2020 TAMC Traffic Signal Study

Project Report

December 8, 2020

Peter Meingast, Research Engineer
Center for Technology & Training

Tim Colling, PhD, PE, Director
Center for Technology & Training

Laura Bufanda, Student Intern
Center for Technology & Training

Michigan Transportation Asset Management Council

Michigan Technological University
Civil and Environmental Engineering

ACKNOWLEDGEMENTS

The Center for Technology & Training at Michigan Technological University wish to acknowledge the contribution of all those who participated in the development of this report through sharing their experiences through providing signal data.

Douglas Adelman, Michigan Department of Transportation

Ryan Whitcare, Michigan Department of Transportation

John Bartlett, PE, City of Grand Rapids

Jim Hoekstra, Road Commission of Kalamazoo County

Matthew Wright, Gratiot County Road Commission

We would also like to acknowledge Sgt. Scott L. Carlson Michigan State Police Traffic Crash Reporting Unit for his assistance in researching the history of UD-10 crash report fields.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The goals of this study were, first, to estimate the total number of local-agency-owned signalized intersections using crash data as a proxy for their detection and, second, to estimate the total infrastructure value of traffic signals in the state of Michigan using average cost data from bid lettings in the Michigan Department of Transportation's (MDOT) bid system for projects that included traffic signals.

The study defined a "signalized intersection" as an intersection of two public roads shown on the Michigan Geographic Framework Base Map version 20 that contained at least one traffic control signal head, a three-light (i.e., red-yellow-green) device that alternates the designation of right of way at the intersection. Traffic signals at intersections having at least one MDOT trunkline leg were considered MDOT owned while traffic signals at intersections having no MDOT trunkline legs were considered local-agency owned. Traffic signals that were not located at road intersections, such as pre-emption signals, and that were located at railroads were considered signals when collecting ground truth but were not detected using the method outlined in this study.

The study created a ground truth data set consisting of approximately 1261 signalized local-agency intersections by manually searching for them on geolocated aerial- and street-level images. Ground truth data sets were quality-control checked using peer review and information from local-agency inventories. The ground truth data set included all local jurisdictions within the following geographic counties: Otsego County, Grand Traverse County, Midland County, Houghton County, Gratiot County, Saginaw County, Kalamazoo County, Kent County, and Washtenaw County. Ground truth also was created for the following large cities: City of Marquette, Bay City, City of Saginaw, City of Ann Arbor, City of Grand Rapids, City of Kalamazoo.

The signal detection method relied on the traffic control field in Michigan crash records, specifically the UD-10 form, to determine if a traffic signal was likely present. If the traffic control field in UD-10 crash records indicated that a traffic signal was likely present, the study aggregated the crash data geographically that occurred within 50 feet of an intersection. Crash data was aggregated from the most currently available data in 2020 back three years to 2017. Intersections that had 52 percent or more aggregated crash data records indicating a traffic control relevant to the crash were marked as a detected signal location. The study optimized the distance from the intersection, the number of years of crash data, and the consensus percentage to increase the detection accuracy.

The optimized detection method accurately predict (i.e., had a detection accuracy of) 99.0% of the number of ground truth local-agency traffic signals. Detected locations correctly pinpointed (i.e., had a location precision of) 89.5% of the ground truth locations.

The detection method identified 6690 local-agency-owned signalized intersections and 4050 MDOT-owned signalized intersections for an estimate statewide total of 10740 signalized intersections. The detection method was not optimized to identify MDOT-owned signals, but anecdotal evidence indicates reasonable performance.

To estimate the monetary value of traffic signal assets, twenty-four MDOT let construction projects from 2019 that included traffic signals were identified and bid tabulations were evaluated. Project costs were separated based on professional opinion on what constituted traffic signal work and other non-signal related pay items. Reviewers used project descriptions and pay item quantities to estimate the number of signalized intersections addressed by the project. Project costs were divided by the number of traffic signals addressed by the project to develop an average cost per signalized intersection. Per intersection average signal costs were calculated at approximately $193,000.

An estimate of total infrastructure investment in signaled intersections was calculated using the estimate of total intersections and the average cost per intersection. The study estimates that Michigan has approximately $1.29 billion in local-agency-owned traffic signal infrastructure and $780 million in MDOT-owned traffic signal infrastructure for a total of $2.07 billion dollars in traffic signal investment.

The method outlined in this study enables future updates of the estimated number of traffic signal assets with little effort as new crash data becomes available. This provides a potential for the Michigan Transportation Asset Management Council (TAMC) to updates its statewide inventory without the need to develop and deploy a survey- and reporting–based data collection method, which would require input from various owners of the road and bridge transportation network. Since the system uses three years of crash data, re-running this method would be recommended after three years.

BACKGROUND

Public Act 325 of 2018 provided a specific charge for the Michigan Transportation Asset Management Council (TAMC) to oversee *"…assets that impact system performance, safety, or risk management, including signals and culverts"*. Having the number of traffic signals and the cost associated with installing them would enable the TAMC to determine the level of oversight that is appropriate for traffic signal assets. If, for example, traffic signals represent a small portion of the total cost of local infrastructure or if traffic signals are asymmetrically distributed, the TAMC may elect to collect minimal data on signals.

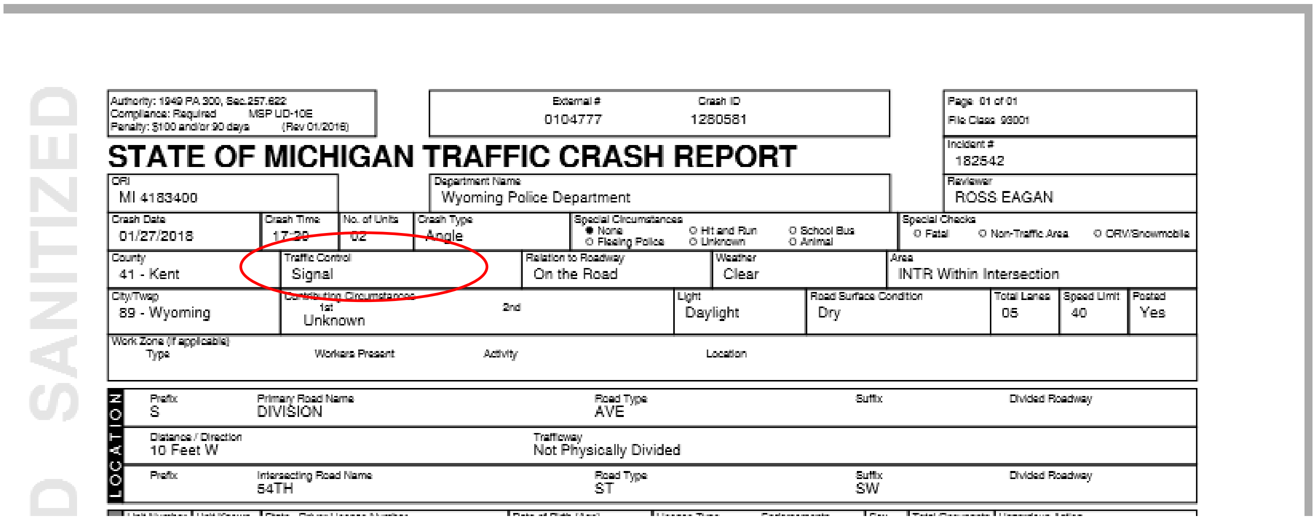
Traffic signal data for the Michigan Department of Transportation (MDOT) is available in a single database; however, Michigan's 83 counties and 533 cities and villages each have their own data storage practices, which makes it difficult to determine the overall number and distribution of Michigan's traffic signal assets. Furthermore, to obtain accurate data from the numerous local road-owning agencies would require more than 600 contacts.

This project has the following tasks: 1) establish an estimated total number of local-agency-owned traffic signals, 2) determine an average construction cost per local-agency signalized intersection, and 3) produce an estimated infrastructure value of the total local-agency-owned traffic signal assets based on task 1 and 2.

Crash Data as a Proxy

In 2019, Michigan had 314,376 traffic crashes, of which 97,188 were at an intersection (Michigan Office of Highway Safety Planning, 2019). Crashes are widely distributed throughout the road network, and provide data about road features, including the type of traffic control at intersections. Because of this, crash data can serve in lieu of collecting an asset-specific inventory for determining features about the road network.

In this study, Michigan crash data was used as a proxy to determine the total number of signalized intersections in Michigan. The Michigan UD-10 crash form includes a field for indicating the traffic control when crashes occur at intersections. Figure 1 illustrates the traffic control field on the current UD-10 form which has been present since at least 1999.



D SANITIZED

Authority: 1949 PA 300, Sec.257.622
Compliance: Required MSP UD-10E
Penalty: $100 and/or 90 days (Rev 01/2016)

External # 0104777 | Crash ID 1280581

Page 01 of 01
File Class 93001

STATE OF MICHIGAN TRAFFIC CRASH REPORT

Incident # 182542

ORI: MI 4183400
Department Name: Wyoming Police Department
Reviewer: ROSS EAGAN

Crash Date: 01/27/2018
Crash Time: 17:20
No. of Units: 02
Crash Type: Angle
Special Circumstances: ● None ○ Fleeing Police ○ Hit and Run ○ Unknown ○ School Bus ○ Animal
Special Checks: ○ Fatal ○ Non-Traffic Area ○ ORV/Snowmobile

County: 41 - Kent
Traffic Control: Signal
Relation to Roadway: On the Road
Weather: Clear
Area: INTR Within Intersection

City/Twsp: 89 - Wyoming
Contributing Circumstances: 1st Unknown; 2nd
Light: Daylight
Road Surface Condition: Dry
Total Lanes: 05
Speed Limit: 40
Posted: Yes

Work Zone (if applicable): Type; Workers Present; Activity; Location

LOCATION

Prefix: S
Primary Road Name: DIVISION
Road Type: AVE
Suffix:
Divided Roadway:

Distance / Direction: 10 Feet W
Trafficway: Not Physically Divided

Prefix:
Intersecting Road Name: 54TH
Road Type: ST
Suffix: SW
Divided Roadway:

Figure 1: State of Michigan UD-10 traffic crash report form

The current Michigan UD-10 instruction manual indicates that the traffic signal field should be completed as follows:

> *"If a Traffic Control [sic] device was relevant to the crash, select which type of Traffic Control was present. If the crash occurred within 150 feet of an intersection and a Traffic Control device was present, indicate which type of Traffic Control was present at the intersection. If a Traffic Control device was not involved, select 96-None.*
>
> *A traffic signal is a 3-light (red-yellow-green) devise [sic] that alternately assigns right of way. If the signal is in a red-yellow flashing pattern, it is still considered a signal. Select 1-Signal regardless of whether or not the traffic signal was operating properly at the time of the crash.*
>
> *A single light overhead beacon that flashes red or yellow is not a traffic signal, but would be considered either a 2-Stop Sign or 4-Yield Sign."* (Michigan State Police, 2018)

The instructions for this field indicate that an officer should include the traffic control data if a traffic control device was "relevant to the crash" or if "the crash occurred within 150 feet of an intersection **and** a traffic control device was present" (emphasis applied). The instructions also provide the guidance to "select 96-None"if a traffic control device was "**not involved**" (emphasis applied). This field is left to the officer's judgement to determine whether the traffic control device was involved as a factor in the crash, and does not automatically indicate the presence of traffic control.

If every crash near an intersection was related to the traffic control and if crash data was flawless, it would be trivial to use this field to determine the presence of a signalized intersection. However, on a national level, crash data has a high number of fields, a large number of officers recording crash data, and is often a necessary afterthought for officers who must maintain control and safety at the crash site itself.

Traffic Signal Estimates from Crash Data Using a Consensus Approach

This study used a consensus approach to identify signalized intersections from crash data. In other words, this study used spatially-aggregated crash data for an intersection as a repeated measure for determining if the intersection in question was signalized. Traffic signal detections made by the process were compared to ground truth data sets (i.e., verified data sets of intersections used as a control) in order to adjust the process, by modifying one of five controlling factors, to produce the most accurate results.

In this study, a "traffic signal installation" was defined as an intersection of two public roads, shown on the Michigan Geographic Framework Base Map version 20, that contained at least one three-light (i.e., red-amber-green) traffic control signal head for the purpose of alternating the designation of right of way at the intersection. Traffic signals that are not located at road intersections, such as pre-emption signals and traffic signals at railroads, were considered signals when collecting ground truth; however, the detection method could not detect these locations accurately since they do not occur in the Framework Base Map road-to-road intersections (i.e., where one road intersection with another road). Flashing beacons, such as the one illustrated in Figure 2, were not considered traffic signals for the purposes of this study. Traffic signals considered "local-agency owned" were those that occurred at intersections of local roads with other local roads, while traffic signals considered “MDOT owned” were those located on an intersection with at least one MDOT-owned leg.

Figure 2: Flashing beacon, which was not considered a traffic signal for the purposes of this study

Ground truth data sets relied on traffic signal counts or traffic signal databases from Michigan local agencies that were verified by geolocated aerial and street-level images. Initial efforts to use traffic signal counts or traffic signal databases from local agencies and MDOT encountered disparate definitions of what is considered a traffic signal; often, these data sets included a wider array of electronic traffic control devices in the definition in comparison to how traffic control devices are being defined by this study. For example, some local agencies did not differentiate between traffic control signals and flashers or pedestrian signals. Some local-agencies also included traffic signals from other jurisdictions on road assets that they maintain but do not own; this included MDOT-owned traffic signals and traffic signals from other jurisdictions that were maintained under contract. Furthermore, some of these data sets had not been updated for many years, thus being potentially no longer accurate. These complications resulted in an imprecise representation of the traffic signal assets and did not provide the quality data that could be used as ground truth. Therefore, this study developed its own ground truth from inspection of geolocated aerial and street-level images for traffic signal locations identified in the data sets.

METHODS

Task 1: Estimating Traffic Signal Assets

Ground Truth

To generate the ground truth data set for this study, several geographical counties were selected. Data sets of the geographical counties included all local roads within a county boundary (i.e., roads owned by both the county road commission and municipalities) but excluded MDOT-owned roads or intersections with at least one MDOT-owned leg. Selected geographical counties represented a wide geographical distribution throughout the state as well as both urban and rural settings. This selection criteria created a large, diverse traffic signal data set that best represents the traffic signal assets across Michigan's 83 counties and 533 cities and villages.

Major cities within geographic counties were segregated into city data sets for separate analysis in order to determine if different factors between counties and cities would impact traffic signal detection.

Geographical counties chosen for the ground truth data set were Otsego, Grand Traverse, Midland, Saginaw, Washtenaw, Kent, and Kalamazoo (see Table 1 and Figure 3). Also included in the geographical county data sets were Houghton and Gratiot Counties. These counties did not have any local-agency-owned traffic signals present. Therefore, these geographical counties acted as a null test to verify false positive performance. Major cities in the ground truth data set were Saginaw, Ann Arbor, Grand Rapids, and Kalamazoo. Also included in the major cities data set were Marquette and Bay City (see Table 1 and Figure 3)).

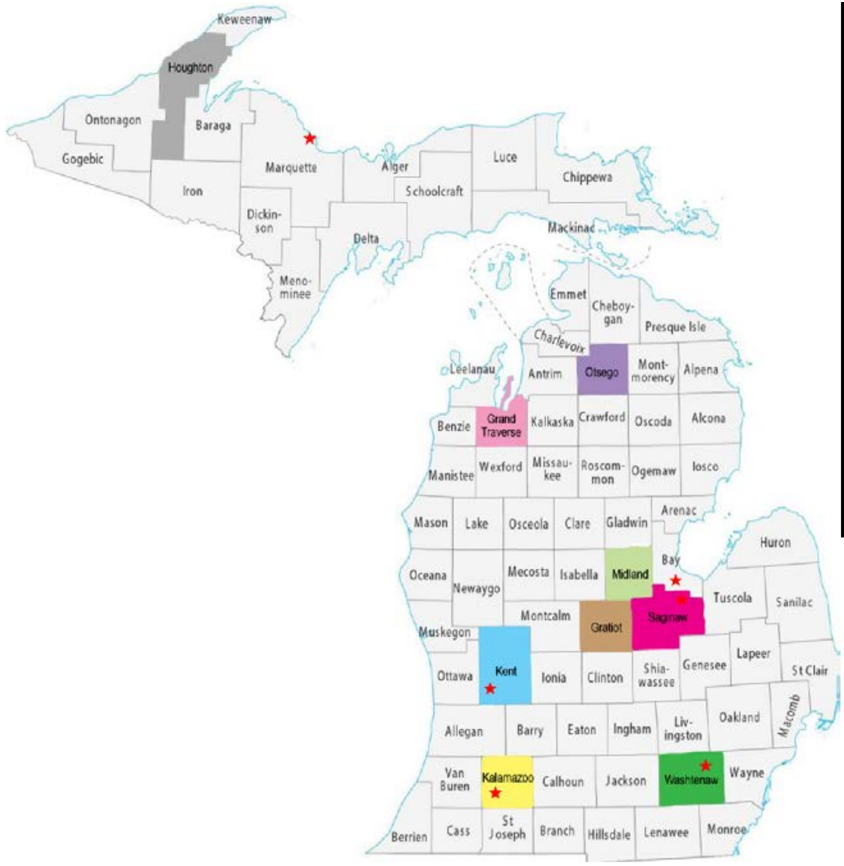


Figure 3: Ground truth locations

Table 1: Ground Truth Locations	
Geographic County	**Major City**
Otsego	Marquette
Grand Traverse	Bay City
Midland	Saginaw
Houghton	Ann Arbor
Gratiot	Grand Rapids
Saginaw	Kalamazoo
Washtenaw	
Kent	
Kalamazoo	

Ground truth was generated by manual visual inspection of traffic signals using geolocated aerial and street-level geo-located images from Google Maps. When available, initial traffic signal data provided by each community was used as a starting point. A technician manually scanned each section of road and each intersection on the Google Maps aerial images searching for traffic signals. Street-level images confirmed traffic signals that appeared in aerial images.

Traffic signal locations were added to a geographic information system (GIS) inventory of intersections using the asset management system Roadsoft. To speed entry and ensure accuracy, the technician used Roadsoft's Google integration for creating the ground truth inventory of traffic signals (Figure 4).

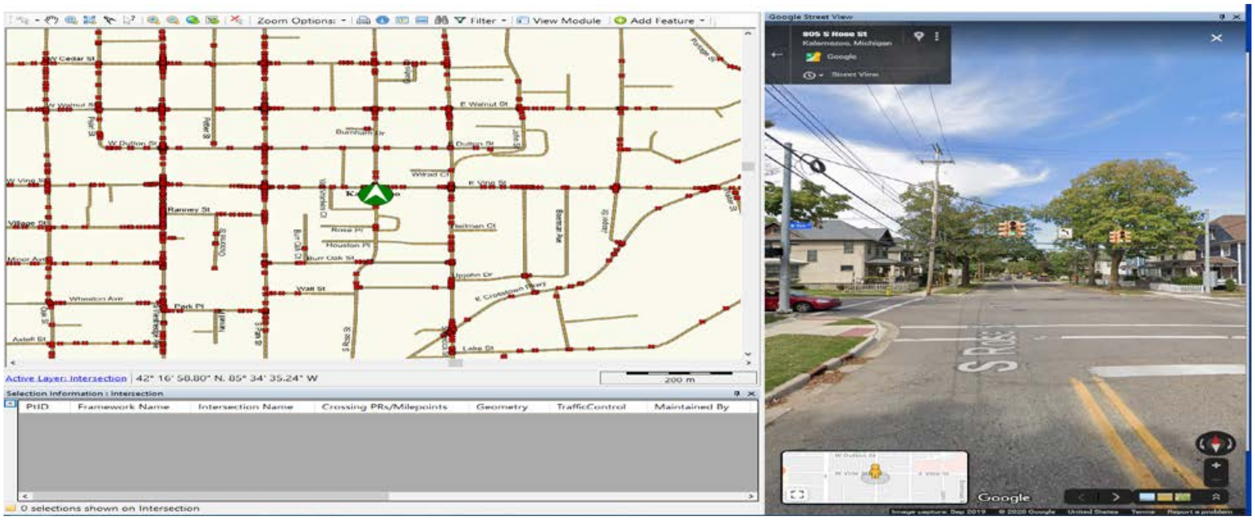


Figure 4: Roadsoft traffic crash module used for traffic signal ground truth verification

The traffic signal ground truth inventories were first checked against agency provided data to verify that all traffic signals were included. A sampling of each jurisdiction was peer reviewed using the aerial image review process to verify that no traffic signals were missed or incorrectly identified. The peer review sampling indicated a very low error rate in ground truth creation.

A second check of ground truth used the traffic signal identification method outlined in this study with a low consensus percentage (25%) to identify all intersections that may have signals followed by a manual review of the identified locations to verify ground truth. The low consensus percentage identification technique is discussed in the Methods and Results sections.

Aggregating Crashes

This study used ten years of geo-located Michigan crash data from all across Michigan. The 2020 data set was only partially complete, ending in May of 2020. To store and analyze the crash data, the study used the Roadsoft software suite, which is a roadway asset management system for collecting, storing, and analyzing data associated with transportation infrastructure. Roadsoft has an existing procedure for importing Michigan crash data, integrates with the Framework Base Map, and has spatial and data query features for manipulating crash data. Roadsoft also has a traffic signal inventory layer that simplifies recording of ground truth and final output of results.

Queries in Roadsoft aggregated crash data based on the spatial distance from a crash location to the nearest road-to-road intersection in the Framework Base Map. The aggregated crashes were associated with the respective Framework Base Map intersection. Roadsoft's crash analysis module includes a Crash Intersection Ranking tool, which provides a ranking of all road intersections based on the number of crashes associated with each intersection (Figure 5). Data queries can be performed on the associated crashes to include or exclude records based on criteria. This study used the Roadsoft query function in combination with the intersection ranking tool to identify intersections that met detection criteria to indicate a traffic signal was present. These detected locations were compared against the ground truth to measure the method's accuracy and to optimize query functions. While this same functionality can be replicated in most GIS software, they often require additional processing when using generic GIS spatial and data query tools.

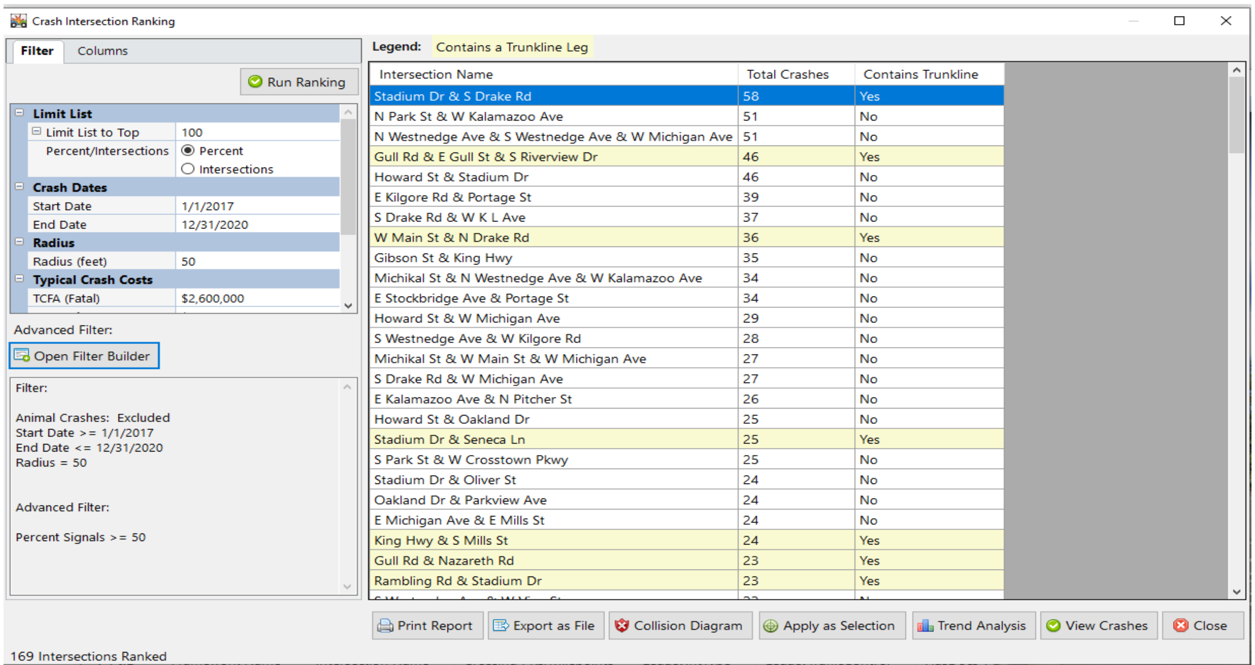


Figure 5: Screenshot of crash data interface in Roadsoft

Performance Criteria

Two performance criteria were developed for this study as a means for optimizing the detection method. The main performance criterion is the detection accuracy percentage, which is calculated by dividing the total count of detected locations by the number of traffic signals in the ground truth and multiplying by 100 (see equation below).

$$\frac{Number\ of\ Locations\ Detected}{Number\ of\ Traffic\ Siganls\ in\ Ground\ Truth} X\ 100 = Detection\ Accuracy\ Percentage$$

This performance criterion only assessed whether the total count of signalized intersection identified by the detection method matched the count in the ground truth. False positives and undetected locations did not directly detract from this performance metric as long as the total count matched.

The second performance criteria is location precision, which is calculated by dividing the number of correctly identified traffic signals divided by the number of traffic signals in ground truth and multiplying by 100 (see formula below). Location precision is a measure of the number of ground truth locations that were detected by the location method, with no penalty for false positives. This criterion was the secondary means for optimizing the detection method since the study was specifically seeking an accurate count of traffic signal assets.

$$\frac{Number\ of\ Correctly\ Identified\ Traffic\ Signal}{Number\ of\ Traffic\ Signals\ in\ Ground\ Truth} X100 = Location\ Precision\ Percentage$$

The two performance metrics were used to assess the results of different detection criteria.

An example of how these criteria work is as follows: If a ground truth set included 100 signalized intersections and if the detection method correctly identified 90 signalized intersections and 10 false positives for a total of 100 detected locations, the detection accuracy would be 100 percent because the errors (i.e., false positives and undetected locations) are complimentary and cancel out each other, but the location precision would measure only 90% due to the ten false positives(see example calculations below) .

$$Dectection\ Accuracy\ \% = \frac{100}{100}\ x\ 100 = 100\%$$

$$Location\ Percision\ \% = \frac{90}{100}\ x\ 100 = 90\%$$

Optimization

The study used four data query factors to optimize the detection of signalized intersection. These query factors included: crash report consensus percentage, crash data year range, crash radius from the intersection, and minimum number of crash incidents.

Crash report consensus percentage: The traffic control data field of the UD-10 report does not always accurately describe the nearest intersection's traffic control (see Background section of this report). Therefore, the study used a consensus approach for detecting traffic signal locations by treating each crash report at a given intersection as a repeated measure. The crash report consensus percentage is the percent of crash reports that indicated a signalized intersection was related to the crash in question in comparison the total number of crash reports for the intersection. An intersection that met or exceeded the consensus percentage threshold of 52 percent was considered a detected signalized location.

Crash data year range: The study had a total of ten years of crash data, from May 2020 back to 2010 available for analysis. Data from 2020 was a partial year ending in May; all other years were full years. Increasing the number of years of crash data used increased the number of crashes that could be used as a repeated measure; however, older crash data has a higher risk of intersections with changed traffic control schemes (i.e., being updated from four-way stop to signalized or from signalized to roundabout). The number of years of crash data included in the analysis ranged from the most recent three years to ten years previous. Three combinations of crash data were analyzed: the most recent three years of crash data (2020-2017), the most recent six years of crash data (2020-2014), and the most recent ten years of crash data (2020-2010).

Crash radius from an intersection: This factor associates the number of crashes to a particular intersection using the distance that the crash was recorded from the crash location to the nearby road-to-road intersection in the Framework Base Map. This factor ranged from 50 feet from an intersection to 150 feet from the intersection. The minimum distance was set at 50 feet because it is the smallest distance that would reasonably encompass a vehicle-to-vehicle crash on an approach leg since it is approximately three-car lengths from the center of an intersection. The maximum distance was set at 150 feet to conform with UD-10 guidance on the type of crashes that can be associated with an intersection and, thus, likely to report traffic control data. Larger radii increased the number of crashes associated with an intersection, but also increased the likelihood that a particular crash was not related to a traffic control device.

Minimum number of crash incidents: This factor screens out intersections that may only have one or two crashes associated with them in order to ensure a minimum number of crashes would function as the repeated measure for each intersection. This factor was set between zero (no minimum) and two crashes.

These four query factors were experimentally varied to optimize both the primary performance metric (detection accuracy) and secondary performance metric (location precision) by comparing detected locations to ground truth. Multiple successive detection runs were conducted on all or part of the ground truth data set during which one query factor was varied while holding the remaining factors constant.

The output of each trial run was a listing of intersections using the appropriate Framework Base Map intersection name that surpassed the detection threshold criteria for the given run, indicating a traffic signal was likely present. The intersection lists were compared with the ground truth traffic signal inventory using a macro-enabled spreadsheet to ensure matches (Figure 6).

	Ground Truth	3 years 75% signals	Misses	False Positives			
2	Alamo Ave & Douglas Ave	N Park St & W Kalamazoo Ave	FALSE	FALSE		Misses	32
3	Angling Rd & Oakland Dr	N Westnedge Ave & S Westnedge Ave & W Michigan Ave	TRUE	FALSE		False Positives	12
4	Balch St & S Park St	Howard St & Stadium Dr	FALSE	FALSE		Number	109
5	Beech Ave & N Drake Rd	E Kilgore Rd & Portage St	FALSE	FALSE		Ground Truth	144
6	Bronson Blvd & Whites Rd	S Drake Rd & W K L Ave	FALSE	FALSE			
7	Campus Dr & Parkview Ave	Michikal St & N Westnedge Ave & W Kalamazoo Ave	FALSE	FALSE			
8	Campus Dr & Parkview Ave & S Drake Rd	E Stockbridge Ave & Portage St	FALSE	FALSE			
9	Croyden Dr & N Drake Rd & Croyden Ave	Howard St & W Michigan Ave	FALSE	FALSE			
10	Douglas Ave & W North St	Michikal St & W Main St & W Michigan Ave	FALSE	FALSE			
11	Douglas Ave & W Paterson St	S Drake Rd & W Michigan Ave	TRUE	FALSE			
12	E Alcott St & Portage St	E Kalamazoo Ave & N Pitcher St	TRUE	FALSE			
13	E Alcott St & S Burdick St	S Park St & W Crosstown Pkwy	FALSE	FALSE			
14	E Cork St & Emerald Dr	Howard St & Oakland Dr	TRUE	FALSE			
15	E Cork St & Fulford St & Moreland St	Oakland Dr & Parkview Ave	FALSE	FALSE			
16	E Cork St & Lovers Ln	Stadium Dr & Oliver St	FALSE	TRUE			
17	E Cork St & Portage St	E Michigan Ave & E Mills St	FALSE	FALSE			
18	E Cork St & S Burdick St & W Cork St	S Westnedge Ave & W Vine St	FALSE	TRUE			
19	E Crosstown Pkwy & E Vine St	E Cork St & S Burdick St & W Cork St	TRUE	FALSE			
20	E Crosstown Pkwy & Portage St	N Rose St & S Rose St & W Michigan Ave	FALSE	FALSE			
21	E Crosstown Pkwy & S Burdick St & W Crosstown Pkwy & Vandersalm Ct	E Kilgore Rd & Portage St	FALSE	FALSE			

Figure 6: Macro-enabled spreadsheet results indicating correctly detected locations, false positives, and missed signalized intersections for a test run with a 75% consensus rating using the most recent three years of data

Task 2: Traffic Signal Cost Study

Data Sources

The study included a cost study to determine a rough-estimated project cost for local-agency traffic signal replacement and new installations. All road construction projects in Michigan on state-owned road projects and local-agency-owned road projects that use federal dollars must be processed through the MDOT bid letting system. This system processes over a billion dollars in construction and maintenance projects each year for roads owned by MDOT and local agencies. However, this system does not contain data for work on non-federal-aid-eligible roads or projects where a local agency used local funds to construct the project. Nonetheless, it was deemed likely that most traffic signal projects would use federal aid. Therefore, cost data was collected from bid tabulations in MDOT's bid letting system.

The MDOT bid letting systems provides detailed information on individual projects that are put out for bid for contractor consideration. Data includes a short description of the project detailing the work type and approximate limits, a listing of the types of pay items associated with the project, the quantity of each of the pay items, and the prices contractors bid for the respective items. The letting systems also include the total prices for each contractor that has bid for the project and an engineer's estimate of costs.

Bid letting data from June 2020 to October 2017 was analyzed to determine bid costs for local-agency-let and MDOT-let traffic signal projects. The narratives in MDOT bid letting reports were parsed to find the description of the work in each bid project (Figure 7). Projects that included descriptions of traffic signal modernization or installation were selected for further analysis.

Information from MDOT's bid letting system provides project cost data that only represents contractor bid cost for specific projects. The bid letting data does not include construction over-runs or under-runs in the construction phase of the project. Current professional practice in Michigan indicates that low bid costs are routinely within plus or minus 10 percent of the final physical construction costs for most projects. The selected low bidder's unit costs for signal-related projects were used in this study.

Letting of January 10, 2020

Letting Call: 2001 001

Project: M 82081-206745

Local Agreement:

Start Date: May 4, 2020

Low Bid: $298,999.55

Engineer Estimate: $339,076.73

Pct Over/Under Estimate: -11.82 %

Completion Date: August 30, 2020

Description:

Traffic signal modernization, concrete curb and gutter, sidewalk, sidewalk ramps and pavement markings on M-153 at Wyoming Avenue in the city of Dearborn, Wayne County.

No DBE participation required

Bidder	As-Submitted	As-Checked	
Dan's Excavating, Inc.	$298,999.55	Same	1 **
Rauhorn Electric, Inc.	$308,291.01	Same	2
J. Ranck Electric, Inc.	$321,175.44	Same	3
Sawyer Services, Inc.	$335,754.08	Same	4
Motor City Electric Utilities Company	$344,602.99	Same	5

Figure 7: MDOT bid letting project report showing overall description and bidder results

Each selected signal project was evaluated to determine the total number of intersections addressed by the project. The project extent description in each bid letting describes the approximate boundaries of each project. This study's reviewers used the start and end point locations described in the bid letter to locate the project on satellite imagery. A count of the intersections involved in the project were recorded in a data sheet along with the bid costs. The number of signal heads contained in the bid were also used as a check to make a determination on the number of intersections that the project addressed.

Cost Relevance Determination

Each let project included hundreds of pay items that comprised the project (Figure 8). The intent of this study was to determine the cost of traffic signal infrastructure separate from other incidental road improvements. The study separated pay items from each traffic signal project into five different cost categories: traffic signal equipment, pavement and roadway improvements, construction, structures, and incidentals.

Secti	Item Description/Supplemental Description	Un	Quantity	Vendor Na	Bid Price	Ext Amount	Vend Ra
1	Sidewalk Ramp Layout	LSUM	1.000	Dan's Excava	$0.01	$0.01	1
1	Mobilization, Max$30,700.00	LSUM	1.000	Dan's Excava	$30,700.00	$30,700.00	1
1	Curb and Gutter, Rem	Ft	139.000	Dan's Excava	$33.88	$4,709.32	1
1	Fence, Rem	Ft	50.000	Dan's Excava	$15.00	$750.00	1
1	Pavt, Rem	Syd	29.000	Dan's Excava	$36.06	$1,045.74	1
1	Sidewalk, Rem	Syd	166.000	Dan's Excava	$30.49	$5,061.34	1
1	Exploratory Investigation, Vertical	Ft	30.000	Dan's Excava	$5.00	$150.00	1
1	Excavation, Earth	Cyd	27.000	Dan's Excava	$33.71	$910.17	1
1	Non Haz Contaminated Material Handling and Disposal, LM	Cyd	50.000	Dan's Excava	$0.01	$0.50	1
1	Erosion Control, Inlet Protection, Fabric Drop	Ea	4.000	Dan's Excava	$204.82	$819.28	1
1	Erosion Control, Maintenance, Sediment Removal	Cyd	2.000	Dan's Excava	$84.25	$168.50	1
1	Erosion Control, Silt Fence	Ft	25.000	Dan's Excava	$12.73	$318.25	1
1	Subbase, LM	Cyd	22.000	Dan's Excava	$71.04	$1,562.88	1
1	Aggregate Base, 6 inch	Syd	21.000	Dan's Excava	$82.67	$1,736.07	1
1	Maintenance Gravel, LM	Cyd	20.000	Dan's Excava	$0.01	$0.20	1
1	Hand Patching	Ton	8.000	Dan's Excava	$243.26	$1,946.08	1
1	Conc Pavt, Nonreinf, 9 inch	Syd	21.000	Dan's Excava	$70.00	$1,470.00	1
1	Managed Field Ethernet Switch, Fiber Capable	Ea	1.000	Dan's Excava	$1,056.98	$1,056.98	1

Figure 8: MDOT bid letting unit cost and volume for a specific projects

Traffic signal equipment included pay items that were related to the traffic signal equipment, such as strain wire, signal cabinets, electrical services, cantilevered poles, pole foundations, and any obvious miscellaneous quantities of excavation or base material that may be related to a traffic signal. Pavement and roadway items were segregated out if there was a significant volume of road construction work, such as asphalt or concrete paving, curb and gutter, earth excavation, sand sub-base, or other quantities that may have been included as part of resurfacing or adding a lane.

Structures pay items included work associated with extension or relocation of storm or sanitary sewers, manholes, catch basins, or culverts.

Construction pay items were items that were necessary for staging and execution of the project, such as temporary traffic control, temporary pavement markers, flagging, and construction barriers or safety measures. Depending on one's perspective, these items may be considered part of the traffic signal cost since they are necessary to put the device in place.

Classification of bid item is not an exact science. Rather, classification was an interpretation without any first-hand knowledge of the project. Nonetheless, items were classified in a consistent manner, which should yield consistent results.

Task 3: Traffic Signal Infrastructure Investment

To determine the level of traffic signal infrastructure investment in the state of Michigan, the total cost for all traffic signal assets must be determined. Task 1 identifies an estimate of traffic signal assets in Michigan while Task 2 estimates rough costs per traffic signal asset. The traffic signal infrastructure investment can be determined by multiplying the estimate of traffic signal assets (Task 1) by the cost per traffic signal (Task 2).

RESULTS

Task 1: Estimate of Traffic Signal Assets

Local-Agency Traffic Signal Estimate

Optimization Results

Crash report consensus percentage: The project used a consensus approach when evaluating crash data to detect signalized intersections. The consensus percentage had the most impact on performance metrics for traffic signal detection. The optimization process ran repeated analyses using different consensus percentage thresholds, ranging from 25% and 75%. Although selecting a lower consensus percentage increased the location precision (i.e., detected locations were more likely to include all ground truth locations), a lower consensus percentage greatly increased the number of false positives skewing the detection accuracy by 24 to 41 percent more than the actual traffic signal count.

Low consensus percentages effectively screened locations for visual inspection. In terms of location precision, between 98 and 99 percent of the ground truth were contained in a detection run using a 25 percent threshold (Table 2). The three-year crash data run with a 25 percent consensus threshold only added about 24 percent more false positive detection locations, which was not acceptable as a standalone estimate of signal number, but which was useful for double checking ground truth in combination with visual inspection to eliminate false positives and to minimize searching for missed traffic signals.

High consensus percentages reduced false positives but also increased undetected traffic signals. A high consensus percentage found locations with a very high probability of traffic signals but left some traffic signals undetected (Table 2). High consensus percentages produce unsatisfactory standalone results although these detection runs are valuable for finding locations with the highest probability of having a traffic signal.

After initial factor sensitivity testing, three of the four factors were fixed at their optimal settings while the consensus percentage was more finely tuned using an expanded data set. The number of years of data was set at the most recent three years (2017-2020), crashes were aggregated in a 50-foot radius from the intersection, and no minimum crash threshold used.

Ground truth was collected for the geographic county and the major cities data sets. The consensus percentage was adjusted from 50 to 60 percent in order to determine the optimal setting for this factor. Results from each test run determined the direction of the consensus percentage for the next run. Performance was optimal for the geographic county data set at a consensus percentage of 52 percent (Table 2).

Table 2: Consensus Percentage Optimization using Geographic County Ground Truth Data Sets from Otsego, Houghton, Saginaw, Grand Traverse, Midland, Gratiot, Washtenaw, Kent, and Kalamazoo Counties (including all local-agency jurisdictions within)

Consensus percentage	50	52	55	60
Missed signals	118	129	133	158
False Positives	185	115	105	101
Signals detected	1266	1185	1171	1145
Ground truth	1199	1199	1199	1199
Detection accuracy	105.6%	98.8%	97.7%	95.2%
Location precision	90.2%	89.2%	88.9%	86.8%

Performance was optimal for the major cities data set at a consensus percentage of 52 percent with data being processed in a manner identical to the geographic county data set (Table 3). The similarity between geographic counties and major cities data sets in the optimal consensus percentage threshold indicates that agency size does not appear to cause an impact. Cities did, however, perform slightly better than geographic counties.

Table 3: Consensus Percentage Optimization using Major Cities Ground Truth using Data Set from City of Marquette, Bay City, City of Saginaw, City of Ann Arbor, City of Grand Rapids, and City of Kalamazoo

Consensus percentage	50	52	55	60
Missed signals	43	41	46	58
False Positives	54	47	44	31
Signals detected	588	583	575	550
Ground truth	577	577	577	577
Detection accuracy	101.9%	101.0%	99.7%	95.3%
Location precision	92.5%	92.9%	92.0%	89.9%

The combined results from all ground truth data sets indicate that 52 percent is the optimal consensus percentage to maximize accuracy when using a consensus approach (Table 4). A detailed list of the accuracy of each geographic county and major city used in the ground truth set is included in Appendix A.

Table 4: Combined Performance Metrics for Total Ground Truth

Consensus percentage	**50**	**52**	**55**	**60**
Missed signals	122	133	138	163
False Positives	197	121	111	107
Signals detected	133	1249	1234	1205
Ground truth	1261	1261	1261	1261
Detection accuracy	105.7%	99.0%	97.9%	95.6%
Location precision	90.3%	89.5%	89.1%	87.1%

Crash data year range: Crash data available for this study was divided into three sets: the most recent three years of crash data (2020-2017), the most recent six years of crash data (2020-2014) and the most recent ten years of crash data (2020-2010). Increasing the number of years of crash data did not significantly improve performance metrics (Table 5), so this factor was set at the most recent three years of data for the remainder of the study.

Table 5: Optimized Results using Consensus Percentage and Number of Years of Data for the City of Kalamazoo

Consensus percentage	25	50	60	75	25	50	60	75	25	50	60	75
Missed signals	3	10	16	36	1	14	15	35	2	9	15	51
False Positives	38	13	6	4	60	46	12	11	61	32	15	12
Signals detected	179	147	134	112	203	176	141	120	203	167	144	105
Ground truth	144	144	144	144	144	144	144	144	144	144	144	144
Detection accuracy	124%	102%	93%	78%	141%	122%	98%	83%	141%	116%	100%	73%
Location precision	98%	93%	89%	75%	99%	90%	90%	76%	99%	94%	90%	65%

Crash radius from an Intersection: The study evaluated crash data for crashes occurring at distances of 50 feet, 100 feet, and 150 feet from the center of the intersection. Intersection radii of 100 and 150 feet created a larger number of crash records per intersection but performed poorly for both performance metrics. An apparent reason for this poor performance was aggregating crashes from closely-spaced intersections at times pulled data from the wrong intersection. For example, two intersections on MacInnes Drive in Houghton, Michigan, are located close together. The MacInnes Drive/Townsend Drive intersection has a three-light traffic signal asset; near to that intersection is the MacInnes Drive and Woodland Road intersection, a stop-sign-controlled intersection. A search radius over 50 feet will associate crashes from the MacInnes Drive/Townsend Drive intersection with the MacInnes Drive/Woodland Road intersection being detected as a signal location (Figure 9).

Figure 9: Example of a closely-spaced local intersection (Woodland Drive and MacInnes Drive) that is near the signalized intersections of US-41 (Townsend Drive) and MacInnes Drive.

The minimum crash radius of 50 feet produced accurate results while also providing a sufficient number of crashes at each signalized intersection to allow detection. This factor was fixed at 50 feet for the remainder of the study due to concerns of miss-associating crash data to adjacent intersections.

Minimum number of crash incidents: The study experimented with requiring a minimum number of crashes for an intersection to be considered as a detected location since a minimum number of crash incidents forces a repeated measure of crash data (more than one) at each intersection. It was assumed that removing intersections with single crashes would be likely to increase accuracy. The study discovered that requiring a minimum number of crashes at an intersection greatly reduced coverage of data and, thus, reduced detection accuracy and location precision.

The minimum number of crash incidents factor was tested and was abandon as not beneficial using a statewide Michigan data set since it required significantly more years of crash data in order to ensure that repeated crashes occur at every intersection. This factor interacts with the crash data year range and may provide some benefit in other studies potentially as a screening method to direct manual review.

Statewide Traffic Signal Estimate

The final optimized detection method was used to address a statewide crash data set consisting of **89,544** individual crash reports with coverage throughout Michigan. Intersections were separated into two categories: those with at least one trunkline leg and those with only local legs. The former were considered traffic signals owned by MDOT and the latter were considered traffic signals owned by local agencies. There were 10,740 total signalized intersections detected in this study (Table 6).

Table 6: Statewide Signal Count	
Local Agency	6690
State Trunkline	4050
Total	**10740**

Back-calculating from the total detected local-agency traffic signals and the total number of ground-truth traffic signals used for this study indicate that ground truth data set comprised approximately 18 percent of the signals in the statewide estimate. Calculating the margin of error using the ground truth size and estimated total traffic signals at a 95-percent confidence interval results in a margin of error for this sample size is 2.5 percent, which indicates that sampling error is likely minimal and provides a high potential that the ground truth is representative of the overall count.

Figure 10 and Figure 11 illustrate the location of local-agency traffic signals detected using this technique. Only 136 local-agency traffic signals (2% of the state total) were located north of a line from the southern boundary of Mason County to Huron County. The three core Detroit Metro geographic counties of Wayne, Oakland, and Macomb possess 3,912 of local-agency traffic signals (58.5% of the state total) detected. Adding Genesee, Kent, and Washtenaw geographic counties to this list finds 5,091 local-agency traffic signals (76% of the state total). is A heat map illustrating the relative concentration of local-agency traffic signals indicates that local-agency traffic signals are mostly a regional phenomenon centered around a few urban geographic counties (Figure 12).

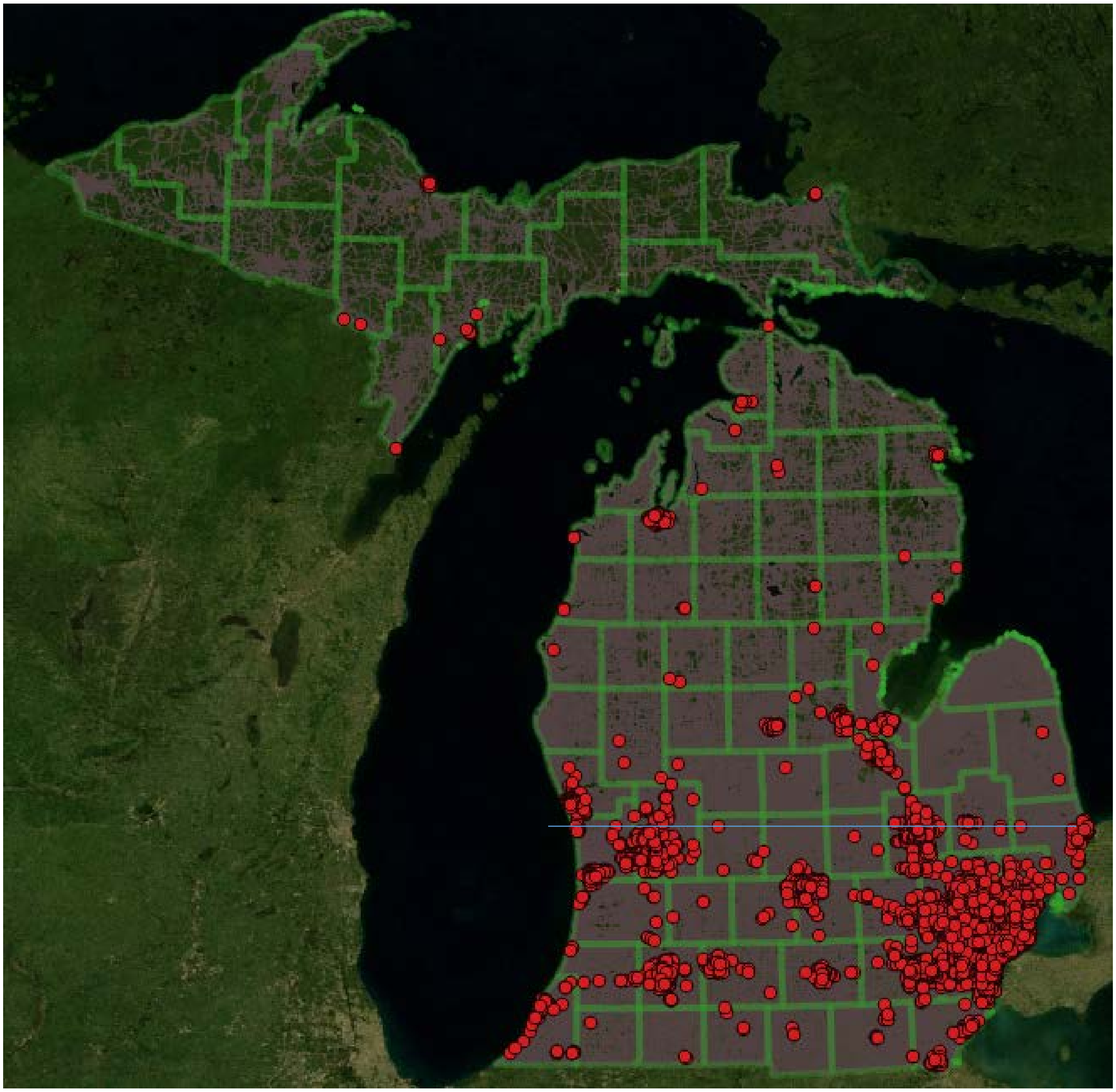


Figure 10: Detected local-agency traffic signal locations. Note that not all signal locations will be apparent due to scale.

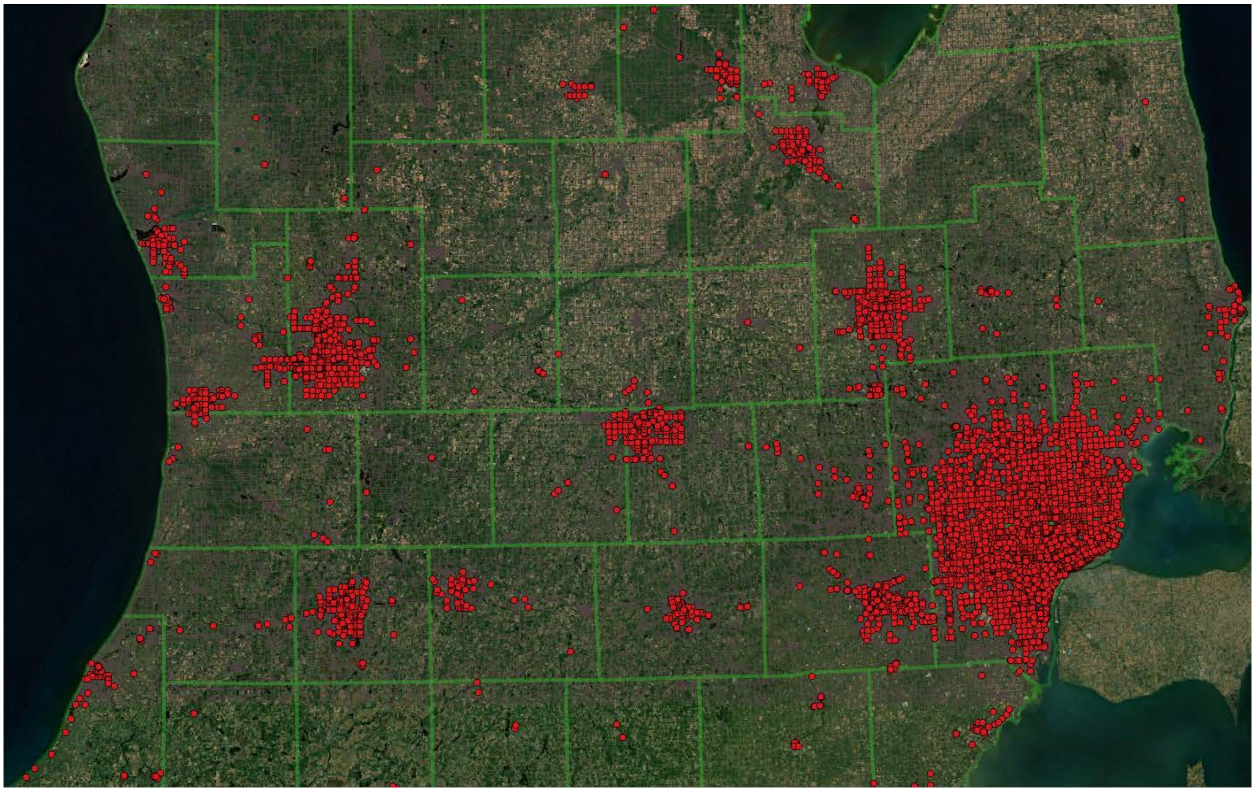


Figure 11: Detected local-agency traffic signal locations. Note that not all signal locations will be apparent due to scale.

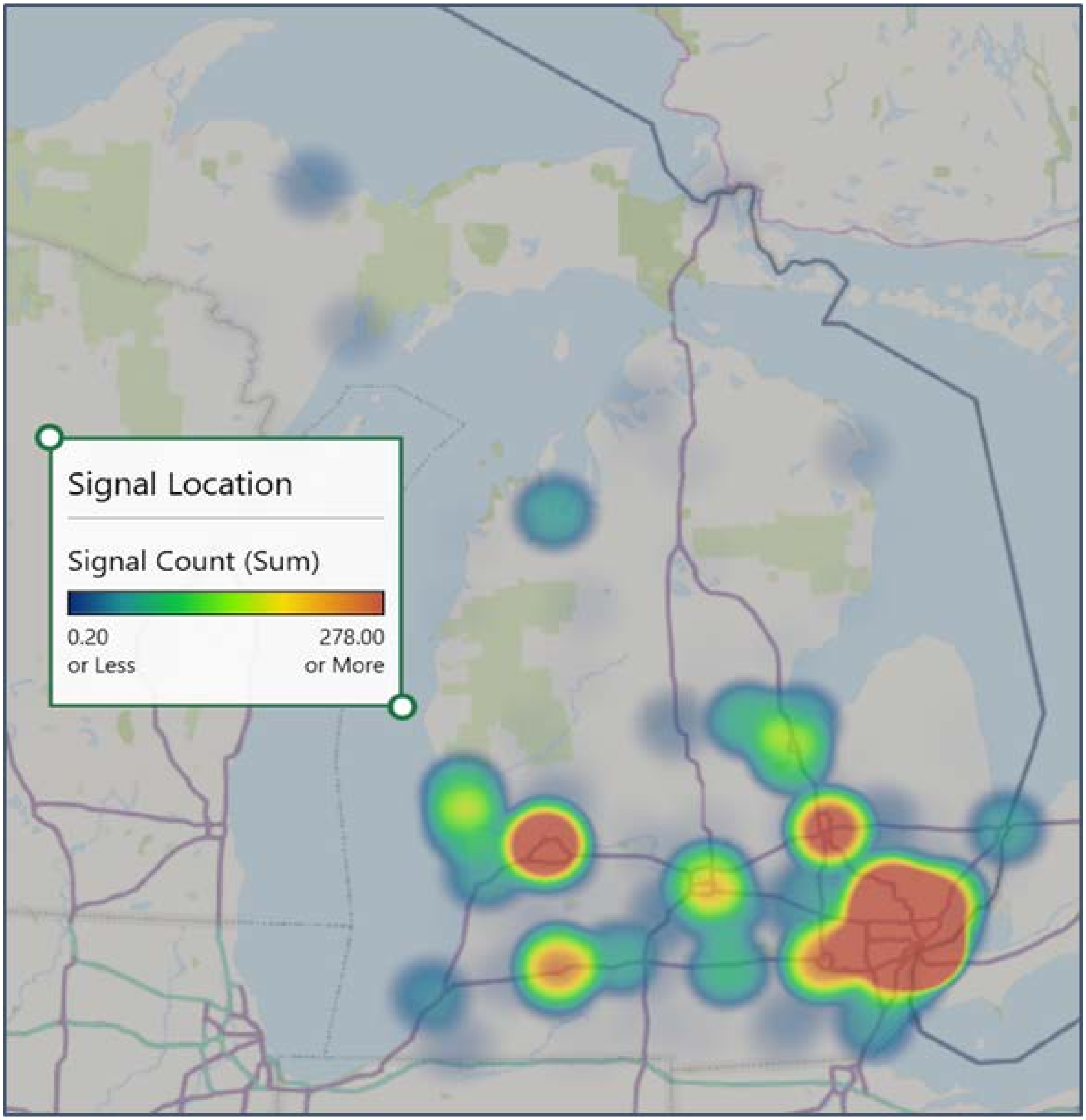


Figure 12: Heat map illustrating the relative concentration of local-agency traffic signals

The design of this study did not include optimizing the method to detect state trunkline traffic signals; however, it appears that the local-agency optimized method performed satisfactorily in detecting traffic signals on state trunkline roads. The process detected 4,050 signalized intersections that had at least one leg owned by MDOT. MDOT's traffic signal database included 3,248 signalized intersections, which appears to be a significant overestimation (additional 24.7%) of the actual MDOT traffic signals. Evaluation of the MDOT signal database and discussions with MDOT managers responsible for the database indicate that the definition of a signalized intersection used for this study differs from what MDOT as a road owner uses to define an intersection. In particular, MDOT's definition of signalized intersections on divided boulevard sections of road differs from this study's definition. MDOT typically counts the associated intersections on a boulevard section as one signal installation although the Framework Base Map shows these sections as two or four discrete intersections that are closely spaced (Figure 13 and Figure 14).

Figure 13: Boulevard section showing five discrete intersections detected marked by blue dots while actual MDOT signal installations according to their GIS database marked by red stars

Figure 14: Boulevard section at street level

Visually comparing detected locations of MDOT traffic signals to the MDOT traffic signal database indicates overall satisfactory agreement. Each data set shows relatively good agreement at different zoom levels (Figure 15, Figure 16, and Figure 17).

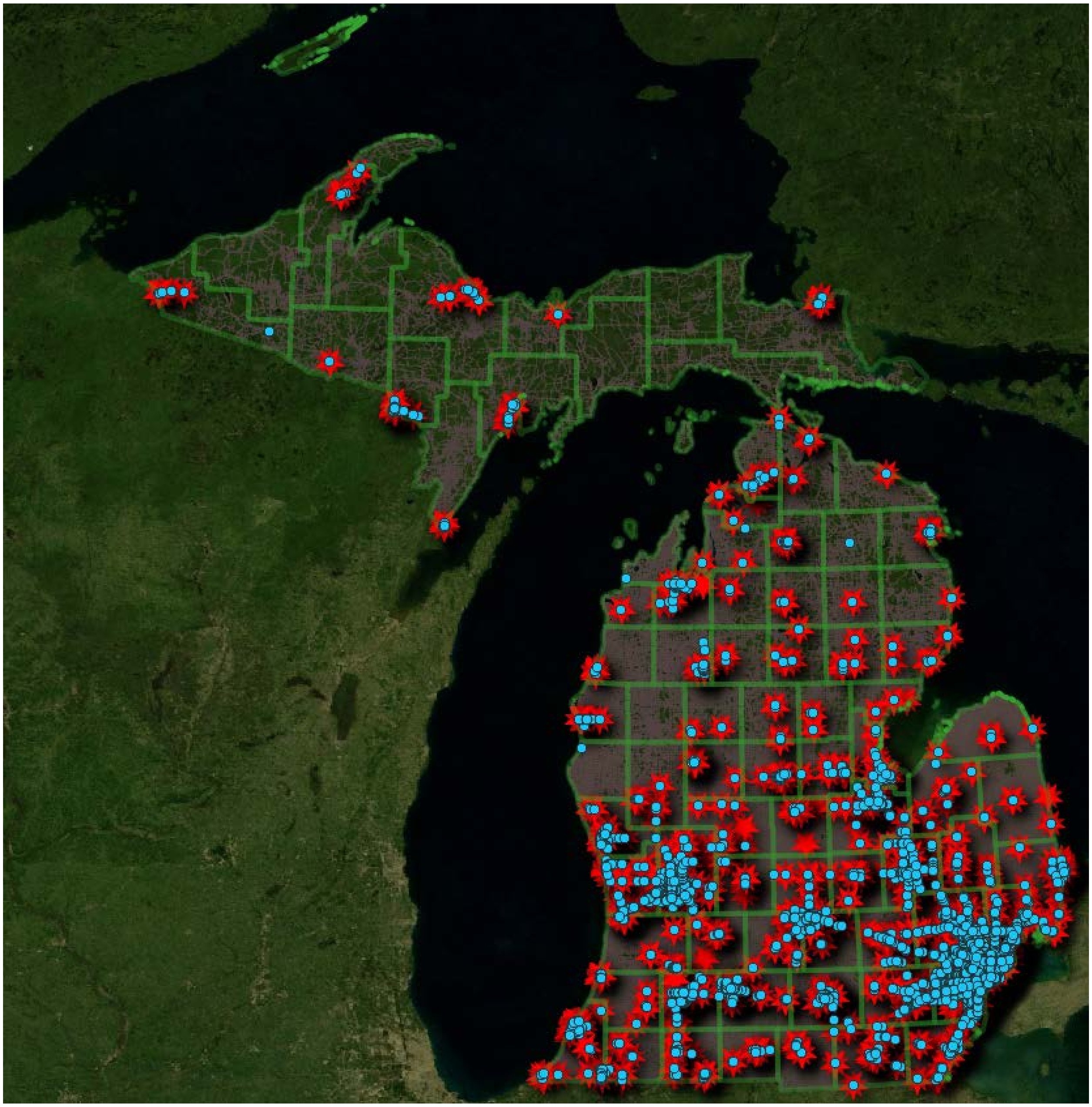


Figure 15: Trunkline traffic signals detected (blue dot) compared to actual (red star)

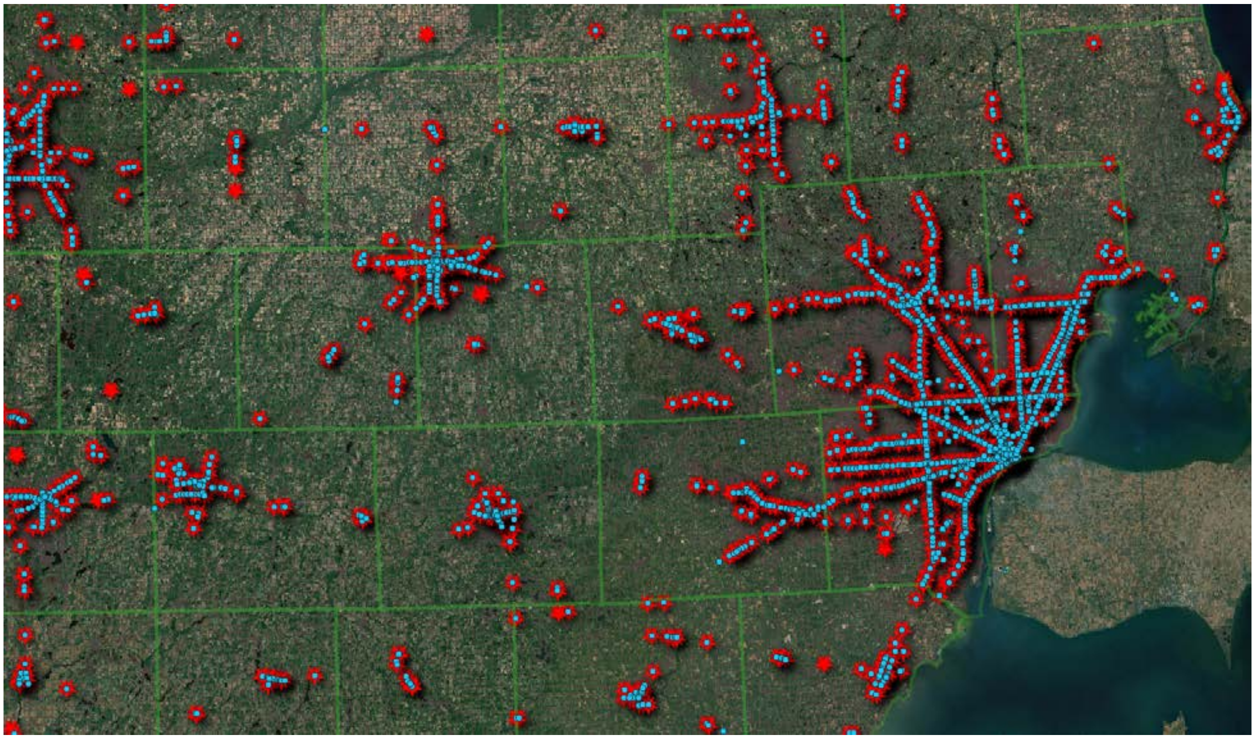


Figure 16: Trunkline traffic signals detected (blue dot) compared to actual (red star)

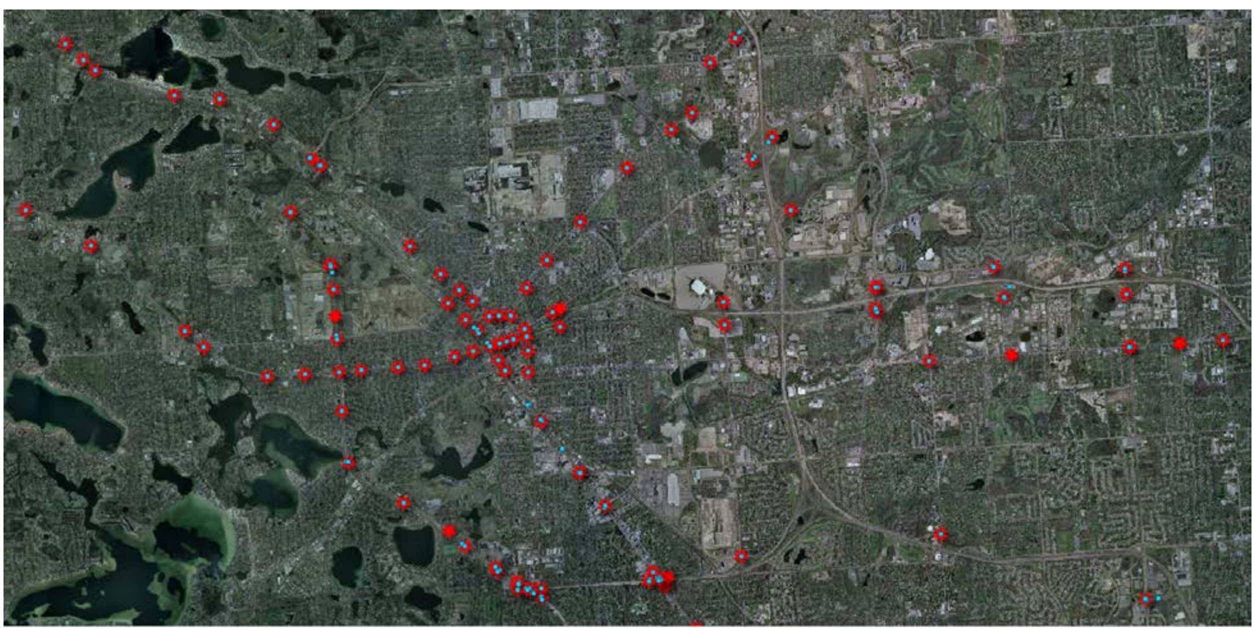


Figure 17: Trunkline traffic signals detected (blue dot) compared to actual (red star)

Using a one-signal-per-1,000-population estimating rule, the traffic signals detected are within 7 percent of the amount generated from the estimating rule. The Institute of Transportation Engineers routinely conducts a traffic signal state of practice report. The first issue of this report in 2004 estimated the number of traffic signals relative to population:

> *There are over 300,000 existing signalized intersections in the United States using a rule-of-thumb of one signalized intersection per 1,000 population. There are 2,550 new signalized intersections in the United States each year based on the US Census Bureau forecast of future population growth (0.85 percent).* (Institute of Transportaton Engineers, 2004)

In 2019, Michigan had population of 9.987 million and, according to the estimating rule, would have an estimated 9,987 traffic signals, which is within 7 percent of the 10,740 traffic signals detected in this study.

Task 2: Traffic Signal Cost Estimate

Literature Review

A few state Departments of Transportation (DOTs) have informational web pages that illustrate the cost of traffic signals anecdotally. While these pages are not research based and do not identify variables or limiters in the costs, they do offer general insight regarding the cost of signalized intersections. Washington DOT's informational traffic signal web page estimates a taxpayer cost of $250,000 to $500,000 to purchase and install a traffic signal (Washington Department of Transportation, 2020). An undated Texas DOT informational flyer indicates that a traffic signal can cost "between $80,000 and $100,000 to install depending on the complexity of the intersection" (Texas Department of Transportation, 2020). And, the Wyoming Department of Transportation's 2012 informational traffic signal brochure indicates that signalized intersections cost between $200,000 and $500,000 (Wyoming Department of Transportation , 2012) .

Furthermore, this study found 24 separate bids from 2019 from which the number of intersections and number of traffic signal heads could be determined. From this bid data, this study extracted only the traffic-signal-related equipment in order to develop an average cost per signalized intersection. The signal cost per intersection ranged from $133,000 to $349,000 with the average close to $193,000 per intersection (Table 7). The full list of projects with detailed cost breakdowns are included in Appendix B.

Table 7: Traffic Signal Cost Summary	
Average number of heads	10.3
Average number of intersections	3.2
Average price per intersection	**$192,849**

Task 3: Traffic Signal Infrastructure Investment

Using the estimate of traffic signal assets from Task 1 and the average per-signalized-intersection cost estimate Task 2, a rough total investment in traffic signal infrastructure was estimated (Table 8). It was beyond the scope of the cost study to differentiate between traffic signal costs for MDOT installations and local-agency installations or to determine differences between simple low-volume or rural signalized intersections and high-volume intersections equipped with infrastructure-to-vehicle communications.

Table 8: Statewide Traffic Signal Total Value			
Agency	**Estimate of Traffic Signal Assets**	**Per-signalized-intersection Cost Estimate**	**Total Value in Billions**
Local agency	6,690	$192,849	$1.29
MDOT	4,050	$192,849	$0.78
Total	**10,740**	**$192,849**	**$2.07**

As a comparison, the TAMC 2018 culvert asset pilot study estimated that there was approximately $1.48 billion dollars of local-agency-owned culverts when considering just the installation of the culvert infrastructure.

DISCUSSION

Estimating Traffic Signal Assets: Method Limitations

The age of the data used for the ground truth data set and the traffic signal estimates is a limiting factor for this study. The process for creating ground truth in this study is limited by the age of the currently-available geolocated aerial- and street-level images on Google products.

These images may be several years old in some cases, most commonly for images of low-volume or rural roads. Despite the age limiter on the ground truth data set, the study team believes the ground truth data set is sound since the crash data used for the traffic signal estimates also lags current conditions. The study team holds that these age-related limitations should not adversely impact prediction.

The detection of several types of signalized locations is also a limiting factor for this study. Signals that are not located at a road-to-road intersection will not be detected correctly using this process. Examples of signalized intersections that would not be correctly detected are road-to-rail-line intersections (Figure 18) and road-to-mid-block intersections that have preemption signals (Figure 19). During the study, these intersections were collected in the ground truth data set and were recorded as errors when they were not detected. In some cases, signals at these non-road-to-road intersections were close enough to a road-to-road intersection to cause a false positive at the road-to-road intersection. Future work on this study's method could improve detection of these non-road-to-road intersections by considering road-to-rail-line intersections as intersections for aggregated crash data, similar to road-to-road intersections. Nonetheless, identifying road-to-mid-block intersections, like pedestrian crossings or pre-emption crossings, is difficult since there are no defining features in the Framework Base Map to evaluate.

Figure 18: Railroad crossing

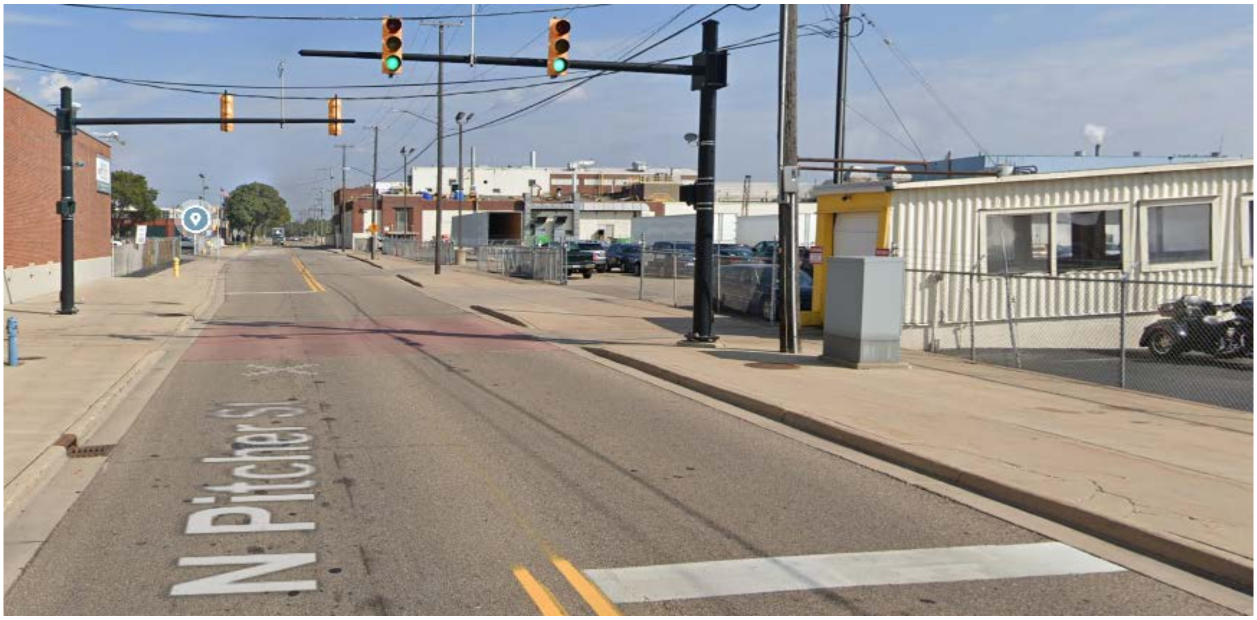


Figure 19: Industrial complex preemption signal

Another limiting factor is closely-spaced intersections. This study's method is subject to false positives at local intersections that are situated close to signalized intersections (Figure 20). For example, the study identified the Oslo Avenue and Michigan Avenue intersection in Iron Mountain as a signalized local intersection when, in fact, the crashes in question occurred at the Michigan Avenue and US-2 intersection, a signalized intersection 100 feet away. Improvements to the location precision metric could be made by spatially identifying detected intersections that are near other intersections and selecting the detected intersections for visual inspection.

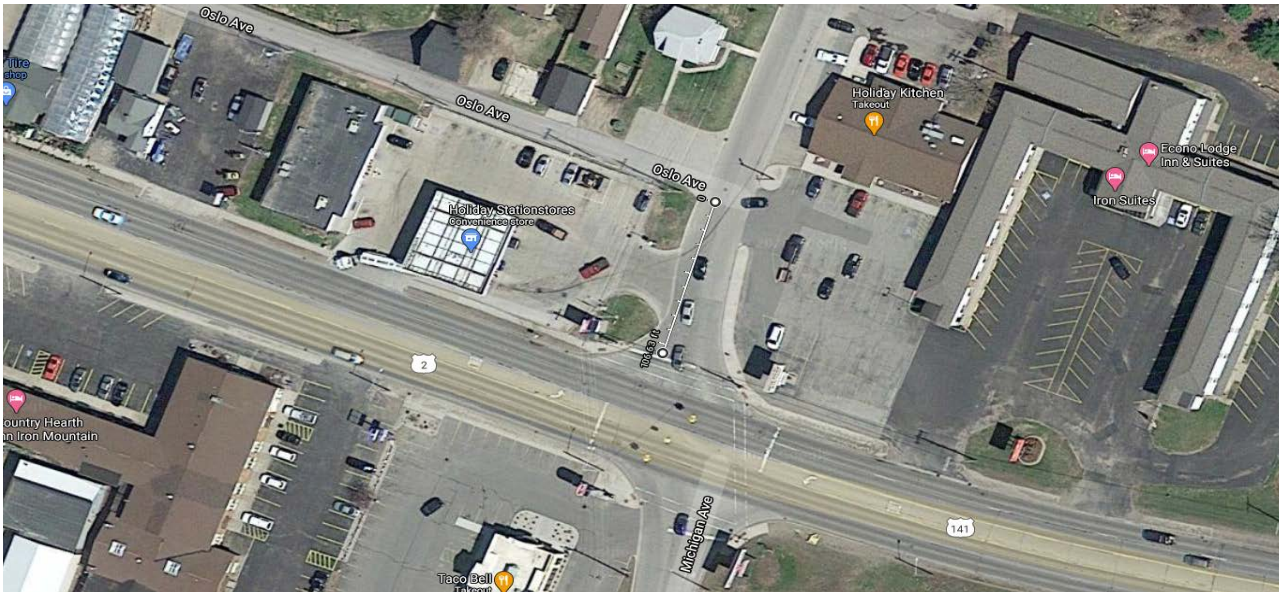


Figure 20: Local road intersection (Olso Avenue and Michigan Avenue) near (100 feet) a signalized trunkline intersection

Finally, estimating traffic signal assets is limited by rural intersections that have a single crash record. The method creates false positives at rural intersections with a single crash record (Figure 21). These single-crash rural intersections are subject to errors because they are highly dependent on the accuracy of the single crash report. In Figure 21's example cases, each detected intersection had a single crash report in which the Traffic Control field was erroneously marked with "signal". This method could be improved by conducting a manual review of intersections with only one related crash report.

Both of these false positive causes—closely-spaced intersections and single-crash rural intersections—do not adversely impact the estimate of traffic signal assets because they are balanced with a complementary number of missed signals. However, the false positives do degrade the location precision metric.

Figure 21: Three examples of false positive rural intersections with single crash records

Traffic Signal Cost Study: Method Limitations

Two method limitations of the traffic signal cost study were infrastructure type used to estimate per-signal costs and there interpretation of the bid item classification. The cost data used to determine the average cost per signalized intersection was primarily MDOT signalization projects with high-end intelligent transportation system or connected-vehicle infrastructure. These infrastructure-to-vehicle-equipped traffic signals are unlikely to represent the whole of the local-agency signal project experience.

Interpretation of the bid item classification is likely a source of error since it was subject to interpretation by people not familiar with the traffic signal project itself. Interpretation errors likely overestimate the extent of the project work since project limits outlined in the bid system are typically the maximum extent of all the work on the project and may not reflect the actual extent of the work.

Another limitation was the inability to find an accurate way to estimate the number of updated intersections. Updated intersections were estimated using a combination of a count of the number of heads in the bid items and visual inspection.

CONCLUSIONS

This study method allows for future updates of the estimate of traffic signal assets to be completed with minimal effort as new crash data becomes available. This method enables TAMC to update its statewide inventory estimate without needing to develop and deploy a data collection and reporting system for the various owners of the transportation network. Since this method uses three years of crash data, re-running this method would be recommended after three years.

The study method successfully located exact positions of most traffic signals even though location precision was not the focus of the study. An increase in location precision could be obtained by using two runs of this method: the first method run with a high consensus percentage (75 percent or greater) would identify locations with a 99-percent probability of having a traffic signal while the second method run with a low consensus percentage (25 percent) would include almost all of the traffic signals. Comparing these two sets would allow reviewers to isolate a set of locations that could be visually inspected using geolocated aerial or street-level images. It is anticipated that this review set would be approximately 46 percent of the total signalized locations, thus greatly reduce search time when extreme accuracy was necessary.

The estimate contained herein of traffic signal assets and the geographic distribution of traffic signal assets should aid the TAMC in determining important considerations and next steps for managing traffic signal assets at a statewide level.

REFERENCES

Michigan Office of Highway Safety Planing . (2019). *2019 Michgian Crash Facts.* State of Michigan.

Institute of Transportaton Engineers. (2004, 11 30). *Signal Timing Practices and Procedures: State of the Practice.* ITE. Retrieved from (https://www.access-board.gov/guidelines-and-standards/streets-sidewalks/144-public-rights-of-way-guidelines/regulatory-assessment#:~:text=There%20are%20over%20300%2C000%20existing,population%20growth%20%280.85%20percent%29

Michigan State Police. (2018). *UD-10 Instruction Manul.*

Texas Department of Transportation. (2020, 11 30). *TXDOT Customer Answer Series* . Retrieved from https://ftp.txdot.gov/pub/txdot-info/pio/casbrochures/pub_signals.pdf

Washington Department of Transportaton. (2020, 11 30). *WSDOT Traffic Signal Informaton Page*. Retrieved from https://wsdot.wa.gov/Operations/Traffic/signals.htm#:~:text=It%20costs%20the%20taxpayer%20%24250%2C000,%2C%20time%20delay%2C%20and%20accidents.

Wyoming Department of Transportation . (2012, march). *WYDOT Quck Facts*. Retrieved from http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Traffic%20data/Traffic%20Signals.pdf

APPENDIX A GROUND TRUTH PERFORMANCE DATA

Gratiot Geographic County				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	0	0	0	0
False Positives	0	0	0	0
Signals Detected	1	1	1	1
Ground Truth	1	1	1	1
Detection Accuracy	100.0%	100.0%	100.0%	100.0%
Location Precision	100.0%	100.0%	100.0%	100.0%

Houghton Geographic County				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	0	0	0	0
False Positives	0	0	0	0
Signals Detected	0	0	0	0
Ground Truth	0	0	0	0
Detection Accuracy	100.0%	100.0%	100.0%	100.0%
Location Precision	100.0%	100.0%	100.0%	100.0%

Kalamazoo Geographic County				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	31	36	34	36
False Positives	51	35	30	30
Signals Detected	270	249	246	244
Ground Truth	250	250	250	250
Detection Accuracy	108.0%	99.6%	98.4%	97.6%
Location Precision	87.6%	85.6%	86.4%	85.6%

Kent Geographic County				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	49	51	54	61
False Positives	75	47	45	43
Signals Detected	523	493	488	479
Ground Truth	497	497	497	497
Detection Accuracy	105.2%	99.2%	98.2%	96.4%
Location Precision	90.1%	89.7%	89.1%	87.7%

Midland Geographic County				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	9	9	9	10
False Positives	9	6	6	6
Signals Detected	73	70	70	69
Ground Truth	73	73	73	73
Detection Accuracy	100.0%	95.9%	95.9%	94.5%
Location Precision	87.7%	87.7%	87.7%	86.3%

Otsego Geographic County				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	0	0	0	0
False Positives	1	0	0	0
Signals Detected	4	3	3	3
Ground Truth	3	3	3	3
Detection Accuracy	133.3%	100.0%	100.0%	100.0%
Location Precision	100.0%	100.0%	100.0%	100.0%

Saginaw Geographic County				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	4	6	6	8
False Positives	16	8	8	7
Signals Detected	117	107	107	104
Ground Truth	105	105	105	105
Detection Accuracy	111.4%	101.9%	101.9%	99.0%
Location Precision	96.2%	94.3%	94.3%	92.4%

Washtenaw Geographic County				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	25	27	30	43
False Positives	33	19	16	15
Signals Detected	278	262	256	242
Ground Truth	270	270	270	270
Detection Accuracy	103.0%	97.0%	94.8%	89.6%
Location Precision	90.7%	90.0%	88.9%	84.1%

City of Ann Arbor				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	9	9	15	18
False Positives	12	8	11	7
Signals Detected	134	130	127	120
Ground Truth	131	131	131	131
Detection Accuracy	102.3%	99.2%	96.9%	91.6%
Location Precision	93.1%	93.1%	88.5%	86.3%

Bay City				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	2	2	3	3
False Positives	6	4	4	4
Signals Detected	47	45	44	44
Ground Truth	43	43	43	43
Detection Accuracy	109.3%	104.7%	102.3%	102.3%
Location Precision	95.3%	95.3%	93.0%	93.0%

City of Grand Rapids				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	18	18	16	22
False Positives	19	19	15	11
Signals Detected	241	241	239	229
Ground Truth	240	240	240	240
Detection Accuracy	100.4%	239	99.6%	95.4%
Location Precision	92.5%	239	93.3%	90.8%

City of Kalamazoo				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	12	10	10	13
False Positives	14	14	12	7
Signals Detected	146	148	146	138
Ground Truth	144	144	144	144
Detection Accuracy	102.1%	102.1%	101.4%	95.8%
Location Precision	91.7%	93.1%	93.1%	91.0%

City of Marquette				
Consensus Percentage	**50**	**52**	**55**	**60**
Missed Signals	2	2	2	2
False Positives	3	2	2	2
Signals Detected	20	19	19	19
Ground Truth	19	19	19	19
Detection Accuracy	105.3%	100.0%	100.0%	100.0%
Location Precision	89.5%	89.5%	89.5%	89.5%

Detected Local Agency Traffic Signals By Ownership

Cities	Signal Count	Cities	Signal Count	Cities	Signal Count	Cities	Signal Count	Cities	Signal Count	Counties	Signal Count
Detroit	1199	Highland Park	22	Harper Woods	8	Coldwater	2	Eaton Rapids	1	Oakland	249
Grand Rapids	235	Traverse City	22	Hudsonville	8	Coloma	2	Ferrysburg	1	Wayne	191
Flint	184	Trenton	22	Mt Pleasant	8	Dewitt	2	Gladstone	1	Macomb	164
Kalamazoo	136	Melvindale	21	Riverview	8	Fowlerville	2	Hartford	1	Genesee	115
Ann Arbor	132	Wixom	21	Utica	8	Frankfort	2	Hersey	1	Washtenaw	106
Dearborn	130	Ypsilanti	21	Adrian	7	Fruitport	2	Homer	1	Kent	105
Troy	130	Burton	20	East Grand Rapids	7	Gaylord	2	Howard City	1	Ottawa	70
Lansing	110	Fenton	20	Milford	7	Gibraltar	2	Howell	1	Ingham	65
Livonia	107	Garden City	20	Niles	7	Grass Lake	2	Huntington Woods	1	Saginaw	52
Warren	104	Lincoln Park	20	Parchment	7	Grosse Pointe Shore	2	Iron Mountain	1	Kalamazoo	48
Southfield	103	Marquette	19	Tecumseh	7	Hastings	2	Lake Orion	1	Monroe	34
Sterling Heights	93	Norton Shores	19	Alpena	6	Hillsdale	2	Lawrence	1	Grand Traverse	33
Royal Oak	86	Ecorse	18	Belleville	6	Imlay City	2	Mackinaw City	1	Jackson	28
Farmington Hills	82	Ferndale	18	Bloomfield Hills	6	Linden	2	Marine City	1	Livingston	26
Pontiac	79	Muskegon Heights	18	Buchanan	6	Manistee	2	Martin	1	St. Clair	24
Wyoming	74	Roseville	18	Milan	6	Marshall	2	Mattawan	1	Berrien	22
Novi	69	Eastpointe	17	Mt Clemens	6	Marysville	2	Metamora	1	Eaton	22
Portage	69	Grosse Pointe Farm:	17	Orchard Lake Village	6	Mason	2	New Baltimore	1	Muskegon	17
Westland	68	Grosse Pointe Wooc	17	Portland	6	Menominee	2	North Muskegon	1	Bay	15
Auburn Hills	64	Inkster	16	Rochester	6	New Haven	2	Norway	1	Isabella	9
Midland	64	Lapeer	16	Rockford	6	Otsego	2	Ortonville	1	Calhoun	8
Rochester Hills	59	River Rouge	16	Sault Ste Marie	6	Oxford	2	Owosso	1	Midland	6
Madison Heights	57	Fraser	14	Dexter	5	Petoskey	2	Plainwell	1	Van Buren	6
Saginaw	57	Plymouth	14	Flushing	5	Springfield	2	Pleasant Ridge	1	Clinton	5
East Lansing	54	Walker	14	Romeo	5	Sturgis	2	Reed City	1	Allegan	4
Battle Creek	53	Clawson	13	Saline	5	Sylvan Lake	2	Richmond	1	Emmet	4
Kentwood	51	Berkley	12	Sparta	5	Wayland	2	Rockwood	1	Alpena	3
Taylor	47	Grand Blanc	11	Cedar Springs	4	Alma	1	Sand Lake	1	Ionia	3
Jackson	46	Grand Haven	11	Flat Rock	4	Auburn	1	Sanford	1	Lenawee	3
Romulus	46	Wayne	11	Mt Morris	4	Bridgman	1	Saugatuck	1	Newaygo	3
Bay City	42	Woodhaven	11	Vicksburg	4	Capac	1	South Haven	1	Arenac	2
St Clair Shores	42	Benton Harbor	10	Birch Run	3	Carleton	1	South Rockwood	1	Lapeer	2
Holland	41	Beverly Hills	10	Cadillac	3	Chelsea	1	St Clair	1	Roscommon	2
Muskegon	41	Brighton	10	Center Line	3	Clinton	1	Stevensville	1	Alcona	1
Wyandotte	37	Farmington	10	Essexville	3	Clio	1	Union City	1	Antrim	1
Grandville	35	Lathrup Village	10	Franklin	3	Coleman	1	Vassar	1	Barry	1
Dearborn Heights	34	Monroe	10	Holly	3	Coopersville	1	Village of Douglas	1	Branch	1
Allen Park	31	Northville	10	Keego Harbor	3	Croswell	1	Webberville	1	Delta	1
Birmingham	31	South Lyon	10	Paw Paw	3	Davison	1	Wolverine Lake	1	Gladwin	1
Oak Park	26	Walled Lake	10	Roosevelt Park	3	Deckerville	1			Hillsdale	1
Port Huron	26	Escanaba	9	St Joseph	3	Dimondale	1			Iosco	1
Southgate	24	Grosse Pointe Park	9	Swartz Creek	3	Dowagiac	1			Mason	1
Hamtramck	23	Zeeland	9	Boyne City	2	Durand	1			Otsego	1
Hazel Park	22	Grosse Pointe	8	Charlotte	2	East Tawas	1			Wexford	1
								City Total	**5233**	**County Total**	**1457**
								Grand Total	**6690**		

Note: some variation between jurisdictions is likely due to uncertainty on jurisdictional ownership of boundary roads

Agencies not shown did not have a detected signal

APPENDIX B SIGNALIZED INTERSECTION COST DATA

Job #	Signal	Road	Incidentals	Construction	Structures	Total	Type of construction	# of heads	# of intersections	Price per intersection
47082-132613	$ 310,647	$ 667,141	$ 770,293	$ 302,660		$ 2,050,740	0.69 mi of hot mix asphalt pavement widening for a center left turn lane including cold milling and resurfacing, signing, traffic signal modernization and pavement markings on M-59 from Cullen Road to Hartland Woods Drive, Livingston County. This project includes a 5 year and a 3 year materials and workmanship pavement warranty.	6	2	$ 155,324
82081-206745	$ 224,387	$ 6,715	$ 34,779	$ 33,118		$ 299,000	pavement markings on M153 at Wyoming Avenue in the city of Dearborn, Wayne County.	4	1	$ 224,387
82101-207228	$ 174,345	$ -	$ 13,491	$ 24,036		$ 211,872	Traffic signal modernization including sidewalk ramp upgrades and ITS/connected vehicle installation on Old M-14 at McClumpha Road, Wayne County	4	1	$ 174,345
41131-202669	$ 199,402	$ 2,686,650	$ 821,587	$ 1,738,470	$ 2,371,009	$ 7,817,117	driveway, curb and gutter, aggregate base, drainage, signals, pavement markings, bridge reconstruction with 27 inch concrete box beams and approaches on 100th Street from west of South Kent Drive west to Division Avenue over US-131, Kent County. This project contains a 5 year materials and workmanship pavement warranty and a 2 year concrete surface coating warranty.	3	1	$ 199,402
39041-132617	$ 323,391	$ -	$ 14,260	$ 39,329		$ 376,980	Install corridor traffic responsive signal system including fiber optic interconnect and necessary signal equipment.	6	2	$ 161,695
28012-113549	$ 4,203,348	$ 42,392	$ 244,937	$ 429,279		$ 4,919,955	Traffic signal modernization and upgrades, ITS device installations, concrete curb, gutter, sidewalk and ramps, and pavement markings on US-31/M-37 from South Airport Road to the Grandview Parkway and on M-72 from M-22 to the north junction of US-31 in the city of Traverse City, Grand Traverse County.	56	17	$ 247,256
82053-127759	$ 422,541	$ 978,229	$ 611,724	$ 176,153		$ 2,188,647	1.30 mi of intersection modification of existing geometrics, ultra-thin hot mix asphalt overlay, sidewalk ramp upgrades, signal work, signing and pavement markings on US-24 from Elmira Street to Wadsworth Street and on Old M-14 (Plymouth Road) from	16	3	$ 140,847
34032-206744	$ 265,575	$ -	$ 2,760	$ 18,950		$ 287,285	Traffic signals modernization and ITS/connected vehicle installations on M-66 at Grand River and David Highway, Ionia County	8	2	$ 132,788
13032-132618	$ 1,745,127	$ 32,631	$ 340,409	$ 129,550		$ 2,247,717	installations on various routes in the cities of Battle Creek and Springfield, Calhoun County	19	5	$ 349,025
37021-204386	$ 146,545	$ 955,103	$ 227,793	$ 196,553		$ 1,525,993	2.06 mi of hot mix asphalt cold milling and resurfacing, concrete driveway, curb, gutter, sidewalk and ramps, aggregate base, drainage, signs, signals and pavement markings on M-20 from Lincoln Road to US-127BR in the city of Mt. Pleasant, Isabella County. This project includes a 3 year and 5 year materials and workmanship pavement warranty	4	1	$ 146,545
11052-206713	$ 237,760	$ 4,750	$ 2,545	$ 11,804		$ 256,859	Traffic signal modernization and pavement markings on M-139 at Red Bud Trail, Berrien County	4	1	$ 237,760
82000-203467	$ 814,915	$ 9,601	$ 248,777	$ 321,764		$ 1,395,056	pavement markings on Harper Avenue from East Grand Boulevard to Morang Avenue in the city of Detroit, Wayne County. This is a Local Agency project.	9	3	$ 271,638
78052-203628	$ 615,443	$ 460	$ 3,348	$ 40,098	$ 615,443	$ 1,274,792	Traffic signals modernization, concrete sidewalk and ramps and ITS/connected vehicle installations and pavement markings on M-40, M-51 and M-66 in the city of Sturgis, Berrien, St. Joseph and Van Buren Counties. This project will be constructed with an innovative contracting method, Job Order Contract.	13	3	$ 205,148
82081-203627	$ 571,485	$ 465	$ 6,014	$ 23,106		$ 601,070	installations and pavement markings on M-153, US-24 and I-75, Wayne County. This project will be constructed with an innovative contracting method, Job Order Contract.	9	3	$ 190,495
15012-203625	$ 617,888	$ 492	$ 3,284	$ 40,965		$ 662,629	Traffic signals modernization, sidewalk ramp upgrades and IT S/connected vehicle installation.	8	3	$ 205,963
28042-206701	$ 228,109	$ -	$ 2,110	$ 23,124		$ 253,343	Signal modernization and ITS/connected vehicle installation on M-72 at Williamsburg/Elk Lake Road, Grand Traverse County	4	1	$ 228,109
50052-206712	$ 193,270	$ 4,590	$ 8,750	$ 27,925		$ 234,535	sidewalk, sidewalk ramps and pavement markings on M-3 at Market Place Boulevard, Macomb County.	4	1	$ 193,270
23042-206747	$ 155,047	$ 16,828	$ 8,239	$ 21,684		$ 201,798	signals, wireless vehicle detection and pavement markings on M-43 at Delta Commerce Drive, Eaton County	4	1	$ 155,047
47082-206746	$ 142,218	$ -	$ 10,620	$ 14,665		$ 167,502	Traffic signal modernization, pedestrian indicators, video vehicle detection and pavement markings on M-59 (Highland Road) at Clark Road, Livingston County.	2	1	$ 142,218
13131-206614	$ 204,372	$ 10,803	$ 16,147	$ 34,501		$ 265,823	ramp upgrades on M-96 (Dickman Road) at Hill Brady Road in the city of Battle Creek, Calhoun County.	4	1	$ 204,372
82022-129392	$ 1,584,410	$ 52,264	$ 103,353	$ 100,539		$ 1,840,566	Traffic signal modernizations, ramp upgrades and ITS/connected vehicles installation at 10 locations	20	10	$ 158,441
82211-207404	$ 163,877	$ 2,880	$ 23,688	$ 58,176		$ 248,621	Signal and pavement markings on various routes in the cities of Dearborn, Plymouth, Livonia and Harper	4	1	$ 163,877
63000-202987	$ 1,475,676	$ 22,721	$ 219,432	$ 184,238		$ 1,902,066	Traffic Signals at 10 locations including mast arms, box spans, signal backplates, countdown pedestrian signals, Harper Woods, Wayne County	26	10	$ 147,568