Pasadena Intersection Safety Study

Final Report
by the

Center for Transportation Safety
Texas Transportation Institute
Texas A&M University System

Prepared
for the

Houston-Galveston Area Council
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DISCLAIMER

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SCOPE OF WORK

The City of Pasadena and the Safety Center within the Houston-Galveston Area Council (H-GAC) identified several locations in the City of Pasadena that have experienced an abnormally high and disproportionate number of traffic crashes in the past few years. The intersection locations are distributed throughout the city. The City of Pasadena in cooperation with the H-GAC Traffic Safety Program engaged the Center for Transportation Safety of the Texas Transportation Institute (TTI) to conduct a detailed study and analysis of the traffic crashes at the identified intersections.

The City of Pasadena provided five locations with high crash experiences that were not currently undergoing intersection improvements:

- SH 225 @ Main
- SH 225 @ Shaver
- Shaver @ Pauline/Queens
- Pasadena @ Curtis
- Preston @ Cherry Brook

This study investigated the above locations and:

- determined possible causative factors and patterns of crashes,
- decided which locations were susceptible to remediation, and
- recommended potential alternative safety improvement countermeasures.

Researchers hope that these remedial engineering actions, if implemented, will result in a reduction in the frequency and/or severity of the current crash experience. However, it should be understood that TTI is a research agency and cannot act in the place of an engineering consulting firm. Some of the countermeasures recommended in this report should be justified by further engineering studies beyond what TTI can perform in its limited research capacity.

OVERVIEW

This report contains a section for each of the five intersections studied. Each section contains the same basic elements:

- Crash Record Analysis,
- Traffic and Operational Data,
- Speed Studies,
- Crash Patterns and Causal Relationships,
- Countermeasure Improvements,
- Crash Reduction Factors,

- Crash Costs,
- Countermeasure Costs,
- Benefit-Cost Analysis, and
- Conclusions and Recommendations.

The objective of the crash analysis was to obtain and analyze all available and relevant crash data within the specified study area, create collision diagrams, and gather general traffic statistics. Traffic and operational data assisted in the analysis of traffic volumes, signal timings, intersection sketches, etc. Land use and street inventory data supported the analysis of relevant crash data and helped determine any cause-and-effect relationships between land use or attractions and crash patterns. Demographic data from the area was utilized to determine if any crash statistics were not consistent with the area demographics. The objective of speed studies was to determine if vehicle speed might have been a significant factor in the area crashes. From the collision and condition diagrams, the common crash types, patterns, locations, and causal relationships were established. Once a causal relationship was documented, corresponding countermeasures were identified, costs estimated, reduction factors calculated, and benefits determined. Based on these costs and benefits, a benefit-cost ratio was calculated.

DATA RESOURCES

With the assistance of all responsible parties, the following data files were obtained from the designated agencies:

1. Intersection turning movement counts (City of Pasadena).
2. Traffic counts (Texas Department of Transportation [TxDOT] maps and TTI databases).
3. Traffic signal timings (City of Pasadena, Traffic Department).
4. Three years of complete, hard copy crash investigation reports from January 2000 to December 2002 (City of Pasadena, Police Department).
5. Demographic information (H-GAC).
6. Crash reduction factors (TxDOT).
7. Cost by crash type (National Safety Council [NSC]).
8. Cost for crash countermeasures (TxDOT bid website: http://www.dot.state.tx.us/business/avgd.htm).

SUMMARY AND COMPARISON OF SITES

Crash Record Analysis

The City of Pasadena provided three years of crash data that were reduced to a total of 275 crash reports for the five study locations. Of these records, 255 were subject to correction (i.e., they did not pertain to alcohol, drugs, or speeding). Almost half of the 255 crash records were right-angle crashes. Left-turn crashes followed with 29 percent of the total crash number. Table 1 shows the total breakdown of crash types by intersection. The diamond interchanges (SH 225 @ Shaver and SH 225 @ Main) were split and tabulated into eastbound (EB) and westbound (WB) directions in order to better understand the dynamics of the location.

Table 1. 2000 to 2002 Intersection Crashes by Type.

Intersection	Right-Turn	Left-Turn	Right-Angle	Rear-End	Driveway	Other	Totals
SH 225 @ Main (EB)		3	9			1	13
SH 225 @ Main (WB)		14	28			1	43
SH 225 @ Shaver (EB)	8	14	40	1		2	65
SH 225 @ Shaver (WB)		2	7	1		1	11
Shaver @ Pauline/Queens		14	14	10		3	41
Preston @ Curtis	2	10	18	5		2	37
Preston @ Cherry Brook	6	17	6	8	4	4	45
Totals	16	74	122	25	4	14	255
Percentages	6%	29%	48%	10%	2%	5%	100%

As expected, the higher volume roadways had a higher crash experience. The right-angle and left-turn crashes were the largest crash type. From the three years of data provided, most of the crashes were not very severe and none were fatal. Eighty five percent of the crashes were either property damage only (69 percent) or possible injury crashes (16 percent). There are five categories for classifying the severity of crashes:

- K = Fatality
- A = Incapacitating Injury
- B = Non-Incapacitating Injury
- C = Possible Injury
- PDO = Property Damage Only

Table 2 lists the crashes in the Pasadena area by their severity.

Table 2. 2000 to 2002 Intersection Crashes by Severity.

Intersection	A	B	C	PDO	Total
SH 225 @ Main (EB)	0	3	2	8	13
SH 225 @ Main (WB)	3	5	8	27	43
SH 225 @ Shaver (EB)	1	8	10	46	65
SH 225 @ Shaver (WB)	1	0	3	7	11
Shaver @ Pauline/Queens	0	7	6	28	41
Pasadena @ Curtis	0	6	10	21	37
Preston @ Cherry Brook	1	3	2	39	45
Totals	6	32	41	176	255
Percentages	2%	13%	16%	69%	100%

State Intersection Crash Frequency Comparison

The crash frequencies from the DPS database were queried for comparison with the Pasadena locations. The DPS data was queried by roadway type and state system volume. Unfortunately, the database does not have the cross street volume to make a more accurate comparison. However, by using the facility type and the state system volume compared with the highest type and the volume for the intersection, a relative comparison was made. This comparison is presented in Table 3 for the Principal Arterial comparison and Table 4 for the Arterial comparison. The Pasadena crash numbers were divided by three years to obtain a yearly average. As shown in these two tables, the Pasadena intersections are far below the state average for similar intersections. In almost all cases and categories, the number of crashes or frequency is one fourth that of the state average, with the exception of Preston at Cherry Brook in the Non-Injury or Property Damage Only category. Overall, the Pasadena locations were far below the state averages and further improvement will be a greater benefit to the citizens of Pasadena.

Table 3. Principal Arterial Table of State System Roadway Only ADT Range by Severity.

	(Accident Severity)					Total
Intersection (ADT)	**Yearly Crash Frequency**					
ADT Range Frequency Percent Row Pct Col Pct	**Incapacitating**	**Non-Incapacitating**	**Possible Injury**	**Fatal**	**Non-Injury**	
SH 225 @ N. Main (11,810)	**0.67**	**2.67**	**4.33**	**0**	**17.67**	**25**
11,500-12,000	9 1.46 3.96 36	40 6.49 17.62 35.4	111 18.02 48.9 35.24	2 0.32 0.88 33.33	65 10.55 28.63 41.4	227 36.85
SH 225 @ Shaver (8,870)	**1**	**2.67**	**3.33**	**0**	**11.67**	**19**
8,500- 9,000	6 0.97 4.35 24	30 4.87 21.74 26.55	59 9.58 42.75 18.73	3 0.49 2.17 50	40 6.49 28.99 25.48	138 22.4
Shaver @ Pauline/Queens (26,210)	**0**	**2.33**	**2**	**0**	**9.33**	**14**
26,000-26,500	10 1.62 3.98 40	43 6.98 17.13 38.05	145 23.54 57.77 46.03	1 0.16 0.4 16.67	52 8.44 20.72 33.12	251 40.75
Total	25 4.06	113 18.34	315 51.14	6 0.97	157 25.49	616 100

Table 4. Arterial Table of State System Only ADT Range by Severity.

	(Accident Severity)					Total
Intersection (ADT)	**Yearly Crash Rate**					
ADT Range **Frequency** **Percent** **Row Pct** **Col Pct**	**Incapacitating**	**Non-incapacitating**	**Possible Injury**	**Fatal**	**Non-Injury**	
Pasadena @ Curtis (17,010)	**0**	**2**	**3.33**	**0**	**7**	**12.33**
16,750-17,250	5 3.94 5.38 71.43	20 15.75 21.51 80	40 31.5 43.01 74.07	0 0 0 0	28 22.05 30.11 70	93 73.23
Preston @ Cherry Brook (24,090)	**0.33**	**1**	**0.67**	**0**	**13**	**15**
23,750-24,250	2 1.57 5.88 28.57	5 3.94 14.71 20	14 11.02 41.18 25.93	1 0.79 2.94 100	12 9.45 35.29 30	34 26.77
Total	7 5.51	25 19.69	54 42.52	1 0.79	40 31.5	127 100

Traffic and Operational Data

The traffic and operational data were used to support the analysis of relevant crash data for the specified intersections in the Pasadena study area. With the assistance of the responsible agencies, TTI obtained operational data related to traffic volumes and counts, vehicular movements, signal timings, and intersection diagrams. Collision diagrams for each intersection are included in Appendix C of this report. The information obtained was based on relevant crash data gathered in the crash analysis.

Traffic Volume Data

Researchers utilized 24-hour traffic counts for crash frequency calculations and volume data. Data were obtained on all major roadways as shown in Figures 1 and 2. Researchers plotted the study locations as well as traffic volume data collected from the City of Pasadena (see Figure 1) and TxDOT (see Figure 2). Traffic volumes were examined for consistency and site investigation combined with cursory traffic analysis of the available traffic data for the area did not reveal any congestion or delay problems. Simple volume-to-capacity ratios, engineering judgment, and site inspections verified these results.

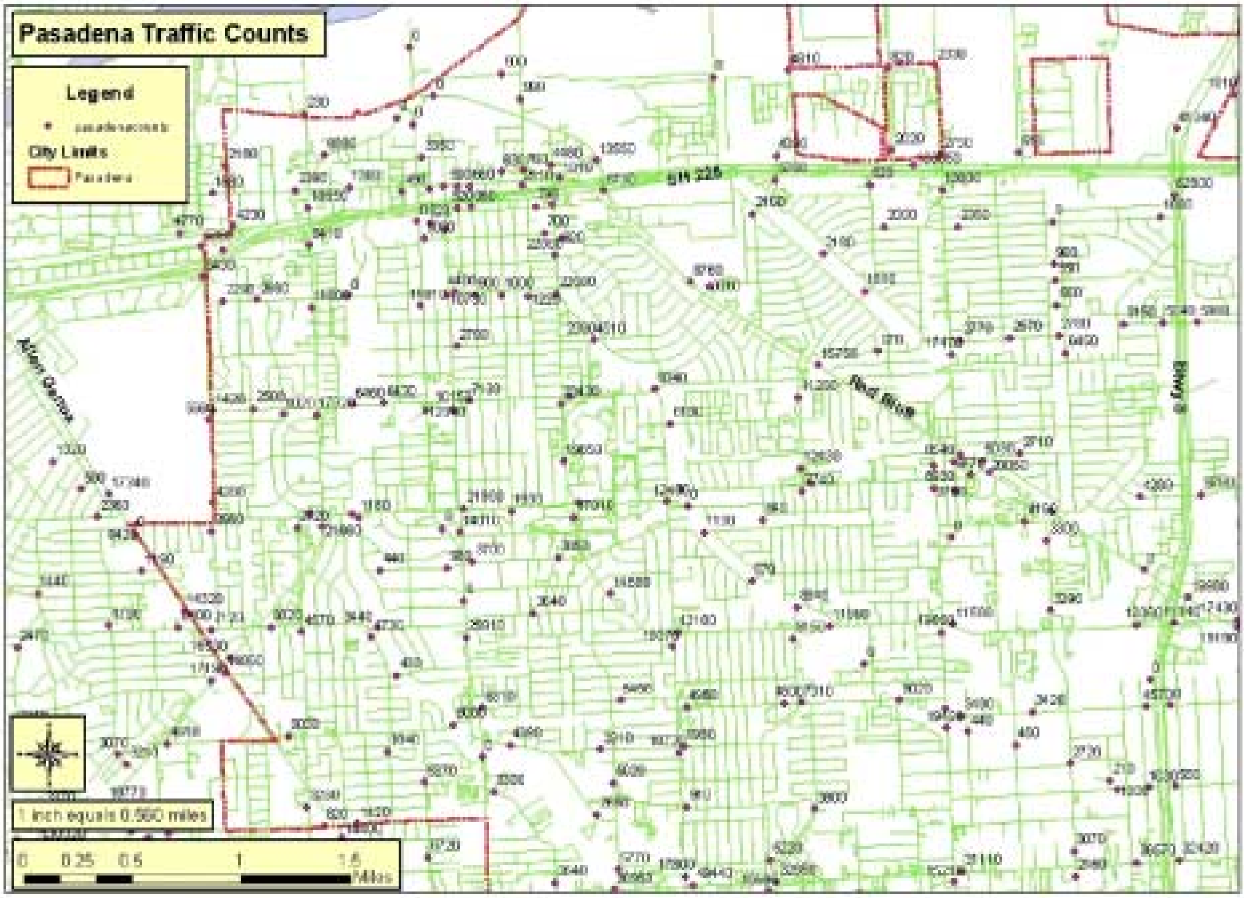

Figure 1. City of Pasadena Traffic Volume Data.

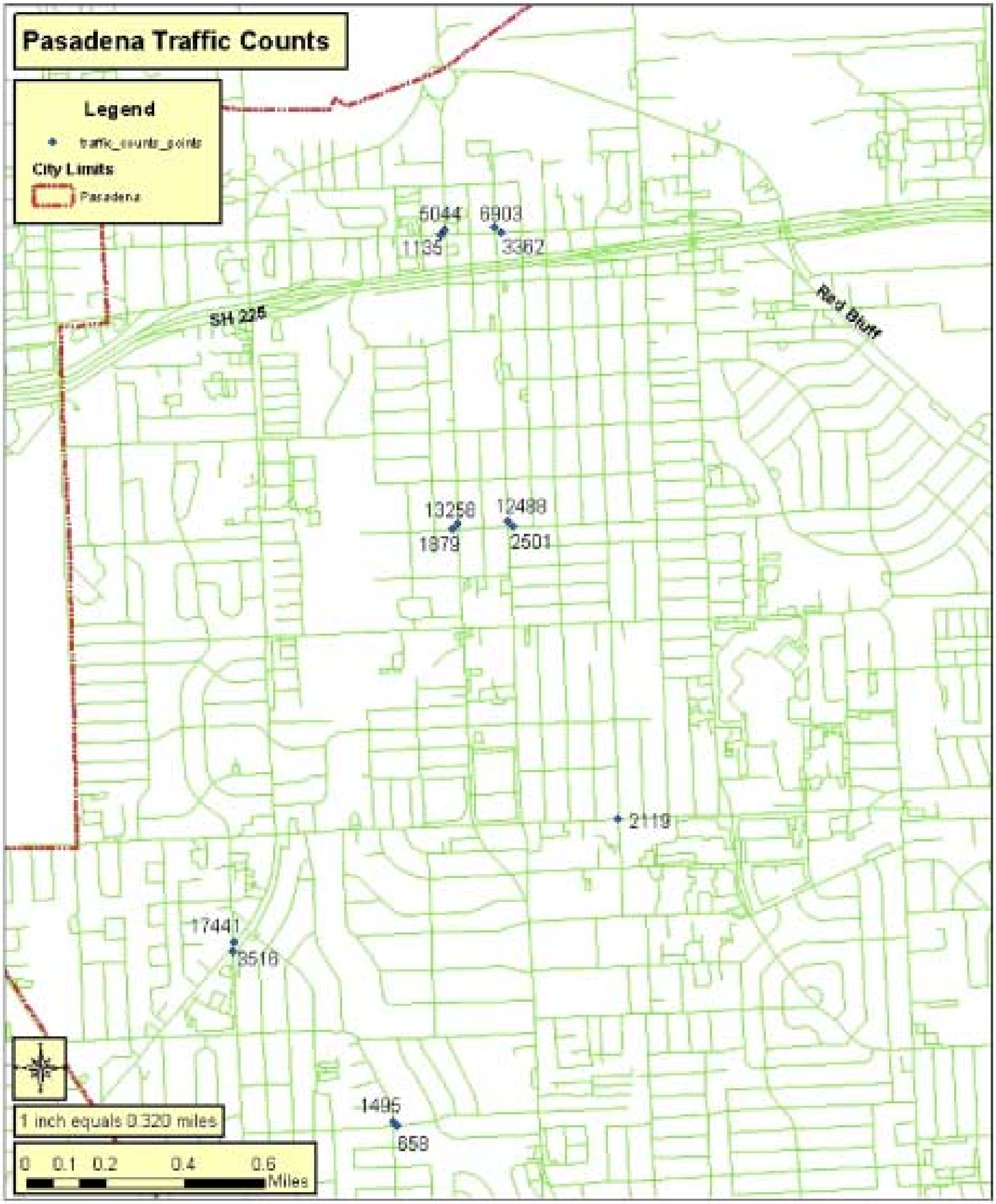

Figure 2. TxDOT Traffic Volume Data.

Turning Movement Counts

The City of Pasadena provided turning movement counts for each site during peak AM, midday, and peak PM periods. These counts are shown in Appendix A. They are supplemented with details of existing site information such as the presence/location of lighting, sidewalks, pavement markings, signal heads, etc.

Signal Timings

The City of Pasadena provided traffic signal timings that were analyzed for red and yellow clearance intervals and all were found to be adequate for the posted and operating speeds on the corridors. These traffic signal timings were utilized to determine causal relationships between signal timing and phasing with crash patterns. These relationships will be discussed in the Crash Patterns and Causal Relationships section of each intersection report.

General Land Use and Street Inventory

Street inventory data such as road width, speed limit, pavement surface, and markings were obtained from both field measurement and from intersection sketches. The following land use and street inventory data were obtained from the designated agencies:

1. Aerial Photographs (TxDOT)
2. Study Boundary Area (TTI)
3. Parcel and Land Use (H-GAC)

The above data were imported into a Geographical Information System (GIS). Aerial photos were used for verification of land use and to confirm inventory information. The road inventory data, traffic counts, and traffic operational data combined with the crash data were used to determine if there were any cause-and-effect relationships between land use or attractions and crash patterns.

Pavement Marking Conditions

Site visits revealed variation in the pavement marking conditions. Markings will be discussed in more detail in the Crash Patterns and Causal Relationships section of each intersection report.

Area Demographics

The demographics for the Pasadena area were collected from the 2000 Census Bureau report and from the Pasadena Chamber of Commerce. The ethnic distribution from the Chamber of Commerce data is displayed in Figure 3 below. The hard copy data from the collision reports provided the ethnicities of the drivers involved in the collisions in the three-year period from 2000 to 2002. There were a total of 551 drivers involved in the collisions reported. The ethnic distribution of the drivers from the collision reports is displayed in Figure 4. From this data, it appears that white drivers were overrepresented in the collisions occurring in the Pasadena area. Black drivers were also slightly overrepresented. A closer inspection of the hard copy data revealed that of the 446 white drivers involved in collisions, 177 of them, or 40 percent, had Hispanic surnames. This indicates that the Hispanic population involved in the Pasadena collisions may be as high as 44 percent of the total number of collisions and the white population may not be as high as originally reported. These numbers more closely relate to the general demographics for the area. No other demographic patterns seemed unusual or problematic.

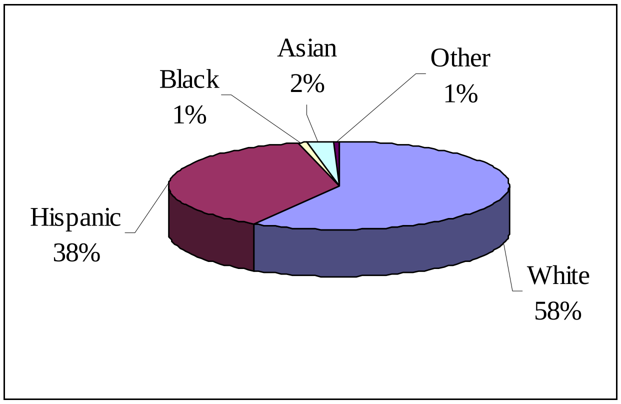

Figure 3. Pasadena 2000 Ethnic Distributions.

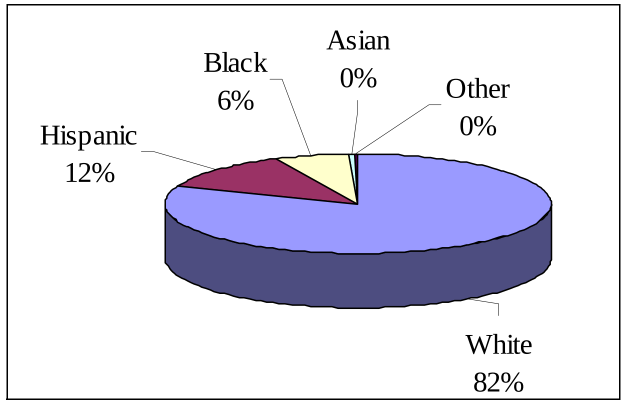

Figure 4. Ethnic Distributions from the 2000 to 2002 Collision Reports.

Vehicle tenure statistics were also considered. The 2000 Census provided vehicle ownership information for the Pasadena area, presented in Figure 5 below.

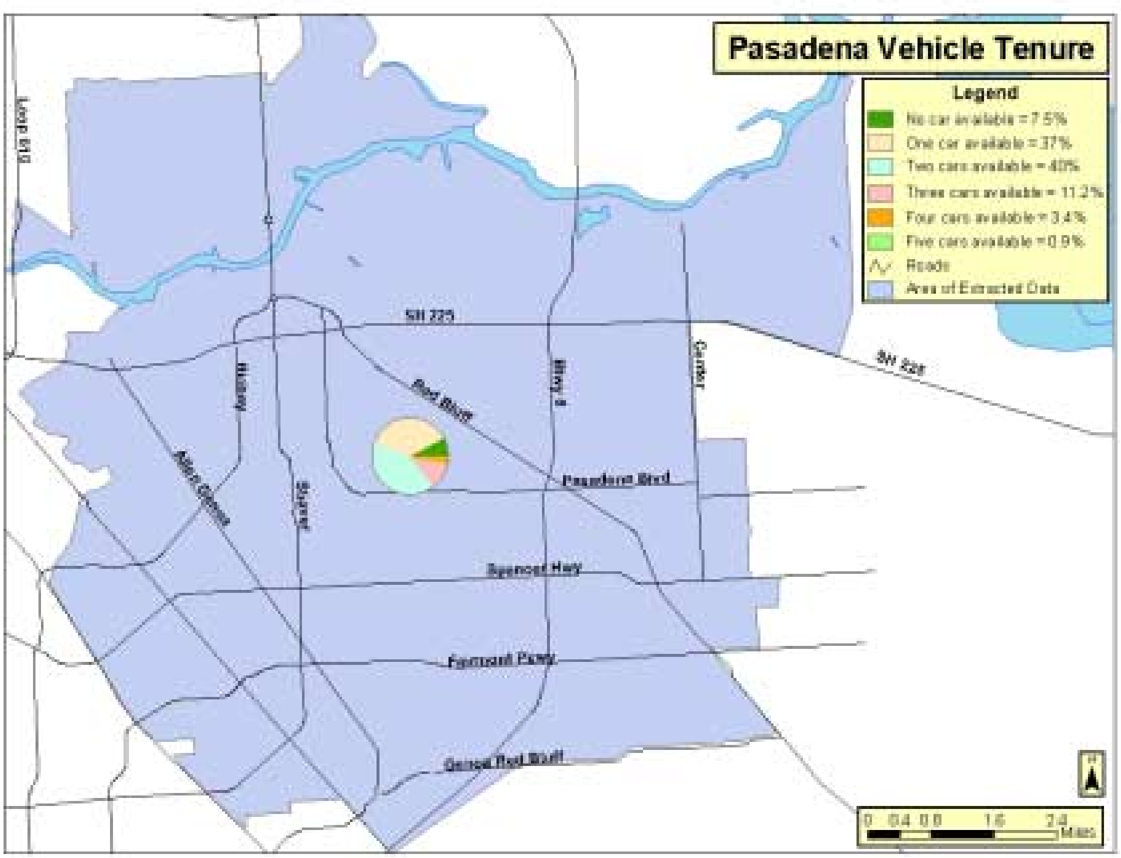

Figure 5. Pasadena Vehicle Tenure.

These statistics indicate that there is a slightly higher than average percentage of the population with no vehicle available, and there are slightly fewer families with one or two cars available. While these statistics are noteworthy, they do not strongly affect the Pasadena crash experience investigated in this report.

Speed Studies

A spot speed study was conducted at selected intersection approaches based on the preliminary crash analysis. The speed study ensured that the red and yellow intervals were based on operating speeds and not posted speeds. A difference could produce an unsafe red or yellow clearance interval.

Speeds of the lead vehicle or non-influenced vehicles were collected at midblock locations with a concealed radar gun to ensure an unbiased sample. Vehicles approaching a red light were not included in the sample. Table 5 presents a summary of the 85th percentile speeds. Figures 6 through 8 map the locations and directions where the speed surveys were conducted. Selected approaches were studied based on the crash data and collision diagrams. Raw tabulated data, speed statistics, and graphs were generated for the selected locations and the conclusions are presented in the tables in the Speed Studies sections of the investigated sites. On 225 at both the Main and Shaver intersections, the speed limits were set properly. Northbound SH 225 @ Main had an 85th percentile speed slightly higher than the posted speed limit. Both the Pasadena @ Curtis and Preston @ Cherry Brook sites had approaches where the 85th percentile speed was 5 mph or more over the posted speed limit. Speeding could be a concern in these two areas and additional studies are recommended. Further information about the speed studies is detailed in Appendix B.

Table 5. Summary of Spot Speed Study.

Location Number	Intersection	Direction	Posted Speed Limit	85th Percentile Speed
1	SH 225 @ Main	EB	40	37
2	SH 225 @ Main	NB	35	37
3	SH 225 @ Shaver	WB	40	37
4	SH 225 @ Shaver	EB	35	32
5	Pasadena @ Curtis	SB	30	31
6	Pasadena @ Curtis	NB	30	35
7	Preston @ Cherry Brook	SB	35	41

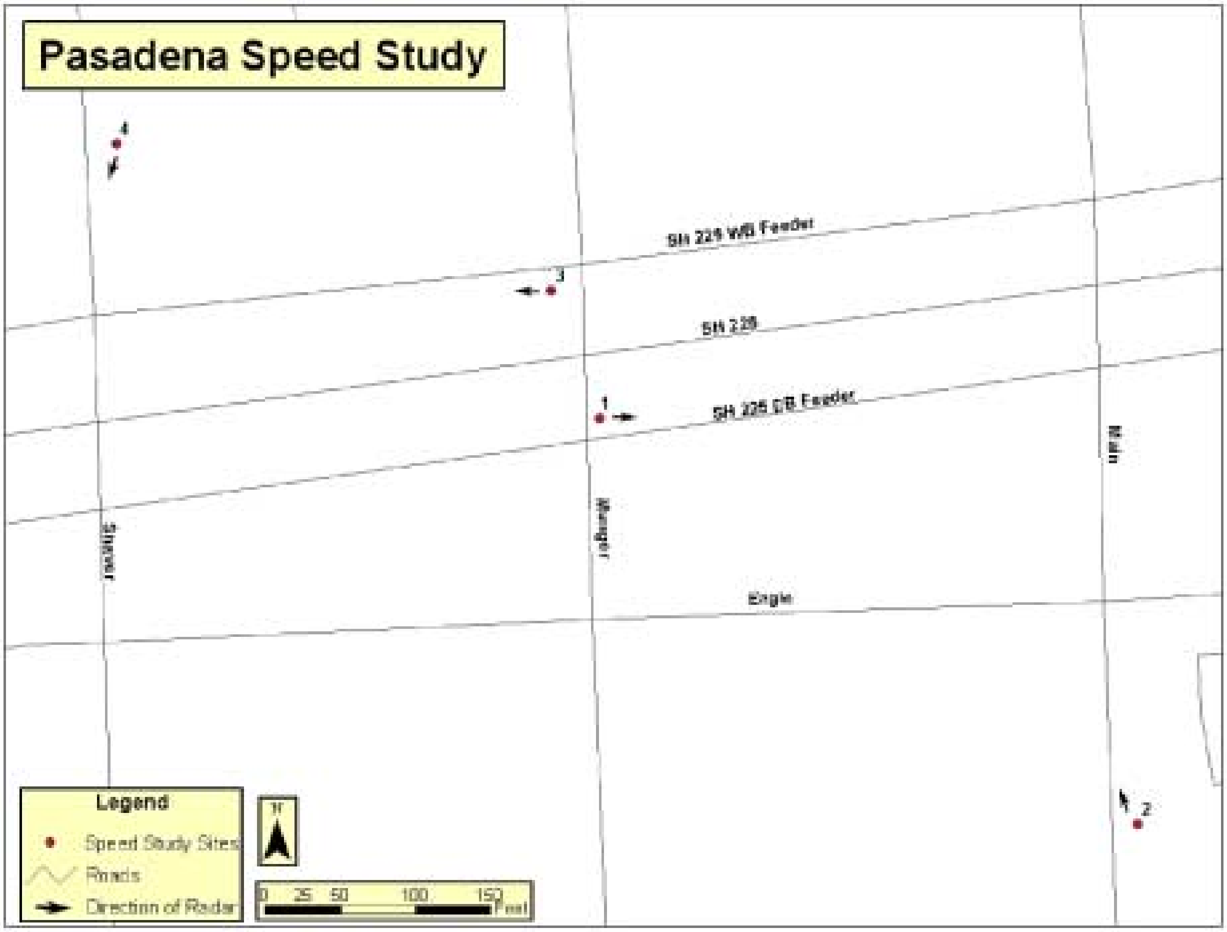

Figure 6. Spot Speed Study Locations on SH 225 at Main and Shaver.

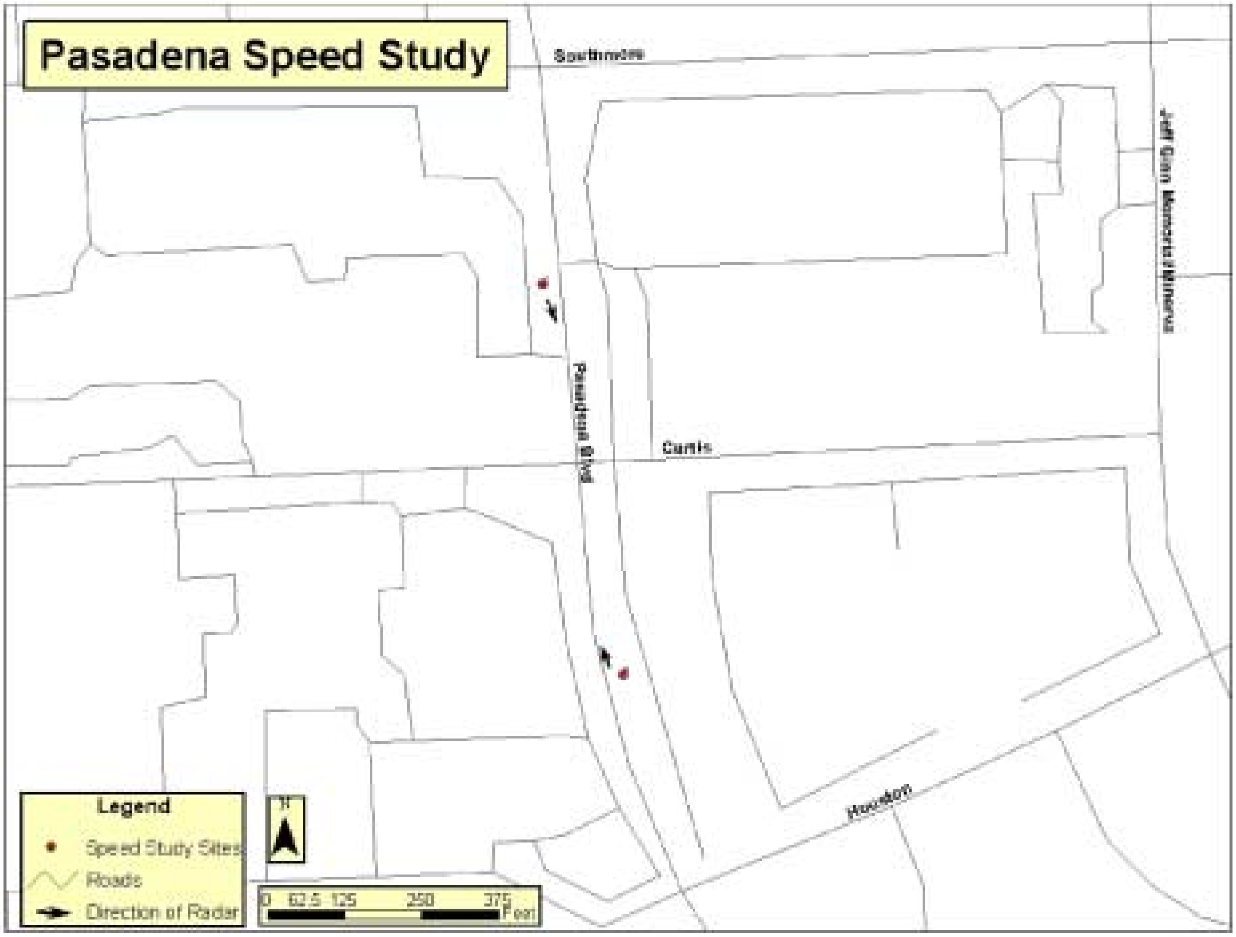

Figure 7. Spot Speed Study Locations on Pasadena at Curtis.

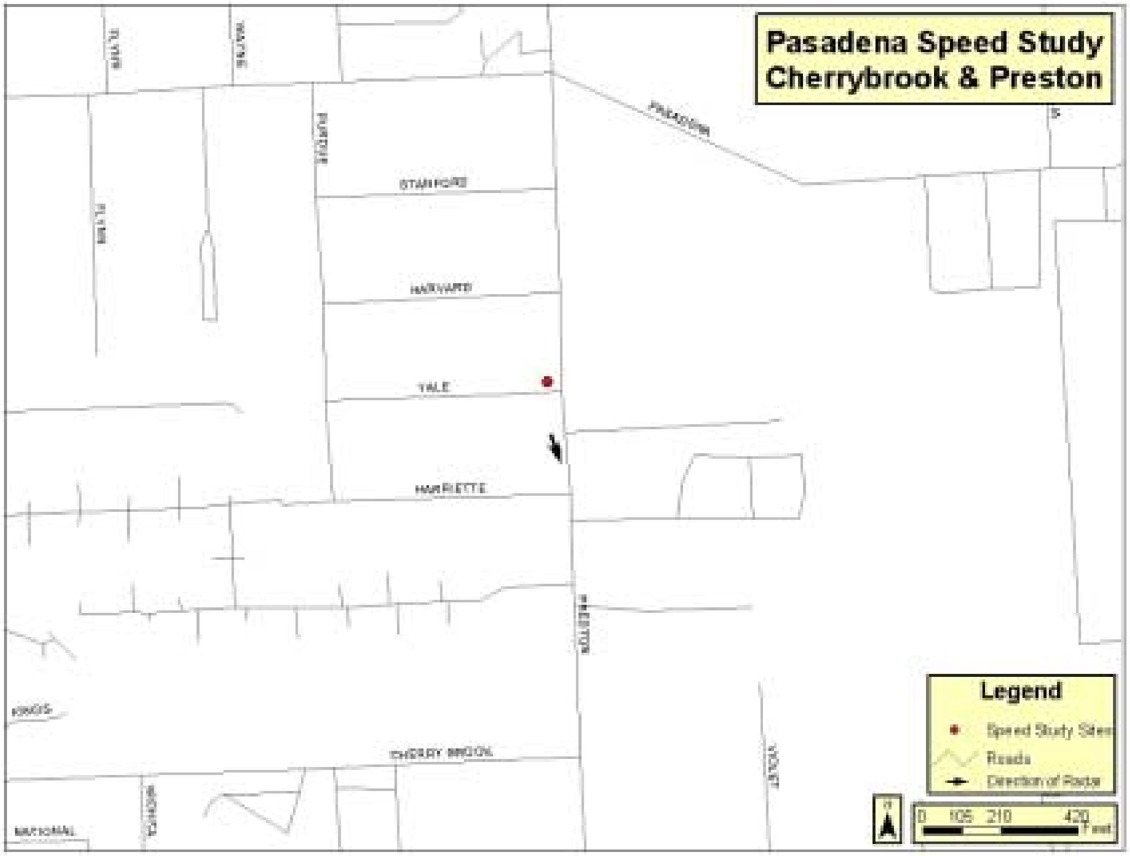

Figure 8. Spot Speed Study Location at Preston at Cherry Brook.

Crash Patterns and Causal Relationships

The following five sections describe each of the respective intersections and the related crash data. Collision diagrams were generated from the hardcopy data and are presented in Appendix C. These diagrams and officer comments served as the primary analysis tool to determine the crash patterns and resulting causal relationships. The diagrams show the approximate location of each crash and information related to the crash such as time of day, weather, pavement condition, accident codes, contributing factors, the driver at fault, and severity based on the crash report. General intersection information is provided such as the number of lanes, road width, lighting, and speed limit. Also provided is a summary of crashes by type and a breakdown by severity.

Possible causal relations were investigated from the crash patterns by utilizing information from the table entitled *General Countermeasures for Accident Patterns and Their Probable Causes*. This table, listed in Appendix D, was taken from the National Cooperative Highway Research Program (NCHRP) Report No. 91 (*1*).

Countermeasure Improvements

From the crash patterns and causal relationships determined in the section above, associated alternative countermeasures were established. Appendix E includes diagrams of the intersections with the recommended countermeasures in place. These are useful in providing the detailed information as to what signs and pavement markings, etc., are recommended and where. The countermeasures are listed in each section by work code and definition as outlined by TxDOT guidelines for safety improvements instituted under the Federal Hazard Elimination and Safety (HES) Program. A complete listing – by category – of each work code, description, definition, directed preventable accident, and related accident reduction factor is provided in Appendix F.

Crash Reduction Factors

For each designated engineering improvement countermeasure, a value for the expected reduction in selected frequency and type of crash will be assigned to enable a calculation of benefits. These crash (or accident) reduction factors have been established historically through research studies and Department of Transportation experience. Values used by TxDOT in Safety Improvement Index (SII) calculations are shown in Appendix F by individual work code. A national survey of comparative accident reduction factors was conducted by TTI in 1995. These survey results are given in Appendix G.

Crash Costs

Crash severities and associated costs are shown in Table 6. These severity classifications and National Safety Council comprehensive crash costs were used to calculate annual safety benefits estimated from expected crash reductions resulting from the implementation of safety improvement countermeasure recommendations. Each intersection will have a similar table showing the number of crashes by severity, the crash reduction factor associated with the countermeasure, and the resulting cost. The costs of the crash reduction were then expanded over the useful life of the countermeasure. The HES program provided the lifespan data for each countermeasure, and service lives are listed in Appendix H.

Table 6. Crash Severities and Associated Costs.

Crash Code	Crash Severity	Crash Cost
K	Fatality	$3,470,000
A	Incapacitating Injury	$172,000
B	Non-Incapacitating Injury	$44,000
C	Possible Injury	$21,000
PDO	Property Damage Only	$2,000

Countermeasure Costs

The cost of each countermeasure varies by type and intersection. Each countermeasure may have a different benefit depending on the service life of the project and the reduction factor for the improvement. A more detailed and site-specific cost and benefit analysis is covered in each individual site's section of this report. This analysis includes equipment costs, construction costs, and maintenance costs. Cost data for the recommended safety improvement countermeasures were obtained from TxDOT's project bid prices submitted for contract lettings in recent months. This information was accessed from the TxDOT website at <http://www.dot.state.tx.us.instdot\geodist\hov\cserve\uidprice\solol.htm>. A breakdown of the countermeasure improvement costs can be found in Appendix I.

Benefit-Cost Analysis

For each countermeasure identified, a benefit-cost analysis was conducted. This included preliminary benefit-cost ratio calculations for all countermeasures and alternatives and a funding and implementation prioritization. Each section summarizes the expected benefit-costs and recommended prioritization of the safety improvements established.

Several references (*2, 3, 4*) were used in benefit-cost calculations to establish funding priorities for the previously designated safety improvement countermeasures to be considered for implementation within the Pasadena study area.

Safety Improvement Index Analysis

TxDOT has developed a formula as part of the Federal Hazard Elimination and Safety Program that assesses the attributes of a safety improvement project and converts it to an index ratio by which each project can be ranked or prioritized in order of importance. This formula is called the Safety Improvement Index. In its most basic form, it is a benefit-cost ratio that computes the ratio of the potential reduction in crash costs to the cost of constructing the improvements. This formulated value is weighted heavily on the percentage of the expected reduction of the number of crashes that occurred prior to the improvement. Thus, an SII greater than or equal to 1.0 is considered to be cost effective. However, the ratio is not designed to measure the effectiveness of individual projects. Rather, it is a method by which many projects can be compared using the same set of criteria. By way of this comparison, a prioritization list of improvement projects can be formed.

With this prioritized list, the projects are funded beginning with the most important project, and each subsequent safety improvement project is then funded individually and sequentially.

The Safety Improvement Index formula is defined as follows:

$$S = \frac{R(C_f F + C_i I + C_p P)}{Y} - M, \qquad Q = \left(\frac{\frac{A_a - A_b}{A_b}}{L} \right) S$$

$$B = \frac{S + 1/2Q}{1.04} + \sum_{i=2}^{L} \left[\frac{(S + 1/2Q) + (i-1)Q}{(1.04)^1} \right]$$

$SII = \frac{B}{C}$, B = Present Worth of Project Benefits over Service Life

C = Initial Cost of Project

Where:

S	=	annual savings in accident cost (equal to accident cost savings per year less annual maintenance costs)
R	=	percentage reduction factor
F	=	number of fatal and/or incapacitating injury accidents
C_f	=	weighted cost of fatal and/or incapacitating injury accident ($232,700)
I	=	number of non-incapacitating and/or possible injury accidents
C_i	=	weighted cost of non-incapacitating and/or possible injury accidents ($16,900)
P	=	number of property damage only accidents
C_p	=	weighted cost of PDO accidents ($2,220)
Y	=	number of years of accident data
M	=	change in annual maintenance costs for the proposed project relative to the existing situation
Q	=	annual change in accident cost savings
A_a	=	projected average annual ADT at the end of the project service life
A_b	=	average annual ADT during the year before the project is implemented
L	=	Project Service Life

A four percent interest rate was used for the value of money. A 2.75 percent growth rate was used for the increase in traffic over the service life.

The change in cost savings is reflected by a change in traffic volume divided by the service life of the countermeasure installed and multiplied by the annual savings. The annual savings equals the cost of each crash type multiplied by the number of that type of crash divided by the number of years of crash data being considered. From this value, the annual maintenance cost must be subtracted out. Once the savings and annual change in crash costs (based on the change in traffic volume) are calculated, the standard compound interest formula is used to calculate the total benefit of the improvement for the life of the project. The SII is the benefit gained from reduced crashes divided by the cost of the project.

The SII formula is the best tool to evaluate the benefit-cost worth and relative priority of the recommended safety improvement countermeasures. Cost numbers are based on TxDOT statewide averages.

Conclusions and Recommendations

Based on the Safety Improvement Index (SII) as a measure of cost effectiveness, the recommended countermeasures are presented in each of the following intersection reports. The installation of directional and regulatory signs, the study and adjustment of signal timings, and the upgrading of traffic signals to LEDs with backplates typically had the highest SII ratio due to the number of crashes that would be reduced. Most of the projects were very cost effective with SII calculations ranging from 0.33 to 112.55. Although the driveway access management project had a low SII ratio, a citywide access management policy has the greatest potential to reduce crashes citywide. These policies not only improve safety but also traffic operations and general traffic flow. Generally, signs and markings have good SII numbers and can be typically done through routine maintenance. Similarly, the timing and coordination of traffic signal timings should be evaluated on the basis not only from an operations perspective but from the safety aspects as well. Utilizing the techniques demonstrated in this report should allow the City of Pasadena the tools to perform these safety checks as part of its routine business. Further development and automation of a safety database and evaluation tool should be considered. Elements of time of day, crash type, and severity by intersection could be used to better identify safety related intersections.

SITE 1: SH 225 @ MAIN

Crash Record Analysis

SH 225 @ Main is a diamond interchange with Main being the northbound street of a one-way pair with Shaver. The crash pattern showed that almost three times more crashes occurred on the far side (or north side) of the intersection with almost ten times the cost associated with these crashes. Therefore, the intersection was divided into two parts with Table 7 representing the frequency and severity of the crashes for the westbound direction of SH 225 and Table 8 representing the eastbound direction.

Table 7. Northbound Main and Westbound SH 225 Frontage Road.

Crash Type / Severity	Right-Turn	Left-Turn	Right-Angle	Rear-End	Driveway	Other	Totals
Fatal (K)	0	0	0	0	0	0	0
Incapacitating (A)	0	0	3	0	0	0	3
Non-Incapacitating (B)	0	1	4	0	0	0	5
Possible Injury (C)	0	3	5	0	0	0	8
Property Damage Only (PDO)	0	10	16	0	0	1	27
Total	0	14	28	0	0	1	43
Percentage of Total (%)	0	33	65	0	0	2	100

Table 8. Northbound Main and Eastbound SH 225 Frontage Road.

Crash Type / Severity	Right-Turn	Left-Turn	Right-Angle	Rear-End	Driveway	Other	Totals
Fatal (K)	0	0	0	0	0	0	0
Incapacitating (A)	0	0	0	0	0	0	0
Non-Incapacitating (B)	0	0	3	0	0	0	3
Possible Injury (C)	0	0	2	0	0	0	2
Property Damage Only (PDO)	0	3	4	0	0	1	8
Total	0	3	9	0	0	1	13
Percentage of Total (%)	0	23	69	0	0	8	100

The predominant crash type was right-angle crashes in the far side of the diamond interchange. Over 65 percent of the WB crashes were right-angle crashes and nearly 33 percent were left-turn crashes. Eastbound SH 225 has considerably fewer crashes but approximately the same proportions.

Traffic and Operational Data

General traffic counts from the area were provided by the City of Pasadena. Intersection turning movement counts were also provided for each intersection for the AM peak, Midday, and PM peak periods shown in Figure A-1 in Appendix A. Overall, the volumes were fairly consistent over the course of the day, but there were some peaking characteristics worth noting. During the

AM peak period, the WB SH 225 through traffic and the northbound (NB) Main left-turning traffic had the highest volumes (see Figure 9). During the PM peak period, the dominant movement was the EB SH 225 traffic turning right onto to NB Main. In addition to traffic count data, signal timings were also provided. All red and yellow clearance intervals were adequate based on standard practice.

Figure 9. View of Westbound traffic at SH 225 @ Main.

Speed Studies

There were two speed studies for this location, previously shown in Figure 6, sites 1 and 2. All of the 85th percentile speeds at these locations, with the exception of NB Main, were below the speed limit. Thus, speeding did not seem to be an issue during the time the speed study was conducted. NB Main had a 37 mph 85th percentile speed while the speed limit was 35 mph. This indicated that a fair number of people tend to speed on this approach. Increased police enforcement is suggested at this location. Increasing the speed limit to 40 mph could be done, but it would require adjusting the signal timing in the area. A more detailed study would be needed to determine the impact of increasing the speed limit. See Appendix B for the specifics on the speed studies performed at this location.

Crash Patterns and Causal Relationships

Based on the collision diagrams (see Figure C-1 in Appendix C), crash patterns were established.

1. *Left-Turn Sideswipes Pattern-*
   - Accounted for almost 33% of crashes on WB frontage road and NB Main and 23% of crashes on EB frontage road and NB Main.
   - Caused by cars crashing into other left-turners (i.e., drivers in the Left Turn Only lane tried to go straight while the through/left lane is turning left; or, both vehicles turned left but failed to maintain the lane and caused a sideswipe type crash).
   - Crashes coded as improper lane utilization (Disregard Turn Marks at Intersection) or failure to maintain lane.
   - The crashes could be caused, in part, by:
     - the poor condition of pavement markings under the bridge which delineate lane usage;
     - the lack of advanced signage placed before the intersection for all of the allowable directional movements;
     - the presence of a through-lane past the intersection which could encourage drivers in the far left-lane to go straight; and
     - a tight corner radius for left-turners in the wide (18-ft) turn-only lane which forces them into the center lane on the WB frontage road and puts them in contact with other left-turners.

2. *Right-Angle Crash Pattern-*
   - Accounted for 65% of crashes on WB frontage road and NB Main and 69% of crashes on EB frontage road and NB Main.
   - The crashes from WB SH 225 and NB Main had the highest frequency, severity, and cost of the crash patterns occurring at this intersection.
   - These crashes occurred mostly on the far side of the intersection, an indication that drivers were making it through the first intersection of EB SH 225 and NB Main but were getting trapped at the second intersection of WB SH 225 and NB Main.
   - Most of the crashes in this group were coded as Disregard Stop and Go Signal or Disregard Stop Sign or Signal.
   - The crashes could be caused, in part, by:
     - violation of driver expectancy that if they make it through the first light in the diamond interchange then they will be able to make it through the second one as well.

Countermeasure Improvements

Left-Turn Sideswipes

For improving the crash record for the left-turn sideswipe pattern on the NW side of the diamond interchange, the following countermeasures are recommended:

1. **cat tracks –** painting cat tracks on the NB Main and WB 225 frontage road intersection will aid turning vehicles in knowing which lane to turn into during the dual-left-turn phase; AND
2. **signage –** improving the current signing to include the allowable directional movements for ALL lanes and including a new sign on the signal arm of the EB 225 frontage road and NB Main intersection might increase driver awareness of what lane they should be in in advance; AND
3. **lane removal and realignment** – removing one of the through-lanes after the WB 225 frontage road and NB Main intersection and realigning the new, 3-lane road with the existing lane widths marked under the bridge will reduce driver confusion on where they can and cannot drive; AND
4. **painted buffer area –** painting a buffer area in the far left Turn-Only lane under the bridge will slim down the drivable area of the 18-ft wide lane and push vehicles to the outer portion of the lane and thus increase the radius of the corner so that traffic turning onto the WB 225 frontage road can more easily make the turn; AND
5. **candle stick delineation –** adding candle stick (a plastic piling with reflector) delineation on the far side of the intersection will physically block off the lane after the intersection and reinforce the turning requirement for drivers in the far left Turn-Only lane.

For improving the crash record for the left-turn sideswipe pattern on the SE side of the diamond interchange, the following countermeasures are recommended:

1. **signage –** improving the current signing on the EB 225 frontage road approach to NB Main to include the allowable directional movements for ALL lanes of traffic will increase driver awareness of what lane they should be in and prevent cars in the center lane from trying to turn left onto Main.

Right-Angle Crashes

For improving the crash record for the right-angle crash pattern, the following countermeasures are recommended:

1. **detection –** adding detection (such as cameras or loop detectors) to the intersection will allow the controller to “know” that there is a vehicle in between the two signals and keep the signal green until the vehicle has passed through the intersection; OR
2. **signal timing overlap phase –** including an approximately 3-second overlap phase for the far side (WB 225) of the diamond interchange will provide a little longer green time than the eastbound side; this will give a red light to the near side intersection (EB 225) and keep the far side green for a set amount of time (possibly 3 seconds) to allow the vehicles to progress through the far interchange without getting trapped; OR
3. **all-red clearance interval –** increasing the all-red and yellow clearance interval slightly will allow a little more time for motorists to pass through the intersection without conflict, but may potentially make drivers accustomed to such intervals and breed indifference for traffic control devices at other intersections; AND
4. **programmed heads –** using programmed heads on the far side (WB 225) of the intersection along with one of the three signal timing changes suggested above will

prevent the driver from seeing the Green light on the far side of the intersection and running the Red light that is on the near side, but it will still allow vehicles the time needed to clear the intersection.

General Crash Reduction for the Intersection

For reducing the overall amount of crashes occurring at this intersection, the following countermeasures are recommended to be applied to the intersection as a whole:

1. **LEDs –** installing 12-inch lenses or 12 inch Light Emitting Diodes (LEDs) with signal backplates will generally reduce the amount of collisions at a given intersection and improve the visibility of the signal. A TTI research study (*6*) found that larger lenses and LEDs increased the visibility of the light. Adding backplates as well increased the conspicuity of the signal head and reduced the red light running experience by 13 to 25 percent. In this report, TTI will recommend the upgrade of all signal sections to LED signal heads with backplates at all intersections discussed, based on knowledge from the study mentioned above, other national research results, and general field experience. At this location, 12-inch LEDs are currently present for the Red light indication on the frontage roads, but all other colors are incandescent and no LEDs exist on the intersecting street.
2. **pavement markings** - improving pavement markings and reflectorized Raised Pavement Markers (RPMs) at the intersection as a whole will assist traffic in maintaining proper lane assignment; currently, these treatments are faded and in very poor condition across the board.

Crash Reduction Factors

Table 9 shows the reduction factors, service life, and work codes associated with the countermeasures suggested in the section above. The reduction factors and work codes were obtained from Appendix F and the service life of the improvement was taken from Appendix H. These reduction factors are based on calculations provided by the Texas Department of Transportation. Alterations made to accommodate the local environment are listed at the bottom of the table.

Table 9. Suggested Countermeasures and Reduction Factors.

Countermeasure	Reduction Factor (%)	Service Life	Work Code
Improved pavement markings (including reflectorized RPMs, cat tracks, painted buffer areas with candle stick delineation, re-striped lanes, turn arrows and text, stop bars and crosswalks)	25	2*	401/406
Improved advanced directional signs	20	6	101
Signal timing changes: extension of green phase (with detection) AND/OR signal overlap OR all red clearance phase	15**	10	108
Vehicle Detection for extension of green phase	15**	10	108
12-inch LED signal heads with backplates	15	7.5	108
Programmed Heads	15**	10	108

*Service life reduced to 2 years rather than 3 to provide an average lifespan of both paint and RPMs.
**Reduction factor reduced from 22% to 15% since signals met specs but signal timings needed improvement.

Crash Costs

The annual crash costs for both sides of the intersection are presented in Tables 10 and 11. The number of crashes in these tables may not equal the numbers in Tables 5 and 6 due to the fact that sideswipe, driveway, and other rarely experienced crash types were not included here. These are true crash costs and have not been reduced based on potential countermeasure reduction factors. Right-angle crashes tend to be the most severe and as a result are the most costly. The crash costs are conservative due to the fact that if multiple injuries were experienced, only the most severe was used in the calculation.

Table 10. Three-Year Crash Costs for WB SH 225 at Main.

Crash Type/ Severity	Left-Turn	Cost	Right-Angle	Cost	Total # of Crashes	Total Cost	Annual Cost
A	0	$0	3	$516,000	3	$516,000	$172,000
B	1	$44,000	4	$176,000	5	$220,000	$73,333
C	3	$63,000	5	$105,000	8	$168,000	$56,000
PDO	10	$20,000	16	$32,000	26	$52,000	$17,333
Total	14	$127,000	28	$829,000	42	$956,000	$318,667

Table 11. Three-Year Crash Costs for EB SH 225 at Main.

Crash Type/ Severity	Left-Turn	Cost	Right-Angle	Cost	Total # of Crashes	Total Cost	Annual Cost
B	0	$0	3	$132,000	3	$132,000	$44,000
C	0	$0	2	$42,000	2	$42,000	$14,000
PDO	3	$6,000	4	$8,000	7	$14,000	$4,667
Total	3	$6,000	9	$182,000	12	$188,000	$62,667

Countermeasure Costs

Table 12 includes estimates of the cost of the improvements suggested for this intersection. The pavement marking costs include the cleaning, painting, and installation costs of all the painted countermeasures listed at their designated approaches. Lane stripes must be painted 100 feet out from the intersection approach. If there are two lane stripes to be painted, 200 ft of paint is needed. Cat tracks have two feet of paint alternating with two feet of unpainted space. For a 100 ft line, it would require 50 linear feet of paint. Prep costs for lane arrows, solid lines and reflectorized RPMs are included in the estimate below. For the rest of this report, the above information pertaining to lane stripes will be valid and implicit.

These costs were derived from the TxDOT website <http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/bidprice/s_6001.htm> that lists the statewide average low bid unit price for the construction of these projects.

Costs for signal timings adjustments will be dependent on agency costs, complexity of the timing plan, data required, etc. An estimate of $3000 is given in this report to account for the cost to hire a consultant to perform signal timing calculations and to implement the recommendations through an in-house crew.

The use of vehicle detection could be used in place of the overlap phase and would cost about $1,500 per detector for an overhead microwave detector unit to be installed on the signal arm.

Table 12. Estimated Countermeasure Costs.

Countermeasure	Cost
Pavement Markings (Total)	$1940.20
Reflectorized RPMs	$534.48
Solid Lines	$127.90
Cat Tracks	$9.14
Stop Bars	$169.00
Crosswalks	$240.00
Turn Arrows and Text	$206.00
Crosshatching for Barrier Areas	$313.27
Candle Stick Delineation (of Barrier Areas)	$340
Signage	$1021.00
Detection	$4500.00
Signal Timing Changes (only one of the options below)	$3,000.00
Extended Green Phase (using detection)	$3000.00
Overlap Phase	$3000.00
All-red Clearance Interval	$3,000.00
Programmed Heads	$3510.00
LEDs with Backplates	$4679.82

Please refer to Appendix I for a detailed list and description of what each countermeasure includes for this intersection and a further breakdown of the costs of these treatments. Also, see Figure E-1 in Appendix E for a diagram of where these countermeasures are to be implemented. Figures in Appendix E show the specific text to be put on the signs and pavement and the location of the countermeasures across the intersection. On the drawings, most of the changes to be made are coded in orange. The black signal head boxes indicate signal heads with backplates, and orange skip lines are drawn at the potential locations for reflective RPMs. These assumptions pertain to the other intersections as well and will not be mentioned again in this report.

Benefit-Cost Analysis

To give the City of Pasadena some flexibility in their safety improvement project options and to apply the countermeasures to specific locations of the diamond interchange, the suggested countermeasures were grouped as follows for the SII calculation and cost analysis:

- **Project No. 1**: Improve pavement markings at both locations of the diamond interchange at Main and SH 225. This includes lane stripes, stop bars, crosshatched barrier areas with candle stick delineation, turning arrows and text, crosswalks, and cat tracks (see diagram in Appendix E)
- **Project No. 2**: Improve advance warning signs at all the approaches to the intersection of Main and SH 225. This includes signs with arrows describing lane assignments and allowable movements through the intersection.
- **Project No. 3**: Upgrade existing signal heads (even though some already have LED red sections) to signal heads with backplates and LEDs on all sections.
- **Project No. 4**: Install detection devices to detect the presence of cars under the bridge and extend the green phase to allow them to clear the intersection.

- **Project No. 5**: Adjust the timing for the signals on NB Main before and after the 225 bridge to extend the green time (using detection devices), include an overlap phase, or allow a greater all-red clearance interval.
- **Project No. 6**: Place programmed heads on NB Main on the far side of the intersection.

The data in Table 13 were input into the SII formula provided by the HES program to determine an index ratio of the importance and cost-effectiveness of each recommended countermeasure. Table 14 presents the priority ranking of the safety improvement projects as concluded by the SII formula calculations. As illustrated in the table, the signal timing changes, programmed heads, LED upgrades and the detection devices are all highly cost effective countermeasures. To improve the pavement markings on the entire diamond intersection or to install advanced warning signs are only slightly less cost-beneficial improvements. This is most likely because neither of these two countermeasures could be linked to any K- or A-type crashes, crashes which are the most severe and costly and usually linked to red-light running. Overall, the recommended safety treatments at this location appear to be very valuable over time in reducing collisions and collision costs, and they are well-worth the initial expense.

Table 13. Safety Improvement Project Input Data for SII Calculations.

Safety Improvement Project Number	# of A+K Crashes	# of B+C Crashes	# of PDO Crashes	Years of Crash Data	Initial Cost of Project ($)	Project Service Life	ADT Before Project	ADT After Project Service Life	Crash Reduct. Factor	Present Worth of Project ($)
1	0	4	14	3	1940	2	22397	23646	25	15,065.40
2	0	4	14	3	1021	6	22397	26356	20	32,899.91
3	3	9	16	3	4680	7.5	22397	27450	15	267,574.41
4	3	9	16	3	4500	10	22397	29376	15	337,639.78
5	3	9	16	3	3000	10	22397	29376	15	337,639.78
6	3	9	16	3	3510	10	22397	29376	15	337,639.78

Table 14. Safety Improvement Index Priority Rankings.

Recommended Safety Improvement	Safety Improvement Index Value
1. Signal Timing Changes	112.55
2. Programmed Heads	96.19
3. Detection	75.03
4. LED/Backplate Upgrade	57.17
5. Signage	32.22
6. Pavement Markings	7.77

SITE 2: SH 225 @ SHAVER

Crash Record Analysis

SH 225 @ Shaver is a diamond interchange with Shaver being the southbound street of a one-way pair with Main. The crash pattern shows that almost 6 times more crashes occurred on the far side (or south side) of the intersection with almost ten times the cost associated with these crashes. Therefore, the intersection was divided into two parts. Table 15 represents the frequency and severity of the crashes for the eastbound direction of SH 225 and Table 16 represents the westbound direction.

Table 15. Southbound Shaver and Eastbound SH 225 Frontage Road.

Crash Type / Severity	Right-Turn	Left-Turn	Right-Angle	Rear-End	Driveway	Other	Totals
Fatal (K)	0	0	0	0	0	0	0
Incapacitating (A)	0	0	1	0	0	0	1
Non-Incapacitating (B)	0	0	8	0	0	0	8
Possible Injury (C)	0	0	9	1	0	0	10
Property Damage Only (PDO)	8	14	22	0	0	2	46
Total	8	14	40	1	0	2	65
Percentage of Total (%)	12	22	61	2	0	3	100

Table 16. Southbound Shaver and Westbound SH 225 Frontage Road.

Crash Type / Severity	Right-Turn	Left-Turn	Right-Angle	Rear-End	Driveway	Other	Totals
Fatal (K)	0	0	0	0	0	0	0
Incapacitating (A)	0	0	1	0	0	0	1
Non-Incapacitating (B)	0	0	0	0	0	0	0
Possible Injury (C)	0	0	3	0	0	0	3
Property Damage Only (PDO)	0	2	3	1	0	1	7
Total	0	2	7	1	0	1	11
Percentage of Total (%)	0	18	64	9	0	9	100

Similar to Site 1, SH 225 @ Main, the predominant crashes were right-angle crashes in the far eastbound side of the diamond interchange. Over 61 percent of the EB crashes were right-angle crashes, 22 percent were left-turns, and 12 percent were right-turns. Westbound SH 225 had considerably fewer crashes but approximately the same proportions.

Traffic and Operational Data

General traffic counts from the area were provided by the City of Pasadena. Intersection turning movement counts were also provided for each intersection for the AM peak, Midday, and PM peak periods (shown in Figure A-2 in Appendix A). The turning movement count diagram also shows the current condition of pavement markings, signal heads, signs, and other safety treatments at the intersection. Overall, the volumes were fairly consistent over the course of the day, but there are some peaking characteristics worth noting. During the AM peak period, the southbound (SB) traffic on Shaver and the WB traffic on the SH 225 through and left turn lanes had the highest volumes (see Figure 10). During the PM peak period, the dominant movement was the EB traffic on SH 225 turning right onto SB Shaver. In addition to traffic count data, signal timings were also provided. All red and yellow clearance intervals were adequate based on standard practice, but signal timings will be discussed later in this report.

Figure 10. Southbound Traffic at SH 225 @ Shaver.

Speed Studies

There were two speed studies for this location, shown as sites 3 and 4 in Figure 6. All of the 85th percentile speeds at these locations were below the speed limit. Thus, speeding did not seem to be an issue during the time the speed study was conducted. See Appendix B for the specifics on these studies.

Crash Patterns and Causal Relationships

Based on the collision diagrams (see Figure C-2 in Appendix C), three crash patterns were established:

1. *Left-Turn Sideswipes Pattern-*
   - Accounted for 18% of crashes on WB frontage road and SB Shaver and 22% of crashes on EB frontage road and SB Shaver.
   - Caused by cars crashing into other left-turners (i.e., drivers in the Left Turn Only lane tried to go straight while the through/left lane is turning left; or, both vehicles turned left but caused a sideswipe type crash)
   - Crashes coded as improper lane utilization (Disregard Turn Marks at Intersection), failure to maintain lane (Turned Improperly- Wrong Lane), or Driver Inattention.
   - The crashes could be caused, in part, by:
     - the poor condition of pavement markings under the bridge which delineate proper lane usage;
     - the lack of advanced signage placed before the intersection for all of the allowable directional movements;
     - alignment issues with the through-lanes past the intersection which could encourage drivers in the far left-lane to go straight;

2. *Right-Angle Crash Pattern-*
   - Accounted for 64% of crashes on WB frontage road and SB Shaver and 61% of crashes on EB frontage road and SB Shaver.
   - The crashes from EB SH 225 and SB Shaver had the highest frequency, severity, and cost of the crash patterns occurring at this intersection.
   - These crashes occurred mostly on the far side of the intersection, an indication that drivers were making it through the first intersection of WB SH 225 and SB Shaver but were getting trapped at the second intersection of EB SH 225 and SB Shaver.
   - Most of the crashes in this group were coded as Disregard Stop and Go Signal or Disregard Stop Sign or Signal.
   - The crashes could be caused, in part, by:
     - violation of driver expectancy that if they make it through the first light in the diamond interchange then they will be able to make it through the second one as well.

3. *Right-Turn Sideswipes Pattern-*
   - Accounted for 12% of crashes on EB frontage road and SB Shaver
   - Caused by cars crashing into other right-turners (i.e., drivers in the Right Turn Only lane tried to go straight while the through/right lane is turning right; or, both vehicles turned right but failed to maintain proper lane and caused a sideswipe type crash)

- Crashes coded as improper lane utilization (Disregard Turn Marks at Intersection), failure to maintain lane (Turned Improperly- Wide Right), or Failed to Drive in Single Lane.
- The crashes could be caused, in part, by:
  - the poor condition of pavement markings on the approach to the 225 EB frontage road intersection with SB Shaver which delineate proper lane usage;
  - the lack of advanced signage placed before the intersection for all of the allowable directional movements; and
  - alignment issues with the through-lanes past the intersection which could encourage drivers in the far right-lane to try to go straight.

Countermeasure Improvements

Left-Turn Sideswipes

For improving the crash record for the left-turn sideswipe pattern, the following countermeasures are recommended:

1. **cat tracks –** enhancing existing lane markings under the bridge and painting a straight line of cat tracks on SB Shaver (on the east side of the intersection with EB 225) will tell vehicles in the middle lane to go straight rather than to turn; AND
2. **signage –** improving the current signing to include the allowable directional movements for ALL lanes and including a new sign on the signal arm of the WB 225 frontage road and SB Shaver intersection might increase driver awareness of what lane they should be in; AND
3. **lane realignment** – realigning the three-lane road past the intersection with the existing three through-lane widths marked under the bridge will reduce driver confusion on where they can and cannot drive; AND
4. **candle stick delineation –** adding candle stick delineation on the far side of the intersection will physically block off the lane after the intersection and reinforce the turning requirement for drivers in the far left Turn-Only lane on SB Shaver.

Right-Angle Crashes

For improving the crash record for the right-angle crash pattern, particularly on SB Shaver at the far (east) side of the intersection, the following countermeasures are recommended:

1. **detection –** adding detection (such as cameras or loop detectors) to the intersection will allow the controller to "know" that there is a vehicle in between the two signals and keep the signal green until the vehicle has passed through the intersection; OR
2. **signal timing overlap phase –** including an approximately 3-second overlap phase for the far side (EB 225) of the diamond interchange will provide a little longer green time than the eastbound side; this will give a red light to the near side intersection (WB 225) and keep the far side green for a set amount of time (possibly 3 seconds) to allow the vehicles to progress through the far interchange without getting trapped; OR

3. **all-red clearance interval –** increasing the all-red and yellow clearance interval slightly will allow a little more time for motorists to pass through the intersection without conflict, but may potentially make drivers accustomed to such intervals and breed indifference for traffic control devices at other intersections; AND
4. **programmed heads –** using programmed heads on the far side (EB 225) of the intersection along with one of the three signal timing changes suggested above will prevent the driver from seeing the Green light on the far side of the intersection and running the Red light that is on the near side, but it will still allow vehicles the time needed to clear the intersection.

Right-Turn Sideswipes

For improving the crash record for the right-turn sideswipe pattern in the far SW corner of the intersection, the following countermeasures are recommended:

1. **cat tracks –** painting cat tracks from the EB 225 frontage road onto SB Shaver will help dual-right-turning vehicles maintain their respective lanes.
2. **signage –** adding signing that includes the allowable directional movements for ALL lanes of the EB 225 frontage road and SB Shaver intersection might increase driver awareness of what lane they should be in and which lanes can turn; AND
3. **candle stick delineation –** adding candle stick delineation on the far side of the intersection will physically block off the right lane after the intersection and reinforce the turning requirement for drivers in the far Right Turn-Only lane.

General Crash Reduction for the Intersection

For reducing the overall amount of crashes occurring at this intersection, the following countermeasures are recommended to be applied to the intersection as a whole:

1. **LEDs –** installing 12-inch lenses or 12 inch Light Emitting Diodes (LEDs) with signal backplates will generally reduce the amount of collisions at a given intersection and improve the visibility of the signal. A TTI research study found that larger lenses and LEDs increased the visibility of the light. Adding backplates as well increased the conspicuity of the signal head and reduced the red light running experience by 13 to 25 percent. At this location, only the red lights on the frontage roads currently have the 12-inch LEDs, and all others are incandescent.
2. **pavement markings** - improving pavement markings and reflectorized RPMs to the intersection as a whole will assist traffic in maintaining proper lane assignment; currently, these treatments are faded and in very poor condition across the board.

Crash Reduction Factors

Table 9 in the SH 225 @ Main section provides the reduction factors, service life, and work codes for the countermeasures suggested above.

Crash Costs

The annual crash costs for EB and WB SH 225 @ Shaver are presented in Tables 17 and 18. These are true crash costs and have not been reduced based on potential countermeasure reduction factors. Right-angle crashes tend to be the most severe and as a result are the most costly. The crash costs are conservative due to the fact that if multiple injuries were experienced, only the most severe was used in the calculation.

Table 17. Three-Year Crash Costs for EB SH 225 at Shaver.

Crash Type/ Severity	Right-Turn	Cost ($)	Left-Turn	Cost ($)	Right-Angle	Cost ($)	Rear-End	Cost ($)	Total # of Crashes	Total Cost	Annual Cost ($)
A	0	0	0	0	1	172,000	0	0	1	172,000	57,333
B	0	0	0	0	8	352,000	0	0	8	352,000	117,333
C	0	0	0	0	9	189,000	1	21,000	10	210,000	70,000
PDO	8	16,000	14	28,000	22	44,000	0	0	46	88,000	29,333
Total	8	16,000	14	28,000	40	757,000	1	21,000	63	822,000	274,000

Table 18. Three-Year Crash Costs for WB SH 225 at Shaver.

Crash Type/ Severity	Right-Turn	Cost ($)	Left-Turn	Cost ($)	Right-Angle	Cost ($)	Rear-End	Cost ($)	Total # of Crashes	Total Cost	Annual Cost ($)
A	0	0	0	0	1	172,000	0	0	1	172,000	57,333
C	0	0	0	0	3	63,000	0	0	3	63,000	21,000
PDO	0	0	2	4,000	3	6,000	1	2,000	6	12,000	4,000
Total	0	0	2	4,000	7	241,000	1	2,000	10	247,000	82,333

Countermeasure Costs

Since SH 225 at Shaver is very similar in design to SH 225 @ Main and is experiencing similar crash patterns, many of the recommended countermeasures and costs will be similar. Table 19 includes estimates of the cost of the improvements suggested for SH 225 at Shaver. The same assumptions apply as stated in the SH 225 at Main section of this report.

Table 19. Estimated Countermeasure Costs.

Countermeasure	Cost
Pavement Markings (Total)	$2260.32
Reflectorized RPMs	$489.95
Solid Lines	$160.70
Cat Tracks	$13.16
Stop Bars	$169.00
Crosswalks	$240.00
Turn Arrows and Text	$481.00
Crosshatching for Barrier Areas	$281.47
Candle Stick Delineation (of Barrier Areas)	$425
Signage	$816.80
Detection	$6000.00
Signal Timing Changes (only one of the options below)	$3,000.00
Extended Green Phase (using detection)	$3000.00
Overlap Phase	$3000.00
All-red Clearance Interval	$3,000.00
Programmed Heads	$3510.00
LEDs with Backplates	$4159.84

Please refer to Appendix I for a detailed list and description of what each countermeasure includes for this intersection (see Figure E-2 in Appendix E for a diagram of where these countermeasures are to be implemented) and a further breakdown of the costs of these treatments.

Benefit-Cost Analysis

The suggested countermeasures were grouped identically to the countermeasures for the SH 225 at Main intersection for the SII calculation and cost analysis:

- **Project No. 1**: Improve pavement markings at both locations of the diamond interchange at Shaver and SH 225. This includes lane stripes, stop bars, crosshatched barrier areas with candle stick delineation, turning arrows and text, crosswalks, and cat tracks (see diagram in Appendix E)
- **Project No. 2**: Improve advance warning signs at all the approaches to the intersection of Shaver and SH 225. This includes signs with arrows describing lane assignments and allowable movements through the intersection.
- **Project No. 3**: Upgrade existing signal heads (even though some already have LED red sections) to signal heads with backplates and LEDs on all sections.
- **Project No. 4**: Install detection devices to detect the presence of cars under the bridge and extend the green phase to allow them to clear the intersection.
- **Project No. 5**: Adjust the timing for the signals on SB Shaver before and after the 225 bridge to extend the green time (using detection devices), include an overlap phase, or allow a greater all-red clearance interval.
- **Project No. 6**: Place programmed heads on SB Shaver on the far side of the intersection.

The data in Table 20 were input into the SII formula provided by the HES program to determine an index ratio of the importance and cost-effectiveness of each recommended countermeasure. Table 21 presents the priority ranking of the safety improvement projects as concluded by the SII formula calculations. Like the Main @ 225 intersection, the signal timing changes, programmed heads, LED upgrades and the detection devices look to be highly cost effective countermeasures, and improving the pavement markings or signage on the entire diamond intersection would be only slightly less cost-effective.

Table 20. Safety Improvement Project Input Data for SII Calculations.

Safety Improvement Project Number	# of A+K Crashes	# of B+C Crashes	# of PDO Crashes	Years of Crash Data	Initial Cost of Project ($)	Project Service Life	ADT Before Project	ADT After Project Service Life	Crash Reduct. Factor	Present Worth of Project ($)
1	0	0	22	3	2260	2	25845	27286	25	7,456.32
2	0	0	22	3	816.8	6	25845	30414	20	16,283.39
3	1	15	15	3	4159.84	7.5	25845	31676	15	156,940.24
4	1	15	15	3	6000	10	25845	33900	15	198,040.02
5	1	15	15	3	3000	10	25845	33900	15	198,040.02
6	1	15	15	3	3510	10	25845	33900	15	198,040.02

Table 21. Safety Improvement Index Priority Rankings.

Recommended Safety Improvement	Safety Improvement Index Value
1. Signal Timing Changes	66.01
2. Programmed Heads	56.42
3. LED/Backplate Upgrade	37.73
4. Detection	33.01
5. Signage	19.94
6. Pavement Markings	3.30

SITE 3: SHAVER @ PAULINE/QUEENS

Crash Record Analysis

A total of 57 crashes were reported at the intersection of Shaver and Pauline/Queens. Of those crashes, 41 occurred at an intersection or were intersection-related, and 16 were not intersection-related. The breakdown of the type of the crashes based on the collision diagram is presented in Table 22.

Table 22. Types of Crashes at Shaver @ Pauline/Queens.

Crash Type / Severity	Right-Turn	Left-Turn	Right-Angle	Rear-End	Driveway	Other	Totals
Fatal (K)	0	0	0	0	0	0	0
Incapacitating (A)	0	0	0	0	0	0	0
Non-Incapacitating (B)	0	3	4	0	0	0	7
Possible Injury ©	0	3	1	2	0	0	6
Property Damage Only (PDO)	0	8	9	8	0	3	28
Total	0	14	14	10	0	3	41
Percentage of Total (%)	0	34	34	24	0	8	100

Thirty four percent of the crashes were left-turn crashes: four were from NB Shaver to WB Queens, five were from EB Pauline to NB Shaver, and five were from WB Queens to SB Shaver. Four of the right-angle crashes were from SB Shaver and WB Pauline, three were from SB Shaver and EB Queens, five were from NB Shaver and WB Pauline, and two were from EB Queens and NB Shaver.

Traffic and Operational Data

Intersection turning movement counts were provided by the City of Pasadena for the AM peak, Midday, and PM peak periods, as shown in Figure A-3 of Appendix A. This figure also contains a sketch of the current condition of the features at this intersection including pavement markings, lane widths, and signal heads. The predominant movement during the AM period was the eastbound and westbound movement on Queens and Pauline (see Figure 11). During the PM peak period, the predominant movement was northbound and southbound on Shaver. Working collision diagrams were produced for each intersection for all complete, hard copy crash data obtained from the City of Pasadena for the time period between January 2000 and December 2002 (see Figure C-1 in Appendix C).

Figure 11. Westbound Traffic on Shaver @ Queens.

Speed Studies

No speed study was conducted for this location, but based on the crash patterns occurring a formal engineering speed study is suggested.

Crash Patterns and Causal Relationships

Based on the collision diagrams (see Figure C-3 in Appendix C), three crash patterns were established:

1. *Left-Turn Crash Pattern-*
   - There were 14 left-turning vehicle collisions which accounted for 34% of crashes at the Shaver and Pauline/Queens intersection.
   - 10 of the 14 involved movement from vehicles turning from Pauline or Queens onto Shaver, while the other 4 were from NB vehicles on Shaver turning onto Queens.
   - Most of the crashes were coded as a Failure to Yield ROW – Turning Left, but a couple were attributed to Driver Inattention or Disregard Stop and Go Signal.
   - The crashes could be caused, in part, by a lack of education (provided by signage) as to who is required to yield the ROW.

2. *Right-Angle Crash Pattern-*
   - Accounted for 34% of crashes at the Shaver and Pauline/Queens intersection.
   - Most of the crashes in this group were coded as Disregard Stop and Go Signal or Disregard Stop Sign or Signal.
   - The crashes could be caused, in part, by:
     - violation of driver expectancy that the light will remain green,
     - inattentiveness of driver to the signal,
     - poor conspicuity of the light, or
     - a lack of law enforcement in the area.

3. *Rear-End Crash Pattern-*
   - Accounted for 24% of crashes at the Shaver and Pauline/Queens intersection.
   - Most of the crashes in this group were coded as Followed Too Closely or Failed to Control Speed.
   - The crashes could be caused, in part, by:
     - violation of driver expectancy that the light will remain green and that the car in front will not be braking for a yellow or red light,
     - inattentiveness of driver to the signal, or
     - poor conspicuity of the light.

Countermeasure Improvements

Left-Turn Crashes

For improving the crash record for the left-turn sideswipe pattern, the following countermeasures are recommended:

1. **exclusive left-turn phase –** change the signal sequence to include an exclusive left-turn phase for cars on Pauline and Queen wishing to turn onto Shaver and add appropriate signage (e.g. Left Turn Protected on Green) to the signal arm above the two side streets); OR
2. **signage –** adding regulatory signs to the signal arms above Pauline and Queens that say Left-Turn Yield on Green will help drivers know that they must yield to oncoming traffic.

Right-Angle Crashes

Right-angle crashes are most often associated with red-light running. Red-light running is a nationwide problem resulting in more than 1.8 million intersection crashes (*5*). Preliminary estimates for 2002 indicate that 207,000 crashes, 178,000 injuries, and about 920 deaths can be attributed to red-light running. At this intersection, a large portion of the crashes can also be attributed to red-light running. The following countermeasures are recommended to improve the stop compliance of drivers at red lights:

1. **all-red clearance interval –** increasing the all-red and yellow clearance interval slightly will allow a little more time for motorists to pass through the intersection without

conflict, but may potentially make drivers accustomed to such intervals and breed indifference for traffic control devices at other intersections; TTI recommends that an engineering study be performed to determine the delay impacts of this countermeasure and its overall value to the improvement of the safety at the intersection; AND

2. **pavement markings** – applying fresh pavement markings such as stop bars may reinforce the boundaries of the intersection and increase the awareness of drivers as to the proper stopping location.
3. **enforcement** – although a speed study was not conducted at this location, it is recommended that one be performed as a justification for enhanced enforcement in this area; enforcement of both speed limits and red-light stop compliance should help reduce the number and seriousness of the crashes at this intersection.

Rear-End Crashes

Some rear-end crashes may be reduced by incorporating the treatments listed above for the right-angle crash pattern. Another recommended countermeasure is:

1. **coordination** – while the signal may presently be coordinated with the Fresa and surrounding signals, field observations reflect that the time-based coordination is off and should be checked and readjusted accordingly; AND

General Crash Reduction for the Intersection

For reducing the overall amount of crashes occurring at this intersection, the following countermeasures are recommended to be applied to the intersection as a whole:

1. **LEDs** – installing 12-inch lenses or 12 inch Light Emitting Diodes (LEDs) with signal backplates may help to improve the visibility of the signals and reduce the red-light running behavior associated with many of the crashes at this intersection. Currently, all of the signal heads at Shaver and Pauline/Queens have incandescent lights with no backplates.
2. **pavement markings** - improving pavement markings and reflectorized RPMs to the intersection as a whole will assist traffic in maintaining proper lane assignment; currently, these treatments are faded and in very poor condition across the board.
3. **signage** – improving the current signing to include the allowable directional movements for ALL lanes at each approach is suggested.

Crash Reduction Factors

Table 23 shows the reduction factors, service life, and work codes associated with the countermeasures suggested above. The reduction factors and work codes were obtained from Appendix F and the service life of the improvement was taken from Appendix H.

Table 23. Suggested Countermeasures and Reduction Factors.

Countermeasure	Reduction Factor (%)	Service Life	Work Code
Improved pavement markings (including reflectorized RPMs, re-striped lanes, turn arrows and text, and stop bars)	25	2*	401/406
Improved advance directional signs	20	6	101
Signal timing changes: all red clearance phase AND/OR left-turn exclusive phase AND/OR coordination with other intersections	15**	10	108
12-inch LED signal heads with backplates	15	7.5	108

*Service life reduced to 2 years rather than 3 to provide an average lifespan of both paint and RPMs.
**Reduction factor reduced from 22% to 15% since signal timing met specs but still needed improvement.

Crash Costs

The total crash cost for this intersection is $490,000 for the three years, resulting in an average total crash cost of $163,333. Table 24 includes the costs of all types of crashes except the "Other" category, which, at this intersection, includes three PDO crashes not used in calculations. If the above countermeasures are implemented and the associated crash reduction factors are applied, the cost of crashes that might be corrected by the associated countermeasures is approximately $79,050 for the three-year period and $26,350 annually. Breaking this down by countermeasure, $17,250 is for the left-turn crashes that might be corrected using a left-turn phase, and $9,100 is for right-angle and rear-end crashes that might be corrected with larger, more conspicuous, 12-inch LED signal heads with backplates.

Table 24. Three-Year Crash Costs for Shaver @ Pauline/Queens.

Crash Type/ Severity	Right-Turn	Cost ($)	Left-Turn	Cost ($)	Right-Angle	Cost ($)	Rear-End	Cost ($)	Total # of Crashes	Total Cost	Annual Cost ($)
B	0	0	3	132,000	4	176,000	0	0	7	308,000	102,667
C	0	0	3	63,000	1	21,000	2	42,000	6	126,000	42,000
PDO	0	0	8	16,000	9	18,000	8	16,000	25	50,000	16,667
Total	0	0	14	211,000	14	215,000	10	58,000	38	484,000	161,333

Countermeasure Costs

Table 25 includes estimates of the cost of the improvements suggested for this intersection. The cost for signal timing adjustments and coordination is again difficult to determine since agency costs and the complexity of the interconnections vary. For all purposes and calculations in this report, the cost of coordinating intersection signals will be cautiously estimated at around $3000 to account for the cost to hire a consultant to perform signal timing calculations and to implement the recommendations through an in-house crew.

Table 25. Estimated Countermeasure Costs.

Countermeasure	Cost
Pavement Markings (Total)	$1879.68
Reflectorized RPMs	$534.48
Solid Lines	$669.20
Stop Bars	$127.00
Turn Arrows and Text	$549.00
Signage	$786.94
Signal Timing Changes (one or more of the options below)	$3,000.00 to $9,000.00
Exclusive Left-Turn Phase	$3000.00
All-Red Clearance Interval	$3000.00
Re-coordination with Fresa intersection	$3,000.00
LEDs with Backplates	$5171.62

Please refer to Appendix I for a detailed list and description of what each countermeasure includes for this intersection (see Figure E-3 in Appendix E for a diagram of where these countermeasures are to be implemented) and a further breakdown of the costs of these treatments.

Benefit-Cost Analysis

For the Shaver @ Pauline/Queens intersection, the suggested countermeasures were grouped as follows for the SII calculation and cost analysis:

- **Project No. 1**: Improve pavement markings at all approaches to the Shaver @ Pauline/Queens intersection. This includes RPMs, solid lane stripes, stop bars, turning arrows and text.
- **Project No. 2**: Improve advance warning signs at the NB and SB approaches on Shaver to the intersection of Shaver and Pauline/Queens to include arrows describing all lane assignments and allowable movements through the intersection. It also adds “Left Turn Yield on Green” signs for traffic turning from Pauline or Queens onto Shaver.
- **Project No. 3**: Upgrade existing incandescent signal heads to ones with backplates and LEDs on all sections.
- **Project No. 4**: Adjust the timing for the signals on Shaver and Pauline/Queens to coordinate with surrounding intersections, provide an exclusive left-turn phase, or allow a greater all-red clearance interval.

The data in Table 26 were input into the SII formula provided by the HES program to determine an index ratio of the importance and cost-effectiveness of each recommended countermeasure. Table 27 presents the priority ranking of the safety improvement projects as concluded by the SII formula calculations. As illustrated in the table, signage change is an inexpensive project that is worth much more than its initial value over time. The signal timing changes and pavement marking improvements are also indicated to be highly beneficial and cost-effective over their lifespan. The new signal heads, while ranked slightly below the other safety treatments for this intersection, are still estimated to be a worthy investment.

Table 26. Safety Improvement Project Input Data for SII Calculations.

Safety Improvement Project Number	# of A+K Crashes	# of B+C Crashes	# of PDO Crashes	Years of Crash Data	Initial Cost of Project ($)	Project Service Life	ADT Before Project	ADT After Project Service Life	Crash Reduct. Factor	Present Worth of Project ($)
1	0	6	13	3	1879.92	2	32155	33948	25	19,886.65
2	0	6	13	3	786.94	6	32155	37838	20	43,428.18
3	0	6	13	3	5171.62	7.5	32155	39412	15	39,352.56
4	0	6	6	3	3000	10	32155	42177	15	43,732.93

Table 27. Safety Improvement Index Priority Rankings.

Recommended Safety Improvement	Safety Improvement Index Value
1. Signage	55.19
2. Signal Timing Changes	14.58
3. Pavement Markings	10.58
4. LED/Backplate Upgrade	7.61

SITE 4: PASADENA @ CURTIS

Crash Record Analysis

The intersection of Pasadena @ Curtis experienced 37 crashes over three years (2000 to 2002). The breakdown of the type of the crash based on factor codes is presented in Table 28. Many of these crashes are caused by left-turning vehicles from SB Pasadena to EB Curtis who failed to yield the right-of-way to vehicles traveling on Pasadena heading NB. The largest group was right-angle crashes. The right-angle crashes were caused most often by a disregard of traffic signal and were twice as likely to occur on the far side of the intersection (i.e., the vehicle with ROW has traveled through two to four lanes of traffic before being struck by a red-light runner; this implies that the traffic signal is red for many seconds before the violation occurs).

Table 28. Types of Crashes at Pasadena @ Curtis.

Crash Type / Severity	Right Turn	Left Turn	Right Angle	Rear End	Side Swipe (opposite direction)	Side Swipe (same direction)	Totals
Fatal (K)	0	0	0	0	0	0	0
Incapacitating (A)	0	0	0	0	0	0	0
Non-Incapacitating (B)	0	1	5	0	0	0	6
Possible Injury (C)	0	4	4	2	0	0	10
Property Damage Only (PDO)	2	5	9	3	1	1	21
Total	2	10	18	5	1	1	37
Percentage of Total (%)	5	27	49	14	2.5	2.5	100

Traffic and Operational Data

General traffic counts from the area were provided by the City of Pasadena. Intersection turning movement counts were also provided for each intersection for the AM peak, Midday, and PM peak periods, as shown in Figure A-4 in Appendix A. The traffic trend is to flow NB in the AM period and SB in the PM peak period on Pasadena with very little traffic on Curtis (see Figure 12).

Figure 12. Traffic Moving Northbound through the Pasadena @ Curtis Intersection.

Speed Studies

There were two speed studies for this location, shown previously in Figure 7. The posted speed limit on Pasadena was 30 mph on both approaches to the intersection. However, the SB traffic on Pasadena had a 31 mph 85th percentile speed and the NB traffic had a 35 mph 85th percentile speed. This indicated that a fair number of people tend to speed through this intersection. Increased police enforcement is suggested, not only to slow down speeding vehicles but to catch the red-light violators. Of the right angle crashes, 15 of the 18 (or 83 percent) were due to a disregard of the red light. While police may not write tickets for people going slightly over the speed limit, their presence alone in the area may help to reduce these driving behaviors. Increasing the speed limit to 35 mph could be done, but it would require adjusting the signal timing in the area, and its effect on the clearance interval would be negligible. A more detailed study would be needed to determine the impact of this increase. See Appendix B for the rest of the information pertaining to the speed study conducted at this location.

Crash Patterns and Causal Relationships

Based on the collision diagrams (see Figure C-4 in Appendix C), three crash patterns were established:

1. *Left-Turn Crash Pattern-*
   - Left-turning vehicle collisions accounted for 27% of crashes at the Pasadena and Curtis intersection.
   - 7 of the 10 involved movement from vehicles turning from SB Pasadena onto EB Curtis, while the other 3 were from NB vehicles on Pasadena turning onto WB Curtis.
   - All of the crashes were coded as a Failure to Yield ROW – Turning Left.
   - The crashes could be caused, in part, by:
     - a lack of education (provided by signage) as to who is required to yield the ROW, or
     - inadequate available gap time for left-turning vehicles due to the high volume of traffic on Pasadena.

2. *Right-Angle Crash Pattern-*
    - Accounted for 49% of crashes at the Pasadena and Curtis intersection.
    - Most of the crashes in this group were coded as Disregard Stop and Go Signal or Disregard Stop Sign or Signal.
    - The crashes could be caused, in part, by:
        - violation of driver expectancy that the light will remain green,
        - inattentiveness of driver to the signal,
        - poor conspicuity of the light, or
        - a lack of law enforcement in the area.

3. *Rear-End Crash Pattern-*
    - Accounted for 14% of crashes at the Pasadena and Curtis intersection.
    - Most of the crashes in this group were coded as Failed to Control Speed. One was classified as Followed Too Closely and Defective or No Vehicle Brakes.
    - The crashes could be caused, in part, by:
        - violation of driver expectancy that the light will remain green (insufficient green time) and that the car in front will not be braking for a yellow or red light,
        - inattentiveness of driver to the signal, or
        - poor conspicuity of the light.

Countermeasure Improvements

Left-Turn Crashes

For improving the crash record for the left-turn sideswipe pattern, the following countermeasures are recommended:

1. **signage –** adding regulatory signs to the signal arms above all approaches that say Left-Turn Yield on Green will help drivers know that they must yield to oncoming traffic; AND
2. **overlap phase –** changing the current signal sequence (see Figure 13) to include an overlap phase (see Figure 14) and adding appropriate signage (e.g. Left Turn Protected on Green) to the signal arms on Pasadena. With this signal phase change, there is no need to have an additional lane to store turning vehicles. However, as with all signal timing changes recommended in this report, additional studies may be required to determine the impact on delay.

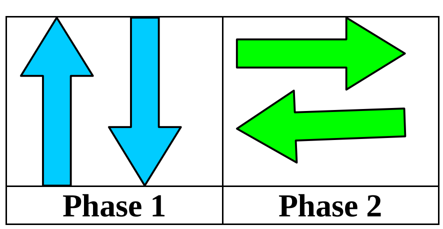

Figure 13. Current Phasing.

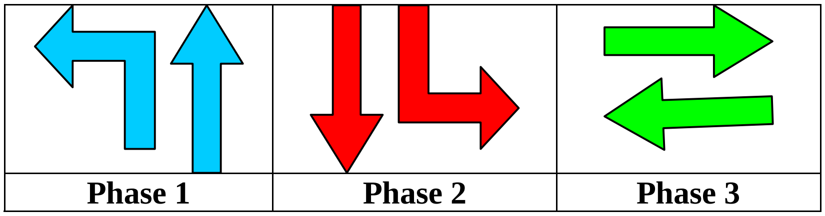

Figure 14. Potential Overlap Phasing.

One more long-range possibility is to add a left-turn bay to Pasadena. This will involve buying right-of-way to expand the intersection, re-striping the pavement markings, changing the signal timing to include either an overlap phase or an exclusive left-turn phase, and adding an arrow head to the signal in each direction on Pasadena. This improvement should be justified by an engineering study that examines turning volumes at this location. If a capital improvement program is already underway, this project would be a good candidate for consideration. For the purposes of this study, however, no cost-benefit analysis will be performed on this countermeasure.

Right-Angle Crashes

Since the right-angle crash pattern has been associated with red-light running, the following countermeasures are recommended to improve the stop compliance of drivers at red lights:

1. **pavement markings** – applying fresh pavement markings such as stop bars may reinforce the boundaries of the intersection and increase the awareness of drivers as to the proper stopping location; AND
2. **enforcement** – a speed study conducted at this location determined that the 85^{th} percentile speed was higher than the posted speed, and it is recommended that an official speed study be performed as a justification for enhanced enforcement in this area; enforcement of both speed limits and red-light stop compliance should help reduce the number and seriousness of the crashes at this intersection; AND
3. **speed limit change** – after a speed study has been performed, it may be necessary to change the speed limit in the area and alter the signal timings to include the new clearance interval; AND
4. **signage** - adding regulatory signs to the corners of all approaches that say Stop Here on Red will help right-turning drivers to know where they must stop to avoid edging into the intersection and causing a right-angle crash.

Since the intersection appears to be coordinated with the Southmore intersection, no coordination of signals is necessary at this time.

Rear-End Crashes

Some rear-end crashes may be reduced by incorporating the treatments listed above for the right-angle crash pattern. Another recommended countermeasure which will improve the visibility of the signal heads is:

1. **LEDs –** installing 12-inch lenses or 12 inch Light Emitting Diodes (LEDs) with signal backplates may help to draw drivers' attention to the signals and reduce the rear-end crash types. Currently, all of the signal heads at Pasadena and Curtis have LEDs on the Red and Yellow signals, but it is recommended that all signal heads be upgraded to LEDs and backplates be included as well.

General Crash Reduction for the Intersection

For reducing the overall amount of crashes occurring at this intersection, the following countermeasures are recommended to be applied to the intersection as a whole:

1. **pavement markings** - improving pavement markings and reflectorized RPMs to the intersection as a whole will assist traffic in maintaining proper lane assignment; currently, these treatments are faded and in very poor condition across the board.

Crash Reduction Factors

Table 29 below shows the reduction factors, service life, and work codes associated with the countermeasures suggested above.

Table 29. Suggested Countermeasures and Reduction Factors.

Countermeasure	Reduction Factor (%)	Service Life	Work Code
Improved pavement markings (including reflectorized RPMs, re-striped lanes, turn arrows and text, and stop bars)	25	2*	401/406
Improved regulatory signs	20	6	101
Signal timing changes: overlap phase	15**	10	108
12-inch LED signal heads with backplates	15	10	108
Speed limit change (determined after further study)	15	10	101/108

*Service life reduced to 2 years rather than 3 to provide an average lifespan of both paint and RPMs.
**Reduction factor reduced from 22% to 15% since signal timing met specs but still needed improvement.

Crash Costs

The annual crash costs for this side of the intersection are presented in Table 30. These are true crash costs and have not been reduced based on potential countermeasure reduction factors. Right-angle crashes tend to be the most severe and as a result are the most costly. The crash costs are conservative due to the fact that if multiple injuries were experienced, only the most severe was used in the calculation.

Table 30. Three-Year Crash Costs for Pasadena @ Curtis.

Crash Type/ Severity	Right-Turn	Cost ($)	Left-Turn	Cost ($)	Right-Angle	Cost ($)	Rear-End	Cost ($)	Total # of Crashes	Total Cost	Annual Cost ($)
B	0	0	1	44,000	5	220,000	0	0	6	264,000	88,000
C	0	0	4	84,000	4	84,000	2	42,000	10	210,000	70,000
PDO	2	4,000	5	10,000	9	18,000	3	6,000	19	38,000	12,667
Total	2	4,000	10	138,000	18	322,000	5	48,000	35	512,000	170,667

Countermeasure Costs

Table 31 shows a summary of the costs for the countermeasures recommended at this location. The cost of adding a left-turn overlap phase would include the cost of a new four-section signal head for both NB and SB Pasadena approaches. Cost data below include equipment and installation; these costs do not reflect the potential additional delay incurred by the motoring public based on the added signal phase. Depending on the countermeasure, the cost of delay may be high and additional consultant work, out of the range of TTI's research scope, may be necessary to determine the costs and impacts of these changes.

Table 31. Estimated Countermeasure Costs.

Countermeasure	Cost
Pavement Markings (Total)	$852.66
Reflectorized RPMs	$178.16
Solid Lines	$314.90
Stop Bars	$84.60
Turn Arrows and Text	$275.00
Signage	$1514.16
Signal Timing Changes- Overlap Phase	$3,000.00
LEDs with Backplates	$4159.84
Speed Limit Study and Alteration	$3000

Please refer to Appendix I for a detailed list and description of what each countermeasure includes for this intersection (see Figure E-4 in Appendix E for a diagram of where these countermeasures are to be implemented) and a further breakdown of the costs of these treatments.

Benefit-Cost Analysis

For the Pasadena @ Curtis intersection, the suggested countermeasures were grouped as follows for the SII calculation and cost analysis:

- **Project No. 1**: Improve pavement markings at all approaches to the Pasadena @ Curtis intersection. This includes RPMs, solid lane stripes, stop bars, turning arrows and text.
- **Project No. 2**: Include "Left Turn Yield on Green" signs on all mast arms (or "Left Turn Protected on Green Arrow" if a left-turn arrow is placed on Pasadena); also include the sign "Stop Here On Red" at all corners of the intersection.

- **Project No. 3**: Upgrade existing signal heads to ones with backplates and LEDs on all sections.
- **Project No. 4**: Adjust the timing for the signals on Pasadena and Curtis to provide an overlap phase for left-turners.
- **Project No. 5**: Conduct a speed study to determine if speed limit changes need to be made.

The data in Table 32 were input into the SII formula provided by the HES program to determine an index ratio of the importance and cost-effectiveness of each recommended countermeasure. Table 33 presents the priority ranking of the safety improvement projects as concluded by the SII formula calculations. As illustrated in the table, the signal timing and speed limit studies (and possible alterations) tied as the most cost-effective countermeasure. The LED upgrade was only slightly less cost-beneficial improvements. The initial cost of the signage and pavement marking upgrades is minimal, and the SII indicates that it will be marginally beneficial at the most conservative of projected cost-value estimates.

Table 32. Safety Improvement Project Input Data for SII Calculations.

Safety Improvement Project Number	# of A+K Crashes	# of B+C Crashes	# of PDO Crashes	Years of Crash Data	Initial Cost of Project ($)	Project Service Life	ADT Before Project	ADT After Project Service Life	Crash Reduct. Factor	Present Worth of Project ($)
1	0	0	4	3	852.36	2	20710	21864	25	1,355.67
2	0	0	4	3	1514.16	6	20710	24370	20	2,960.54
3	0	9	9	3	4159.84	7.5	20710	25382	15	51,984.64
4	0	11	12	3	3000	10	20710	27166	15	81,025.07
5	0	11	12	3	3000	10	20710	27166	15	81,025.07

Table 33. Safety Improvement Index Priority Rankings.

Recommended Safety Improvement	Safety Improvement Index Value
1. Signal Timing Changes	27.01
2. Speed Limit Study/Change	27.01
3. LED/Backplate Upgrade	12.50
4. Signage	1.96
5. Pavement Markings	1.59

SITE 5: PRESTON @ CHERRY BROOK

Crash Record Analysis

Preston @ Cherry Brook is a T-intersection with open access to several businesses on the top of the T. Table 34 shows a breakdown of the crashes at this intersection. Eight crashes involved vehicles that were trying to access those businesses. An equal amount, almost 20 percent, of the crashes at this intersection were rear-end crashes. Although the left-turn crashes seem to be the largest crash type, these crashes were split amongst several approaches.

Table 34. Preston @ Cherry Brook Crash Type by Severity.

Crash Type / Severity	Right-Turn	Left-Turn	Right-Angle	Rear-End	Driveway	Other	Totals
Fatal (K)							0
Incapacitating (A)		1					1
Non-Incapacitating (B)		3					3
Possible Injury ©		1	1				2
Property Damage Only (PDO)	6	12	5	8	4	4	39
Total	6	17	6	8	4	4	45
Percentage of Total (%)	13	38	13	18	9	9	100

Traffic and Operational Data

General traffic counts from the area were provided by the City of Pasadena. Intersection turning movement counts were also provided for each intersection for the AM peak, Midday, and PM peak periods, shown in Figure A-5 in Appendix A. The predominant movement is northbound and southbound along Preston with a large number of vehicles turning WB on Cherry Brook during the AM peak period (see Figure 15). In addition to traffic count data, signal timings were also provided. All red and yellow clearance intervals were adequate based on standard practice.

Figure 15. View of Preston @ Cherry Brook from the Eastbound Approach.

Speed Studies

One speed study was conducted at this location, previously shown in Figure 8, site 7. It was conducted for the SB approach to the intersection on Preston, the approach with the highest rate of rear-end collisions. The 85th percentile speed was 41 mph while the speed limit was 35 mph. This indicated that many people tend to speed on this approach, 75% of those recorded in the study (see Appendix B for more specifics on the speed study performed at this location). Increased police presence is suggested at this intersection to reduce both speeding and red-light running behaviors that may be leading to rear-end and right-angle crashes. Increasing the speed limit to 40 mph could be done, but it would require adjusting the signal timing in the area. A more detailed study would be needed to determine the impact of increasing the speed limit.

Crash Patterns and Causal Relationships

Based on the collision diagrams (see Figure C-5 in Appendix C), five crash patterns were established:

1. *Left-Turn Crash Pattern-*
   - Left-turning vehicle collisions accounted for 17% of crashes at the Preston and Cherry Brook intersection.
   - Some of the crashes were coded as a Failure to Yield ROW – Turning Left while many others were Disregard Stop and Go signal or Disregard Stop Sign or Signal.
   - The crashes could be caused, in part, by:
     - a lack of education (provided by signage) by drivers turning from Cherry Brook onto Preston as to who is required to yield the ROW, or
     - by red-light running behavior occurring on Preston.

2. *Right-Angle Crash Pattern-*
   - Accounted for 13% of crashes at the Preston and Cherry Brook intersection.
   - These crashes were more sporadically laid out across the intersection and were coded as Disregard Stop and Go Signal or Disregard Stop Sign or Signal or Driver Inattention.
   - The crashes could be caused, in part, by:
     - violation of driver expectancy that the light will remain green,
     - inattentiveness of driver to the signal,
     - poor conspicuity of the light, or
     - a lack of law enforcement in the area.

3. *Rear-End Crash Pattern-*
   - Accounted for 18% of crashes at the Preston and Cherry Brook intersection.
   - Most of the crashes in this group occurred at the SB approach to the intersection on Preston and were coded as Failed to Control Speed.
   - The crashes could be caused, in part, by:
     - violation of driver expectancy that the light will remain green and that the car in front will not be braking for a yellow or red light,
     - inattentiveness of driver to the signal,

   - excessive speed, or
   - poor conspicuity of the light.

4. *Right-Turn Crash Pattern-*
   - Accounted for 13% of crashes at the Preston and Cherry Brook intersection.
   - Most of the crashes in this group were coded as Failure to Yield Right of Way – Turn on Red, and a couple were speed-related.
   - The crashes could be caused, in part, by:
     - violators rolling through the red light or failing to look for vehicles before turning right.

5. *Driveway Crash Pattern-*
   - Accounted for at least 9% of crashes at the Preston and Cherry Brook intersection.
   - These crashes may overlap with the left-turning or right-angle groups, but they have also been influenced by movement into or out of the driveway adjacent to the intersection.
   - The crashes could be caused, in part, by:
     - violation of driver expectancy of the alignment of the driveway,
     - lack of signalization protecting movement coming out of the driveway, or
     - other vehicles making erratic movements into or out of the driveway.

Countermeasure Improvements

Left-Turn Crashes

For improving the crash record for the left-turn sideswipe pattern, the following countermeasure is recommended:

1. **signage –** adding a regulatory sign to the signal arm on Preston that says Left-Turn Yield on Green will help drivers on Cherry Brook to know that they must yield to oncoming traffic.

Right-Angle Crashes

Since the right-angle crash pattern has been associated with red-light running and a speed test confirmed that speed limit violation is high in the area, the following countermeasures are recommended to improve the stop compliance of drivers at red lights:

1. **pavement markings –** applying fresh pavement markings such as stop bars may reinforce the boundaries of the intersection and increase the awareness of drivers as to the proper stopping location; AND
2. **all-red clearance interval –** increasing the all-red and yellow clearance interval slightly will allow a little more time for motorists to pass through the intersection without conflict, but may potentially make drivers accustomed to such intervals and breed indifference for traffic control devices at other intersections; TTI recommends that an

engineering study be performed to determine the delay impacts of this countermeasure and its overall value to the improvement of the safety at the intersection; AND

3. **enforcement –** a speed study conducted at this location determined that the 85th percentile speed was higher than the posted speed, and it is recommended that an official speed study be performed as a justification for enhanced enforcement in this area; enforcement of both speed limits and red-light stop compliance should help reduce the number and seriousness of the crashes at this intersection; AND
4. **speed limit change –** after a speed study has been performed, it may be necessary to change the speed limit in the area and alter the signal timings to include the new clearance interval.

Rear-End Crashes

Some rear-end crashes may be reduced by incorporating the treatments listed above for the right-angle crash pattern, such as speed reduction techniques. Other recommended countermeasures are:

1. **LEDs –** installing 12-inch lenses or 12 inch Light Emitting Diodes (LEDs) with signal backplates may help to draw drivers' attention to the signals and reduce the rear-end crash types; currently, all of the signal heads at Preston and Cherry Brook have LEDs on the Red and Yellow signals, but it is recommended that all signal heads be upgraded to LEDs and backplates be included as well; AND
2. **coordination –** while the signal may – on record – be coordinated with the surrounding signals, field observations reflect that the time-based coordination is off and should be checked and readjusted accordingly.

Right-Turn Crashes

Some right-turn crashes may be reduced by incorporating the treatments listed earlier for the right-angle crash pattern, such as re-painting stop bars which may give right-turning vehicles a better view of traffic flowing through the intersection. Another recommended countermeasure for right-turn crash types is:

1. **signage** - adding regulatory signs to the corners of all approaches that say Stop Here on Red will help right-turning drivers to know where they must stop to avoid edging into the intersection and causing a right-angle crash.

Driveway Crashes

The crashes occurring as a result of the presence of the driveway could be prevented by driveway reconfiguration and access management. This would involve pouring curbs to close up two sections of the driveway before and after the intersection and aligning the driveway opening with the current intersection, making it a fourth leg. A mast arm and two signal heads would have to be installed for traffic coming out of the driveway, appropriate regulatory signage would need to be placed, and lanes and pavement markings would need to be painted. This improvement is recommended only after an engineering study has been performed to confirm a high volume of traffic related to the driveway and a subsequently high crash experience.

General Crash Reduction for the Intersection

For reducing the overall amount of crashes occurring at this intersection, the following countermeasures are recommended to be applied to the intersection as a whole:

1. **pavement markings** - improving pavement markings and reflectorized Raised Pavement Markers (RPMs) to the intersection as a whole will assist traffic in maintaining proper lane assignment; currently, these treatments are faded and in very poor condition across the board.

Crash Reduction Factors

Table 35 shows the reduction factors, service life, and work codes associated with the countermeasures suggested above.

Table 35. Suggested Countermeasures and Reduction Factors.

Countermeasure	Reduction Factor (%)	Service Life	Work Code
Improved pavement markings (including reflectorized RPMs, re-striped lanes, turn arrows and text, and stop bars)	25	2*	401/406
Signal timing changes: all-red phase or coordination	15**	10	108
12-inch LED heads	15	7.5	108
Realign driveway (curb control of access)	10	10	219
Improved regulatory signs	10	6	101
Speed limit change (determined after further study)	15	10	101/108

*Service life reduced to 2 years rather than 3 to provide an average lifespan of both paint and RPMs.
**Reduction factor reduced from 22% to 15% since signal timing met specs but still needed improvement.

Crash Costs

The annual crash costs for this side of the intersection are presented in Table 36. These are true crash costs and have not been reduced based on potential countermeasure reduction factors. The crash costs are conservative due to the fact that if multiple injuries were experienced, only the most severe was used in the calculation.

Table 36. Three-Year Crash Costs for Preston @ Cherry Brook.

Crash Type/ Severity	Right-Turn	Cost ($)	Left-Turn	Cost ($)	Right-Angle	Cost ($)	Rear-End	Cost ($)	Total # of Crashes	Total Cost	Annual Cost ($)
A	0	0	1	172,000	0	0	0	0	1	172,000	57,333
B	0	0	3	132,000	0	0	0	0	3	132,000	44,000
C	0	0	1	21,000	1	21,000	0	0	2	42,000	14,000
PDO	6	12,000	12	24,000	5	10,000	8	16,000	31	62,000	20,667
Total	6	12,000	17	349,000	6	31,000	8	16,000	37	408,000	136,000

Please refer to Appendix I for a detailed list and description of what each countermeasure includes for this intersection and a further breakdown of the costs of these treatments. Figure E-5 in Appendix E is a diagram of where the majority of these countermeasures are to be implemented. Figure E-6 is a separate diagram detailing the changes to be put into effect for the driveway access control project.

Countermeasure Costs

Table 37 provides a summary of the cost to purchase and install the suggested countermeasure equipment.

The cost of consolidating driveways and aligning one of the access points with the intersection is difficult to determine due to the variety of actions that can be taken and the number of different agency and contractor fees. For this study, the cost of driveway access management at this location will be conservatively estimated at $25,000. This rough estimate includes the cost of pouring necessary 8-inch reinforced barrier curbs, adding a signal mast arm with two three-section LED signal heads with backplates, installing signs and painting lane markings and turn arrows. While this cost may be higher than other projects recommended for this intersection, combining this countermeasure with a city-wide access management plan can be one of the strongest, most lasting actions taken to prevent vehicle collisions.

Table 37. Estimated Countermeasure Costs.

Countermeasure	Cost
Pavement Markings (Total) Reflectorized RPMs Solid Lines Stop Bars Turn Arrows and Text	$779.00 $222.70 $65.60 $78.70 $412.00
Signage	$757.08
Signal Timing Changes- (one or both) All-Red Clearance Interval Coordination with Other Signals	$3,000.00 to $6,000.00 $3,000.00 $3,000.00
LEDs with Backplates	$3426.45
Driveway Realignment	$25,000
Speed Limit Study and Alteration	$3000

Benefit-Cost Analysis

For the Preston @ Cherry Brook intersection, the suggested countermeasures were grouped as follows for the SII calculation and cost analysis:

- **Project No. 1**: Improve pavement markings at all approaches to the Preston @ Cherry Brook intersection. This includes RPMs, solid lane stripes, stop bars, turning arrows and text.
- **Project No. 2**: Include a “Left Turn Yield on Green” sign; also include the sign “Stop Here On Red” at all three corners of the intersection.
- **Project No. 3**: Upgrade existing signal heads to ones with backplates and LEDs on all sections.
- **Project No. 4**: Adjust the timing for the signals on Preston and Cherry Brook to provide better coordination with other intersections and/or an all-red clearance interval.
- **Project No. 5**: Conduct a speed study to determine if speed limit changes need to be made.
- **Project No. 6**: Improve access management of driveway and align as a fourth leg of the intersection.

The data in Table 38 were input into the SII formula provided by the HES program to determine an index ratio of the importance and cost-effectiveness of each recommended countermeasure. Table 39 presents the priority ranking of the safety improvement projects as concluded by the SII formula calculations for Preston @ Cherry Brook. As indicated in the table, the speed limit study/change and LED upgrade is the most significant and cost-beneficial safety improvement of the ones recommended for this intersection. The signage, pavement markings, and signal timing changes are, respectively, ranked third, fourth, and fifth in priority, but their cost is still low in comparison to their potential benefit over time. The safety improvement project that failed to be cost-beneficial to implement was the driveway access improvement on Preston. This project ranked below one on the Safety Improvement Index and should be more thoroughly investigated before any decision is made. While there were a number of collisions at this site that could benefit from future access management, the high cost associated with this project makes it a less cost-effective venture. More research into driveway access management, policy, and implementation costs is recommended.

Table 38. Safety Improvement Project Input Data for SII Calculations.

Safety Improvement Project Number	# of A+K Crashes	# of B+C Crashes	# of PDO Crashes	Years of Crash Data	Initial Cost of Project ($)	Project Service Life	ADT Before Project	ADT After Project Service Life	Crash Reduct. Factor	Present Worth of Project ($)
1	0	0	4	3	779	2	32110	33902	25	1,355.73
2	0	0	4	3	757.08	6	32110	37786	20	2,960.59
3	1	0	11	3	3426.45	7.5	32110	39356	15	77,677.12
4	0	0	6	3	3000	10	32110	42118	15	5,077.77
5	1	0	11	3	3000	10	32110	42118	15	98,017.91
6	0	1	7	3	25,000	10	32110	42118	10	8,244.40

Table 39. Safety Improvement Index Priority Rankings.

Recommended Safety Improvement	Safety Improvement Index Value
1. Speed Limit Study/Change	32.67
2. LED/Backplate Upgrade	22.67
3. Signage	3.91
4. Pavement Markings	1.74
5. Signal Timing Changes	1.69
6. Driveway Access Management	0.33

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