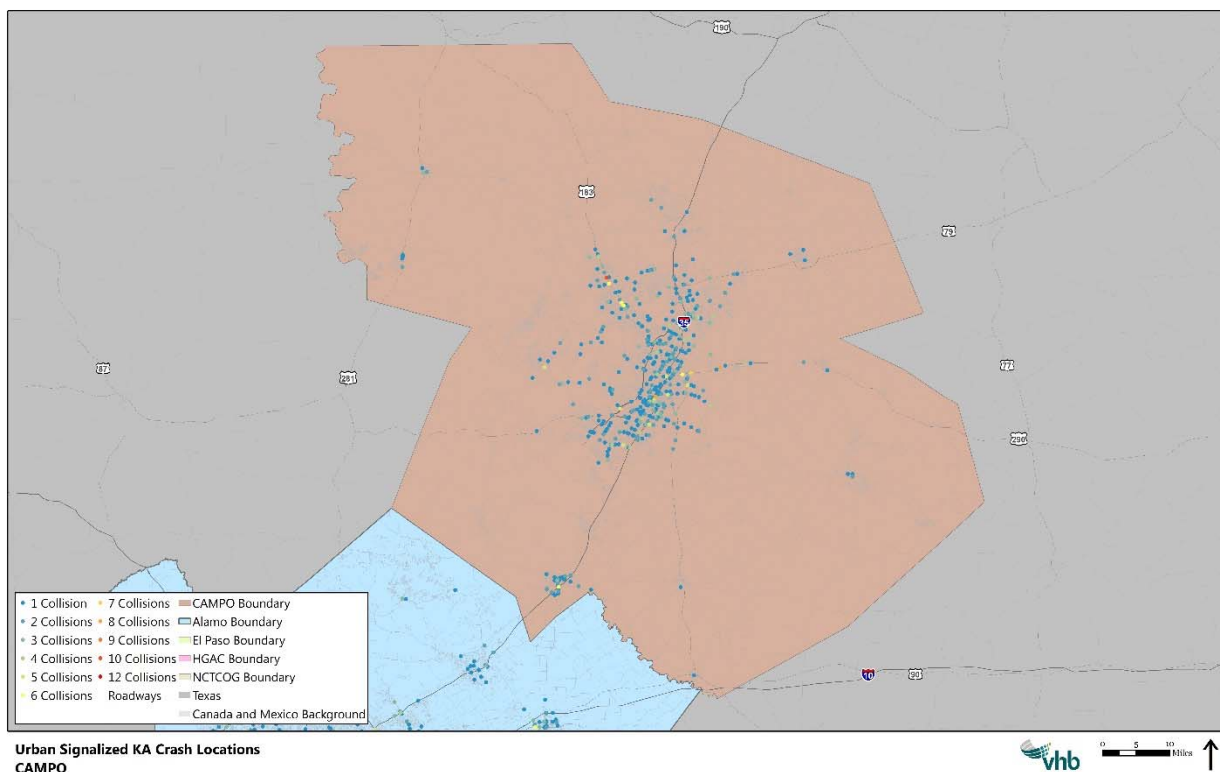


# Texas Intersection Safety Implementation Plan

## Preliminary Findings for Texas's Capital Area Metropolitan Planning Organization



March 30, 2016

*Revised June 15, 2016*



## Introduction

The overall objective of this effort is to develop an Intersection Safety Implementation Plan (ISIP) for the State of Texas by focusing on its five largest Metropolitan Planning Organizations (MPOs):

- Alamo Area MPO (AAMPO) in the San Antonio region.
- Capital Area MPO (CAMPO) in the Austin region.
- El Paso MPO in the El Paso region.
- Houston-Galveston Area Council MPO (H-GAC) in the Houston region.
- North Central Texas Council of Governments (NCTCOG) in the Dallas-Fort Worth region.

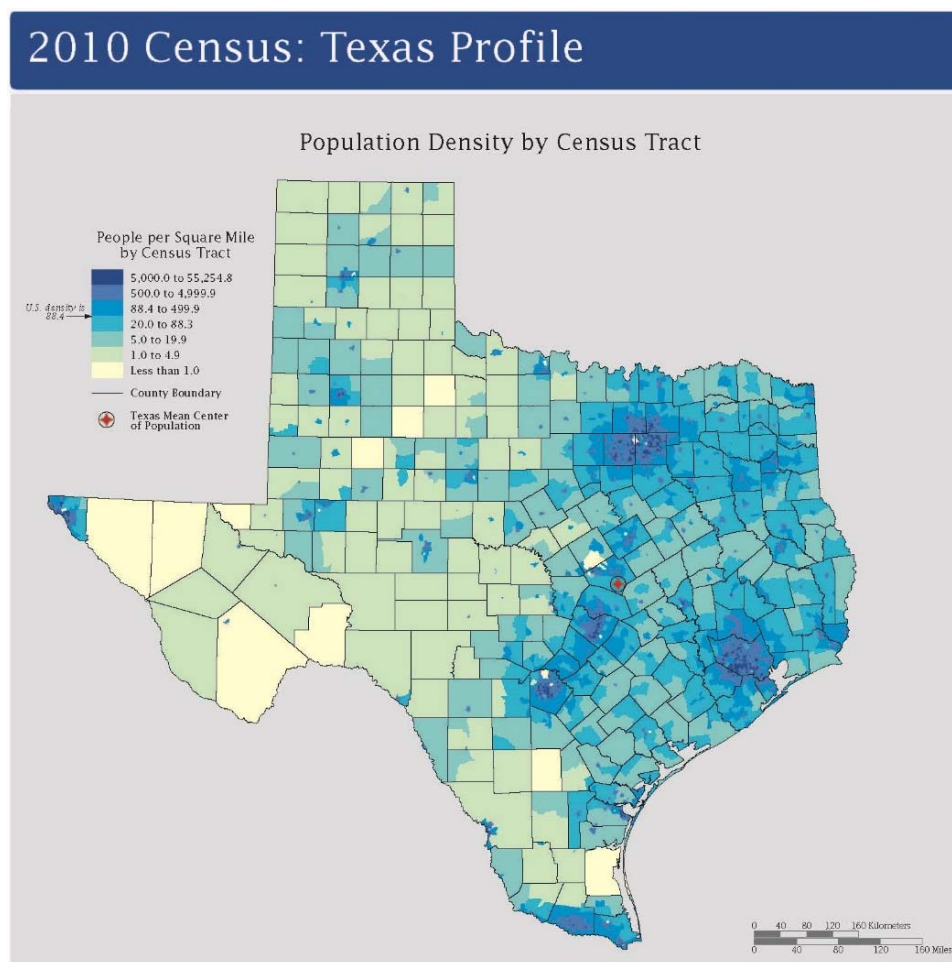
The purpose of this report is to present the preliminary findings from the data analyses completed to date and to select which intersection types have the best potential to be enhanced by systemic measures.

The analysis team analyzed intersection crash trends for the five-year period from January 2010 to December 2014. The Texas Strategic Highway Safety Plan (SHSP) reports that more than a third of Texas's fatal and incapacitating-injury crashes in 2013—5,624 in total—were intersection related. Three-quarters of these (74 percent) occurred in urban areas.

The analysis team coordinated with the Texas Department of Transportation (TxDOT) Crash Data and Analysis Section of the Traffic Operations Division and the five MPOs to obtain crash and roadway data from 2010 – 2014. The team obtained intersection crash data from TxDOT's Crash Records Information System (CRIS) and analyzed each region's intersection crashes both at the regional level and at the intersection level, identifying macro trends at the regional level and tailoring the analysis at the intersection level to prioritize intersections based on various risk factors and facility types. The following sections describe the method for each level of analysis.

## State Data Analysis

Population data from the 2009-2013 American Community Survey (ACS) reported the population of Texas as 25,639,373—a 2013 estimation based on survey data collected over a five-year period.<sup>[1]</sup> Texas has 254 counties and 1,209 municipal governments, which consist of cities, towns, and villages. Figure 1 depicts the population density by census tract for the entire State.



**Figure 1. Texas Population Density, 2010 Census. [2]**

Table 1 presents the State's largest cities by severe intersection crashes and population. For the purpose of this effort, "severe" crashes refer to those resulting in a fatality (K) or incapacitating injury (A), as defined by Texas's crash report form. Three (3) of every 10 severe intersection crashes statewide occurred in these cities.

**Table 1. Six largest Texas cities by 2013 severe intersection crashes and population.** <sup>[1]</sup>

| City         | Severe (K,A)<br>Int. Crashes | Percent of<br>State Severe<br>Int. Crashes | Population (2)   | Population<br>Rank | Percent of<br>State<br>Population |
|--------------|------------------------------|--|------------------|--------------------|-----------------------------------|
| Houston      | 459                          | 8.2%                                       | 2,134,707        | 1                  | 8.3%                              |
| San Antonio  | 360                          | 6.4%                                       | 1,359,033        | 2                  | 5.3%                              |
| Dallas       | 351                          | 6.2%                                       | 1,222,167        | 3                  | 4.8%                              |
| Austin       | 194                          | 3.4%                                       | 836,800          | 4                  | 3.3%                              |
| Fort Worth   | 240                          | 4.3%                                       | 761,092          | 5                  | 3.0%                              |
| El Paso      | 81                           | 1.4%                                       | 660,795          | 6                  | 2.6%                              |
| <b>Total</b> | <b>1,685</b>                 | <b>30.0%</b>                               | <b>6,974,594</b> | <b>---</b>         | <b>27.2%</b>                      |

Expanding the focus from the city level to the regional level, Table 2 presents the five largest MPOs in Texas by severe intersection crashes and population. Collectively these regions comprise 62 percent of the severe intersection crashes in the State and 67 percent of its population.

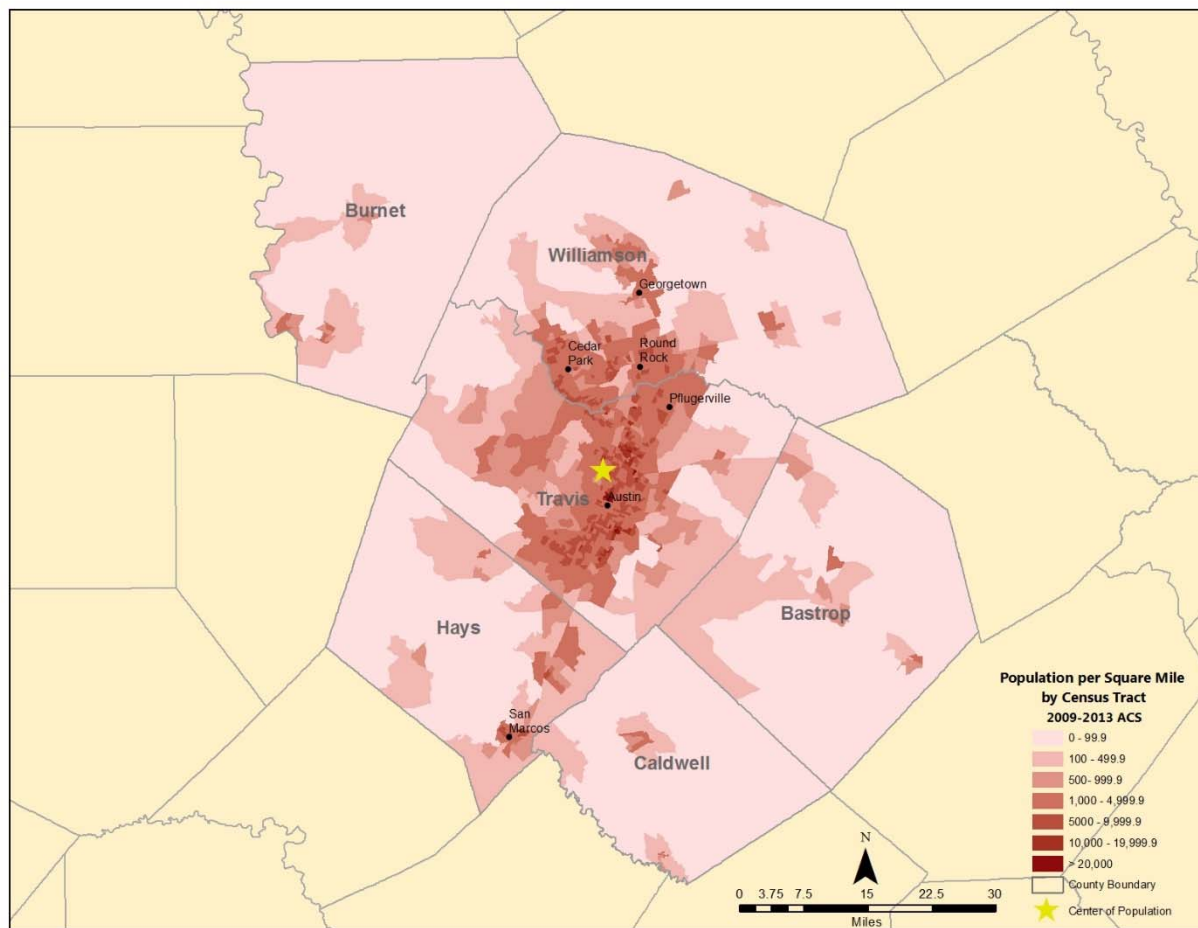
**Table 2. Five largest Texas MPOs by 2013 severe intersection crashes and population.** <sup>[1]</sup>

| MPO          | Severe (K,A)<br>Int. Crashes | Percent of<br>Total Severe<br>Int. Crashes | Population (2)    | Population<br>Rank | Percent of<br>Total<br>Population |
|--------------|------------------------------|--|-------------------|--------------------|-----------------------------------|
| NCTCOG       | 1,413                        | 25.1%                                      | 6,567,296         | 1                  | 25.6%                             |
| H-GAC        | 1,070                        | 19.0%                                      | 6,034,967         | 2                  | 23.5%                             |
| AAMPO        | 496                          | 8.8%                                       | 2,024,087         | 3                  | 7.9%                              |
| CAMPO        | 429                          | 7.6%                                       | 1,825,262         | 4                  | 7.1%                              |
| El Paso MPO* | 97                           | 1.7%                                       | 813,015           | 5                  | 3.2%                              |
| <b>Total</b> | <b>3,505</b>                 | <b>62.3%</b>                               | <b>17,264,627</b> | <b>---</b>         | <b>67.3%</b>                      |

\* Includes only Texas portion of El Paso MPO

## Regional Data Analysis

CAMPO comprises 6 counties in central Texas. According to the 2009-2013 ACS, the population of the MPO was 1,825,262. <sup>[1]</sup> Figure 2 presents the CAMPO population density map.



**Figure 2. Population density of the CAMPO region. <sup>[1]</sup>**

Severe intersection crashes typically mirror population. The 10 most populous cities of the CAMPO region are presented in Table 3 by severe intersection crashes for the five-year period of 2010-2014 and 2013 population. More than two-thirds of the region's severe intersection crashes occurred within these cities, which correlates well with the percentage of the region's population. The five cities listed in bolded text are overrepresented in terms of severe intersection crashes relative to their population.

**Table 3. Ten largest CAMPO cities by severe intersection (KA) crashes and population.**

| City         | Severe Int. Crashes (K,A) | Percent of Region Severe Int. Crashes | Population | Population Rank | Percent of Region Population |
|--------------|---------------------------|---------------------------------------|------------|-----------------|------------------------------|
| Austin       | 970                       | 48.62%                                | 836,800    | 1               | 45.85%                       |
| San Marcos   | 96                        | 4.81%                                 | 48,291     | 6               | 2.65%                        |
| Cedar Park   | 61                        | 3.06%                                 | 54,874     | 3               | 3.01%                        |
| Pflugerville | 54                        | 2.71%                                 | 50,127     | 5               | 2.75%                        |
| Round Rock   | 50                        | 2.51%                                 | 104,070    | 2               | 5.70%                        |
| Georgetown   | 48                        | 2.41%                                 | 50,380     | 4               | 2.76%                        |
| Leander      | 39                        | 1.95%                                 | 28,281     | 8               | 1.55%                        |
| Bastrop      | 17                        | 0.85%                                 | 7,327      | 9               | 0.40%                        |
| Kyle         | 16                        | 0.80%                                 | 29,396     | 7               | 1.61%                        |
| Manor        | 16                        | 0.0%                                  | 5,515      | 10              | 0.30%                        |
| Total        | 1,367                     | 68.52%                                | 1,215,061  | ---             | 66.57%                       |

2009-2013 ACS 5-year estimates (Total MPO population 1,825,262)

There are a total of 12,901 public road miles within the CAMPO service region that are owned by various agency types, including State, county, town, Federal agency, or other, as presented in Table 4. Counties and municipal agencies each maintain approximately 41 percent (for a combined 82 percent) of the public road miles in CAMPO, with the State maintaining most of the remaining 18 percent. There is a nearly-even split between rural and urban areas in terms of their respective total road mileage.

**Table 4. CAMPO public road length (mi) by type of owner. <sup>[3]</sup>**

|       | State Highway Agency | County | Town, Township, Municipal | Other | Federal Agency | Total   |
|-------|----------------------|--------|---------------------------|-------|----------------|---------|
| RURAL | 1,428                | 4,057  | 864                       | 0     | 0              | 6,349   |
|       | 11.07%               | 31.44% | 6.70%                     | 0.00% | 0.00%          | 49.21%  |
| URBAN | 937                  | 1,171  | 4,434                     | 11    | 0              | 6,553   |
|       | 7.27%                | 9.07%  | 34.37%                    | 0.08% | 0.00%          | 50.79%  |
| Total | 2,365                | 5,227  | 5,298                     | 11    | 0              | 12,901  |
|       | 18.33%               | 40.52% | 41.07%                    | 0.08% | 0.00%          | 100.00% |

Table 5 simplifies the information in Table 4 by combining the county and municipal categories into a “local” group and the Federal agency and other categories into an “other” group.

**Table 5. CAMPO public road length (mi) by State, local, or other. <sup>[3]</sup>**

|       | State  | Local  | Other | Total   |
|-------|--------|--------|-------|---------|
| RURAL | 1,428  | 4,921  | 0     | 6,349   |
|       | 11.07% | 38.14% | 0.00% | 49.21%  |
| URBAN | 937    | 5,605  | 11    | 6,553   |
|       | 7.27%  | 43.44% | 0.08% | 50.79%  |
| Total | 2,365  | 10,525 | 11    | 12,901  |
|       | 18.33% | 81.58% | 0.08% | 100.00% |

Table 6 presents the distribution of intersection crashes by severity for the analysis. Each crash is described by the most severe injury that resulted. The following crash severities are used in Texas:

- Fatal (K).
- Incapacitating injury (A).
- Non-incapacitating injury (B).
- Possible Injury (C).
- Non-injury (PDO).

**Table 6. Approximate number of CAMPO intersection crashes by severity and year.**

| YEAR            | K          | A            | B             | C            | PDO           | UNKNOWN    | TOTAL         | KA           | KA as % of Total Crashes |
|-----------------|------------|--------------|---------------|--------------|---------------|------------|---------------|--------------|--------------------------|
| 2010            | 46         | 319          | 1,974         | 2,080        | 5,236         | 167        | 9,822         | 365          | 3.72%                    |
| 2011            | 30         | 359          | 1,991         | 2,328        | 5,088         | 151        | 9,947         | 389          | 3.91%                    |
| 2012            | 42         | 370          | 2,156         | 2,270        | 5,018         | 113        | 9,969         | 412          | 4.13%                    |
| 2013            | 33         | 396          | 2,328         | 2,348        | 5,860         | 154        | 11,119        | 429          | 3.86%                    |
| 2014            | 55         | 345          | 2,215         | 2,221        | 6,386         | 148        | 11,370        | 400          | 3.52%                    |
| <b>SUBTOTAL</b> | <b>206</b> | <b>1,789</b> | <b>10,664</b> | <b>1,247</b> | <b>27,588</b> | <b>733</b> | <b>52,227</b> | <b>1,995</b> | <b>3.82%</b>             |

Discounting the crashes of unknown severity, the analysis team estimated the total cost of CAMPO intersection crashes to be more than \$3.3 billion—or \$670 million annually—over the five-year analysis period. The total estimated cost of the KA intersection crashes across the five regions for the same period was \$29.6 billion, which corresponds to nearly \$6 billion per year. These costs were based on the 2013 average comprehensive costs by injury severity presented in the National Safety Council's *Estimating the Costs of Unintentional Injuries, 2013*. <sup>[4]</sup> Severe (KA) intersection crashes accounted for

3.8 percent of all intersection crashes and nearly 48 percent of the total cost of intersection crashes within the CAMPO region.

Since KA crashes comprise such a significant portion of the total crash costs, the intersection-level analysis in the following sections will primarily focus on severe crashes. The KA crashes also represent an opportunity to focus the potential countermeasure packages.

## Intersection-Level Analysis

The analysis team joined TxDOT's CRIS data with pertinent roadway inventory data from its 2013 Road-Highway Inventory Network (RHiNo) database as the primary data source to determine the ownership (State, county, local, Federal, or other) of the roadway on which the crash occurred and analyze the focus intersection types and crash types by severity. The RHiNo data included the classification of government agency associated with the street on which the crash occurred. The rural/urban classifications were extracted from the traffic analysis zone (TAZ) shapefiles from the travel demand model provided by CAMPO.

For the purposes of this effort, "intersection ownership" is determined by the ownership of the intersecting streets. An intersection involving at least one TxDOT-maintained cross street is considered State-owned. An intersection involving at least one local street but not involving a TxDOT-maintained street is considered locally-owned. All other intersections fall under the "other" category.

Table 7 presents a breakdown of CAMPO intersection-related crashes according to area type and owner. Fifty-five (55) percent of the intersection-related crashes occurred at intersections involving at least one State road, and 86 percent of the crashes occurred in urban areas.

**Table 7. Distribution of CAMPO intersection crashes by owner and area type.**

|       | State                          | Local                          | Other                      | Total                           |
|-------|--------------------------------|--------------------------------|----------------------------|---------------------------------|
| RURAL | 5,728<br>10.97%                | 1,455<br>2.79%                 | 42<br>0.08%                | 7,225<br>13.83%                 |
| URBAN | 23,017<br>44.07%               | 21,773<br>41.69%               | 212<br>0.41%               | 45,002<br>86.17%                |
| Total | <b>28,745</b><br><b>55.04%</b> | <b>23,228</b><br><b>44.48%</b> | <b>254</b><br><b>0.49%</b> | <b>52,227</b><br><b>100.00%</b> |

The analysis team used crash data as the starting point to extract and interpolate locations and characteristics and to determine where the severe crashes are concentrated (e.g., urban intersections, unsignalized intersections, etc.). A unique field for intersection number did not exist. The analysis team used geographic information system (GIS) analysis with a 528-foot buffer to identify the potential intersection node ID at which an individual crash occurred. The corresponding ESRI Street file was used



to identify the node locations, as its shapefile is more detailed than that of RHiNo since ESRI includes private roads in its database. (ESRI is a leading GIS software and mapping developer.) Crashes with an identical node ID value were flagged as occurring at the same location, allowing the analysis team to quantify the total number of crashes and compare with the total number of unique (non-duplicating) locations. This initial level of analysis helped to determine the primary intersection types on which to focus. It is likely this method underestimated the number of intersections; however, the method was not expected to bias the preliminary results as it was assumed the approach would treat all intersection types in a similar manner. Nodes were underestimated because approximately two percent of crashes occurred at the intersection with a private driveway or dirt road and were not included in the ESRI database.

Only the severe (KA) crashes that could be assigned to an intersection are included in this portion of the analysis, as it is an intersection-level analysis. More discussion on assigning crashes to intersections is provided in the *Analysis Methodology* section.

## **Analysis Methodology**

### *Assigning Crashes to Intersections*

TxDOT does not currently have a single database of all intersections in the State, so the analysis team manually compiled an intersection inventory from ESRI Street layer datasets. The team considered all intersection crashes (regardless of severity) within the CRIS database to develop the inventory and assigned a unique intersection identification number to each intersection with one or more crashes in the five-year analysis period.

During the analysis period, there were 1,995 severe injury (KA) intersection crashes in the CAMPO region. Approximately three percent (64) of these crashes were not assigned an intersection identification number because they occurred at an intersection involving a private driveway or dirt road that was not included in the ESRI database. The remaining crashes (1,931) were assigned an intersection ID, resulting in 1,362 identified intersections in CAMPO with at least one severe injury crash in the five-year period.

### *Characterizing Intersections*

The intersections identified were characterized by maintenance jurisdiction and traffic control and area type. This was done using a combination of fields from CRIS crash data and roadway inventory data.

The analysis team categorized maintenance jurisdiction by State-maintained, locally-owned, or other. The traffic control at each of these intersections was interpreted as signalized or unsignalized based on the CRIS crash data. The criteria listed in Table 8 were used for classifying the control type for the intersection based on the traffic control description (TRAFFIC\_CNTL\_DESC) field within the crash data.

**Table 8. Interpreted traffic control type based on police-reported crash data.**

| ID | TRAFFIC_CNTL_DESC                          | Interpreted Control Type |
|----|--|--------------------------|
| 1  | NONE                                       | Unsignalized             |
| 2  | INOPERATIVE (EXPLAIN IN NARRATIVE)         | Unknown                  |
| 3  | OFFICER                                    | Unknown                  |
| 4  | FLAGMAN                                    | Unknown                  |
| 5  | SIGNAL LIGHT                               | Signalized               |
| 6  | FLASHING RED LIGHT                         | Unsignalized             |
| 7  | FLASHING YELLOW LIGHT                      | Unsignalized             |
| 8  | STOP SIGN                                  | Unsignalized             |
| 9  | YIELD SIGN                                 | Unsignalized             |
| 10 | WARNING SIGN                               | Unsignalized             |
| 11 | CENTER STRIPE/DIVIDER                      | Unsignalized             |
| 12 | NO PASSING ZONE                            | Unsignalized             |
| 13 | RR GATE/SIGNAL                             | Signalized               |
| 15 | CROSSWALK                                  | Unsignalized             |
| 16 | BIKE LANE                                  | Unsignalized             |
| 17 | OTHER (EXPLAIN IN NARRATIVE)               | Unsignalized             |
| 20 | MARKED LANES                               | Unsignalized             |
| 21 | SIGNAL LIGHT WITH RED LIGHT RUNNING CAMERA | Signalized               |
| 94 | REPORTED INVALID                           | Unknown                  |
| 95 | NOT REPORTED                               | Unknown                  |

This method is described as “estimating” the traffic control at the intersection because the TRAFFIC\_CNTL\_DESC field of the crash database has some inherent unreliability. The law enforcement officer reports the control under which crash-involved vehicles were operating, not necessarily the traffic control for the intersection. This reporting likely underestimates the occurrence of signalized control.

The rural/urban classifications were extracted from the CAMPO travel demand model traffic analysis zone (TAZ) shapefile provided by CAMPO.

### *Prioritizing Intersections*

The analysis team developed a Microsoft Access database of the severe injury crashes at each intersection that allows focus on and consideration of the following intersection attributes and crash characteristics:

- Location identification information including:
  - Intersection ID.
  - Street names.
  - Jurisdiction.
- Intersection characteristics including:
  - Traffic control.
  - Area type.
- Total fatal and severe injury crashes (injury severity K, or A) occurring at the intersection from 2010 to 2014.
- Crash characteristics (fatal and severe injury only) including the following:
  - Injury severity level.
  - Lighting condition.
  - Surface condition (e.g., dry).
  - Collision type (e.g., angle – both going straight).
  - Reported harmful event (e.g., motor vehicle in transport).

### **Analysis of the Results**

The analysis team used the Systemic Safety Project Selection Tool to provide a consistent framework for the ISIP process.<sup>[5]</sup> The tool is a process that focuses on identifying statewide or regional roadway safety concerns and strategies to address these concerns. Based on the safety data provided, the Tool allows analysts to determine which common risk factors are influencing driver behavior and how crashes occur. Different risk factors may include various system, crash, or facility types.

There are three distinct components of the Systemic Safety Project Selection Tool, as depicted in Figure 2:<sup>[5]</sup>

- Element 1: Systemic Safety Planning Process.
- Element 2: Framework for Balancing Systemic and Traditional Safety.
- Element 3: Evaluation of a Systemic Safety Program.

Element 1 is the focus of this preliminary findings report. The Systemic Safety Planning Process comprises four steps: identifying focus crash types and risk factors; screening and prioritizing candidate locations; selecting low-cost, highly effective countermeasures; and prioritizing the resulting projects. Each of the four steps is discussed in the following sections.

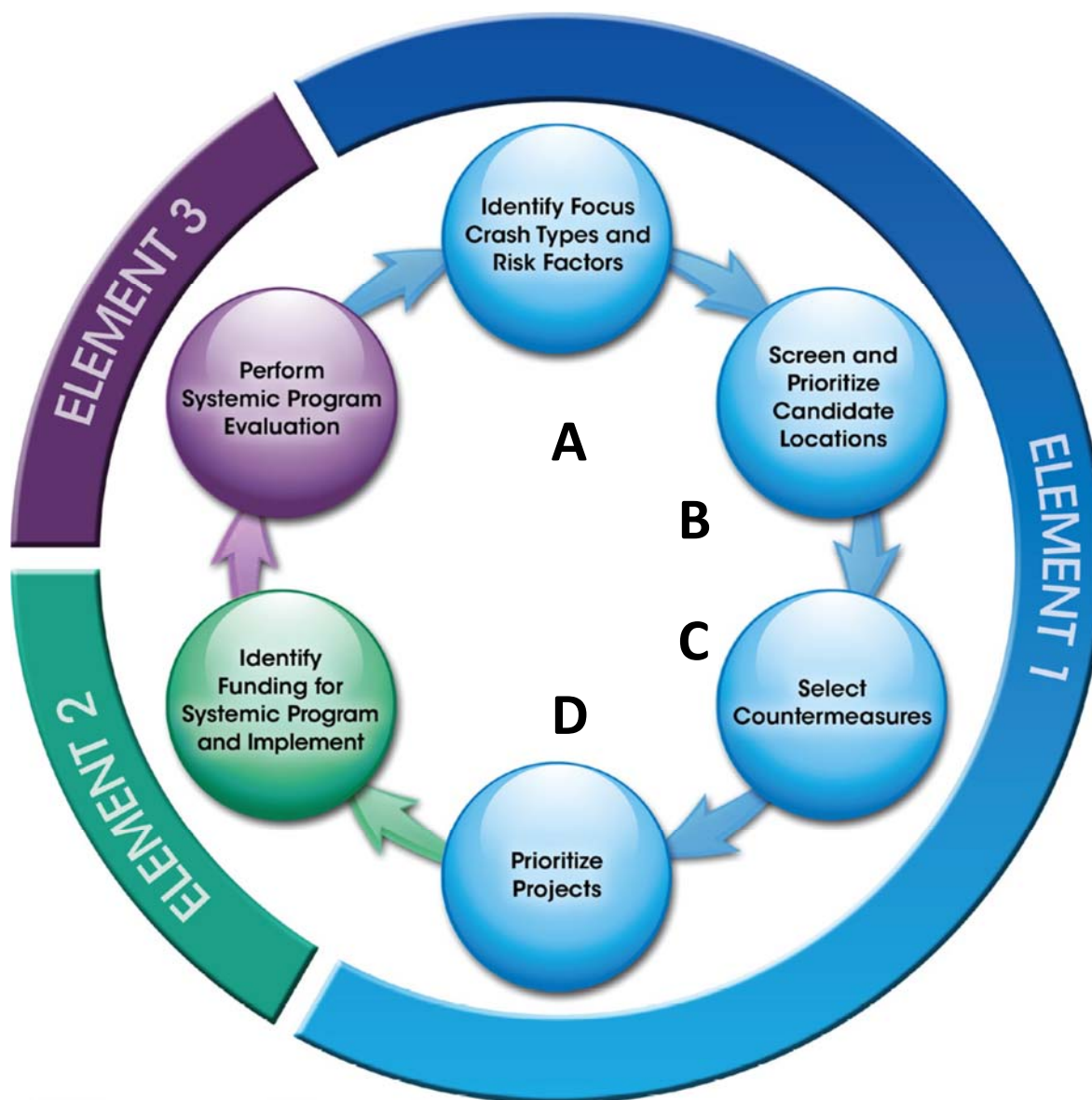


Figure 3. Systemic Safety Project Selection Tool. <sup>[5]</sup>

### A. Identify Focus Crash Types and Risk Factors

The objective of Step A in the process is to identify risk factors commonly associated with each focus crash type experienced across a system. The analysis team examined regional safety data in order to determine common risk factors among the crashes by looking not only at the specific location of the crash but also at the characteristics of the locations. Within this first step are three tasks that allow for improved analysis—

- Task A-1: Selecting Focus Crash Types.
- Task A-2: Selecting Focus Facilities.
- Task A-3: Identifying and Evaluating Risk Factors.

### *Task A-1: Select Focus Crash Types*

The objective of this task is to identify whether the systemic approach will be applied to segments, curves, or intersections. The Texas SHSP identifies four roadway safety emphasis areas, the first of which is *Crash Type & Location*. Included in this area are intersection crashes. According to the SHSP, “an intersection crash is one that occurs within the boundaries of an intersection or in which the first harmful event occurred on an approach to or exit from an intersection and resulted from an activity, behavior, or control related to the movement of traffic through an intersection.”

The strategies that should be considered to reduce intersection crashes include countermeasures installed under the Texas Highway Safety Improvement Program (HSIP) and other emerging treatments, as well as the following countermeasures identified in the Texas SHSP:

#### **Engineering**

- Implement engineering solutions to reduce red-light running, such as changes in signal timing (i.e., longer yellow, all-red phase).
- Enhance advanced warning at intersections through the use of signing, flashing beacons or transverse rumble strips.
- Provide high friction surface treatments at intersection approaches to reduce vehicle stopping distances.
- Consider the use of roundabouts to reduce the number of incapacitating crashes.
- Add more turn bays and acceleration lanes on high speed rural roads.
- Eliminate limited sight distance on all roads. This includes high speed rural and urban intersections where sight distance limitations exist due to vegetation, signing, and other obstructions.
- Construct grade separations.

#### **Enforcement**

- Consider the use of photographic traffic signal enforcement (red light cameras) by municipalities.

#### **Education**

- Add information on gap acceptance and intersection crash frequency to a standardized driver education curriculum and to programs targeting elderly drivers.
- Promote better access management policies and practices by educating consultants and developers on driveway regulations in relation to intersections and by coordinating with city, county, and state engineers.

#### **EMS**

- Encourage the use of emergency vehicle signal preemption.

Table 9 presents a breakdown of the intersection crashes occurring along State-maintained, locally owned, or other roadways for the five-year period.

**Table 9. CAMPO Intersection-related crashes by roadway owner type.**

|                      | State  | Local  | Other | TOTAL  |
|----------------------|--------|--------|-------|--------|
| Intersection Crashes | 28,745 | 23,228 | 254   | 52,227 |

*Task A-2: Select Focus Facilities*

Task A-2 concentrates on the details of where each crash took place, such as in rural or urban areas, at signalized or unsignalized intersections, along State-owned or locally-owned roads, etc. Table 10 depicts the distribution of intersection crashes by owner type, traffic control type, and area type.

**Table 10. Distribution of CAMPO intersection crashes by owner, traffic control, and area type.**

| STATE        | Area Type | Total # of Crashes | Fatal | A     | B     | C     | PDO    | Unknown |
|--------------|-----------|--------------------|-------|-------|-------|-------|--------|---------|
| Signalized   | Rural     | 2,220              | 12    | 106   | 337   | 403   | 1,341  | 21      |
|              | Urban     | 13,540             | 63    | 479   | 2,851 | 3,060 | 7,013  | 74      |
| Unsignalized | Rural     | 3,482              | 47    | 226   | 564   | 589   | 2,013  | 43      |
|              | Urban     | 9,403              | 28    | 273   | 1,633 | 2,099 | 5,262  | 108     |
| Unknown      | Rural     | 26                 | 0     | 0     | 4     | 2     | 19     | 1       |
|              | Urban     | 74                 | 0     | 1     | 13    | 16    | 44     | 0       |
| Subtotal     |           | 28,745             | 150   | 1,085 | 5,402 | 6,169 | 15,692 | 247     |
| LOCAL        |           |                    |       |       |       |       |        |         |
| Signalized   | Rural     | 256                | 0     | 6     | 62    | 45    | 140    | 3       |
|              | Urban     | 9,137              | 14    | 286   | 2,310 | 2,234 | 4,227  | 66      |
| Unsignalized | Rural     | 1,192              | 9     | 58    | 179   | 194   | 693    | 59      |
|              | Urban     | 12,564             | 33    | 342   | 2,630 | 2,549 | 6,658  | 352     |
| Unknown      | Rural     | 7                  | 0     | 1     | 1     | 0     | 5      | 0       |
|              | Urban     | 72                 | 0     | 4     | 25    | 11    | 31     | 1       |
| Subtotal     |           | 23,228             | 56    | 697   | 5,207 | 5,033 | 11,754 | 481     |
| OTHER        |           |                    |       |       |       |       |        |         |
| Signalized   | Rural     | 3                  | 0     | 0     | 0     | 1     | 2      | 0       |
|              | Urban     | 118                | 0     | 4     | 34    | 21    | 59     | 0       |
| Unsignalized | Rural     | 39                 | 0     | 1     | 10    | 6     | 22     | 0       |
|              | Urban     | 94                 | 0     | 2     | 11    | 17    | 59     | 5       |
| Unknown      | Rural     | 0                  | 0     | 0     | 0     | 0     | 0      | 0       |
|              | Urban     | 0                  | 0     | 0     | 0     | 0     | 0      | 0       |
| Subtotal     |           | 254                | 0     | 7     | 55    | 45    | 142    | 5       |

Per Table 10, approximately 99 percent of both the total crashes and KA crashes can be captured in the following seven intersection types (listed in order of decreasing total crashes):

- |                             |                             |
|-----------------------------|-----------------------------|
| 1. State Urban Signalized   | 5. State Rural Unsignalized |
| 2. Local Urban Unsignalized | 6. State Rural Signalized   |
| 3. State Urban Unsignalized | 7. Local Rural Unsignalized |
| 4. Local Urban Signalized   |                             |

Therefore, the following 11 intersection types (also listed in order of decreasing total crashes) were eliminated from further consideration, as they collectively accounted for approximately one percent of these crashes:

- |                             |                           |
|-----------------------------|---------------------------|
| 1. Local Rural Signalized   | 7. State Rural Unknown    |
| 2. Other Urban Signalized   | 8. Local Rural Unknown    |
| 3. Other Urban Unsignalized | 9. Other Rural Signalized |
| 4. State Urban Unknown      | 10. Other Rural Unknown   |
| 5. Local Urban Unknown      | 11. Other Urban Unknown   |
| 6. Other Rural Unsignalized |                           |

### *Task A-3: Identify and Evaluate Risk Factors*

In the current analysis, the analysis team identified the following potential risk factors using engineering judgment based upon the focus intersection types selected in Task A-2. Many of these risk factors will be reviewed in Step C as a random sample of selected intersection types are reviewed using online visualization tools:

- |   |   |
|---|---|
| • Number of lanes.                        | • Presence of advanced warning signs.                                     |
| • Number of legs.                         | • Intersection located in or near horizontal curve.                       |
| • Traffic volumes.                        | • Presence of left-turn or right-turn lanes.                              |
| • Lane and shoulder widths.               | • Left turn phasing.  |
| • Channelization.                         | • Allowance of right-turn on red.   |
| • Median width and type.                  | • Overhead vs. pedestal-mounted signal heads.                             |
| • Pavement condition and friction.        | • Pedestrian crosswalk presence, crossing distance, and signal head type. |
| • Driveway presence, design, and density. | • Posted speed limit or operating speed.                                  |
| • Presence of lighting.                   | • Presence of automated enforcement.                                      |
| • Presence of on-street parking.          | • Adjacent land use type.   |
| • Intersection skew angle.                | • Location and presence of bus stops.                                     |
| • Intersection traffic control device.    |   |
| • Number of signal heads vs. lanes.       |   |
| • Presence of backplates.                 |   |

## **B. Screen and Prioritize Candidate Locations**

The objective of Step B of the Systemic Safety Planning Process is “to develop a prioritized list of potential locations on the roadway system that could benefit from systemic safety improvement projects.” The process to screen and prioritize candidate locations helps to further explore the specific risk factors found in Step A. In order to do this, the analysis team performed the following three tasks (with the first two presented together below):

- Task B-1: Identify Network Elements to Analyze.
- Task B-2: Conduct Risk Assessment.
- Task B-3: Prioritize Focus Facility Elements.

Using the information collected in Step A, the main focus of Step B is crashes classified as K or A. KA crashes account for 3.8 percent of all intersection crashes in the CAMPO region during the analysis period.

### *Task B-1: Identify Network Elements to Analyze and Task B-2: Conduct Risk Assessment*

This section presents the following:

- A summary of the combined results of the data analyses of the five largest MPOs in Texas.
- The results of the data analyses specific to the CAMPO region.
- The recommended intersection type(s) on which the ISIP should focus.

### *Combined Analysis of Texas’s Five Largest MPOs*

The statewide ISIP is being developed from the analyses of not only the CAMPO data but also data from the AAMPO, El Paso, H-GAC and NCTCOG regions. Table 11 presents a general summary of the intersections at which the KA crashes occurred relative to the total number of intersections across the five regions. Some key takeaways include the following:

- More than 9 out of 10 KA intersection crashes occur in urban areas.
- There is nearly a 50/50 split between crashes at State- and locally-maintained intersections (i.e., between intersections comprising at least one State-maintained road and intersections not comprising a State-maintained road).
- Signalized intersections are significantly overrepresented in terms of comparing the proportion of KA crashes to the proportion of intersections



**Table 11. Common attributes related to the severe injury (KA) intersection crashes in the five largest MPOs in Texas.**

| Location Type               | No. of KA Crashes | Percent KA Crashes | Total No. of Intersections | Percent of Intersections |
|-----------------------------|-------------------|--------------------|----------------------------|--------------------------|
| Rural                       | 1,623             | 9.9%               | 8,817                      | 8.4%                     |
| Urban                       | 14,854            | 90.1%              | 95,777                     | 91.6%                    |
| <b>Subtotal</b>             | <b>16,477</b>     | <b>100%</b>        | <b>104,594*</b>            | <b>100%</b>              |
| <b>Ownership Type</b>       |                   |                    |                            |                          |
| State                       | 7,810             | 47.4%              | 25,054                     | 22.9%                    |
| Local                       | 8,518             | 51.7%              | 83,345                     | 76.1%                    |
| Other                       | 149               | 0.9%               | 1,132                      | 1.0%                     |
| <b>Subtotal</b>             | <b>16,477</b>     | <b>100%</b>        | <b>109,531*</b>            | <b>100%</b>              |
| <b>Traffic Control Type</b> |                   |                    |                            |                          |
| Signalized                  | 7,653             | 46.4%              | 25,512                     | 20.3%                    |
| Unsignalized                | 8,756             | 53.1%              | 97,709                     | 77.7%                    |
| Unknown                     | 68                | 0.4%               | 2,499                      | 2.0%                     |
| <b>Subtotal</b>             | <b>16,477</b>     | <b>100%</b>        | <b>125,720*</b>            | <b>100%</b>              |

\* As the safety data were derived from various sources (e.g., CRIS and ESRI Street layer), the intersection characteristic data correlate to the crashes rather than the intersections themselves. Consequently, there were instances when conflicting data elements (e.g., signalized and unsignalized) were coded to the same intersection due to multiple crash reports tied to the same location. This created duplicate intersections within the database, which led to the variable intersection subtotals among the categories.

Figure 4 depicts the comparison of the proportions of the five MPOs' KA intersection crashes to the specific intersection types. Five intersection categories show a measurable overrepresentation when comparing the proportion of KA crashes to the proportion of total intersections. The most meaningful overrepresentation in terms of KA crashes is seen in the State Urban Signalized and Local Urban Signalized categories.

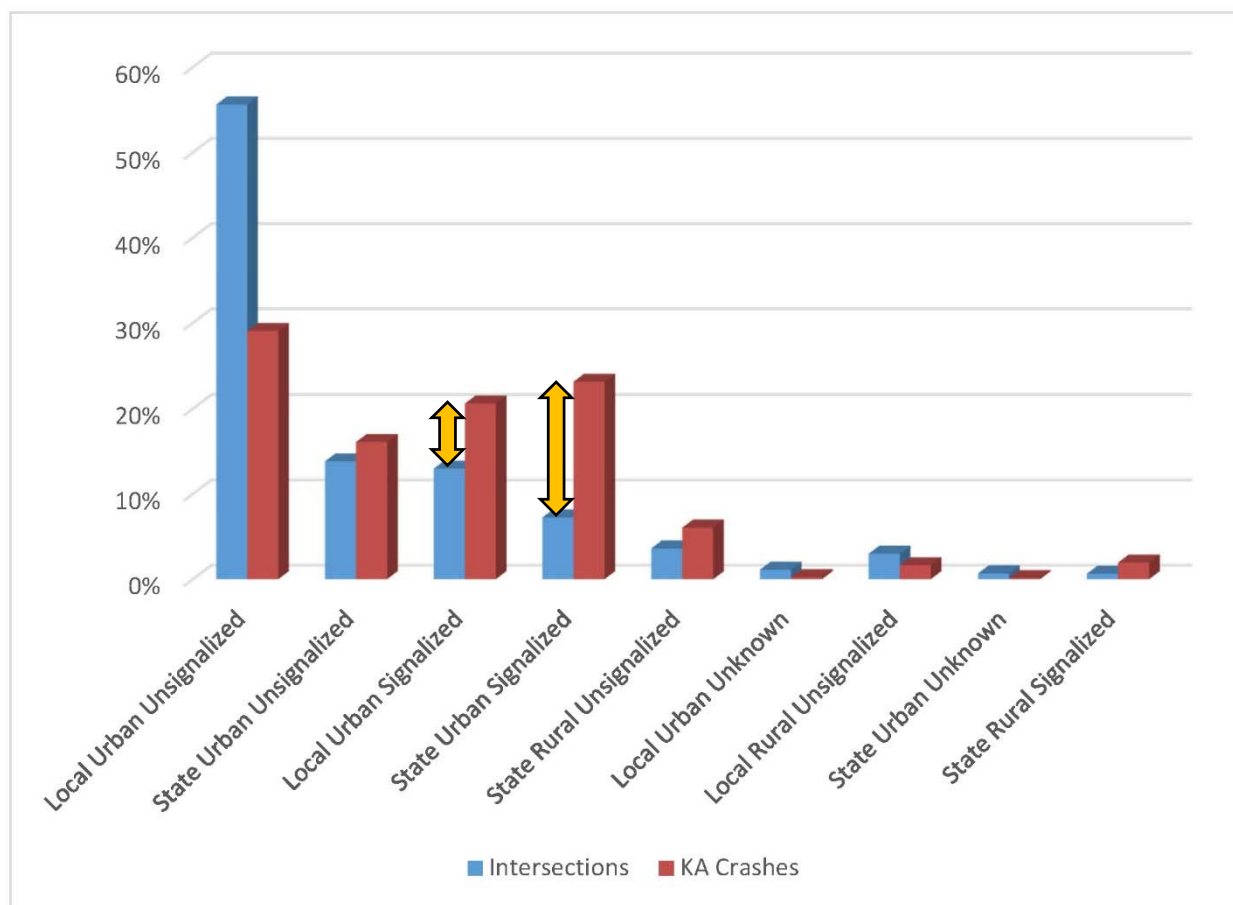


Figure 4. Distribution of the five largest Texas MPOs' severe injury (KA) intersection crashes by area type and traffic control.

**CAMPO Regional Analyses**

This section presents the results of the data analyses specific to the CAMPO region. Table 12 presents a general summary of the intersections at which the KA crashes occurred relative to the total number of intersections across the region.

**Table 12. Common attributes related to CAMPO severe injury (KA) intersection crashes.**

| Location Type               | No. of KA Crashes | Percent of KA Crashes | Total No. of Intersections | Percent of Intersections |
|-----------------------------|-------------------|-----------------------|----------------------------|--------------------------|
| Rural                       | 466               | 23%                   | 1,702                      | 18%                      |
| Urban                       | 1,529             | 77%                   | 7,729                      | 82%                      |
| <b>Subtotal</b>             | <b>1,995</b>      | <b>100%</b>           | <b>9,431*</b>              | <b>100%</b>              |
| <b>Ownership Type</b>       |                   |                       |                            |                          |
| State                       | 1,235             | 62%                   | 3,134                      | 32%                      |
| Local                       | 753               | 38%                   | 6,642                      | 67%                      |
| Other                       | 7                 | 0%                    | 93                         | 1%                       |
| <b>Subtotal</b>             | <b>1,995</b>      | <b>100%</b>           | <b>9,869*</b>              | <b>100%</b>              |
| <b>Traffic Control Type</b> |                   |                       |                            |                          |
| Signalized                  | 970               | 49%                   | 2,222                      | 20%                      |
| Unsignalized                | 1,019             | 51%                   | 8,781                      | 79%                      |
| Unknown                     | 6                 | 0%                    | 162                        | 1%                       |
| <b>Subtotal</b>             | <b>1,995</b>      | <b>100%</b>           | <b>11,165*</b>             | <b>100%</b>              |

\* Because the CAMPO safety data were derived from various sources (e.g., CRIS and ESRI Street layer), the intersection characteristic data correlate to the crashes rather than the intersections themselves. Consequently, there were instances when conflicting data elements (e.g., signalized and unsignalized) were coded to the same intersection due to multiple crash reports tied to the same location. This created duplicate intersections within the database, which led to the variable intersection subtotals among the categories. The actual intersection count for the CAMPO region was determined to be 9,296.

The analysis team highlights the following roadway inventory attributes to describe where these KA intersection crashes occurred:

- Land use—77 percent of CAMPO’s KA intersection crashes occurred in urban areas compared to 23 percent rural.
- Ownership type—62 percent of the KA intersection crashes occurred at intersections involving at least one State-maintained road despite only 32 percent of CAMPO’s intersections being State-owned.
- Traffic control—considering the 1,989 crashes for which the traffic control type is known, approximately half (49 percent) of the crashes occurred at signalized intersections despite the fact that only an estimated 20 percent of CAMPO intersections are signalized.

## DRAFT: PRELIMINARY FINDINGS – NOT FOR DISTRIBUTION

Each of the focus intersection types are further divided into different elements to determine which would be the most beneficial to analyze. Table 13 depicts the number of KA intersection crashes and the number of associated intersection types categorized by the following attributes:

- Owner type (State-maintained, locally-owned, or other intersections).
- Land use (rural or urban area).
- Traffic control (signalized, unsignalized, or unknown).

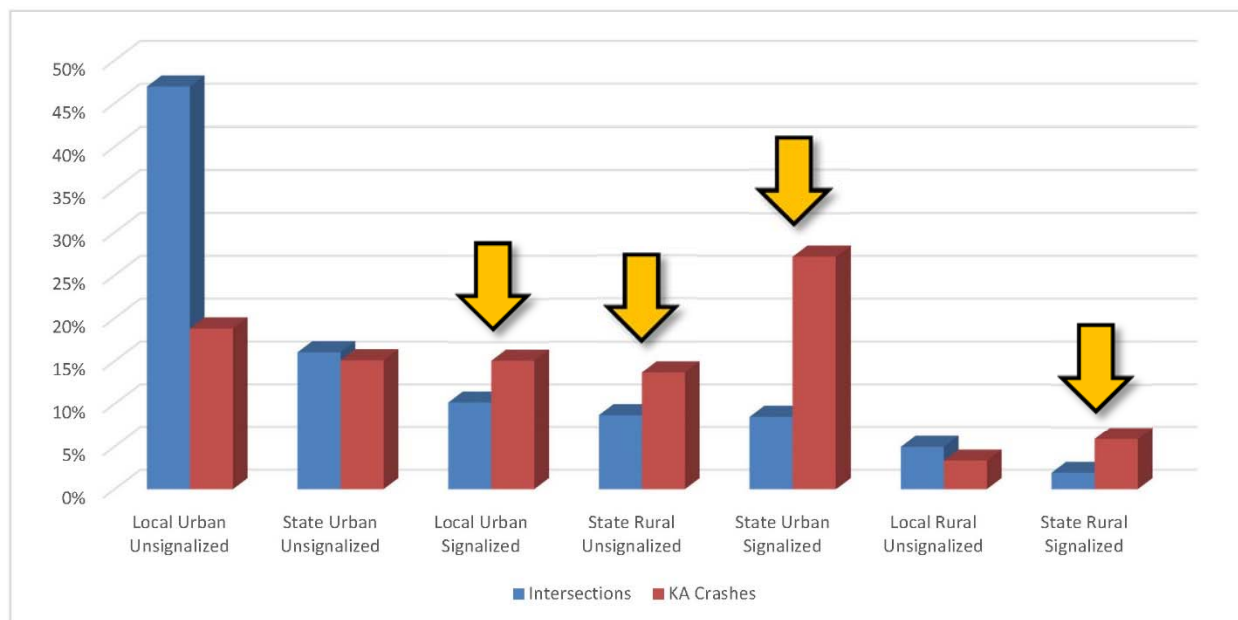
The seven focus categories identified in Table 10—which capture 99.1 percent of the region’s KA crashes—are listed in boldface type

**Table 13. Distribution of CAMPO severe intersection crashes by traffic control and area type.**

| STATE                 | Area Type | KA Crashes | Percent of KA | Total Intersections | Percent of Intersections | Ratio of % KA to % Ints |
|-----------------------|-----------|------------|---------------|---------------------|--------------------------|-------------------------|
| Signalized            | Rural     | 118        | 5.91%         | 230                 | 1.92%                    | 3.07                    |
|                       | Urban     | 542        | 27.17%        | 1,013               | 8.48%                    | 3.21                    |
| Unsignalized          | Rural     | 273        | 13.68%        | 1,038               | 8.68%                    | 1.58                    |
|                       | Urban     | 301        | 15.09%        | 1,916               | 16.03%                   | 0.94                    |
| Unknown               | Rural     | 0          | 0.00%         | 25                  | 0.21%                    | 0.00                    |
|                       | Urban     | 1          | 0.05%         | 62                  | 0.52%                    | 0.10                    |
| Subtotal              |           | 1,235      | 61.90%        | 4,284               | 35.84%                   | -                       |
| <b>LOCAL</b>          |           |            |               |                     |                          |                         |
| Signalized            | Rural     | 6          | 0.30%         | 67                  | 0.56%                    | 0.54                    |
|                       | Urban     | 300        | 15.04%        | 1,214               | 10.16%                   | 1.48                    |
| Unsignalized          | Rural     | 67         | 3.36%         | 594                 | 4.97%                    | 0.68                    |
|                       | Urban     | 375        | 18.80%        | 5,611               | 46.95%                   | 0.40                    |
| Unknown               | Rural     | 1          | 0.05%         | 7                   | 0.06%                    | 0.86                    |
|                       | Urban     | 4          | 0.20%         | 70                  | 0.59%                    | 0.34                    |
| Subtotal              |           | 753        | 37.74%        | 7,563               | 63.28%                   | -                       |
| <b>OTHER</b>          |           |            |               |                     |                          |                         |
| Signalized            | Rural     | 0          | 0.00%         | 2                   | 0.02%                    | 0                       |
|                       | Urban     | 4          | 0.20%         | 19                  | 0.16%                    | 0.47                    |
| Unsignalized          | Rural     | 1          | 0.05%         | 17                  | 0.14%                    | 0.36                    |
|                       | Urban     | 2          | 0.10%         | 67                  | 0.56%                    | 0.4                     |
| Unknown               | Rural     | 0          | 0.00%         | 0                   | 0.00%                    | -                       |
|                       | Urban     | 0          | 0.00%         | 0                   | 0.00%                    | -                       |
| Subtotal              |           | 7          | 0.35%         | 105                 | 0.88%                    | -                       |
| <b>TABLE SUBTOTAL</b> |           | 1,995      | 100.00%       | 11,952              | 100.00%                  |                         |

Four of the intersection categories listed in boldface type in Table 13 show a measurable overrepresentation when comparing the proportion of KA crashes to the proportion of total CAMPO intersections. Figure 5 depicts the comparison of the proportions of CAMPO KA intersection crashes to

CAMPO intersection types. The most meaningful overrepresentation in terms of KA crashes is seen in the State Urban Signalized, Local Urban Signalized, State Rural Signalized, and State Rural Unsignalized categories.



**Figure 5. Distribution of CAMPO severe (KA) intersection crashes by area type and traffic control.**

### ***Recommended ISIP Focus***

The analysis team suggests to focus on urban signal-controlled intersections, regardless of whether these intersections are State-maintained or locally owned. State and Local Urban Signalized intersections comprise less than 19 percent of the intersections within the CAMPO region, yet nearly 42 percent of the severe (KA) intersection crashes—842 of them during the five-year study period—occurred at such intersections. These KA crashes occurred at 507 urban signalized intersections, which equates to 5.5 percent of the 9,296 intersections analyzed. Similar trends emerge when considering all five MPO regions collectively, as approximately 20 percent of the intersections are State and Local Urban Signalized, yet nearly 44 percent of the KA crashes occur at such intersections.

The distribution of the CAMPO State and Local Urban Signalized KA intersection crashes in terms of the TxDOT collision types is presented in Table 14 and Figure 6. Not surprisingly, nearly four of every five severe intersection crashes involved more than one vehicle, with nearly half of these classified as angle type collisions characterized by “two vehicles approaching each other at an angle.”

**Table 14. Detailed distribution of CAMPO severe intersection collision types.**

| Collision Type                      | Count      | Percent     |
|-------------------------------------|------------|-------------|
| OD ONE STRAIGHT-ONE LEFT TURN       | 226        | 27%         |
| ANGLE - BOTH GOING STRAIGHT         | 220        | 26%         |
| OMV VEHICLE GOING STRAIGHT          | 121        | 14%         |
| SD ONE STRAIGHT-ONE STOPPED         | 117        | 14%         |
| OMV VEHICLE TURNING LEFT            | 46         | 5%          |
| ANGLE - ONE STRAIGHT-ONE LEFT TURN  | 29         | 3%          |
| SD BOTH GOING STRAIGHT-REAR END     | 20         | 2%          |
| SD ONE STRAIGHT-ONE LEFT TURN       | 13         | 2%          |
| ANGLE - ONE STRAIGHT-ONE RIGHT TURN | 12         | 1%          |
| OMV VEHICLE TURNING RIGHT           | 11         | 1%          |
| SD BOTH GOING STRAIGHT-SIDESWIPE    | 5          | 1%          |
| OD BOTH GOING STRAIGHT              | 4          | 0%          |
| SD ONE STRAIGHT-ONE RIGHT TURN      | 3          | 0%          |
| OMV OTHER                           | 3          | 0%          |
| OD ONE STRAIGHT-ONE STOPPED         | 2          | 0%          |
| OD ONE RIGHT TURN-ONE LEFT TURN     | 2          | 0%          |
| SD BOTH LEFT TURN                   | 2          | 0%          |
| NOT REPORTED                        | 1          | 0%          |
| OD ONE LEFT TURN-ONE STOPPED        | 1          | 0%          |
| ANGLE - ONE RIGHT TURN-ONE STOPPED  | 1          | 0%          |
| ANGLE - ONE STRAIGHT-ONE STOPPED    | 1          | 0%          |
| SD ONE LEFT TURN-ONE STOPPED        | 1          | 0%          |
| SD BOTH RIGHT TURN                  | 1          | 0%          |
| <b>Total</b>                        | <b>842</b> | <b>100%</b> |

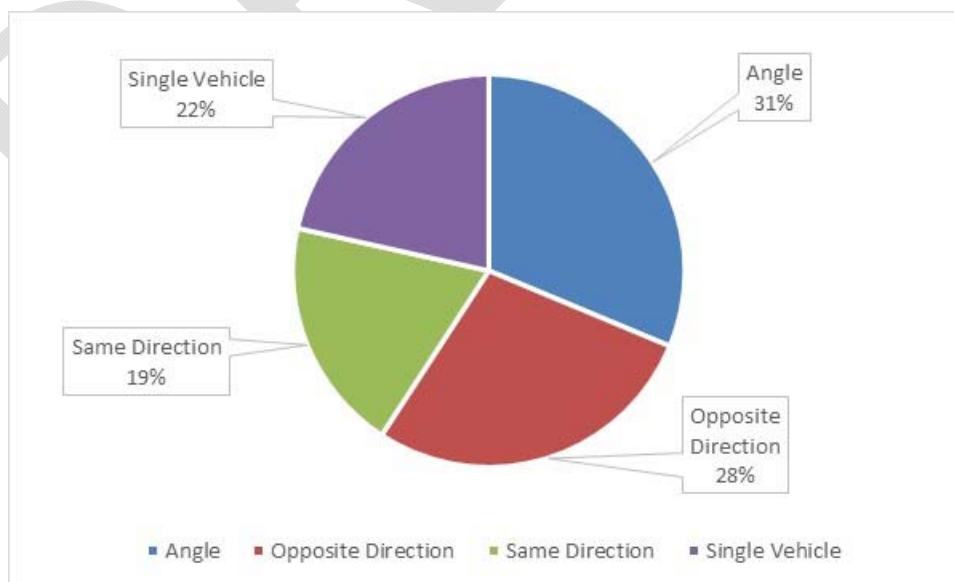
**Figure 6. General distribution of CAMPO severe intersection collision types.**

Table 15 presents the nature of the severe (KA) intersection crashes according to the reported harmful event description, which provides additional insight on the nature of the collision. Four (4) of every 5 crashes involved another motor vehicle, while more than 1 of every 7 crashes involved a pedestrian or bicyclist.

**Table 15. Reported harmful event for CAMPO severe intersection collisions.**

| Harmful Event              | Count      | Percent     |
|----------------------------|------------|-------------|
| MOTOR VEHICLE IN TRANSPORT | 661        | 79%         |
| PEDESTRIAN                 | 85         | 10%         |
| PEDALCYCLIST               | 47         | 6%          |
| FIXED OBJECT               | 35         | 4%          |
| OVERTURNED                 | 12         | 1%          |
| PARKED CAR                 | 1          | 0%          |
| ANIMAL                     | 1          | 0%          |
| <b>Total</b>               | <b>842</b> | <b>100%</b> |

Basic crash analyses were also conducted to explore trends in the reported lighting condition, surface condition, and weather condition for the severe intersection crashes, and these will be considered when selecting crash countermeasures.

### *Task B-3: Prioritize Focus Facility Elements*

The selected 842 severe injury (KA) crashes in CAMPO occurred at 507 intersections, which may be too many locations to effectively treat in a short timeframe with limited resources. Therefore, the analysis team suggests applying a threshold to the KA crashes to assist with prioritizing a subset of the urban signalized intersections. While the analyses have centered on KA crashes, additional prioritization alternatives are derived by also considering the number of non-incapacitating injury (B) crashes that occurred at the focus intersections. Table 16 presents a breakdown of intersections that can be targeted based on various crash thresholds. The first three rows consider only KA crashes, while the remaining rows also apply thresholds to the B crashes occurring during the analysis period. If a threshold of three or more KA crashes is selected, nearly 35 percent of CAMPO's KA intersection crashes can be addressed by targeting less than 15 percent of the KA intersection crash locations; likewise, if a threshold of either three or more KA crashes or two KA crashes and four or more B crashes is applied, then more than 52 percent of the KA crashes can be addressed by targeting 29 percent of the KA crash locations.

**Table 16. Potential crash thresholds for CAMPO systemic treatments.**

| Crash Threshold   | KA Crashes |         | Intersections |         | B Crashes |
|---|------------|---------|---------------|---------|-----------|
|   | Number     | Percent | Number        | Percent |           |
| 2 or more KA crashes  | 516        | 61.7%   | 186           | 36.8%   | 1,610     |
| 3 or more KA crashes  | 292        | 34.9%   | 74            | 14.6%   | 881       |
| 4 or more KA crashes  | 175        | 20.9%   | 35            | 6.9%    | 520       |
| 3 or more KA crashes OR<br>2 KA crashes and 10 or<br>more B crashes | 344        | 41.1%   | 100           | 19.8%   | 1,257     |
| 3 or more KA crashes OR<br>2 KA crashes and 8 or<br>more B crashes  | 378        | 45.2%   | 117           | 23.1%   | 1,399     |
| 3 or more KA crashes OR<br>2 KA crashes and 6 or<br>more B crashes  | 404        | 48.3%   | 130           | 25.7%   | 1,483     |
| 3 or more KA crashes OR<br>2 KA crashes and 5 or<br>more B crashes  | 422        | 50.5%   | 139           | 27.5%   | 1,528     |
| 3 or more KA crashes OR<br>2 KA crashes and 4 or<br>more B crashes  | 438        | 52.4%   | 147           | 29.1%   | 1,560     |

Similarly, Table 17 presents the potential crash thresholds and their corresponding reach for the five MPOs combined. The rightmost column provides a simple estimate of how an overall statewide funding amount—\$45 million in this case—would translate as a per-intersection average for the various thresholds identified. For example, selecting a threshold of three or more KA crashes or two KA crashes and four or more B crashes would allow nearly 40 percent of the five regions' KA intersection crashes to be addressed by targeting 19 percent of the KA intersection crash locations, with an allowable average cost of nearly \$50,000 per intersection.



**Table 17. Potential crash thresholds for statewide systemic treatments.**

| Crash Threshold   | KA Crashes |         | Intersections |         | B Crashes | Avg. per-intersection<br>cost assuming \$45M<br>funding |
|---|------------|---------|---------------|---------|-----------|---|
|   | Number     | Percent | Number        | Percent |           |   |
| 2 or more KA crashes  | 3,782      | 52.5%   | 1,373         | 28.7%   | 8,242     | \$ 32,775   |
| 3 or more KA crashes  | 2,006      | 27.9%   | 485           | 78.9%   | 4,507     | \$ 92,784   |
| 4 or more KA crashes  | 1,178      | 16.4%   | 209           | 34.0%   | 2,919     | \$ 215,311  |
| 3 or more KA crashes<br>OR 2 KA crashes and<br>10 or more B crashes | 2,162      | 30.0%   | 563           | 11.8%   | 5,518     | \$ 79,929   |
| 3 or more KA crashes<br>OR 2 KA crashes and<br>8 or more B crashes  | 2,298      | 31.9%   | 631           | 13.2%   | 6,088     | \$ 71,315   |
| 3 or more KA crashes<br>OR 2 KA crashes and<br>6 or more B crashes  | 2,506      | 34.8%   | 735           | 15.4%   | 6,751     | \$ 61,224   |
| 3 or more KA crashes<br>OR 2 KA crashes and<br>5 or more B crashes  | 2,660      | 37.0%   | 812           | 17.0%   | 7,136     | \$ 55,419   |
| 3 or more KA crashes<br>OR 2 KA crashes and<br>4 or more B crashes  | 2,846      | 39.5%   | 905           | 18.9%   | 7,508     | \$ 49,724   |

Ultimately, the threshold applied for this effort will be determined by TxDOT and the participating local agencies based on the (1) selected package of systemic countermeasures (and its associated cost), (2) actual funding level available, and (3) decisions on prioritization across all participating MPOs.

### C. Select Countermeasures

The third step of the Systemic Safety Planning Process involves developing “low-cost, highly effective countermeasures” that can be utilized at the candidate locations. Once the preliminary findings are approved and the selection of the suggested intersection types receive concurrence from the MPOs, TxDOT, and FHWA, the analysis team will move forward to estimate current deployment levels, crash thresholds, and a planning-level benefit-cost ratio analysis for each possible systemic countermeasure that may address the selected intersection types and current crash types. The team also will ask for feedback on the current use or acceptance of the proposed countermeasures and eliminate any measures that may not be used in Texas.

## D. Prioritize Projects

Developing a list of safety-improvement projects is the last step in the Systemic Safety Planning process. Throughout this step, each crash location will be evaluated using the criteria calculated in Step C to help determine which countermeasures would be most effective for these areas. Finally, each countermeasure package will be prioritized based on its cost relative to current funding availability, benefits through expected crash reduction, and ability to be quickly deployed relative to any contractual issues or institutional constraints.

## Conclusions and Next Steps

The methodology utilized to identify the best systemic approach aligns with the State SHSP's statement that "Texas must continue to seek safety improvements by deploying a diverse set of countermeasures that address both engineering and behavioral issues." The selected approach embodies the data-driven decision making noted by the SHSP to achieve Texas's mission of reducing the "human and societal costs of motor vehicle crashes, deaths, and injuries by implementing effective highway safety countermeasures." As roadway safety data—particularly intersection data (e.g., number of approach legs, entering traffic volumes, maintenance jurisdiction)—become more available and more accurate, this approach can be modified to better address intersection safety systemically and encompass all public roadways.

The SHSP identifies intersections as a focus of its critical emphasis area, *Crash Type & Location*. This proposed systemic approach will complement the ongoing SHSP initiative to reduce the number of fatal and incapacitating injury intersection-involved crashes by five percent. Based on the preliminary analysis, the project team proposes that the best systemic approach is to target the severe KA intersection crashes. The severe crashes comprise nearly 50 percent of the total cost of intersection crashes. Analyzing the severe crash intersections further reveals the top intersection type as **urban signalized**. CAMPO's 842 severe intersection crashes occurred at 507 locations across the region, and these crashes comprise 37 percent of the region's total severe intersection crashes.

In order to focus the systemic approach within the CAMPO region, the project team suggests looking at a subset of the urban signalized intersections. Several thresholds were presented in Table 16 to indicate how many crashes could be targeted relative to the number of intersections treated. The project team will assist the MPOs, TxDOT, and FHWA in determining the final threshold to be applied for the entire effort.

Based upon feedback from CAMPO, TxDOT, and FHWA, the project team will continue to develop and refine a number of countermeasure packages as part of Step C. These packages will be presented in a straw man outline as part of Step D.

## References

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2. “2010 Census: Texas Profile,”  
[http://www2.census.gov/geo/maps/dc10\\_thematic/2010\\_Profile/2010\\_Profile\\_Map\\_Texas.pdf](http://www2.census.gov/geo/maps/dc10_thematic/2010_Profile/2010_Profile_Map_Texas.pdf)
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5. “Systemic Safety Project Selection Tool,” U.S. Department of Transportation Federal Highway Administration, July 2013, <http://safety.fhwa.dot.gov/systemic/fhwasa13019/sspst.pdf>