57	282	1.86	1.33	
142.65	ex	23	1.44	303	2.21	0.68	
142.71		37	1.42	186	1.36	1.24	
142.88		24	1.53	177	0.92	1.15	
143.00		140	1.44	180	2.69	1.52	x
143.67		77	1.84	277	0.27	0.58	x
143.95		113	2.11	267	0.88	0.56	x
143.95	ex	10	2.97	148	0.01	0.38	
143.95	en	26	3.83	219	0.47	1.01	
144.30	en	26	3.83	219	0.47	1.01	x
144.31	ex	10	2.97	148	0.01	0.38	
144.36	ex	26	3.15	445	1.54	1.88	x
144.36		4	2.12	65	0.60	-0.28	x
144.36	en	18	4.05	293	0.23	0.12	
144.42		279	1.19	583	9.22	5.25	x
144.80		133	1.33	888	7.61	4.56	x
144.92	ex	23	1.55	342	2.52	2.41	x
144.92		8	1.90	194	0.52	-0.47	x
144.96		416	2.26	836	6.78	3.13	x
145.38	ex	19	1.64	282	2.20	1.11	
145.42		58	1.67	524	2.78	1.67	x
145.52		187	1.40	620	5.97	3.13	x
145.78		19	1.82	403	1.59	0.83	x
145.78	en	14	5.59	351	-0.13	0.14	
145.82		13	1.62	115	0.01	-0.17	
145.82	en	8	4.67	300	-0.18	-0.41	
145.82	ex	31	3.00	277	0.33	1.52	
145.94		322	1.74	616	3.72	1.44	x
146.38	ex	40	1.28	483	3.61	2.24	x
146.44		161	1.41	353	4.59	2.91	x
146.64	en	40	3.91	136	-1.16	-0.73	
146.76	ex	18	3.06	239	-0.13	0.95	
146.85		31	1.37	341	2.48	0.65	x
146.85	en	10	1.73	184	0.49	0.04	x
146.89	ex	12	1.33	227	1.43	0.92	x
146.93		128	1.67	165	4.18	2.01	x
147.45	en	17	1.94	218	2.19	0.68	
147.51	en	10	1.38	65	-0.12	-0.20	
147.51	en	10	1.38	65	-0.12	-0.20	
147.67		27	1.54	104	0.00	0.24	
147.67	en	3	1.93	66	-0.29	0.10	
147.91	ex	3	1.26	68	0.13	-0.32	
147.96		30	1.19	199	2.17	1.88	x
148.07		53	1.33	191	1.90	1.44	x
148.07	ex	2	1.16	51	-0.19	-0.34	
148.31		13	2.01	115	0.12	-0.34	x
148.31	en	6	5.04	103	-1.21	-0.60	
148.34	ex	8	3.52	191	0.01	0.68	
148.43		31	2.73	159	-1.32	-0.94	
148.43	ex	5	1.49	131	0.54	-0.20	x
148.64	ex	5	1.49	131	0.54	-0.20	x
148.66		79	1.17	149	1.56	0.83	
149.14		2	1.63	60	-0.37	-0.45	
149.14	ex	2	1.23	65	0.02	-0.27	
149.17		43	2.78	313	0.35	-0.37	

EACFM = Expected average crash frequency per mile, with EB adjustment

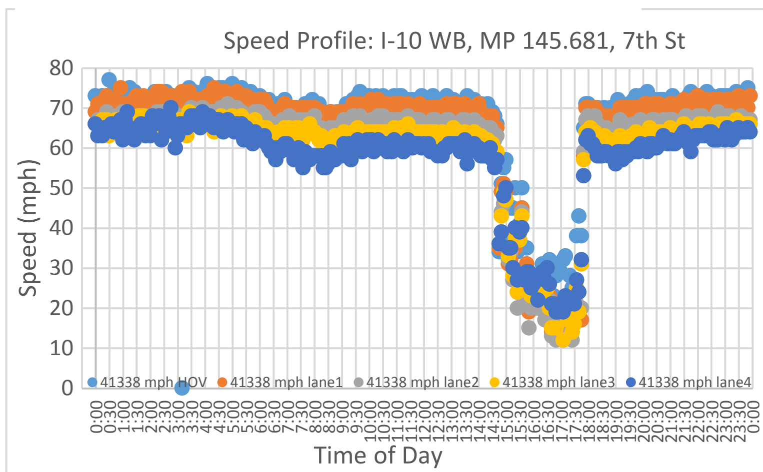
APPENDIX D – SPEED AND CONGESTION PROFILES

Crash Frequency Distribution by Time of Day (Segment: I-10 WB, MP 145.777)

Time of Day	Frequency	Percent
0:00	0	0.00%
1:00	0	0.00%
2:00	0	0.00%
3:00	0	0.00%
4:00	0	0.00%
5:00	0	0.00%
6:00	0	0.00%
7:00	0	0.00%
8:00	0	0.00%
9:00	0	0.00%
10:00	0	0.00%
11:00	0	0.00%
12:00	0	0.00%
13:00	2	9.09%
14:00	1	4.55%
15:00	3	13.64%
16:00	3	13.64%
17:00	4	18.18%
18:00	6	27.27%
19:00	1	4.55%
20:00	0	0.00%
21:00	0	0.00%
22:00	1	4.55%
23:00	1	4.55%
Total	**22**	**100.00%**



Speed Profile for westbound I-10, MP 146.823



Speed Profile for westbound I-10, MP 145.681

Collision Type Distribution (Segment: I-10 WB, MP 145.777)

Collision Type	Frequency	Percent
REAR_END	19	86.36%
SIDESWIPE_SAME_DIRECTION	1	4.55%
SINGLE VEHICLE	2	9.09%
Total	**22**	**100.00%**

Drivers' Maneuvering/Action (Segment: I-10 WB, MP 145.777)

Drivers Action	Frequency	Percent
AVOIDING_VEHICLE_OBJECT	1	1.96%
CHANGING_LANES	2	3.92%
GOING_STRAIGHT_AHEAD	14	27.45%
SLOWING_IN_TRAFFICWAY	19	37.25%
STOPPED_IN_TRAFFICWAY	13	25.49%
UNKNOWN	**2**	3.92%
Total	51	100.00%

Distribution of Slowing/Stopped in the Traffic Way Distribution by Time of Day (Segment: I-10 EB, MP 145.777)

Time of Day	Frequency	Percent
0:00	0	0.00%
1:00	0	0.00%
2:00	0	0.00%
3:00	0	0.00%
4:00	0	0.00%
5:00	0	0.00%
6:00	0	0.00%
7:00	0	0.00%
8:00	0	0.00%
9:00	0	0.00%
10:00	0	0.00%
11:00	0	0.00%
12:00	0	0.00%
13:00	4	12.50%
14:00	1	3.13%
15:00	6	18.75%
16:00	3	9.38%
17:00	8	25.00%
18:00	9	28.13%
19:00	0	0.00%
20:00	0	0.00%
21:00	0	0.00%
22:00	0	0.00%
23:00	1	3.13%
Total	**32**	100.00%

APPENDIX E – 2012-2013 CRASH DATA SUMMARY BY SEGMENT

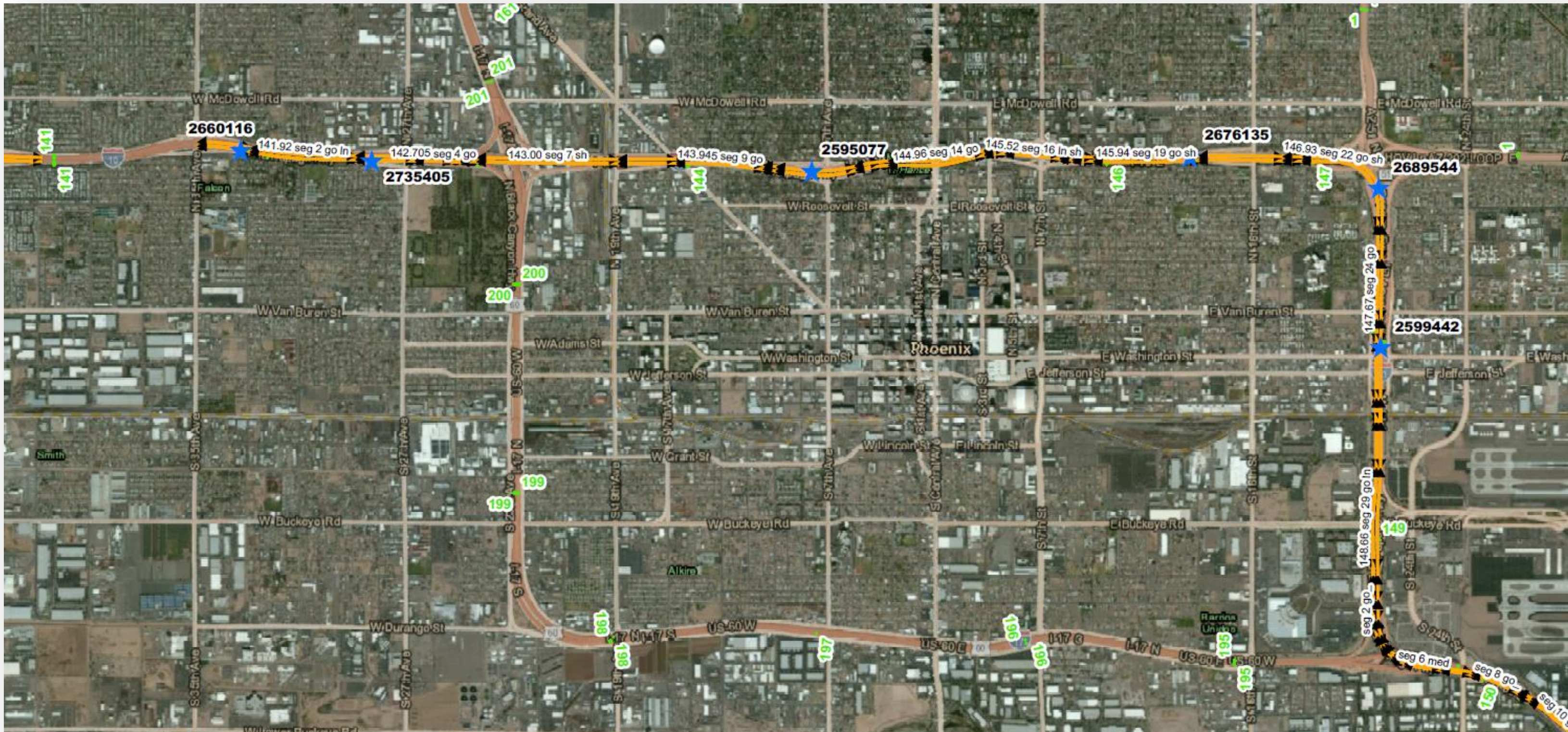
Roadway Features/ Mile Post	Diagnostic Summary	Contributing Factors
Eastbound MP142.993 to MP143.667	Total crashes occurred - 86, Crash reports reviewed - 15. Ramp traffic from both northbound and southbound I-17 merge with I-10 eastbound traffic just east of this segment. Eastbound I-10 traffic from west of I-17 comes at a high speed and suddenly encounters slowing and/or stopped traffic.	Congestion, Speed, and Merging traffic
Westbound MP142.993 to MP143.667	Total crashes occurred - 63, Crash reports reviewed - 15. This is an upgrade segment. Ramp traffic from northbound and southbound I-17 merge with westbound I-10 traffic just west of this segment. Westbound I-10 motorists may think that congestion has been eliminated and starts accelerating, and often encounters slowing and/or stopped traffic.	Congestion, Speed, and Lane changing
Eastbound MP144.359 to MP144.418	Total crashes occurred - 32, Crash reports reviewed - 15. There is a left-side HOV exit to 5th Ave in this segment. Slowing traffic tends to rear-end stopped traffic on this down grade, mainly in lane 1.	Congestion
Westbound MP144.359 to MP144.418	Total crashes occurred - 17, Crash reports reviewed - 15. Traffic from 7th Ave merges just west of this segment. There is also a HOV entrance from 5th Ave. There is a significant amount of lane changing resulting in slowing traffic which leads to side-swipe or rear-end crashes.	Congestion, and Lane changing
Eastbound MP144.419 to MP144.800	Total crashes occurred - 178, Crash reports reviewed - 15. This segment has a down grade slope and is located west of the tunnel. Traffic comes at relatively high speeds and encounters congestion, resulting in rear-end crashes.	Congestion, Speed, and Downgrade slope
Westbound MP144.419 to MP144.800	Total crashes occurred - 118, Crash reports reviewed - 15. This segment contains the merge area from a right-side lane drop. After leaving the tunnel traffic starts accelerating, but due to congestion, traffic slows. There is lane changing at the lane drop along with weaving activities.	Congestion, Speed, Lane drop, and Lane changing
Eastbound MP144.801 to MP144.919	Total crashes occurred - 54, Crash reports reviewed - 15. This segment is the west end of the tunnel and has a downgrade slope. Traffic travels at a relatively high speed and encounters congestion. There is also lane changing from 7th Ave entrance (unmetered heavy flow) that tends to slow traffic.	Congestion, Speed, Lane changing, and Downgrade slope
Westbound MP144.801 to MP144.919	Total crashes occurred - 70, Crash reports reviewed - 15. This segment is at the west end of the tunnel (including the 7th Ave exit ramp) and the sun is also often at eye-level during the afternoon peak. After exiting the tunnel, traffic starts accelerating but slowing from congestion often results in rear-end crashes.	Congestion, Speed, and Sun at eye level in PM peak
Eastbound MP144.960 to MP145.416	Total crashes occurred - 36, Crash reports reviewed - 15. This is a majority of the tunnel segment. Traffic is congested, higher speed traffic encounters slowing and/or stopped traffic and a change in lighting conditions. The 7th St exit starts at the east end of the tunnel segment.	Congestion, Speed, and Differential lighting
Westbound MP144.960 to MP145.416	Total crashes occurred - 23, Crash reports reviewed - 15. This is a majority of the tunnel segment. Traffic is very congested, there is a curve in the tunnel and it may be challenging for motorists to be in the correct lane due to the change in lighting conditions. The 7th Ave exit that starts at the west end of the tunnel.	Congestion, Differential lighting, and Horizontal curve
Eastbound MP145.517 to MP145.776	Total crashes occurred -110, Crash reports reviewed - 15. There is a right-side lane drop prior to and a HOV entrance just east of this segment. This segment contains a right side lane merge area. Traffic experiences congestion with slowing or stopped traffic.	Congestion, Lane drop, Merging, and HOV entrance

Roadway Features/ Mile Post	Diagnostic Summary	Contributing Factors
Westbound MP145.517 to MP145.776	Total crashes occurred - 85, Crash reports reviewed - 15. High speed traffic encounters congestion of either slowing or stopped traffic approaching the tunnel. Motorists attempting to change lanes are often involved in crashes.	Congestion, and Lane changing
Eastbound MP145.777 to MP145.835	Total crashes occurred - 22, Crash reports reviewed - 15. There is a HOV entrance on this segment from 3rd St. There is a significant amount of lane-changing activities. Traffic slows and comes to sudden stop resulting in crashes.	Congestion, Lane changing, and HOV entrance
Westbound MP145.777 to MP145.835	Total crashes occurred - 22, Crash report reviewed - 15. This segment is just west of the 3rd St off-ramp. Higher speed traffic encounters slowing/stopped traffic.	Congestion and Speed
Eastbound MP145.937 to MP146.435	Total crashes occurred - 219, Crash reports reviewed - 15. This segment has a merging ramp from 7th St (add lane) and a exit ramp to 16th St. Relatively high speed traffic collides with slow and/or stopped traffic. Lane 4 is the critical location on this segment.	Congestion, Lane changing, and Weaving between merging and diverging traffic
Westbound MP145.937 to MP146.435	Total crashes occurred - 151, Crash reports reviewed - 15. This segment contains a one lane on ramp from 16th Street and two lane off ramp to 7th Street. Higher speed traffic encounters congestion. Some of these motorists collide with slowing or stopped vehicles.	Congestion, Weaving, and Speed
Eastbound MP146.436 to MP146.835	Total crashes occurred - 143, Crash reports reviewed - 15. This segment contains a HOV diverging lane to Loop 202 and the start of the diverging lanes to Loop 202 and SR-51 (two lanes must exit to Loop 202, and a third is an optional exit to SR-51). There is a significant amount of lane changing, weaving, and slowing. Higher speed traffic hits slowing traffic and/or stopped traffic.	Congestion, Speed, HOV entrance, and Lane changing
Westbound MP146.436 to MP146.835	Total crashes occurred - 75, Crash reports reviewed - 15. Traffic from southbound SR-51, westbound Loop 202, westbound I-10, and an additional left-side HOV lane from Loop 202 merge together. Higher speed traffic encounters a significant amount of lane changing and slowed traffic and often fails to stop in time.	Congestion, Speed, Lane changing, and HOV merging
Eastbound MP146.926 to MP147.520	Total crashes occurred - 70, Crash reports reviewed - 15. This segment is on a curve and ends prior to the on-ramp from southbound SR-51 and westbound Loop 202. Relatively high speed traffic hits slowed/congested traffic.	Congestion, Speed, Horizontal curve
Westbound MP146.926 to MP147.520	Total crashes occurred - 88, Crash reports reviewed - 15. The segment is on a curve and westbound I-10 traffic merges with on-ramp traffic from southbound SR 51 and westbound Loop 202 just west of this segment. There are lane changing activities, and relatively high speed traffic encounters slowed and/or stopped traffic.	Congestion, Speed, and Lane changing
Eastbound MP148.313 to MP148.422	Total crashes occurred - 8, Crash reports reviewed - 8. Traffic past the curve starts accelerating, and suddenly encounters the slowed and/or stopped traffic. This segment ends in advance of the Jefferson/Washington St on-ramp.	Congestion, and Speed
Westbound MP148.313 to MP148.422	Total crashes occurred - 17, Crash reports reviewed - 15. Traffic is very unstable, there is a left-side HOV diverging ramp to northbound SR-51 in this segment. The right side diverging ramp to northbound SR-51 and eastbound loop 202 is just north of this segment (one lane must exit and a second lane is an optional exit). Relatively high speed traffic encounters slowed and/or stopped traffic.	Speed, Lane changing, HOV diverging, and Weaving

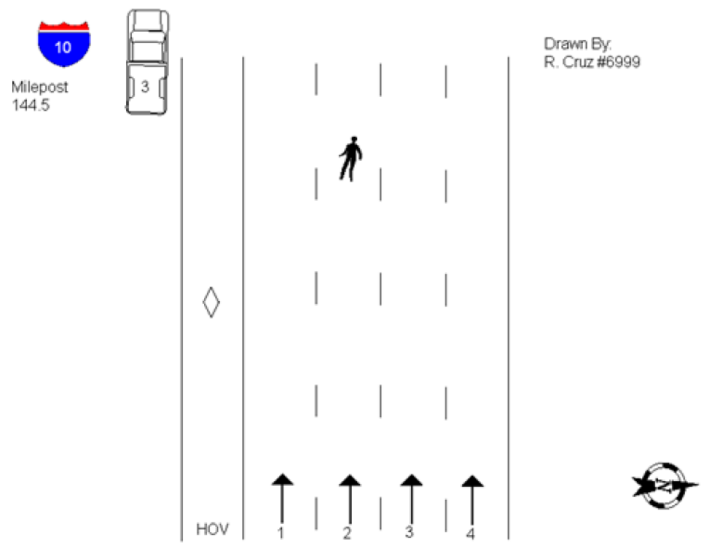
Roadway Features/ Mile Post	Diagnostic Summary	Contributing Factors
Both Directions - HOV associated I-17 to 7th St, MP143.67 to MP145.416, Westbound 5th Ave HOV Entrance, Westbound Loop 202 HOV Merging, and Eastbound 3rd St HOV Entrance	Total crashes occurred - 314, Crash reports reviewed - 84. Rear-end crashes due to motorists making a sudden lane change from lane 1 to HOV trying to skip congestion (18 crashes). 5th Ave, 3rd St, and Loop 202 HOV entrance motorists may not be not aware of mainline congestion and are involved in rear-end crashes near the merging area (5 crashes). Higher speed vehicles encounter slowed and/or stopped vehicles. Vehicles collide with lane-changing vehicle in the tunnel (38 crashes).	Open access to HOV, Congestion, Speed, and Uncontrolled HOV entrance
Both Directions - Lighting Effect Tunnel Influential area MP144.92 to MP145.516	Total crashes occurred - 574, Crash reports reviewed - 60. The position of the sun is at eye level for westbound west of tunnel & creates a vision problem (3 crashes). Drivers drift to the adjacent lane due to lighting differential and a curve in the tunnel (5 crashes). Drivers lose control (2 crashes).	Differential lighting, Sun position, and Horizontal curve
Westbound Weaving, Sky Harbor Blvd to Washington St, MP148.43 to MP148.659	Total crashes occurred - 73, Crash reports reviewed - 30. Significant amount of lane changing activities occur (10 crashes). Rear end collisions occur due to slowed/stopped traffic (20 crashes). Sideswipe is also another dominating crash type. Of the 30 crashes, 20 occurred in right two lanes.	Speed, Lane changing, and Weaving
Eastbound Lane Drop, Washington/Jefferson St, MP147.966 to MP148.312	Total crashes occurred - 37, Crash reports reviewed - 21. Rear-end collisions due to lane drop and congestion downstream (4 crashes). Last minute merging vehicles also sideswipe vehicles in lane 3 at lane drop. 13 of 21 crashes occurred in right two lanes.	Congestion, Speed, and Lane drop
Eastbound 35th Ave Entrance to 27th Ave Exit, MP141.92 to MP142.925	Total crashes occurred - 189, Crash reports reviewed - 28. Traffic encounters stop-and-go condition due to congestion resulting in rear-end collisions (10 crashes). Sideswipe crashes involving lane changing (10 crashes).	Congestion, Speed, and Lane changing
Westbound 27th Ave Entrance to 35th Ave Exit MP141.936 to MP142.417	Total crashes occurred - 126, Crash reports reviewed - 49. This segment contains an add-lane from 27th Ave (lane #6) that exits at the 35th Ave off-ramp. There is an additional lane drop west of the 35th Ave exit. Traffic from I-17 involved in rear-end and sideswipe crashes due to lane changing and congestion (8 crashes). Traffic from westbound I-10 starts speeding up and encounters slowed merging traffic (39 crashes).	Congestion, Speed, Lane changing, and Merging traffic
Westbound Weaving, 16th St Entrance to 7th St Exit , MP145.837 to MP146.835	Total crashes occurred - 261, Crash reports reviewed - 40. There is an add-lane from 16th Street on-ramp that terminates at the 7th Street exit. Two lanes must exit at 7th St. Higher speed traffic encounters slow traffic (26 crashes). Lane changing traffic involved in rear-end and sideswipe collisions due to congestion (12 crashes).	Lane Changing, Congestion, and Speed
Eastbound Weaving, 1360 feet west of 16th St to SR-51 & Loop 202 HOV Exit, MP146.436 to MP146.925	Total crashes occurred - 172, Crash reports reviewed - 42. This segment contains a left side HOV exit and right-side advance exit lanes for Loop 202 (two lanes) and one optional exit lane for SR-51. Higher speed vehicles encounter slowing traffic and stop-and-go traffic which results in rear-end crashes (33 crashes). Weaving and lane changing traffic also involved in rear-end collisions (7 crashes).	Congestion, Speed, Weaving, and Lane changing
Eastbound Lane Drop, East of 7th St Exit, MP145.42 to MP145.776	Total crashes occurred - 146, Crash reports reviewed - 15. This segment begins at the lane drop starting 400 feet east of the tunnel and contains the merge area, and ends at the left-side HOV on-ramp. Traffic in lane 4 and lane 5 involved in rear-end crashes from congestion due to merging traffic (4 crashes).	Congestion, Speed, and Lane changing
Westbound Lane Drop West of 7th Ave Exit MP144.42 to MP144.919	Total crashes occurred - 188, Crash reports reviewed - 18. This segment starts at the right-side lane drop starting 180 feet west of 5th Ave and contains the merge area. The segment ends at the left-side HOV on-ramp from 5th Ave. After leaving the tunnel traffic starts accelerating, but due to congestion from the reduction in lanes, traffic slows. There is lane changing at the lane drop (6 crashes).	Congestion, Speed, and Lane drop

APPENDIX F – FATAL AND SERIOUS INJURY CRASH DETAILS

Fatal Crash Locations:



Fatal Crash Summaries

ID: 2595077 Date: 03/03/2012 (Saturday) Time: 0:12 am Total Injuries: 0 Total Fatalities: 1 Units involved: 3 Conditions: Dark-lighted, Clear, Dry, Level Manner of Impact: Other Travel direction: EB / V2, V3 - WB Lane: HOV Description: None V1: Pedestrian D1: DOB 1984 Action: Walking against traffic Officer Estimated Speed: Unknown Violation: Walked on wrong side of road / Other Note: Drug test results = 1 V2: Unknown D2: Unknown Action: Unknown Officer Estimated Speed: Unknown Violation: Unknown Note: None V3: 2005 Ford Sedan D2: DOB: 1957 Action: Going straight Officer Estimated Speed: 65 mph Violation: None Note: None	 Reviewer comments: Possible roadway factors: None Possible driver factors: Yes – Inattention, drugs? Possible vehicle factors: None Possible environmental factor: None Congestion related: No

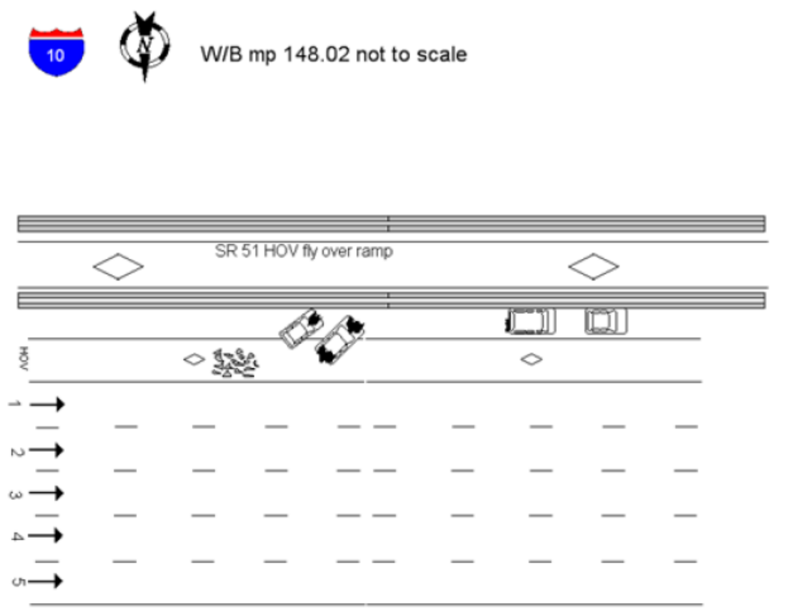
ID: 2599442
Date: 04/12/2012 (Thursday)
Time: 5:08 pm
Total Injuries: 4
Total Fatalities: 1
Units involved: 4
Conditions: Daylight, Cloudy, Dry, Level
Manner of Impact: Rear-End
Travel direction: WB
Lane: HOV
Description: None

V1: 2000 Dodge Sedan
- D1: DOB 1927
- Action: Going straight
- Officer Estimated Speed: 65 mph
- Violation: Speed too fast for conditions
- Note: Condition: Other

V2: 2008 Infinity Sedan
- D2: DOB 1976
- Action: Stopped in Traffic
- Officer Estimated Speed: Unknown
- Violation: None
- Note: None

V3: 2012 Dodge Caravan
- D2: DOB 1959
- Action: Stopped in Traffic
- Officer Estimated Speed: Unknown
- Violation: None
- Note: None

V4: 2008 Toyota Sedan
- D2: DOB 1975
- Action: Going straight
- Officer Estimated Speed: 50 mph
- Violation: None
- Note: None



Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes – Inattention, Speed, Age related capability (visual recognition) to drive
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

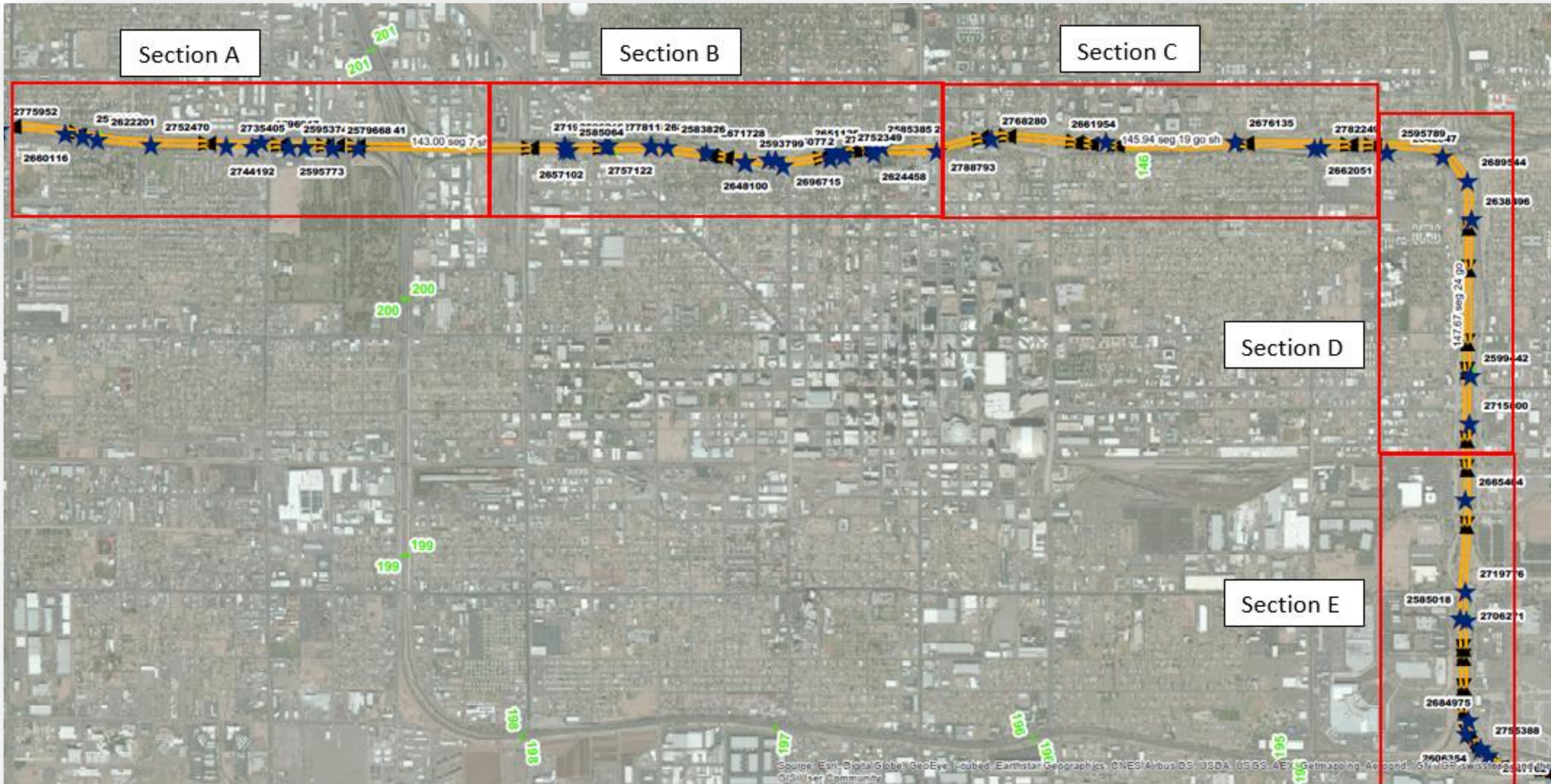
ID: 2660116 (MP:140.1) Date: 10/24/2012 (Wednesday) Time: 10:30 am Total Injuries: 0 Total Fatalities: 1 Units involved: 4 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Other Travel direction: EB (D1) / WB Lane: 3 / 4 Description: None V1: 2008 Freightliner Tractor Trailer D1: DOB 1971 Action: Going straight Officer Estimated Speed: 65 mph Violation: None Note: Motor Vehicle: Wheels V2: 1999 Jeep Sedan D2: DOB 1990 Action: Going straight Officer Estimated Speed: 65 mph Violation: None Note: None (Fatal Injury) V3: 2011 International Tractor Trailer D2: DOB 1959 Action: Going straight Officer Estimated Speed: 45 mph Violation: None Note: None V4: 2012 Kia Sedan D2: DOB 1972 Action: Going straight Officer Estimated Speed: 65 mph Violation: None Note: None	Reviewer comments: Possible Roadway factors: None Possible driver factors: None Possible vehicle factors: Yes Possible environmental factor: None Congestion related: No

ID: 2676135 (MP: 145.6) Date: 11/15/2012 (Thursday) Time: 4:47 am Total Injuries: 0 Total Fatalities: 1 Units involved: 2 Conditions: Dark lighted, Clear, Dry, Level Manner of Impact: Other Travel direction: WB Lane: 3 / 2 Description: None V1: Pedestrian D1: DOB 1985 Action: Crossing road Officer Estimated Speed: Unknown Violation: Walking on wrong side of road Note: Alcohol V1: 1997 Mitsubishi Truck D1: DOB 1985 Action: Going straight Officer Estimated Speed: 60 mph Violation: None Note: None	Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes Possible vehicle factors: None Possible environmental factor: None Congestion related: No

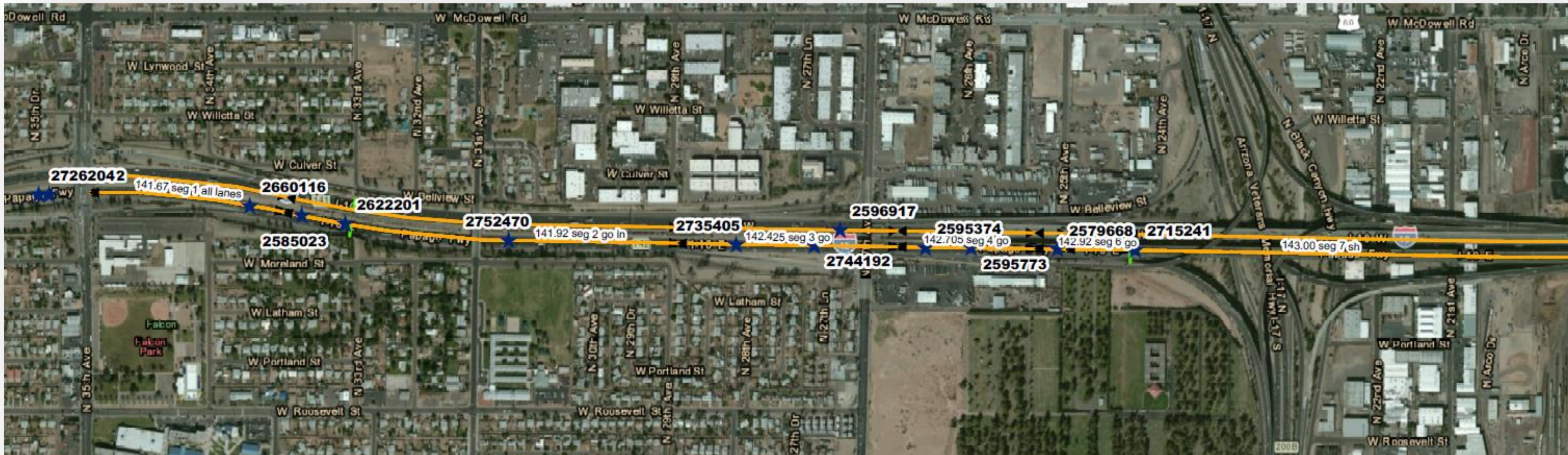
ID: 2689544 (MP: 146.65) Date: 12/15/2012 (Saturday) Time: 12:11 pm Total Injuries: 0 Total Fatalities: 1 Units involved: 1 Conditions: Daylight, Rain, Wet, Level Manner of Impact: Single vehicle Travel direction: WB Lane: 3 Description: None V1: 2000 GMC Sedan D1: DOB 1983 Action: Negotiating a curve Officer Estimated Speed: 70 mph Violation: Speed too fast for conditions Note: Drug/alcohol test given	Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes (speeding) Possible vehicle factors: None Possible environmental factor: Yes (wet) Congestion related: No

ID: 2735405 (MP: 142.5) Date: 06/13/2013 (Friday) Time: 9:29 pm Total Injuries: 0 Total Fatalities: 1 Units involved: 1 Conditions: Dark lighted, Clear, Dry, Uphill Manner of Impact: Single vehicle Travel direction: EB Lane: 4 Description: None V1: 2001 Dodge Pickup D1: DOB 1967 Action: Unknown Officer Estimated Speed: Unknown Violation: Unknown Note: Drug blood test given	Reviewer comments: Possible Roadway factors: No Possible driver factors: Yes (drugs, inattention) Possible vehicle factors: None Possible environmental factor: None Congestion related: No

Serious Injury Crash Locations

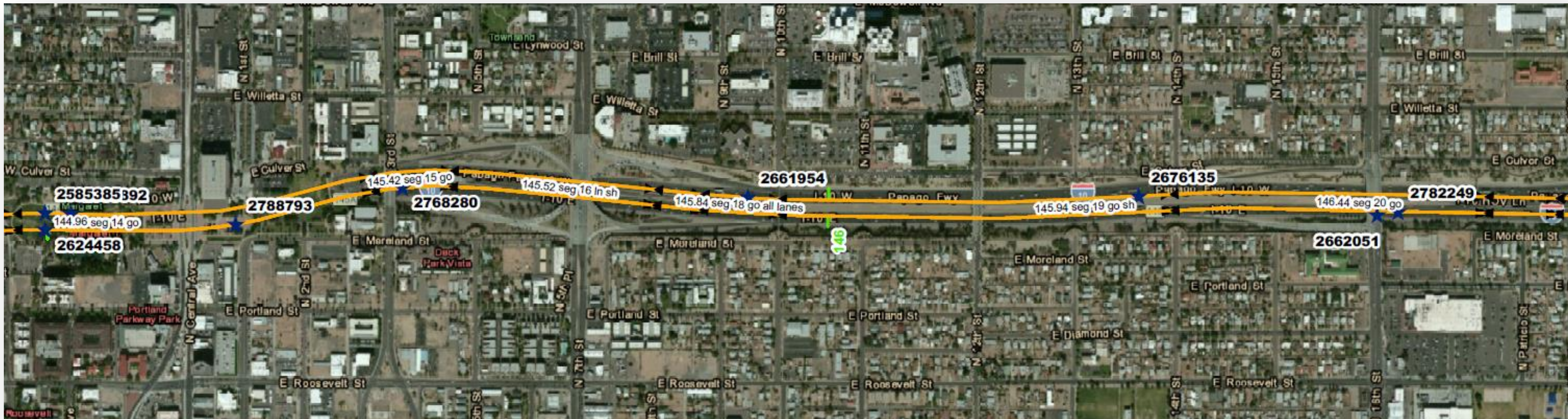


- ***Section A***



- ***Section B***

- ***Section C***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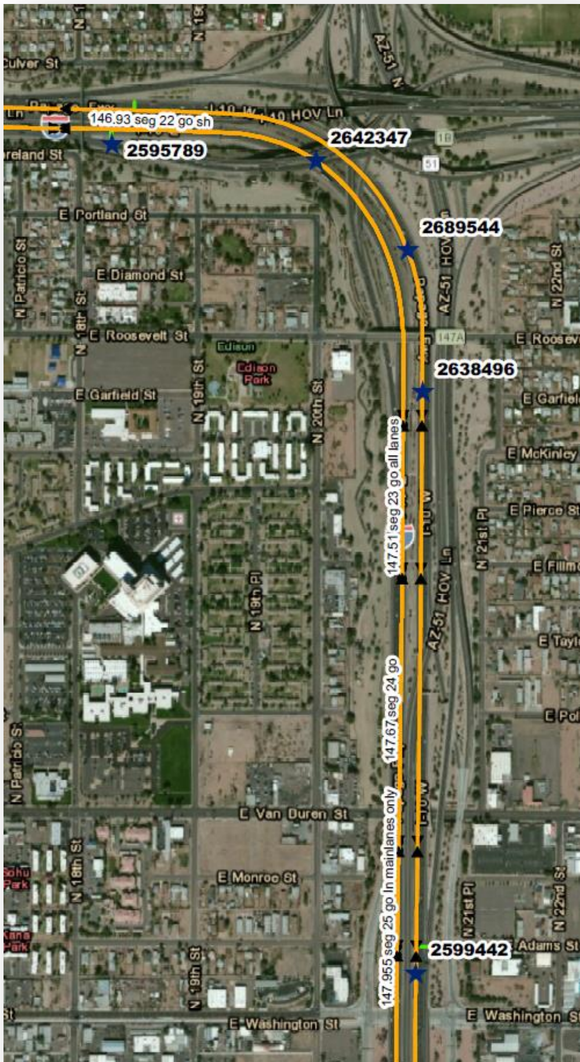
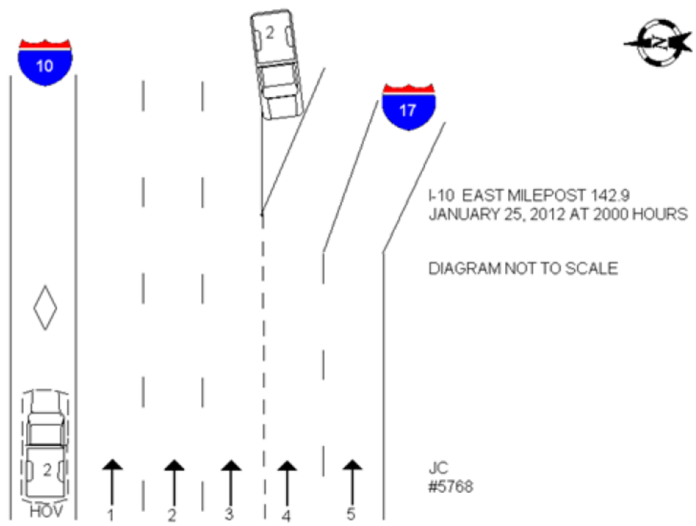
146.44 seg 20 go

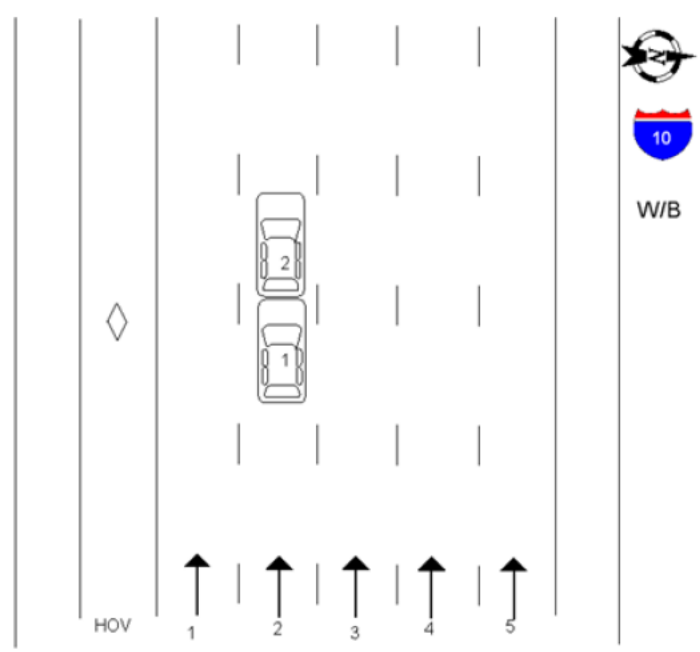


▪ *Section D*

▪ *Section E*

Serious Injury Crash Summaries

ID: 2579668 Date: 01/25/2012 (Wednesday) Time: 8:00 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 2 Conditions: Dark – Lighted, Clear, Dry, Level Manner of Impact: Unknown Travel direction: EB Lane: HOV Description: None V1: Unknown D1: Unknown Action: Unknown Officer Estimated Speed: Unknown Violation: Unknown Note: None V2: 1996 Dodge Pickup D2: DOB 1948 Action: Going Straight Officer Estimated Speed: 40 mph Violation: Unknown Note: None	 Reviewer comments: Possible roadway factors: None Possible driver factors: Unknown Possible vehicle factors: None Possible environmental factor: None Congestion related: No

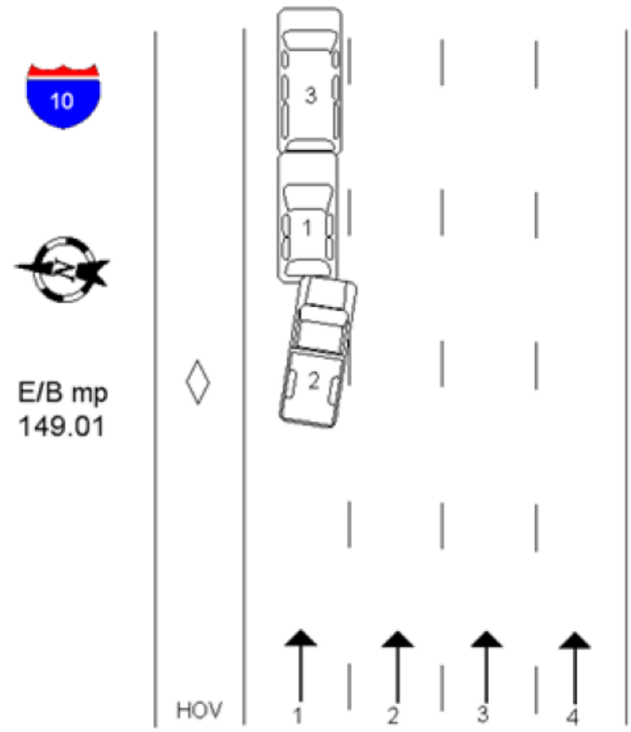
ID: 2583826 (MP: 143.8) Date: 01/19/2012 (Thursday) Time: 4:33 pm Total Injuries: 2 Total Fatalities: 0 Units involved: 2 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Rear-End Travel direction: WB Lane: 2 Description: D1 left the scene. Few days later reported that D1 was distracted by police vehicle. V1: 1993 Hyundai Sedan D1: DOB 1968 Action: Going straight Officer Estimated Speed: Unknown Violation: Inattention / Distraction Note: D1 left the scene. Few days later D1 reported he was distracted by police vehicle to his right, which stopped another vehicle. V2: 2008 Chevrolet Sedan D2: DOB 1980 Action: Stop in traffic Officer Estimated Speed: Unknown Violation: None Note: None	 Reviewer comments: Possible roadway factors: None Possible driver factors: Yes - distraction Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

ID: 2585018
Date: 02/22/2012 (Wednesday)
Time: 5:58 pm
Total Injuries: 1
Total Fatalities: 0
Units involved: 3
Conditions: Dusk, Clear, Dry, Level
Manner of Impact: Rear-end
Travel direction: EB
Lane: 1
Description: None

V1: 2001 Mitsubishi sedan
- D1: 1994
- Action: Going straight
- Officer Estimated Speed: 5 mph
- Violation: Speed too fast for conditions
- Note: None

V2: 1994 Chevrolet Pickup
- D2: DOB 1962
- Action: Going straight
- Officer Estimated Speed: 50 mph
- Violation: Speed too fast for conditions
- Note: None

V3: 2001 Ford VAN
- D2: DOB 1971
- Action: Going straight
- Officer Estimated Speed: 5 mph
- Violation: None
- Note: None

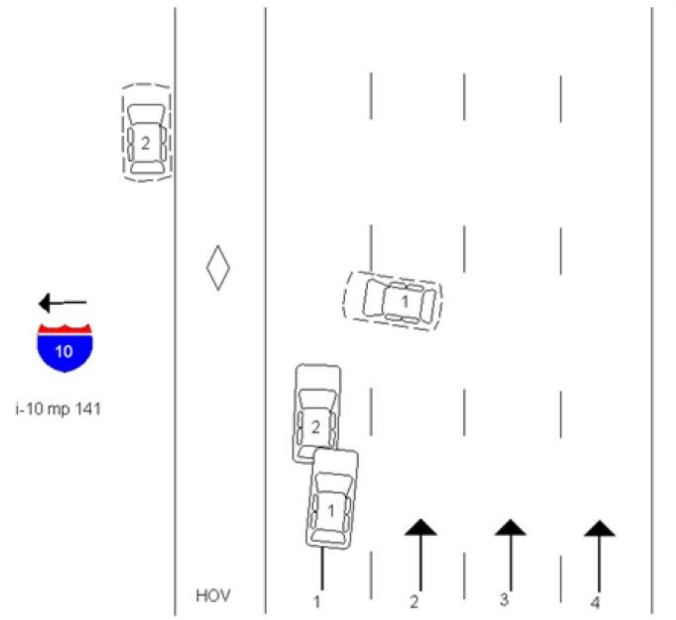


Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes - Inattention
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

ID: 2585023
Date: 02/22/2012 (Wednesday)
Time: 8:35 am
Total Injuries: 2
Total Fatalities: 0
Units involved: 2
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Rear-end
Travel direction: EB
Lane: 1
Description: D1 tried to change lanes possible to avoid collision

V1: 2007 Mazda Sedan
- D1: DOB 1989
- Action: Going straight
- Officer Estimated Speed: 65 mph
- Violation: Speed too fast for conditions
- Note: None

V2: 2011 Mercedes Sedan
- D2: DOB 1981
- Action: Slowing in traffic
- Officer Estimated Speed: 15 mph
- Violation: None
- Note: None



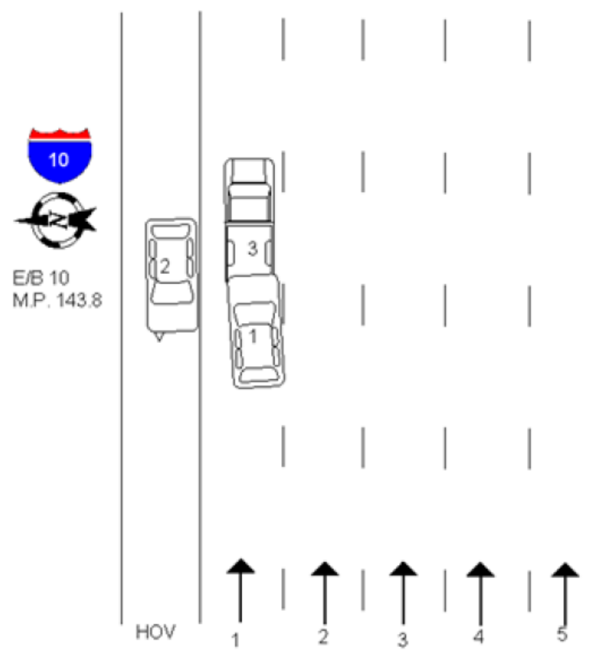
Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes - Inattention
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

ID: 2585064
Date: 02/20/2012 (Monday)
Time: 3:24 pm
Total Injuries: 2
Total Fatalities: 0
Units involved: 3
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Rear-end
Travel direction: EB
Lane: 1
Description: None

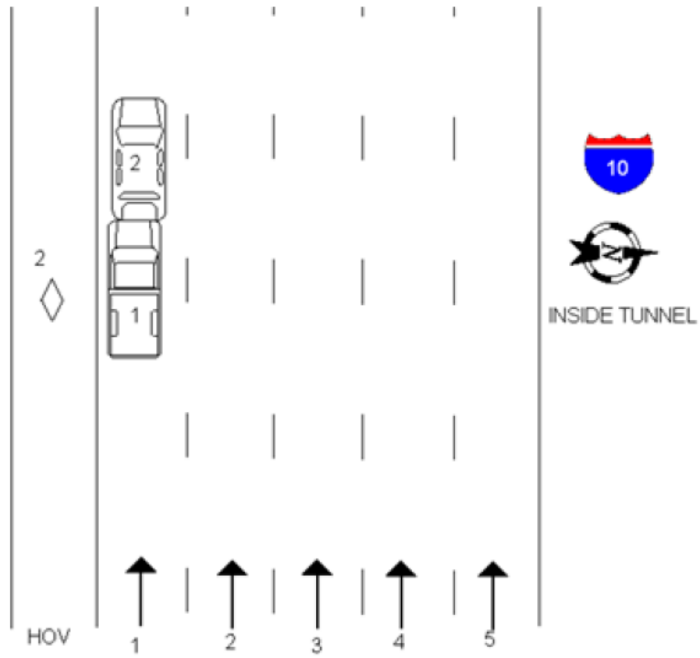
V1: 2010 Chevrolet Sedan
- D1: 1964
- Action: Going straight
- Officer Estimated Speed: 55 mph
- Violation: Speed too fast for conditions
- Note: None

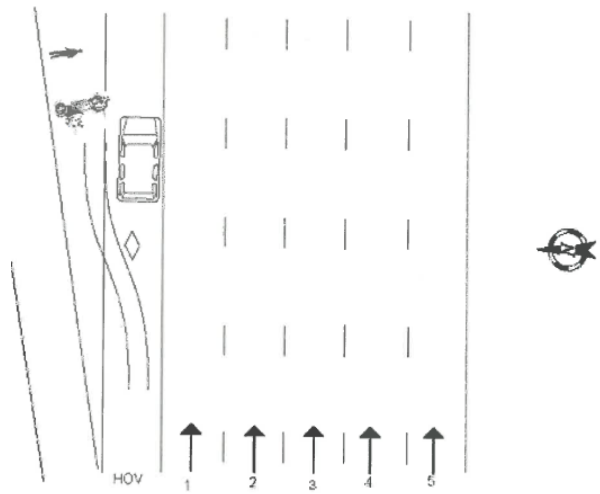
V2: 2005 Kia Sedan
- D2: DOB 1976
- Action: Stopped in traffic
- Officer Estimated Speed: None
- Violation: None
- Note: None

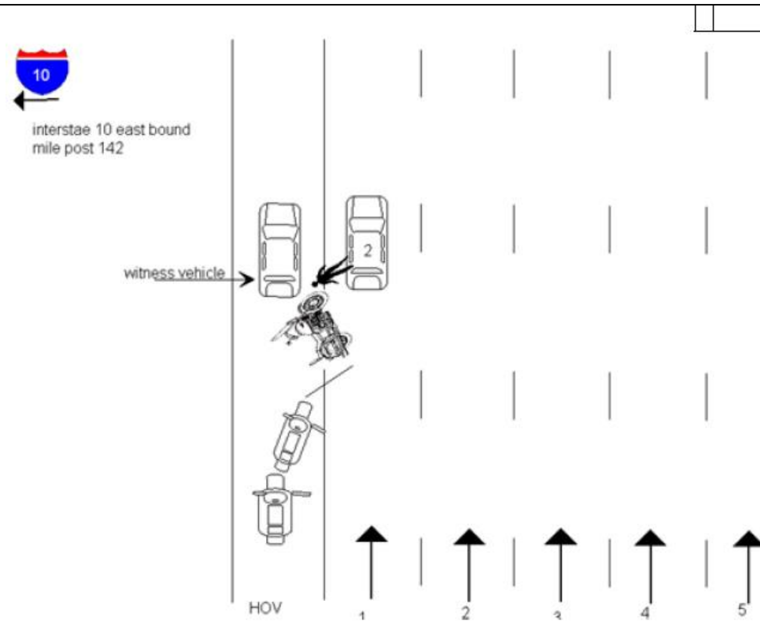
V3: 2004 Chevrolet Pickup
- D2: DOB 1965
- Action: Stopped in traffic
- Officer Estimated Speed: None
- Violation: None
- Note: None



Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes - Inattention
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

ID: 2585385 (MP: 145) Date: 02/24/2012 (Friday) Time: 9:30 am Total Injuries: 2 Total Fatalities: 0 Units involved: 2 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Rear-end Travel direction: WB Lane: 1 Description: None V1: 2007 Dodge Pickup D1: DOB 1938 Action: Changing Lanes Officer Estimated Speed: 60 mph Violation: Speed too fast for conditions Note: None V2: 2012 Toyota Camry D2: DOB 1960 Action: Slowing in traffic Officer Estimated Speed: 55 mph Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes - Inattention Possible vehicle factors: None Possible environmental factor: None (crash location: Tunnel) Congestion related: Yes

ID: 2593799 (MP: 144.5) Date: 03/14/2012 (Saturday) Time: 5:11 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 1 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Single vehicle Travel direction: EB Lane: HOV Description: None V1: 2011 Harley Motorcycle D1: DOB 1963 Action: Going straight Officer Estimated Speed: 65 mph Violation: Speed too fast for conditions Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes – Inattention Possible vehicle factors: None Possible environmental factor: None Congestion related: No

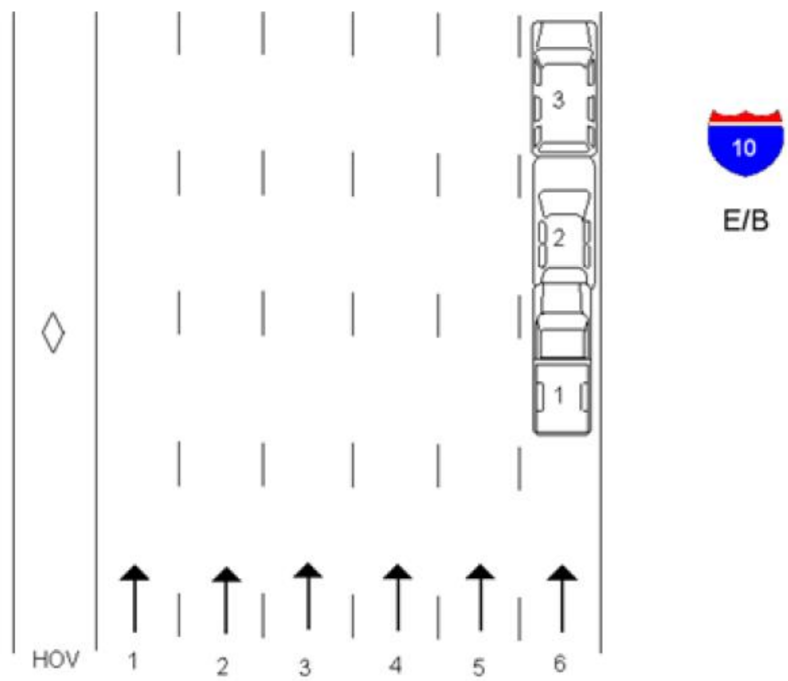
ID: 2595374 Date: 03/27/2012 (Tuesday) Time: 7:50 am Total Injuries: 1 Total Fatalities: 0 Units involved: 2 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Other Travel direction: EB Lane: HOV / 1 Description: Motorcyclist followed too close. D2 applied brakes due to traffic. D1 lost control V1: 2011 Suzuki Motorcycle D1: DOB 1990 Action: Going straight Officer Estimated Speed: 40 mph Violation: Speed too fast for conditions Note: None V2: 2009 Nissan Sedan D2: DOB 1969 Action: Slowing in Traffic Officer Estimated Speed: 20 mph Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes-Inattention Possible vehicle factors: None Possible environmental factor: None Congestion related: No

ID: 2595773 (MP:142.8)
Date: 03/30/2012 (Friday)
Time: 2:53 pm
Total Injuries: 2
Total Fatalities: 0
Units involved: 3
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Rear-End
Travel direction: EB
Lane: 6
Description: None

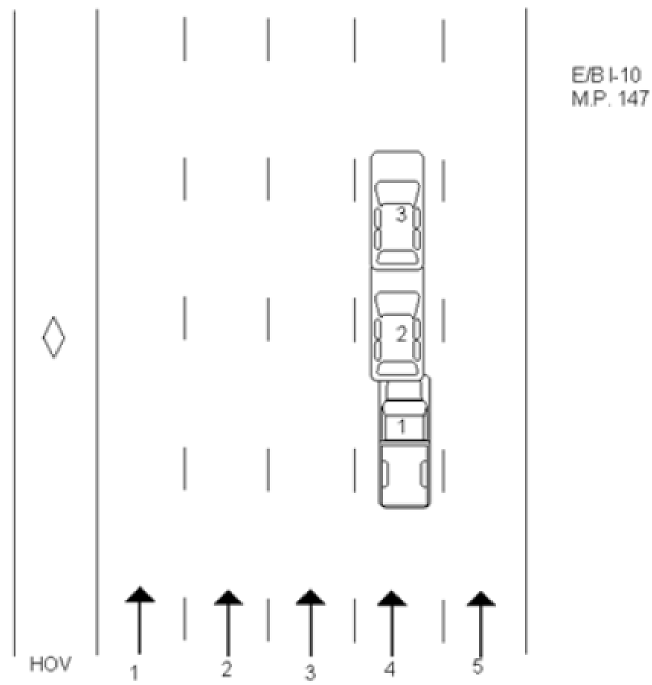
V1: 2008 Dodge Pickup
D1: DOB 1983
Action: Changing Lanes
Officer Estimated Speed: 30 mph
Violation: Speed too fast for conditions
Note: None

V2: 2002 Dodge Sedan
D2: DOB 1957
Action: Stopped in Traffic
Officer Estimated Speed: Unknown
Violation: None
Note: None

V3: 2002 Chrysler Sedan
D2: DOB 1993
Action: Stopped in Traffic
Officer Estimated Speed: Unknown
Violation: None
Note: None



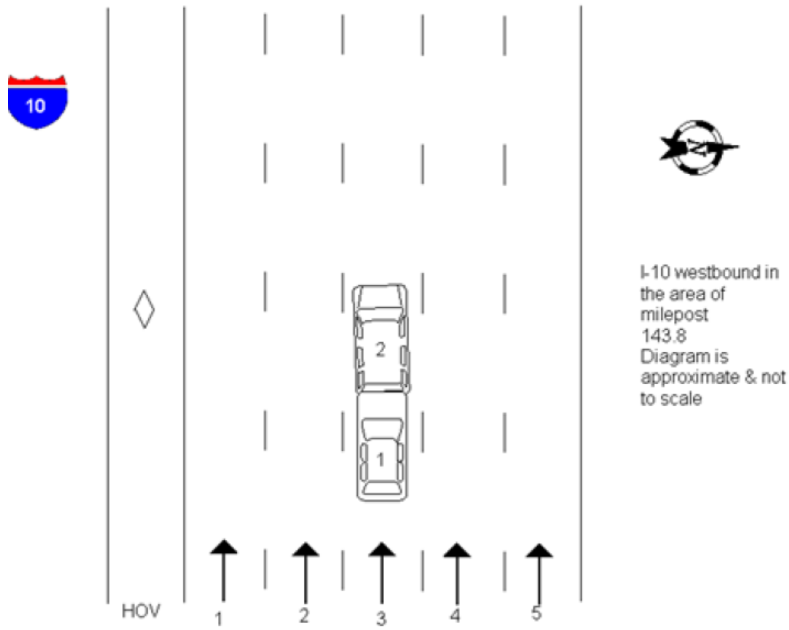
Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes-Inattention
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

ID: 2595789 Date: 03/28/2012 (Wednesday) Time: 4:03 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 3 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Rear-End Travel direction: EB Lane: 4 Description: None V1: 2000 GMC Pickup D1: DOB 1993 Action: Going straight Officer Estimated Speed: 40 mph Violation: Speed too fast for conditions Note: None V2: 2004 Dodge Sedan D2: DOB 1985 Action: Stopped in Traffic Officer Estimated Speed: Unknown Violation: None Note: None V3: 2004 Acura Sedan D2: DOB 1988 Action: Stopped in Traffic Officer Estimated Speed: Unknown Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes-Inattention Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

ID: 2596216
Date: 03/27/2012 (Tuesday)
Time: 9:43 pm
Total Injuries: 3
Total Fatalities: 0
Units involved: 2
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Rear-End
Travel direction: WB
Lane: 3
Description: None

V1: Hyundai Sedan
- D1: DOB 1987
- Action: Going straight
- Officer Estimated Speed: 40 mph
- Violation: Speed too fast for conditions
- Note: None

V2: 2008 Ford Sedan
- D2: DOB 1957
- Action: Slowing in Traffic
- Officer Estimated Speed: 15 mph
- Violation: None
- Note: None



Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes-Inattention
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

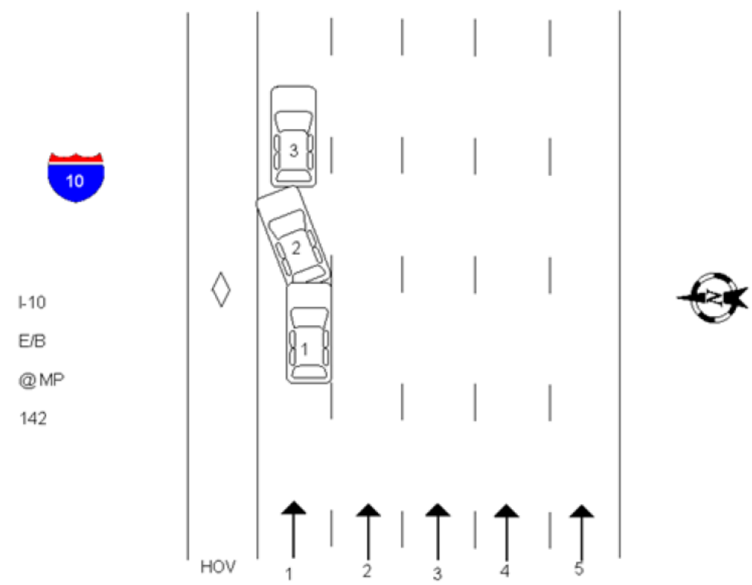
ID: 2596917 Date: 03/27/2012 (Tuesday) Time: 4:05 pm Total Injuries: 2 Total Fatalities: 0 Units involved: 1 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Single vehicle Travel direction: WB Lane: 3 Description: None V1: 2010 Kawasaki Motorcycle D1: DOB 1992 Action: Going straight Officer Estimated Speed: 40 mph Violation: Speed too fast for conditions Note: None	Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes-Inattention, speed Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes (?)

ID: 2622201
Date: 06/21/2012 (Thursday)
Time: 8:24 pm
Total Injuries: 1
Total Fatalities: 0
Units involved: 3
Conditions: Daylight, Cloudy, Dry, Level
Manner of Impact: Rear-End
Travel direction: EB
Lane: 1
Description: None

V1: 2008 Nissan Sedan
- D1: DOB 1956
- Action: Going straight
- Officer Estimated Speed: 55 mph
- Violation: Speed too fast for conditions
- Note: Condition: Other

V2: 2002 Honda Sedan
- D2: DOB 1983
- Action: Stopped in Traffic
- Officer Estimated Speed: Unknown
- Violation: None
- Note: None

V3: 2012 Toyota Sedan
- D2: DOB 1990
- Action: Stopped in Traffic
- Officer Estimated Speed: Unknown
- Violation: None
- Note: None



Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes – Inattention, speed
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

ID: 2624458 (MP: 145)
Date: 07/09/2012 (Monday)
Time: 4:23 pm
Total Injuries: 3
Total Fatalities: 0
Units involved: 5
Conditions: Daylight, Cloudy, Dry, Level
Manner of Impact: Rear-End
Travel direction: EB
Lane: 4 / 3
Description: None

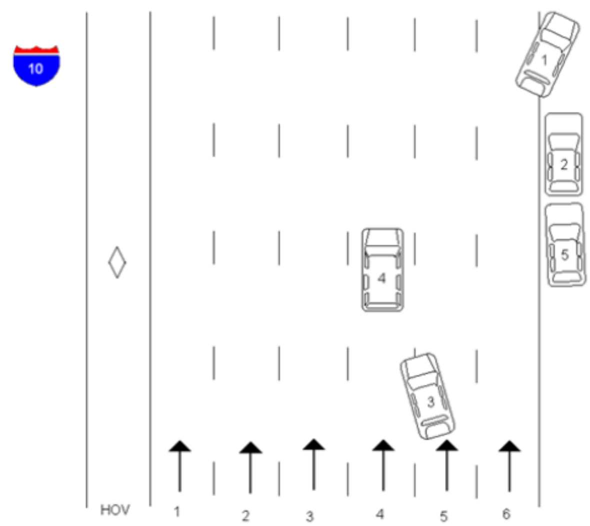
V1: 2001 Buick Sedan
- D1: DOB 1957
- Action: Going straight
- Officer Estimated Speed: 65 mph
- Violation: Speed too fast for conditions
- Note: Condition: Other

V2: 1993 Honda Sedan
- D2: DOB 1961
- Action: Going straight
- Officer Estimated Speed: 65 mph
- Violation: Speed too fast for conditions
- Note: None

V3: 2010 Chrysler Sedan
- D2: DOB 1972
- Action: Going straight
- Officer Estimated Speed: 65 mph
- Violation: Speed too fast for conditions
- Note: None

V4: 2001 Jeep Sedan
- D2: DOB 1987
- Action: Stopped in traffic
- Officer Estimated Speed: Unknown
- Violation: None
- Note: None

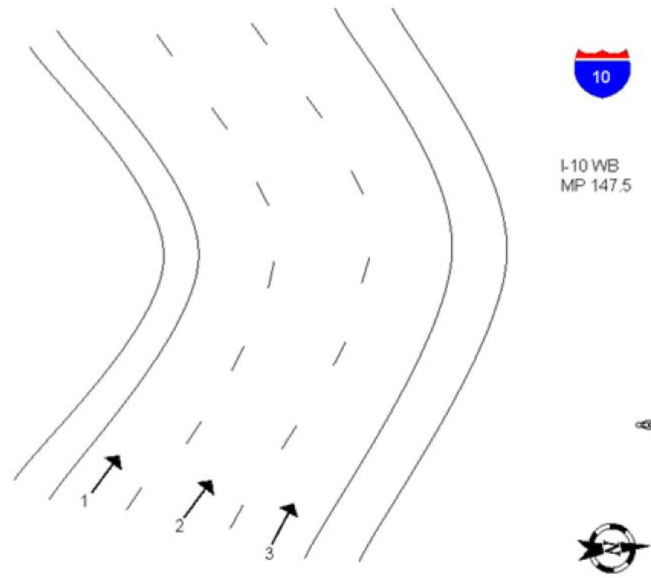
V5: 2007 Toyota Sedan
- D2: DOB 1984
- Action: Stopped in traffic
- Officer Estimated Speed: Unknown
- Violation: None
- Note: None



Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes – Inattention, speed
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

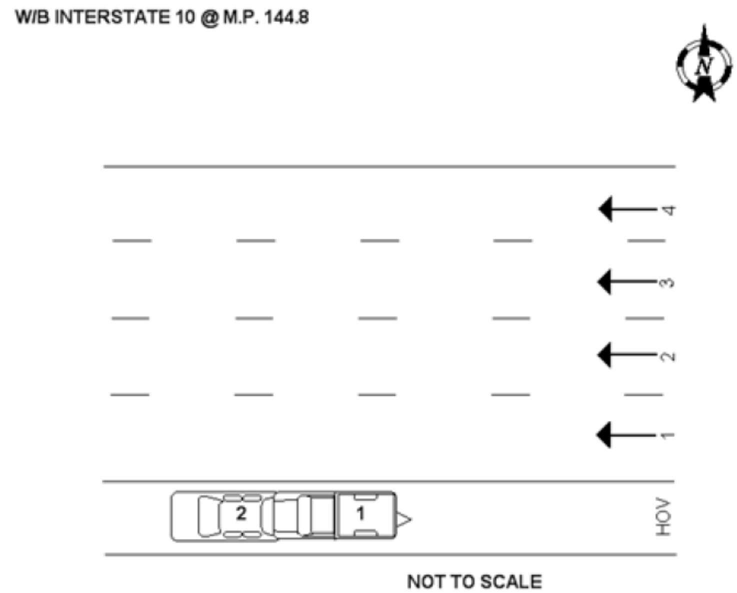
ID: 2638496
Date: 08/10/2012 (Friday)
Time: 11:40 pm
Total Injuries: 1
Total Fatalities: 0
Units involved: 1
Conditions: Dark - lighted, Clear, Dry, Level
Manner of Impact: Single vehicle
Travel direction: WB
Lane: 3
Description: Roadway curve left.

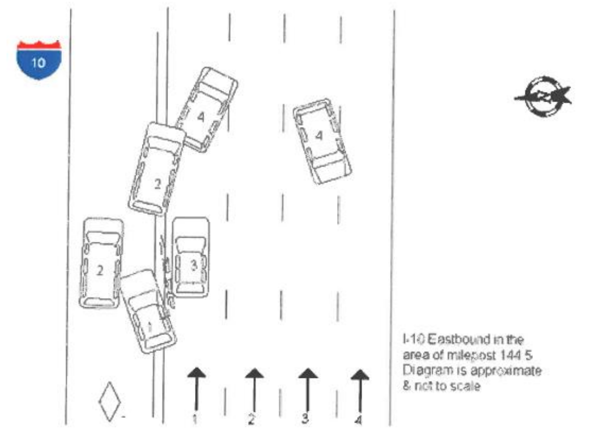
V1: 2012 Yamaha motorcycle
D1: DOB 1976
Action: Avoiding vehicle/object/ped/cyclist
Officer Estimated Speed: 75 mph
Violation: Speed too fast for conditions
Note: None

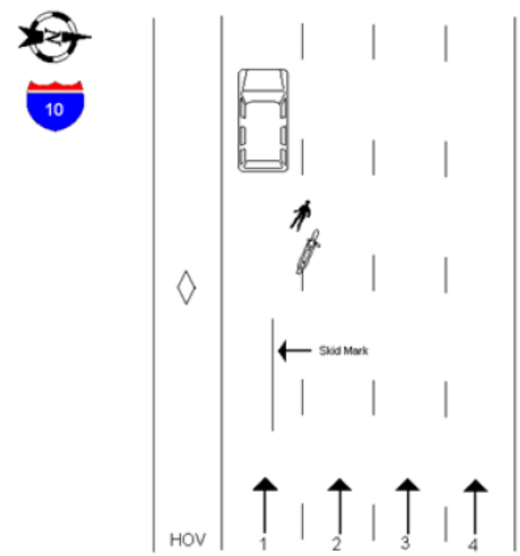


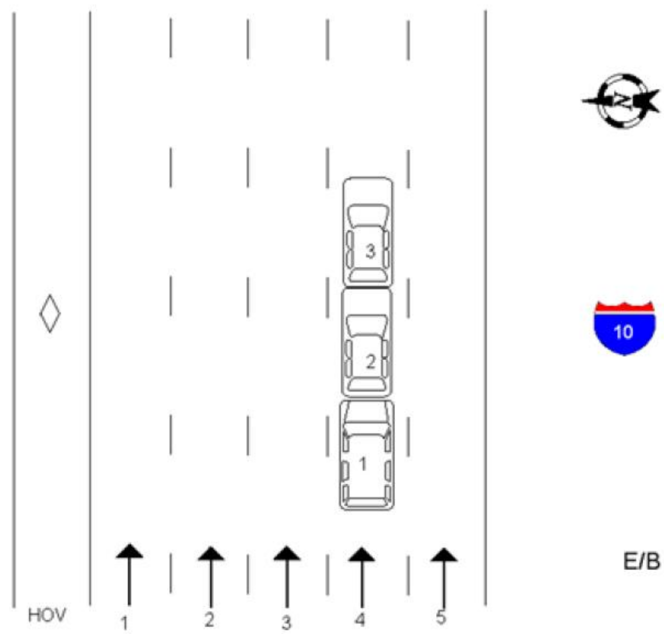
Reviewer comments:
Possible Roadway factors: Yes (Curve)
Possible driver factors: Yes – Inattention, speed
Possible vehicle factors: None
Possible environmental factor: None (report: moving vehicle)
Congestion related: No

ID: 2642347 Date: 07/19/2012 (Thursday) Time: 6:57 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 1 Conditions: Dusk, Cloudy, Dry, Downhill Manner of Impact: Single vehicle Travel direction: EB Lane: Non-roadway Description: None V1: 2003 Suzuki Motorcycle D1: DOB 1979 Action: Negotiating a curve Officer Estimated Speed: 45 mph Violation: Speed too fast for conditions Note: None	Reviewer comments: Possible Roadway factors: None (alignment – curve right) Possible driver factors: Yes – Inattention, speed Possible vehicle factors: None Possible environmental factor: None Congestion related: No

ID: 2651125 Date: 09/25/2012 (Tuesday) Time: 7:16 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 2 Conditions: Dark-lighted, Clear, Dry, Uphill Manner of Impact: Rear-End Travel direction: WB Lane: HOV Description: D2 applied brakes to stop. D1 tried to stop but did not have enough time. V1: 2006 Chevrolet 3500 D1: DOB 1988 Action: Going straight Officer Estimated Speed: 40 mph Violation: Speed too fast for conditions Note: None V2: 2012 Chevrolet Sedan D2: DOB 1974 Action: Stopped in traffic Officer Estimated Speed: Unknown Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes – Inattention, speed Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

ID: 264810 Date: 09/17/2012 (Monday) Time: 8:09 am Total Injuries: 3 Total Fatalities: 0 Units involved: 4 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Angle Travel direction: EB Lane: 1 / HOV / 1 Description: None V1: 2003 Toyota Sedan D1: DOB 1963 Action: Slowing in traffic Officer Estimated Speed: 40 mph Violation: Speed too fast for conditions Note: None V2: 2001 Dodge Van D2: DOB 1984 Action: Going straight Officer Estimated Speed: 55 mph Violation: None Note: None V3: 2005 Honda Sedan D2: DOB 1994 Action: Stopped in traffic Officer Estimated Speed: 40 mph Violation: None Note: None V4: 2012 Ford Sedan D2: DOB 1948 Action: Going straight Officer Estimated Speed: 55 mph Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes – Inattention, speed Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

ID: 2661954 (MP: 144.1) Date: 10/29/2012 (Monday) Time: 6:49 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 2 Conditions: Dark Lighted, Clear, Dry, Level Manner of Impact: Rear-end Travel direction: WB Lane: HOV / 1 Description: Changed lanes from HOV into 1. Traffic stopped in lane 1. D1 did not have enough time to stop. V1: 2006 Yamaha Motorcycle D1: DOB 1993 Action: Changing lanes Officer Estimated Speed: Unknown Violation: Speed too fast for conditions Note: None V2: 2010 Lexus Sedan D2: DOB 1959 Action: Slowing in traffic Officer Estimated Speed: Unknown Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes (inattention) Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

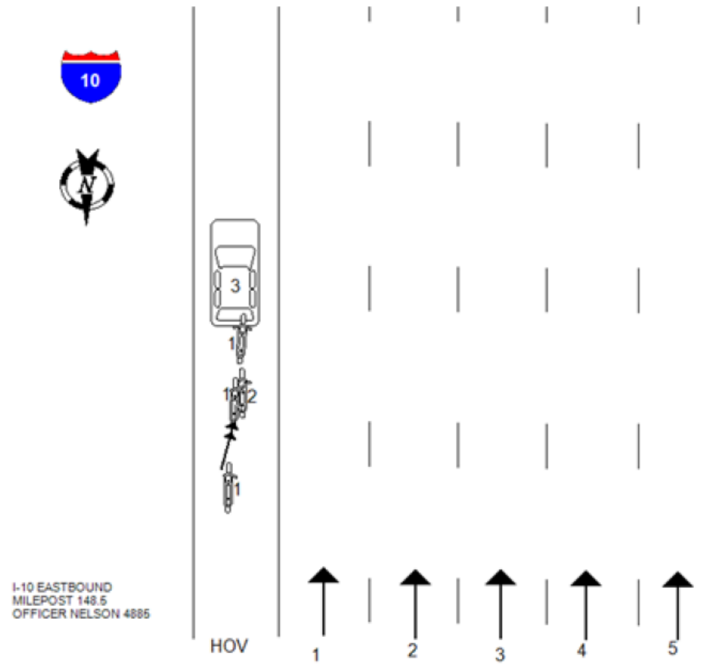
ID: 2662051 (MP: 146.7) Date: 10/31/2012 (Monday) Time: 4:54 pm Total Injuries: 3 Total Fatalities: 0 Units involved: 3 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Rear-end Travel direction: EB Lane: 4 Description: Traffic abruptly stopped in front of D1. D1 applied brake as well as gas. V1: 2002 Mitsubishi sedan D1: DOB 1976 Action: Slowing in traffic Officer Estimated Speed: 35 mph Violation: Other Note: None V2: 2007 Ford Sedan D2: DOB 1962 Action: Stopped in traffic Officer Estimated Speed: Unknown Violation: None Note: None V3: 2006 Volkswagen Sedan D2: DOB 1973 Action: Stopped in traffic Officer Estimated Speed: Unknown Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

ID: 2665404
Date: 11/15/2012 (Thursday)
Time: 5:40 pm
Total Injuries: 2
Total Fatalities: 0
Units involved: 3
Conditions: Dusk, Cloudy, Dry, Level
Manner of Impact: Sideswipe, same direction
Travel direction: EB
Lane: HOV
Description: Vehicle in front of D1 in the HOV swerved into the shoulder. D1 observed other vehicle stopped in HOV lane. D1 tried to avoid impact, sideswiped D2 and hit V3.

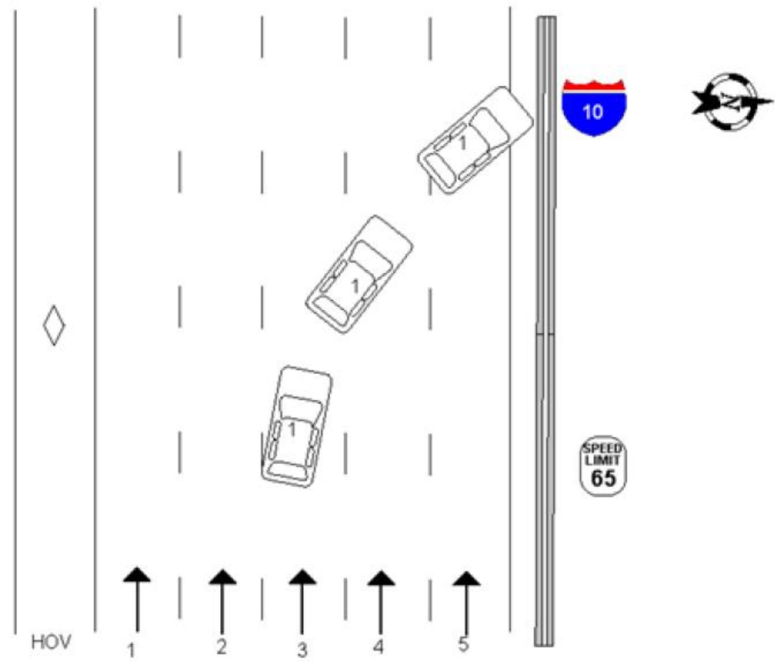
V1: 2009 Harley Motorcycle
D1: DOB 1961
Action: Going straight
Officer Estimated Speed: Unknown
Violation: Speed too fast for condition, inattention/distraction
Note: None

V2: 2009 Harley Motorcycle
D2: DOB 1957
Action: Slowing in traffic
Officer Estimated Speed: Unknown
Violation: None
Note: None

V3: 1993 Chevrolet Sedan
D2: DOB 1962
Action: Stopped in traffic
Officer Estimated Speed: Unknown
Violation: None
Note: None



Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

ID: 2665932 (MP: 143.38) Date: 11/11/2012 (Sunday) Time: 2:55 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 1 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Single vehicle Travel direction: WB Lane: 3 Description: None V1: 1996 Acura Sedan D1: DOB 1992 Action: Going straight Officer Estimated Speed: 65 mph Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes Possible vehicle factors: None Possible environmental factor: None Congestion related: No

<table>
<tr>
<td>
ID: 2671728
Date: 11/23/2012 (Friday)
Time: 4:15 am
Total Injuries: 1
Total Fatalities: 0
Units involved: 1
Conditions: Dark lighted, Clear, Dry, Level
Manner of Impact: Single vehicle
Travel direction: WB
Lane: HOV
Description: None

V1: 2006 Pontiac Sedan
D1: DOB 1992
Action: Going straight
Officer Estimated Speed: 85 mph
Violation: Speed too fast for condition
Note: Fell asleep/fatigued
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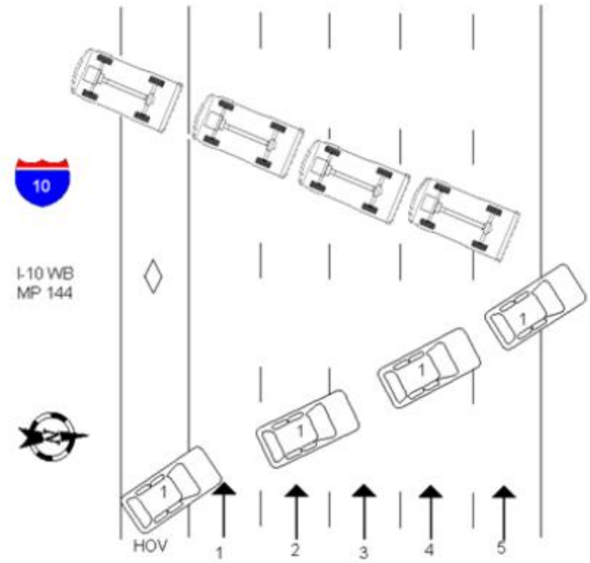

Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: No
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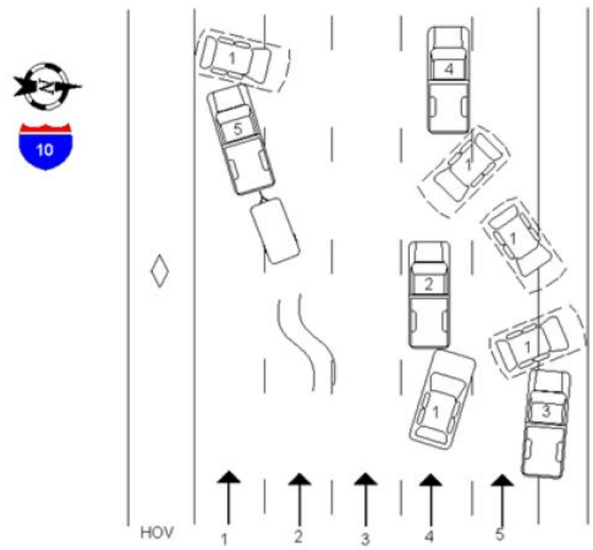
ID: 2689512 (MP:143.87)
Date: 01/19/2013 (Saturday)
Time: 9:35 am
Total Injuries: 3
Total Fatalities: 0
Units involved: 5
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Rear-end
Travel direction: WB
Lane: 4 / Unknown / 1
Description: D3 (in lane 5) observed D1 passing by at higher rate of speed (in lane 4). D3 observed D1 brake hard and swerved toward lane 5 in front of D3 and collided with D2.

V1: 2005 Toyota Sedan
- D1: DOB 1973
- Action: Going straight
- Officer Estimated Speed: 50 mph
- Violation: Speed too fast for conditions
- Note: D1 does not remember the collision

V2: Unknown
- D1: Unknown
- Action: Slowing in traffic
- Officer Estimated Speed: Unknown
- Violation: Unknown
- Note: fled the scene

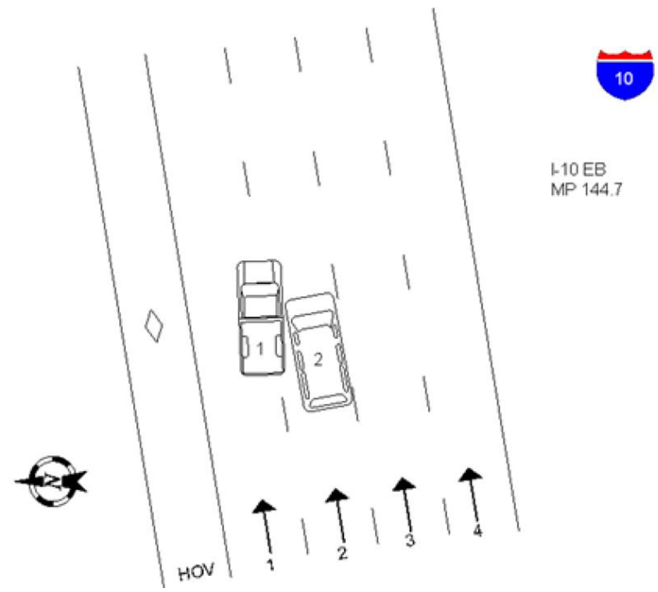
V3: 2011 Chevrolet Pickup
- D1: DOB 1960
- Action: Slowing in traffic
- Officer Estimated Speed: 50 mph
- Violation: None
- Note: None

V4: 2012 Toyota Pickup
- D1: DOB 1958
- Action: Going straight
- Officer Estimated Speed: 40 mph
- Violation: None
- Note: None



Reviewer comments:
Possible Roadway factors: None
Possible driver factors: Yes
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: No/Yes

V5: 2003 Chevrolet Pickup D1: DOB: 1983 Action: Going straight Officer Estimated Speed: 65 mph Violation: None Note: None	

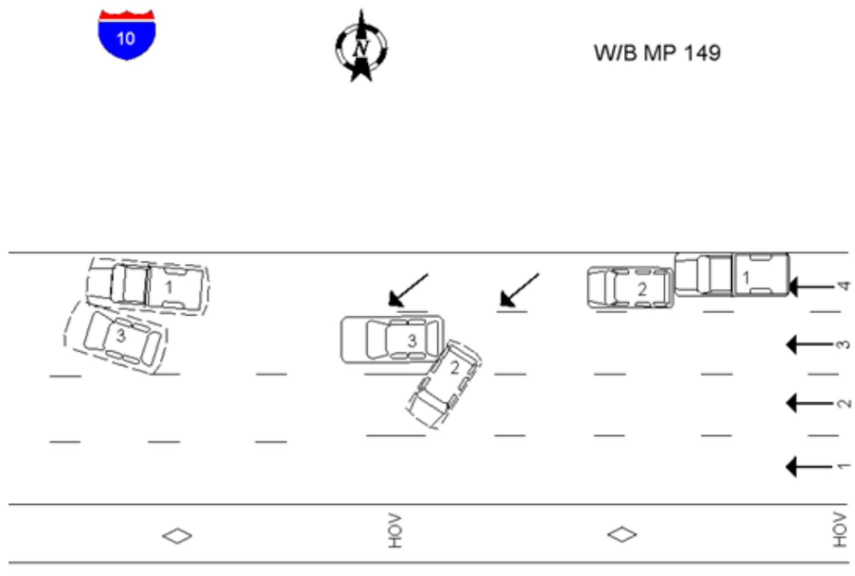
ID: 2696715 Date: 02/23/2013 (Saturday) Time: 03:30 am Total Injuries: 2 Total Fatalities: 0 Units involved: 2 Conditions: Dark lighted, Clear, Dry, Level Manner of Impact: Sideswipe same direction Travel direction: EB Lane: 1 / 2 Description: D1 turn right and sideswipe V2. V1: 2003 Chevrolet Pickup D1: DOB 1990 Action: Changing lanes Officer Estimated Speed: 60 mph Violation: Unsafe passing Note: None V2: 2010 Kia Sedan D1: DOB 1956 Action: Going Straight Officer Estimated Speed: 60 mph Violation: None Note: None	 Reviewer comments: Possible Roadway factors: None Possible driver factors: Yes (inattention) Possible vehicle factors: None Possible environmental factor: None Congestion related: No

ID: 2706271
Date: 03/21/2013 (Thursday)
Time: 03:29 pm
Total Injuries: 1
Total Fatalities: 0
Units involved: 3
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Rear-end
Travel direction: WB
Lane: 3 / 4 / 3
Description: Changing Road Width. Warning Sign present. D1 changed lanes from 1 into 2 and then into 3. When changing lanes into lane 4,traffic stopped abruptly in front of D1. D1 attempt to brake but struck V2 at 55 mph. Before the impact, D2 applied brakes to slow down due to traffic in front. Heavy traffic. Lane drop.

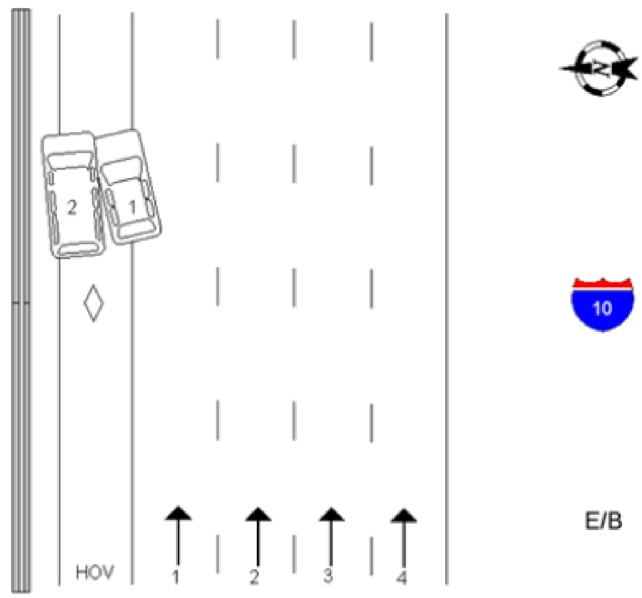
V1: 1997 Chevrolet Pickup
- D1: DOB 1981
- Action: Changing lanes
- Officer Estimated Speed: 55 mph
- Violation: Speed too fast for conditions
- Note: None

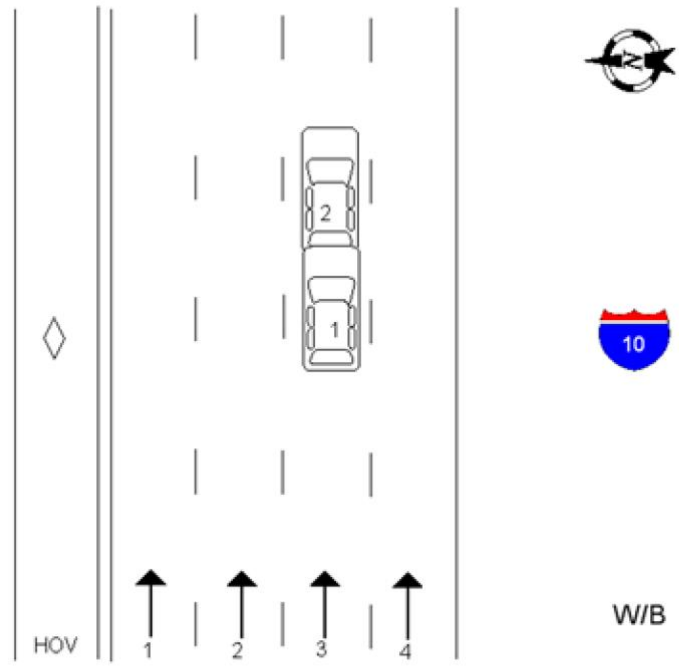
V2: 2007 Hyundai SUV
- D1: DOB 1968
- Action: Slowing in traffic
- Officer Estimated Speed: 10 mph
- Violation: None
- Note: None

V2: 2003 Hyundai Sedan
- D1: DOB 1977
- Action: Slowing in traffic
- Officer Estimated Speed: 5 mph
- Violation: None
- Note: None



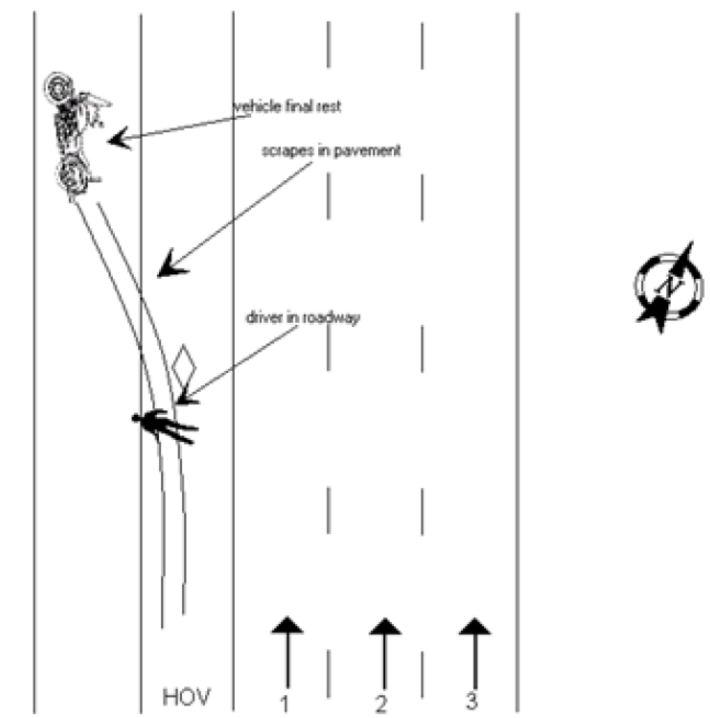
Reviewer comments:
Possible Roadway factors: Yes (lane drop)
Possible driver factors: Yes (inattention)
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

ID: 2715241 (MP: 143) Date: 04/19/2013 (Friday) Time: 03:13 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 2 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Sideswipe same direction Travel direction: EB Lane: HOV Description: D2 stated that he was in HOV. D1 changed from lane 1 into HOV (to avoid impacting another vehicle in lane 1) and collided with V2. V1: 2003 Volkswagen Sedan D1: DOB 1993 Action: Changing lanes Officer Estimated Speed: 50 mph Violation: Speed too fast for conditions Note: None V2: 2013 Toyota Sedan D1: DOB 1958 Action: Going straight Officer Estimated Speed: 60 mph Violation: None Note: None	 Reviewer comments: Possible Roadway factors: No Possible driver factors: Yes (inattention) Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

ID: 2715800 (MP: 147.8) Date: 04/25/2013 (Thursday) Time: 6:33 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 2 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Rear-end Travel direction: WB Lane: 3 Description: Traffic in front of D1 slowed down. D1 applied brakes but could not stop. V1: 2012 Chrysler Sedan D1: DOB 1956 Action: Going straight Officer Estimated Speed: 50 mph Violation: Inattention/Distraction Note: None V2: 2009 Honda Sedan D1: DOB 1975 Action: Stopped in traffic Officer Estimated Speed: 30 mph Violation: None Note: None	 Reviewer comments: Possible Roadway factors: No Possible driver factors: Yes (inattention) Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

ID: 2719776 (MP: 147.15)
Date: 04/19/2013 (Friday)
Time: 2:58 pm
Total Injuries: 1
Total Fatalities: 0
Units involved: 1
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Single vehicle
Travel direction: WB
Lane: HOV
Description: None

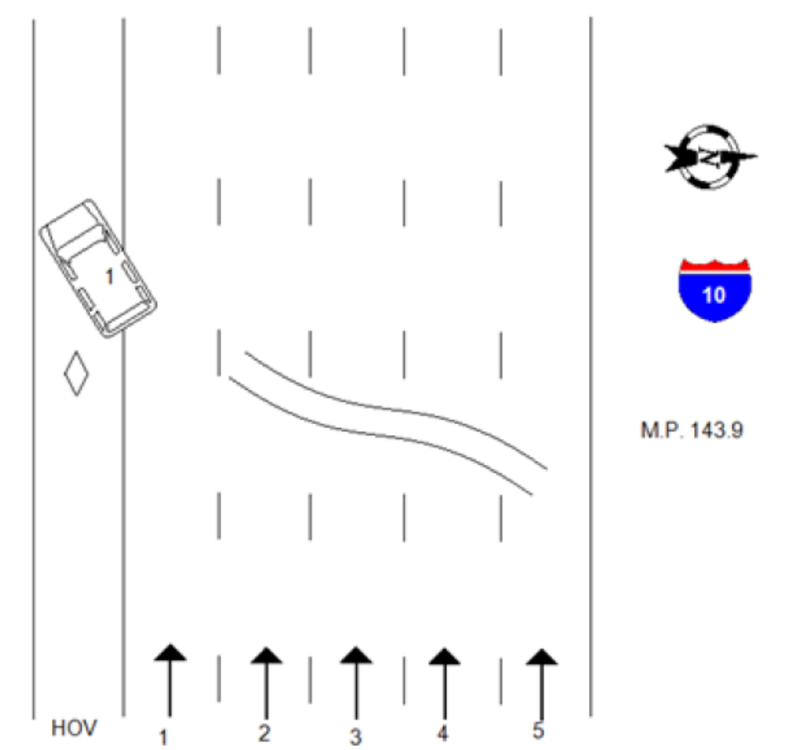
V1: 2006 Yamaha Motorcycle
- D1: DOB 1954
- Action: Going straight
- Officer Estimated Speed: 45 mph
- Violation: Speed too fast for conditions
- Note: None



Reviewer comments:
Possible Roadway factors: No
Possible driver factors: Yes (inattention, speed)
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: No

ID: 2719871
Date: 03/29/2013 (Friday)
Time: 10:35 pm
Total Injuries: 1
Total Fatalities: 0
Units involved: 1
Conditions: Dark lighted, Clear, Dry, Level
Manner of Impact: Single vehicle
Travel direction: WB
Lane: 5
Description: D1 lost control, veered left and hit concrete wall.

V1: 2002 Chevrolet Sedan
D1: DOB 1988
Action: Going straight
Officer Estimated Speed: 65 mph
Violation: Unknown
Note: Alcohol

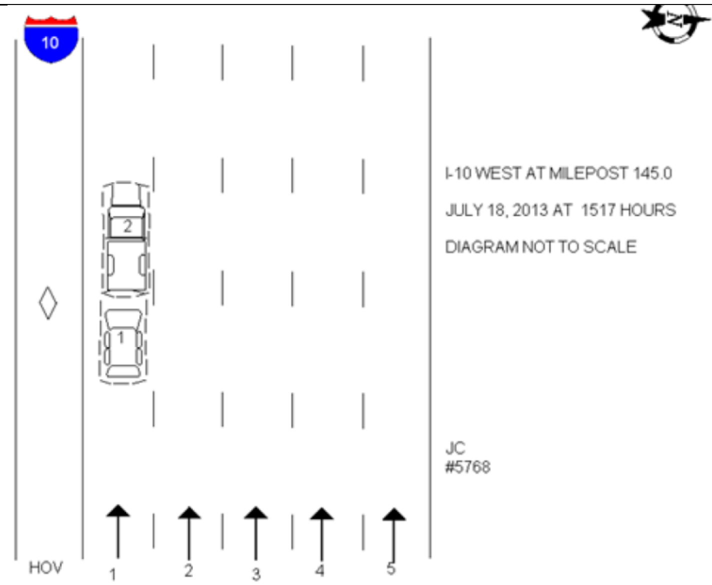


Reviewer comments:
Possible Roadway factors: No
Possible driver factors: Yes (inattention, speed, alcohol)
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: No

ID: 2738892
Date: 07/18/2013 (Thursday)
Time: 3:17 pm
Total Injuries: 3
Total Fatalities: 0
Units involved: 2
Conditions: Daylight, Cloudy, Dry, Level
Manner of Impact: Rear-end
Travel direction: WB
Lane: 1
Description: Environmental factor: stopped/parked vehicle

V1: 1996 Ford Sedan
- D1: DOB 1992
- Action: Slowing in traffic
- Officer Estimated Speed: 50 mph
- Violation: Speed too fast for conditions
- Note: None

V2: 2006 Chevrolet Pickup
- D1: DOB 1971
- Action: Slowing in traffic
- Officer Estimated Speed: 20 mph
- Violation: None
- Note: None



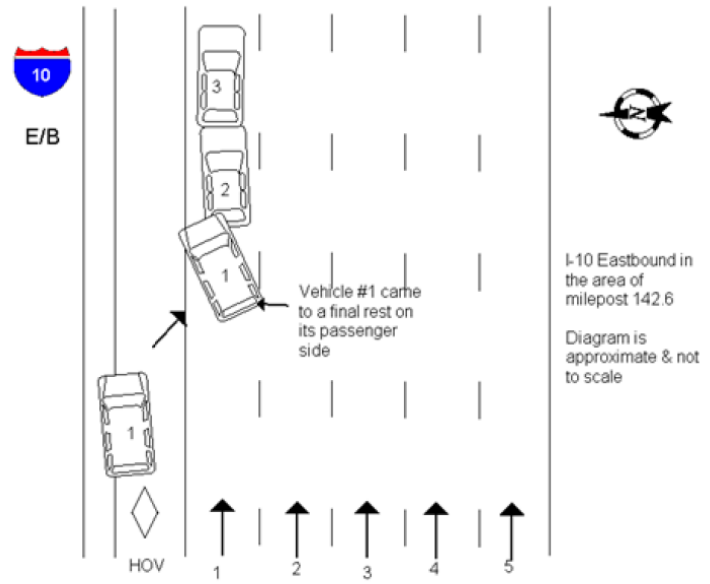
Reviewer comments:
Possible Roadway factors: No
Possible driver factors: Yes (inattention)
Possible vehicle factors: None
Possible environmental factor: Yes (stopped/parked vehicle)
Congestion related: Yes

ID: 2744192
Date: 07/22/2013 (Monday)
Time: 7:20 am
Total Injuries: 1
Total Fatalities: 0
Units involved: 3
Conditions: Daylight, Clear, Dry, Uphill
Manner of Impact: Rear-end
Travel direction: EB
Lane: 1
Description: None

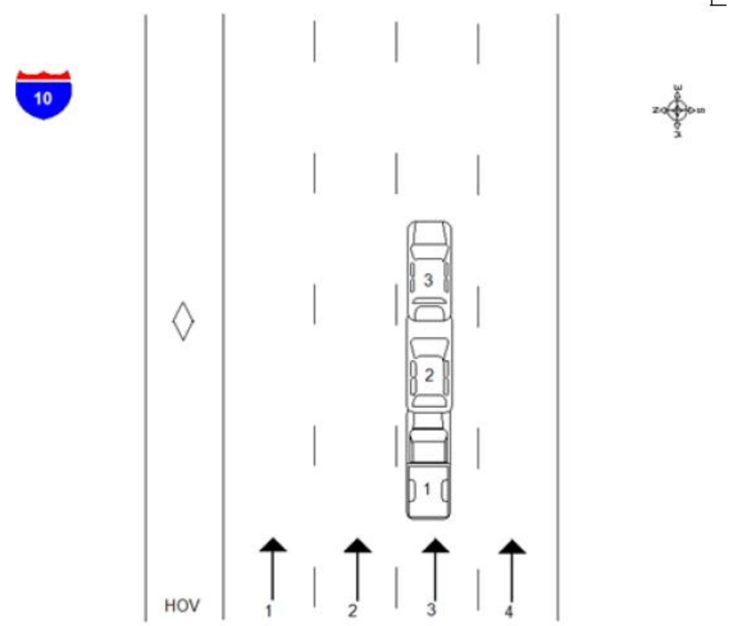
V1: 1995 Ford Sedan
D1: DOB 1990
Action: Going straight
Officer Estimated Speed: 50 mph
Violation: Speed too fast for conditions
Note: None

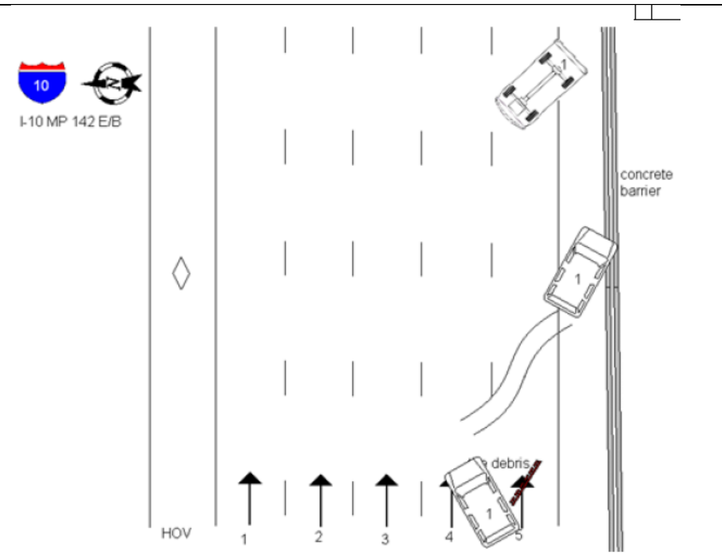
V2: 2003 Chevrolet Sedan
D1: DOB 1956
Action: Slowing in traffic
Officer Estimated Speed: 10 mph
Violation: None
Note: None

V3: 2010 Hyundai Sedan
D1: DOB 1953
Action: Slowing in traffic
Officer Estimated Speed: 10 mph
Violation: None
Note: None



Reviewer comments:
Possible Roadway factors: No
Possible driver factors: Yes (inattention)
Possible vehicle factors: None
Possible environmental factor: None
Congestion related: Yes

ID: 2752349 (MP: 144.88) Date: 08/16/2013 (Friday) Time: 5:20 pm Total Injuries: 1 Total Fatalities: 0 Units involved: 3 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Rear-end Travel direction: EB Lane: 3 Description: Traffic stopped suddenly in front of D1. D1 tried to brake but could not stop. V1: 1998 Ford Pickup D1: DOB 1981 Action: Going straight Officer Estimated Speed: 65 mph Violation: Speed too fast for conditions Note: None V2: 2000 Ford Sedan D1: DOB 1990 Action: Stopped in traffic Officer Estimated Speed: Unknown Violation: None Note: None V3: 2002 Saturn Sedan D1: DOB 1976 Action: Stopped in traffic Officer Estimated Speed: Unknown Violation: None Note: None	 Reviewer comments: Possible Roadway factors: No Possible driver factors: Yes (inattention, speeding) Possible vehicle factors: None Possible environmental factor: None Congestion related: Yes

ID: 2752470 Date: 09/03/2013 (Tuesday) Time: 6:39 am Total Injuries: 3 Total Fatalities: 0 Units involved: 1 Conditions: Daylight, Clear, Dry, Level Manner of Impact: Single vehicle Travel direction: EB Lane: 5 Description: D1 tried to avoid piece of tire/debris in the roadway. Lost control. V1: 1998 Ford SUV D1: DOB 1966 Action: Avoiding vehicle/object/ped/cyclist Officer Estimated Speed: 50 mph Violation: Speed too fast for conditions Note: None	 Reviewer comments: Possible Roadway factors: No Possible driver factors: Yes (inattention) Possible vehicle factors: None Possible environmental factor: Yes (debris) Congestion related: No

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<td>
ID: 2757122
Date: 08/29/2013 (Thursday)
Time: 8:51 pm
Total Injuries: 1
Total Fatalities: 0
Units involved: 1
Conditions: Dark lighted, Clear, Dry, Level
Manner of Impact: Single vehicle
Travel direction: WB
Lane: HOV
Description: None

V1: 2005 Chrysler Van
D1: DOB 1949
Action: Unknown
Officer Estimated Speed: 50 mph
Violation: Speed too fast for conditions
Note: Fell Asleep/Fatigue
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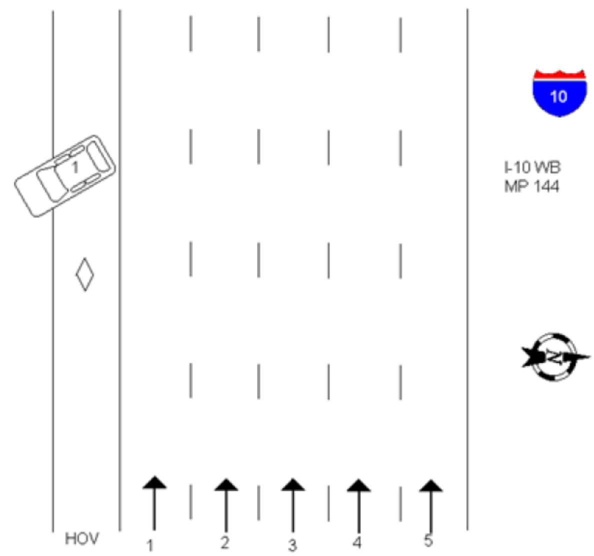
<td>


Reviewer comments:
Possible Roadway factors: No
Possible driver factors: Yes (inattention, fatigue)
Possible vehicle factors: None
Possible environmental factor: No
Congestion related: No
</td>
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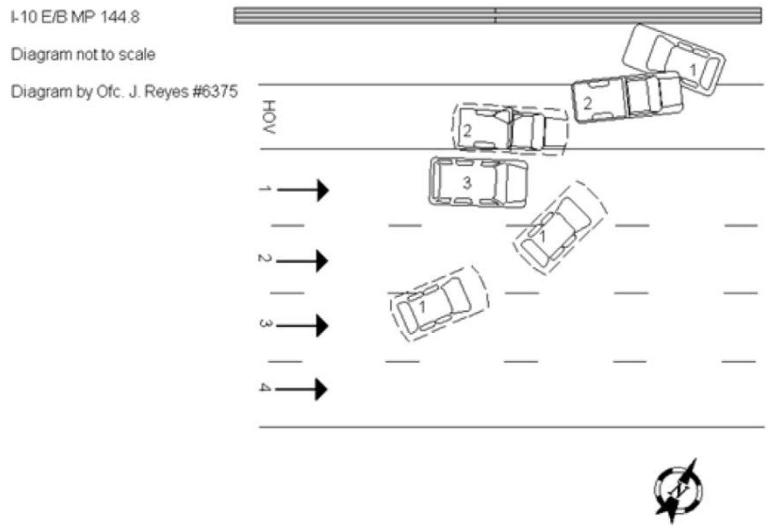
</table>

ID: 2762880
Date: 09/26/2013 (Thursday)
Time: 4:11 pm
Total Injuries: 3
Total Fatalities: 0
Units involved: 3
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Angle
Travel direction: EB
Lane: 3 / HOV /1
Description: None

V1: 1995 BMW Sedan
- D1: DOB 1990
- Action: Avoiding vehicle/object/ped/cyclist
- Officer Estimated Speed: 50 mph
- Violation: Speed too fast for conditions
- Note: None

V1: 2007 Chevrolet Pickup
- D1: DOB 1984
- Action: Going straight
- Officer Estimated Speed: 60 mph
- Violation: None
- Note: Note

V1: 2007 Toyota SUV
- D1: DOB 1984
- Action: Going straight
- Officer Estimated Speed: 65 mph
- Violation: None
- Note: None



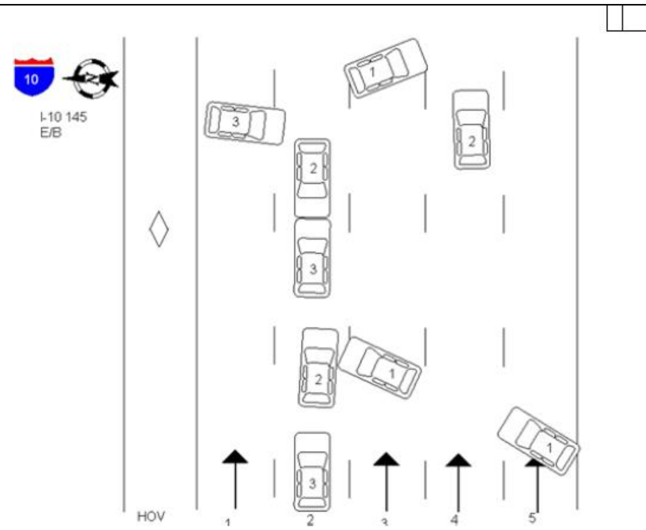
Reviewer comments:
Possible Roadway factors: No
Possible driver factors: Yes (inattention, speed)
Possible vehicle factors: None
Possible environmental factor: No
Congestion related: No/Yes

ID: 2768280
Date: 10/16/2013 (Wednesday)
Time: 7:02 am
Total Injuries: 2
Total Fatalities: 0
Units involved: 3
Conditions: Daylight, Clear, Dry, Level
Manner of Impact: Angle
Travel direction: EB
Lane: 5 /2 / 2
Description: None

V1: 2002 Honda Sedan
- D1: DOB 1991
- Action: Avoiding vehicle/object/ped/cyclist
- Officer Estimated Speed: 65 mph
- Violation: Speed too fast for conditions
- Note: None

V1: 2005 Hyundai Sedan
- D1: DOB 1968
- Action: Going straight
- Officer Estimated Speed: 65 mph
- Violation: None
- Note: Note

V1: 2005 Hyundai Sedan
- D1: DOB 1971
- Action: Going straight
- Officer Estimated Speed: 65 mph
- Violation: None
- Note: None



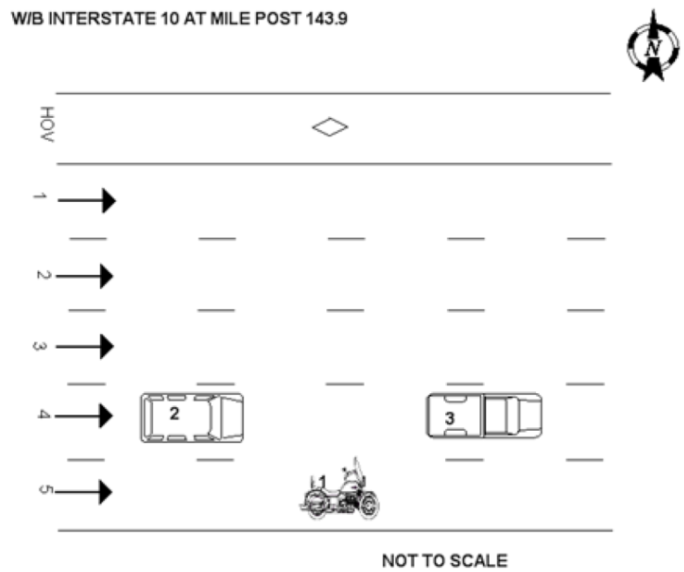
Reviewer comments:
Possible Roadway factors: No
Possible driver factors: Yes (inattention, speed)
Possible vehicle factors: None
Possible environmental factor: No
Congestion related: No/Yes

ID: 2778115
Date: 11/18/2013 (Monday)
Time: 7:37 pm
Total Injuries: 1
Total Fatalities: 0
Units involved: 3
Conditions: Dark-Lighted, Clear, Dry, Uphill
Manner of Impact: Rear-end
Travel direction: WB
Lane: 4
Description: D2 stated that traffic suddenly stopped. Applied brakes and was hit from behind by V1.

V1: 2006 Yamaha Motorcycle
- D1: DOB 1981
- Action: Going straight ahead
- Officer Estimated Speed: 65 mph
- Violation: Speed too fast for conditions
- Note: None

V2: 2010 Kia Sedan
- D1: DOB 1940
- Action: Slowing in traffic
- Officer Estimated Speed: 25 mph
- Violation: None
- Note: Note

V3: 2002 Nissan Pickup
- D1: DOB 1974
- Action: Stopped in traffic
- Officer Estimated Speed: Unknown
- Violation: None
- Note: None



Reviewer comments:
Possible Roadway factors: No
Possible driver factors: Yes (inattention, speed)
Possible vehicle factors: None
Possible environmental factor: No
Congestion related: Yes

ID: 2782249 (MP: 145.27) Date: 11/06/2013 (Wednesday) Time: 10:54 am Total Injuries: 2 Total Fatalities: 0 Units involved: 4 Conditions: Daytime, Clear, Dry, Level Manner of Impact: Rear-end Travel direction: EB Lane: Unknown Description: None V1: 2013 Dodge Pickup D1: DOB 1948 Action: Other Officer Estimated Speed: Unknown Violation: Speed too fast for conditions Note: Illness V2: 2006 Pontiac Sedan D1: DOB Unknown Action: Properly Parked Officer Estimated Speed: Unknown Violation: None Note: Note V3: 2009 Mazda Sedan D1: DOB Unknown Action: Properly Parked Officer Estimated Speed: Unknown Violation: None Note: None V4: Pedestrian D1: DOB 1985 Action: Standing Officer Estimated Speed: Unknown Violation: None Note: None	Reviewer comments: Possible Roadway factors: No Possible driver factors: Yes (inattention, speed, illness) Possible vehicle factors: None Possible environmental factor: Unknown Congestion related: No

ID: 2788793 (MP: 145.24) Date: 11/28/2013 (Thursday) Time: 05:20 am Total Injuries: 3 Total Fatalities: 0 Units involved: 2 Conditions: Dark lighted, Clear, Dry, Level Manner of Impact: Rear-end Travel direction: EB Lane: 3 / 5 Description: None V1: 2003 Chevrolet Sedan D1: DOB 1980 Action: Going Straight Officer Estimated Speed: 65 mph Violation: Speed too fast for conditions, failed to stay in proper lane Note: None V2: 2006 Isuzu Truck D1: DOB 1962 Action: Going straight Officer Estimated Speed: 65 mph Violation: None Note: Note	Reviewer comments: Possible Roadway factors: No Possible driver factors: Yes (inattention, speed) Possible vehicle factors: None Possible environmental factor: None Congestion related: No

APPENDIX G – VARIABLE PPEED LIMIT SYSTEM LITERATURE REVIEW

INTRODUCTION

Variable speed limit (VSL) systems have been widely used to improve safety and operational efficiency around the world. VSL is also known as Dynamic Speed Limit or Dynamic speed display. The principle behind VSL systems is to post a speed limit that is appropriate for current conditions considering time dependent freeway traffic demand, speed profile and/or special conditions like adverse weather and incidents. This provides an opportunity to warn drivers of downstream conditions and decrease headways and encourage more uniform flow. VSL has the capability of increasing safety by reducing both primary and secondary crashes. It also reduces travel time, congestion and emission, and to increase mobility. VSL systems have been one of the most heavily researched ATM techniques, and a number of deployments have occurred, especially at United Kingdom, Germany, Netherland, France and Denmark in the European continent. The purposes of the practice were congestion management, incident management, and or weather condition. The practice could be mandatory or advisory. The following benefits have been reported in different published research documents from their evaluation studies:

- Increase average congested period throughput – 3% to 7%
- Increase overall capacity – 3% to 22%
- Decrease primary incidents – 3% to 30%
- Decrease secondary incidents – 40% to 50%

Recently several state DOTs in the United States including Florida DOT, Caltrans, Washington DOT, Minnesota DOT, Virginia DOT, Missouri DOT, Utah DOT, Colorado DOT, and also in Australia have deployed the concept of VSL in their practice. The purpose of this document is to summarize the practices of VSL around the world, the challenges they have faced and the benefits they have gained in terms of safety and operational capacity improvement.

Overseas Experience: Practices and Benefits

Several countries in Europe including Germany, United Kingdom, Netherland, and Denmark, and Australia have deployed VSL systems on their highway network to improve safety and mobility.

Germany's Experience

In Germany, VSLs have been used since the 1970s. It is estimated that VSL systems are installed on more than 800 km (497 mi) of road in Germany. The German VSL systems use gantries placed over the road to display the VSLs, lane control messages, and pictographs representing congestion, when present. Spacing of overhead gantries varies depending on the roadway. Autobahn A5 uses a gantry spacing of 1 km (0.62 mi), and congestion pictographs are provided on either side of the structure for queue warning. On an 18-km (11.2 mi) stretch of Autobahn A9 near Munich, overhead gantries were placed at an average spacing of 1.8 km (1.12 mi). Inductive loop detectors spaced between 340 and 1750 m (1115 to 5741 ft) on this road were also used to provide detection.

Effects on Traffic Flow and Safety have been found in Germany. Several studies evaluated VSL operational and safety impacts on the German Autobahn. On the A5 Autobahn, crash rates fell by 20% after VSL systems were installed and increased by 10% at a comparable site with no VSL system. There was also a 67 percent decline in secondary crashes. Secondary crashes are generally defined as crashes that occur as a result of congestion caused by an initial primary crash, although the researchers did not specify any time or distance thresholds for identifying secondary crashes in this case. Reduced travel times, decreased fuel consumption, and lower emissions were also cited as benefits of the system. The A5 Autobahn gained several other significant safety improvements after VSLs were installed. A 3% reduction in property damage only (PDO) crashes with light damage and a 27% reduction in PDO crashes with heavy damage occurred. A 30% reduction in injury crashes also occurred. For the A9 Autobahn, researchers found that the VSL system responded well to traffic but congestion and shockwaves were still present.

One set of researchers used available detector data to examine the flow-speed-density relationships on the German Autobahn when VSLs were in use. They found that VSLs decreased the slope of the flow-occupancy diagram at undercritical conditions, shifted occupancy to higher values, and enabled higher flows at the same occupancy in overcritical conditions. The speed-flow diagram showed that a 50 mph VSL clearly had a higher critical flow rate than when no VSL was posted, indicating that heavy flow could be sustained for a longer period before breakdown occurred. Although there was significant stochastic variation in flow and speed, the critical occupancy was about 5% higher with the VSLs active than when they were not.

U.K's Experience

In the United Kingdom, VSL systems have been installed on the M25 and M42 motorways. The M25 systems were installed in 1995. The M25 is a freeway with four lanes in each direction, and VSLs were placed on overhead gantries spaced at 1-km (0.62 mi) intervals. Inductive loops were placed at 500-m (1,640 ft) spacings to monitor traffic and provide data used by the VSL system to determine the appropriate speed limits. The other U.K. VSL system is on a 17-km stretch of the M42. This road has an average annual daily traffic (AADT) of 120,000 vehicles, and a total of 50 gantries holding 250 signs were installed. Gantries were spaced every 0.5 to 1 km (0.31 to 0.62 mi).

A number of studies of the operational and safety effects of VSLs have also been performed in the United Kingdom. A 2-year study on the M25 found that the VSL system produced more even headways. Results from the first year of operation showed a 28% reduction in injuries and a 25% reduction in PDO crashes. A 25% to 30% reduction in rear-end crashes was also observed. Data from the second year of operation showed that these results had been maintained. It was also estimated that the system increased capacity by 5% to 10%.

A subsequent study in 2005 also examined the M25 which reported that the VSLs produced the following impacts:

- Neutral impact on travel time and travel time reliability
- 15% reduction in injury crashes
- Estimated 2% to 8% reduction in emissions
- Estimated fuel consumption reduction of 10%
- 1.5% increase in throughput
- 5% improvement in speed limit compliance.

Another analysis conducted using 7 years of data after the M25 VSL deployment began showed a 10% to 20% reduction in injuries. A subsequent expansion of M25 VSLs by 8 km (4.97 mi) found that travel times did not change significantly but injuries fell by 10% on the new section.

Netherland's Experience

In the Netherlands, VSLs have been used since 1981. Overhead VSLs and lane control signals are deployed every 500 m (1640 ft). Studies of VSL systems in the Netherlands showed that throughput increased between 3% and 5%. Collisions were also reduced by about 16%. A study at 4 test locations in the Netherlands found a 20% to 30% reduction in NOx and a 10% reduction in particulate matter below 10 microns (PM10) when VSLs were implemented.

Denmark's Experience

Several other results were reported from deployments in other European countries. A work zone VSL system was installed on M3 around Copenhagen, Denmark. Incidents did not increase during construction despite reduced lane widths at that site.

Australia's Experience

In Australia, a VSL system was developed for the Western Ring Road, which has an AADT of approximately 100,000 vehicles, with 15% trucks. The system is implemented on a 26-km (16.16 mi) section of road that has a base speed limit of a 100 km/h (62.14 mph). Loop detectors were placed using an 0.5-km (0.31 mi) spacing. VSL system has also been deployed on M4, F3, and the Adelaide-Crafers Highway. The project objective were reduction of rear-end crashes, incident, queue management, and safe traffic operation in adverse weather conditions. The deployment has been able to reduce crash rates by 11-24% on F3 in the first month of installation.

U.S. Experience: Practices and Benefits

There have been several recent successful VSL deployments in the United States in the state of Florida, Washington, Minnesota, Missouri, Virginia, Maine, Colorado and Utah.

Florida's Experience

A VSL system was deployed on a 10-mile section of I-4 in Orlando, Florida, in 2008. The section had an AADT of approximately 200,000 vehicles. A total of 20 VSL signs were installed at 16 locations, and inductive loops were used to measure speed, volume, and occupancy at 30-sec intervals. The Orlando VSL system was evaluated by looking at speed data from 4 P.M.to 6 P.M. for 1 month before VSL activation as compared to 1 month after VSL activation. The data showed that speed changes were more strongly correlated with changes in occupancy than changes in the posted speed limit. The evaluators concluded that the VSL had no significant impact on speed compliance or mean travel speed. A crash analysis was also conducted, but no conclusions could be drawn because of limited data.

Washington's Experience

In August 2010, Washington DOT installed VSL systems on 7 miles of I-5 northbound as it approaches downtown Seattle. Similar systems were installed on 8 miles of S.R. 520 eastbound and westbound in November 2010 and on I-90 eastbound and westbound in June 2011. In Washington, evaluation results were more limited. There was a 6 month time lag between when a crash actually occurred and when it was entered into the DOT crash database, so WSDOT was unable to make definitive assessments of the safety impact of the system as of early 2012. Preliminary analysis examined the ATM segment of I-5, a segment immediately downstream, and 3 other urban segments further removed from the ATM segment. The preliminary 2011 trends showed that collisions at the ATM segment and the segment immediately downstream declined, whereas crashes at the other 3 segments increased. These are preliminary data, however, and no firm conclusions can be drawn. The WSDOT deployment did identify some safety-related benefits in terms of work zone and incident management since speed limits and lane control signs could be used to supplement traditional traffic control.

Minnesota's Experience

The Minnesota DOT is also operating VSL systems, lane control signs on a 10-mile segment of I-35W in the Minneapolis–St. Paul area. Signs are spaced 0.5 mile apart. An extension of the system is planned on an 8-mile section of I-94 between downtown St. Paul and downtown Minneapolis in summer 2012. Minnesota conducted a preliminary evaluation of the safety and operational effects of their system. Measures were compared for 3 months after the VSL system was activated to the same 3 months during the year before the VSL system was installed. Analysis of the detector data showed that the average maximum deceleration declined by 19.6% with the VSL, indicating smoother transitions between flow regimes. Travel times did increase by 13.3% with the VSL, however, because of posting slower speeds while transitioning from free flow to congested flow. It was also estimated that throughput increased by 6.1% at a known bottleneck because of reduced shock wave impacts. Crashes were not evaluated in this study.

Missouri's Experience

The Missouri DOT installed 65 VSL signs along 38 miles of I-270 and I-255 in St. Louis. Data from the St. Louis deployment were evaluated using 150 days of data before and after the deployment. Conditions on typical weekdays were examined using 3 point sensors, and the speed-occupancy-flow relationships were examined before and after the VSLs were activated. The results indicated that the speed-flow-occupancy curve changed after the VSLs were activated, although direction of the change was not consistent at the three sites. Capacity increased at one site, declined at another, and remained the same at the third. The same trends were observed in mean speed. Speed variance did decline at all sites, however.

Virginia's Experience

As of early 2012, VDOT had installed VSL systems on several bridge and tunnel facilities. These VSLs are used to reduce speeds primarily because of incidents and weather conditions and are reduced manually by operators. Two VSL systems are currently in development to mitigate safety issues related to foggy conditions on I-64 at Afton Mountain and I-77 at Fancy Gap, but they have not yet been deployed.

Maine's Experience

Analysis of compliance with the Maine VSLs during poor weather showed low compliance to the 45 mph limit. The researchers did note, however, that the system was often left active when it was not warranted which may have eroded confidence in the system. A small survey of drivers was also conducted to assess driver perceptions of the system. Of 62 drivers surveyed, only 56% found the system to be useful and only 45% said they altered their speed in response to the VSLs. The researchers recommended that speed limits in the future be set based on available stopping sight distance and surface conditions.

State of Utah and Colorado have also successfully deployed VSL systems on their state and inter-state highway system very recently and the study on the effectiveness is in process now.

APPENDIX H – COST ESTIMATES

Variable Speed Limit System for the I-10 Study Section

Item No.	Description	Unit	Est Qty	Unit Price	Extended Price
6060036	BRIDGE SIGN STRUCTURE (SD9.52, TYPE 3F, DMS)	EACH	4	$115,000.00	$460,000
6060037	BRIDGE SIGN STRUCTURE (SD9.52, TYPE 4F, DMS)	EACH	8	$135,000.00	$1,080,000
6060080	FOUNDATION FOR BRIDGE SIGN STRUCTURE (SD9.20, TYPE 3F, DMS)	EACH	6	$12,500.00	$75,000
6060083	FOUNDATION FOR BRIDGE SIGN STRUCTURE (SD9.20, TYPE 4F, DMS)	EACH	14	$13,000.00	$182,000
6070055	SIGN POST (PERFORATED) (2 1/2 S)	L. FT.	540	$15.00	$8,100
6070060	FOUNDATION FOR SIGN POST (CONCRETE)	EACH	36	$170.00	$6,120
6080005	WARNING, MARKER OR REGULATORY SIGN PANEL	SQ. FT.	270	$25.00	$6,750
7020011	IMPACT ATTENUATION DEVICE (SAND BARRELL CRASH CUSHION, TYPE A)	EACH	3	$6,000.00	$18,000
7320070	ELECTRICAL CONDUIT (3") (PVC)	L. FT.	1,200	$13.00	$15,600
7320073	ELECTRICAL CONDUIT (2-3") (PVC)	L. FT.	2,800	$15.00	$42,000
7320420	PULL BOX (NO.7)	EACH	32	$625.00	$20,000
7320455	PULL BOX (NO.9)	EACH	10	$2,400.00	$24,000
7320540	CONDUCTOR (NO. 4)	L. FT.	30,000	$1.30	$39,000
7320585	CONDUCTOR (INSULATED BOND) (NO.8 GREEN BOND)	L. FT.	15,000	$0.80	$12,000
7320765	SINGLE MODE FIBER OPTIC CABLE (12 FIBERS)	L. FT.	8,400	$2.25	$18,900
7320794	FIBER OPTIC SPLICE CLOSURE (FMS)	EACH	14	$1,800.00	$25,200
7340103	CONTROL CABINET	EACH	40	$8,000.00	$320,000
7340251	CONTROLLER (MODEL 2070)	EACH	40	$3,000.00	$120,000
7340304	CONTROL CABINET FOUNDATION (CABINET & TRANSFORMER)	EACH	40	$1,200.00	$48,000
7350030	LOOP DETECTOR FOR TRAFFIC SURVEILLANCE (6'X6')	EACH	66	$550.00	$36,300
7350051	DETECTOR CARD	EACH	33	$170.00	$5,610
7350165	LOOP DETECTOR LEAD-IN CABLE	L. FT.	6,600	$0.60	$3,960
7360250	MODIFY LOAD CENTER	EACH	4	$2,500.00	$10,000
7370430	TRANSFORMER (CABINET ASSEMBLY) (3 KVA)	EACH	26	$2,000.00	$52,000
7370431	TRANSFORMER (CABINET ASSEMBLY) (7.5 KVA)	EACH	14	$2,800.00	$39,200
7379111	VARIABLE MESSAGE SIGN ASSEMBLY	EACH	83	$25,000.00	$2,075,000
9240121	MISCELLANEOUS WORK (Microwave/non intrusive detector)	EACH	16	$6,000.00	$96,000
9240122	MISCELLANEOUS WORK (GigE SWITCH)	EACH	40	$2,000.00	$80,000
9240133	MISCELLANEOUS WORK (In Tunnel mounting signs)	EACH	2	$75,000.00	$150,000
9240133	MISCELLANEOUS WORK (MEDIAN BARRIER TRANSITION)	EACH	7	$30,000.00	$210,000
9240133	MISCELLANEOUS WORK (Special Foundation for Sign Structure Elevated area)	EACH	4	$40,000.00	$160,000
9240133	MISCELLANEOUS WORK (Cable BARRIER relocatation)	EACH	2	$15,000.00	$30,000
	SUBTOTAL				**$5,468,740**
	Including Design, System integration, Contingency, Communications and other Miscellaneous (1.5*Subtotal)				$8,203,110.00
	Per mile cost would be ((G36)/3)				$2,734,370
	Per mile Variable Speed Limit system capital cost would be				***2.73*** million dollars

Extend the WB Lane Drop at 7th Ave.

ENGINEER'S ESTIMATE

Item No.	Description	Unit	Est. Qty	Unit Price	Extended Price
2010001	CLEARING AND GRUBBING	L.SUM	1	$2,000.00	$2,000
2020021	REMOVAL OF CONCRETE CURB AND GUTTER	L.FT.	2,300	$10.00	$23,000
2020027	REMOVAL OF CONCRETE BARRIER	L.FT.	20	$50.00	$1,000
2020031	REMOVAL OF PORTLAND CEMENT CONCRETE PAVEMENT	SQ.YD.	195	$100.00	$19,500
2020041	REMOVAL OF PIPE	L.FT.	60	$30.00	$1,800
2020072	REMOVE AND SALVAGE GUARD RAIL	L.FT.	100	$20.00	$2,000
2020156	REMOVE (CATCH BASIN)	EACH	3	$300.00	$900
2030301	ROADWAY EXCAVATION	CU.YD.	1,100	$20.00	$22,000
3030022	AGGREGATE BASE, CLASS 2	CU.YD.	1,100	$30.00	$33,000
4010012	PORTLAND CEMENT CONCRETE PAVEMENT (12")	SQ.YD.	3,200	$100.00	$320,000
4150040	ASPHALTIC CONCRETE (ASPHALT- RUBBER) (END PRODUCT)	TON	350	$70.00	$24,500
4150042	ASPHALT RUBBER MATERIAL (FOR AR-AC) (END PRODUCT)	TON	30	$550.00	$16,500
4150044	MINERAL ADMIXTURE (FOR AR-AC) (END PRODUCT)	TON	4	$100.00	$400
5010011	PIPE, CORRUGATED METAL, 24"	L.FT.	45	$100.00	$4,500
5010111	PIPE, CORRUGATED METAL, SLOTTED, 24"	L.FT.	60	$150.00	$9,000
5030080	CONCRETE CATCH BASIN (C-15.30) SINGLE, H =8' OR LESS (Type F Barrier)	EACH	3	$4,000.00	$12,000
5030702	JUNCTION STRUCTURE	EACH	3	$3,000.00	$9,000
7015052	OBLITERATE PAVEMENT MARKING (STRIPE)	L.FT.	6,000	$1.00	$6,000
7042001	PAVEMENT MARKING (PCCP WHITE SPRAYED THERMOPLASTIC)(0.060')	L.FT.	6,000	$0.50	$3,000
7042031	PRIMER-SEALER FOR PCCP THERMOPLASTIC STRIPING	L.FT.	6,000	$0.30	$1,800
7042051	REMOVAL OF CURING COMPOUND FROM PCCP STRIPING	L.FT.	6,000	$1.00	$6,000
7320480	RELOCATE EXISTING PULL BOXES	L.SUM	8	$1,000.00	$8,000
9100037	CONCRETE BARRIER (SPECIAL HALF) (32" w/GUTTER)	L.FT.	1,800	$125.00	$225,000
9100038	CONCRETE BARRIER (SPECIAL HALF) (32" w/CATCH BASIN)	L.FT.	30	$150.00	$4,500
	Misc Items (20%)				$151,080
	SUBTOTAL				$906,480
	DESIGN	15%			$135,972
	EROSION CONTROL	2%			$18,130
	QUALITY CONTROL	3%			$27,194
	CONSTRUCTION TRAFFIC CONTROL	10%			$90,648
	MOBILIZATION	10%			$90,648
	CONSTRUCTION SURVEY	2%			$18,130
	CONSTRUCTION ENGINEERING AND CONTINGENCIES	20%			$181,296
	TOTAL				**$1,468,498**

Extend EB Lane Drop at 7th St

ENGINEER'S ESTIMATE

Item No.	Description	Unit	Est. Qty	Unit Price	Extended Price
2010001	CLEARING AND GRUBBING	L.SUM	1	$2,000.00	$2,000
2020021	REMOVAL OF CONCRETE CURB AND GUTTER	L.FT.	1,900	$10.00	$19,000
2020027	REMOVAL OF CONCRETE BARRIER	L.FT.	20	$50.00	$1,000
2020031	REMOVAL OF PORTLAND CEMENT CONCRETE PAVEMENT	SQ.YD.	165	$100.00	$16,500
2020041	REMOVAL OF PIPE	L.FT.	100	$30.00	$3,000
2020072	REMOVE AND SALVAGE GUARD RAIL	L.FT.		$20.00	
2020156	REMOVE (CATCH BASIN)	EACH	5	$300.00	$1,500
2030301	ROADWAY EXCAVATION	CU.YD.	1,200	$20.00	$24,000
3030022	AGGREGATE BASE, CLASS 2	CU.YD.	850	$30.00	$25,500
4010012	PORTLAND CEMENT CONCRETE PAVEMENT (12")	SQ.YD.	2,600	$100.00	$260,000
4150040	ASPHALTIC CONCRETE (ASPHALT- RUBBER) (END PRODUCT)	TON	280	$70.00	$19,600
4150042	ASPHALT RUBBER MATERIAL (FOR AR-AC) (END PRODUCT)	TON	25	$550.00	$13,750
4150044	MINERAL ADMIXTURE (FOR AR-AC) (END PRODUCT)	TON	3	$100.00	$300
5010011	PIPE, CORRUGATED METAL, 24"	L.FT.	200	$100.00	$20,000
5010111	PIPE, CORRUGATED METAL, SLOTTED, 24"	L.FT.	100	$150.00	$15,000
5030080	CONCRETE CATCH BASIN (C-15.30) SINGLE, H =8' OR LESS (Type F Barrier)	EACH	5	$4,000.00	$20,000
5030702	JUNCTION STRUCTURE	EACH	5	$3,000.00	$15,000
7015052	OBLITERATE PAVEMENT MARKING (STRIPE)	L.FT.	5,000	$1.00	$5,000
7042001	PAVEMENT MARKING (PCCP WHITE SPRAYED THERMOPLASTIC)(0.060')	L.FT.	5,000	$0.50	$2,500
7042031	PRIMER-SEALER FOR PCCP THERMOPLASTIC STRIPING	L.FT.	5,000	$0.30	$1,500
7042051	REMOVAL OF CURING COMPOUND FROM PCCP STRIPING	L.FT.	5,000	$1.00	$5,000
7320480	RELOCATE EXISTING PULL BOXES	L.SUM	8	$1,000.00	$8,000
9100037	CONCRETE BARRIER (SPECIAL HALF) (32" w/GUTTER)	L.FT.	1,700	$125.00	$212,500
9100038	CONCRETE BARRIER (SPECIAL HALF) (32" w/CATCH BASIN)	L.FT.	50	$150.00	$7,500
	Misc Items (20%)				$139,630
	SUBTOTAL				$837,780
	DESIGN	15%			$125,667
	EROSION CONTROL	2%			$16,756
	QUALITY CONTROL	3%			$25,133
	CONSTRUCTION TRAFFIC CONTROL	10%			$83,778
	MOBILIZATION	10%			$83,778
	CONSTRUCTION SURVEY	2%			$16,756
	CONSTRUCTION ENGINEERING AND CONTINGENCIES	20%			$167,556
	TOTAL				**$1,357,204**

Deck Park Tunnel Lighting Upgrade

Deck Park Tunnel Lighting System Planning Level ENGINEER'S ESTIMATE					
Item No.	**Description**	**Unit**	**Est. Qty**	**Unit price**	**Extended Price**
	Fixtures	EACH	3,760	$3,000.00	$11,280,000.00
	Fixture Control	EACH	3,760	$125.00	$470,000.00
	Mounting Bracket	EACH	3,760	$50.00	$188,000.00
	Miscellaneous Items (20% of Items Above)	L. SUM	1	$2,387,600.00	$2,387,600.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
					$0.00
	SUBTOTAL				**$14,325,600.00**
	Design, CE, ICAP, Contingency (40% of Subtotal)				$5,730,240.00
	PROJECT TOTAL				**$20,055,840.00**