Highway Safety Manual Applied in Missouri – Freeway/Software

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16. Abstract

AASHTO's Highway Safety Manual (HSM) facilitates the quantitative safety analysis of highway facilities. In a 2014 supplement, freeway facilities were added to the original HSM manual which allows the modeling of highway interchanges. This report documents the calibration of the most vital freeway interchange facility types in Missouri. These facility types include nine freeway interchange terminals, including diamond, partial cloverleaf, and full cloverleaf interchanges. The non-terminal facilities included entrance and exit speed-change lanes, and entrance and exit ramps. The calibrated facilities applied to both rural and urban locations. For each facility type, sample sites were randomly selected from an exhaustive master list. Four types of data were collected for each site: geometric, AADT, traffic control, and crash. Crash data was especially noteworthy because of the crash landing problem, i.e. crashes were not located on the proper interchange facility. A significant companion crash correction project was undertaken involving the review of 12,409 crash reports, and the detailed review of 9,169 crash reports. Using the corrected data, 44 calibration values were derived for freeway terminal and non-terminal facilities. These values are the first reported freeway interchange calibration values since the release of the 2014 HSM supplement.

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DISCLAIMER

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EXECUTIVE SUMMARY

AASHTO released a revision to the Highway Safety Manual (HSM) that includes models for freeway segments, speed-change lanes (transitional area between mainline and ramps), ramps, and interchange terminals. These predictive models for freeway interchanges need to be calibrated to local conditions in order to accurately model local conditions. The calibration of HSM freeway interchange models ensures that Missouri driver population, conditions, and environment are captured. This calibration process requires detailed data types, such as crash frequencies, traffic volumes, geometrics, traffic control, and land-use. HSM does not document in detail the techniques used for gathering such data for calibration since data systems vary significantly across states. The calibration process also requires specific decisions on the correct sampling approach, determination of the influence area of terminals and interchanges, and how to locate crashes within the appropriate interchange facility.

A major challenge encountered on this project was the crash landing problem which refers to the issue of locating crashes correctly within the freeway interchange area. The crash landing problem and the solutions devised for solving the problem in Missouri are documented in a separate report entitled, "Crash Location Correction for Freeway Interchange Modeling" (Report No. cmr 16-010). For the Missouri calibration of freeway interchanges, there were 12,409 crashes that were reviewed, and 9,168 crash reports that were reviewed in detail. The crash review correctly relocated 69% of the crashes that were previously located on the wrong interchange facility.

In order to obtain samples for each interchange facility type, every single freeway interchange in Missouri was catalogued according to HSM classification. This was done since the Transportation Management System (TMS) database does not classify interchanges

according to the HSM definitions such as A2 or D4SCU. Freeways in Missouri include interstates, US highways, and Missouri highways. From this master list of all Missouri interchanges, sample sites were selected randomly while maintaining geographical coverage across all seven MoDOT districts. Whenever possible, at least 30 different samples were selected for each facility type, although some facility types had fewer than 30 samples in the entire state.

HSM calibration is a data-intensive process that uses four main types of data. One type is geometric data which involves the collection of characteristics such as lane width, shoulder type, median type, ramp skewness, horizontal curvature, and traffic control. Measurements were usually derived from aerial photographs using either a web-based tool or with CAD by importing the aerial photograph as a background. Another type is AADT which is obtained by querying the MoDOT TMS database. The third type is crash data which requires the finding of the appropriate extents of interchanges, usually 1500 feet from the interchange center. All crashes within the extents of interchanges were recorded and landed correctly within interchange facilities after a detailed review of the original crash reports. The last type of data is the traffic control type at the terminal; this information was provided by the applicable MoDOT district traffic engineers.

Table ES1 shows the results from the Missouri freeway interchange calibration. The first eight rows are for the most common interchange terminals occurring in Missouri. Since the number of freeway lanes does not affect interchange modeling, these eight calibration values can apply to various freeway lane configurations, including four lane and six lane freeways. Since full cloverleaf interchanges do not involve intersections, they can be modeled using only the calibrated speed-change lane and ramp values. The first eight values in Table ES1 show a trend that the PDO calibration values are consistently above 1.0. Rows 9 through 14 show values for speed-change lanes, and rows 15 through 22 show values for ramps. Separate values were derived for fatal/injury crashes (FI) and property damage only (PDO) crashes. In addition, separate values were derived for single vehicle (SV) and multiple vehicle (MV) crashes for ramp facilities. This separation of ramp calibration values into SV and MV by the HSM is problematic since very few MV crashes occur on single lane ramps or on ramps in general. Four of the ramp calibration values resulted in values of 0.000 due to no crashes being observed in Missouri. These four ramp calibration values are replaced by 1.000; thus national data is used for these four values. This change in the four ramp calibration values has very little impact on the overall safety modeling of an interchange facility as ramps contain the fewest crashes of all freeway interchange facilities. The calibration values from Table ES1 can be published on the MoDOT Engineering Policy Guide so that they are readily available for modeling interchanges using the HSM.

Table ES1 Freeway Interchange Calibration Values

Freeway Interchange Facility	Calibration Value	
	FI	PDO
Ramp Terminals		
Rural Stop-Controlled D4 Diamond Interchange Terminal	0.843	2.251
Urban Stop-Controlled D4 Diamond Interchange Terminal	1.226	2.025
Signalized D4 Diamond Interchange with Two Lane Crossroads Terminal	1.087	2.360
Signalized D4 Diamond Interchange with Four Lane Crossroads Terminal	0.853	1.830
Signalized D4 Diamond Interchange with Six Lane Crossroads Terminal	0.874	2.150
Rural Stop-Controlled A2 Partial Cloverleaf Interchange Terminal	0.290	1.504
Urban Stop-Controlled A2 Partial Cloverleaf Interchange Terminal	1.035	1.594
Signalized Partial A2 Cloverleaf Interchange Terminal	0.535	1.172
Speed-Chang Lanes		
Rural Entrance Speed-Change Lane	0.714	1.152
Rural Exit Speed-Change Lane	0.811	1.162
Urban Four-Lane Entrance Speed-Change Lane	0.598	1.314
Urban Four-Lane Exit Speed-Change Lane	0.455	0.519
Urban Six-Lane Entrance Speed-Change Lane	0.431	0.739
Urban Six-Lane Exit Speed-Change Lane	0.443	0.482
Ramps		
Rural Entrance Ramp for Single Vehicle Crashes	1.000*	0.769
Rural Entrance Ramp for Multiple Vehicle Crashes	1.000*	2.489
Rural Exit Ramp for Single Vehicle Crashes	0.356	1.531
Rural Exit Ramp for Multiple Vehicle Crashes	1.000*	1.000*
Urban Entrance Ramp for Single Vehicle Crashes	0.913	1.121
Urban Entrance Ramp for Multiple Vehicle Crashes	2.681	6.360
Urban Exit Ramp for Single Vehicle Crashes	0.840	1.266
Urban Exit Ramp for Multiple Vehicle Crashes	2.354	5.252

*A value of 1.000 (i.e., national data) was used because Missouri data contained too few ramp crashes.

CHAPTER 1 INTRODUCTION

The Highway Safety Manual (HSM) provides methods and tools to assist in the quantitative evaluation of safety. The HSM added the modeling of freeways including segments, speed-change lanes, and interchanges. These new models need to be calibrated in order to reflect local driver populations, conditions, and environments. Some relevant local conditions include driver population, geometric design, signage, traffic control devices, signal timing practices, climate, and animal population. This project involves the systematic calibration of HSM freeway interchange models to account for such conditions in Missouri.

This project directly supports all four key focus areas of MoDOT and USDOT: enhancing safety, improving the state of good repair, improving economic competiveness, and improving environmental sustainability of the U.S. surface transportation system. The most obvious area that this project supports is enhancing safety. The HSM can be used to identify possible locations for reducing high crash frequencies or severities and the factors contributing to crashes as well as appropriate countermeasures to mitigate safety issues. The safety benefits can be achieved throughout the planning, design, and operation stages. Another focus area is assisting with the repair of infrastructure. Because of the elevated risks associated with work zones, it is important to include safety in implementing maintenance and rehabilitation work. This project also supports the area of economic competiveness because the HSM facilitates the estimation of crash reduction benefits, design alternatives, and project improvements. Lastly, the HSM can be a useful tool during the NEPA (National Environmental and Policy Act) process for performing environmental and traffic impact analysis. In examining design alternatives during the NEPA process, safety is a major concern.

In general, safety calibration involves the iterative process of aligning the expected average crash frequencies estimated using HSM methodologies with the observed crash frequencies from selected field sites. HSM recommends that calibration be performed every two to three years. Thus, the goal is to develop a long term process for calibration and not just produce a set of calibration values once. The calibration process will be carefully documented so that future calibrations can follow the same procedures using the same types of data.

The following five step calibration process was followed: (1) identification of interchange facility types, (2) selection of representative field sites, (3) collection of relevant site data, (4) prediction of HSM crash frequencies, and (5) fine-tuning calibration parameters by comparing predicted with observed crash frequencies. For step (1), a subset of critical facility types was determined from the following general types: interchange terminals, ramps, and speed-change lanes. Both rural and urban facilities were selected. Step (2) involved the identification of adequate field sites of a minimum of 30 to 50 samples and at least 100 crashes per year. The data for Step (3) were obtained from MoDOT's Transportation Management System (TMS), aerial photographs, and MoDOT district offices. Steps (4) and (5) involve the estimation of crash frequencies using HSM SPFs and the comparison with observed crash frequencies.

As the research was progressing through steps (1)-(3), a major challenge was identified. As previously discussed, step (3) involves the collection of site data, including crash data. In Missouri, as in other states, crash reports are completed by police agencies such as local law enforcement (LEO) agencies or the state highway patrol. Thus, there are a large number of police agencies involved in crash reporting and a resulting variance in reporting accuracy despite the existence of a uniform reporting standard. Freeway interchange facilities are particularly challenging for crash reporting because of their complexity. As will be discussed in detail in later sections of this report, freeway interchanges often involve multiple terminals (ramp intersections), on and off ramps, speed-change lanes, and freeway segments. Due to this complexity, the location data from crash reports were often in error. For example, a crash that should be located on a ramp terminal could be assigned instead to the crossroad in between two ramp terminals. The prevalence of location errors, the so-called “crash landing problem”, meant that the existing crash data was not adequate for the calibration of freeway interchanges. After this problem was discovered, researchers met with the project technical advisory committee that included members from MoDOT’s traffic safety and research divisions. A joint decision was reached to expand the scope of research to include the correction of crash reports needed for the calibration of freeway facilities. Crash correction is a significant undertaking since crash reports need to be scanned manually by carefully reviewing data fields, collision diagrams, and narratives and statements. In addition, consistent methodology and training need to be developed so that a large team could perform the crash review in a consistent manner. Subsequently, MoDOT funded an additional project to produce the accurate data necessary for calibration.

The types of freeway interchange facilities calibrated included both ramp terminals and non-terminal facilities. Table 1.1 shows the list of the 10 terminal, 6 speed-change lane, and 4 ramp facilities that were calibrated for Missouri. Note that ramp terminal models are not affected by the number of freeway lanes, thus signalized diamond interchange terminals with four crossroad lanes all share the same calibration value regardless of the number of freeway lanes. These facilities were chosen because they are the facilities most common in Missouri, thus samples existed for performing calibration. All facilities were calibrated separately for FI (fatal and injury) and PDO (Property Damage Only) crash severities, and some were further calibrated according to MV (multiple vehicle) and SV (single vehicle) crashes. Thus a total of 16 terminal, 12 speed-change lane, and 16 ramp calibration values were produced for a total of 44 calibration values.

Table 1.1 HSM Interchange Site Facilities Calibrated for Missouri

HSM Chapter	Facility Type	Calibration Values
19	Rural Stop-Controlled Diamond Interchange Terminals	FI, PDO
19	Urban Stop-Controlled Diamond Interchange Terminals	FI, PDO
19	Signalized Diamond Interchange Terminals, 2 Crossroad Lanes, 4 Freeway Lanes	FI, PDO
19	Signalized Diamond Interchange Terminals, 4 Crossroad Lanes, 4 Freeway Lanes*	FI, PDO
19	Signalized Diamond Interchange Terminals, 4 Crossroad Lanes, 6 Freeway Lanes*	FI, PDO
19	Signalized Diamond Interchange Terminals, 6 Crossroad Lanes, 6 Freeway Lanes	FI, PDO
19	Rural Stop-Controlled Parclo (A2) Interchange Terminals	FI, PDO
19	Urban Stop-Controlled Parclo (A2) Interchange Terminals	FI, PDO
19	Signalized Parclo (A2), 4 Crossroad Lanes	FI, PDO
18 & 19	Full Cloverleaf Interchanges**	*N/A
18	Rural Entrance Speed-Change Lanes, 4 Freeway Lanes	FI, PDO
18	Urban Entrance Speed-Change Lanes, 4 Freeway Lanes	FI, PDO
18	Urban Entrance Speed-Change Lanes, 6 Freeway Lanes	FI, PDO
18	Rural Exit Speed-Change Lanes, 4 Freeway Lanes	FI, PDO
18	Urban Exit Speed-Change Lanes, 4 Freeway Lanes	FI, PDO
18	Urban Exit Speed-Change Lanes, 6 Freeway Lanes	FI, PDO
19	Rural Single Lane Entrance Ramps	MV_FI, SV_FI, MV_PDO, SV_PDO
19	Rural Single Lane Exit Ramps	MV_FI, SV_FI, MV_PDO, SV_PDO
19	Urban Single Lane Entrance Ramps	MV_FI, SV_FI, MV_PDO, SV_PDO
19	Urban Single Lane Exit Ramps	MV_FI, SV_FI, MV_PDO, SV_PDO

*Ramp terminal models are not affected by the number of freeway lanes, thus both type of these diamond interchanges use the same calibration values.
** Full cloverleafs do not contain intersections thus they rely on calibration values for speed-change lanes and ramps.

CHAPTER 2 LITERATURE REVIEW

Several states have calibrated facility types in the Highway Safety Manual (HSM); some using the draft version that existed before the official release in 2010. Depending on the state, the calibrated facilities ranged from just a few to almost all the non-freeway facilities. However, due to the newness of the freeway chapters, released in 2014, there is very little literature on how states are calibrating and modeling freeway facilities, especially freeway interchanges. Some states have reported the calibration of freeway segments in the interchange area (e.g., MDOT, 2012; Lu et al., 2012), but there are not reported values for ramp terminals, speed-changes lanes, and ramps. Lu et al. (2012) point to the difficulty of separating a freeway network into interchange areas and basic freeway segments, despite the HSM definition of the interchange influence area. There are on-going efforts in several states to calibrate and model freeway safety, prime examples being those who are part of NCHRP 17-50 HSM implementation lead states, but not much has been published yet. The authors have communicated with several of those states on the issues they face concerning the unique challenges of calibrating freeways, especially freeway interchanges.

There are several states who have published significant details about their general HSM calibration efforts. Sun et al. (2006) documented the calibration of rural two-lane highways in Louisiana. Srinivasan and Carter (2011) described calibration efforts in North Carolina that included both roadway segments and intersections, but no freeways. Banihashemi (2011) compared new models versus calibration for rural two-lane segments in the state of Washington. Sivaramakrishnan et al. (2011) produced calibration factors for rural two-lane and multilane segments, and urban and suburban arterial segments and intersections. Alluri (2011) compared Oregon and Georgia calibration values for rural two-way, two-lane roads. Brimley et al. (2012)

described in detail the calibration of rural, two-lane highways in Utah. Dixon et al. (2012) presented calibration results in Oregon on rural two-lane, two-way roads, rural multilane roads, and urban and suburban arterial roads. Williamson and Zhou (2012) calibrated rural two-lane highways in Illinois. Mehta and Lou (2013) described both the calibration and development of safety performance functions for two-lane, two-way rural roads and four-lane divided highways in Alabama. Sun et al. (2013) reported on the comprehensive calibration effort in Missouri involving eight segment and eight intersection facilities, including rural and urban highways, freeway segments, stop-controlled intersections, and signalized intersections. Kweon et al. (2014) published guidance for the state of Virginia on not just calibration but also on customizing HSM procedures and on SPF development.

There have even been efforts of calibrating the HSM for other countries. For example, Martinelli et al. (2009) calibrated rural two-lane highways in the Italian province of Arezzo. Sacchi et al. (2012) assessed the transferability of HSM models internationally. Young and Park (2012) compared the use of HSM with locally developed models in Regina, Canada.

As this literature review revealed, there is very little information concerning HSM freeway interchange calibration efforts. This is unsurprising since the freeway chapters were only recently published in 2014. Thus, Missouri, along with the other NCHRP 17-50 lead states, is leading the effort in calibrating freeway facilities. Because there is little guidance concerning the details of freeway interchange calibration, there are several issues that the authors, in conjunction with the Technical Advisory Committee, had to resolve on their own. One is the issue of crash location accuracy, or the so-called crash landing problem. Another is the definition of the interchange influence area and how to properly assign crashes to an interchange. And within the interchange area, consistent procedures had to be established in order to assign crashes to the appropriate facility, be it mainline segments, ramps, speed-change lanes, or terminals. The state of Missouri is thus leading the national effort in establishing procedures and standards that will bring about wider usage of the HSM within the state and nationally.

CHAPTER 3 HSM INTERCHANGE CALIBRATION METHODOLOGY

This chapter presents the methodology used for the HSM calibration of freeway interchanges. The methodology involves classification of facility type, sampling, site selection, and data collection.

3.1 Facility Types

An initial step in this project involved meeting with MoDOT technical advisors Michael Curtit, John Miller, and Andrew Williford, MoDOT experts in highway safety, to discuss the specific facilities to be calibrated. The site types for calibration shown in Tables 3.1.1 and 3.1.2 were selected based upon state priorities as well as the availability of sufficient samples. Some facilities, such as D3, three-leg ramp terminal with diagonal exit or entrance ramp, B4, four-leg ramp terminal at four-quadrant Parclo B, and C-D, collector-distributor roadways connected to interchanges, were not calibrated due to a lack of sufficient samples in Missouri. Since A2 and B2 have the same intersection configuration, i.e. the number of legs and movements are the same at the terminal, the HSM SPFs are the same for A2 and B2. Note that even though a full cloverleaf interchange is listed under Table 3.1.1 as a terminal, it is not a controlled terminal between a ramp and a crossroad, but instead involves crossroad speed-change lanes, i.e. uncontrolled terminals between a ramp and a crossroad. Therefore, cloverleaf interchanges, unlike other terminal types, are not covered under Chapter 19 of the HSM. However, cloverleaf interchanges can still be modeled by the HSM using calibrated values of ramps and speed-change lanes.

Table 3.1.1 Terminal Interchange Facility Types Calibrated

Acronym	Terminal Facility	Signalization	Crossroad Lanes	Urban/ Rural
D4SCR	Diamond (D4)	Stop-Controlled	All	Rural
D4SCU	Diamond (D4)	Stop-Controlled	All	Urban
D4SG2	Diamond (D4)	Signalized	2	Both
D4SG4F4*	Diamond (D4)	Signalized	4 (4 freeway lanes)	Both
D4SG4F6*	Diamond (D4)	Signalized	4 (6 freeway lanes)	Both
D4SG6	Diamond (D4)	Signalized	6	Both
A2SCR	Parclo (A2)	Stop-Controlled	All	Rural
A2SCU	Parclo (A2)	Stop-Controlled	All	Urban
A2SG4	Parclo (A2)	Signalized	4	Both
Clover	Full Cloverleaf	N/A	N/A	N/A

* Since the number of freeway lanes do not affect interchange safety modeling, both of these facility types share the same calibration values.

Table 3.1.2 Non-Terminal Interchange Facility Types Calibrated

Acronym	Facility Type	Entrance/Exit	Lanes	Urban/Rural
SCLREN	Speed-Change Lane	Entrance	4	Rural
SCLU4EN	Speed-Change Lane	Entrance	4	Urban
SCLU6EN	Speed-Change Lane	Entrance	6	Urban
SCLREX	Speed-Change Lane	Exit	4	Rural
SCLU4EX	Speed-Change Lane	Exit	4	Urban
SCLU6EX	Speed-Change Lane	Exit	6	Urban
RPREN	Ramp	Entrance	1	Rural
RPREX	Ramp	Exit	1	Rural
RPUEN	Ramp	Entrance	1	Urban
RPUEX	Ramp	Exit	1	Urban

Figure 3.1.1 shows the HSM diagram for the four-leg diamond interchange terminal, i.e. D4. This intersection contains movements from an off-ramp and the movements from the opposing crossroad legs. The two terminals shown in Figure 3.1.1 are symmetric. Figure 3.1.2 shows a Missouri example of the D4 freeway interchange. Each interchange contains two terminals or samples for HSM calibration.

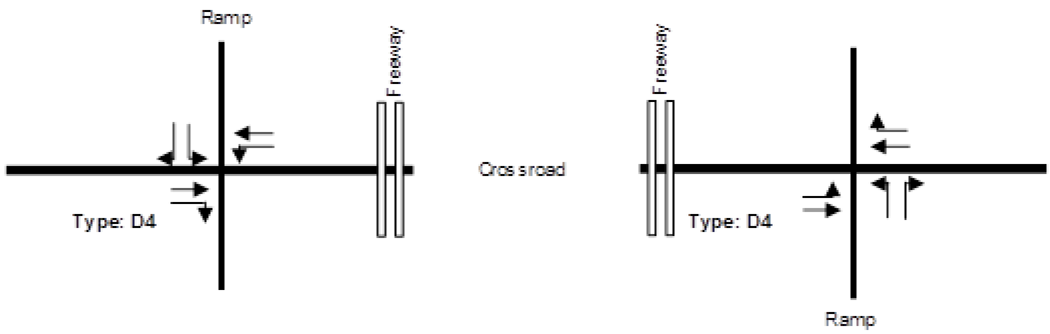

Figure 3.1.1 Four-Leg Ramp Terminal with Diagonal Ramps (D4) (HSM, 2014)

Figure 3.1.2 Missouri Example of D4

Figure 3.1.3 shows the HSM diagram for the three-leg two-quadrant partial cloverleaf (Parclo) interchange terminal, i.e. A2. This intersection contains movements from an off-ramp and the movements from the opposing crossroad legs. A major difference with the D4 is that the on-ramp is a circular ramp so that freeway access is provided via a right turn and not a left turn. The two terminals shown in Figure 3.1.3 are symmetric. Figure 3.1.4 shows a Missouri example of the A2 freeway interchange at the west terminal.

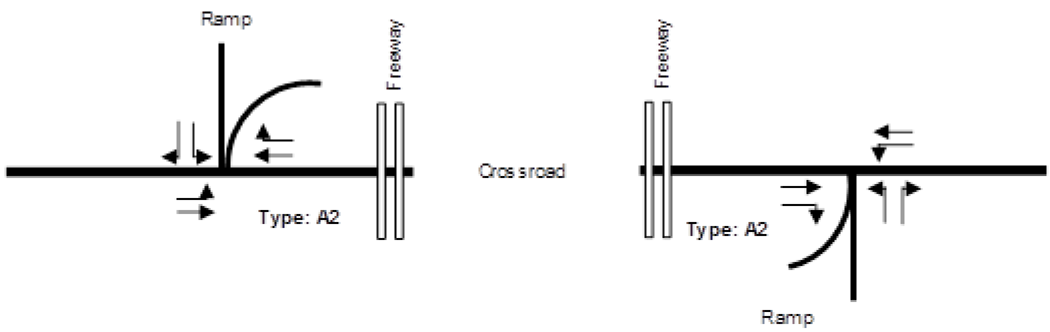

Figure 3.1.3 Three-Leg Ramp Terminal at Two-Quadrant Parclo A (A2) (HSM, 2014)

Figure 3.1.4 Missouri Example of A2

A speed-change lane is a unidirectional, uncontrolled terminal between a freeway and ramp segments (Bonneson et al., 2012). There are two types of speed-change lanes: exit and entrance. An exit speed-change lane gradually adds additional lane(s) to separate exiting traffic from through traffic and connects to the exit ramp segment. This gradual transition area in the speed-change lane is called the taper. An entrance speed-change lane gradually drops ramp lane(s), allowing vehicles to merge safely with the freeway through traffic. Typically, an interchange has four speed-change lanes. The length of speed-change lanes is measured from the gore point to the beginning or end of the taper. Figure 3.1.5 shows a typical entrance and exit ramp with the associated speed-change lane, gore point, and taper.

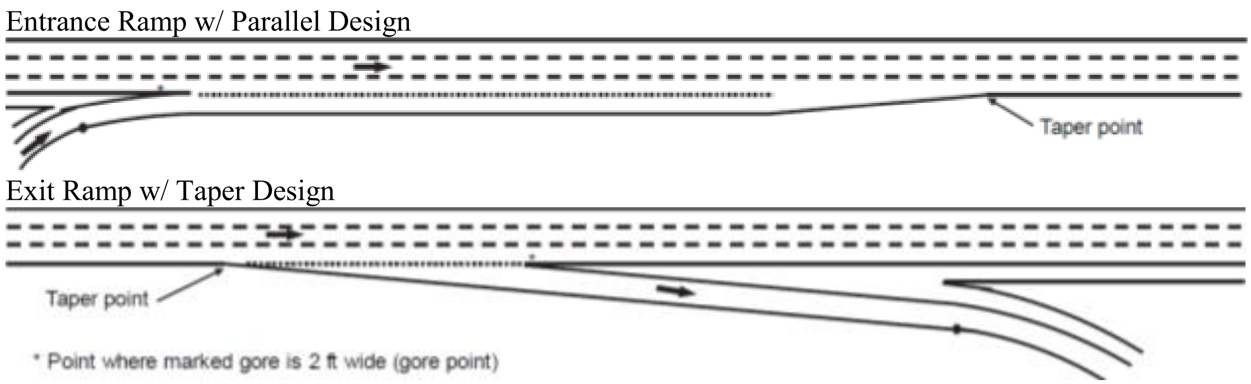

Figure 3.1.5 Speed-Change Lanes

3.1.1 HSM Predictive Models for Terminal Facilities

The HSM predictive models for ramp terminal facilities are summarized in this subsection. The model equations include the calibration factors that are the focus of this research project. The predictive model for one-way stop-controlled crossroad ramp terminals is shown in HSM Equations 19-12 to Equation 19-14 (AASHTO, 2014). These equations can be used for modeling D4, A2, and B2 interchanges. These equations show that the total crashes is the sum of the FI and PDO crashes. These equations also show that the number of crashes for each severity type is computed by multiplying together the calibration factor, the predicted average crash frequency, and all the crash modification factors.

HSM Equations 19-12 to 19-14:

$$N_{p,w,ST,at,as} = N_{p,w,ST,at,fi} + N_{p,w,ST,at,pdo}$$

$$N_{p,w,ST,at,fi} = C_{aS,ST,at,fi} \times N_{spf,w,ST,at,fi} \times \left(CMF_{1,aS,ST,at,fi} \times \ldots \times CMF_{m,aS,ST,at,fi}\right)$$

$$N_{p,w,ST,at,pdo} = C_{aS,ST,at,pdo} \times N_{spf,w,ST,at,pdo} \times \left(CMF_{1,aS,ST,at,pdo} \times \ldots \times CMF_{m,aS,ST,at,pdo}\right)$$

Where:

$N_{p,w,ST,at,z}$ = predicted average crash frequency of a stop-controlled crossroad ramp terminal of site type *w* (*w* = D4, A2, B2), all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$N_{spf,w,ST,at,z}$ = predicted average crash frequency of a one-way stop-controlled crossroad ramp terminal of site type *w* (*w* = D4, A2, B2) with base conditions, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

$CMF_{m,aS,ST,at,z}$ = crash modification factor for a stop-controlled crossroad ramp terminal (any site type *aS*) with features *m*, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only); and

$C_{aS,ST,at,z}$ = calibration factor for a stop-controlled crossroad ramp terminal (any site type *aS*) with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

The predictive model for signal-controlled crossroad ramp terminals is shown in HSM Equations 19-15 to Equation 19-17 (AASHTO, 2014). These equations can be used for modeling D4, A2, and B2 interchanges in Missouri. Similar to the stop-controlled equations, the total number of crashes is summed from the two crash severities of FI and PDO. Again, the number of crashes for each severity type is computed by multiplying together the calibration factor, the predicted average crash frequency, and all the crash modification factors.

HSM Equations 19-15 to 19-17:

$$N_{p,w,SGn,at,as} = N_{p,w,SGn,at,fi} + N_{p,w,SGn,at,pdo}$$

$$N_{p,w,SGn,at,fi} = C_{aS,SG,at,fi} \times N_{spf,w,SGn,at,fi} \times \left(CMF_{1,aS,SGn,at,fi} \times \ldots \times CMF_{m,aS,SGn,at,fi}\right)$$

$$N_{p,w,SGn,at,pdo} = C_{aS,SG,at,pdo} \times N_{spf,w,SGn,at,pdo} \times \left(CMF_{1,aS,SGn,at,pdo} \times \ldots \times CMF_{m,aS,SGn,at,pdo}\right)$$

Where:

$N_{p,w,SGn,at,z}$ = predicted average crash frequency of a signal-controlled crossroad ramp terminal of site type *w* (*w* = D4, A2, B2) with *n* crossroad lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$N_{spf,w,SGn,at,z}$ = predicted average crash frequency of a signal-controlled crossroad ramp terminal of site type *w* (*w* = D4, A2, B2) with base conditions, *n* crossroad lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

$CMF_{m,aS,SGn,at,z}$ = crash modification factor for a signal-controlled crossroad ramp terminal (any site type *aS*) on a crossroad with *n* lanes, features *m*, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only); and

$C_{aS,SG,at,z}$ = calibration factor for a signal-controlled crossroad ramp terminal (any site type *aS*) with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

3.1.2 HSM Predictive Models for Non-Terminal Facilities

The HSM predictive models for non-terminal facilities are summarized in this subsection.

The predictive model for entrance and exit ramp segments is shown in HSM Equations 19-2 to Equation 19-6 (AASHTO, 2014). When applying these equations for exit ramps, the index EN (entrance) is replaced with EX (exit). The total number of crashes is the sum of the crashes by severities FI and PDO, and the number of vehicles MV (multiple vehicles) and SV (single vehicle). In other words, the four combinations of severities and number of vehicles give rise to four separate equations that need to be summed together. These equations show that the number of crashes for each severity type and number of vehicles is computed by multiplying together the calibration factor, the predicted average crash frequency, and all the crash modification factors.

HSM Equations 19-2 to 19-6:

$$N_{p,rps,nEN,at,as} = N_{p,rps,nEN,mv,fi} + N_{p,rps,nEN,sv,fi} + N_{p,rps,nEN,mv,pdo} + N_{p,rps,nEN,sv,pdo}$$

$$N_{p,rps,nEN,mv,fi} = C_{rps,EN,mv,fi} \times N_{spf,rps,nEN,mv,fi} \times (CMF_{1,rps,ac,mv,fi} \times \ldots \times CMF_{m,rps,ac,mv,fi}) \times (CMF_{1,rps,ac,at,fi} \times \ldots \times CMF_{m,rps,ac,at,fi})$$

$$N_{p,rps,nEN,sv,fi} = C_{rps,EN,sv,fi} \times N_{spf,rps,nEN,sv,fi} \times (CMF_{1,rps,ac,sv,fi} \times \ldots \times CMF_{m,rps,ac,sv,fi}) \times (CMF_{1,rps,ac,at,fi} \times \ldots \times CMF_{m,rps,ac,at,fi})$$

$$N_{p,rps,nEN,mv,pdo} = C_{rps,EN,mv,pdo} \times N_{spf,rps,nEN,mv,pdo} \times (CMF_{1,rps,ac,mv,pdo} \times \ldots \times CMF_{m,rps,ac,mv,pdo}) \times (CMF_{1,rps,ac,at,pdo} \times \ldots \times CMF_{m,rps,ac,at,pdo})$$

$$N_{p,rps,nEN,sv,pdo} = C_{rps,EN,sv,pdo} \times N_{spf,rps,nEN,sv,pdo} \times (CMF_{1,rps,ac,sv,pdo} \times \ldots \times CMF_{m,rps,ac,sv,pdo}) \times (CMF_{1,rps,ac,at,pdo} \times \ldots \times CMF_{m,rps,ac,at,pdo})$$

Where:

$N_{p,\,rps,\,nEN,\,y,\,z}$ = predicted average crash frequency of an entrance ramp segment with *n* lanes, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$N_{spf,\,rps,\,nEN,\,y,\,z}$ = predicted average crash frequency of an entrance ramp segment with base conditions, *n* lanes, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

$CMF_{m,\ rps,\ ac,\ y,\ z}$= crash modification factor for a ramp segment with any cross section *ac*, features *m*, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only); and

$C_{rps,\ EN,\ y,\ z}$ =calibration factor for entrance ramp segments with any lanes, crash type *y* (*y* = *sv*: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

The predictive model for entrance speed-change lanes is shown in HSM Equations 18-7 to 18-9 (AASHTO, 2014). The equations show the number of crashes for each speed-change lane facility is the sum of the two severity types, FI and PDO. And each severity type is computed by multiplying together the calibration factor, the predicted average crash frequency, and all the crash modification factors.

HSM Equations 18-7 to 18-9:

$$N_{p,sc,nEN,at,as} = N_{p,sc,nEN,at,fi} + N_{p,sc,nEN,at,pdo}$$

$$N_{p,sc,nEN,at,fi} = C_{sc,EN,at,fi} \times N_{spf,sc,nEN,at,fi} \times \left(CMF_{1,sc,nEN,at,fi} \times \ldots \times CMF_{m,sc,nEN,at,fi}\right) \times \left(CMF_{1,sc,ac,at,fi} \times \ldots \times CMF_{m,sc,ac,at,fi}\right)$$

$$N_{p,sc,nEN,at,pdo} = C_{sc,EN,at,pdo} \times N_{spf,sc,nEN,at,pdo} \times \left(CMF_{1,sc,nEN,at,pdo} \times \ldots \times CMF_{m,sc,nEN,at,pdo}\right) \times \left(CMF_{1,sc,ac,at,pdo} \times \ldots \times CMF_{m,sc,ac,at,pdo}\right)$$

Where:

$N_{p,\ sc,\ nEN,\ at,\ z}$ = predicted average crash frequency of ramp entrance speed-change lane on a freeway with *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$N_{spf,\,sc,\,nEN,\,at,\,z}$ = predicted average crash frequency of a ramp entrance speed-change lane on a freeway with base conditions, *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

$CMF_{m,\,sc,\,x,\,at,\,z}$ = crash modification factor for a speed-change lane with features *m*, cross section *x* (*x* = *nEN*: ramp entrance adjacent to a freeway with *n* lanes, *nEX*: ramp exit adjacent to a freeway with *n* lanes, *ac*: any cross section), all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only); and

$C_{sc,\,EN,\,at,\,z}$ = calibration factor for a ramp entrance speed-change lane with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

The predictive model for exit speed-change lanes is the mirror of the entrance speed-change lane model and is shown in HSM Equations 18-10 to 18-12 (AASHTO, 2014). The equations show the number of crashes for each speed-change lane facility is the sum of the two severity types, FI and PDO. And each severity type is computed by multiplying together the calibration factor, the predicted average crash frequency, and all the crash modification factors. HSM Equations 18-10 to 18-12:

$$N_{p,sc,nEX,at,as} = N_{p,sc,nEX,at,fi} + N_{p,sc,nEX,at,pdo}$$

$$N_{p,sc,nEX,at,fi} = C_{sc,EX,at,fi} \times N_{spf,sc,nEX,at,fi} \times \left(CMF_{1,sc,nEX,at,fi} \times \ldots \times CMF_{m,sc,nEX,at,fi}\right) \times \left(CMF_{1,sc,ac,at,fi} \times \ldots \times CMF_{m,sc,ac,at,fi}\right)$$

$$N_{p,sc,nEX,at,pdo} = C_{sc,EX,at,pdo} \times N_{spf,sc,nEX,at,pdo} \times \left(CMF_{1,sc,nEX,at,pdo} \times \ldots \times CMF_{m,sc,nEX,at,pdo}\right) \times \left(CMF_{1,sc,ac,at,pdo} \times \ldots \times CMF_{m,sc,ac,at,pdo}\right)$$

Where:

$N_{p,\,sc,\,nEX,\,at,\,z}$ = predicted average crash frequency of ramp exit speed-change lane on a freeway with *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*:

property damage only, *as*: all severities) (crashes/yr);

$N_{spf,\ sc,\ nEX,\ at,\ z}$ = predicted average crash frequency of a ramp exit speed-change lane on a freeway with base conditions, *n* lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr); and

$C_{sc,\ EX,\ at,\ z}$ = calibration factor for a ramp exit speed-change lane with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

3.2 Sample Size

HSM recommends that 30 to 50 sites be used for calibrating SPFs. The HSM also recommends a minimum of 100 crashes per year, aggregated among all the samples from a particular facility. An attempt to evaluate the reliability of calibration factors achieved from different sample sizes was performed by Banihashemi (2012). Rural two-lane, rural multilane and urban/suburban arterial highways in Washington State were calibrated by using different sizes of datasets. The calibration factor calculated from the complete data set was considered as ideal, and sensitivity analysis was conducted to evaluate the reliability computed from various percentages of the complete dataset. Instead of the uniform sampling requirements recommended by the HSM, Banihashemi recommends different sample sizes for each facility type in Washington and also claims that such a procedure could be used for other states with some adjustment. Trieu, Park and McFadden (2014) assessed the accuracy of sampling criteria suggested by HSM, such as sample size and number of crashes in each year. They used Monte Carlo simulation for resampling sites to examine the association between the predicted values and sensitivity of the calibration factor. The study included 372 sites. When 10 percent of samples were used to calibrate SPFs, the computed calibration factor was highly variable. After applying different percentages, a conclusion was arrived that an accurate calibration factor needs to use at least 30 percent of the sites. Hence, Trieu et al. recommended that when a jurisdiction is larger than a specific number, then a percentage should be applied instead of a specific number for the sample size. Trieu et al. also suggested keeping a portion of the sample for a testing set to compare with training results. The HSM recommendations for sampling are practical and easily implemented. However, if the calibration value of a particular facility type turns out to be extreme, then a modified sampling approach could be attempted.

3.3 Site Selection

Freeway interchange sites were selected randomly in order to avoid bias. To the extent possible, sites were distributed from all seven MoDOT districts in order to achieve geographical diversity. When available, at least 15 interchanges or 30 samples were used for each interchange facility type. For non-terminal facilities, such as speed-change lanes and ramps, samples were selected to represent a wide range of terminal types. HSM does not differentiate between speed-change lanes and ramps from different terminal types, although differences are captured via CMFs. For example the extreme horizontal curvature differences between D4 and A2 ramps are captured via CMFs. Each interchange can provide two sites, since each half of an interchange can provide a full set of freeway facilities: a terminal, ramps, speed-change lanes, and mainline segments. Additional site selection criteria consisted of: 1) sites that did not undergo any geometric changes and 2) sites without prolonged and high impact maintenance, expansion, or construction projects.

One problem encountered in site selection is the lack of sufficient samples for certain facilities. For example, diamond interchanges with six crossroad lanes and six freeways lanes were uncommon. In such cases, all the available freeway interchanges in Missouri were exhausted. Also in those cases, geographical diversity was not achieved since the samples only originated from the urban areas of St. Louis, Kansas City, and Springfield. Another problem was the incompatibility of PDO reporting by the City of Columbia due to the use of a higher PDO threshold. Thus, data compiled by the Columbia Police Department were excluded.

3.4 Data Collection

The two types of data that need to be collected for HSM calibration are site characteristic data and historic crash data. Since the HSM recommends data for 3 consecutive years in developing calibration factors, data was collected for the most recently available years of 2010 to 2012. This project started in July, 2013, thus very little crash data was even available for 2013. Both types of data were entered into the Enhanced Interchange Safety Analysis Tool (ISATe) for deriving calibration values (Bonneson et al., 2012).

There are various variables related to sites characteristics that were collected. For each facility type, the HSM requires a different set of variables. Various data sources were used to acquire all the different types of data required. Aerial photographs were used for collecting geometric design data such as distances between intersections and ramp terminals, length of freeway and ramp segments, ramp skew angle, and number of lanes. MoDOT TMS map was used for finding the node numbers in order to perform crash data collection. MoDOT TMS Safety Browser was then used to gather all the crash image numbers that pertain to specific nodes. After finding the crash image numbers, a request was then submitted to MoDOT TMS for the digital crash records associated with the crash image numbers. These crash records that contain various crash fields, diagrams, and narratives were then reviewed one-by-one in a companion project. AADTs were collected from TMS for different parts of the intersection by year. The type of signal control at an interchange terminal was provided by local MoDOT districts and consolidated by MoDOT Traffic and Safety Division. Table 3.4.1 shows an example of the site-related variables collected for two ramp terminals and entered into the ISATe worksheet.

As shown in Table 3.4.1, the top data involved geometrics and signalization while the bottom data involved AADTs. For details on the use of ISATe, the reader is referred to the ISATe manual (Bonneson et al., 2012).

Table 3.4.1 ISATe Site Characteristics Data Example for Terminals

Intersection DATA			Terminal 1	Terminal 2
Ramp terminal traffic control type			One stop	One stop
Exit ramp skew angle (degrees)			17	23
Distance to the next public street intersection (mi)			0.15	0.07
Distance to the adjacent ramp terminal (mi)			0.13	0.13
Right-turn control type in exit ramp			Yield	Stop
Crossroad median width (ft)			1.5	1.5
Number of lanes serving through vehicles in crossroad			3	3
Number of lanes in exit ramp			2	2
Crossroad	Inside approach	Left-turn lane or bay presence	No	Yes
		Width of left-turn lane or bay (ft)	-	13
	Outside approach	Right-turn Lane or bay present	Yes	Yes
Number of public street approaches on the outside crossroad leg			1	0
Annual Average Daily Traffic (AADT)	Inside Crossroad Leg Data	2010	3606	8417
		2011	3606	8417
		2012	3366	8161
	Outside Crossroad Leg Data	2010	3400	5104
		2011	3400	5319
		2012	3336	5302
	Exit Ramp Data	2010	1836	1081
		2011	1836	1081
		2012	1830	1077
	Entrance Ramp Data	2010	3388	1507
		2011	3388	1507
		2012	3327	1499

The following sections will discuss the details of data collection for geometric data, AADT, and crash data.

3.4.1 Geometric Data Collection

For the various highway facilities, geometric data was collected using images from Google Earth. Geometric design elements, such as lane and cross section characteristics, ramp type, or other qualitative information, were obtained through aerial photographs and street view photographs. Minor quantitative measurements, such as crossroad median distances, shoulder widths, and distance to adjacent streets, were determined using the Google Earth measuring tool. Ramp skewness was measured using a compass tool as part of the program. For larger facility measurements, including speed-change lanes and curved ramp segments, the aerial images were imported into AutoCAD. From there, the segment lengths, arc lengths, and horizontal curve radii were measured for the entire interchnage. An example of using photographs to obtain highway segment dimensions is shown in Figure 3.4.1.1. These geometric data were cumulated and entered into ISATe spreadsheets and used to determine crash predictions for all desired interchange facilities.

Figure 3.4.1.1 Geometric CAD Measurement Examples (Google, 2015)

3.4.2 AADT Data Collection

AADT data were collected from the TMS database. For each interchange, the Travelway ID was first found, if available, or the street address for a location in the vicinity of the interchange. Using the TMS Maps application, the interchange was searched as shown in Figure 3.4.2.1. Then the "Services" tab was used to check the "State of the System" box and then the "Intersection" box as shown in Figure 3.4.2.2.

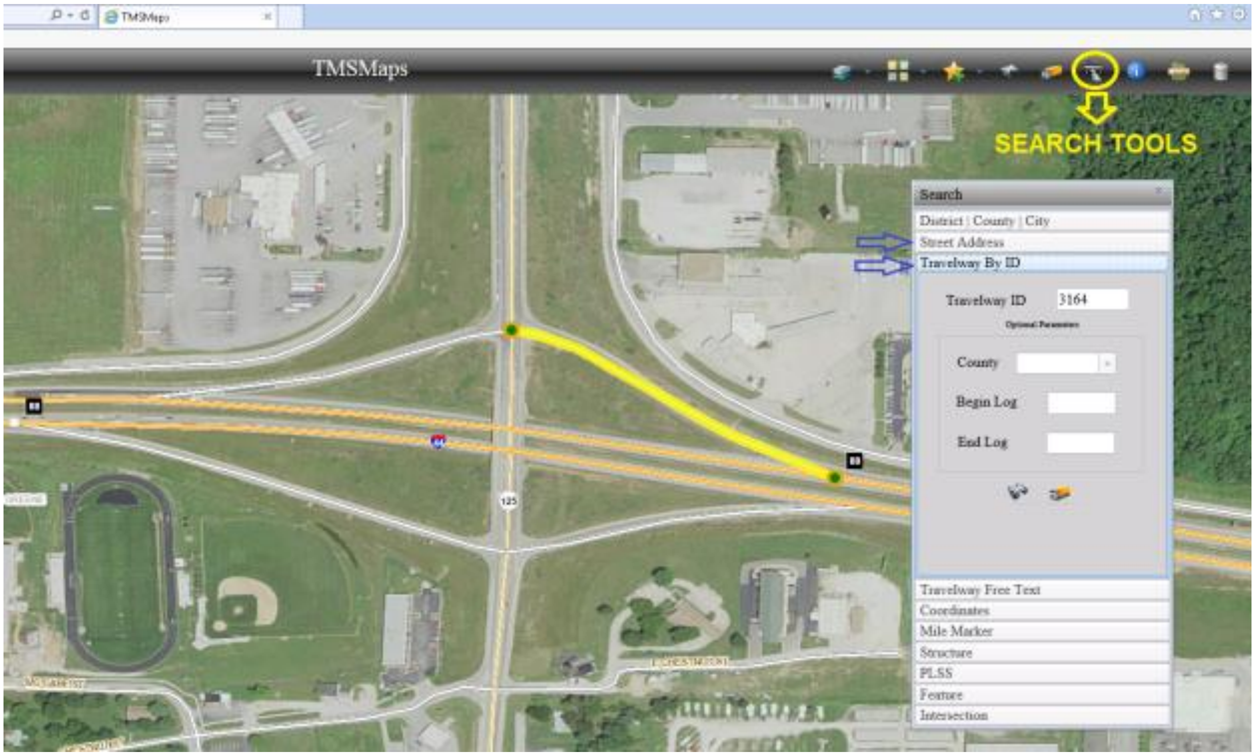

Figure 3.4.2.1 Searching for Interchange Using TMS Maps

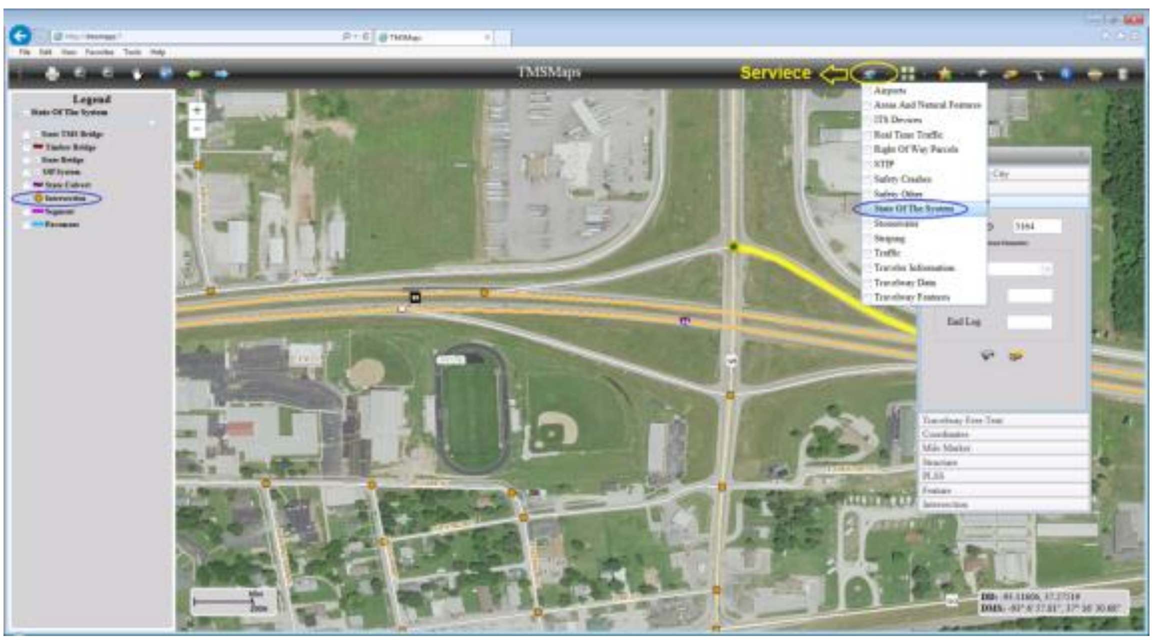

Figure 3.4.2.2 Searching Using "State of the System"

By clicking on the "Identify" icon and then the intersection of interest, the intersection number was found as shown in Figure 3.4.2.3. Using the intersection number and the years needed, a Microsoft Access database query was used to find the relevant AADTs. Figure 3.4.2.4 shows the TMS table TMS_SS_INTERSECTION being queried for the example of intersection number 506492 for the years 2010 to 2012. Figure 3.4.2.5 shows the results of the AADT query example. The example shows the AADT for the southbound MO 125 leg, the northbound MO 125 leg, and the exit ramp for the years 2010 to 2012.

Figure 3.4.2.3 Find Intersection Number

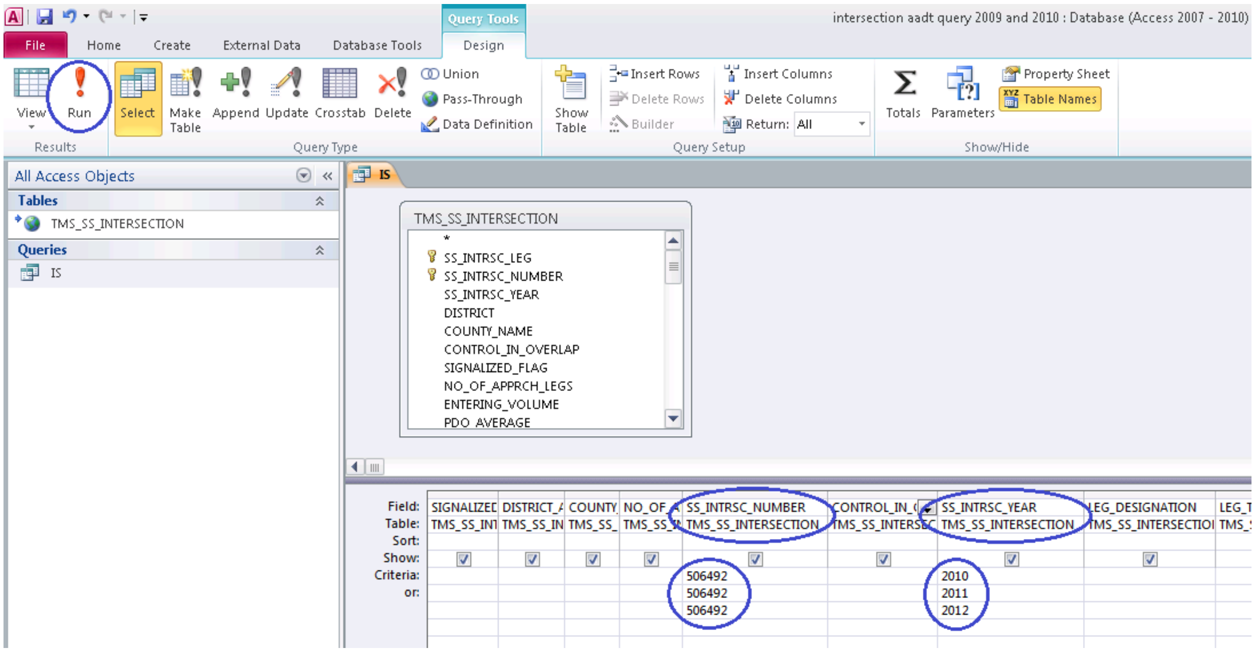

Figure 3.4.2.4 Example of TMS_SS_INTERSECTION Query

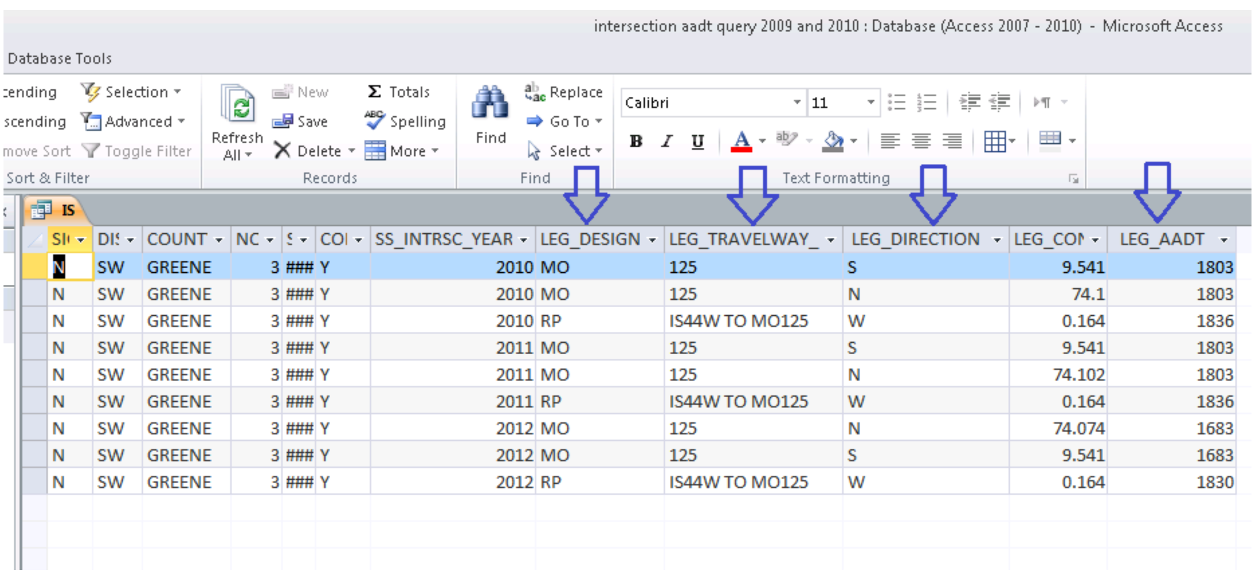

Figure 3.4.2.5 Example of TMS_SS_INTERSECTION Query Results

3.4.3 Crash Data Collection

The crash data were obtained using the following procedure. As in Section 3.4.2, a street address was located in the vicinity of the interchange by using a third-party map tool such as

Google Earth. Then the street address was entered into the TMS Maps application to find the interchange of interest. By clicking on the TMS Location icon, as shown in Figure 3.4.3.1, the roadway of interest was found. In order to query for crash image numbers, the Travelway ID and beginning and ending Log Miles are needed. Figure 3.4.3.1 shows the example of Travelway 5878 with the beginning Log Mile being 122.352.

In defining the beginning and ending locations of an interchange for crash querying purposes, the physical dimensions of interchanges were expanded beyond the TMS polygon in order to capture all potential crashes related to an interchange. For mainline freeway segments, interchange-related crashes could occur upstream from the taper of exit ramps. This is especially true of short exit ramps, where weaving or queuing from exit ramps could result in crashes upstream of the ramp. The HSM does not provide direct guidance on the determination of interchange-related crashes, i.e. how far upstream from the interchange should crashes be classified as interchange-related. However, the HSM does discuss the physical dimensions required for geometric data. For this project, a threshold of 1500 feet upstream from the center of the interchange for exit ramps shorter than 1500 feet was used. This threshold is consistent with the HSM definition of a weaving section and has been used by other studies in differentiating between interchange and non-interchange crashes.

Figure 3.4.3.1 Example of TMS Location Lookup

The TMS Safety Browser was used to find all the crash image numbers within a section of roadway. In using the web-based TMS application, the TMS Client Manager must first be enabled. Figure 3.4.3.2 shows how the Client Manager login was accessed via clicking on “Client Server Applications”, then “Client Manager”, and then “Client Manager.lnk”. After the “Client Manager” window appeared, the “TMSPROD” server was selected by clicking on “Server” and then “Enable”, as shown in Figure 3.4.3.3. The TMSPROD server status then changed to “connected”.

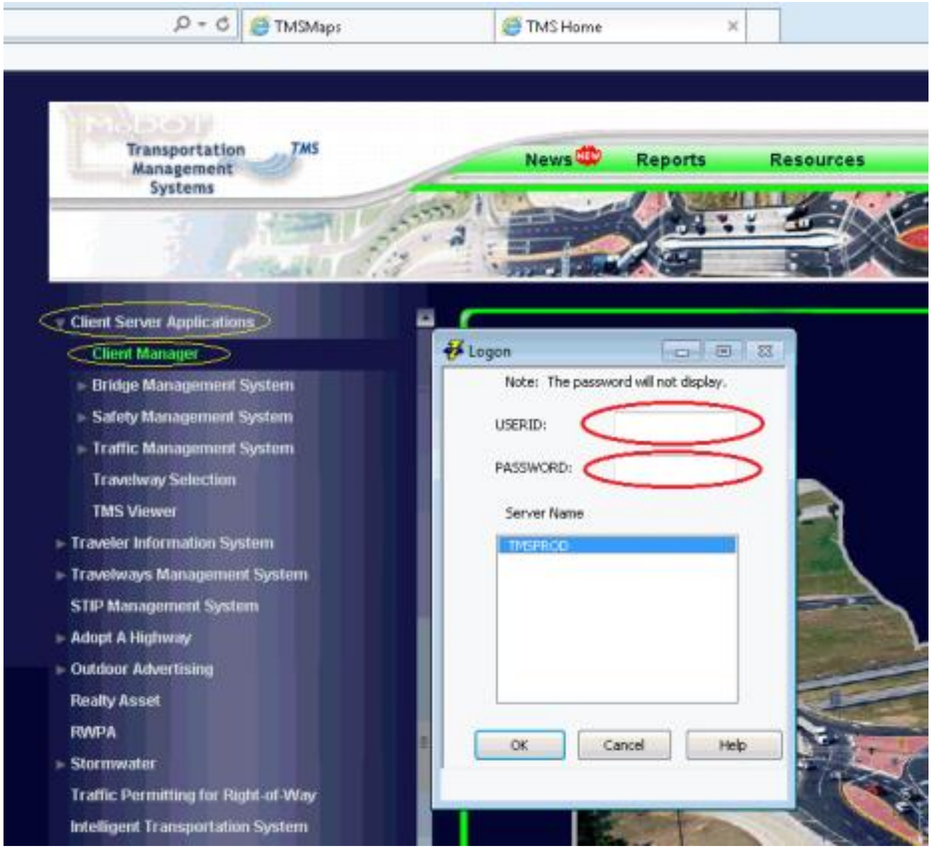

Figure 3.4.3.2 Enabling the Web-Based TMS Client Manager

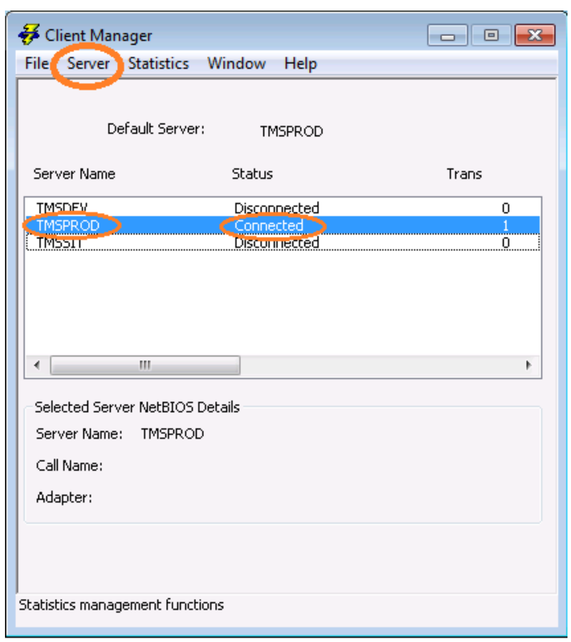

Figure 3.4.3.3 Connecting to TMSPROD Server

After enabling the connection to the TMSPROD server and the Client Server Applications, the Safety Management System application, Accident Browser, was used as shown in Figure 3.4.3.4. In Accident Browser, the “Travelway Selection Criteria” window was used to enter the Travel ID. The “Travelways” button was used to enable the entering of the beginning and ending log miles collected from the TMS Maps application. The “Select” button then narrowed the query to the segment of interest as shown in Figure 3.4.3.5.

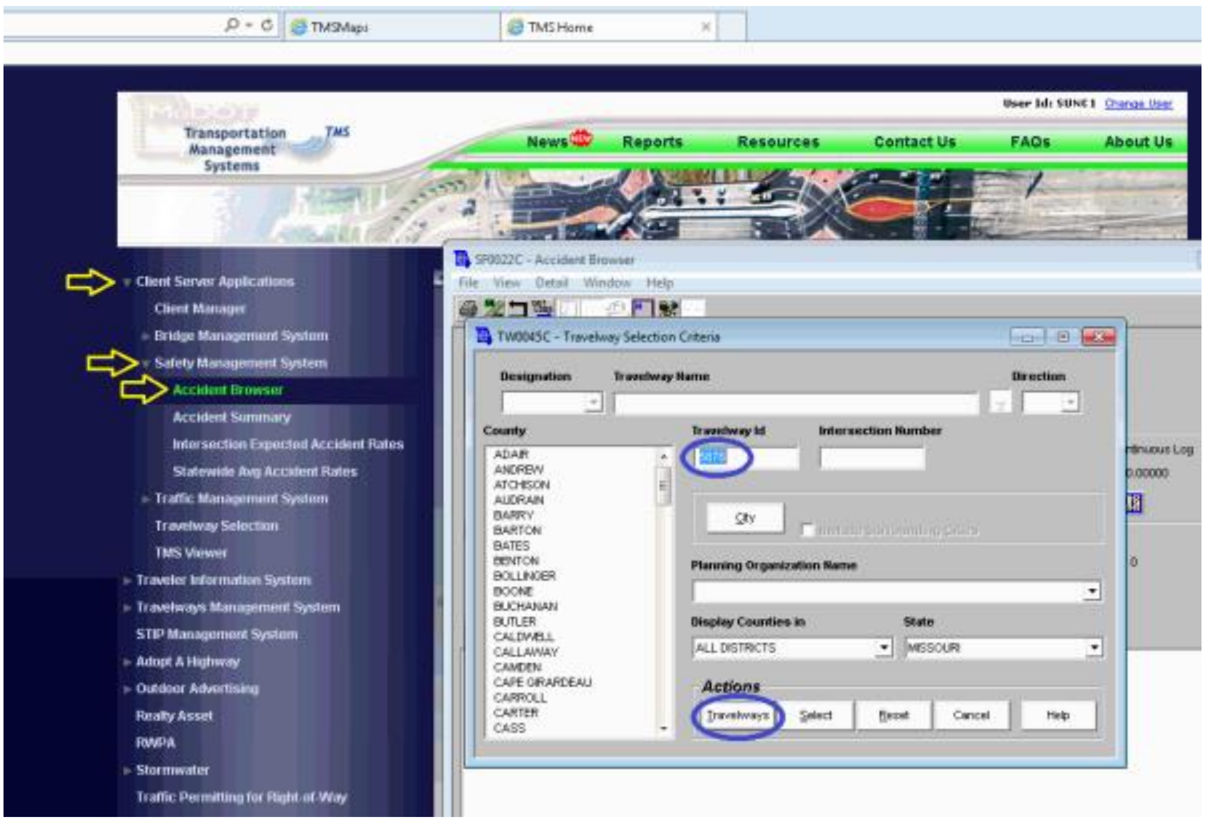

Figure 3.4.3.4 Using the Accident Browser Application

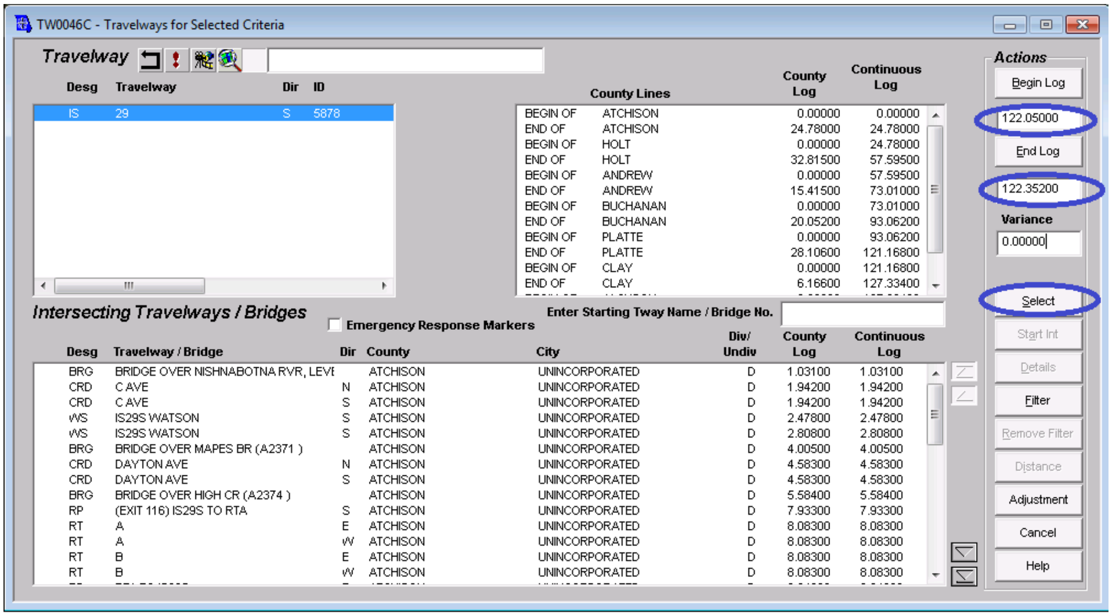

Figure 3.4.3.5 Narrowing the Travelway Segment

After the segment was narrowed, the years were selected via the "Accident Browser" by entering the beginning and end dates as shown in Figure 3.4.3.6. The "Range and Intersection Accidents" checkbox should be selected before clicking on "Execute Query". The export of the resulting query for further processing was accomplished via the "File" menu and using "Print Contents to File". As shown in Figure 3.4.3.7 in the "Print Accidents" window, the "Select All" box was selected before clicking on "OK". Then, a spreadsheet will be generated containing the results of the crash query. Note that the number of vehicles was not available from this spreadsheet; this information had to be obtained separately from the TMS using an ODBC (Open Database Connectivity) query. The number of vehicles was needed because calibration values for ramps were separated into single vehicle and multiple vehicles.

The results of the crash query had to be first corrected before it was used for HSM interchange calibration. This was because Missouri crash reports are completed by various police jurisdictions in Missouri, and a high percentage of interchange crashes are landed incorrectly. For example, some crashes are arbitrarily placed in the middle of an interchange instead of at one of the ramp terminals, and some crashes are placed in the middle of the freeway segment instead of on one of the speed-change lanes. Crash correction involves the review of original crash reports while paying special attention to the sections on crash location, crash diagram, and narrative/witness statements.

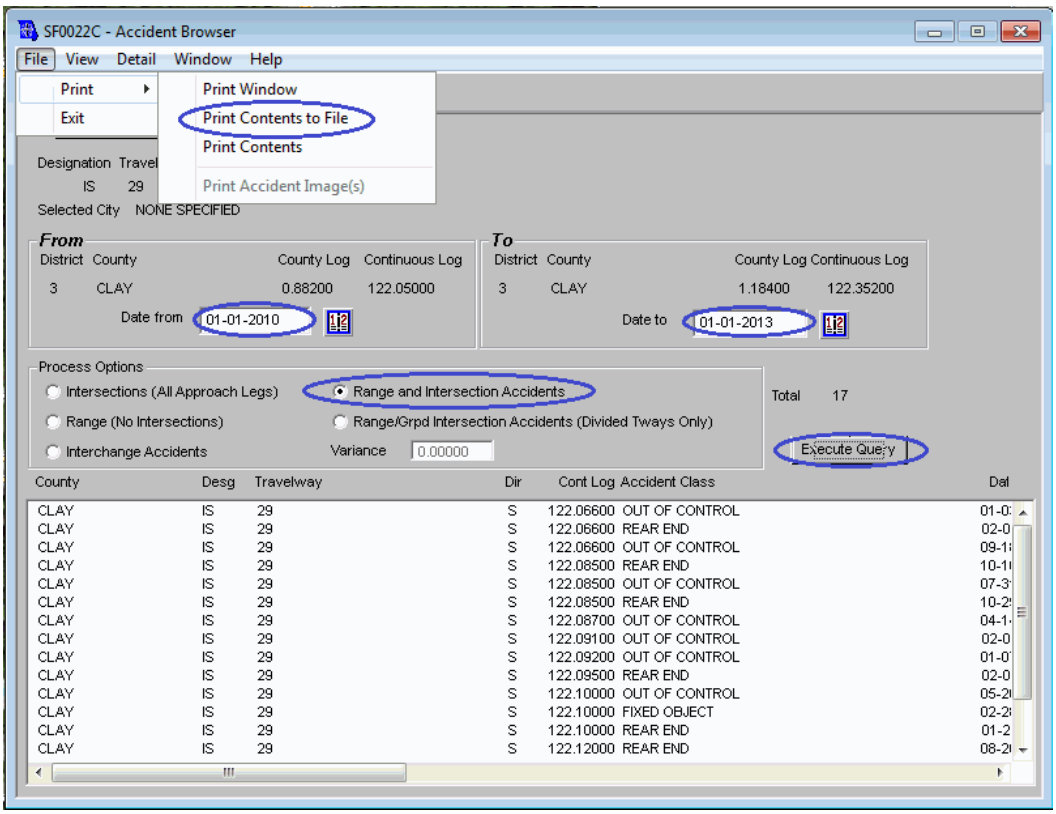

Figure 3.4.3.6 Specifying Query Years

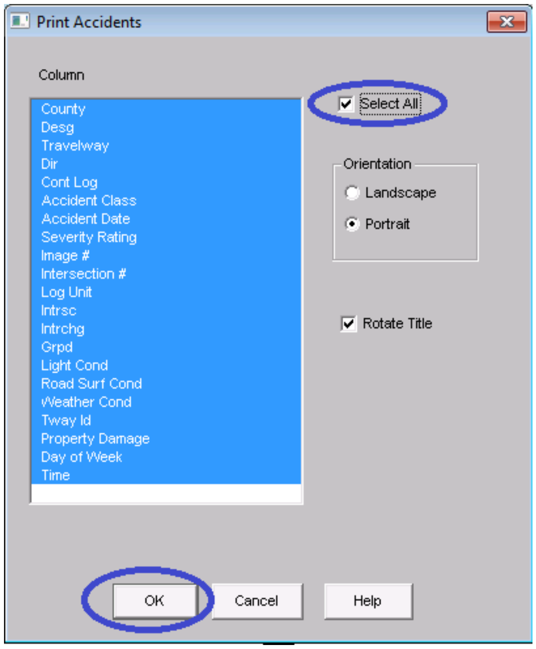

Figure 3.4.3.7 Exporting Crash Query to a Spreadsheet

3.6 Derivation of Calibration Values

The calibration factor for each freeway interchange facility type was determined by dividing the observed crash frequency by the predicted crash frequency. Crash prediction was implemented using ISATe worksheets. The reader is referred to the ISATe manual for details on using the ISATe software (Bonneson et al., 2012). Crash prediction can also be computed directly using the HSM manual equations as summarized in Section 3.1.1 for terminals and Section 3.1.2 for no-terminal facilities.

CHAPTER 4 DATA SAMPLE SELECTION

The methodology for sample size and size selection was previously presented in Sections 3.2 and 3.3. To the extent possible, all the recommended methods were followed in deriving the freeway interchange samples for calibration. There were a few instances when the methodology was not followed completely. One challenge is the HSM recommendation of a minimum of 100 crashes per year for a particular facility type. This minimum is problematic for facility types that are most popular in rural areas where the traffic volumes are low or for facilities where there are low volumes such as on ramps. The reason why such a challenge cannot be easily remedied in the context of freeway interchange calibration is related to the crash landing errors associated with the electronic crash database. With an overall crash landing error rate of 69% and rates as high as 90% for ramps, it was difficult to estimate the number of crashes that pertain to each interchange facility until detailed crash review was completed. Thus only after conducting the review of 12,409 crash reports and the detailed review of 9168 crash reports, was the correct number of crashes determined for each interchange facility type. Because the HSM interchange calibration process was intrinsically tied to the crash correction process, changes in the number and selection of HSM calibration sites required commensurate crash report corrections.

Another issue, although rare, concerns the lack of 30 available samples of a particular facility type in Missouri. In that situation, the samples comprised the entire population in Missouri. This is actually not a problem in terms of statistical inference because the data from the entire population was captured. An example of a facility type where fewer than 30 sites were used was the signalized diamond interchange with six lane crossroads (D4SG6). The nine sites or 18 corresponding samples were all the interchanges in Missouri that fit the HSM criteria, and most of them were from the Kansas City or St. Louis metropolitan areas. Another example was the signalized partial cloverleaf interchange (A2SG4).

In order to find samples for each type of interchange facility, a master list of all Missouri interchanges was first generated. The MoDOT TMS database does not classify interchange facilities according to the HSM criteria. HSM classifies interchange terminals, for example, in terms of four-legged diamond interchanges (D4), two –quadrant partial cloverleaf interchanges (A2), and full cloverleaf interchanges. More importantly, HSM's definition of the number of crossroad lanes differs from TMS's definition. According to the HSM, the number of through lanes on the crossroad approach includes only the shared or exclusive lanes that continue through the intersection. Thus each interchange in Missouri was reviewed manually to ensure that all HSM criteria were met. Each freeway in Missouri, including interstates, US highways, and Missouri highways, were tracked throughout the length of each freeway to identify and record interchanges. Table 4.1 shows the number of Missouri freeway interchanges which includes 574 interstate, 262 US highway, and 54 Missouri highway interchanges. Note that the total of 890 interchanges includes interchanges that are double counted if they are freeway to freeway (i.e., directional) interchanges. As seen in Table 4.1, some facility types, such as D4SG4, have a large population set to sample from. While other facility types, such as A2SG, has fewer than 15 population sites, or 30 half interchange samples.

Table 4.1 Summary of Missouri Freeway Interchanges

Type		IS	US	MO	TOTAL
D4	Signalized controlled terminal with 2 cross lane	12	19	1	32
	Signalized controlled terminal with 4 cross lane	81	35	6	122
	Signalized controlled terminal with 6 cross lane	8	1	1	10
	Stop controlled terminal with 2 cross lane	191	97	18	306
A2	Signalized controlled terminal with 4 cross lane	10	3	0	13
	Stop controlled terminal with 2 cross lane	12	11	3	26
Full Clover		17	5	1	23
Single Point Urban Interchange		11	3	4	18
Diverging Diamond Interchange		3	3	0	6
D4/A2		5	18	2	25
Others		207	60	18	285
TOTAL		574	262	54	890

Seventeen Missouri interstates were examined for applicable interchanges. As shown in Table 4.2, stop-controlled diamond interchanges were the most common with 191 interchanges. Unsurprisingly, the major corridors of I-70 and I-44 had the largest number of interchanges with 130 and 91, respectively. Table 4.3 shows the list of Missouri freeway interchanges on US highways. There were 25 US highways containing interchanges. Of those, US-36, US-54, US-63, US-65, and US-67 had the most number of interchanges. Similar to interstates, D4SC and D4SG4 were the two most frequent terminal types. There were 262 US highway interchanges, some of whom were already included in Table 4.2. The ten Missouri highways shown in Table 4.4 had a total of 54 interchanges, with some previously accounted for in Tables 4.2 and 4.3. The Missouri highways with the most number of interchanges were MO-21, MO-141, MO-364, MO-13, and MO-7. D4SC and D4SG4 were, again, the most frequent interchange types.

Table 4.2 List of Missouri Interstate Interchanges

Type	Config.	29	229	35	435	635	49	55	57	255	44	64	70	170	270	470	670	72	Total
D4	SG 2	2	0	0	0	0	3	2	0	0	3	0	0	0	1	1	0	0	12
D4	SG 3	0	0	2	0	0	0	1	0	0	1	2	0	0	0	1	0	0	7
D4	SG 4	3	0	3	5	1	5	8	0	0	15	8	21	2	4	5	0	1	81
D4	SG 4-6	4	0	0	2	0	0	0	0	0	2	1	5	1	1	0	0	0	16
D4	SG 5	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	3
D4	SG 6	1	0	1	1	0	0	1	0	0	1	0	2	0	1	0	0	0	8
D4	SC	16	3	17	7	0	38	27	1	0	43	1	33	0	1	1	0	3	191
A2	SG 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2	SG 4	0	0	0	1	0	1	2	0	0	0	2	1	2	0	1	0	0	10
A2	SG 6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
A2	SC	3	0	1	2	0	3	0	0	0	1	0	2	0	0	0	0	0	12
Full Clover		2	0	0	2	0	1	2	0	0	2	0	4	0	2	2	0	0	17
SPUI		0	0	0	0	0	0	2	0	0	0	3	2	2	1	0	0	1	11
DDI		0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	3
D4/A2		0	0	0	0	0	0	2	0	0	2	0	0	1	0	0	0	0	5
Others		10	9	14	14	0	10	12	0	4	21	32	59	4	12	4	2	0	207
Total		41	12	39	35	1	62	59	1	4	91	51	130	12	24	15	2	5	584

Table 4.3 List of Missouri US Highway Interchanges

Type	Config.	24	36	136	40	50	54	56	60	160	62	66	166	400	412	460	59	159	61	63	65	67	69	169	71	275	Total
D4	SG 2	1	2	0	0	2	1	0	1	0	0	0	0	0	0	0	0	0	2	0	4	3	0	1	2	0	19
D4	SG 3	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	5
D4	SG 4	2	1	0	0	7	4	0	2	1	0	0	0	0	0	0	0	0	1	7	3	3	0	2	2	0	35
D4	SG 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D4	SG 6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
D4	SC	3	14	1	0	6	16	0	13	0	0	0	0	0	0	0	0	0	13	12	8	8	0	1	2	0	97
A2	SG 2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2
A2	SG 4	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3
A2	SG 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2	SC	4	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	0	11
Full Clover		0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	5
SPUI		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3
DDI		0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3
D4/A2		1	1	0	0	3	2	0	3	0	0	0	0	0	0	0	0	0	1	3	0	3	0	1	0	0	18
Others		5	4	0	0	4	6	1	6	0	0	0	1	0	0	0	0	0	1	5	4	5	2	3	13	0	60
Total		16	26	1	0	23	33	1	30	1	0	0	1	0	0	0	0	0	20	28	26	25	2	10	19	0	262

Table 4.4 List of Missouri Highway Interchanges

Type	Config.	21	30	79	100	141	364-90	M	370	13	7	Total
D4	SG 2	0	0	0	1	0	0	0	0	0	0	1
D4	SG 3	0	0	0	0	0	0	0	0	0	0	0
D4	SG 4	2	0	1	0	0	2	0	1	0	0	6
D4	SG 5	0	0	0	0	0	0	0	0	0	0	0
D4	SG 6	0	1	0	0	0	0	0	0	0	0	1
D4	SC	5	0	1	0	0	0	0	1	6	5	18
A2	SG 2	0	0	0	0	0	0	0	0	0	0	0
A2	SG 4	0	0	0	0	0	0	0	0	0	0	0
A2	SG 6	0	0	0	0	0	0	0	0	0	0	0
A2	SC	0	0	0	0	0	0	1	0	1	1	3
Full Clover		0	0	0	0	1	0	0	0	0	0	1
SPUI		0	0	0	0	4	0	0	0	0	0	4
DDI		0	0	0	0	0	0	0	0	0	0	0
D4/A2		0	0	0	0	0	0	0	1	1	0	2
Others		1	0	0	0	3	8	0	3	1	2	18
Total		8	1	2	1	8	10	1	6	9	8	54

Sections 4.1 and 4.2 list the sites used for interchange calibration for terminal and non-terminal sites. The first column shows an identification number, ID, that was assigned to each interchange site. Sometimes a non-contiguous number appears for the reason that a specific site was replaced with another. Site replacement was due to a particular site not meeting the definition for a particular facility upon further examination. For example, in signalized diamond interchanges, the number of crossroad lanes is sometimes inconsistent between the two terminals. Such a site was dropped because only half of the interchange was usable. An example was where one terminal had three crossroad lanes while the other terminal had four crossroad lanes. Thus only the four-lane terminal can be used for calibrating D4SG4, even though the crashes from the entire interchange would have to be reviewed due to the crash landing problem.

To the extent possible, sites were selected from all seven MoDOT districts in order to achieve geographical diversity. For example, for rural stop-controlled diamond interchanges (DESCR), 2 sites were from Northwest, 2 from Northeast, 2 from Kansas City, 2 from Central, 2 from St. Louis, 4 from Southwest, and 2 from Southeast. In contrast, for signalized diamond interchange with six lane crossroads (D4SG6), only 4 districts were represented, with most of the sites coming from either Kansas City or St. Louis districts.

For non-terminal sites, the sites were distributed among different types of ramp terminals even though this is not required by the HSM. Thus ramps and speed-change lanes were selected among the various ramp terminals types under diamond and Parclo configurations. HSM assumes that the modeling inputs such as AADT and CMFs for ramps and speed-change lanes are sufficient for modeling without regard to the terminal type.

4.1 Terminal Sites

The sites used for calibrating the ramp terminals are shown in Tables 4.1.1 through 4.1.8.

Table 4.1.1 Rural Stop-Controlled Diamond Interchange Sites (D4SCR)

ID	Main Highway	Crossroad	Location	County	District
1	I-35	Route N	Eagleville	Harrison	Northwest
2	I-35	Route DD	S. of Pattonsburg	Daviess	Northwest
3	US-36	Route C/Route O	Bevier	Macon	Northeast
4	US-61	Route P/Oak St.	Canton	Lewis	Northeast
5	I-70/US-40	Route M/Route O	E of Odessa	Lafayette	Kansas City
6	I-70/US-40	MO-13	S of Higginsville	Lafayette	Kansas City
7	I-70	Route J/Route O	E of Rocheport	Boone	Central
8	MO-5/MO-7	Pier 31 Rd.	NW of Camdenton	Camden	Central
9	MO-21	Old MO-21	S of Otto	Jefferson	St. Louis
10	I-55	US-61	S. of Festus	Jefferson	St. Louis
11	I-44	Route B	W of Marshfield	Webster	Southwest
12	I-44	Route PP/Route K	S of Plano	Greene	Southwest
13	I-55/US-61	Route J/Route U	S of Hayti	Pemiscot	Southeast
14	US-67	MO-72	W of Fredericktown	Madison	Southeast
15	I-44	High St.	Sarcoxie	Jasper	Southwest
16	I-44	MO-37	W of Sarcoxie	Jasper	Southwest

Table 4.1.2 Urban Stop-Controlled Diamond Interchange Sites (D4SCU)

ID	Main Highway	Crossroad	Location	County	District
1	I-44	MO-125	Strafford	Greene	Southwest
2	I-44	MO-17	Buckhorn	Pulaski	Central
3	I-44	MO-30	St. Clair	Franklin	St. Louis
4	I-49	Civil War Rd.	Kendricktown	Jasper	Southwest
5	I-49	Outer Rd./Industrial Pkwy.	Nevada	Vernon	Southwest
6	I-49	MO-2/ S. Commercial St.	Harrisonville	Cass	Kansas City
7	I-49	Route HH/W. Fir Rd.	Carthage	Jasper	Southwest
8	I-55	Main St./Lasalle Ave.	Jackson	Cape Girardeau	Southeast
9	I-55	Route HH	Miner	Scott	Southeast
10	I-70	Route A	Gilmore	St. Charles	St. Louis
11	I-435	MO-45	E of Waldron	Platte	Kansas City
12	US-36	US-63/N. Missouri St.	Macon	Macon	Northeast
13	US-63	N. Morley St.	Moberly	Randolph	Northeast
14	US-63	N. Oakland Gravel Rd.	Prathersville	Boone	Central
15	US-63	Route EE/E. Rollins St.	Moberly	Randolph	Northeast

Table 4.1.3 Signalized Diamond Interchange with Two Lane Crossroads Sites (D4SG2)

ID	Main Highway	Crossroad	Location	County	District
1	I-29	US-169/Rochester Rd.	Country Club	Andrew	Northwest
2	I-44	Route H/Ichord Center	Near Waynesville	Pulaski	Central
3	I-49	Route J/Route C	Peculiar	Cass	Kansas City
5*	I-55	MO-51/S. Perryville Blvd.	Perryville	Perry	Southeast
6	US-24	MO-7	NE of Independence	Jackson	Kansas City
7	US-61	MO-47	Troy	Lincoln	Northeast
8	US-65	Route CC/Route J	Fremont Hills	Christian	Southwest
9	MO-100	MO-109	Wildwood	St. Louis	St. Louis
10	US-61	Route C	Moscow Mills	Lincoln	Northeast
11	US-67	MO-32	Leadington	St. Francois	Southeast
12	US-36	US-69	Cameron	Clinton	Northwest
13	US-36	Route AC	St. Joseph	Buchanan	Northwest
14	I-44	Hy Point Industrial Dr.	Near Dillon	Phelps	Central
15	MO-13	W. Broadway St	Bolivar	Polk	Southwest
16	US-60	MO-95	Mountain Grove	Wright	Southeast
17	MO-13	Aldrich Rd.	Bolivar	Polk	Southwest
18	US-65	Route YY/E. Division St.	Springfield	Greene	Southwest

* A non-contiguous numbering means that a problematic sample was replaced.

Table 4.1.4 Signalized Diamond Interchange with Four Lane Crossroads Sites (D4SG4)

ID	Main Highway	Crossroad	Location	County	District
2*	I-29	MO-6	St. Joseph	Buchanan	Northwest
3	US-54	MO-179	Jefferson City	Cole	Central
4	US-65	W. Jackson St.	Ozark	Christian	Southwest
5	I-72/MO-110	MO-79	Hannibal	Marion	Northeast
6	I-64	S. Mason Rd.	NW of Town & Country	St. Louis	St. Louis
7	I-44	MO-109	Eureka	St. Louis	St. Louis
8	I-70	Bryan Rd.	O'Fallon	St. Charles	St. Louis
9	I-29	NW 112th St.	Ferrelview	Platte	Kansas City
11*	I-70	Little Blue Pkwy.	Independence	Jackson	Kansas City
12	US-60	MO-25/E. Business US-60	Dexter	Stoddard	Southeast
13	US-60	US-61/US-62	Sikeston	New Madrid	Southeast
14	US-67	MO-180	St. Ann	St. Louis	St. Louis
15	US-61	Route A	Wentzville	St. Charles	St. Louis
16	I-49	US-60	Near Neosho	Newton	Southwest
17	US-60	MO-413	Brookline	Greene	Southwest
18	I-55	US-61	Fruitland	Cape Girardeau	Southeast
19	I-44	MO-64/MO-5	Lebanon	Laclede	Central
20	US-50	Eastland Dr.	Jefferson City	Cole	Central

* A non-contiguous numbering means that a problematic sample was replaced.

Table 4.1.5 Signalized Diamond Interchange with Six Lane Crossroads Sites (D4SG6)

ID	Main Highway	Crossroad	Location	County	District
1	I-49	E. 163rd St.	Belton	Cass	Kansas City
2	I-70	Noland Rd.	Independence	Jackson	Kansas City
5*	I-435	MO-210	Randolph	Clay	Kansas City
6	I-55	Butler Hill Rd.	Concord	St. Louis	St. Louis
8*	I-70	Lake St.	Gilmore	St. Charles	St. Louis
9	MO-364	Bennington Place	Maryland Heights	St. Louis	St Louis
10	I-255	MO-231/Telegraph Rd.	Mehlville	St. Louis	St. Louis
11	US-65	MO-14/W. Jackson St.	Ozark	Christian	Southwest
12	I-55	William St./Route K	Cape Girardeau	Cape Girardeau	Southeast

* A non-contiguous numbering means that a problematic sample was replaced.

Table 4.1.6 Rural Stop-Controlled Partial Cloverleaf Interchange Sites (A2SCR)

ID	Main Highway	Crossroad	Location	County	District
1	I-29	Route K	W of Savannah	Andrew	Northwest
2	US-24/US-61	MO-168	Palmyra	Marion	Northeast
3	US-24	13th St.	Lexington	Lafayette	Kansas City
4	US-24	MO-13	Lexington	Lafayette	Kansas City
5	I-44	Route Z/Route O	NE of Mt. Vernon	Lawrence	Southwest
6	MO-7/MO-13	MO-52	Clinton	Henry	Southwest
7	I-49/US-71	Route H	S of Anderson	McDonald	Southwest
8	US-36	MO-3	W of Macon	Macon	Northeast
9	US-54	Route M	Eldon	Miller	Central

Table 4.1.7 Urban Stop-Controlled Partial Cloverleaf Interchange Sites (A2SCU)

ID	Main Highway	Crossroad	Location	County	District
1	US-36	22nd St.	St. Joseph	Buchanan	Northwest
2	I-29/I-435/US-71	Mexico City Ave.	Platte City	Platte	Kansas City
3	I-29	NW Vivion/US-29	E of Riverside	Clay	Kansas City
4	I-35	NE Parvin Rd.	N of Kansas City	Clay	Kansas City
5	I-70	Manchester Trfy./ Raytown Rd.	Kansas City	Jackson	Kansas City
6	US-169/ Arrowhead Trfy.	NE Cookingham Dr./ MO-291	S of Smithville	Clay	Kansas City
7	I-435	NE Cookingham Dr./ MO-291	NW of Liberty	Clay	Kansas City
8	I-49/MO-7/US-71	W. Wall St. /MO-2	Harrisonville	Cass	Kansas City
9	Route M	Old MO-21	N of Hillsboro	Jefferson	St. Louis
10	US-54/US-63	Cedar City Dr./ Route W	Jefferson City	Callaway	Central
11	US-67	Fairground Rd.	N of Farmington	St. Francois	Southeast
12	I-255/US-50	Koch Rd.	Oakville	St. Louis	St. Louis
13	US-50	Big Horn Dr.	W of Jefferson City	Cole	Central
15*	US-60	US-60	Dexter	Stoddard	Southeast
16	I-55	MO-74	Cape Girardeau	Cape Girardeau	Southeast

* A non-contiguous numbering means that a problematic sample was replaced.

Table 4.1.8 Signalized Partial Cloverleaf Interchange Sites (A2SG4)

ID	Main Highway	Crossroad	Location	County	District
1	I-470/MO-291	E. 39th St.	S of Independence	Jackson	Kansas City
2	I-435/US-24	E. Winner Rd.	Kansas City	Jackson	Kansas City
3	US-54	Missouri Blvd.	Jefferson City	Cole	Central
4	I-64/US-40	Lake St. Louis Blvd.	Lake St. Louis	St. Charles	St. Louis
5	I-170/ Inner Belt Expy.	Ladue Rd.	Clayton	St. Louis	St. Louis
6	I-49/US-49	FF/E. 32nd St.	Joplin	Jasper	Southwest
7	I-55	US-62	Sikeston	Scott	Southeast
8	US-65	MO-76/W. Main St.	Branson	Taney	Southeast
9	US-63	US-24	Moberly	Randolph	Central
10	US-50	W. Truman Blvd.	Jefferson City	Cole	Central
11	I-44	MO-266/W. Chestnut Expy.	Springfield	Greene	Southwest

4.2 Non-Terminal Sites

For non-terminal sites, an interchange is often symmetric in the sense that it contains a pair of facilities in each direction. In other words, in each direction of travel there is both an exit ramp and an entrance ramp, and the associated entrance speed-change lane and exit speed-change lane. Thus the same interchange site was used for both the entrance and the exit facilities. By using the same interchange site, considerable effort was saved in terms of crash landing correction. The samples described in this section apply to the calibration of rural entrance/exit speed-change lanes, urban entrance/exit speed-change lanes, rural entrance/exit ramps, and urban entrance/exit ramps. Tables 4.2.1 through 4.2.3 show the facilities used for calibrating speed-change lanes and Table 4.2.4 and 4.2.5 show the facilities used for calibrating ramps.

Table 4.2.1 Rural Entrance and Exit Speed-Change Lane Sites (SCLREN/EX)

ID	Main Highway	Crossroad	Location	County	District
1	I-35	Route N	E of Eagleville	Harrison	Northwest
2	US-24	13th St.	Lexington	Lafayette	Kansas City
3	US-36	Route C/O	Bevier	Macon	Northeast
4	I-35	Route DD	S of Pattonsburg	Daviess	Northwest
5	MO-7/MO-5	Pier 31 Rd.	N of Camdenton	Camden	Central
6	I-70	MO-13	S of Higginsville	Lafayette	Kansas City
7	I-44	Route B	N of Northview	Webster	Southwest
8	I-70	Route M/O	E of Odessa	Lafayette	Kansas City
9	I-55	US-61	S of Festus	Jefferson	St. Louis
10	MO-21	Old MO-21	S of Otto	Jefferson	St. Louis
11	I-44	Route K/Route PP	Plano	Greene	Southwest
12	I-29	Route K	N of Amazonia	Andrew	Northwest
13	US-36	MO-3	Callao	Macon	Northeast
14	I-55	Route U/Route J	S of Hayti	Pemiscot	Southeast
15	US-67	MO-72	Fredericktown	Madison	Southeast

Table 4.2.2 Urban Four-Lane Entrance and Exit Speed-Change Lane Sites (SCLU4EN/EX)

ID	Main Highway	Crossroad	Location	County	District
1	I-29	MO-6	St. Joseph	Buchanan	Northwest
2	US-36	US-63	Macon	Macon	Northeast
3	I-72	MO-79	Hannibal	Marion	Northeast
4	I-49	163rd St.	Belton	Cass	Kansas City
5	I-435	NE Cookingham Dr.	NW of Liberty	Clay	Kansas City
6	US-65	MO-76	Branson	Taney	Southeast
7	US-54	MO-179	Jefferson City	Cole	Central
8	I-44	MO-17	Buckhorn	Pulaski	Central
9	I-64	Lake St. Louis Blvd.	Lake St. Louis	St. Charles	St. Louis
10	US-61	Route A	Wentzville	St. Charles	St. Louis
11	US-36	S. 22nd St.	St. Joseph	Buchanan	Northwest
12	I-49	Civil War Rd.	Kendricktown	Jasper	Southwest
13	I-49	Route HH	S of Carthage	Jasper	Southwest
14	US-60	US-61/US-62	Sikeston	New Madrid	Southeast
15	I-55	Route HH	Miner	Scott	Southeast

Table 4.2.3 Urban Six-Lane Entrance and Exit Speed-Change Lane Sites (SCLU6EN/EX)

ID	Main Highway	Crossroad	Location	County	District
1	US-65	Route YY/E. Division St.	Springfield	Greene	Southwest
2	I-44	MO-109	Eureka	St. Louis	St. Louis
3	I-70	Bryan Rd.	O'Fallon	St. Charles	St. Louis
4	I-70	Noland Rd.	Independence	Jackson	Kanas City
5	I-70	Cave Springs Rd.	St. Charles	St. Charles	St. Louis
6	I-255	Koch Rd.	Mehlville	St. Louis	St. Louis
7	I-29	NW Tiffany Springs Pkwy.	S of Ferrelview	Platte	Kansas City
8	US-65	E. Battlefield Rd.	Fox Grape	Greene	Southwest
9	I-29	MO-45/NW 64th St.	NE of Parkville	Platte	Kansas City
10	I-29	NW 72nd St.	Platte Woods	Platte	Kansas City
11	I-70	NW Woods Chapel Rd.	Blue Springs	Jackson	Kansas City
12	I-70	Lake St. Louis Blvd.	Lake St. Louis	St. Charles	St. Louis
13	I-470	Raytown Rd.	S of Raytown	Jackson	Kansas City
14	I-70	Route A	S of Gilmore	St. Charles	St. Louis
15	I-70	S. Lee's Summit Rd.	SE of Independence	Jackson	Kansas City

Table 4.2.4 Rural Entrance and Exit Ramp Sites (RPREN/EX)

ID	Main Highway	Crossroad	Location	County	District
1	US-36	Route C/Route O	Bevier	Macon	Northeast
2	US-61	Route P	Canton	Lewis	Northeast
3	I-70	Route M/Route O	E of Odessa	Lafayette	Kansas City
4	I-70	MO-13	S of Higginsville	Lafayette	Kansas City
5	I-29	Route K	N of Amazonia	Andrew	Northwest
6	I-35	Route N	Eagleville	Harrison	Northwest
7	I-44	Route B	N of Northview	Webster	Southwest
8	I-44	Route PP/Route K	S of Plano	Greene	Southwest
9	US-24	MO-168	Palmyra	Marion	Northeast
10	US-24	13th St.	S of Lexington	Lafayette	Kansas City
11	I-55	Route J/Route U	S of Hayti	Pemiscot	Southeast
12	MO-13	US-24	Lexington	Lafayette	Kansas City
13	I-44	Route Z/Route O	Halltown	Lawrence	Southwest
14	MO-7/MO-13	MO-52	Clinton	Henry	Southwest
15	US-67	MO-72	W of Fredericktown	Madison	Southeast

Table 4.2.5 Urban Entrance and Exit Ramp Sites (RPUEN/EX)

ID	Main Highway	Crossroad	Location	County	District
1	I-44	MO-17	Buckhorn	Pulaski	Central
2	I-44	MO-30	St. Clair	Franklin	St. Louis
3	I-29	MO-6	St. Joseph	Buchanan	Northwest
4	I-55	US-67	S of Festus	Jefferson	St. Louis
5	US-54	MO-179	Jefferson City	Cole	Central
6	I-72	MO-79	Hannibal	Marion	Northeast
7	US-60	US-61/US-62	S of Sikeston	New Madrid	Southeast
8	I-49	Civil War Rd.	NW of Kendricktown	Jasper	Southwest
9	I-170	Ladue Rd.	W of North Clayton	St. Louis	St. Louis
10	I-49	MO-2	Harrisonville	Cass	Kansas City
11	I-49	Route HH/W. Fir Rd.	S of Carthage	Jasper	Southwest
12	I-55	E. Main St.	E of Jackson	Cape Girardeau	Southeast
13	US-36	S. 22nd St.	St. Joseph	Buchanan	Northwest
14	I-70	Route A	S of Gilmore	St. Charles	St. Louis
15	US-36	US-63	Macon	Macon	Northeast

CHAPTER 5 CALIBRATION RESULTS

5.1 Terminal Facilities

Tables 5.1.1 through 5.1.8 show the calibration values derived for Missouri freeway interchange terminals. Of the 16 calibration values, four were slightly high, exceeding the value of 2.0. They were D4SCR, D4SCU, D4SG2 and D4SG4, and they were all for the severity of PDO. All of the PDO terminal calibration values were above 1.0, indicating that the HSM always under-predicts the number of PDO crashes in Missouri. The states used for HSM ramp terminal model development used crash data from California, Maine, and Washington. The high PDO calibration values were also evident for the previously calibrated freeway segments facilities (Sun et al., 2013). In the previous freeway segment calibration, the PDO calibration values for rural four lane SV, rural four lane MV, urban four lane SV, urban four lane MV, urban six lane SV, and urban six lane MV were 1.51, 1.98, 1.62, 3.59, 0.88, and 1.63, respectively. The typical factors suggested for jurisdictional differences among states are climate, animal population, driver behavior, crash reporting threshold, geometric design, signage, traffic control devices, and signal timing practices. Of those factors, crash reporting threshold and practice appear to be highly influential here since the high calibration values apply only to PDO calibration values and not to FI. Thus one possible explanation is that PDO crashes are underreported in California, Maine, and Washington compared to Missouri. However, it is difficult to identify exactly how much contribution each of the eight aforementioned factors added to the differences between Missouri and HSM PDO crash estimation.

Table 5.1.1 Rural Stop-Controlled Diamond Interchange (D4SCR)

Sample	Terminal	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	W	1	0.178	2	0.312
1	E	0	0.155	0	0.330
2	W	0	0.019	0	0.026
2	E	0	0.002	0	0.005
3	N	0	0.128	0	0.190
3	S	0	0.259	2	0.158
4	W	0	0.110	0	0.200
4	E	0	0.225	1	0.434
5	N	0	0.066	0	0.154
5	S	0	0.122	0	0.232
6	N	1	1.112	3	2.181
6	S	1	0.940	7	2.080
7	N	0	0.096	0	0.236
7	S	0	0.105	1	0.261
8	W	0	0.187	1	0.526
8	E	0	0.059	3	0.174
9	W	0	0.167	0	0.402
9	E	0	0.155	0	0.398
11	N	0	0.198	2	0.323
11	S	1	0.219	0	0.341
12	N	0	0.300	1	0.536
12	S	0	0.184	1	0.399
13	W	0	0.760	1	1.026
13	E	0	0.481	0	0.658
14	W	1	0.421	6	0.727
14	E	0	0.857	0	1.472
15	N	0	0.089	1	0.201
15	S	1	0.114	1	0.217
16	N	1	0.087	1	0.203
16	S	0	0.507	0	0.706
Total		7	8.302	34	15.108
Calibration Factor		**0.843**		**2.251**	
Standard Deviation		0.423	0.281	1.688	0.525

Table 5.1.2 Urban Stop-Controlled Diamond Interchange (D4SCU)

Sample	Terminal	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	N	0	0.569	4	1.521
1	S	0	1.122	10	2.696
2	N	0	0.373	0	0.949
2	S	0	0.350	0	1.006
3	W	0	0.630	2	1.686
3	E	0	1.046	2	2.409
4	N	0	0.337	0	0.615
4	S	0	0.335	0	0.656
5	W	0	0.162	1	0.422
5	E	1	0.183	1	0.409
6	W	0	0.780	4	1.813
6	E	2	1.080	3	2.323
7	W	3	0.656	6	1.691
7	E	1	0.273	3	0.753
8	W	0	0.379	0	0.935
8	E	0	0.021	4	0.067
9	W	2	0.625	8	1.308
9	E	0	0.519	0	1.237
10	N	1	1.771	8	3.979
10	S	0	1.294	4	3.447
11	W	4	0.434	4	1.291
11	E	2	0.679	2	1.510
12	N	2	1.120	6	2.795
12	S	2	1.562	13	3.587
13	W	0	0.433	0	0.921
13	E	0	0.190	0	0.542
14	W	0	0.600	0	1.686
14	E	0	0.467	3	0.831
15	W	1	0.635	2	1.526
15	E	2	0.140	1	0.336
Total		23	18.765	91	44.948
Calibration Factor		**1.226**		**2.025**	
Standard Deviation		1.086	0.422	3.261	0.994

Table 5.1.3 Signalized Diamond Interchange with Two Lane Crossroads (D4SG2)

Sample	FI		PDO	
	Observation	Prediction	Observation	Prediction
1	1	1.729	8	3.081
2	4	2.961	15	5.268
3	1	0.465	12	1.669
4	2	0.180	15	0.544
5	2	3.223	11	5.179
6	5	1.940	16	3.518
7	2	2.124	3	3.580
8	0	0.716	3	1.365
9	6	2.898	25	4.973
10	7	5.908	11	9.313
11	8	6.497	23	12.600
12	7	3.356	30	4.877
13	1	4.542	7	7.234
14	7	4.657	24	7.262
15	0	1.624	11	4.553
16	2	1.736	6	4.981
17	3	3.461	9	6.890
18	3	3.263	8	4.876
19	1	3.888	11	5.659
20	9	3.619	19	7.484
21	6	4.356	7	7.694
22	0	3.312	4	4.265
23	2	2.908	6	3.869
24	0	1.342	5	1.490
25	1	0.998	2	1.243
26	0	1.545	4	1.347
27	1	0.592	6	0.575
28	0	0.699	0	0.769
29	0	0.377	0	0.424
30	3	2.384	10	5.185
Total	84.000	77.300	311.000	131.767
Calibration Factor	**1.087**		**2.360**	
Standard Deviation	1.611	2.725	2.859	7.517

Table 5.1.4 Signalized Diamond Interchange with Four Lane Crossroads (D4SG4)

No.	FI		PDO	
	Prediction	Observation	Prediction	Observation
1	20	9.211	32	15.783
2	19	13.531	46	19.109
3	6	4.708	11	7.008
4	6	5.204	7	7.440
5	6	4.291	22	7.661
6	2	5.621	18	6.756
7	1	4.296	3	5.686
8	6	4.202	13	11.451
9	7	4.137	31	7.720
10	9	14.206	36	15.915
11	7	14.037	24	14.163
12	2	13.879	8	21.907
13	0	1.512	6	2.956
14	12	5.044	36	10.072
15	3	0.363	14	0.900
16	1	3.457	6	8.789
17	5	4.686	10	14.024
18	1	3.348	4	5.261
19	6	5.687	29	8.632
20	10	17.038	41	20.792
21	0	1.728	12	2.342
22	0	3.272	15	4.398
23	3	2.287	9	2.359
24	3	2.279	8	2.992
25	6	11.586	4	21.225
26	9	7.009	14	11.104
27	0	2.760	10	4.407
28	1	2.291	4	4.853
29	6	8.044	20	9.686
30	1	5.771	15	7.065
31	3	1.957	8	1.750
32	0	1.398	7	1.549
Total	161.000	188.842	523.000	285.756
Calibration Factor	**0.853**		**1.830**	
Standard Deviation	4.392	4.940	6.002	11.762

Table 5.1.5 Signalized Diamond Interchange with Six Lane Crossroads (D4SG6)

Sample	Terminal	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	W	10	7.336	13	14.805
2	S	29	8.725	48	16.306
5	E	6	9.913	18	12.780
6	W	7	7.905	33	17.937
8	N	2	1.730	16	2.763
8	S	5	2.400	30	2.904
9	N	6	7.230	22	14.692
10	S	7	42.038	85	61.230
11	W	7	4.104	23	9.113
12	W	9	9.364	69	13.524
Total		88	100.744	357	166.052
Calibration Factor		**0.874**		**2.150**	
Standard Deviation		7.040	10.993	23.013	15.683

Table 5.1.6 Rural Stop-Controlled Partial Cloverleaf Interchange (A2SCR)

Sample	Terminal	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	N	0	0.098	1	0.047
1	S	0	0.066	0	0.044
2	W	0	0.286	0	0.113
2	E	0	0.211	0	0.048
3	N	0	1.596	0	1.790
3	S	0	1.188	1	1.519
4	W	0	0.556	2	0.542
4	E	1	0.494	1	0.522
5	N	1	0.134	1	0.051
5	S	0	0.144	0	0.053
6	N	0	0.593	2	0.564
6	S	0	0.724	1	0.701
7	W	0	0.234	0	0.204
7	E	0	0.185	1	0.164
8	N	0	0.113	0	0.043
9	S	0	0.283	0	0.245
Total		2	6.905	10	6.650
Calibration Factor		**0.290**		**1.504**	
Standard Deviation		0.331	0.416	0.696	0.517

Table 5.1.7 Urban Stop-Controlled Partial Cloverleaf Interchange (A2SCU)

Sample	Terminal	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	N	1	0.591	3	1.555
1	S	0	0.644	2	1.192
2	N	1	0.431	0	0.472
2	S	0	0.719	1	1.101
3	W	0	1.492	4	2.351
4	W	2	0.665	1	1.634
4	E	0	0.841	4	1.685
5	N	0	0.701	5	1.693
5	S	1	1.053	2	1.944
6	W	0	0.445	0	0.490
6	E	0	0.629	2	1.023
7	W	2	1.386	1	3.340
7	E	0	1.350	1	3.231
8	W	5	1.863	11	1.005
8	E	2	0.963	4	1.844
9	W	0	0.323	0	0.552
9	E	1	0.358	2	0.555
10	W	0	0.234	0	0.281
11	S	1	0.047	0	0.044
12	S	0	0.940	1	1.506
13	S	2	0.404	0	0.621
15	N	0	0.787	0	0.957
16	W	1	1.491	7	2.927
Total		19	18.359	51	32.000
Calibration Factor		**1.035**		**1.594**	
Standard Deviation		1.167	0.452	2.637	0.898

Table 5.1.8 Signalized Partial Cloverleaf Interchange (A2SG4)

Sample	Terminal	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	W	11	7.410	51	20.098
1	E	22	7.583	63	19.280
2	W	4	8.846	11	13.711
2	E	3	5.298	16	9.977
3	W	7	14.030	19	18.256
3	E	3	14.324	10	17.876
4	S	2	5.282	10	4.596
4	N	3	11.632	4	10.509
5	W	2	7.301	6	9.825
5	E	4	18.702	10	29.268
6	W	3	12.131	17	11.379
6	E	2	5.562	3	5.279
7	W	0	3.781	5	4.692
7	E	3	3.513	1	3.978
8	W	9	4.637	14	10.386
8	E	1	5.683	14	12.873
9	E	0	13.333	3	13.262
10	S	10	11.060	14	12.433
11	W	0	6.257	2	5.245
Total		89	166.365	273	232.924
Calibration Factor		**0.535**		**1.172**	
Standard Deviation		5.171	4.156	15.665	6.374

5.2 Non-Terminal Facilities

Tables 5.2.1 through 5.2.6 show the calibration values for speed-change lanes, and Tables 5.2.7 through 5.2.14 show the calibration values for ramps. For ramps, separate calibration values are presented for SV and MV according to HSM modeling requirements. None of the other interchange facility types calibrated in this project have separate SV and MV calibration values. The Missouri speed-change calibration values were all smaller than 1.0 for FI crashes. Three of the speed-change lane calibration values for PDO were slightly higher than 1.0 while three other ones were less than 1.0. None of the speed-change calibration values appear to be extreme.

The eight ramp calibration values show some significant variability with the MV values being the largest. For FI, the urban ramp entrance and exit MV values are 2.681 and 2.354, respectively. And for PDO, the rural ramp entrance, urban ramp entrance, and urban ramp exit MV values are 2.489, 6.360, and 5.252. The main reason for the wide behavior of the ramp MV calibration values is the fact that there are very few MV ramp crashes which makes the modeling of MV ramp crashes very difficult. This difficulty applies not only to the Missouri calibration but also to the development of the original HSM ramp prediction models. The NCHRP 17-45 report (Bonneson et al., 2012) states that most ramp crashes are single-vehicle crashes. This is especially true with the Missouri calibration effort since only single lane ramps were calibrated. Based on the Missouri crash review experience, many collisions reported on ramps are terminal-related since they are caused by queues that backed up from ramp terminals, or they are speed-change related since they are caused by diverge and merge conflicts associated with speed-change lanes. Thus collisions located on ramps are most often properly classified as terminal or speed-change lane crashes. Run off the road crashes are one of the few types of crashes that are observed on ramps, and those are SV crashes. Thus MV crashes on single lane ramps are extremely rare.

The following is an illustration of the problem of calibrating a value in which the predicted number of crashes is very small, i.e. less than 1, as in the case of ramp MV calibration values. For example, consider the calibration of the rural entrance ramp for MV crashes. The predicted number of crashes for three years is 0.101 for FI and 0.402 for PDO. When there are no observed crashes in the sample sites, as in the Missouri FI case, then the calibration value is 0.0 because of the 0 observed crashes in the numerator. And when a single crash appears in the sample sites, as in the Missouri PDO case, then the calibration value becomes 2.489 because of the less than 1.0 value in the denominator. In other words, when the observed values are discrete values (i.e., 0, 1, 2, …) and small, and the predicted values are small, then a high variance results in the calibration value due to the division by the small predicted value.

The data used for HSM ramp modeling support the notion that MV ramp crashes are rare. Two of the three states used for ramp data collection in the HSM, California and Maine, had very few MV ramp crashes. Even though the total length of ramps used was significant, with 65 miles of California ramps and 49 miles of Maine ramps, the number of MV crashes were very few. For California, the five year FI MV crashes on exit ramps were 3 for connector, 0 for diagonal, and 3 for loop type, or a total of 6 crashes. Hook type exit ramps, i.e., connectors to frontage roads, were not part of the Missouri calibration, thus the crashes for these types of ramps are not discussed here. The MV crashes on entrance ramps in California were 6 for connectors, 3 for diagonal, and 7 for loop type, or a total of 16 crashes. For Maine, the five year FI MV crashes on exit ramps were 0 for connector, 3 for diagonal, and 0 for loop type, or a total of 3 crashes. The MV crashes on entrance ramps were 8 for connectors, 4 for diagonal, and 5 for loop type, or a total of 17. The details of the PDO crashes were not reported in the NCHRP 17-45 report, although FI crashes represented 33 percent of the total ramp crashes; therefore, there were approximately twice as many PDO crashes as FI crashes. Considering the relatively small number of MV ramp crashes from the national NCHRP study, it is unsurprising that the number of MV ramp crashes in Missouri were also small.

A practical consideration in the use of ramp calibration values, and especially the MV values, is that ramp crashes are the least significant component of the freeway interchange safety model from a numerical perspective. For example, consider a Missouri urban interchange which has a high urban entrance ramp MV calibration value. For MV crashes, the urban entrance ramp PDO crashes for three years are 1.258 (predicted). The urban entrance four-lane speed-change PDO crashes for three years are 23.598 (predicted). The signalized diamond interchange with four crossroad lanes has three-year PDO crash numbers of 285.756 (predicted). Comparing the magnitude of crash numbers, the MV predicted ramp crashes is only around 5% of the speed-change lane crashes and 0.44% of the terminal predicted crashes. If the goal is to estimate the safety of an overall interchange facility, then high MV ramp calibration values have little impact on the overall interchange numbers.

This project recommends two approaches in working with the ramp calibration values for MV. One is simply to apply them as is, even though some values are high or even very high. Since MV ramp crashes are relatively few, the net effect on the modeling of an entire interchange is small. Another approach is to recognize the difficulty in modeling MV crashes on ramps. The difficulty of having very few MV crashes occurring on ramps extends beyond the Missouri calibration effort to the original HSM models. This approach recommends the use of a calibration value of 1.0 for all MV ramp facilities. In other words, this approach recognizes the difficulty of MV ramp calibration, and relies on national data instead.

Table 5.2.1 Rural Entrance Speed-Change Lane (SCLREN)

Sample	SCL	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	0	0.158	0	0.464
1	s	0		0	
2	n	0	0.033	1	0.089
2	s	0		0	
3	n	0	0.103	2	0.326
3	s	0		0	
4	n	0	0.127	0	0.575
4	s	0		0	
5	n	0	0.242	0	0.676
5	s	0		0	
6	n	1	0.675	3	1.632
6	s	2		3	
7	n	0	0.413	1	1.409
7	s	0		0	
8	n	0	0.512	0	1.776
8	s	0		1	
9	w	0	0.377	0	1.053
9	e	0		0	
10	w	0	0.242	0	0.721
10	e	0		0	
11	n	0	0.662	2	1.901
11	s	0		1	
12	n	0	0.167	0	0.772
12	s	0		0	
13	n	0	0.075	0	0.268
13	s	0		0	
14	w	0	0.320	0	1.101
14	e	0		1	
15	w	0	0.095	0	0.261
15	e	0		0	
Total		3	4.201	15	13.023
Calibration Factor		**0.714**		**1.152**	
Standard Deviation		0.396	0.201	0.885	0.566

Table 5.2.2 Rural Exit Speed-Change Lane (SCLREX)

Sample	SCL	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	0	0.288	1	0.662
1	s	0		0	
2	n	0	0.053	0	0.106
2	s	0		1	
3	n	0	0.230	0	0.539
3	s	0		0	
4	n	0	0.187	0	0.416
4	s	0		0	
5	n	1	0.339	0	0.818
5	s	0		0	
6	n	0	0.366	0	0.793
6	s	0		1	
7	n	0	0.505	1	1.185
7	s	1		3	
8	n	0	0.322	1	0.622
8	s	0		0	
9	w	0	0.557	0	1.328
9	e	0		0	
10	w	1	0.437	0	0.983
10	e	0		0	
11	n	0	0.481	1	1.050
11	s	0		2	
12	n	0	0.413	0	0.963
12	s	0		0	
13	n	0	0.214	0	0.500
13	s	1		0	
14	w	0	0.435	0	0.998
14	e	0		0	
15	w	0	0.104	2	0.222
15	e	0		0	
Total		4	4.930	13	11.184
Calibration Factor		**0.811**		**1.162**	
Standard Deviation		0.340	0.144	0.761	0.338

Table 5.2.3 Urban Four-Lane Entrance Speed-Change Lane (SCLU4EN)

Sample	SCL	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	w	0	0.954	2	1.931
1	e	0		2	
2	n	1	0.165	0	0.375
2	s	0		0	
3	n	1	0.433	1	0.985
3	s	0		1	
4	w	1	2.071	4	5.065
4	e	0		0	
5	w	0	0.541	0	1.252
5	e	0		2	
6	w	0	0.631	2	1.311
6	e	0		3	
7	w	0	0.847	0	2.091
7	e	0		2	
8	n	0	0.538	0	1.493
8	s	0		1	
9	n	1	1.001	3	2.388
9	s	1		0	
10	w	0	1.123	2	2.305
10	e	1		2	
11	w	0	0.562	1	1.374
11	e	0		1	
12	n	0	0.246	1	0.794
12	s	0		0	
13	w	0	0.316	0	0.777
13	e	0		0	
14	n	0	0.246	0	0.522
14	s	0		0	
15	w	0	0.352	0	0.935
15	e	0		1	
Total		6	10.026	31	23.598
Calibration Factor		**0.598**		**1.314**	
Standard Deviation		0.400	0.471	1.110	1.112

Table 5.2.4 Urban Four-Lane Exit Speed-Change Lane (SCLU4EX)

Sample	SCL	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	w	0	0.749	1	1.848
1	e	0		0	
2	n	0	0.121	0	0.262
2	s	0		1	
3	n	0	0.687	4	1.648
3	s	0		0	
4	w	0	1.619	0	3.938
4	e	2		2	
5	w	0	0.520	0	1.244
5	e	0		0	
6	w	0	0.451	1	1.084
6	e	1		0	
7	w	0	0.750	0	1.977
7	e	0		0	
8	n	0	0.442	1	0.994
8	s	0		0	
9	n	0	0.895	0	2.170
9	s	0		1	
10	w	0	0.486	0	1.117
10	e	0		0	
11	w	0	0.393	0	0.871
11	e	0		0	
12	n	0	0.358	0	0.896
12	s	0		0	
13	w	0	0.361	0	0.858
13	e	0		0	
14	n	0	0.444	0	1.069
14	s	1		0	
15	w	0	0.512	0	1.216
15	e	0		0	
Total		4	8.788	11	21.192
Calibration Factor		**0.455**		**0.519**	
Standard Deviation		0.427	0.333	0.836	0.827

Table 5.2.5 Urban Six-Lane Entrance Speed-Change Lane (SCLU6EN)

Sample	SCL	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	w	1	1.486	0	3.463
1	e	0		0	
2	n	0	1.745	0	3.721
2	s	1		3	
3	n	1	4.620	1	9.401
3	s	1		2	
4	w	2	4.556	12	8.869
4	e	1		5	
5	n	0	6.666	6	12.920
5	s	4		7	
6	n	1	1.486	1	4.082
6	s	0		1	
7	w	1	1.934	1	4.434
7	e	1		0	
8	w	1	1.892	1	3.957
8	e	0		3	
9	w	1	3.746	3	7.693
9	e	1		0	
10	w	0	1.875	2	9.007
10	e	0		2	
11	n	0	3.023	4	4.781
11	s	0		2	
12	n	0	4.506	1	6.699
12	s	1		2	
13	w	0	1.854	0	4.891
13	n	0		0	
14	s	0	3.370	5	8.098
14	s	0		5	
15	n	0	3.616	1	8.079
15	s	2		4	
Total		20	46.375	74	100.095
Calibration Factor		**0.431**		**0.739**	
Standard Deviation		0.869	1.479	2.630	2.667

Table 5.2.6 Urban Six-Lane Exit Speed-Change Lane (SCLU6EX)

Sample	SCL	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	w	0	0.888	1	2.050
1	e	0		0	
2	n	2	1.990	1	5.122
2	s	0		0	
3	n	0	3.275	1	8.004
3	s	0		1	
4	w	0	2.036	1	4.580
4	e	1		0	
5	n	2	4.001	10	9.891
5	s	0		1	
6	n	0	1.222	3	2.878
6	s	0		2	
7	w	1	1.758	1	4.571
7	e	1		0	
8	w	0	1.002	0	2.343
8	e	0		1	
9	w	1	3.075	4	7.859
9	e	2		3	
10	w	0	2.015	1	4.058
10	e	1		1	
11	n	2	2.608	0	6.611
11	s	0		2	
12	n	0	1.644	1	10.208
12	s	0		1	
13	n	0	1.957	0	5.136
13	s	0		0	
14	n	0	2.611	1	6.174
14	s	0		0	
15	n	0	1.548	1	3.506
15	s	1		2	
Total		14	31.63	40	82.991
Calibration Factor		**0.443**		**0.482**	
Standard Deviation		0.718	0.840	1.886	2.473

Table 5.2.7 Rural Entrance Ramp for Single Vehicle Crashes (RPRENSV)

Sample	Ramp	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	0	0.021	0	0.031
1	s	0	0.070	0	0.091
2	w	0	0.032	0	0.044
2	e	0	0.079	0	0.110
3	n	0	0.025	0	0.040
3	s	0	0.011	0	0.017
4	n	0	0.119	0	0.156
4	s	0	0.136	0	0.196
5	n	0	0.016	0	0.062
5	s	0	0.048	0	0.024
6	n	0	0.044	0	0.096
6	s	0	0.047	0	0.225
7	n	0	0.048	0	0.064
7	s	0	0.043	0	0.064
8	n	0	0.046	1	0.063
8	s	0	0.055	0	0.071
9	w	0	0.096	0	0.121
9	e	0	0.225	0	0.322
10	n	0	0.134	0	0.170
10	s	0	0.194	0	0.231
11	w	0	0.058	1	0.085
11	e	0	0.015	0	0.022
12	n	0	0.193	0	0.140
12	s	0	0.101	0	0.321
13	n	0	0.064	0	0.075
13	s	0	0.159	0	0.239
14	n	0	0.257	0	0.214
14	s	0	0.140	0	0.420
15	w	0	0.039	0	0.057
15	e	0	0.097	1	0.130
Total		0	2.614	3	3.900
Calibration Factor		**1.000***		**0.769**	
Standard Deviation		0.000	0.065	0.300	0.100

*A value of 1.000 (i.e., national data) was used because Missouri data contained too few ramp crashes.

Table 5.2.8 Rural Entrance Ramp for Multiple Vehicle Crashes (RPRENMV)

Sample	Ramp	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	0	0.001	0	0.002
1	s	0	0.003	0	0.013
2	w	0	0.002	0	0.004
2	E	0	0.004	0	0.016
3	N	0	0.001	0	0.006
3	S	0	0.001	0	0.001
4	N	0	0.005	1	0.040
4	S	0	0.005	0	0.041
5	N	0	0.001	0	0.003
5	S	0	0.003	0	0.000
6	N	0	0.002	0	0.003
6	S	0	0.002	0	0.006
7	N	0	0.002	0	0.006
7	S	0	0.002	0	0.006
8	N	0	0.002	0	0.009
8	S	0	0.003	0	0.011
9	W	0	0.003	0	0.003
9	E	0	0.006	0	0.012
10	N	0	0.006	0	0.027
10	S	0	0.008	0	0.052
11	W	0	0.003	0	0.012
11	E	0	0.001	0	0.001
12	N	0	0.005	0	0.013
12	S	0	0.004	0	0.018
13	N	0	0.003	0	0.004
13	S	0	0.004	0	0.006
14	N	0	0.006	0	0.028
14	S	0	0.006	0	0.027
15	W	0	0.002	0	0.007
15	E	0	0.004	0	0.025
Total		0	0.101	1	0.402
Calibration Factor		**1.000***		**2.489**	
Standard Deviation		0.000	0.002	0.180	0.013

*A value of 1.000 (i.e., national data) was used because Missouri data contained too few ramp crashes.

Table 5.2.9 Rural Exit Ramp for Single Vehicle Crashes (RPREXSV)

Sample	Ramp	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	N	0	0.096	1	0.118
1	S	0	0.027	0	0.035
2	W	0	0.083	1	0.107
2	E	0	0.045	0	0.061
3	N	0	0.020	0	0.025
3	S	0	0.046	0	0.062
4	N	0	0.108	0	0.138
4	S	0	0.247	0	0.340
5	N	0	0.045	0	0.393
5	S	0	0.287	0	0.064
6	n	0	0.051	1	0.078
6	s	0	0.078	0	0.111
7	n	0	0.092	0	0.106
7	s	0	0.078	2	0.097
8	n	0	0.087	1	0.101
8	s	0	0.053	0	0.064
9	w	0	0.313	0	0.366
9	e	1	0.000	0	0.295
10	n	0	0.851	0	1.080
10	s	0	1.303	0	1.824
11	w	0	0.017	0	0.023
11	e	0	0.075	1	0.090
12	n	0	0.336	1	0.213
12	s	0	0.189	0	0.534
13	n	1	0.327	4	0.472
13	s	0	0.085	0	0.126
14	n	0	0.317	0	0.243
14	s	0	0.201	0	0.473
15	w	0	0.113	0	0.142
15	e	0	0.039	0	0.055
Total		2	5.611	12	7.836
Calibration Factor		**0.356**		**1.531**	
Standard Deviation		0.249	0.265	0.841	0.362

Table 5.2.10 Rural Exit Ramp for Multiple Vehicle Crashes (RPREXMV)

Sample	Ramp	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	0	0.001	0	0.005
1	s	0	0.000	0	0.001
2	w	0	0.001	0	0.005
2	e	0	0.000	0	0.002
3	n	0	0.000	0	0.000
3	s	0	0.000	0	0.003
4	n	0	0.001	0	0.010
4	s	0	0.002	0	0.020
5	n	0	0.001	0	0.004
5	s	0	0.000	0	0.000
6	n	0	0.000	0	0.002
6	s	0	0.001	0	0.004
7	n	0	0.001	0	0.003
7	s	0	0.001	0	0.003
8	n	0	0.001	0	0.005
8	s	0	0.000	0	0.002
9	w	0	0.001	0	0.005
9	e	0	0.001	0	0.002
10	n	0	0.003	0	0.023
10	s	0	0.004	0	0.020
11	w	0	0.000	0	0.000
11	e	0	0.001	0	0.004
12	n	0	0.001	0	0.006
12	s	0	0.001	0	0.007
13	n	0	0.001	0	0.003
13	s	0	0.000	0	0.001
14	n	0	0.001	0	0.010
14	s	0	0.001	0	0.007
15	w	0	0.001	0	0.007
15	e	0	0.000	0	0.002
Total		0	0.027	0	0.163
Calibration Factor		**1.000***		**1.000***	
Standard Deviation		0.000	0.001	0.000	0.006

*A value of 1.000 (i.e., national data) was used because Missouri data contained too few ramp crashes.

Table 5.2.11 Urban Entrance Ramp for Single Vehicle Crashes (RPUENSV)

Sample	Ramp	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	0	0.064	0	0.098
1	s	0	0.041	0	0.074
2	n	0	0.096	0	0.148
2	s	0	0.100	0	0.152
3	w	0	0.181	0	0.280
3	e	0	0.093	0	0.148
4	w	0	0.350	0	0.652
4	e	3	0.432	2	0.773
4	w	0	0.070	1	0.104
4	e	2	0.128	3	0.215
5	w	0	0.165	0	0.268
5	e	0	0.152	2	0.269
6	n	0	0.096	0	0.159
6	s	0	0.146	0	0.209
7	n	0	0.148	1	0.235
7	s	0	0.179	1	0.303
8	w	0	0.096	0	0.151
8	e	0	0.029	0	0.047
9	w	0	0.875	1	1.438
9	e	0	1.201	0	1.857
10	w	0	0.129	0	0.206
10	e	0	0.079	0	0.124
11	w	0	0.138	0	0.228
11	e	0	0.160	0	0.265
12	w	0	0.130	0	0.222
12	e	0	0.066	0	0.111
13	w	0	0.235	1	0.344
13	e	0	0.464	0	0.803
14	n	0	0.123	0	0.194
14	s	1	0.220	0	0.338
15	n	0	0.107	0	0.175
15	s	0	0.076	0	0.115
Total		6	6.573	12	10.704
Calibration Factor		**0.913**		**1.121**	
Standard Deviation		0.634	0.240	0.740	0.386

Table 5.2.12 Urban Entrance Ramp for Multiple Vehicle Crashes (RPUENMV)

Sample	Ramp	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	1	0.016	0	0.009
1	s	0	0.009	0	0.009
2	n	0	0.021	0	0.023
2	s	0	0.022	0	0.019
3	w	0	0.041	0	0.094
3	e	0	0.020	0	0.038
4	w	0	0.043	1	0.023
4	e	1	0.050	4	0.029
4	w	0	0.056	0	0.020
4	e	1	0.076	1	0.052
5	w	0	0.032	0	0.029
5	e	0	0.029	0	0.030
6	n	0	0.020	0	0.019
6	s	0	0.031	0	0.022
7	n	0	0.030	0	0.044
7	s	0	0.033	0	0.056
8	w	0	0.023	1	0.017
8	e	0	0.008	0	0.003
9	w	0	0.115	0	0.197
9	e	0	0.110	0	0.135
10	w	0	0.027	0	0.033
10	e	0	0.016	0	0.017
11	w	0	0.029	0	0.029
11	e	0	0.031	0	0.037
12	w	0	0.025	0	0.036
12	e	0	0.015	0	0.009
13	w	0	0.035	0	0.032
13	e	0	0.048	0	0.041
14	n	0	0.026	0	0.029
14	s	0	0.043	0	0.078
15	n	0	0.021	1	0.034
15	s	0	0.016	0	0.016
Total		3	1.119	8	1.258
Calibration Factor		**2.681**		**6.360**	
Standard Deviation		0.291	0.024	0.750	0.038

Table 5.2.13 Urban Exit Ramp for Single Vehicle Crashes (RPUEXSV)

Sample	Ramp	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	0	0.081	1	0.132
1	s	0	0.198	0	0.277
2	n	0	0.097	0	0.153
2	s	0	0.125	0	0.148
3	w	0	0.202	1	0.271
3	e	1	0.360	0	0.609
4	w	1	0.758	0	1.279
4	e	0	0.659	0	1.010
4	w	5	0.584	11	0.803
4	e	0	0.132	0	0.197
5	w	0	0.191	0	0.268
5	e	1	0.295	0	0.400
6	n	0	0.206	3	0.298
6	s	0	0.241	1	0.333
7	n	0	0.243	0	0.322
7	s	0	0.178	0	0.251
8	w	0	0.123	0	0.171
8	e	0	0.024	0	0.037
9	w	0	2.435	1	3.478
9	e	1	0.753	0	1.106
10	w	0	0.219	0	0.297
10	e	0	0.098	1	0.153
11	w	0	0.077	0	0.128
11	e	0	0.118	0	0.173
12	w	0	0.094	0	0.131
12	e	0	0.170	1	0.265
13	w	0	0.426	0	0.570
13	e	0	0.911	0	1.254
14	n	0	0.329	0	0.646
14	s	0	0.140	0	0.310
15	n	0	0.119	0	0.150
15	s	0	0.128	0	0.178
Total		9	10.713	20	15.798
Calibration Factor		**0.840**		**1.266**	
Standard Deviation		0.909	0.438	1.965	0.632

Table 5.2.14 Urban Exit Ramp for Multiple Vehicle Crashes (RPUEXMV)

Sample	Ramp	FI		PDO	
		Observation	Prediction	Observation	Prediction
1	n	0	0.002	0	0.003
1	s	0	0.007	0	0.015
2	n	0	0.004	0	0.007
2	s	0	0.005	0	0.006
3	w	0	0.007	0	0.021
3	e	0	0.024	2	0.103
4	w	0	0.014	1	0.018
4	e	0	0.013	0	0.018
4	w	1	0.466	3	0.946
4	e	0	0.099	2	0.101
5	w	0	0.007	0	0.015
5	e	0	0.009	0	0.019
6	n	0	0.007	0	0.012
6	s	0	0.008	0	0.017
7	n	0	0.008	0	0.022
7	s	0	0.006	0	0.011
8	w	0	0.005	0	0.005
8	e	0	0.001	0	0.000
9	w	1	0.035	0	0.066
9	e	0	0.038	0	0.124
10	w	0	0.006	0	0.010
10	e	0	0.003	0	0.007
11	w	0	0.003	0	0.006
11	e	0	0.004	0	0.006
12	w	0	0.003	0	0.003
12	e	0	0.006	0	0.009
13	w	0	0.009	0	0.012
13	e	0	0.014	0	0.015
14	n	0	0.018	0	0.077
14	s	0	0.008	0	0.025
15	n	0	0.004	1	0.006
15	s	0	0.004	0	0.009
Total		2	0.850	9	1.714
Calibration Factor		**2.354**		**5.252**	
Standard Deviation		0.242	0.081	0.717	0.163

CHAPTER 6 CONCLUSION

AASHTO's publication of the HSM enabled the widespread safety analysis of highway facilities using a national guide. HSM-based safety analysis can be used in different transportation applications, including planning, design, construction, operations, and maintenance. The 2014 HSM supplement introduced the capability of modeling a wide range of freeway interchanges. These new freeway interchange models were calibrated for Missouri as documented in this report. Calibration is the process of accounting for differences between local conditions and national conditions. Some of the local differences include climate, animal population, driver behavior, crash reporting threshold, geometric design, signage, traffic control devices, and signal timing practices.

The details of the calibration process were documented in this report which allows any future re-calibration to be compatible with the current results. A companion report discussed the elaborate process of crash landing correction for crash reports. The steps of the calibration process include facility type selection, sampling, data collection, and modeling. Facility type selection is the process of determining which of the HSM interchange facilities to calibrate. The selection criteria include the existence of the facility type in Missouri, the frequency of occurrence of each facility type, and MoDOT priorities. The calibrated sites include nine terminal types, six speed-change lanes, and four ramps. As separate calibration values were derived for FI versus PDO, and for SV versus MV for ramps, the total number of calibration values produced for all the facility types was 44. Sampling is the process of selecting a number of freeway interchange sites that are representative of the Missouri facilities in general. In order to select sample sites, an exhaustive list of Missouri interchanges was produced. The selection of sites was performed in an unbiased and random fashion, while reflecting geographical diversity across all seven MoDOT districts. Calibration was a very data intensive process that required the collection of geometric, signal, AADT, and crash data. The modeling and calibration was performed using the ISATe software.

A major lesson learned from this calibration process was how to address the significant problem associated with incorrect crash landing. The crash landing problem was caused by crashes not being located on the correct interchange facility. The discovery of the crash landing problem led to a significant delay in the calibration process. Ultimately, the crash landing correction process provided significant understanding of the scope and extent of the problem. The crash landing error rates for different interchange facilities were discovered with the overall error rate being 69%. This means crash data correction is a necessary step in accurately modeling Missouri interchanges using the HSM. The crash correction process also produced two separate formalized procedures for the crash correction of terminal facilities and non-terminal facilities. These procedures can be used to train analysts for correcting crashes in a uniform manner.

One recommendation for a future revision of the HSM is to merge the ramp calibration factors for SV and MV crashes. Separating the number of crashes for road segments makes sense when there are a large number of MV crashes. However, as discussed in NCHRP 17-45 (Bonneson et al. 2012), there are very few MV crashes on ramps and even fewer on single lane ramps. In addition, the coefficients estimated for the SPF coefficients for multiple-vehicle crashes on ramp segments also appear to be problematic. The SPF model form, Equation 19-20 in the HSM, is

$$N_{spf,rps,x,mv,z} = L_r \times \exp\left(a + b \times \ln[c \times AADT_r] + d[c \times AADT_r]\right)$$

Where:

$N_{spf,rps,x,mv,z}$ = predicted average multiple-vehicle crash frequency of a ramp segment with base conditions, cross section x (x = nEN: n-lane entrance ramp, nEX: n-lane exit ramp), and severity z (z = fi: fatal and injury, pdo: property damage only) (crashes/yr);

L_r = length of ramp segment (mi);

$AADT_r$ = AADT volume of ramp segment (veh/day); and

a, b, c, d = regression coefficients.

Coefficient a is a constant term and is not multiplied with the exposure variable of ramp volume. The coefficient a is the only coefficient that changes between a one-lane and a two-lane ramp. The other coefficients, b, c, and d, are all the same regardless the number of ramp lanes. This could be problematic since MV crashes on one lane versus two lane ramps are fundamentally different, since MV crashes on two-lane ramps have the additional element of lane-changing involved.

ACRONYMS

A2SCR	Rural Stop-Controlled Partial Cloverleaf Interchange
A2SCU	Urban Stop-Controlled Partial Cloverleaf Interchange
A2SG4	Signalized Partial Cloverleaf Interchange with Four Crossroad Lanes
AASHTO	American Association of State Highway and Transportation Officials
CMF	Crash Modification Factor
Clover	Full Cloverleaf Interchange
D4SCR	Rural Stop-Controlled Diamond Interchange
D4SCU	Urban Stop-Controlled Diamond Interchange
D4SG2	Signalized Diamond Interchange with Two Crossroad Lanes
D4SG4	Signalized Diamond Interchange with Four Crossroad Lanes
D4SG6	Signalized Diamond Interchange with Six Crossroad Lanes
HSM	Highway Safety Manual
ISATe	Interchange Safety Analysis Tool Enhanced, NCHRP 17-45
MoDOT	Missouri Department of Transportation
MUAR	Missouri Uniform Accident Record
MUCR	Missouri Uniform Crash Record
MV	Multiple Vehicle
NCHRP	National Cooperative Highway Research Program
Parclo	Partial cloverleaf interchange
PDO	Property Damage Only
RPREN	Rural Entrance Ramp
RPREX	Rural Exit Ramp
RPUEN	Urban Entrance Ramp
RPUEX	Urban Exit Ramp
SPF	Safety Performance Function
SCLREN	Rural Entrance Speed-Change Lane
SCLREX	Rural Exit Speed-Change Lane
SCLU4EN	Urban Entrance Speed-Change Lane with Four Freeway Lanes
SCLU6EN	Urban Entrance Speed-Change Lane with Six Freeway Lanes
SCLU4EX	Urban Exit Speed-Change Lane with Four Freeway Lanes
SCLU6EX	Urban Exit Speed-Change Lane with Six Freeway Lanes
SV	Single Vehicle
STARS	Statewide Traffic Accident Records Systems
TMS	Transportation Management Systems
TRB	Transportation Research Board

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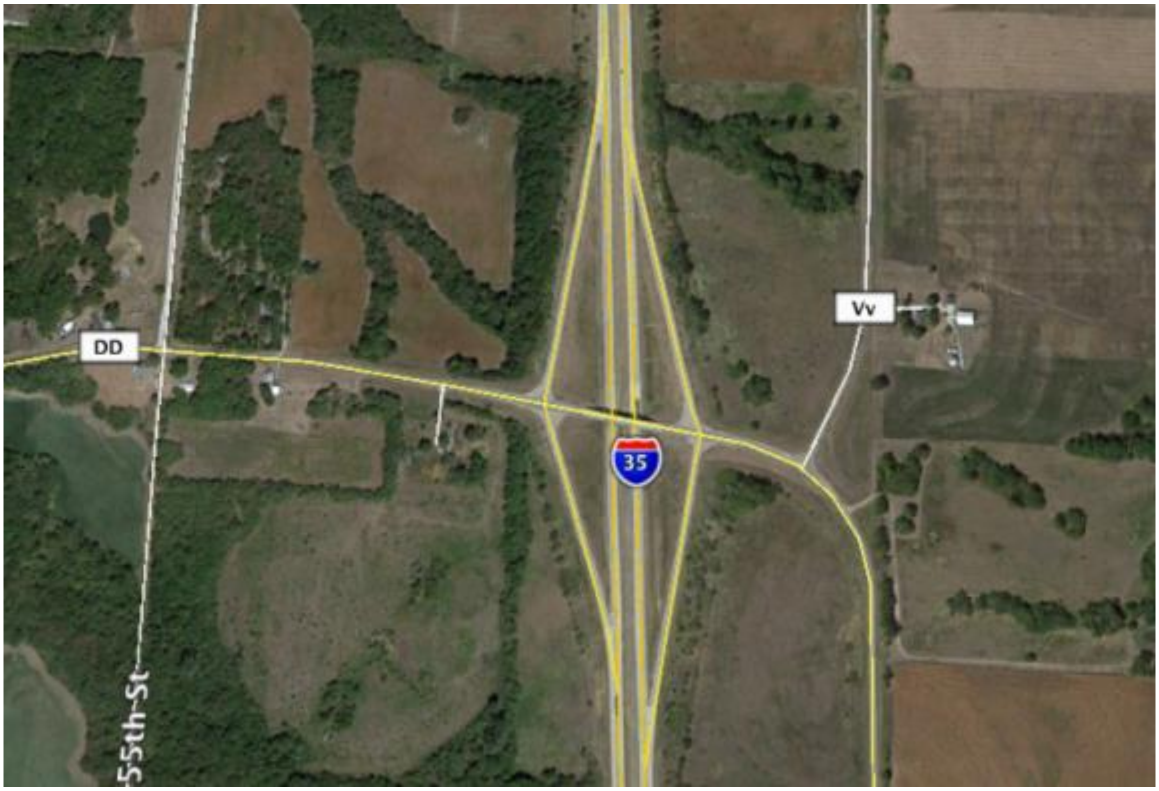
APPENDIX A. AERIAL PHOTOGRAPHS AND SITE DESCRIPTIONS

All aerial photographs were obtained from Google (2015).

A.1 D4SCR Sites

ID Number: 1
Main Highway: I-35
Crossroad: Route N
Location: Eagleville
County: Harrison
District: Northwest



ID Number: 2
Main Highway: I-35
Crossroad: Route DD
Location: South of Pattonsburg
County: Daviess
District: Northwest

ID Number: 3
Main Highway: US 36
Crossroad: Route C/Route O
Location: Bevier
County: Macon
District: Northeast

ID Number: 4
Main Highway: US 61
Crossroad: Route P/Oak Street
Location: Canton
County: Lewis
District: Northeast

ID Number: 5
Main Highway: I-70/US 40
Crossroad: Route M/Route O
Location: East of Odessa
County: Lafayette
District: Kansas City

ID Number: 6
Main Highway: I-70/US 40
Crossroad: MO 13
Location: South of Higginsville
County: Lafayette
District: Kansas City

ID Number: 7
Main Highway: I-70
Crossroad: Route J/Route O
Location: East of Rocheport
County: Boone
District: Central

ID Number: 8
Main Highway: MO 5/MO 7
Crossroad: Pier 31 Road
Location: Northwest of Camdenton
County: Camden
District: Central

ID Number: 9
Main Highway: MO 21
Crossroad: Old MO 21
Location: South of Otto
County: Jefferson
District: St. Louis

ID Number: 10
Main Highway: I-55
Crossroad: US 61
Location: South of Festus
County: Jefferson
District: St. Louis

ID Number: 11
Main Highway: I-44
Crossroad: Route B
Location: West of Marshfield
County: Webster
District: Southwest

ID Number: 12
Main Highway: I-44
Crossroad: Route PP/Route K
Location: Southwest of Plano
County: Greene
District: Southwest

ID Number: 13
Main Highway: I-55/US 61
Crossroad: Route J/Route U
Location: South of Hayti
County: Pemiscot
District: Southeast

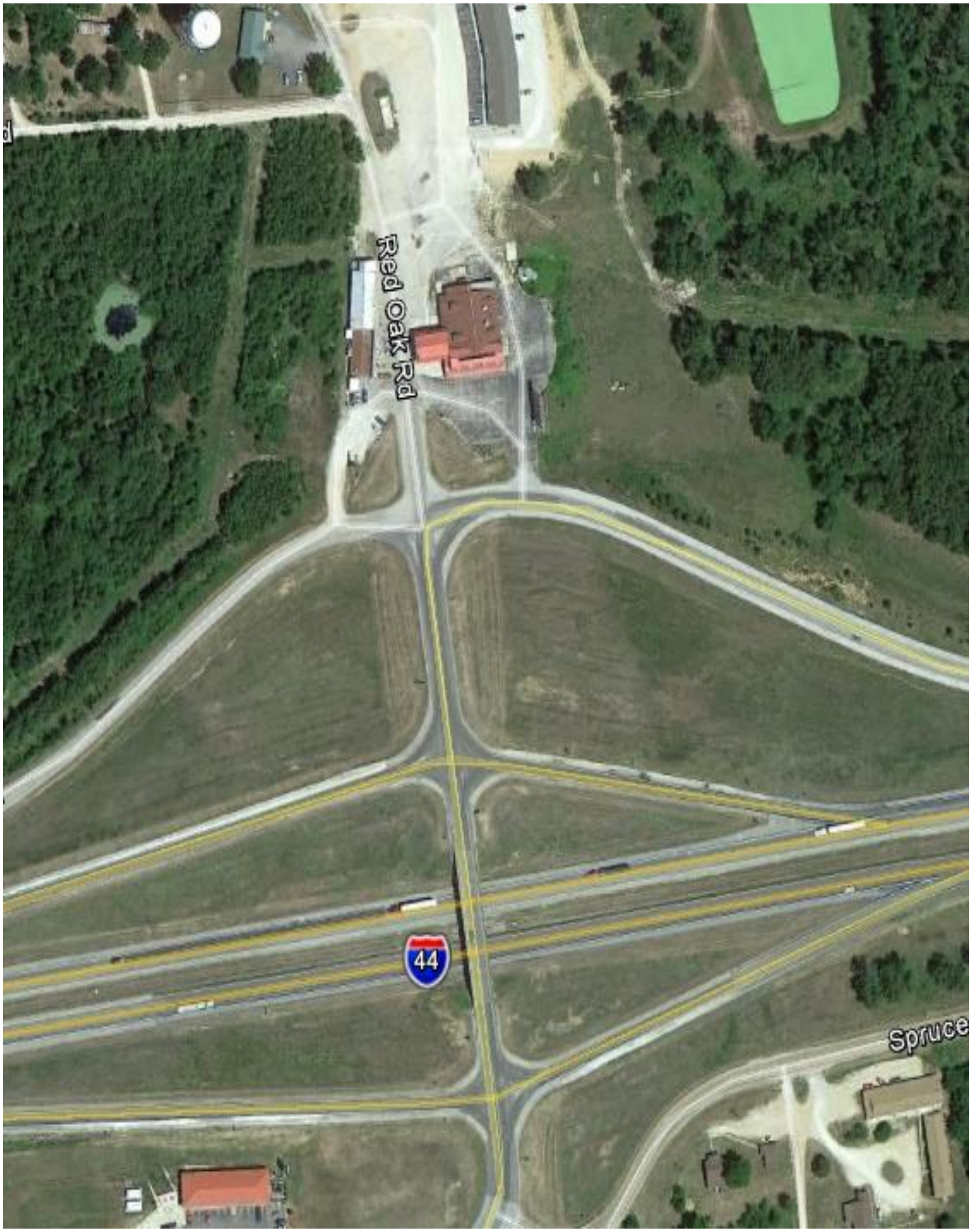
ID Number: 14
Main Highway: US 67
Crossroad: MO 72
Location: West of Fredericktown
County: Madison
District: Southeast

ID Number: 15
Main Highway: I-44
Crossroad: High Street
Location: Sarcoxie
County: Jasper
District: Southwest

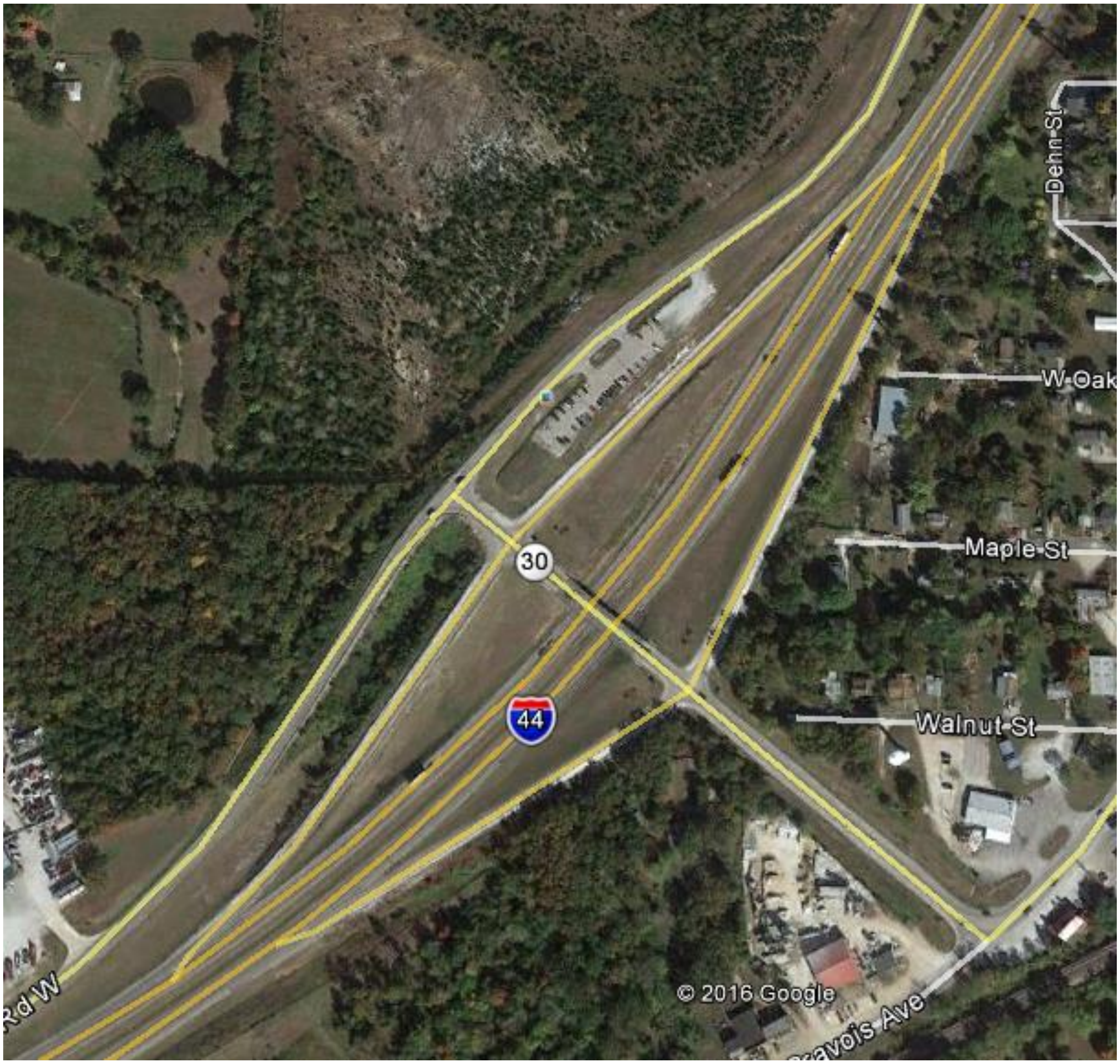
ID Number: 16
Main Highway: I-44
Crossroad: MO 37
Location: West of Sarcoxie
County: Jasper
District: Southwest

A.2 D4SCU Sites

ID Number: 1
Main Highway: I-44
Crossroad: MO 125
Location: Strafford
County: Greene
District: Southwest

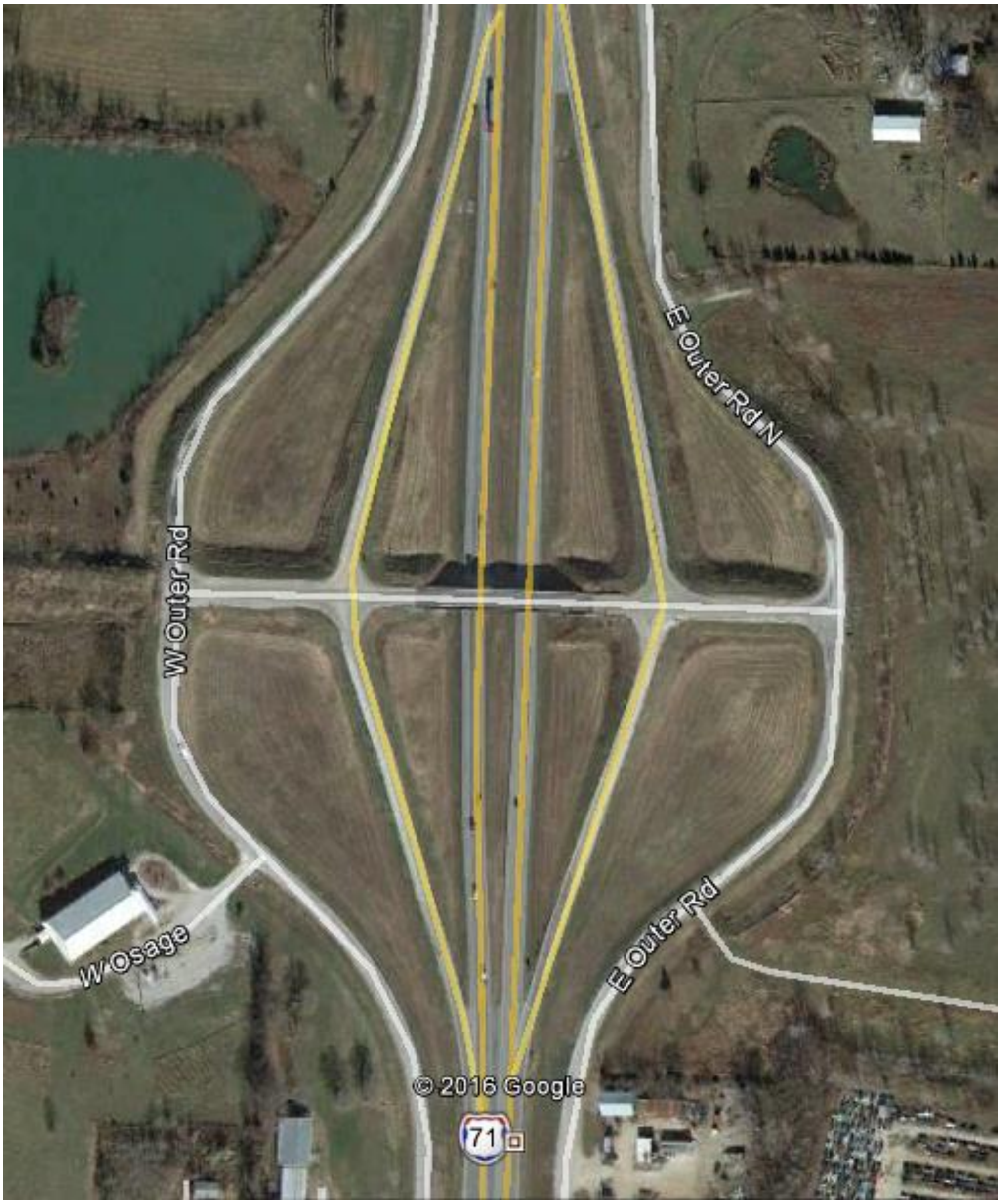


ID Number: 2
Main Highway: I-44
Crossroad: MO 17
Location: Buckhorn
County: Pulaski
District: Central



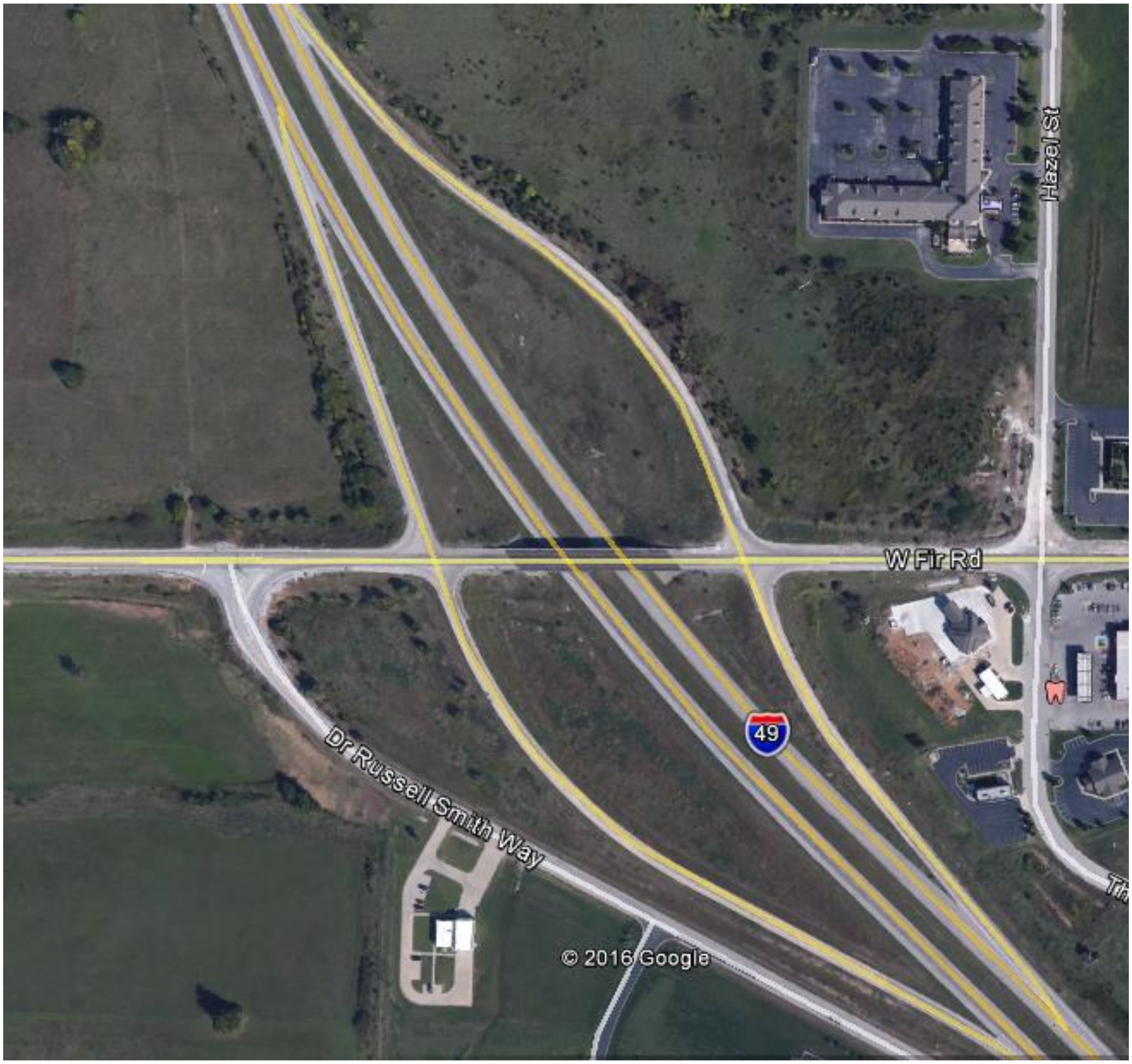
ID Number: 3
Main Highway: I-44
Crossroad: MO 30
Location: St. Clair
County: Franklin
District: St. Louis

ID Number: 4
Main Highway: I-49
Crossroad: Civil War Road
Location: Kendricktown
County: Jasper
District: Southwest

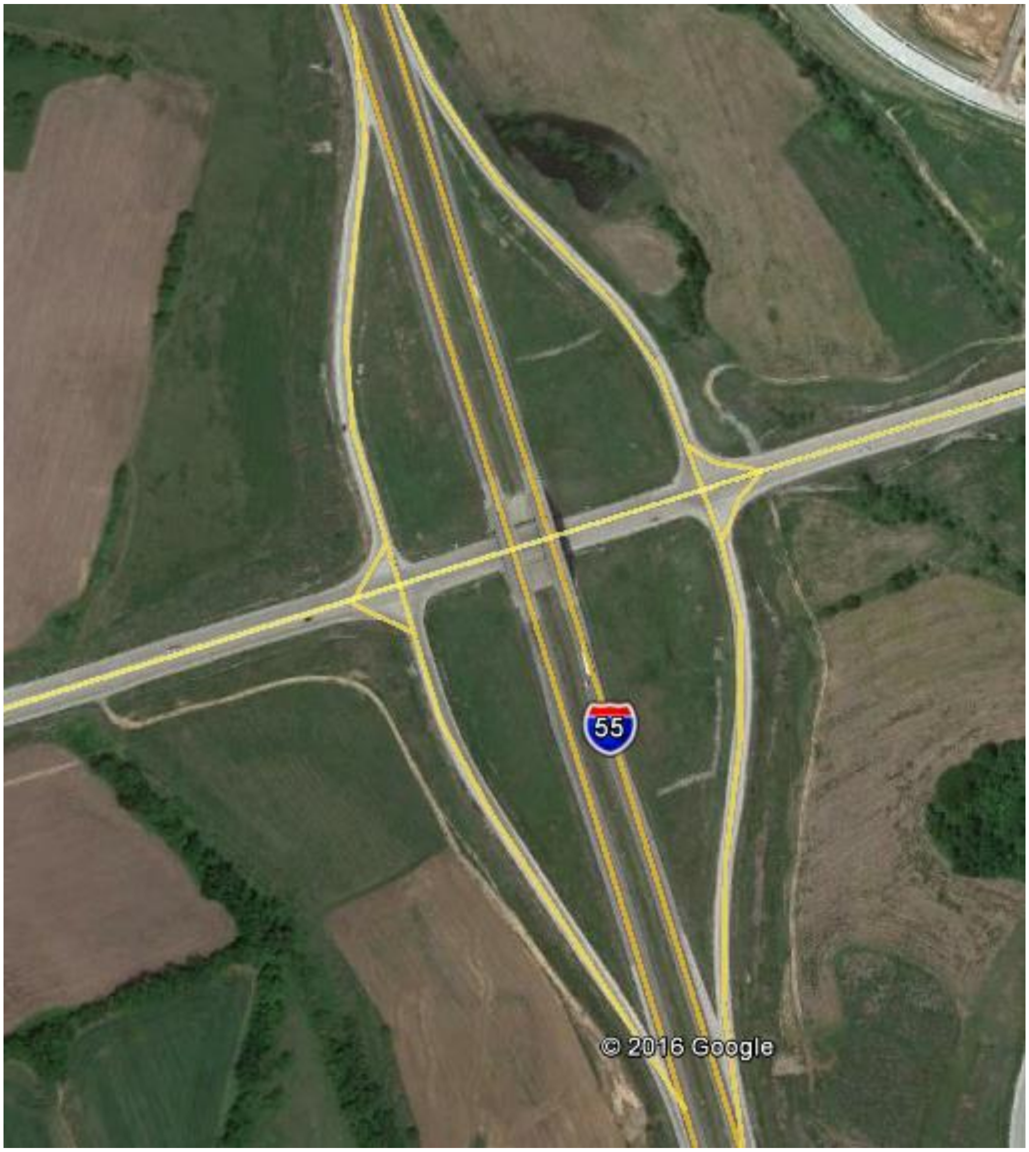


ID Number: 5
Main Highway: I-49
Crossroad: Outer Road/Industrial Parkway
Location: Nevada
County: Vernon
District: Southwest

ID Number: 6
Main Highway: I-49
Crossroad: MO 2/S. Commercial Street
Location: Harrisonville
County: Cass
District: Kansas City

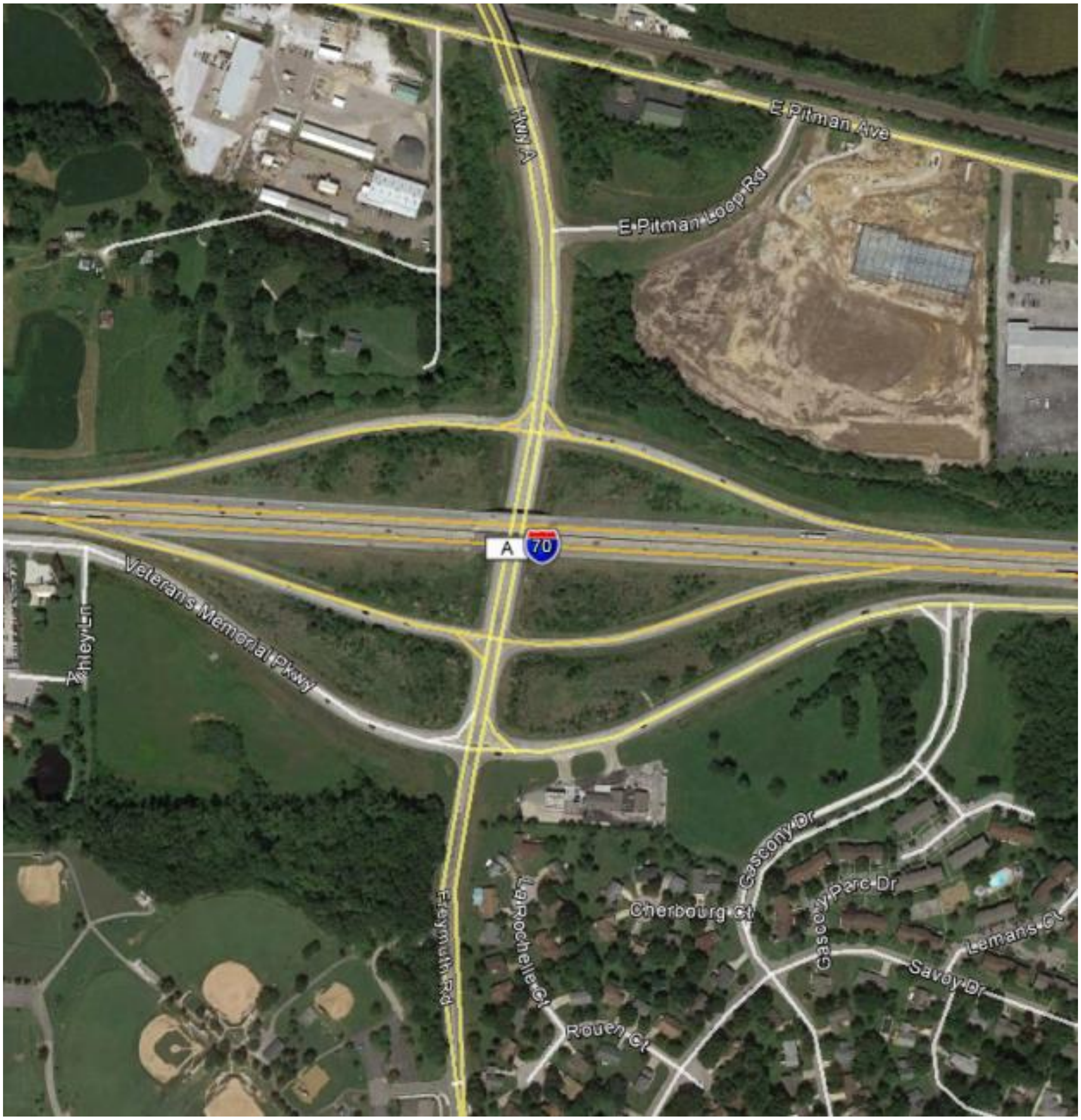


ID Number: 7
Main Highway: I-49
Crossroad: Route HH/W. Fir Road
Location: Carthage
County: Jasper
District: Southwest



ID Number: 8
Main Highway: I-55
Crossroad: Main Street/Lasalle Avenue
Location: Jackson
County: Cape Girardeau
District: Southeast

ID Number: 9
Main Highway: I-55
Crossroad: Route HH
Location: Miner
County: Scott
District: Southeast

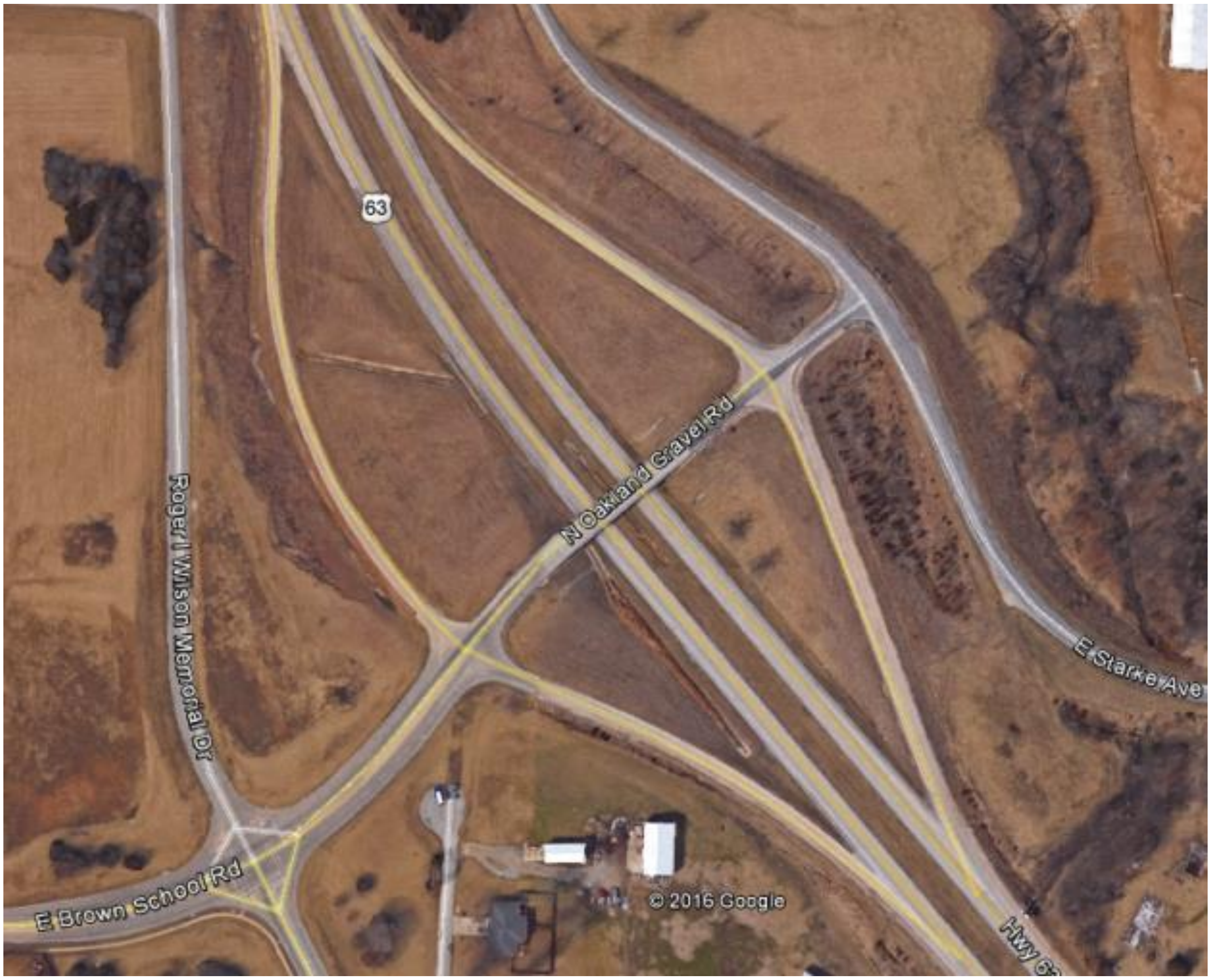


ID Number: 10
Main Highway: I-70
Crossroad: Route A
Location: Gilmore
County: St. Charles
District: St. Louis

ID Number: 11
Main Highway: I-435
Crossroad: MO 45
Location: East of Waldron
County: Platte
District: Kansas City

ID Number: 12
Main Highway: US 36
Crossroad: US 63/N. Missouri Street
Location: Macon
County: Macon
District: Northeast

ID Number: 13
Main Highway: US 63
Crossroad: N. Morley Street
Location: Moberly
County: Randolph
District: Northeast



ID Number: 14
Main Highway: US 63
Crossroad: N. Oakland Gravel Road
Location: Prathersville
County: Boone
District: Central

ID Number: 15
Main Highway: US 63
Crossroad: Route EE/E. Rollins Street
Location: Moberly
County: Randolph
District: Northeast

A.3 D4SG2 Sites

ID Number: 1
Main Highway: I-29
Crossroad: US 169/Rochester Road
Location: Country Club
County: Andrew
District: Northwest

ID Number: 2
Main Highway: I-44
Crossroad: Route H/Ichord Center
Location: Near Waynesville
County: Pulaski
District: Central

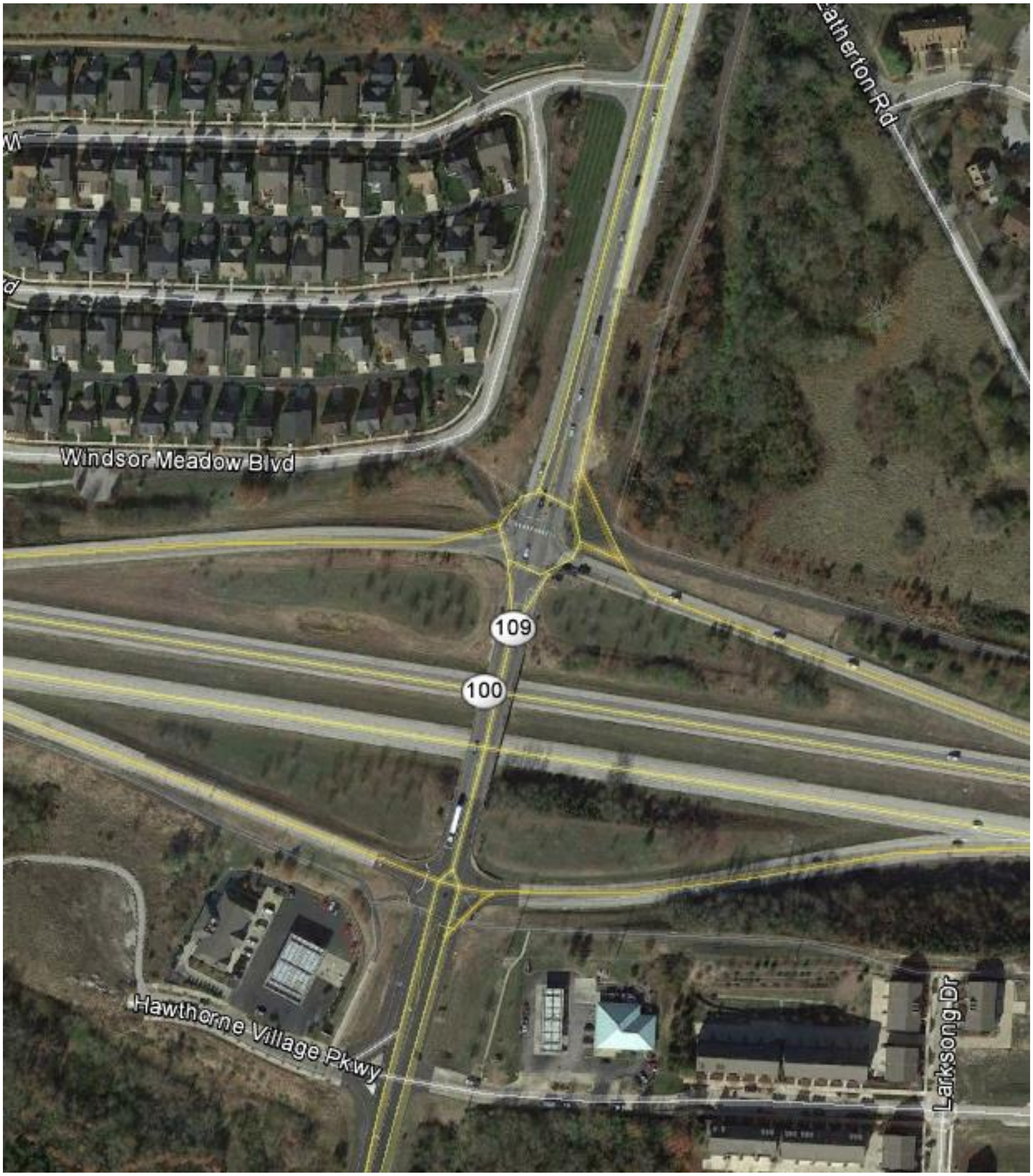
ID Number: 3
Main Highway: I-49
Crossroad: Route J/Route C
Location: Peculiar
County: Cass
District: Kansas City

ID Number: 5
Main Highway: I-55
Crossroad: MO 51/S. Perryville Blvd.
Location: Perryville
County: Perry
District: Southeast

ID Number: 6
Main Highway: US 24
Crossroad: MO 7
Location: Northeast of Independence
County: Jackson
District: Kansas City

ID Number: 7
Main Highway: US 61
Crossroad: MO 47
Location: Troy
County: Lincoln
District: Northeast

ID Number: 8
Main Highway: US 65
Crossroad: Route CC/Route J
Location: Fremont Hills
County: Christian
District: Southwest



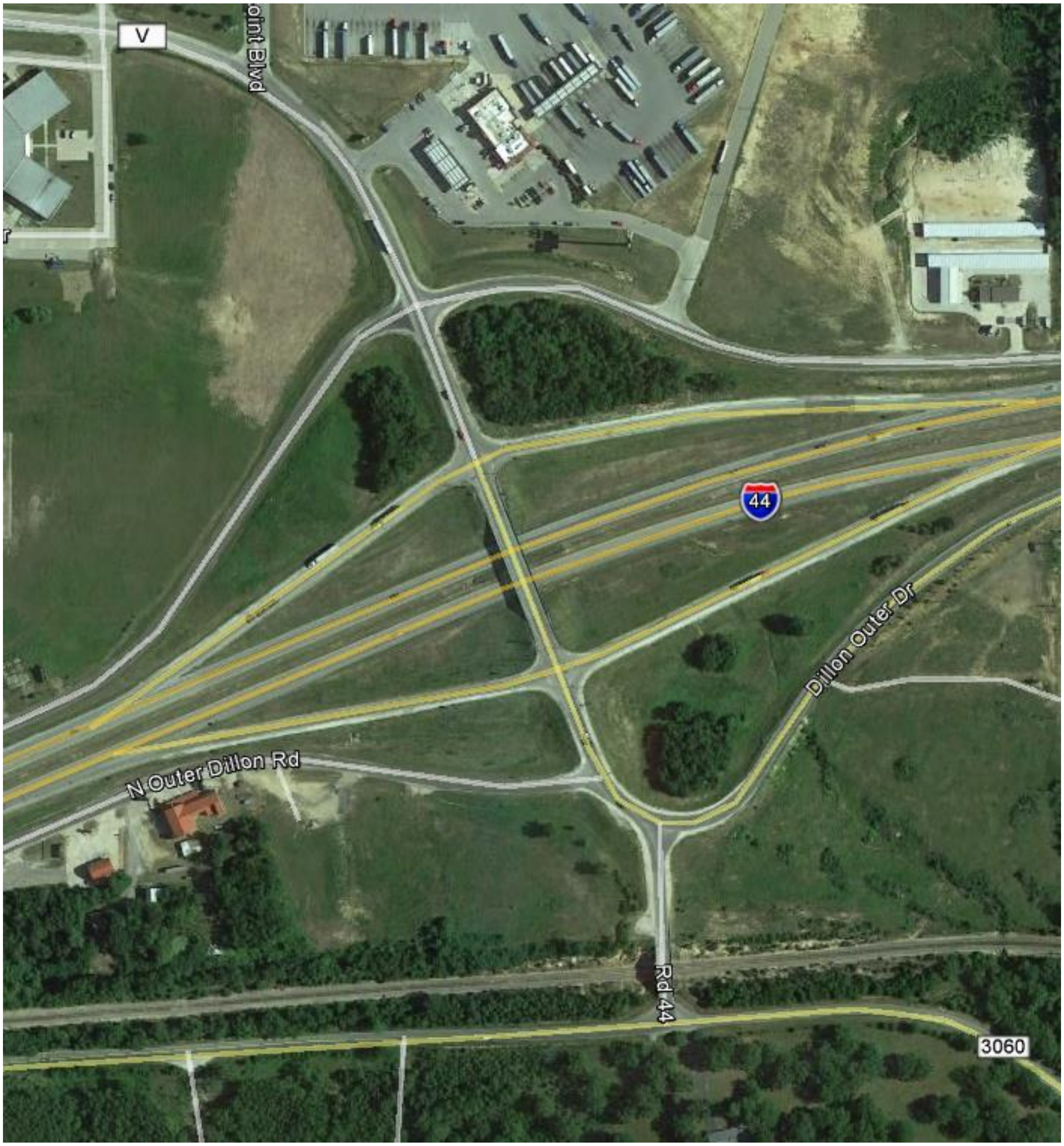
ID Number: 9
Main Highway: MO 100
Crossroad: MO 109
Location: Wildwood
County: St. Louis County
District: St. Louis

ID Number: 10
Main Highway: US 61
Crossroad: Route C
Location: Moscow Mills
County: Lincoln
District: Northeast

ID Number: 11
Main Highway: US 67
Crossroad: MO 32
Location: Leadington
County: St. Francois
District: Southeast

ID Number: 12
Main Highway: US 36
Crossroad: US 69
Location: Cameron
County: Clinton
District: Northwest

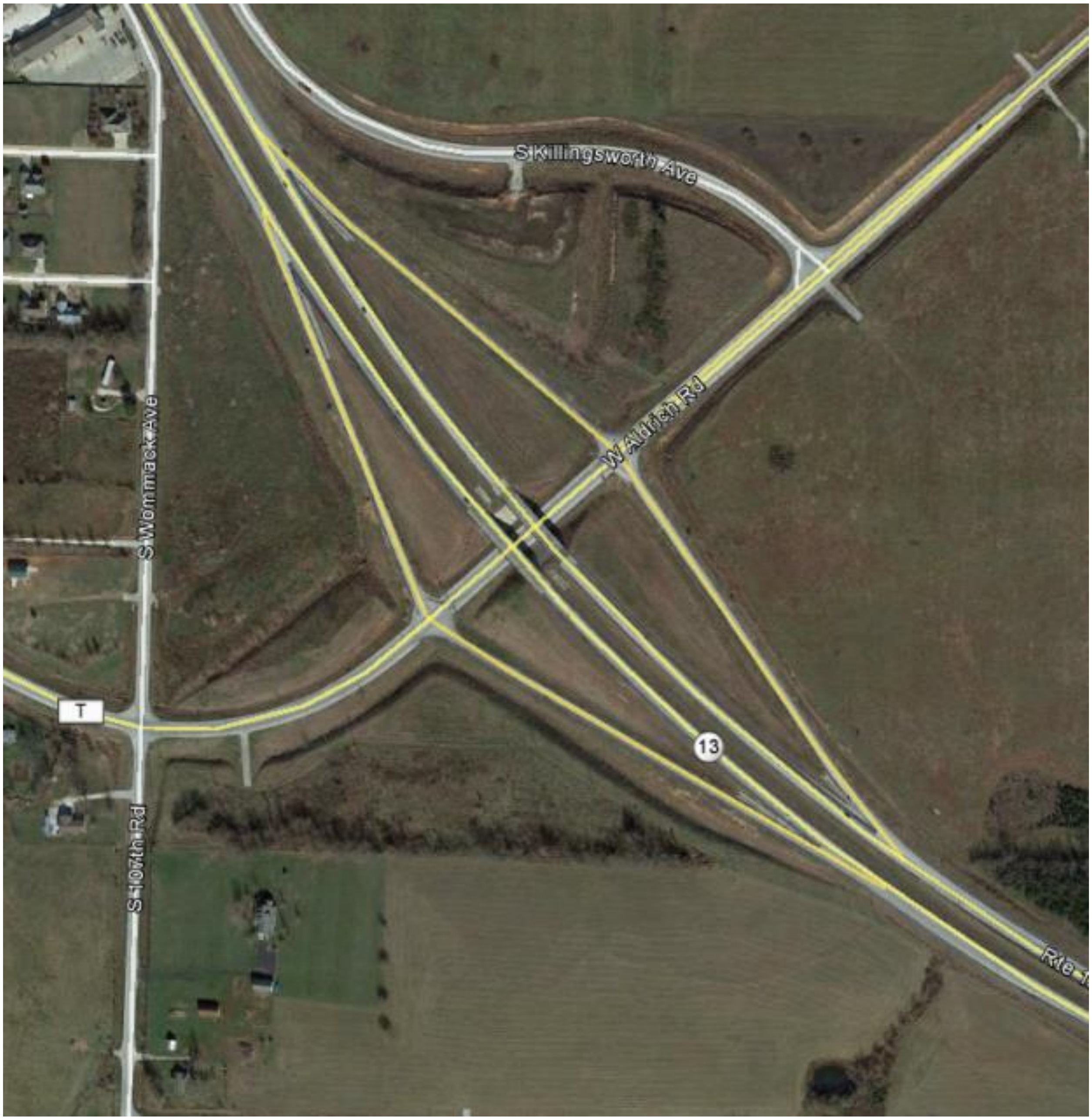
ID Number: 13
Main Highway: US 36
Crossroad: Route AC
Location: St. Joseph
County: Buchanan
District: Northwest



ID Number: 14
Main Highway: I-44
Crossroad: Hy Point Industrial Drive
Location: Near Dillon
County: Phelps
District: Central

ID Number: 15
Main Highway: MO 13
Crossroad: W. Broadway Street
Location: Bolivar
County: Polk
District: Southwest

ID Number: 16
Main Highway: US 60
Crossroad: MO 95
Location: Mountain Grove
County: Wright
District: Southeast



ID Number: 17
Main Highway: MO 13
Crossroad: Aldrich Road
Location: Bolivar
County: Polk
District: Southwest

ID Number: 18
Main Highway: US 65/Schoolcraft Freeway
Crossroad: Route YY/E. Division Street
Location: Springfield
County: Greene
District: Southwest

A.4 D4SG4 Sites

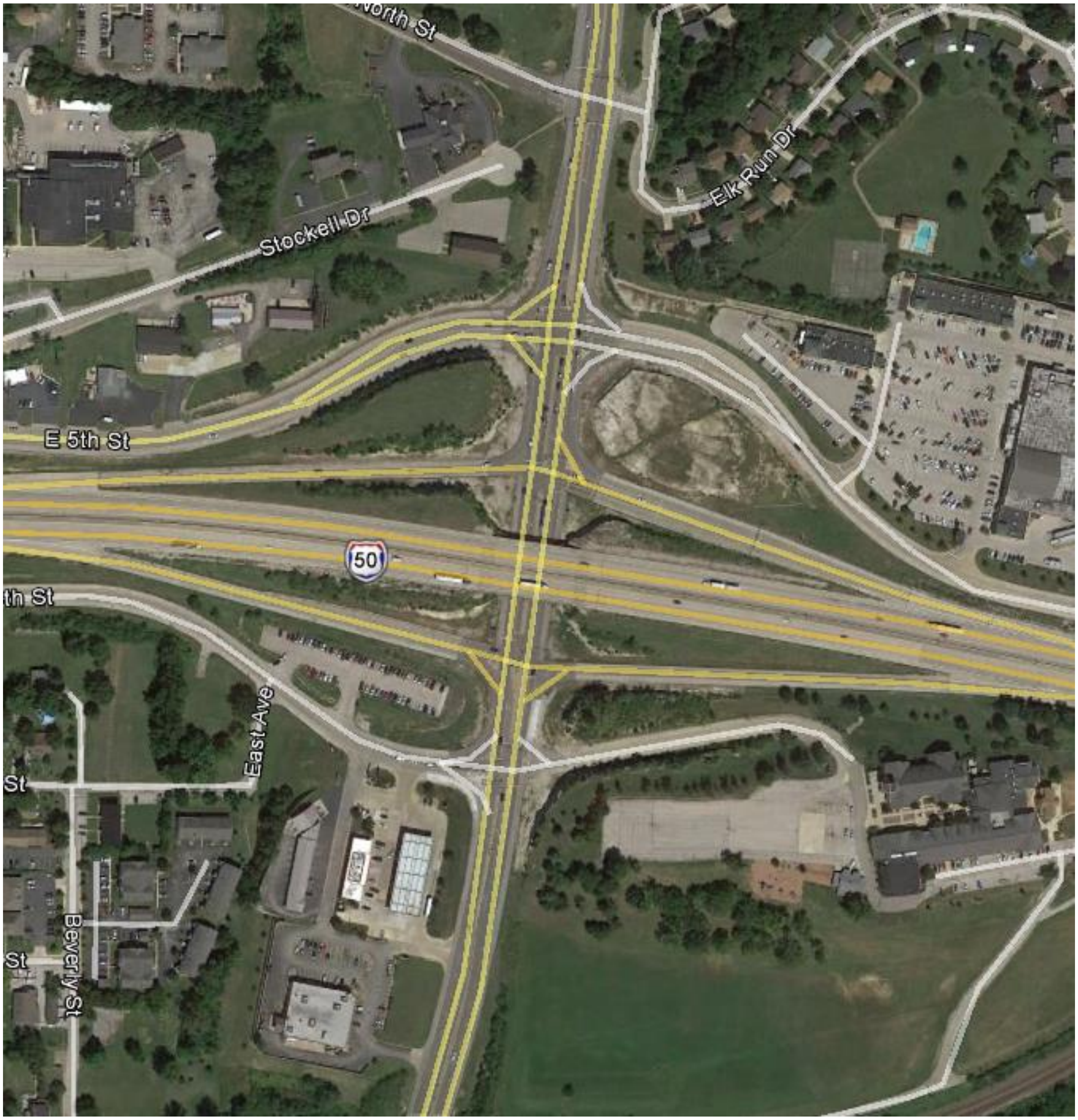
ID Number: 2
Main Highway: I-29
Crossroad: MO 6
Location: St. Joseph
County: Buchanan
District: Northwest

ID Number: 3
Main Highway: US 54
Crossroad: MO 179
Location: Jefferson City
County: Cole
District: Central

ID Number: 4
Main Highway: US 65
Crossroad: W. Jackson Street
Location: Ozark
County: Christian
District: Southwest

ID Number: 5
Main Highway: I-72/MO 110
Crossroad: MO 79
Location: Hannibal
County: Marion
District: Northeast

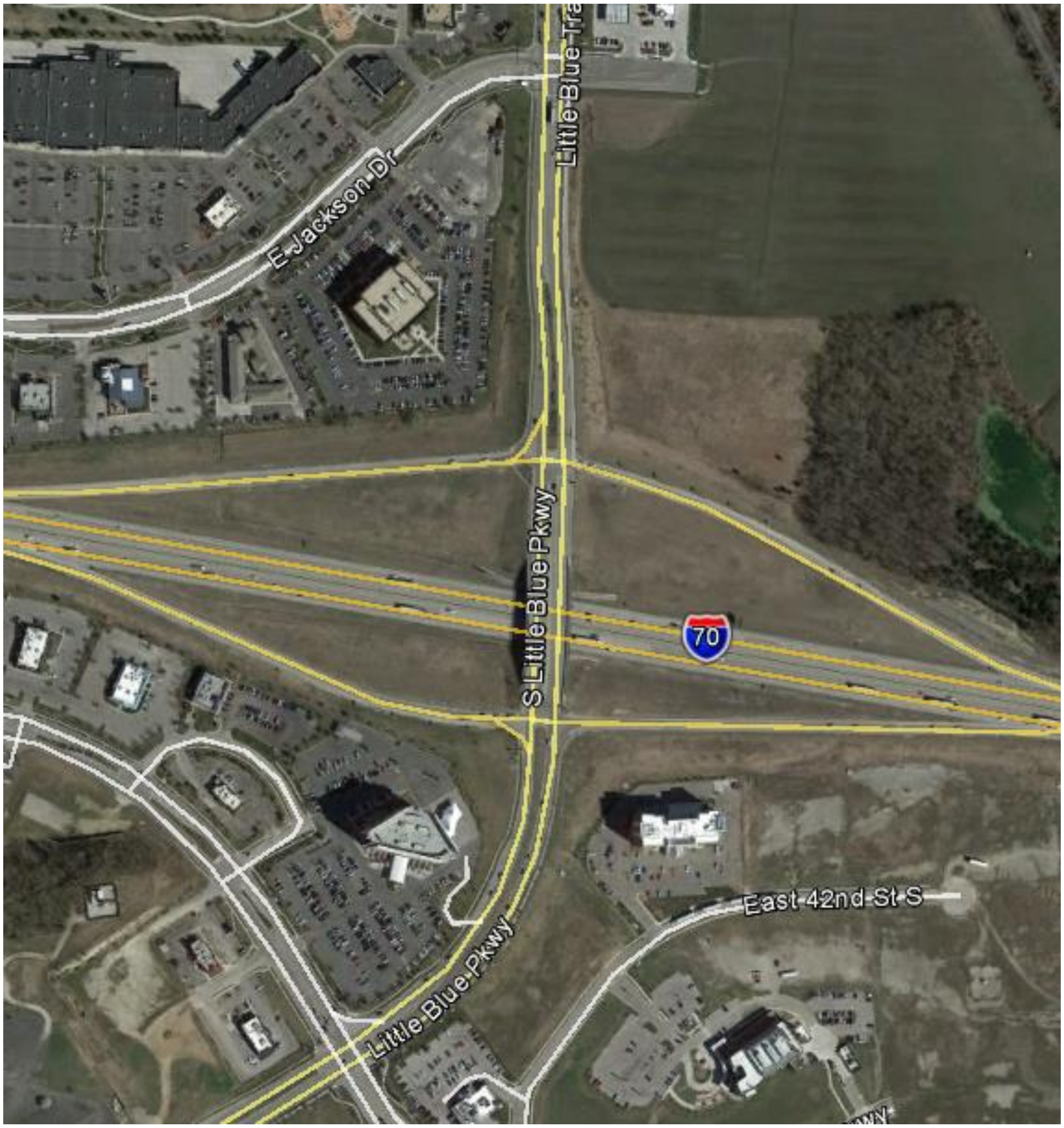
ID Number: 6
Main Highway: I-64
Crossroad: S. Mason Road
Location: Northwest of Town and Country
County: St. Louis County
District: St. Louis



ID Number: 7
Main Highway: I-44
Crossroad: MO 109
Location: Eureka
County: St. Louis County
District: St. Louis

ID Number: 8
Main Highway: I-70
Crossroad: Bryan Road
Location: O'Fallon
County: St. Charles
District: St. Louis

ID Number: 9
Main Highway: I-29
Crossroad: NW 112th Street
Location: Ferrelview
County: Platte
District: Kansas City



ID Number: 11
Main Highway: I-70
Crossroad: Little Blue Parkway
Location: Independence
County: Jackson
District: Kansas City

ID Number: 12
Main Highway: US 60
Crossroad: MO 25/E. Business US 60
Location: Dexter
County: Stoddard
District: Southeast

ID Number: 13
Main Highway: US 60
Crossroad: US 61/US 62
Location: Sikeston
County: New Madrid
District: Southeast

ID Number: 14
Main Highway: US 67
Crossroad: MO 180
Location: St. Ann
County: St. Louis County
District: St. Louis

ID Number: 15
Main Highway: US 61
Crossroad: Route A
Location: Wentzville
County: St. Charles
District: St. Louis

ID Number: 16
Main Highway: I-49
Crossroad: US 60
Location: Near Neosho
County: Newton
District: Southwest

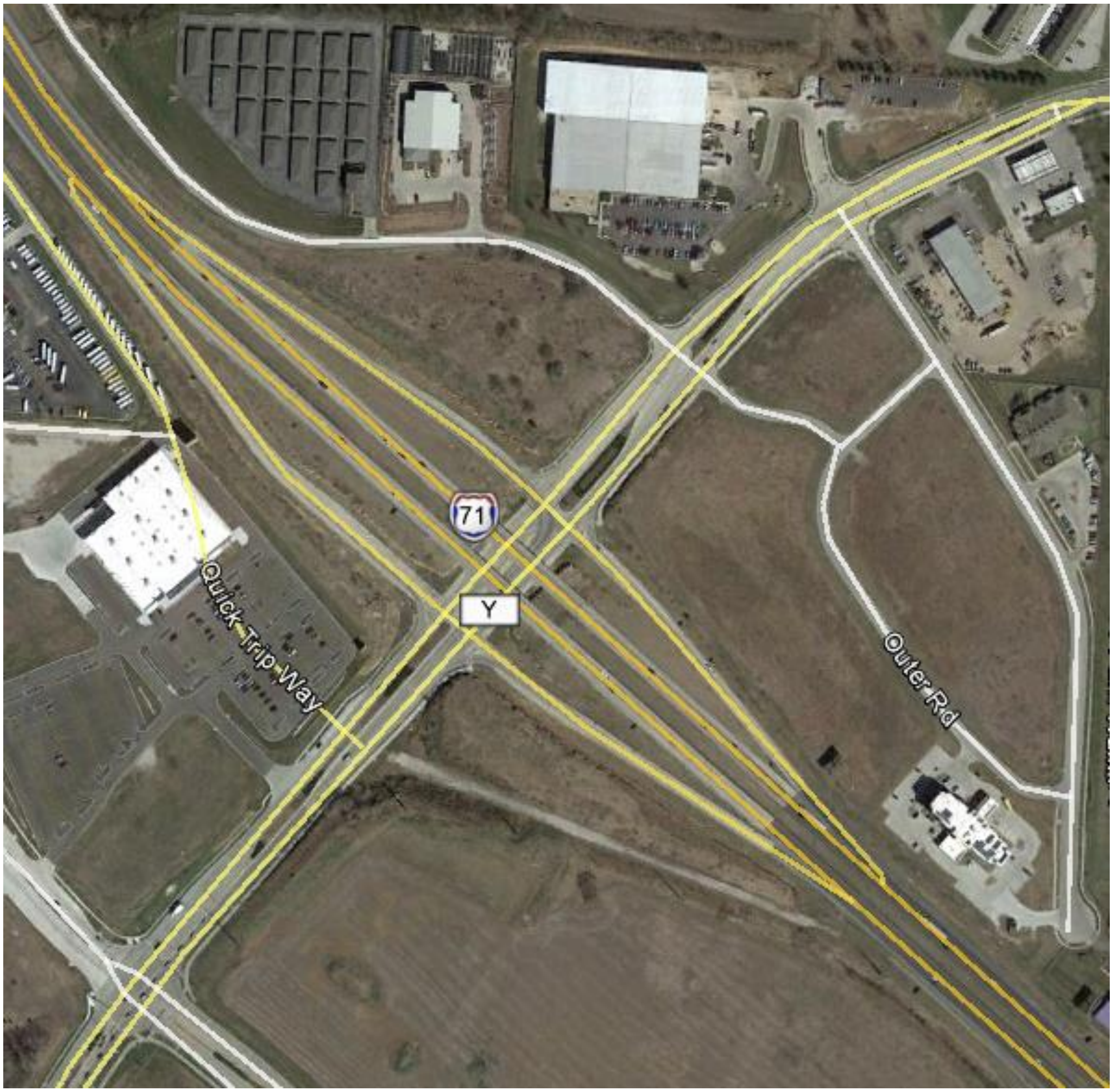
ID Number: 17
Main Highway: US 60
Crossroad: MO 413
Location: Brookline
County: Greene
District: Southwest

ID Number: 18
Main Highway: I-55
Crossroad: US 61
Location: Fruitland
County: Cape Girardeau
District: Southeast

ID Number: 19
Main Highway: I-44
Crossroad: MO 64/MO 5
Location: Lebanon
County: Laclede
District: Central

ID Number: 20
Main Highway: US 50
Crossroad: Eastland Drive
Location: Jefferson City
County: Cole
District: Central

A.5 D4SG6 Sites



ID Number: 1
Main Highway: I-49
Crossroad: E. 163rd Street
Location: Belton
County: Cass
District: Kansas City

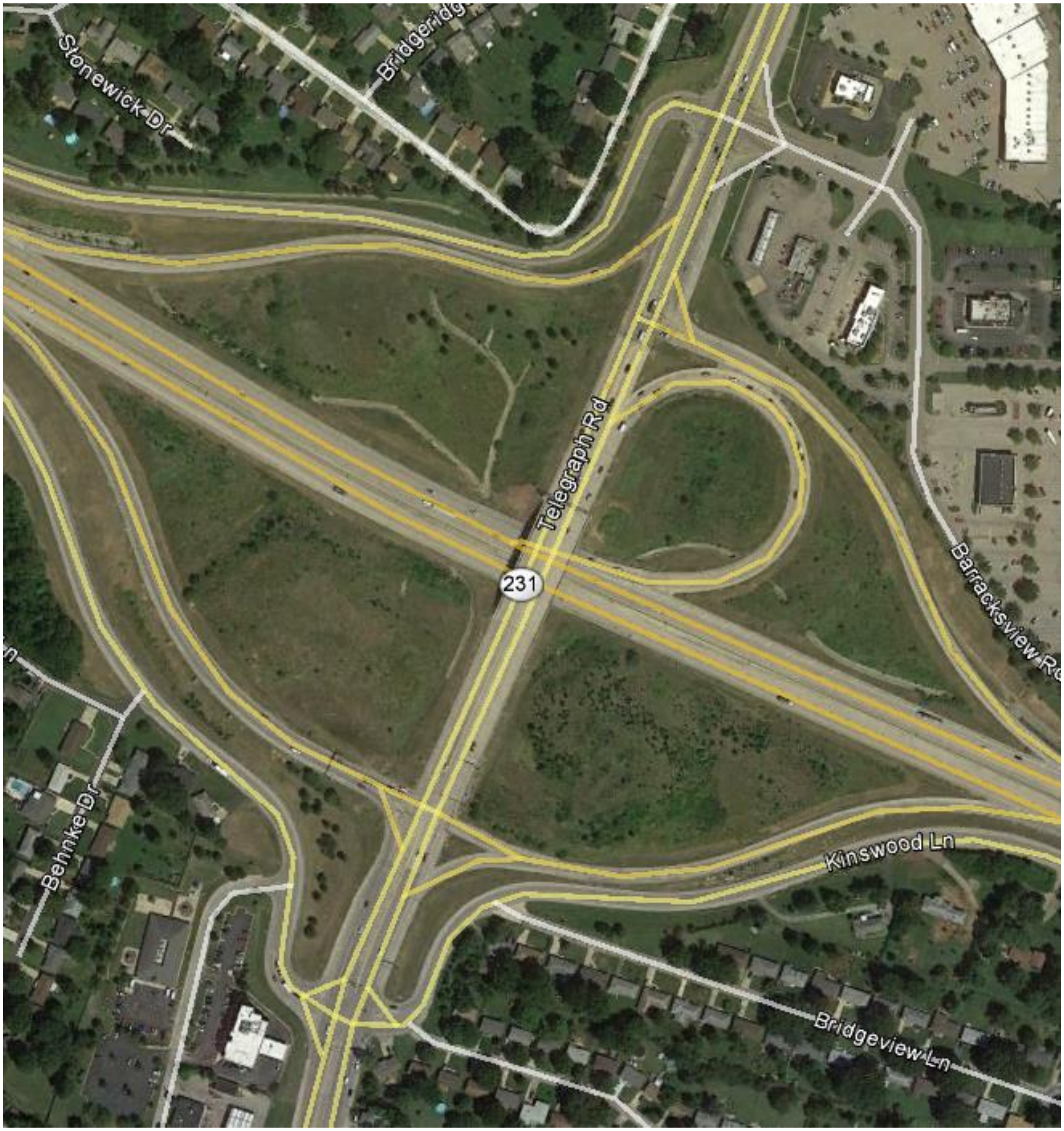
ID Number: 2
Main Highway: I-70
Crossroad: Noland Road
Location: Independence
County: Jackson
District: Kansas City

ID Number: 5
Main Highway: I-435
Crossroad: MO 210
Location: Randolph
County: Clay
District: Kansas City

ID Number: 6
Main Highway: I-55
Crossroad: Butler Hill Road
Location: Concord
County: St. Louis County
District: St. Louis

ID Number: 8
Main Highway: I-70
Crossroad: Lake Street
Location: Gilmore
County: St. Charles
District: St. Louis

ID Number: 9
Main Highway: MO 364
Crossroad: Bennington Place
Location: Maryland Heights
County: St. Louis County
District: St. Louis



ID Number: 10
Main Highway: I-255
Crossroad: MO 231/Telegraph Road
Location: Mehlville
County: St. Louis County
District: St. Louis

ID Number: 11
Main Highway: US 65
Crossroad: MO 14/West Jackson Street
Location: Ozark
County: Christian
District: Southwest

ID Number: 12
Main Highway: I-55
Crossroad: William Street/Route K
Location: Cape Girardeau
County: Cape Girardeau
District: Southeast

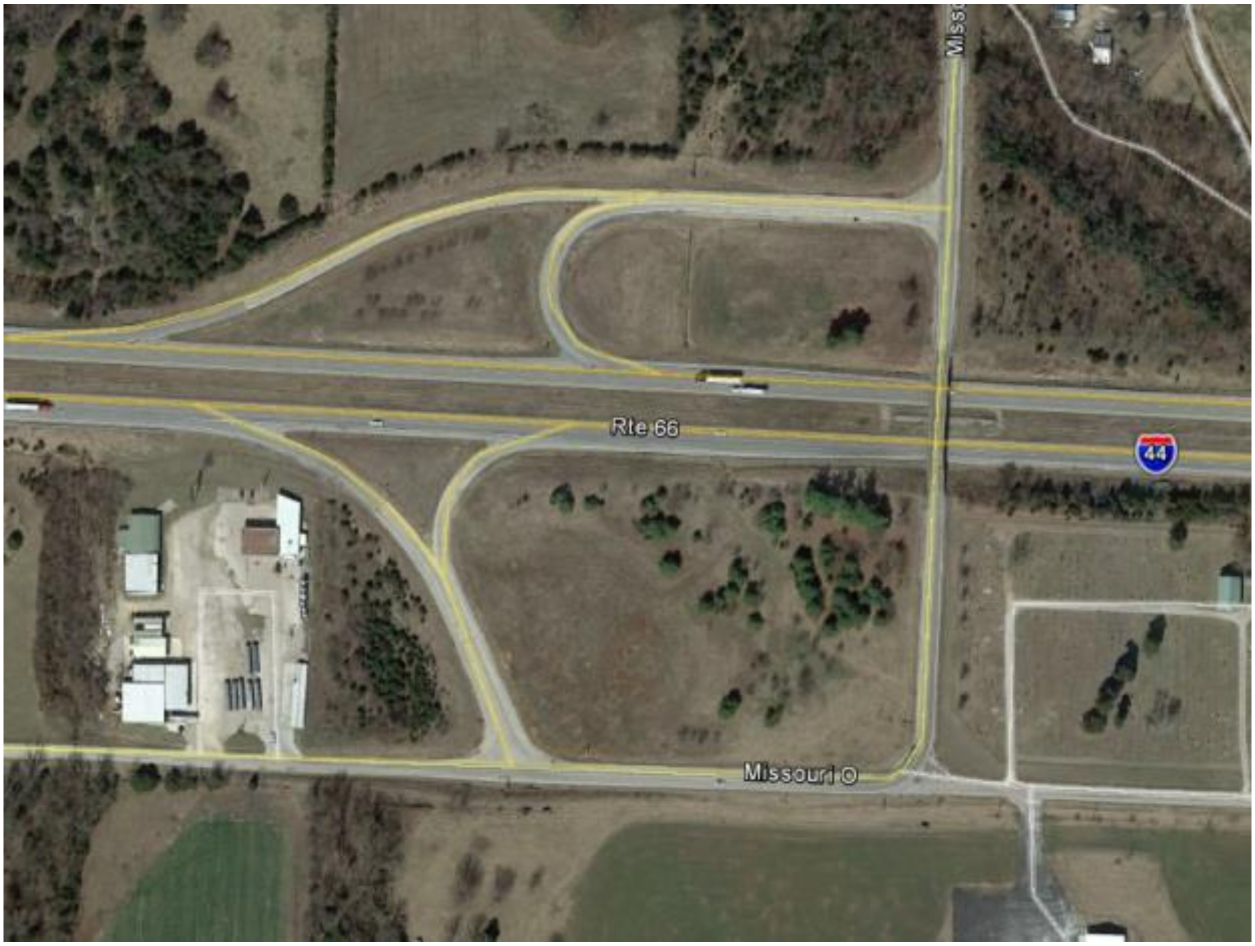
A.6 A2SCR Sites

ID Number: 1
Main Highway: I-29
Crossroad: Route K
Location: West of Savannah
County: Andrew
District: Northwest

ID Number: 2
Main Highway: US 24/US 61
Crossroad: MO 168
Location: Palmyra
County: Marion
District: Northeast

ID Number: 3
Main Highway: US 24
Crossroad: 13th Street
Location: Lexington
County: Lafayette
District: Kansas City

ID Number: 4
Main Highway: US 24
Crossroad: MO 13
Location: Lexington
County: Lafayette
District: Kansas City



ID Number: 5
Main Highway: I-44
Crossroad: Route Z/Route O
Location: Northeast of Mt. Vernon
County: Lawrence
District: Southwest

ID Number: 6
Main Highway: MO-7/MO-13
Crossroad: MO 52
Location: Clinton
County: Henry
District: Southwest

ID Number: 7
Main Highway: I-49/US 71
Crossroad: Route H
Location: South of Anderson
County: McDonald
District: Southwest

ID Number: 8
Main Highway: US 36
Crossroad: MO 3
Location: West of Macon
County: Macon
District: Northeast

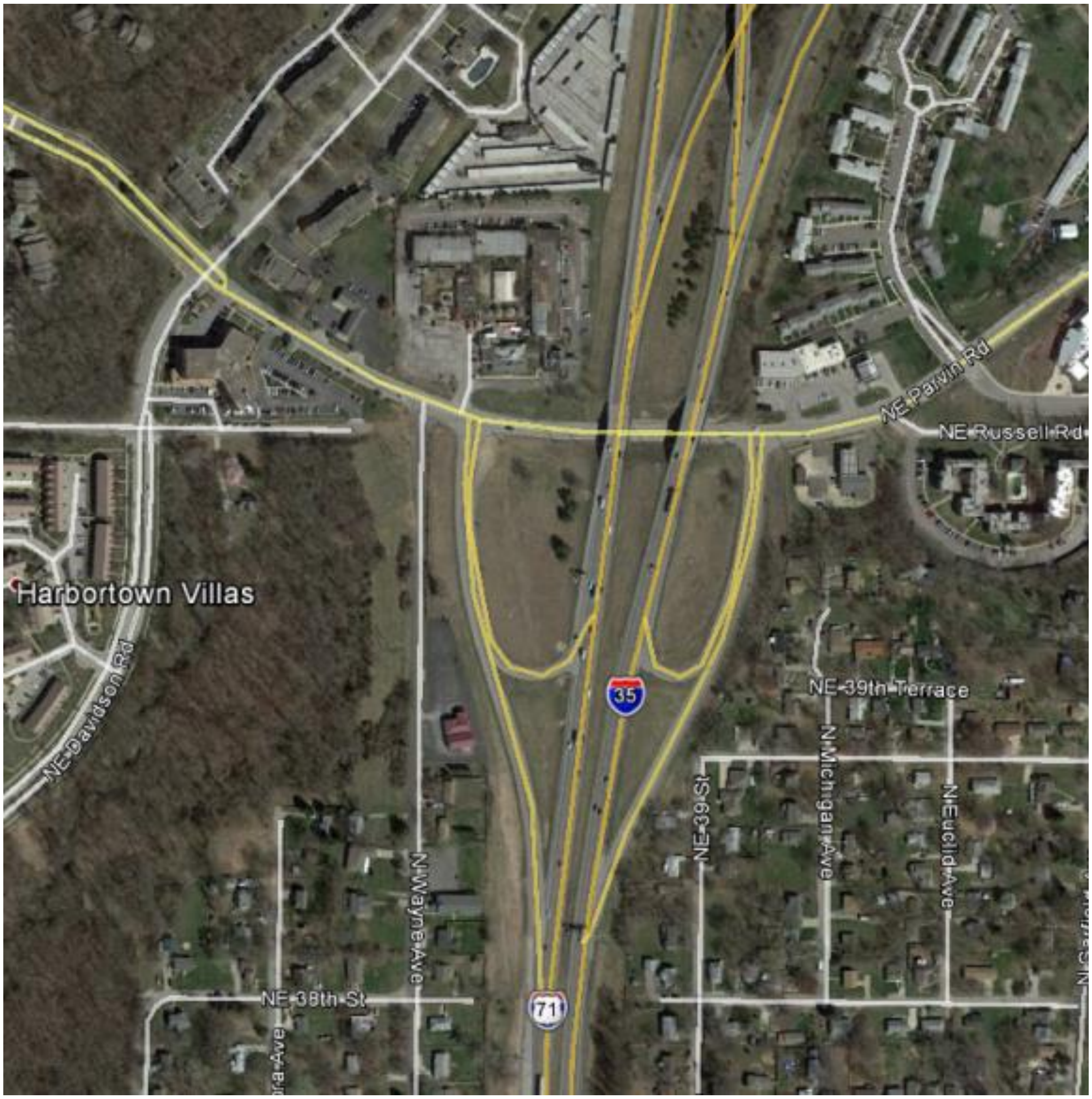
ID Number: 9
Main Highway: US 54
Crossroad: Route M
Location: Eldon
County: Miller
District: Central

A.7 A2SCU Sites

ID Number: 1
Main Highway: US 36
Crossroad: S. 22nd Street
City: St. Joseph
County: Buchanan
District: Northwest

ID Number: 2
Main Highway: I-29/I-435/US 71
Crossroad: Mexico City Avenue
City: Platte City
County: Platte
District: Kansas City

ID Number: 3
Main Highway: I-29
Crossroad: NW Vivion Rd/US 69
Location: East of Riverside
County: Clay
District: Kansas City



ID Number: 4
Main Highway: I-35
Crossroad: NE Parvin Road
Location: North of North Kansas City
County: Clay
District: Kansas City

ID Number: 5
Main Highway: I-70
Crossroad: Manchester Trafficway/Raytown Road
City: Kansas City
County: Jackson
District: Kansas City

ID Number: 6
Main Highway: US 169/Arrowhead Trafficway
Crossroad: NE Cookingham Drive/MO 291
Location: South of Smithville
County: Clay
District: Kansas City

ID Number: 7
Main Highway: I-435
Crossroad: NE Cookingham Drive/MO 291
Location: Northwest of Liberty
County: Clay
District: Kansas City

ID Number: 8
Main Highway: I-49/MO 7/US 71
Crossroad: W. Wall Street/MO 2
City: Harrisonville
County: Cass
District: Kansas City

ID Number: 9
Main Highway: Route M
Crossroad: Old MO 21
Location: North of Hillsboro
County: Jefferson
District: St. Louis

ID Number: 10
Main Highway: US 54/US 63
Crossroad: Cedar City Drive/Route W
City: Jefferson City
County: Callaway
District: Central

ID Number: 11
Main Highway: US 67
Crossroad: Fairground Rd
Location: North of Farmington
County: St. Francois
District: Southeast

ID Number: 12
Main Highway: I-255/US 50
Crossroad: Koch Road
City: Oakville
County: St. Louis County
District: St. Louis

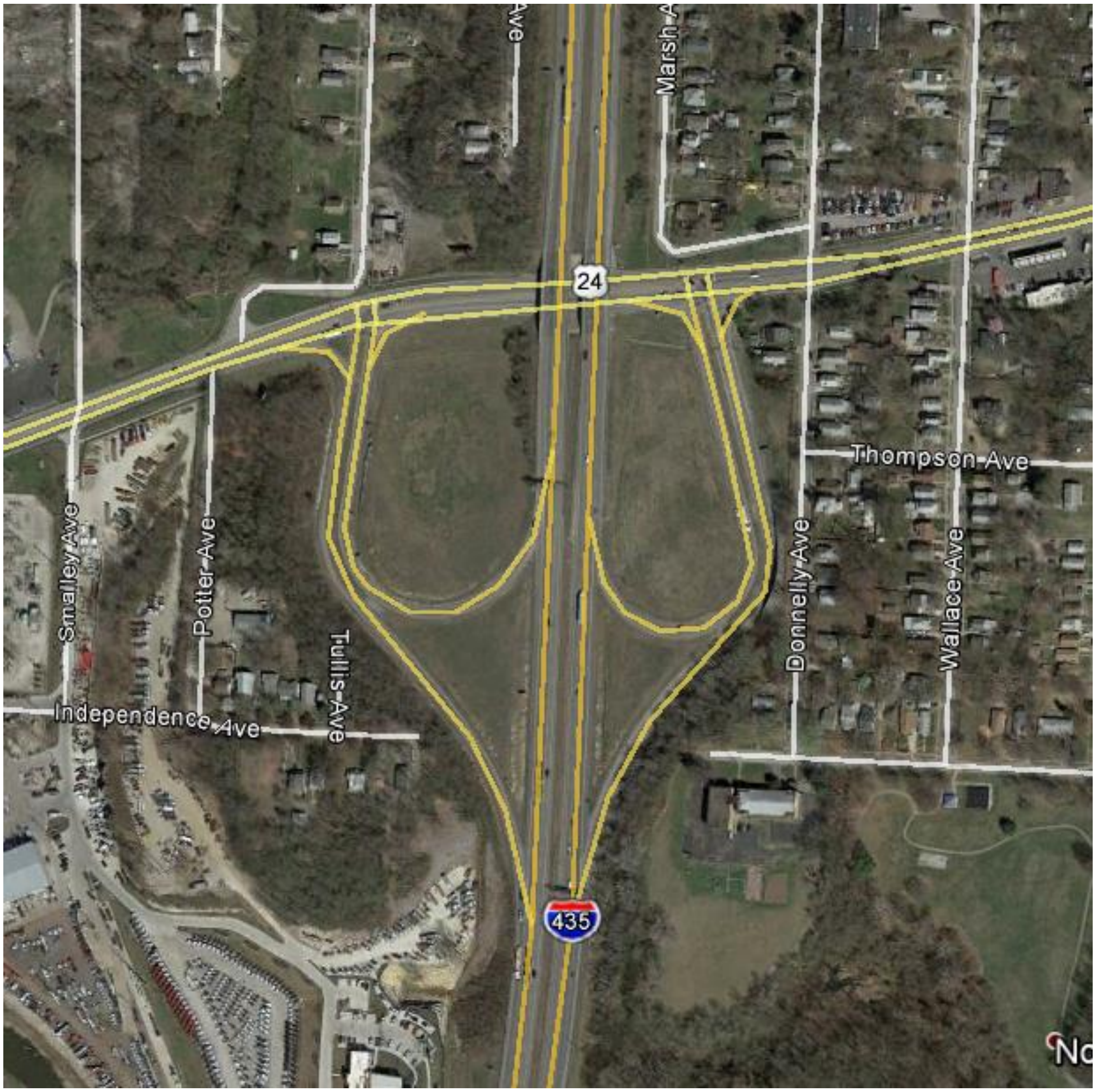
ID Number: 13
Main Highway: US 50
Crossroad: Big Horn Drive
Location: West of Jefferson City
County: Cole
District: Central

ID Number: 15
Main Highway: US 60
Crossroad: N 1 Mile Road
City: Dexter
County: Stoddard
District: Southeast

ID Number: 16
Main Highway: I-55
Crossroad: MO 74
City: Cape Girardeau
County: Cape Girardeau
District: Southeast

A.8 A2SG4 Sites

ID Number: 1
Main Highway: I-470/MO 291
Crossroad: E. 39th Street
Location: South of Independence
County: Jackson
District: Kansas City



ID Number: 2
Main Highway: I-435/US 24
Crossroad: E. Winner Road
City: Kansas City
County: Jackson
District: Kansas City

ID Number: 3
Main Highway: US 54/Business 50
Crossroad: Missouri Boulevard
City: Jefferson City
County: Cole
District: Central

ID Number: 4
Main Highway: I-64/US 40
Crossroad: Lake St. Louis Boulevard
City: Lake St. Louis
County: St. Charles
District: St. Louis

ID Number: 5
Main Highway: I-170/Inner Belt Expressway
Crossroad: Ladue Road
City: Clayton
County: St. Louis County
District: St. Louis

ID Number: 6
Main Highway: I-49/US 49
Crossroad: Route FF/E. 32nd Street
Location: Joplin
County: Jasper
District: Southwest

ID Number: 7
Main Highway: I-55
Crossroad: US 62
City: Sikeston
County: Scott
District: Southeast

ID Number: 8
Main Highway: US 65
Crossroad: MO 76/W. Main Street
City: Branson
County: Taney
District: Southeast

ID Number: 9
Main Highway: US 63
Crossroad: US 24
City: Moberly
County: Randolph
District: Central

ID Number: 10
Main Highway: US 50
Crossroad: W. Truman Boulevard
City: Jefferson City
County: Cole
District: Central

ID Number: 11
Main Highway: I-44
Crossroad: MO 266/W. Chestnut Expressway
City: Springfield
County: Greene
District: Southwest

A.9 SCLREN/EX Sites

ID Number: 1
Main Highway: I-35
Crossroad: Route N
Location: East of Eagleville
County: Harrison
District: Northwest

ID Number: 2
Main Highway: US 24
Crossroad: 13th Street
Location: Lexington
County: Lafayette
District: Kansas City

ID Number: 3
Main Highway: US 36
Crossroad: Route C/O
Location: Bevier
County: Macon
District: Northeast

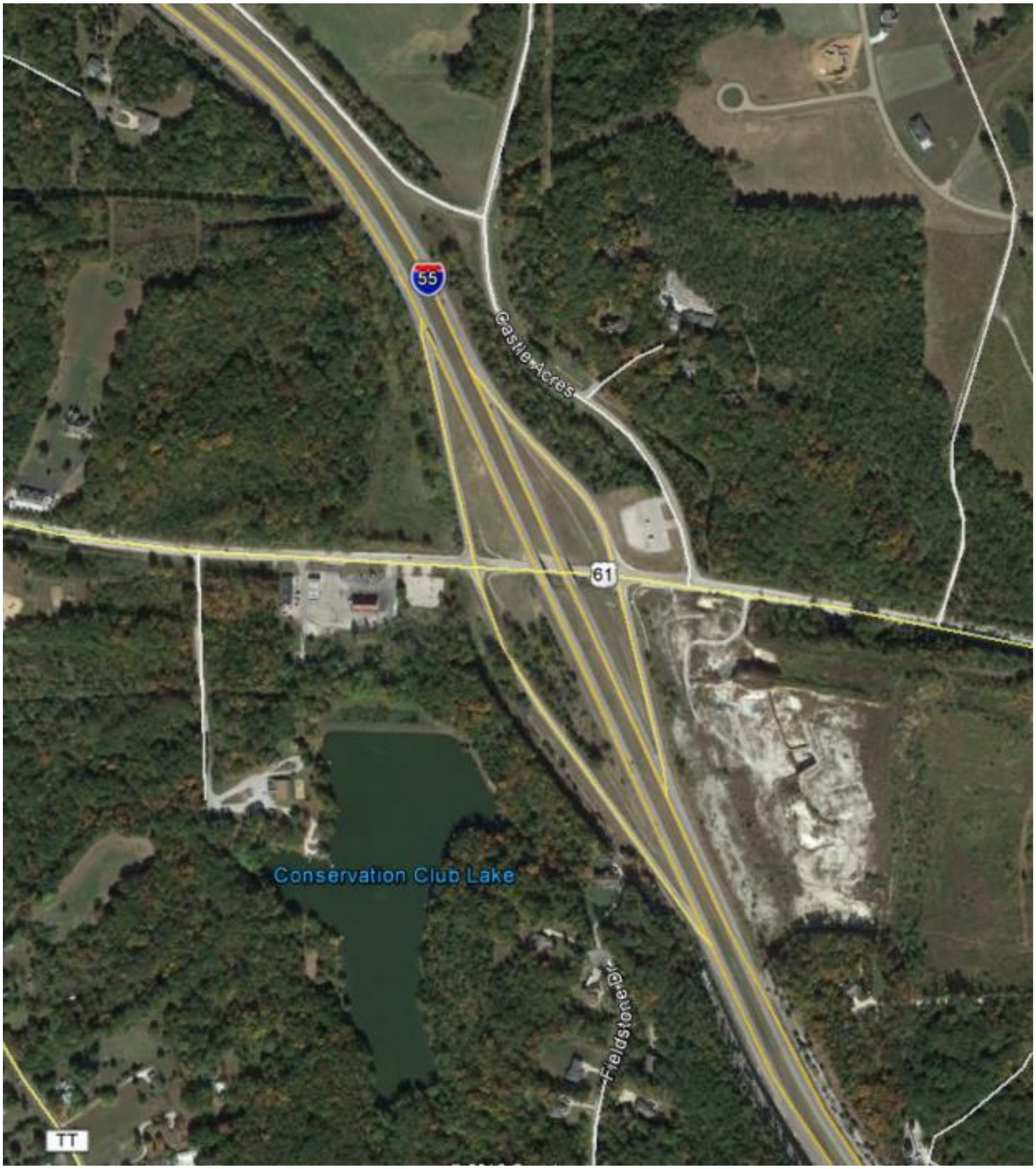
ID Number: 4
Main Highway: I-35
Crossroad: Route DD
Location: South of Pattonsburg
County: Daviess
District: Northwest

ID Number: 5
Main Highway: MO 7/MO 5
Crossroad: Pier 31 Road
Location: Northeast of Camdenton
County: Camden
District: Central

ID Number: 6
Main Highway: I-70
Crossroad: MO 13
Location: South of Higginsville
County: Lafayette
District: Kansas City

ID Number: 7
Main Highway: I-44
Crossroad: Route B
Location: North of Northview
County: Webster
District: Southwest

ID Number: 8
Main Highway: I-70
Crossroad: Route M/O
Location: East of Odessa
County: Lafayette
District: Kansas City



ID Number: 9
Main Highway: I-55
Crossroad: US 61
Location: South of Festus
County: Jefferson
District: St. Louis

ID Number: 10
Main Highway: MO 21
Crossroad: Old MO 21
Location: South of Otto
County: Jefferson
District: St. Louis

ID Number: 11
Main Highway: I-44
Crossroad: Route K/Route PP
Location: Plano
County: Greene
District: Southwest

ID Number: 12
Main Highway: I-29
Crossroad: Route K
Location: North of Amazonia
County: Andrew
District: Northwest

ID Number: 13
Main Highway: US 36
Crossroad: MO 3
Location: Callao
County: Macon
District: Northeast

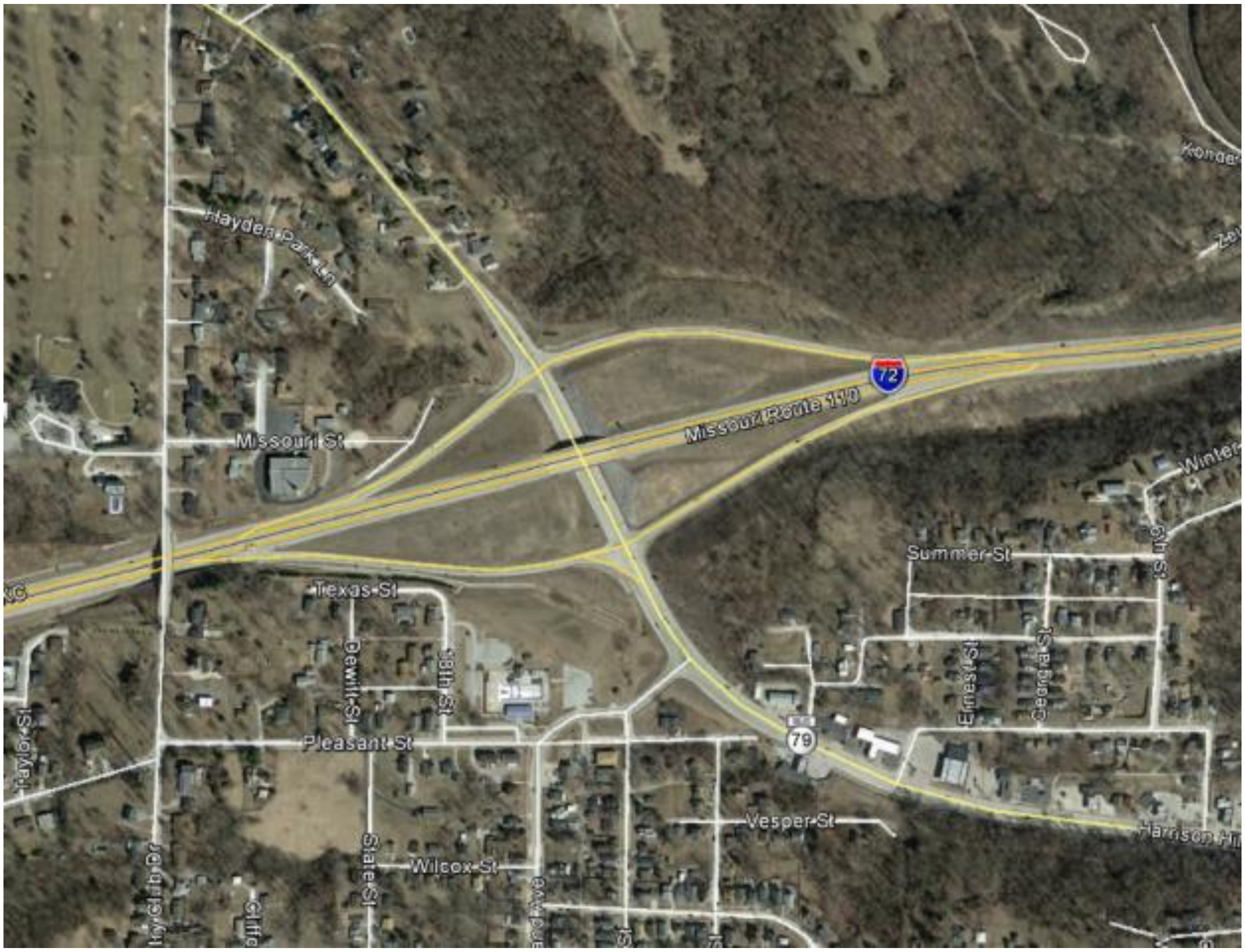
ID Number: 14
Main Highway: I-55
Crossroad: Route U/Route J
Location: South of Hayti
County: Pemiscot
District: Southeast

ID Number: 15
Main Highway: US 67
Crossroad: MO 72
Location: Fredericktown
County: Madison
District: Southeast

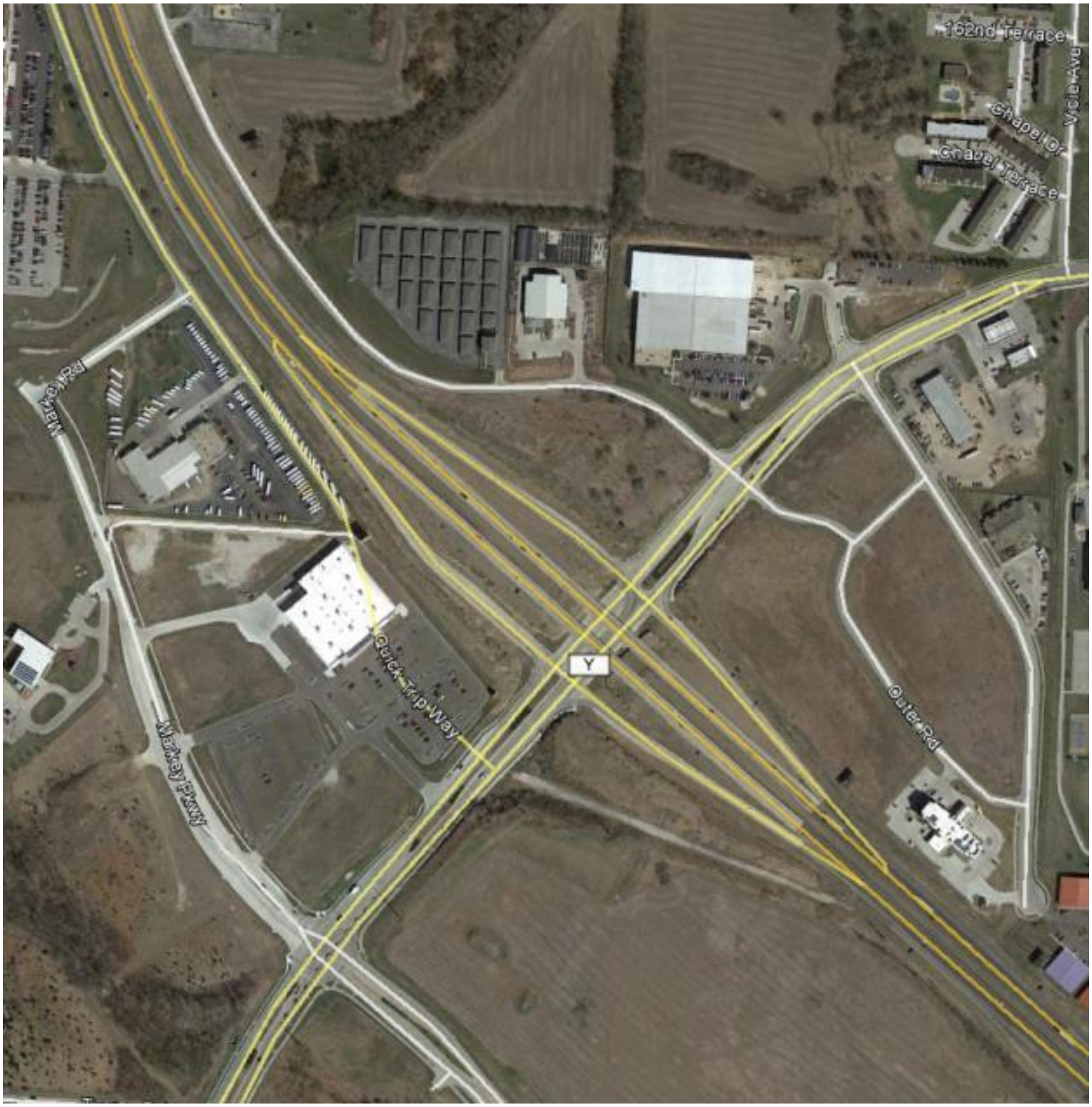
A.10 SCLU4EN/EX Sites

ID Number: 1
Main Highway: I-29
Crossroad: MO 6
Location: St. Joseph
County: Buchanan
District: Northwest

ID Number: 2
Main Highway: US 36
Crossroad: US 63
Location: Macon
County: Macon
District: Northeast



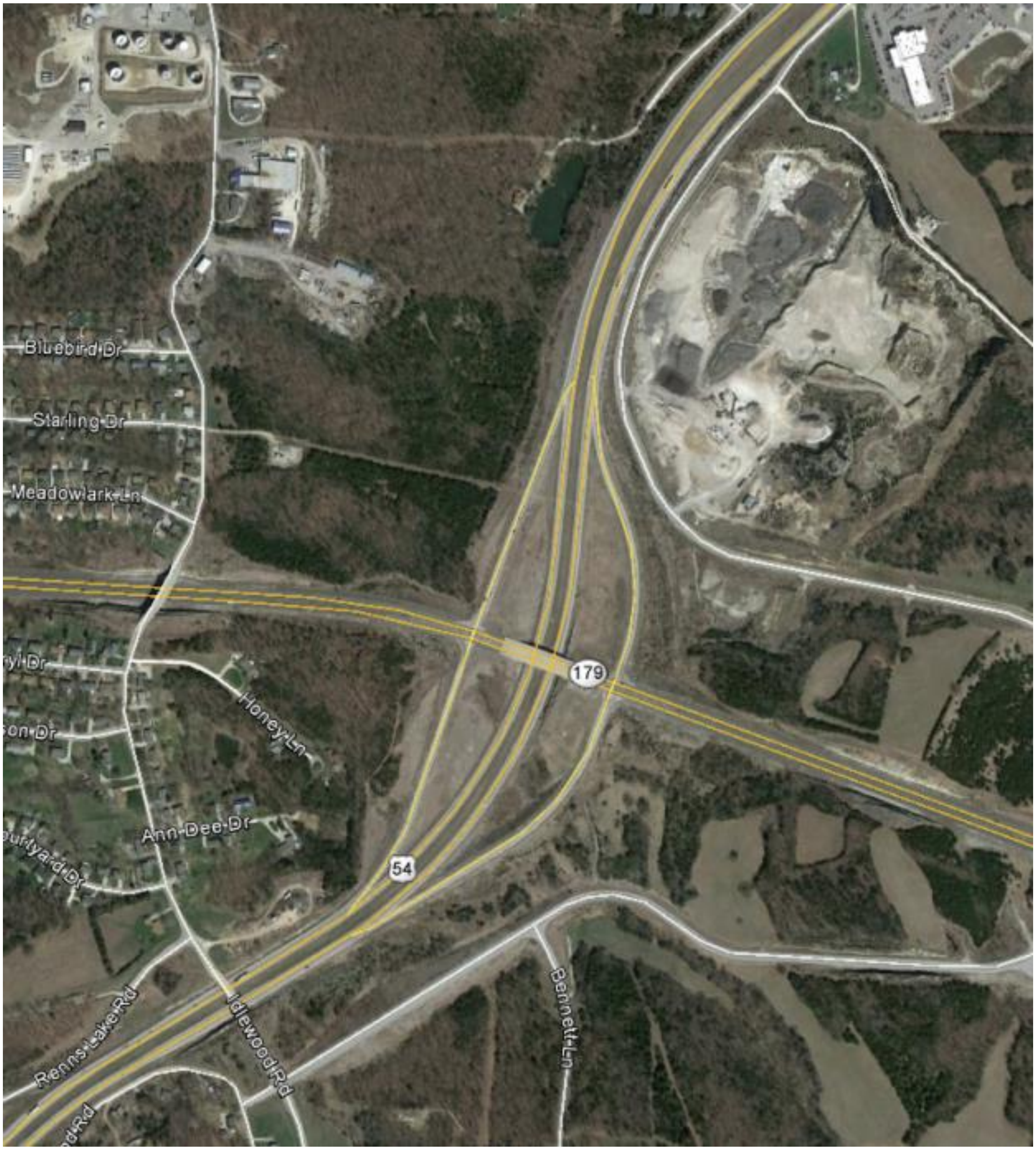
ID Number: 3
Main Highway: I-72
Crossroad: MO 79
Location: Hannibal
County: Marion
District: Northeast



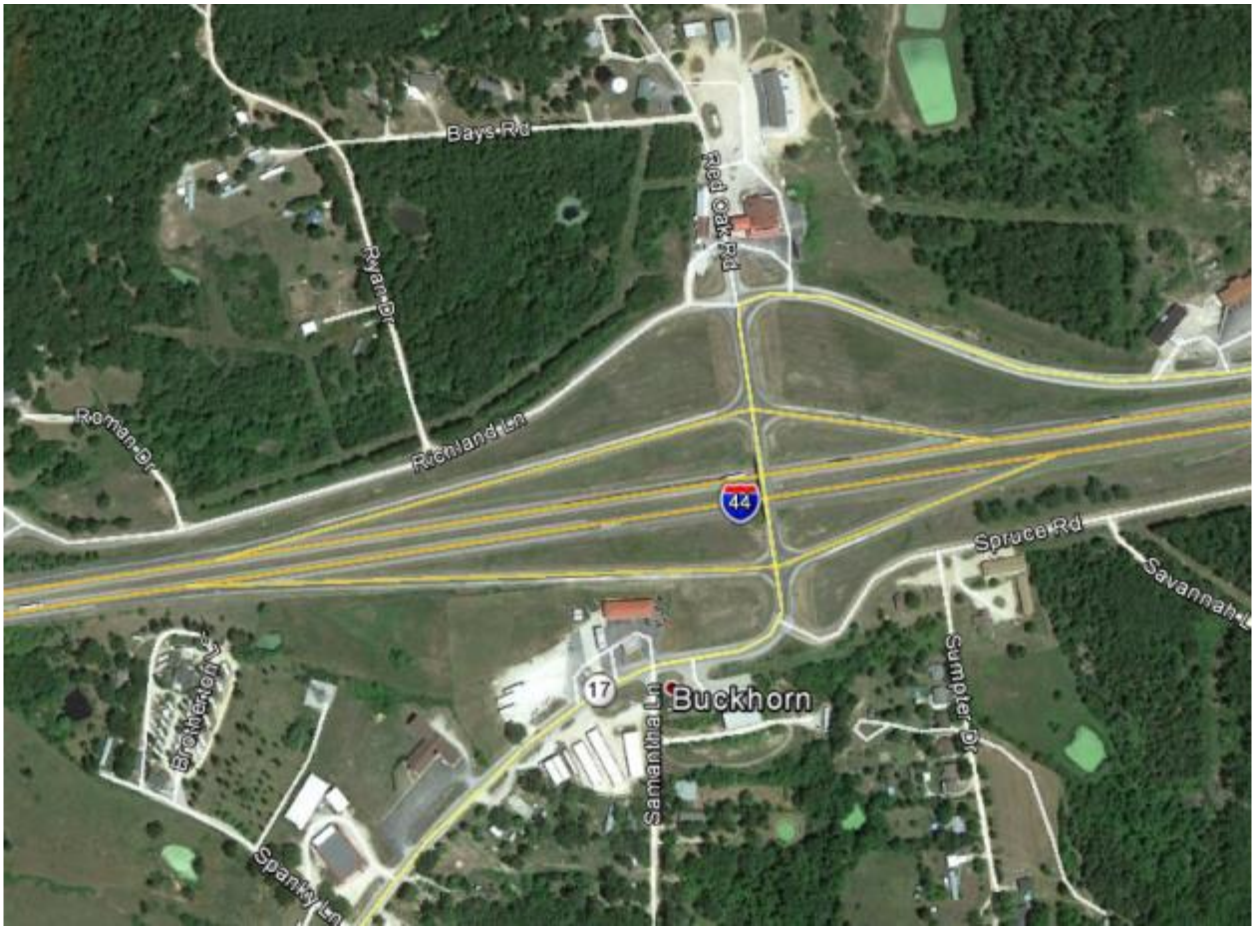
ID Number: 4
Main Highway: I-49
Crossroad: 163rd Street
Location: Belton
County: Cass
District: Kansas City

ID Number: 5
Main Highway: I-435
Crossroad: NE Cookingham Drive
Location: Northwest of Liberty
County: Clay
District: Kansas City

ID Number: 6
Main Highway: US 65
Crossroad: MO 76
Location: Branson
County: Taney
District: Southeast



ID Number: 7
Main Highway: US 54
Crossroad: MO 179
Location: Jefferson City
County: Cole
District: Central



ID Number: 8
Main Highway: I-44
Crossroad: MO 17
Location: Buckhorn
County: Pulaski
District: Central

ID Number: 9
Main Highway: I-64
Crossroad: Lake St. Louis Boulevard
Location: Lake St. Louis
County: St. Charles
District: St. Louis

ID Number: 10
Main Highway: US 61
Crossroad: Route A
Location: Wentzville
County: St. Charles
District: St. Louis

ID Number: 11
Main Highway: US 36
Crossroad: S 22nd Street
Location: St. Joseph
County: Buchanan
District: Northwest

ID Number: 12
Main Highway: I-29
Crossroad: Civil War Road
Location: Kendricktown
County: Jasper
District: Southwest

ID Number: 13
Main Highway: I-49
Crossroad: Route HH
Location: South of Carthage
County: Jasper
District: Southwest

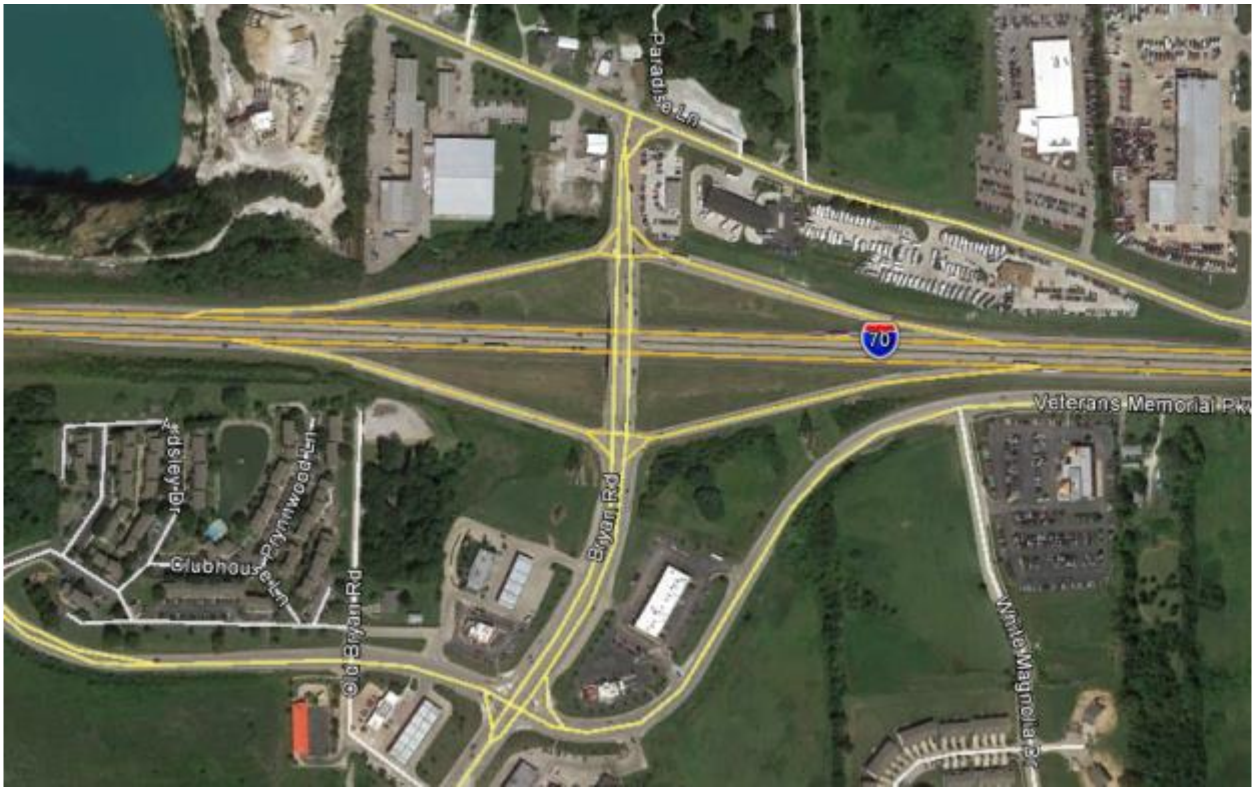
ID Number: 14
Main Highway: US 60
Crossroad: US 61/US 62
Location: Sikeston
County: New Madrid
District: Southeast

ID Number: 15
Main Highway: I-55
Crossroad: Route HH
Location: Miner
County: Scott
District: Southeast

A.11 SCLU6EN/EX Sites

ID Number: 1
Main Highway: US 65
Crossroad: Route YY/E Division Street
Location: Springfield
County: Greene
District: Southwest

ID Number: 2
Main Highway: I-44
Crossroad: MO 109
Location: Eureka
County: St. Louis County
District: St. Louis

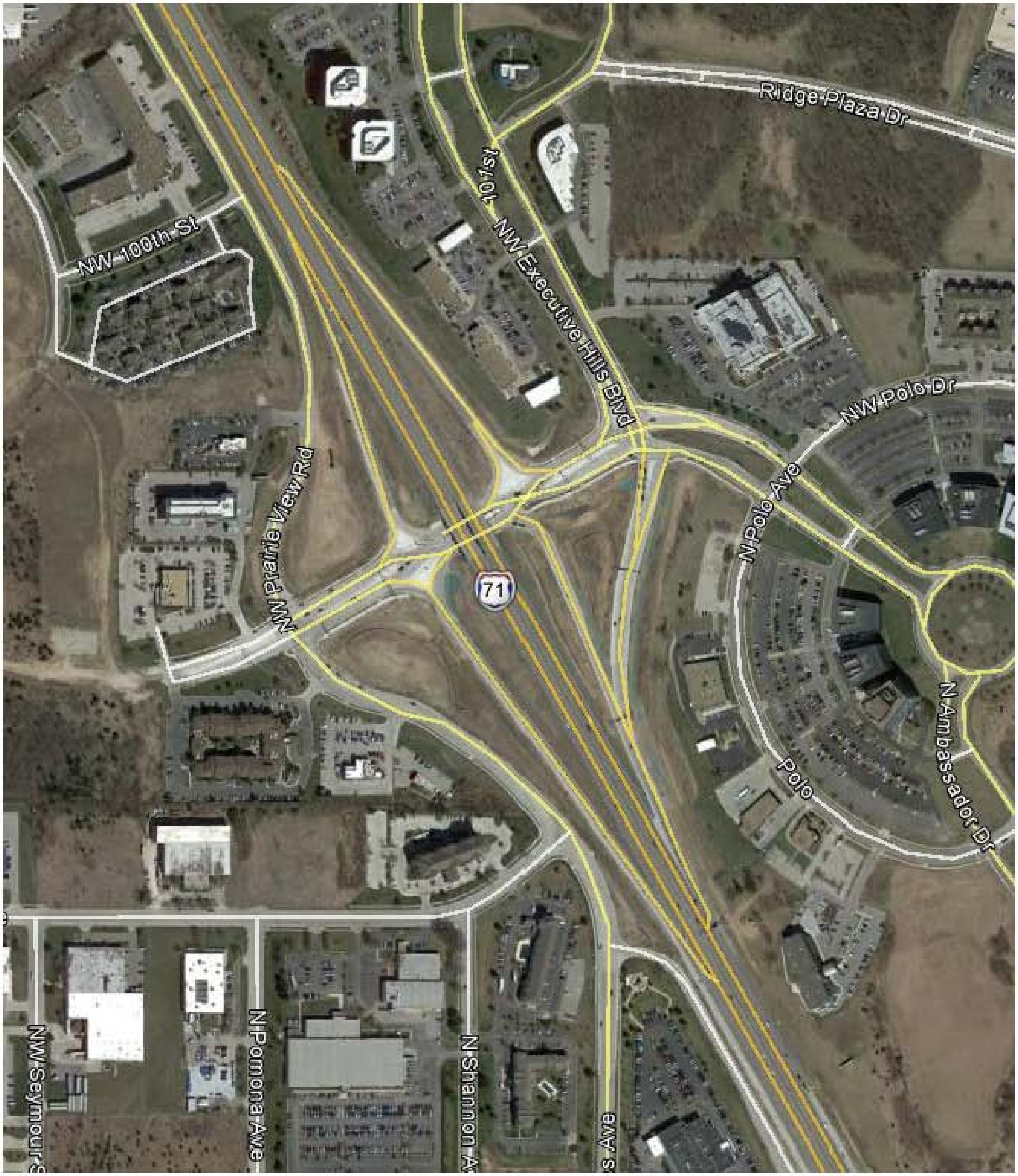


ID Number: 3
Main Highway: I-70
Crossroad: Bryan Road
Location: O'Fallon
County: St. Charles
District: St. Louis

ID Number: 4
Main Highway: I-70
Crossroad: Noland Road
Location: Independence
County: Jackson
District: Kansas City

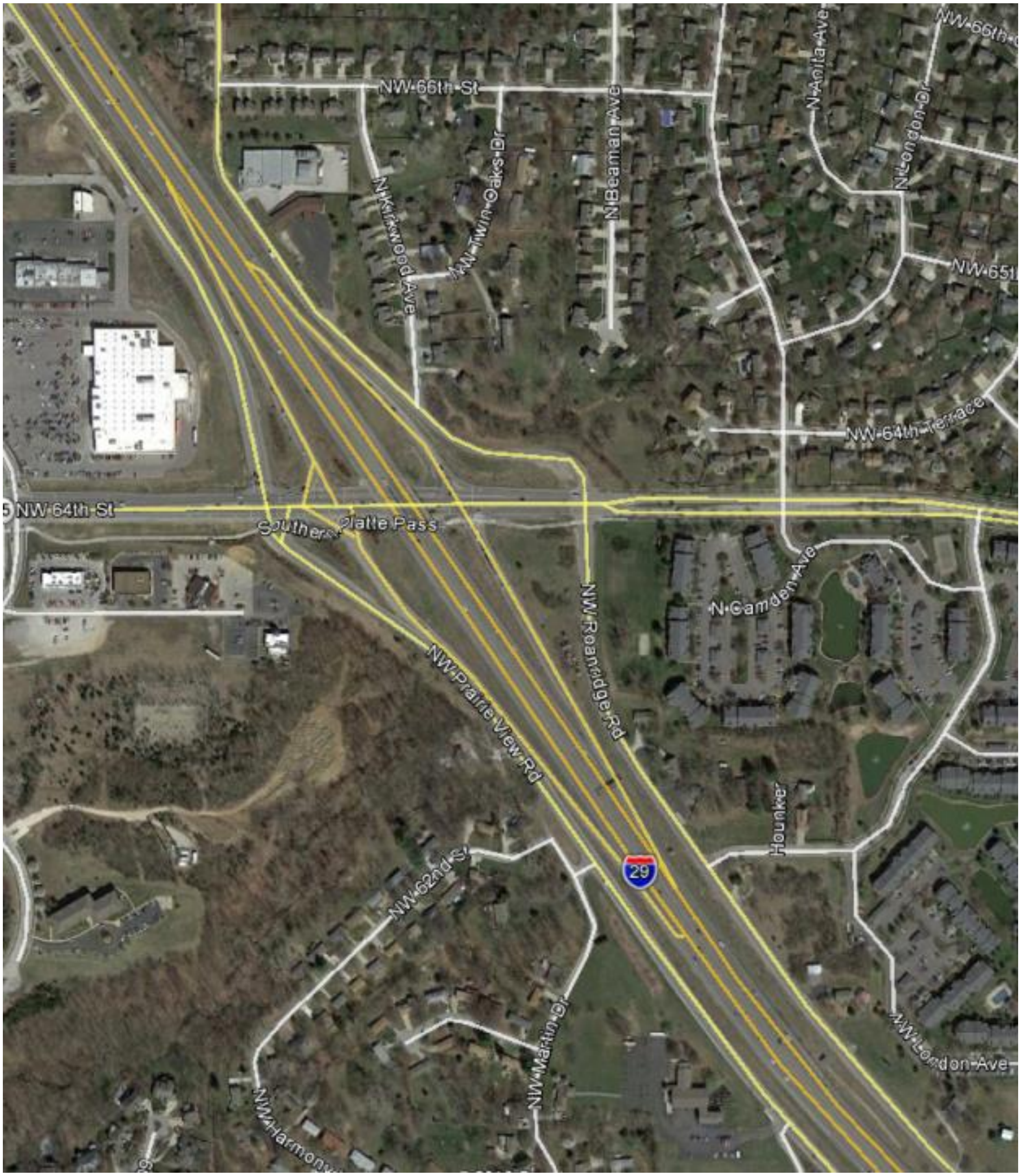
ID Number: 5
Main Highway: I-70
Crossroad: Cave Springs Road
Location: St. Charles
County: St. Charles
District: St. Louis

ID Number: 6
Main Highway: I-255
Crossroad: Koch Road
Location: Mehlville
County: St. Louis County
District: St. Louis

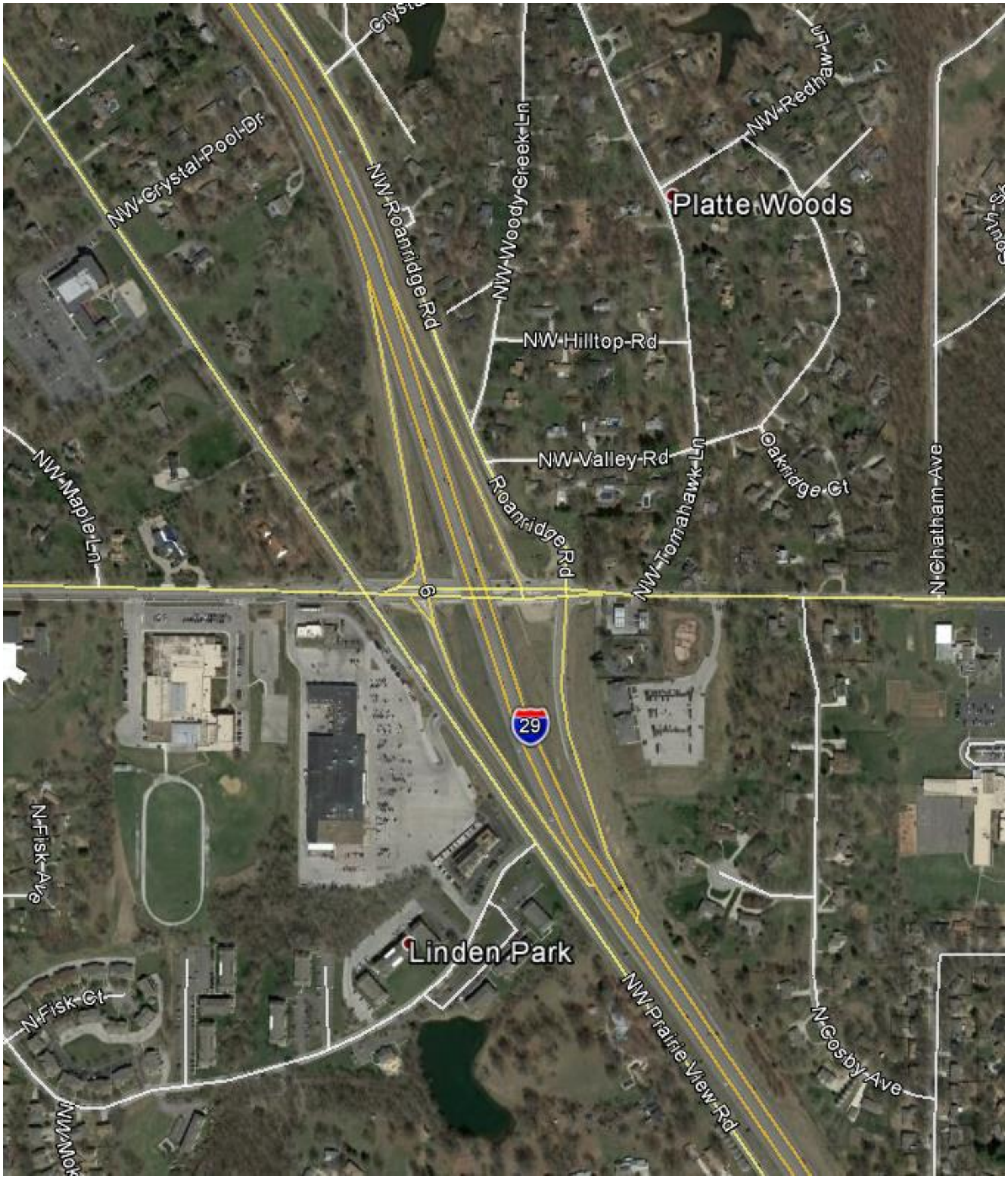


ID Number: 7
Main Highway: I-29
Crossroad: NW Tiffany Springs Parkway
Location: South of Ferrelview
County: Platte
District: Kansas City

ID Number: 8
Main Highway: US 65
Crossroad: E. Battlefield Road
Location: Fox Grape
County: Greene
District: Southwest



ID Number: 9
Main Highway: I-29
Crossroad: MO 45/NW 64th Street
Location: Northeast of Parkville
County: Platte
District: Kansas City



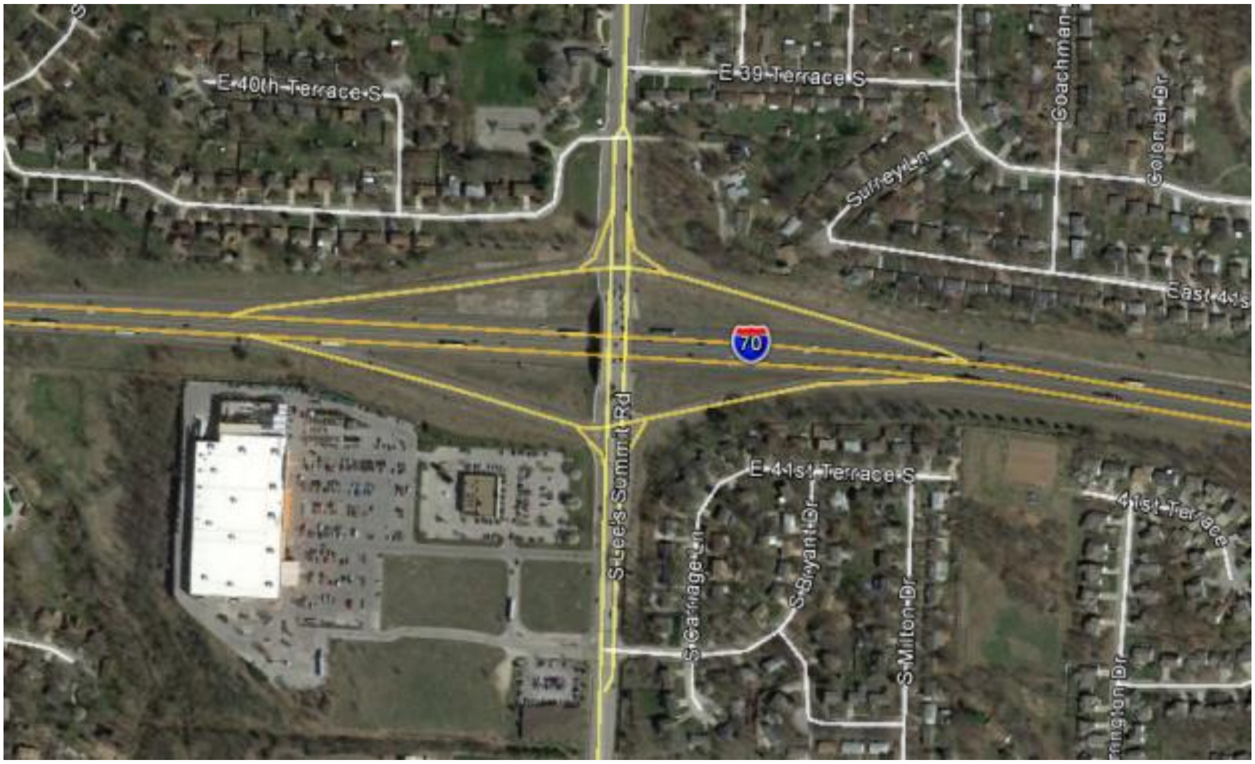
ID Number: 10
Main Highway: I-29
Crossroad: NW 72nd Street
Location: Platte Woods
County: Platte
District: Kansas City

ID Number: 11
Main Highway: I-70
Crossroad: NW Woods Chapel Road
Location: Blue Springs
County: Jackson
District: Kansas City

ID Number: 12
Main Highway: I-70
Crossroad: Lake St. Louis Boulevard
Location: Lake St. Louis
County: St. Charles
District: St. Louis

ID Number: 13
Main Highway: I-470
Crossroad: Raytown Road
Location: South of Raytown
County: Jackson
District: Kansas City

ID Number: 14
Main Highway: I-70
Crossroad: Route A
Location: South of Gilmore
County: St. Charles
District: St. Louis



ID Number: 15
Main Highway: I-70
Crossroad: S. Lee’s Summit Road
Location: Southeast of Independence
County: Jackson
District: Kansas City

A.12 RPREN/EX Sites

ID Number: 1
Main Highway: US 36
Crossroad: Route C/Route O
Location: Bevier
County: Macon
District: Northeast

ID Number: 2
Main Highway: US 61
Crossroad: Route P
Location: Canton
County: Lewis
District: Northeast

ID Number: 3
Main Highway: I-70
Crossroad: Route M/Route O
Location: East of Odessa
County: Lafayette
District: Kansas City

ID Number: 4
Main Highway: I-70 (US-40)
Crossroad: MO 13
Location: South of Higginsville
County: Lafayette
District: Kansas City

ID Number: 5
Main Highway: I-29
Crossroad: Route K
Location: North of Amazonia
County: Andrew
District: Northwest

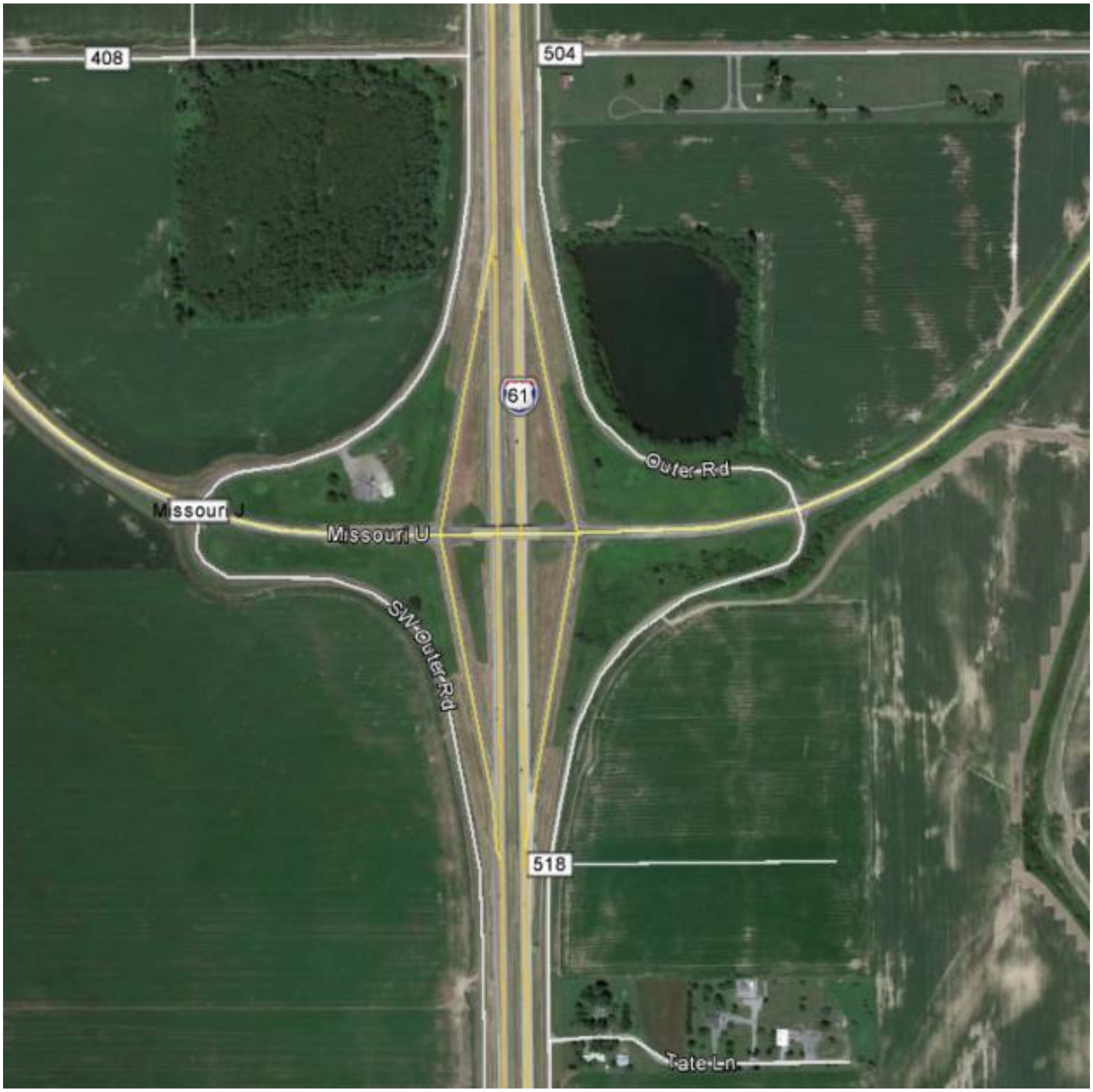
ID Number: 6
Main Highway: I-35
Crossroad: Route N
Location: Eagleville
County: Harrison
District: Northwest

ID Number: 7
Main Highway: I-44
Crossroad: Route B
Location: North of Northview
County: Webster
District: Southwest

ID Number: 8
Main Highway: I-44
Crossroad: Route PP/Route K
Location: Southwest of Plano
County: Greene
District: Southwest

ID Number: 9
Main Highway: US 24
Crossroad: MO 168
Location: Palmyra
County: Marion
District: Northeast

ID Number: 10
Main Highway: US 24
Crossroad: 13th Street
Location: South of Lexington
County: Lafayette
District: Kansas City



ID Number: 11
Main Highway: I-55
Crossroad: Route J/Route U
Location: South of Hayti
County: Pemiscot
District: Southeast

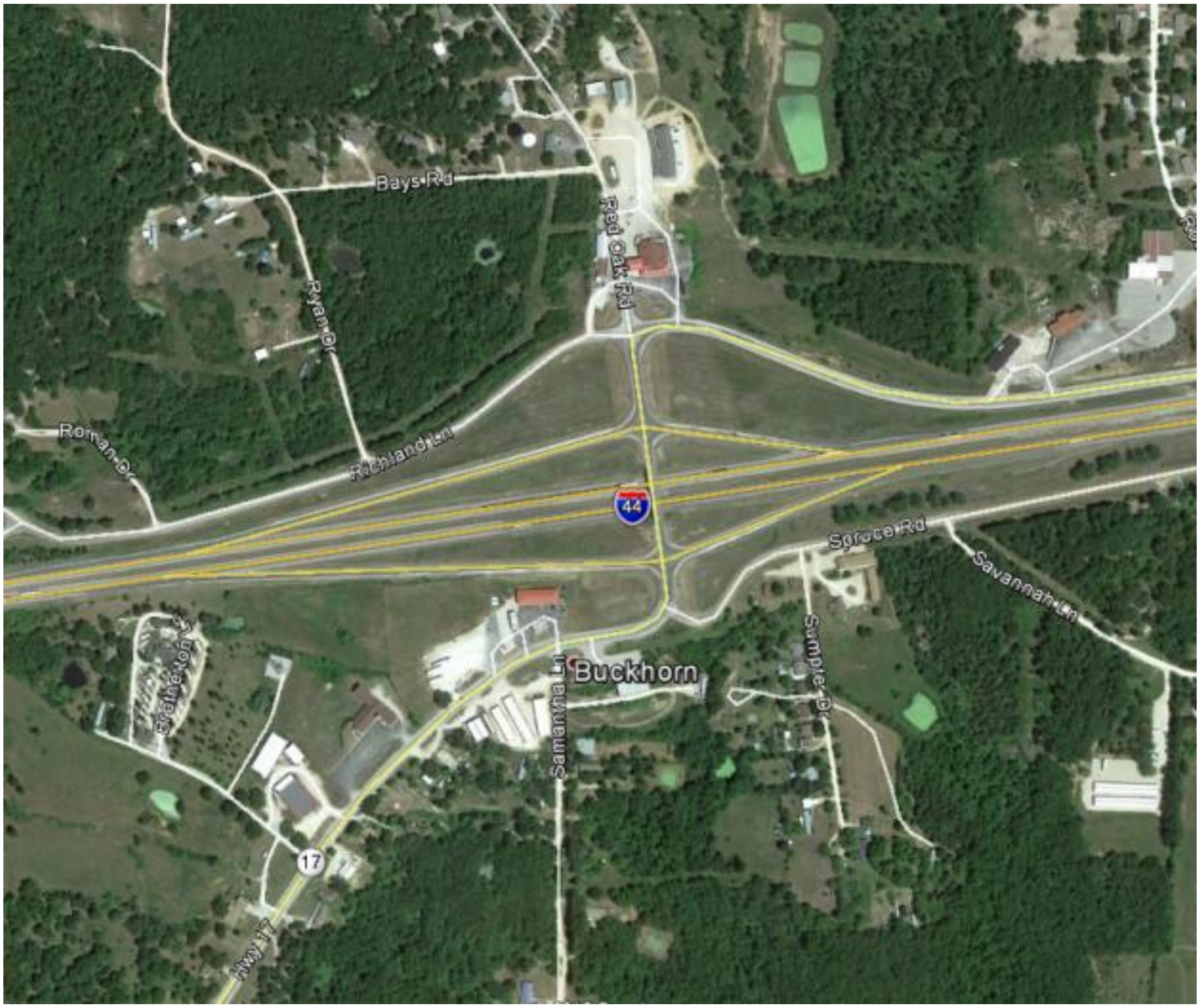
ID Number: 12
Main Highway: MO 13
Crossroad: US 24
Location: Lexington
County: Lafayette
District: Kansas City

ID Number: 13
Main Highway: I-44
Crossroad: Route Z/Route O
Location: Halltown
County: Lawrence
District: Southwest

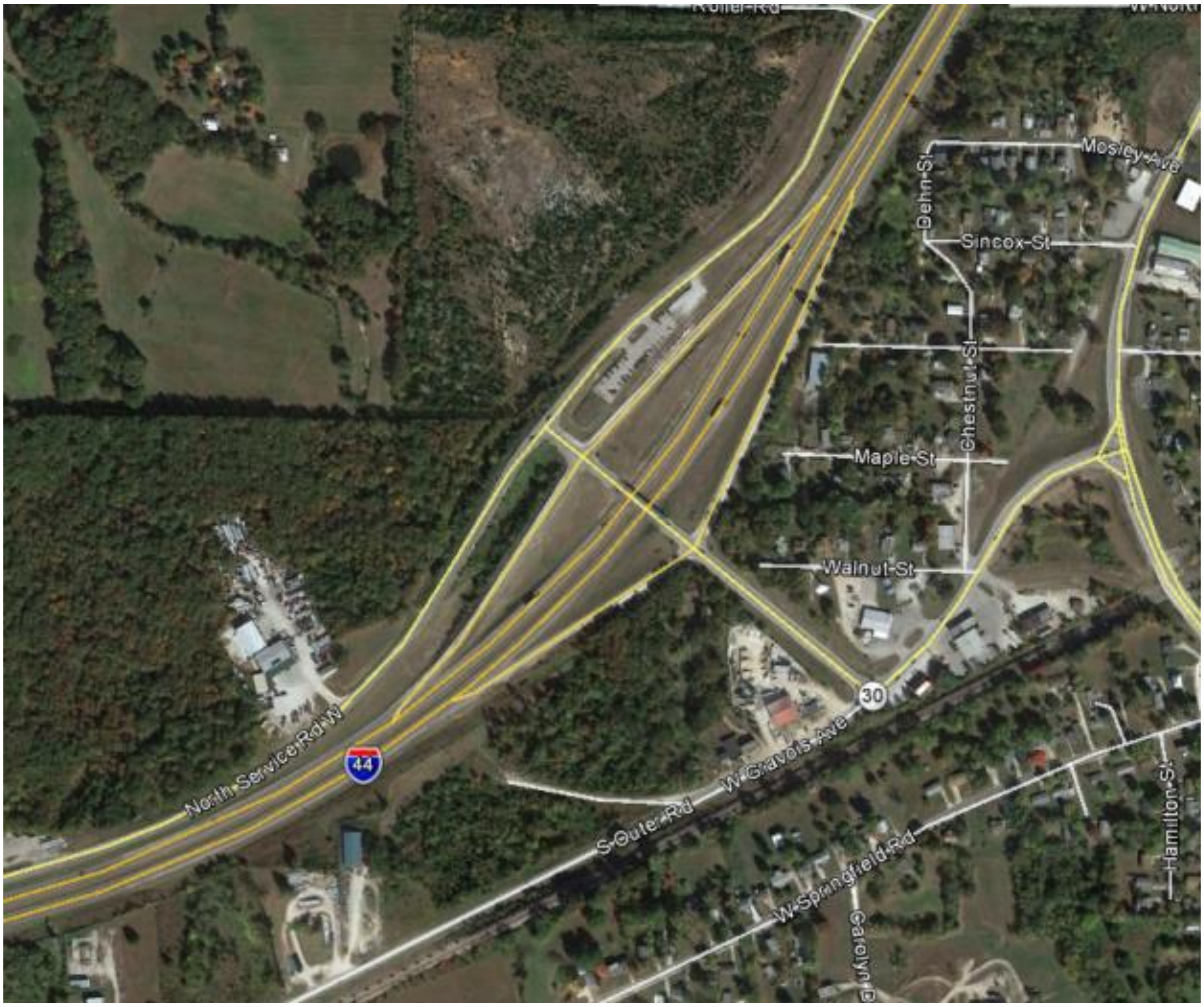
ID Number: 14
Main Highway: MO 7/MO 13
Crossroad: MO 52
Location: Clinton
County: Henry
District: Southwest

ID Number: 15
Main Highway: US 67
Crossroad: MO 72
Location: West of Fredericktown
County: Madison
District: Southeast

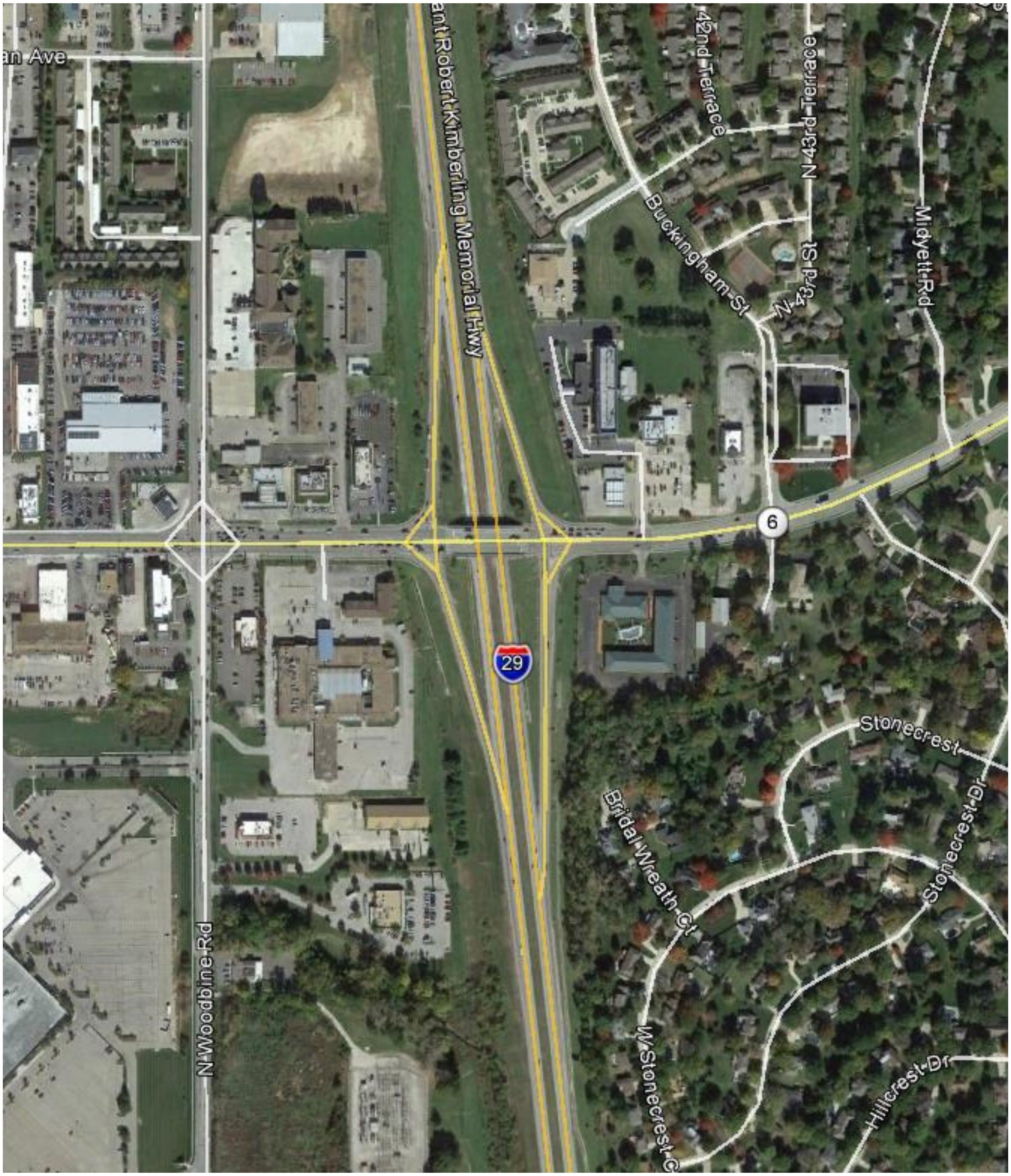
A.13 RPUEN/EX Sites



ID Number: 1
Main Highway: I-44
Crossroad: MO 17
Location: Buckhorn
County: Pulaski
District: Central

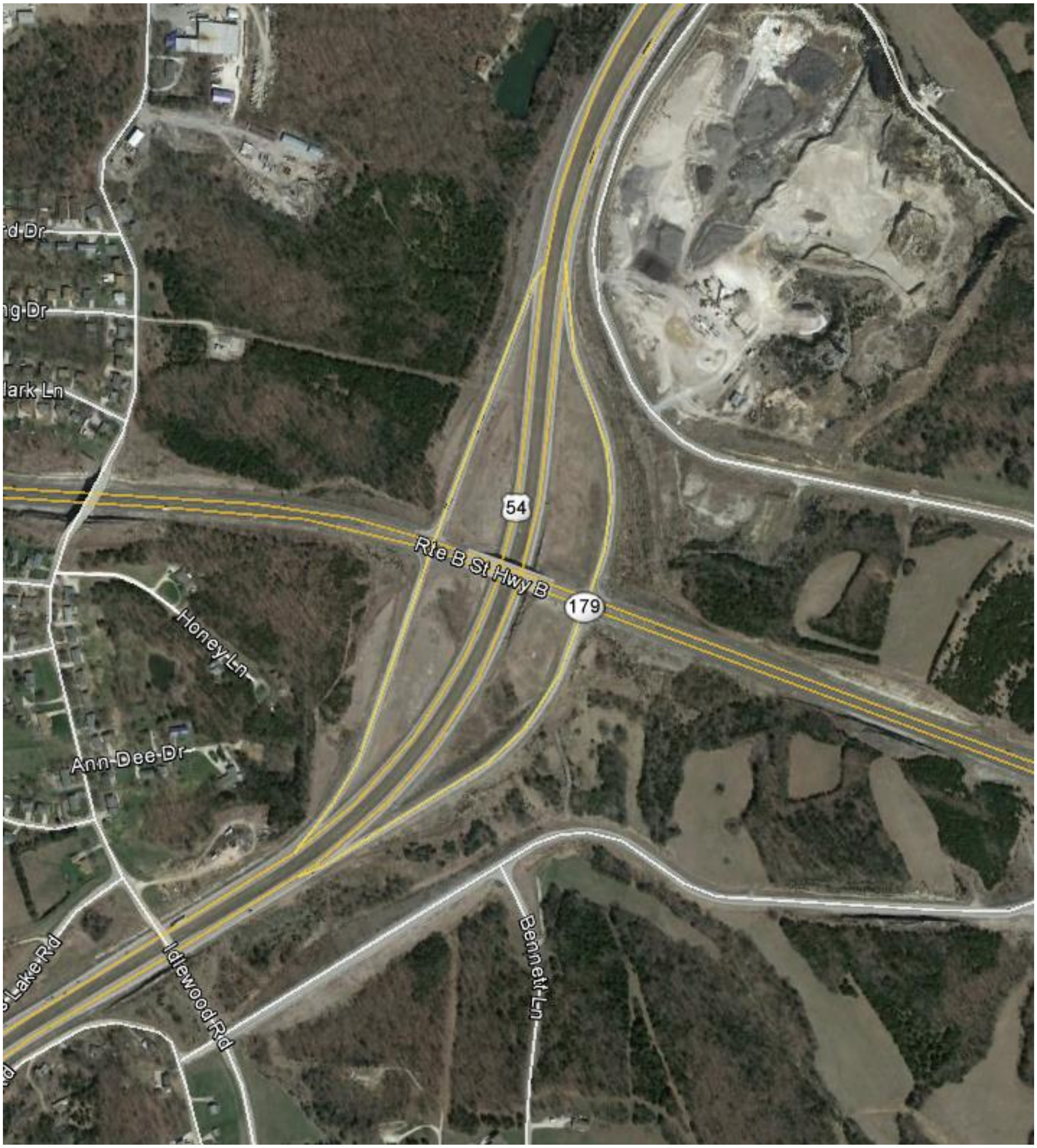


ID Number: 2
Main Highway: I-44
Crossroad: MO 30
Location: St. Clair
County: Franklin
District: St. Louis



ID Number: 3
Main Highway: I-29
Crossroad: MO 6
Location: St. Joseph
County: Buchanan
District: Northwest

ID Number: 4
Main Highway: I-55
Crossroad: US 67
Location: South of Festus
County: Jefferson
District: St. Louis

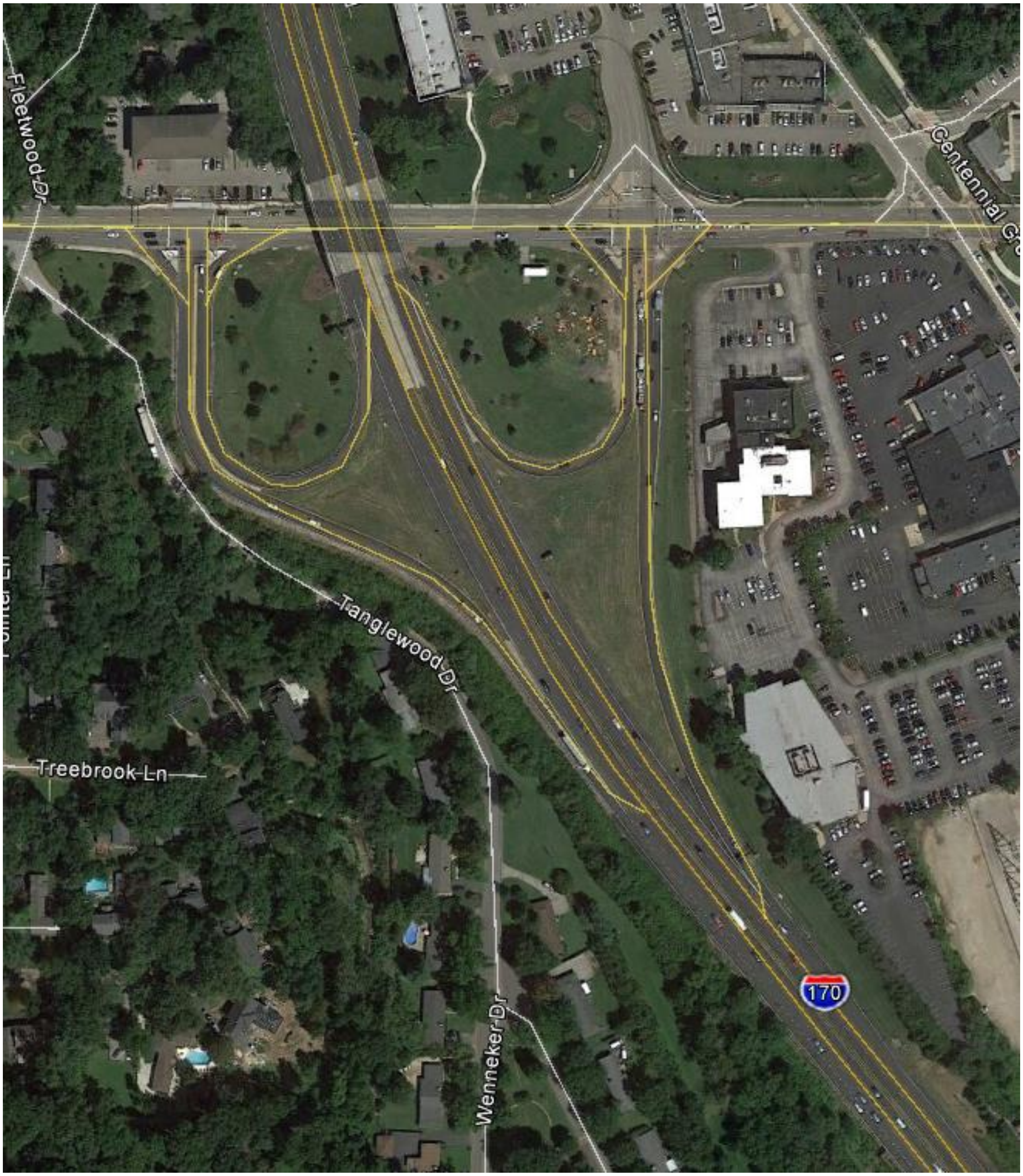


ID Number: 5
Main Highway: US 54
Crossroad: MO 179
Location: Jefferson City
County: Cole
District: Central

ID Number: 6
Main Highway: I-72
Crossroad: MO 79
Location: Hannibal
County: Marion
District: Northeast

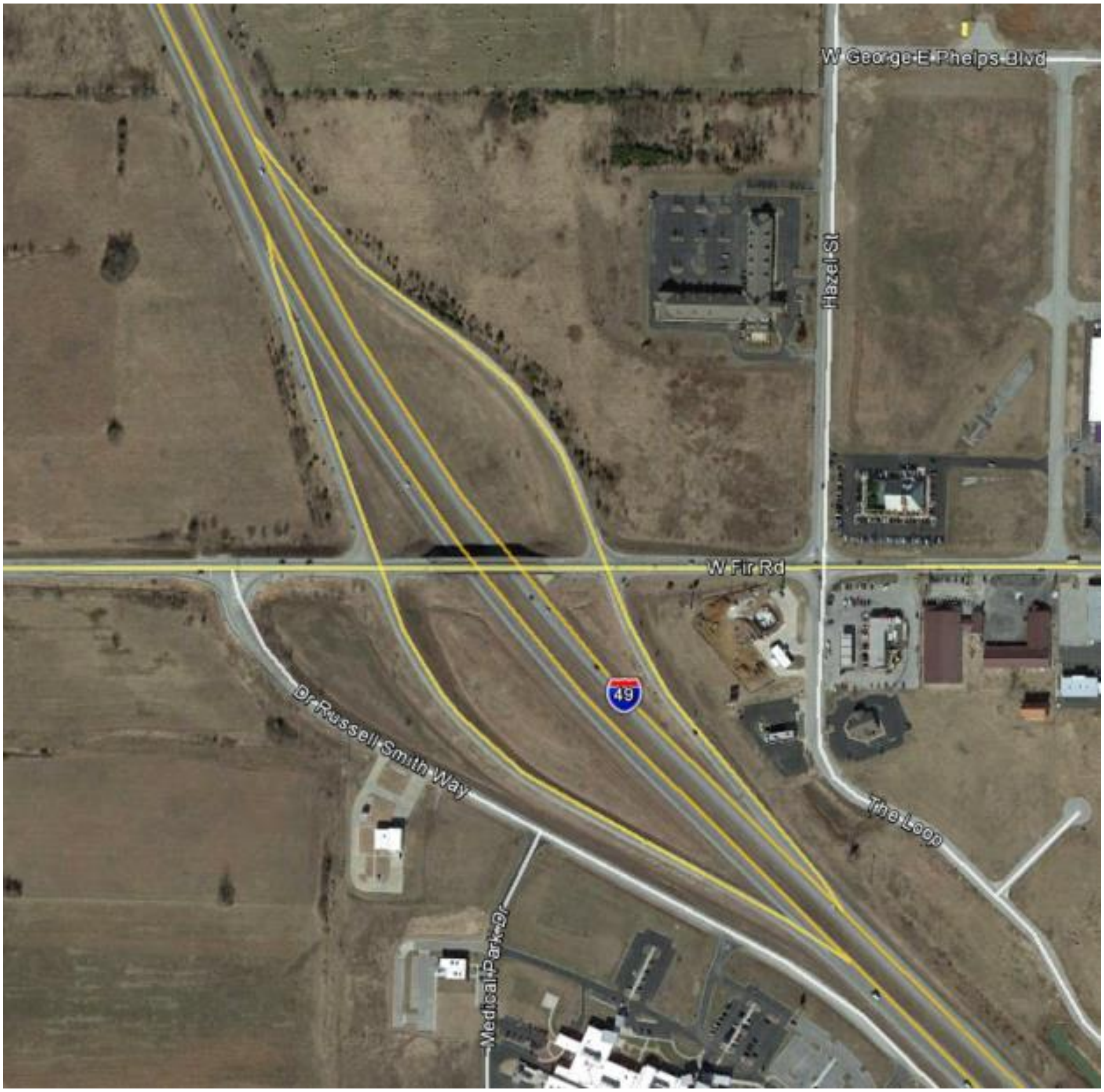
ID Number: 7
Main Highway: US 60
Crossroad: US 61/US 62
Location: South of Sikeston
County: New Madrid
District: Southeast

ID Number: 8
Main Highway: I-49
Crossroad: Civil War Road
Location: Northwest of Kendricktown
County: Jasper
District: Southwest

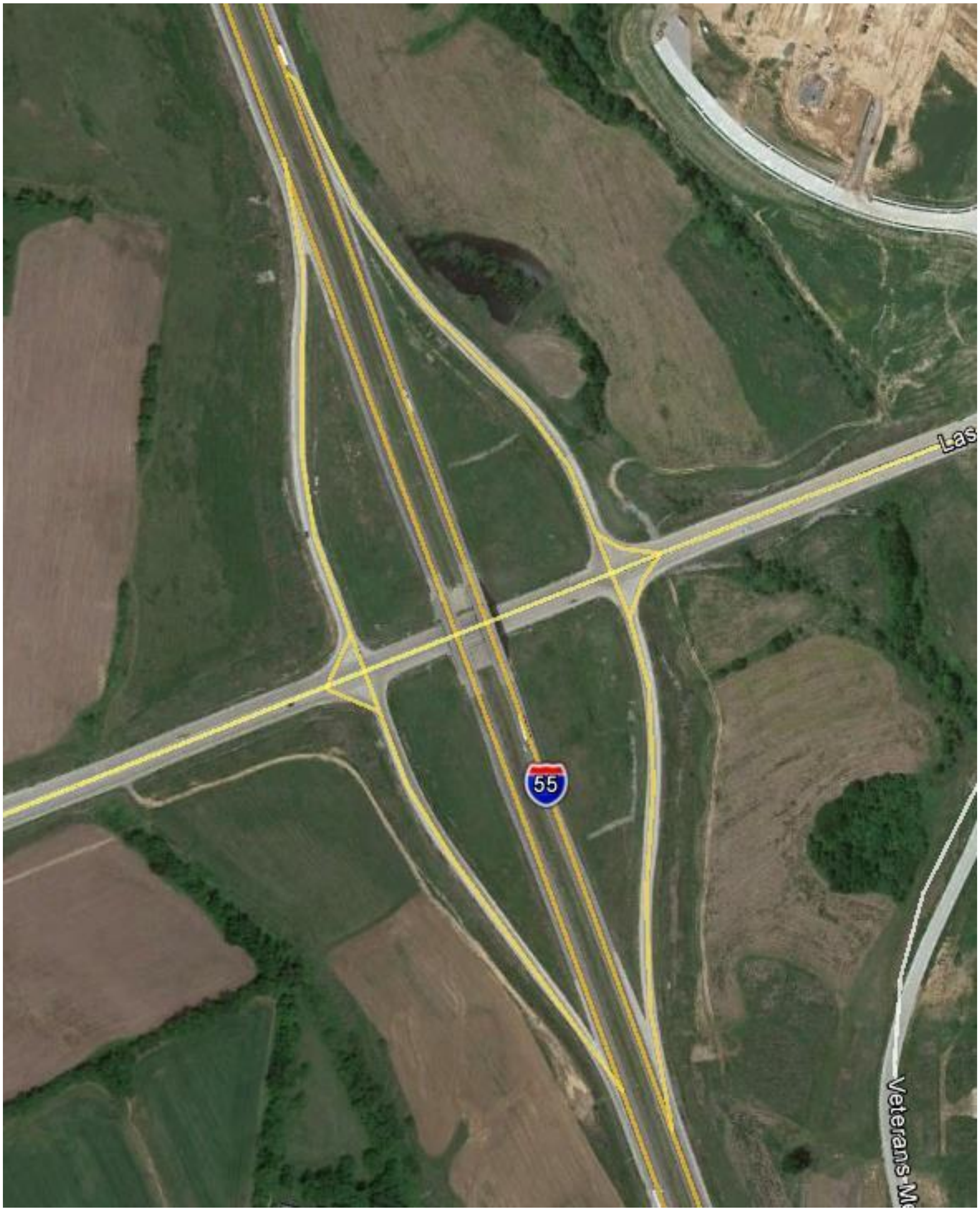


ID Number: 9
Main Highway: I-170
Crossroad: Ladue Road
Location: West of North Clayton
County: St. Louis County
District: St. Louis

ID Number: 10
Main Highway: I-49
Crossroad: MO 2
Location: Harrisonville
County: Cass
District: Kansas City



ID Number: 11
Main Highway: I-49
Crossroad: Route HH/W Fir Road
Location: South of Carthage
County: Jasper
District: Southwest



ID Number: 12
Main Highway: I-55
Crossroad: E. Main Street
Location: East of Jackson
County: Cape Girardeau
District: Southeast

ID Number: 13
Main Highway: US 36
Crossroad: S. 22nd Street
Location: St. Joseph
County: Buchanan
District: Northwest

ID Number: 14
Main Highway: I-70
Crossroad: Route A
Location: South of Gilmore
County: St. Charles
District: St. Louis

ID Number: 15
Main Highway: US 36
Crossroad: US 63
Location: Macon
County: Macon
District: Northeast