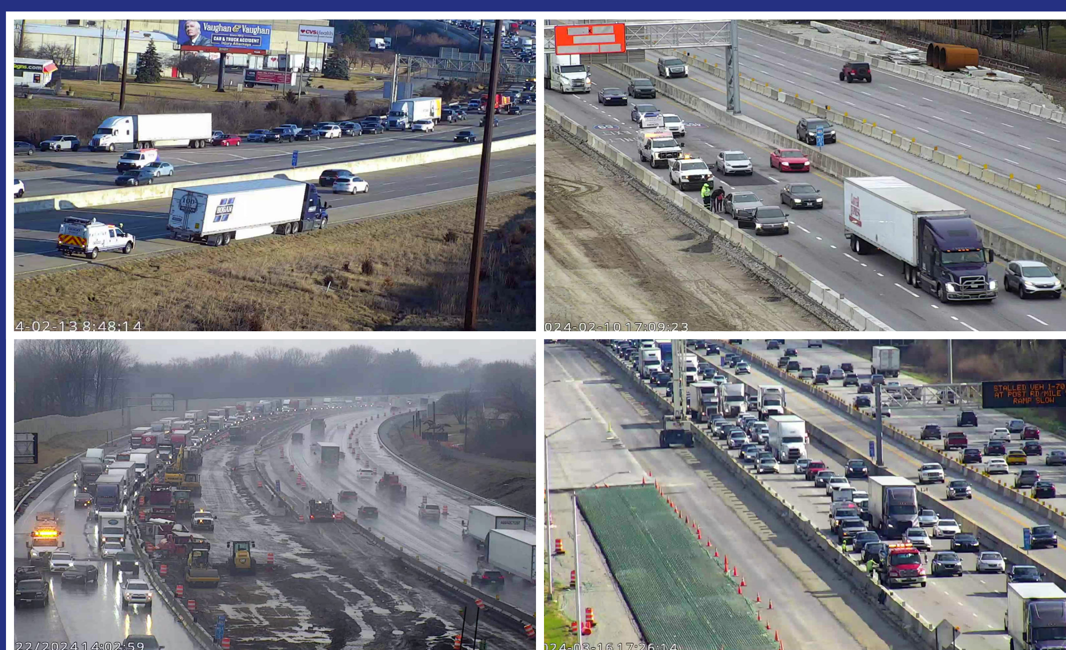
JOINT TRANSPORTATION
RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

Development of Latitude/Longitude (and Route/Milepost) Model for Positioning Traffic Management Cameras



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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract

Traffic Incident Management (TIM) is a FHWA Every Day Counts initiative with the objective of reducing secondary crashes, improving travel reliability, and ensuring the safety of responders. Agency roadside cameras play a critical role in TIM by helping dispatchers quickly identify the precise location of incidents when receiving reports from motorists with varying levels of spatial accuracy. Reconciling position reports that are often mile-marker based with cameras that operate in a Pan-Tilt-Zoom (PTZ) coordinate system relies on dispatchers having detailed knowledge of hundreds of cameras and perhaps some presets. During real-time incident dispatching, reducing the time it takes to identify the most relevant cameras and view the incident improves incident management dispatch times. This research developed a camera-to-mile marker mapping technique that automatically sets the camera view to a specified mile marker within the field-of-view of the camera. A new performance metric on verification time (T_{EYE}) that captures the time it takes for TMC operators to have the first visual on roadside cameras is proposed for integration into the FHWA TIM event sequence. Performance metrics that summarize spatial camera coverage and image quality for use in both dispatch and long-term statewide planning for camera deployments were also developed. Using mobile mapping and LiDAR geospatial data to automate the mapping of mile markers to camera PTZ settings, and the integration of connected vehicle trajectory data to detect incidents and set the nearest camera view on the incident are both discussed for future studies.

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EXECUTIVE SUMMARY

Motivation

Traffic Incident Management (TIM) is an FHWA Every Day Counts initiative seeking to reduce secondary crashes, improve travel reliability, and ensure the safety of responders. Agency roadside cameras play a critical role in TIM by helping dispatchers quickly identify the precise location of incidents after receiving reports from motorists who have varying levels of spatial accuracy. Reconciling position reports that are often mile marker based with cameras that operate in a pan-tilt-zoom coordinate system relies on dispatchers having a detailed knowledge of hundreds of cameras and perhaps some presets. During real-time incident dispatching, reducing the time it takes to identify the most relevant cameras and setting their view on the incident is an important opportunity to improve incident management dispatch times.

Study

This research developed a camera-to-mile marker mapping technique that automatically sets the camera view to a specified mile marker within the field-of-view of the camera. Over 350 traffic cameras along Indiana's 2,250 directional miles of interstate were mapped to approximately 5,000 discrete locations that correspond to approximately 780 directional miles (~35% of interstate) of camera coverage.

Results

This study suggests integrating a new performance metric on verification time (T_{EYE}) into the FHWA TIM event sequence that captures the time it takes for TMC operators to have the first visual on roadside cameras. This is followed by a scalable methodology and a table that stores camera PTZ settings for the mile markers within its field-of-view. Performance metrics that summarize spatial camera coverage and image quality for use in both dispatch and long-term statewide planning for camera deployments were also developed. Results show that nearly 35% of the interstates in Indiana have sufficient camera coverage. Finally, a web application was created to help operators quickly set a camera view to specified mile marker signs on interstate routes.

Several examples are included in the appendices that demonstrate the automatic positioning of the camera on vehicles with telematics devices, such as INDOT Hoosier Helpers. YouTube links with short video clips illustrating the automated mapping are also included.

Using mobile mapping LiDAR geospatial data to automate the mapping of mile markers to camera PTZ settings is also discussed. Integration of CV trajectory data to detect incidents and set the nearest camera view on the incident are also discussed for future studies.

Recommendations

This newly developed technique will allow operators to quickly identify the nearest camera and set them to the reported location. The project team recommends working with the system integrator to deploy these mapping techniques within the INDOT camera management system.

In addition to identifying mapping tables for positioning cameras that cover approximately 35% of the interstate, the tables provided in Appendix H can be used for designers to prioritize future capital investments that will add additional camera coverage.

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LIST OF ACRONYMS

CV	Connected Vehicle
DOT	Department of Transportation
EOP	Exterior Orientation Parameters
GSD	Ground Sampling Distance
IOP	Interior Orientation Parameters
ITS	Intelligent Transportation System
LUT	Look Up Table
MM	Mile Marker
NB	Northbound
NTCIP	National Transportation Communications for ITS Protocol
PTZ	Pan Tilt Zoom
SB	Southbound
SNMP	Simple Network Management Protocol
TIM	Traffic Incident Management
TMC	Traffic Management Center

1. PROJECT OVERVIEW

1.1 Introduction

Traffic Incident Management (TIM) consists of a series of planned and coordinated efforts to detect, respond and clear traffic incidents as safely and quickly as possible to reduce secondary crashes (FHWA, 2023). Studies have shown that crash rates increase by a factor of 24 on congested sections compared to free flowing sections of interstates (Mekker et al., 2020).

Incidents are typically detected and reported by either roadway related Intelligent Transportation System (ITS) sensors or incoming 911 calls. To effectively dispatch appropriate resources, operators in the call centers must verify these incidents, often with a variety of simultaneous cell calls with varying levels of location accuracy. Agency roadside cameras are an important asset for dispatchers to quickly identify the precise roadway location and nature of incidents when receiving reports from motorists. Reconciling position reports that are often mile marker (MM) based, with cameras that operate in a pan-tilt-zoom (PTZ) coordinate system relies on dispatchers having detailed knowledge of these cameras and the interstate system. Although experienced dispatchers are quite efficient at this task, there is a fairly steep learning curve for new staff, and it is important to minimize time "searching" for incidents.

This paper reports on a camera-to-mile marker mapping technique that automatically sets the camera view to specified mile marker signs (nominally every 0.1 mile) within the field-of-view of the camera with a simple mouse click.

1.2 Scope and Objectives

The objective of this report is to demonstrate the process of systematically mapping cameras to mile markers so that operators can rapidly select and set the appropriate camera views during an incident. Not only does this provide opportunities to improve TIM activities, but it also provides an inventory by mile marker if the interstate segment has camera coverage, and quality of that camera coverage. Finally, by formally defining a relationship between mile marker and PTZ camera settings, CV data can be effectively integrated with cameras to automate the camera view when shock waves associated with congestion or incidents are detected in the CV data.

1.3 Dissemination of Research Results

The below research studies were prepared in part during this project to facilitate agile dissemination of results.

- Mathew, J. K., Malackowski, H., Gartner, C., Desai, J., Cox, E., Habib, A., & Bullock, D. M. (2023). Methodology for automatically setting camera view to mile marker for traffic incident management. *Journal of Transportation Technologies*, *13*, 708–730. https://doi.org/10.4236/jtts.2023.134033

This technical paper was prepared throughout the project and distributed to key stakeholders to facilitate early implementation of the research findings as highlighted in the appendices. Appendix A briefly explains the methodology of mapping camera coordinates to mile marker posts and a series of geo-coordinates using LiDAR data. Appendix B discusses the stability analysis used to identify the variation in positional orientation of the cameras after preventive maintenance and camera upgrades. Appendix C describes the benchmarking procedure to calibrate the cameras and reset their native orientation after maintenance and upgrades. Appendix D lists a series of video links showing the camera tours that sweep across the mile marker signs in the vicinity of the camera. Appendix E discusses the real-time application of this research to position the cameras on Hoosier Helpers attending a scene. Appendix F discusses the methodology used to manually interpolate mile marker locations every 0.1 or 0.2 miles for interstate routes with mile marker signs at every half or one mile. Appendix G provides a brief overview of occlusions that obstruct the camera visibility of the roadway. Appendix H illustrates the camera coverage and mile marker visibility for all interstate routes in Indiana. Finally, Appendix I displays the geo-coordinates of the mile marker signs on I-465 from LiDAR data collection. The following sections of the technical report summarize some of the key findings during this research.

2. LITERATURE REVIEW

2.1 Freeway Camera

Traffic cameras were first routinely deployed in the early 1970's by a variety of agencies across the country. Minnesota Department of Transportation was one of the early adopters of freeway cameras (Castleman, 2019; Stehr, 1991). This technology operated on closed circuit television which required a separate monitor at TMCs for each camera, often without PTZ capability. In the early days, cameras were primarily used for qualitative traffic system monitoring, but as technology improved, the use of the cameras grew to include incident verification as well as research into shockwaves and other traffic flow characteristics (Chien et al., 2022; Dahmane et al., 2021; Franke et al., 1995; Fredianelli et al., 2022; Kim et al., 2020; Mahairzi & Reddy, 2017; Masihullah & Kandaswamy, 2022; Mathew et al., 2013; Qiu et al., 2021; Sonnleitner et al., 2020). Similar deployments in large urban areas occurred around the same time and further stimulated interest in deploying cameras to assist with freeway management activities. One of the outcomes of these early freeway monitoring centers was recognizing the opportunity for improving integration between highway agency centers and 911 dispatchers to quickly locate events from calls to verify the nature and precise location of events. Although this coordination has grown rapidly, traffic management centers (TMC) operators reported that the current methods of incident detection were challenging for effective dispatch and needed additional fidelity (Williams & Guin, 2007).

By 2018, interstate camera deployments had grown to approximately 280 cameras per state, and with some states managing over 800 cameras (Laan et al., 2018). With many states now having a large number of cameras deployed, agencies are facing a challenge of how to train a diverse group of users to effectively set these cameras to realize their value (FHWA, 2020). Furthermore, when ITS cameras were first installed, agencies placed them at opportunistic locations where power was easily accessible and there is now a need to go back and systematically backfill camera placement in key areas with limited visibility.

2.2 Connected Vehicle

As cameras deployments have matured, there has been enormous growth in connected vehicle data that can complement freeway cameras (Cao et al., 2021; Hunter et al., 2021; Mathew et al., 2021; Sakhare, Hunter, et al., 2022; Waddell et al., 2020; Yao et al., 2023). In the US, over 500 billion connected vehicles (CV) records per month are accessible in near real time (Desai et al., 2022a, 2022b). Each of these records have a unique trip and data point identifier with GPS position, timestamp, speed, heading, and ignition status. This data represents approximately 5% (Hunter et al., 2021; Sakhare, Hunter, et al., 2022) of the vehicles on the roadway, with a typical latency of under 1 minute (Mathew et al., 2021). This data is used for a variety of real time and after-action analysis (Li et al., 2019; Sakhare, Desai, et al., 2022; Saldivar-Carranza et al., 2023). Integrating this CV data with freeway cameras helps provide real time assessment of traffic flow, weather conditions, and work zone impacts (Desai, Mahlberg et al., 2021; Desai et al., 2020, 2021; Sakhare, Desai, et al., 2022; Sakhare et al., 2021, 2023). When CV data is closely integrated with freeway cameras, it can provide tremendous insight into impacts on freeway flow and help identify opportunities to facilitate improvements in incident management (FHWA, 2023; Shah et al., 2022; Williams & Guin, 2007).

3. CAMERA NETWORK AND COVERAGE OF MILE MARKER MAPPING

Indiana has deployed more than 500 roadside cameras on interstates with PTZ functionality into their TMCs (Table 3.1). Approximately 364 of those cameras have been integrated into a system that can automatically set the camera views by mile markers. This provides coverage of approximately 780 directional miles over 2,250 directional miles of Indiana's Interstates. As legacy cameras with older software are replaced by newer cameras over the next 36 months, we anticipate the proportion of cameras that can be automatically positioned to approach 100%.

TABLE 3.1
Statewide camera integration by Indiana interstates

Interstate	Number of Cameras Deployed	Number of Integrated Cameras	Percent Integrated
I-65	169	108	64
I-69	101	61	60
I-70	81	43	53
I-94	66	56	85
I-465	58	48	83
I-74	23	9	39
I-265	16	15	94
I-64	16	13	81
I-469	15	11	73
Total	*545*	*364*	*67*

4. CURRENT INCIDENT VERIFICATION PROCESS AT TMC

Figure 4.1 provides an overview of the incident verification and coordination process at TMC. During an incident, detection most commonly occurs via incoming 911 calls. Operators frequently receive multiple calls with varying levels of spatial accuracy, usually reported in terms of routes and mile markers. Sometimes those are very precise, sometimes the mile markers correspond to what mile marker the driver is at when the operator queries the motorist for the location. This information is relayed to the TMC where operators must select from hundreds of cameras to identify relevant camera(s). Operators require extensive knowledge of the interstate system and appropriate cameras to search for the event. Once the precise location of the incident is determined, operators typically cycle through multiple cameras to identify the ones with the best view. After verifying the incident, TMC staff coordinate with emergency responders enroute, on the scene, and on some occasions direct additional response such as motorist assist patrols and diversions.

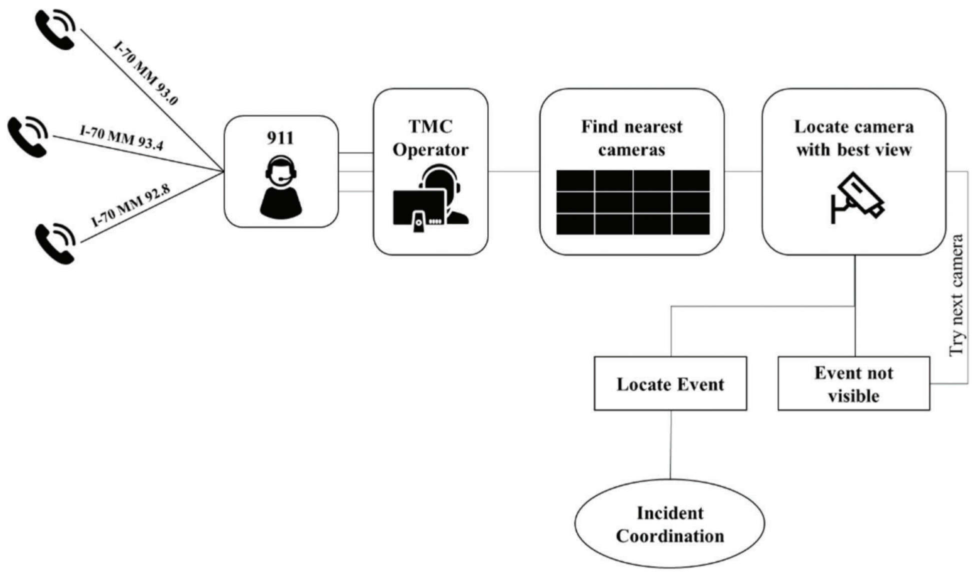
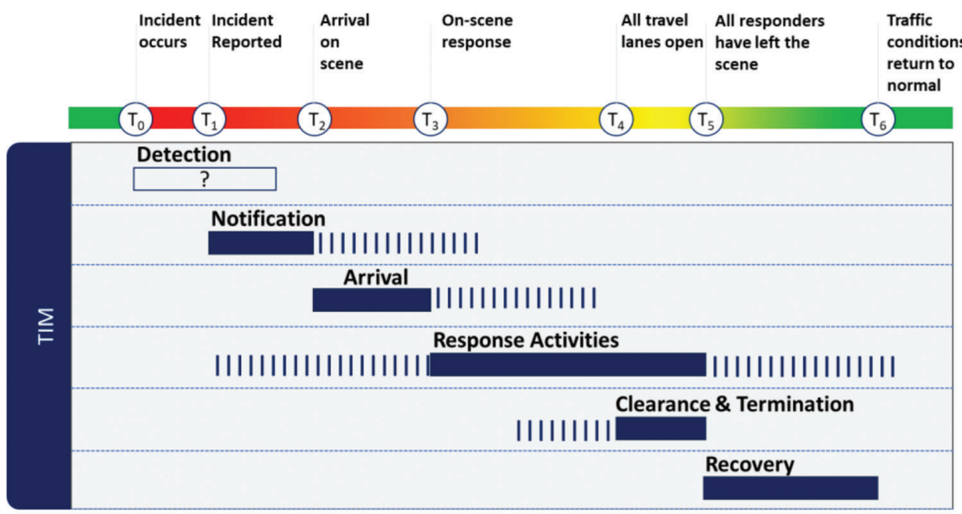


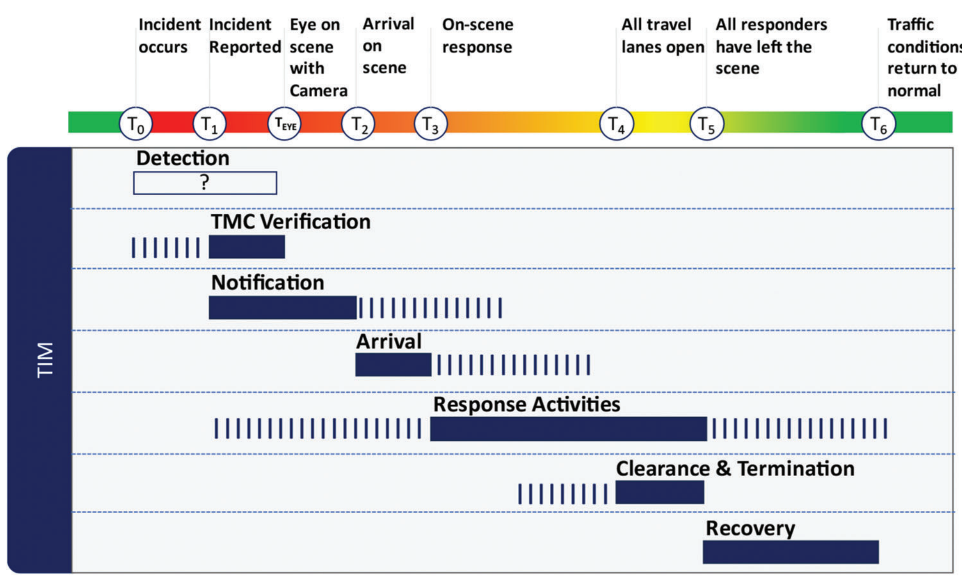
Figure 4.1 Traffic incident verification process.

5. INTEGRATION OF VERIFICATION TIME INTO THE FHWA TIM DIAGRAM

Figure 5.1a illustrates the standard FHWA event sequence for TIM (James et al., 2015) from start of incident to incident resolution. This is a very effective chart to explain the TIM process, but since incident verification is such a critical part of TIM, we believe it is important to add one more reference point on this chart, specifically the verification time to document the time an incident is verified (Figure 5.1b). We refer to this as T_{EYE}, corresponding to when the TMC has camera eyes on the incident. Tracking this reference time is an important part of developing comprehensive TIM performance measures to identify where there are opportunities to improve detection procedures, coordination of activities, or perhaps infrastructure investment (additional cameras). We added this notation as T_{EYE}, to avoid renumbering the time intervals and maintain consistency with FHWA incident verification time notation (James et al., 2015).



(a) FHWA



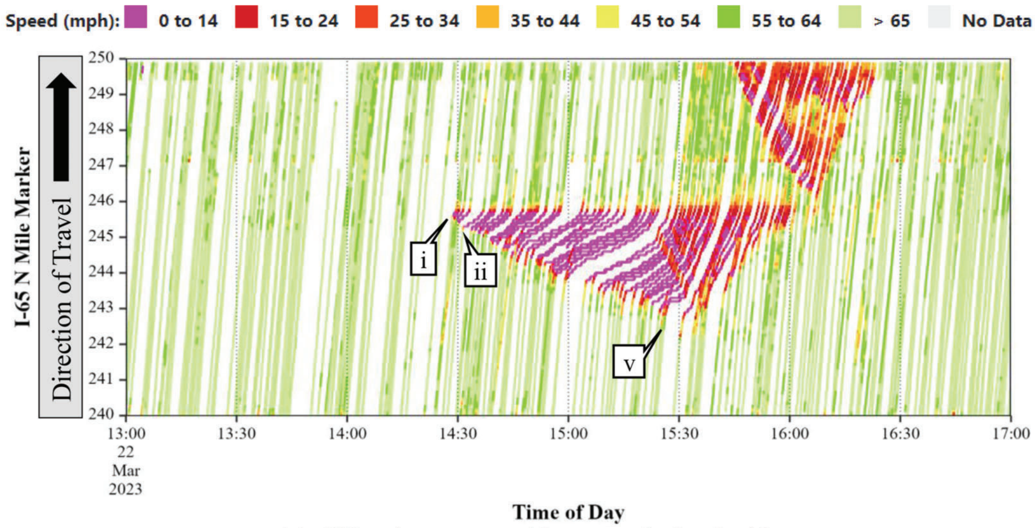
(b) Modified event sequence with TMC verification (T_{EYE}).

Figure 5.1 TIM event sequence.

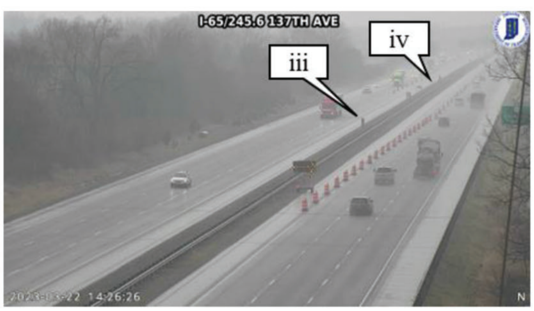
6. CASE STUDY ILLUSTRATING MILE MARKER POSITIONING OF CAMERAS INTEGRATED WITH CV DATA

Although urban areas have evolved to have close integration of 911 dispatch centers with agencies, rural sections of interstate have fewer incidents and cover a diverse set of first responders, many of them volunteers. This can often result in substantial delays in TMC receiving notification of an interstate incident. Two case studies are presented in this section that provides a timeline of the incident occurrence and the subsequent time it took to position the cameras on the incident.

Figure 6.1 illustrates an incident that occurred near MM 246 in the northbound direction of rural I-65 around 14:26 (T_0) on March 22, 2023. This incident was associated with a lane changing crash inside the work zone. Figure 6.1a represents a trajectory speed heatmap which is a time-space diagram of CV trajectories color coded by their speed. The first evidence of slowdown in the CV data is captured around MM 245.6 at 14:28



(a) CV trajectory speed heatmap during incident.



(b) Camera 48: View at time of incident 14:26 (T_0).

(c) Camera 48: First visual of incident 14:32 (T_{EYE}).

(d) Camera 48: Queue cleared just after 16:00.

Figure 6.1 Example of a work zone related incident on I-65N between MM 240 and 250 on March 22, 2023.

(a) Camera 480: View at time of incident 14:36 (T_0) (callout i).

(b) Camera 480: First view of queue formation around 14:40 (callout ii).

(c) Camera 480: View at 15:34 (callout iii).

(d) Camera 480: First camera eyes on the incident 15:36 (T_{eye}) (callout iv).

Figure 6.2 Example truck roll over crash on I-65S between MM 200 and 201 on February 9, 2023.

(callout i)—which is within 2 minutes of the reported 911 incident time. Figure 6.1b shows the nearest camera view at T_0 whereas Figure 6.1c shows the first camera eyes on the incident at 14:32 (T_{EYE}). During this incident, it took the operators just under 6 minutes to locate and verify this incident. Callouts iii and iv on this figure represent the same mile makers on subfigures b and c. One can see the lane restrictions lasted until about 15:20 (callout v on heatmap) and the queue cleared just after 16:00 (Figure 6.1d).

Figure 6.2 illustrates a truck roll-over incident that occurred near MM 201 in the southbound direction of rural I-65 around 14:36 (T_0) on Feb 09, 2023, and Figure 6.2a represents a similar CV time-space diagram. The first evidence of slowdown in the CV data is captured around MM 200.9 at 14:38 (callout i)—approximately 2 minutes after the reported 911 incident time. Figure 6.2b corresponds to the nearest camera view at 14:36 and queue formation can be seen within 6 minutes of the incident (Figure 6.2b). This camera remains in that view for approximately 58 minutes (Figure 6.2c) until positioned on the incident at 15:36 (Figure 6.2d), resulting in a verification time of approximately 1 hour (T_{EYE}-T_0). During real-time incident dispatching, it is important to consistently reduce the time it takes to identify the most relevant cameras and to set their views, and thereby provide opportunities for coordinating diversion routes, message boards, and other complementary TIM resources.

7. METHODOLOGY FOR MAPPING MILE MARKERS TO CAMERA COORDINATES

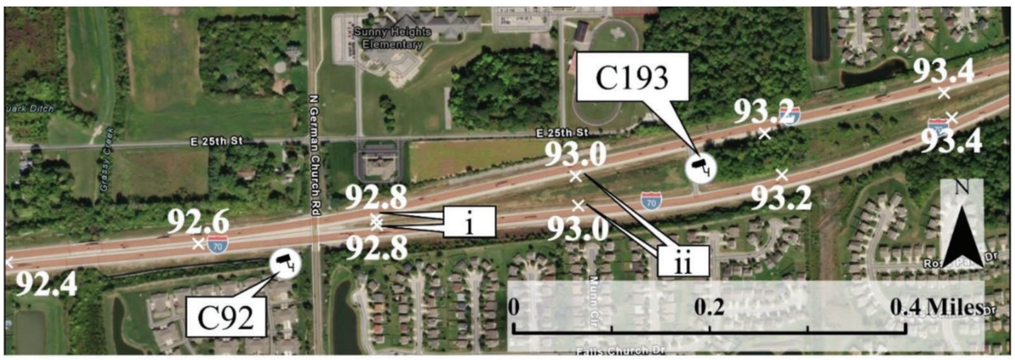
Figure 7.1a shows an aerial map of roadside cameras and mile markers between MM 92.4 and 93.4 along I-70. There are two cameras, C92 and C193, along this section. Figure 7.1b captures a view from C92 showing Camera 193 (callout C193) and mile markers 92.8 (callout i) and 93.0 (callout ii) on both I-70E and I-70W. Figure 7.1c and Figure 7.1d displays a sample view from C193 showing MM 92.8 (callout i) and MM 93.0 on I-70W, respectively. Camera 92, from which Figure 7.1b was captured, is also shown in Figure 7.1c and Figure 7.1d.

To set the camera view to the mile marker in its field-of-view, the corresponding PTZ settings need to be mapped to the respective mile markers. The pan and tilt are two main settings required for this approach. The zoom level is a bit more subjective and is usually selected to cover a view of approximately 0.1 to 0.2 on miles each side of the desired mile marker. These cameras mostly operate on a 30× optical zoom with a maximum digital magnification of 12×.

Figure 7.2 illustrates a graphic that maps PTZ settings of C193 to mile markers 92.8 (callout i) and 93.0 (callout ii) on I-70W. The view showing MM 92.8 (Figure 7.1c) is defined by a set of PTZ settings $\{P_i, T_i, Z_i\}$ and view showing MM 93.0 (Figure 7.1d) is defined by another set of PTZ settings $\{P_{ii}, T_{ii}, Z_{ii}\}$. In general, the mile marker “m” from a camera “c” is a function of PTZ settings of “c” as shown by

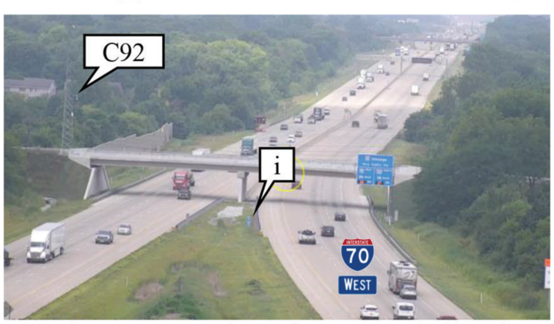
$$MM_{m,c} = \{P_{mc}, T_{mc}, Z_{mc}\} \qquad \text{(Eq. 7.1)}$$

Table 7.1 shows the respective PTZ settings mapped for MM 92.8 and 93.0 from C193. These settings are extracted using a Simple Network Management Protocol (SNMP) GET command based on the standards listed on the National Transportation Communications for ITS Protocol (NTCIP) 1,205 (AASHTO, ITE, NEMA, 2014). A look-up table (LUT) is then established that stores the PTZ settings for every mile marker in the field-of-view of a given camera. Finally, to set the camera view to a specified mile marker, the appropriate settings are sent to the cameras using the SNMP SET commands. For illustration purposes, both camera images in Figure 7.1c and Figure 7.1d are very close with only small variation in the PTZ values as shown in Table 7.1. The subsequent discussion of Table 8.1 in the next section

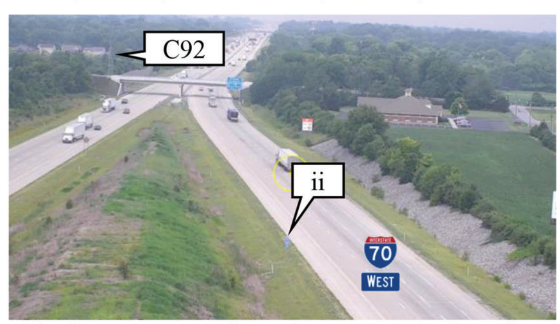


(a) Mile marker vicinity map of Cameras 92 and 193.

(b) Camera 92: View of Camera 193, MM 92.8 (callout i) and MM 93 (callout ii).



(c) Camera 193: View of MM 92.8 (callout i).



(d) Camera 193: View of MM 93.0 (callout ii).

Figure 7.1 Mile markers in the field-of-view of ITS Cameras 92 and 193 on I-70.

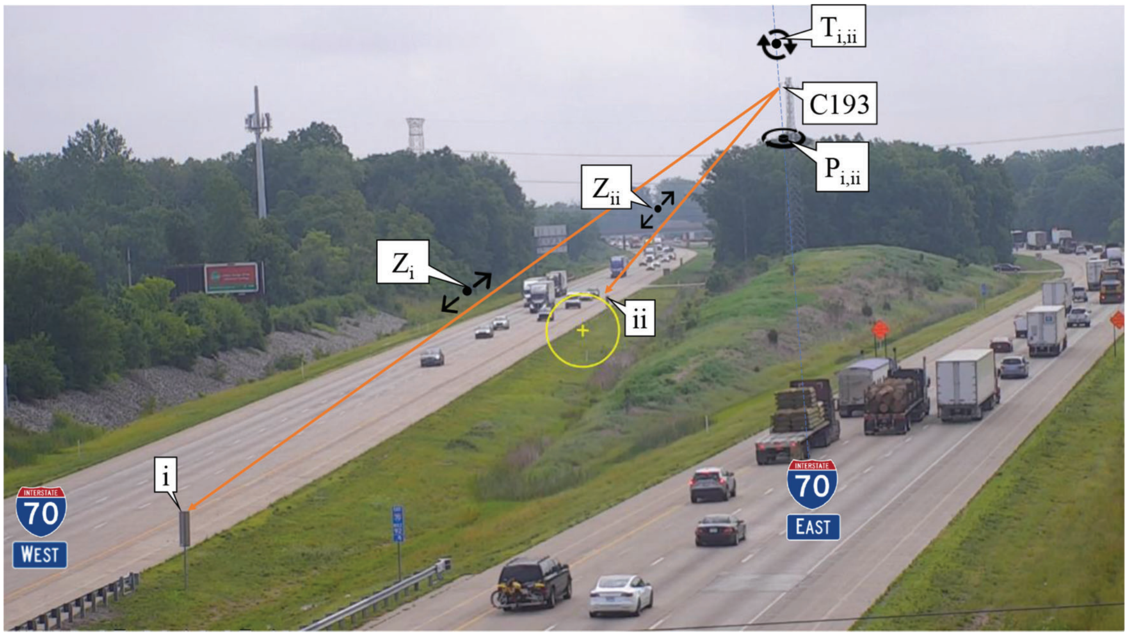


Figure 7.2 Mapping I-70W MM 92.8 and MM 93.0 to PTZ coordinates of Camera 193.

TABLE 7.1
Look-up table of PTZ settings and mile markers for Camera 193

Camera ID	Route	Mile Marker	Pan (degrees)	Tilt (degrees)	Zoom (magnification)
193	I-70W	92.8 (Figure 7.1c callout i)	160.0	0.0	9×
193	I-70W	93 (Figure 7.1d callout ii)	164.0	8.0	3×

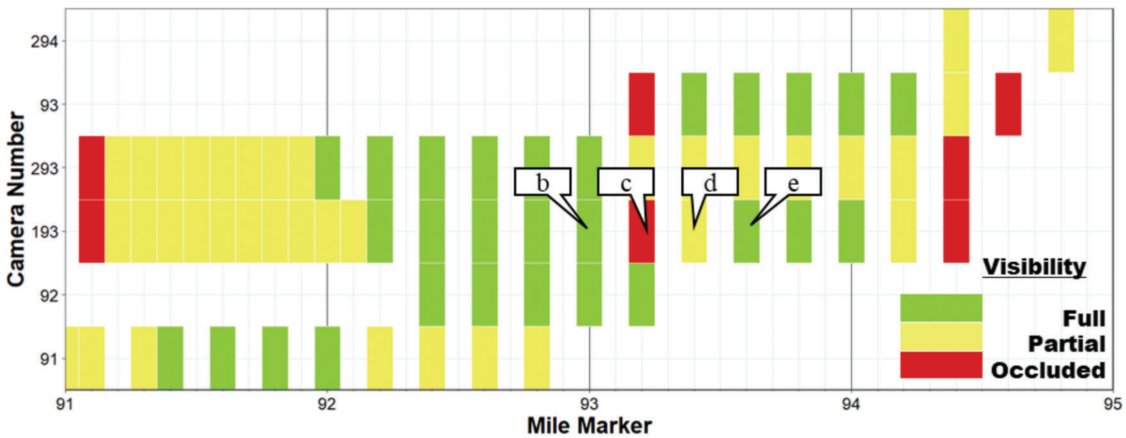
illustrates the importance of this scaling over much larger distances to provide PTZ settings corresponding to over 5,000 discrete mile marker locations covering 780 directional miles of interstate.

8. IMAGE QUALITY ASSESSMENT

In general, the "design" process of camera placement has relied on a combination of placing cameras where we can cost effectively get power and communication coupled with simple heuristics on spacing and placement near curves in the roadway. However, because a camera is near a mile marker does not mean that the section of road is visible to the camera. Camera images of roadways can sometimes be occluded by vegetation, bridge decks, utility poles, vertical curves, horizontal curves, signs, and other roadside items. Also, as distance from the camera extends, air quality haze and zoom resolution can substantially impact image quality. Figure 8.1 shows few examples highlighting the visibility quality of mapped mile markers on I-70W. Figure 8.1a illustrates a plot color coded by visibility of mile markers between MM 91 and 95 from the cameras in this area. Mile markers on this section of interstate are placed every 0.2 miles. Callouts on this plot correspond to the sub figures showing images from Camera 193. MM 93.0 (callout i) and MM 93.6 (callout iv) are fully visible whereas MM 93.4 (callout iii) and MM 93.2 (callout ii) are partially and fully occluded by vegetation, respectively.

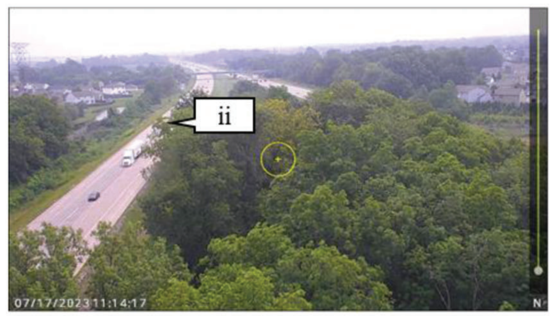
Table 8.1 documents the table mapping PTZ settings, mile markers and visibility assessment of cameras 92, 93 and 193 from Figure 8.1a along the section of I-70W between MM 91 and 94. This table also has an empirical image quality assessment attribute to provide guidance to camera operators to quickly identify the most relevant camera(s) with the highest quality images for use in locating/verifying incidents.

Table 8.1 is used for illustration purposes, but the full table for the 364 cameras (Table 3.1) covering 780 directional miles of interstate and around 5,000 discrete mile markers has over 10,000 records that were generated by manually mapping each camera location to 0.1 or 0.2-mile resolution. Some mile markers are visible from multiple cameras and may therefore have multiple mappings/records. One of the additional benefits of this manual mapping and image quality assessment is the ability to develop visualizations of this camera coverage by image quality. The use case for that data is described in the next section.



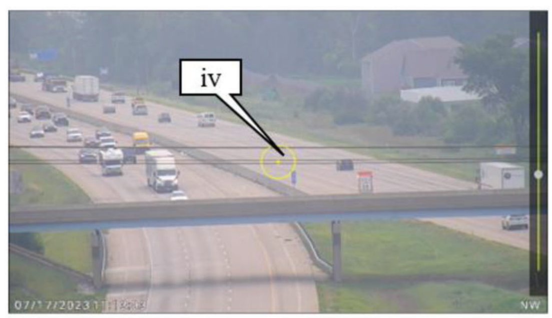
(a) I-70W mile marker visibility by camera.

(b) Camera 193: Full Visibility of MM 93.0.



(c) Camera 193: Occluded View of MM 93.2

(d) Camera 193: Partial Visibility of MM 93.4.



(e) Camera 193: Full Visibility of MM 93.6.

Figure 8.1 Image quality assessment of select mile marker signs from Camera 193.

TABLE 8.1
PTZ settings, mile markers and visibility of MM 91–94 on I-70W (full table for all 364 cameras on all interstates has more than 10,000 rows)

Camera ID	Route	Mile Marker	Pan (degrees)	Tilt (degrees)	Optical/Digital Zoom (magnification)	Visibility
92	I-70 WB	92.4	272.4	-2.6	22x	Full
92	I-70 WB	92.6	281.9	1.3	15x	Full
92	I-70 WB	92.8	69.8	2.5	13x	Full
92	I-70 WB	93	78.3	-1.1	23x	Full
92	I-70 WB	93.2	79.4	-1.7	24x	Full
93	I-70 WB	93.2	273.0	2.5	2x	Occluded
93	I-70 WB	93.4	288.0	6.0	1x	Full
93	I-70 WB	93.6	61.0	4.1	4x	Full
93	I-70 WB	93.8	69.0	0.7	12x	Full
93	I-70 WB	94	70.0	-0.1	18x	Full
93	I-70 WB	94.2	70.0	-0.5	21x	Full
93	I-70 WB	94.4	71.0	-0.5	21x	Partial
93	I-70 WB	94.6	72.0	-0.6	24x	Occluded
193	I-70 WB	91.1	164.0	-1.0	30x+D3	Occluded
193	I-70 WB	91.2	164.0	-1.0	30x+D3	Partial
193	I-70 WB	91.3	164.0	-1.0	30x+D3	Partial
193	I-70 WB	91.4	164.0	-0.9	30x+D3	Partial
193	I-70 WB	91.5	164.0	-0.9	30x+D3	Partial
193	I-70 WB	91.6	164.0	-0.9	30x+D3	Partial
193	I-70 WB	91.7	163.0	-0.9	30x+D3	Partial
193	I-70 WB	91.8	163.0	-0.8	30x+D1	Partial
193	I-70 WB	91.9	163.0	-0.8	30x+D1	Partial
193	I-70 WB	92	163.0	-0.6	30x+D1	Partial
193	I-70 WB	92.1	163.0	-0.4	30x+D1	Partial
193	I-70 WB	92.2	162.0	0.0	24x	Full
193	I-70 WB	92.4	162.0	0.4	18x	Full
193	I-70 WB	92.6	161.0	1.0	22x	Full
193	I-70 WB	92.8	160.0	0.0	9x	Full
193	I-70 WB	93	164.0	8.0	3x	Full
193	I-70 WB	93.2	337.0	3.9	5x	Occluded
193	I-70 WB	93.4	337.0	3.9	5x	Partial
193	I-70 WB	93.6	334.0	1.8	15x	Full
193	I-70 WB	93.8	332.0	1.2	15x	Full
193	I-70 WB	94	331.0	0.9	28x	Full
193	I-70 WB	94.2	330.0	0.7	28x	Partial
193	I-70 WB	94.4	329.0	0.4	28x	Occluded

9. GRAPHICS TO VISUALIZE OPPORTUNITIES FOR FUTURE CAMERA INVESTMENTS AND UPGRADES

Figure 9.1 illustrates a graphical representation of Table 8.1 along the entire stretch of I-70W for 51 unique cameras. The diagram is linear referenced by mile marker and color coded by percent visibility along every mile. Several miles on the east end (callout i) and around the MM 70 region are fully visible. A few miles near MM 6 region are partially visible (callout ii) and a few locations near MM 110 are fully occluded (callout iv). There are several white sections on this route where cameras are not deployed, especially the sections between MM 20–50, MM 110–120 and MM 130–140 (callout v). Areas where cameras were recently deployed but are pending integration are shown in black hatches (callout iii). Appendix H contains graphics like Figure 9.1 for all interstates.

Figure 9.2 shows a map view of the visibility. Figure 9.2a shows the same data as Figure 9.1, but in a map view for I-70. Figure 9.2b shows a map view illustrating the coverage of 545 cameras across all Indiana interstates. In both Figure 9.2a and b, sections where cameras are pending integration are shown in purple instead of black hatch for better contrast in map view. Qualitative assessments show that I-465 and I-94 have almost full coverage, with the urbanized areas of I-65 having good coverage. Potential opportunities for future investments on I-64, I-69, I-70, and I-74 are easy to identify as they are shown as white areas.

Table 9.1 is similar to Table 3.1, but with an additional metric that shows the percent of interstate miles fully or partially visible from integrated cameras along a route. I-265, I-465, and I-94 have more than 90% camera coverage whereas I-64, I-69, I-70, and I-74 have less than 30% coverage. Overall analysis shows that approximately 35% of the interstate routes have full or partial coverage.

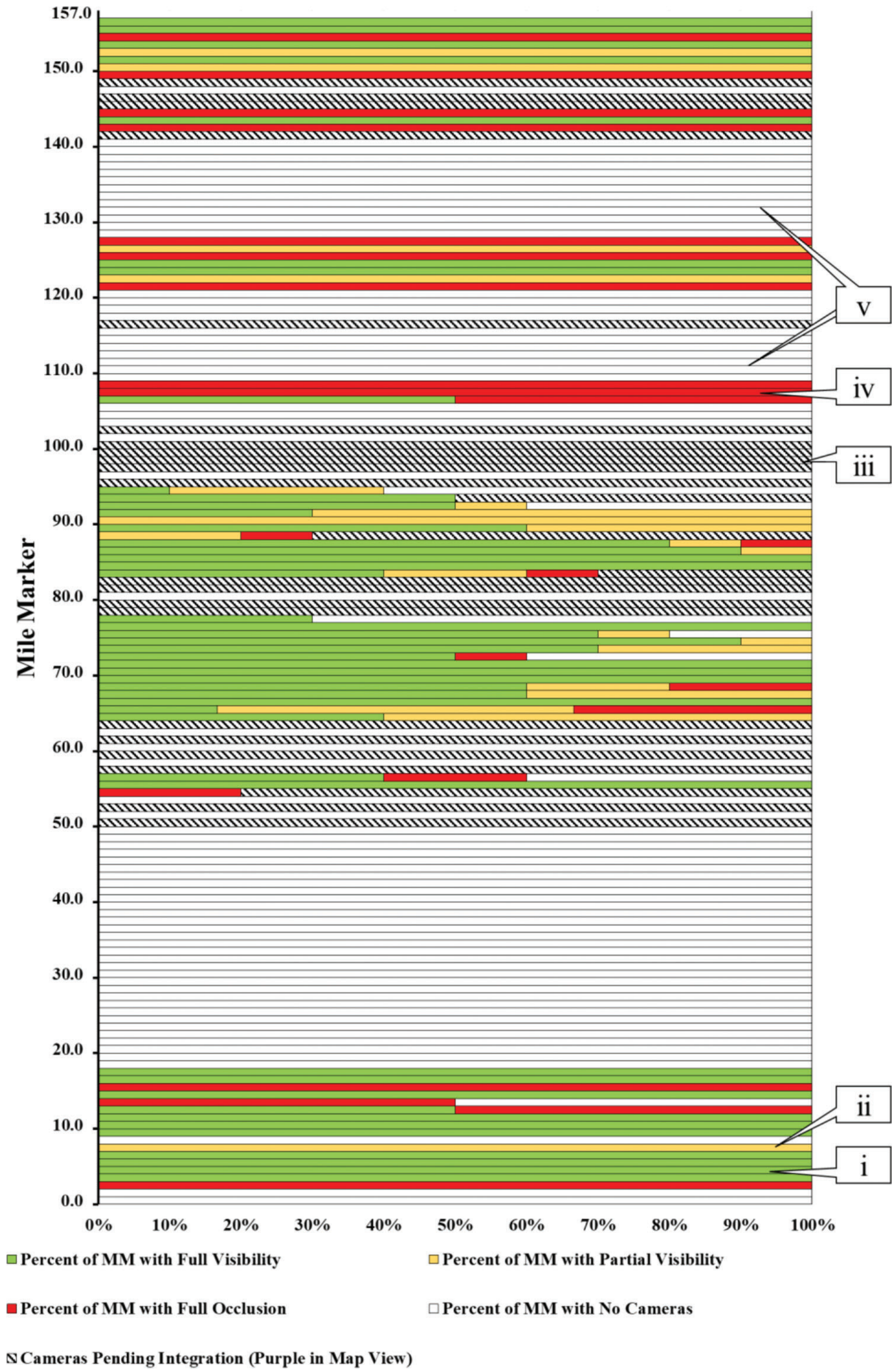
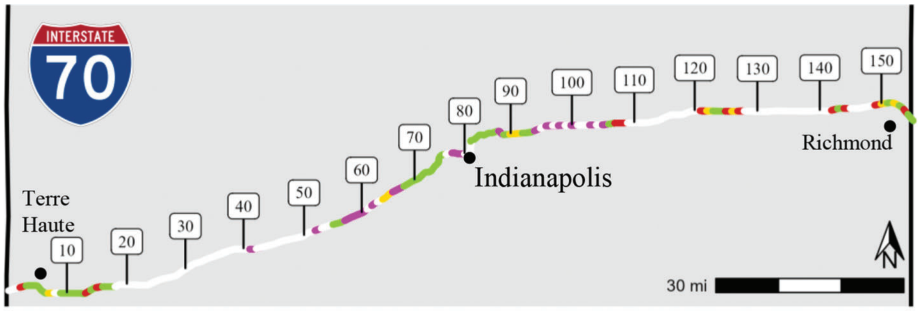


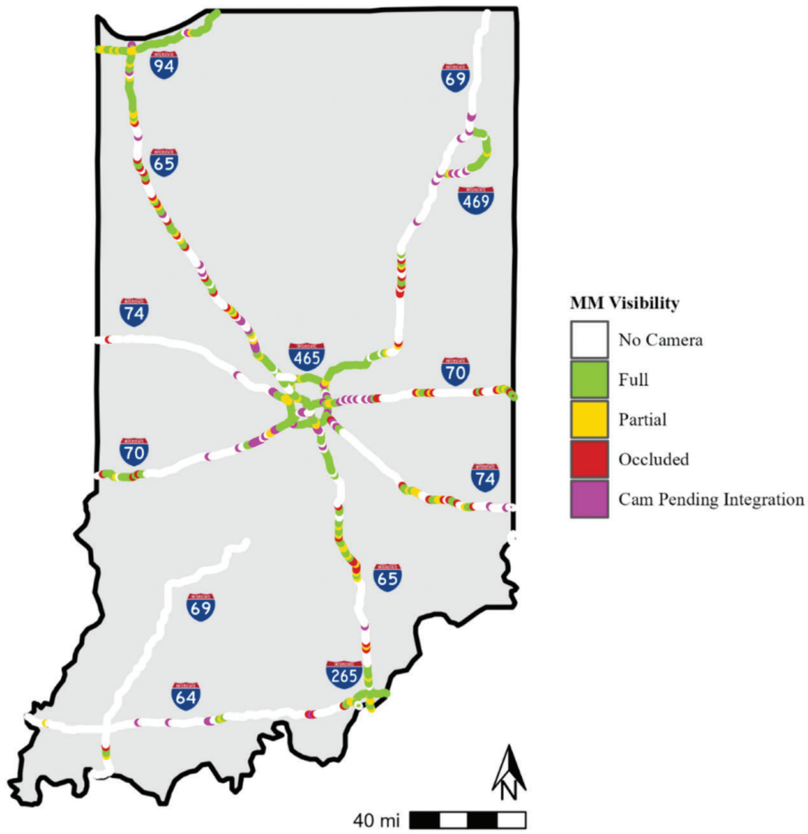
Figure 9.1 I-70W mile marker visibility by camera.

In addition to the percentage of cameras integrated, the percent visibility measure provides an additional metric for decision makers and agencies to consider while prioritizing future deployments and camera upgrades. For example, 81% of currently deployed cameras along I-64 are integrated, however this only covers a little more than 10% of the entire route.

These graphical illustrations and performance metrics are important tools for agencies and decision makers to prioritize future capital investments and camera deployments. Sections with partial/full occlusion may also benefit from additional camera upgrades such as extended/optical zoom and enhanced focus.



(a) I-70 with mile marker callouts every 10 miles.



(b) All interstates.

Figure 9.2 Qualitative assessment of statewide visibility map.

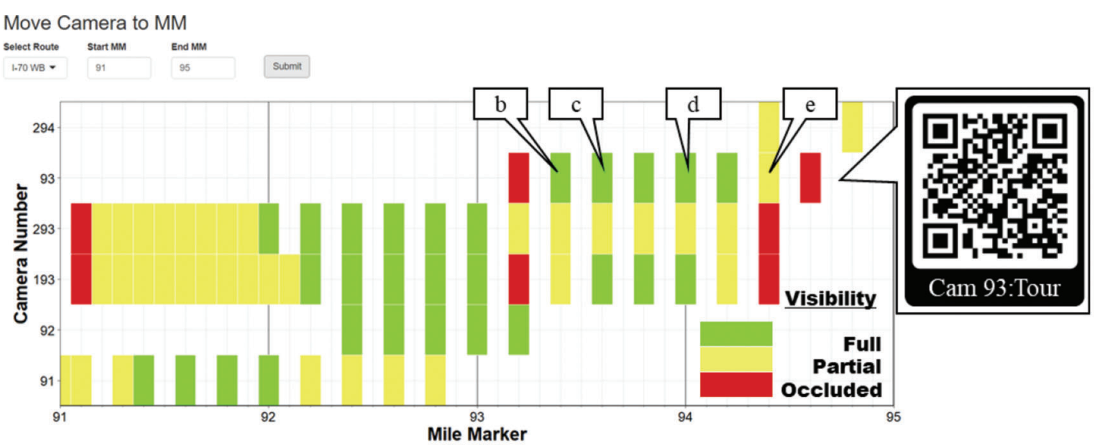
TABLE 9.1
Statewide camera visibility by interstate

Route	Number of Cameras Deployed	Number of Integrated Cameras	Percent Integrated	Percent of Interstate Miles Visible
I-64	16	13	81	11
I-74	23	9	39	17
I-69	101	61	60	17
I-70	81	43	53	30
I-65	169	108	64	49
I-469	15	11	73	71
I-465	58	48	83	91
I-265	16	15	94	92
I-94	66	56	85	96
Total	545	364	67	35

10. IMPLEMENTATION OF MILE MARKER TO PTZ CAMERA MAPPING

10.1 Automate Camera View to Mile Marker Application

After generating the statewide table of mile marker to PTZ settings for the 364 cameras, an application (Figure 10.1) was developed to assist operators to quickly set the camera view to the specified mile marker. Figure 10.1a shows a snapshot of the application where operators can use the dropdown menu to select the route and input the range of mile markers. The application displays a tile for every mile marker (X-axis) in the field-of-view of the available cameras (Y-axis). Double clicking a tile sets the corresponding camera view to the specified mile marker. For example, in Figure 10.1, double clicking callout b moves Camera 93 to MM 93.4 (Figure 10.1b), callout c to MM 93.6 (Figure 10.1c), callout d to MM 93.8 (Figure 10.1d) and callout e to the partially visible MM 94.0 (Figure 10.1e). A “Tour” feature is also implemented that automatically cycles the camera view to all the mile markers available for that camera on the current application view. A YouTube video showing this feature for Camera 93 is presented via a QR code in Figure 10.1a, or by clicking on https://tinyurl.com/I70-CAM93. Appendix D contains several more examples for various cameras along I-465. This feature is particularly helpful for operators while they are trying to quickly identify incidents over a spatial area based on positional reports obtained from 911 calls.



(a) Application interface (link to YouTube tour of Camera 93: https://tinyurl.com/I70-CAM93)

(b) Camera 93: View of MM 93.4.

(c) Camera 93: View of MM 93.6.

(d) Camera 93: View of MM 94.0.

(e) Camera 93: View of MM 94.4.

Figure 10.1 Automated camera view to mile marker application.

10.2 Integration of MM to PTZ Mapping in Incident Verification Process at TMC

As discussed previously, reconciling position reports that are often mile marker based, with cameras that operate in a PTZ coordinate system relies on operators having detailed knowledge for hundreds of cameras. Automatically setting the available cameras views and identifying the best view for them provides an opportunity to reduce human bottlenecks and decrease dispatch times. Figure 10.2 is a revised version of Figure 4.1 that illustrates how the above application can be integrated into the workflow. After receiving reports with varying levels of spatial accuracy, operators can first use the "Tour" feature to locate the nearest mile marker of the incident. After this, they can use the application to identify the camera with the best view of the incident (callout i).

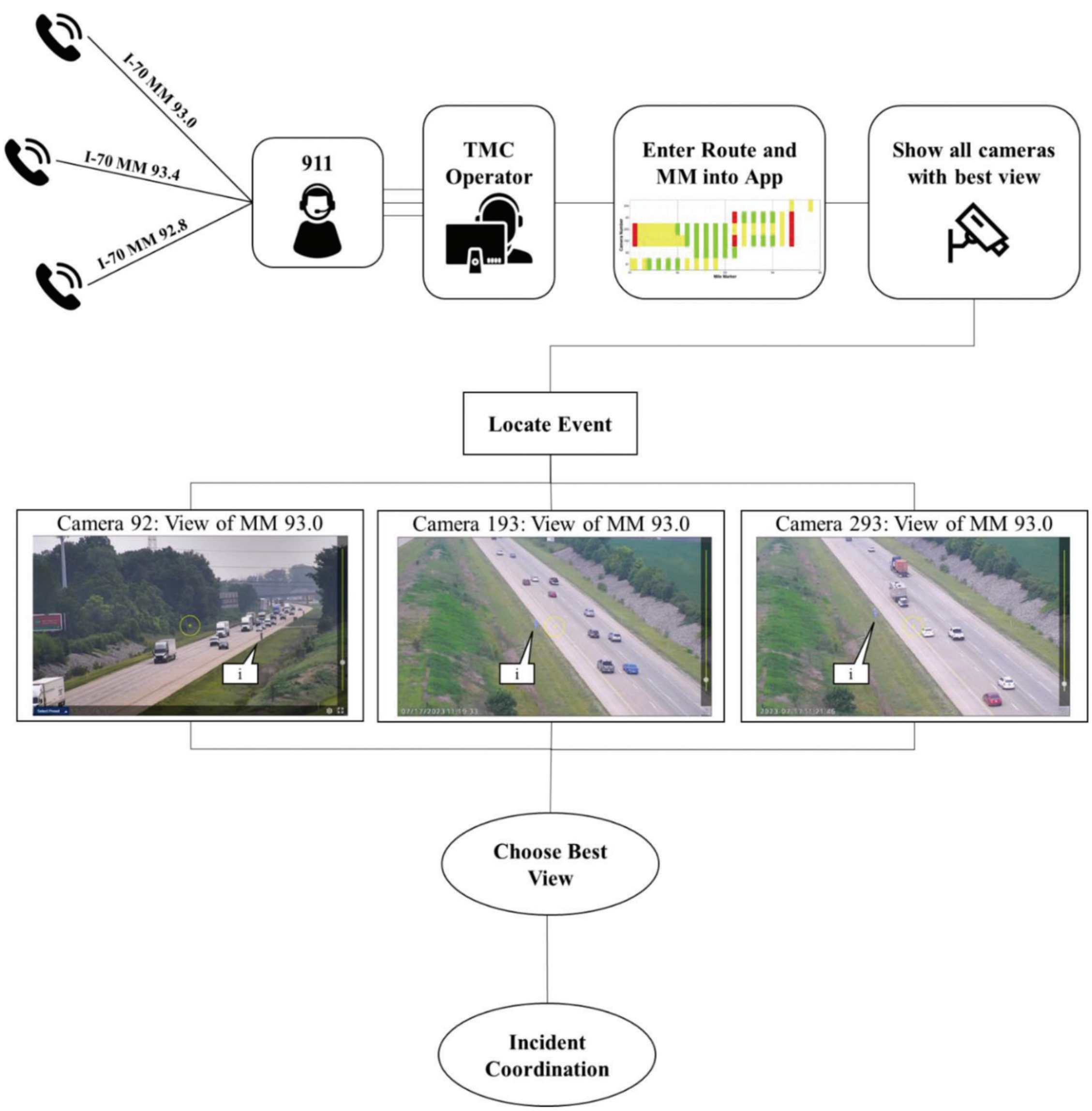


Figure 10.2 Integrating automated camera positioning dashboard into TMC verification workflow.

11. FUTURE RESEARCH

11.1 Systematically Deriving PTZ Settings of Mile Markers Using LiDAR Data

Although 364 cameras with over 10,000-mile markers to PTZ mapping entries were generated manually, this mapping can be done systematically from LiDAR mapping campaigns that generate 3D surveys of both roads and cameras. This data can be used to systematically estimate the Interior/Exterior Orientation Parameters (IOP/EOP) or PTZ coordinates of pre-specified camera settings based on the Direct Linear Transformation model (Abdel-Aziz et al., 2015; El-Ashmawy, 2018).

The proposed strategy for controlling a PTZ camera to have a specific location in its field-of-view is based on using the geospatial data at the camera vicinity to determine the camera's characteristics (IOP/EOP) for the camera when having pre-specified settings (e.g., zero pan and zero tilt). Then, the IOP/EOP together with the geospatial data can be used to define the needed camera settings to have a specific latitude/longitude (location of mile marker) in the field-of-view of the camera while having sufficient geometric resolution (defined by what is known as Ground Sampling Distance or GSD—i.e., the extent of ground covered by a single pixel). Appendix A provides an illustration of the improved accuracy of mile marker mapping that can be realized when mapping is done directly from LiDAR.

11.2 Using CV Trajectory Data to Automatically Identify Incidents and Set Camera View

CV trajectory data is well documented and provides very precise identification of location and time of an incident (Mathew et al., 2021; Sakhare, Desai, et al., 2022). Since this CV data is reported as latitude and longitude, it can be rapidly linear referenced to a miler marker as soon as they occur (Mathew et al., 2021). Figure 11.1 shows a CV trajectory heatmap (similar to Figure 6.1a) on I-70E between MM 90 and 110 during 8 AM to noon on August 27, 2022. Around 9:20 AM a crash occurs near MM 100 (callout i) that causes significant slowdowns and queuing that closes the interstate for approximately 30 minutes. These sudden drops in speeds combined with extensive closure of interstates can be used as a trigger to identify the precise location of incidents and slowdowns on interstates. This latitude/longitude data can then be linear referenced to the nearest mile marker and the PTZ settings can be transmitted to set the nearest camera(s) on the incident.

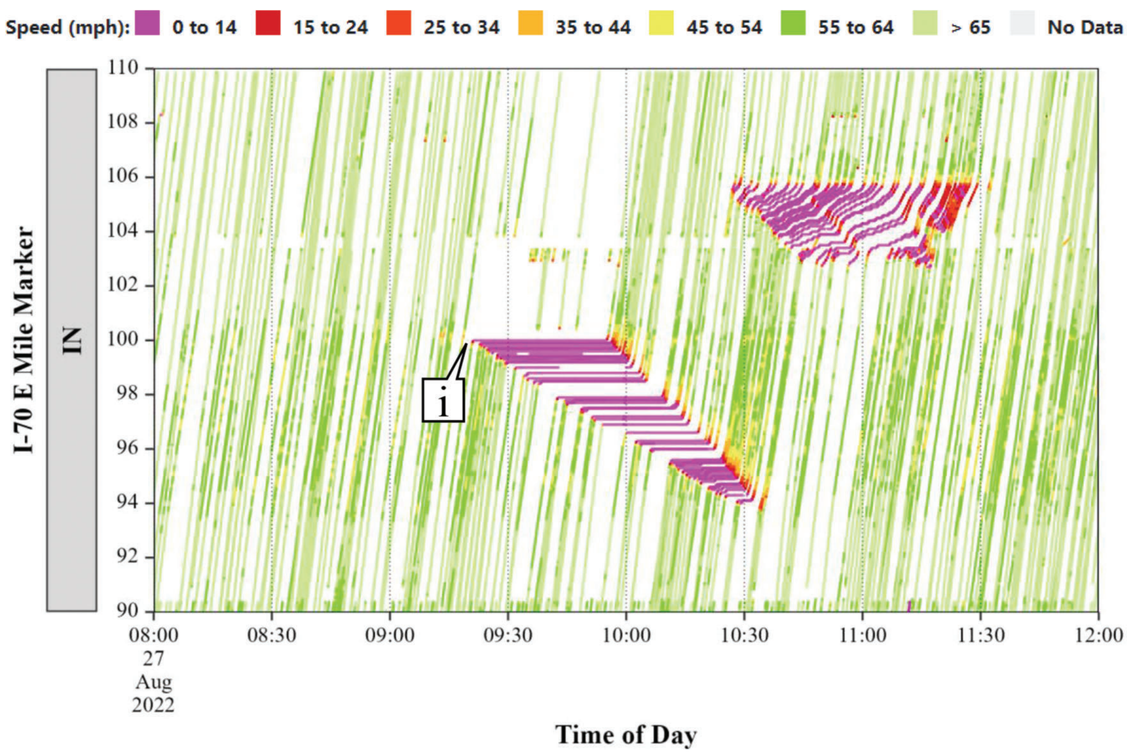


Figure 11.1 Using CV trajectory data to detect incidents and slowdowns.

12. CONCLUSION

An efficient TIM program requires early detection of incidents, quick verification, rapid on-scene response, and swift return of traffic to normal conditions. This study proposes a framework that assists camera operators and dispatchers to quickly identify and verify the incidents using roadside cameras.

A new performance metric on verification time (T_{EYE}) is proposed to be integrated into the FHWA TIM event sequence that captures the time it takes for TMC operators to have the first visual on roadside cameras (Figure 5.1b). This is followed by a scalable methodology and a table that stores camera PTZ settings for the mile markers within its field-of-view (Figure 7.2). Performance metrics that summarize spatial camera coverage and image quality for use in both dispatch and long-term statewide planning for camera deployments are also developed. Images from over 350 cameras along Indiana interstates are mapped to more than 5,000 discrete mile marker signs to generate a statewide spatial camera coverage map (Figure 9.2). Results show that nearly 35% of the interstates in Indiana have sufficient camera coverage (Table 9.1). Finally, a web application is demonstrated that assists operators to quickly set a camera view to specified mile marker signs on interstate routes (Figure 10.1).

Future research briefly discusses the use of LiDAR geospatial data to automate the mapping of mile markers to camera PTZ settings. Integration of CV trajectory data to detect incidents and set the nearest camera view on the incident are also discussed for future studies (Figure 11.1).

The automated camera view to mile marker application is an important tool that allows TMC operators to quickly identify the nearest camera with the best view on the incident. The incident verification time performance metric proposed in this study will help transportation agencies understand how quickly they are able to locate and validate an incident. As new technologies and tools are integrated, this metric will help understand the impact of these tools on the verification time. Finally, the statewide camera coverage map and percent of interstate visibility metric is a valuable performance measure that decision makers can use as guidance for investment planning and camera upgrades.

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APPENDICES

Appendix A. LiDAR Surveys and Calibration of Camera Coordinates

Appendix B. Camera Stability Analysis

Appendix C. Benchmark Logbooks to Reset Camera Coordinates After Preventive Maintenance and Upgrades

Appendix D. Camera Tour Using LiDAR Data

Appendix E. Real-time Detection of Hoosier Helpers on Scene

Appendix F. Manual Mappings Using Interpolation

Appendix G. Occlusions

Appendix H. Statewide Mile Marker Visibility

Appendix I. I-465 True Mile Marker Locations

APPPENDIX A. LiDAR SURVEYS AND CALIBRATION OF CAMERA COORDINATES

The processes outlined in the body of the report are based on manual movement of the camera and data collection methods. However, manually mapping mile markers does not scale well. The continuation of this work was to implement scalable methods to extract coordinates (derived through the calibration process) of interest for all the cameras. The first step was to collect LiDAR data for the interstates that capture the evaluated locations of the cameras. From the collected point cloud, cameras could be calibrated by identifying 20/30 coordinates of corresponding features in camera imagery or LiDAR data respectively. This process is less labor intensive for each camera and can be recalibrated quickly.

The advantage of the LiDAR dataset collection is that we can also provide current conditions of infrastructure with great accuracy. The data set was originally collected for the PTZ camera calibration; however, the same dataset could be analyzed for many different cases such as pavement marking conditions or true locations of roadside signs. For example, we now have accurate GPS locations of every mile marker post on I-465. GIS maps of INDOT mile markers are a reasonable first approximation, but due to physical constraints such as bridge piers, ramps, turn-arounds, etc., there is often some variation between where they should be theoretically and where they are placed. Appendix I shows the accurate mile marker post locations from a LiDAR survey conducted on March 23, 2023. Figure A.1 shows the variation in distance between the true mile marker sign locations compared and the benchmark locations from publicly available INDOT GIS maps. The average error distance between reference point and true location is estimated to be around 129 ft.

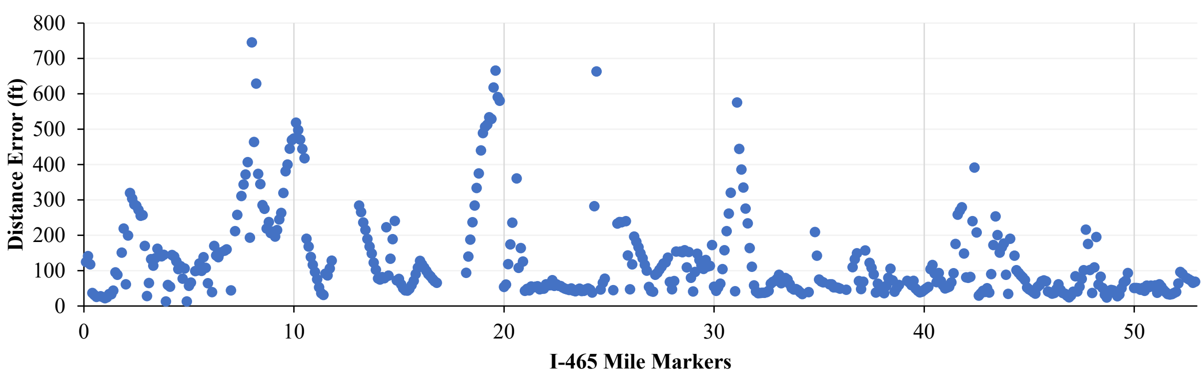


Figure A.1 Distance variation of mile marker signs from LiDAR data and current GIS inventory.

Different LiDAR datasets can be used as references for PTZ camera calibration. For instance, Purdue Airport-based PTZ camera calibration used data collected by the wheel-based mobile mapping systems (PWMMS-HA and PWMMS-UHA) and Geiger-mode LiDAR data (provided by VeriDaaS - https://veridaas.com/). Calibration of the trailer mounted PTZ camera located in Indianapolis required conducting additional UAS data collection to obtain detailed RGB color-coded LiDAR data of the area. Figure A.2 shows PTZ cameras installed at Purdue Airport and Indianapolis, IN.

Figure A.2 Locations of Purdue Airport (left) and Indianapolis, IN (right) PTZ cameras.

LiDAR data was collected over I-465 using two wheel-based mobile mapping systems (PWMMS-HA and PWMMS-UHA). The collected data was employed for internal/external calibration of PTZ cameras over I-465. The PTZ camera calibration procedure estimates interior/exterior orientation parameters (IOP/EOP) of the camera that are essential for precise estimation of pan and tilt settings to focus the camera on a specific location within its field of view (FOV). The strategy for IOP/EOP estimation (hereby referred to as "internal/external calibration") of a given PTZ camera proceeds through the following steps.

1. *Coarse estimation of the PTZ camera's IOP/EOP using Direct Linear Transformation (DLT):* The estimation is based on the Single Photo Resection principle where the distinct point features have been extracted from several camera images (5–6 images). Concurrently, conjugate points in LiDAR data from the same region are derived using a mobile or UAS-based mapping platform. Thereafter, parameters of the camera are calculated for each image separately and used as initial IOP/EOP values in the next step. Examples of used images and extracted point features are presented in Figure A.3.
2. *Fine refinement of the above-mentioned parameters using Unified Multi-Sensor Advanced Triangulation (UMSAT):* The research team uses image and object point features from the previous step together with initial IOP/EOP values for a refined calibration of the PTZ camera. In the case of scarcity of point features within the vicinity of the calibrated camera, linear features are used to enhance the refinement output. As a result, a set of refined IOP/EOP estimates are produced.
3. Estimation of the absolute orientation of the camera at zero degree pan and tilt settings using the derived calibration parameters: The research team uses the absolute position and orientation of the camera to define the camera's Pan and Tilt settings to target points of interest (POI) within the field of view. The Pan/Tilt settings are estimated using POI coordinates as an additional input. The camera's zoom parameter is determined empirically based on the distance between the POI and the PTZ camera. In situations where the distance is substantial, a higher zoom parameter is chosen. Conversely, when the distance is relatively short, the camera is set to a minimum zoom level. A few distinct points (5–15

points) in the camera's vicinity are selected to test the accuracy and repeatability of estimated PTZ settings. Examples of tested POIs and the layout of the points in the used LiDAR data are illustrated in Figure A.4 for a sample PTZ camera.

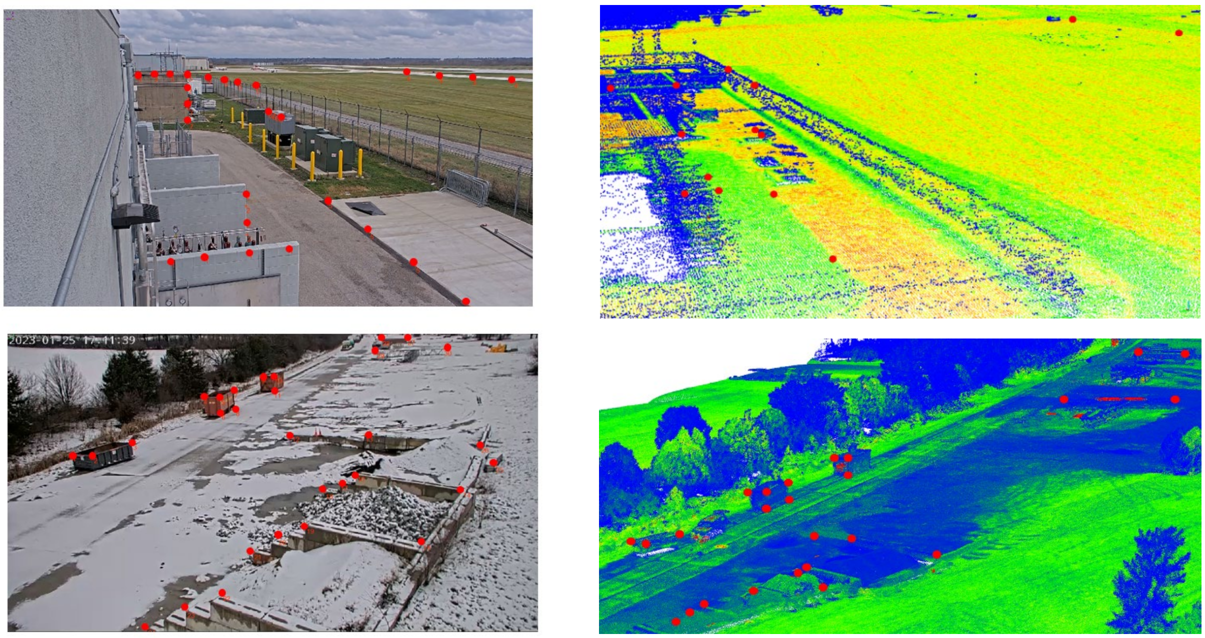


Figure A.3 Illustration of utilized point and linear features from Purdue Airport and Indianapolis, IN, PTZ cameras from PTZ camera view (left) and LiDAR data (right).

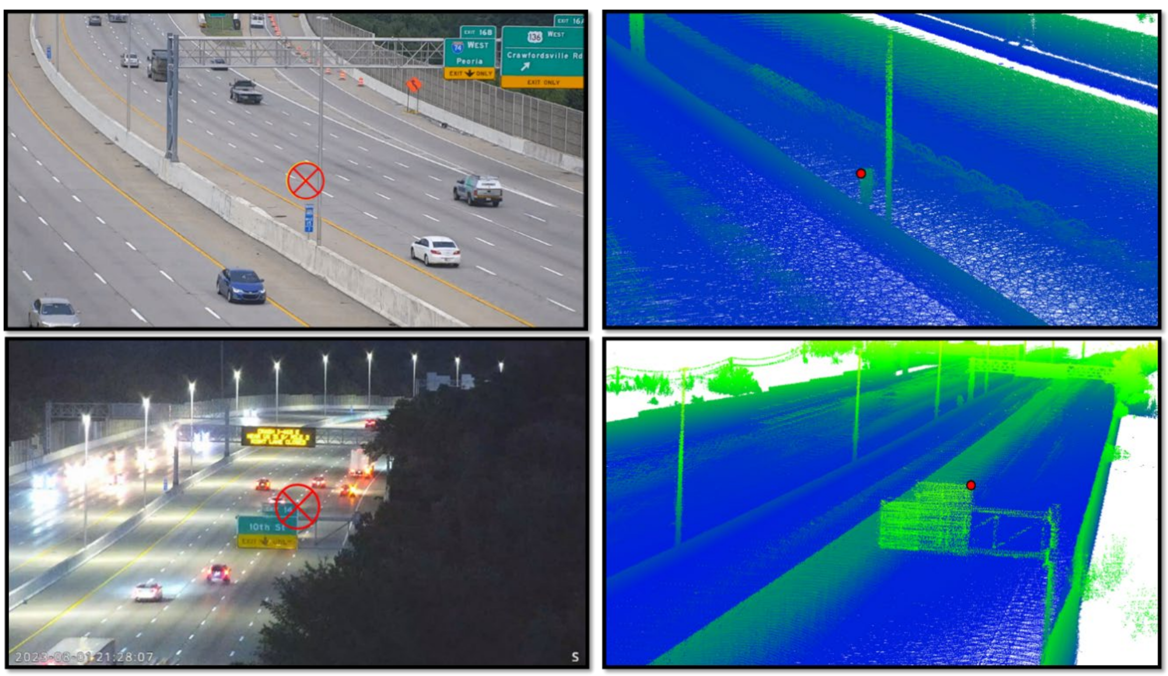


Figure A.4 Examples of points of interest on a PTZ camera view (left) and LiDAR data (right) for a sample camera on I-465.

As an additional validation, the research team conducted the following test.

1. Select 10 mile markers.
2. Derive the coordinates of the Mile Markers from the LiDAR survey.
3. Identify PTZ cameras that can visualize these Mile Markers (within a 1-mile search radius)
4. Evaluate the Pan/Tilt values for these cameras to visualize these mile markers.
5. Provide comments on the validity of the PTZ camera parameter settings and calibration stability.
6. Provide comments on the visibility/occlusion of the Mile Marker in these cameras.

The test results for mile marker 15 and mile marker 19 are presented in Figure A.5 (a) and (b).

(a) **(b)**

Figure A.5 Examples of mile-marker verification test: (a) mile marker 15, and (b) mile-marker 19.

APPENDIX B. CAMERA STABILITY ANALYSIS

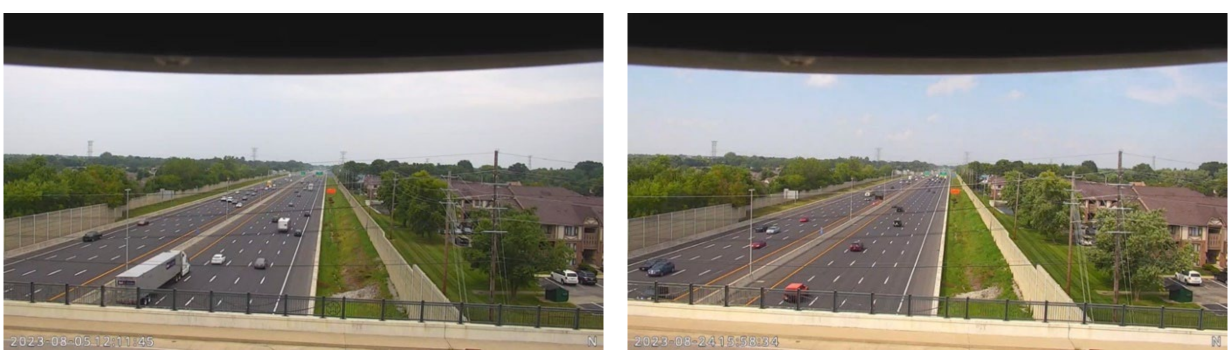
As a part of maintenance, the PTZ cameras are periodically removed from the poles (e.g., to clean the camera). The maintenance could impact the camera calibration results discussed in Appendix A, since the native "home" position or "absolute zero" of pan and tilt parameters could change after the procedure. In order to detect cameras with changes in orientation and to quantify changes a camera stability analysis strategy is developed.

The camera pan/tilt analysis strategy constantly monitors and reports the changes in absolute camera orientation at zero degrees of each calibrated PTZ camera. The strategy employs the following steps:

1. Periodically capture images with constant Pan/Tilt parameters (e.g., 0-degree Pan/Tilt) from a given camera. Depending on the selected frequency, the images can be captured on a daily or weekly basis.
2. Distinct features on the images (e.g., lane markings, bridges, and other permanent road elements) are automatically extracted/matched and used to estimate the camera rotation between successive images.
3. Based on the estimated camera rotation, one can report the camera stability. If the estimated rotation exceeds 1–2 degrees, the camera is flagged for further stability check.

It is assumed that a PTZ camera with a stable (unchanged) absolute orientation will always target the same point when constant Pan/Tilt parameters are applied; thus, resulting in camera rotation between the successive images being close to zero degrees.

The camera stability analysis was tested on the previously calibrated PTZ cameras over I-465. Sample results for two cameras are illustrated in Figure B.1 and Figure B.2. The image (a) in both figures was captured on August 8th, 2023, while the image (b) was captured on August 24th, 2023. Thus, the changes of camera's absolute orientation at zero pan and tilt values were evaluated between the above two dates. Figure B.3 and Figure B.4 represent a fraction (10%) of the extracted and matched features between the PTZ images, which is used for qualitative assessment of the estimated rotation accuracy.



(a) (b)

Figure B.1 Camera stability analysis: camera 18—camera is stable (estimated relative rotation: Pan =-0.08º, Tilt = 0.05º).

(a) (b)

Figure B.2 Camera stability analysis: camera 44—camera is not stable (estimated relative rotation: Pan = 14.66º, Tilt = -0.58º).

(a) (b)

Figure B.3 Camera stability analysis: camera 18—feature matching (number of matched features: 1,203).

(a) (b)

Figure B.4 Camera stability analysis: camera 44—feature matching (number of matched features: 202).

APPENDIX C. BENCHMARK LOGBOOKS TO RESET CAMERA COORDINATES AFTER PREVENTIVE MAINTENANCE AND UPGRADES

With the implementation of system-wide tools that rely on stored PTZ settings for a specific view, as with the mile-marker mappings, the stored settings must always map to the desired viewport. Due to necessary protocols regarding preventative maintenance, upgrades, and utilization of the camera system, stored PTZ settings are regularly left pointing anywhere but the desired location because of the impossible task of replacing the cameras in the exact orientation from which they were removed, as seen in Figure C.1. Thus, a system to efficiently and easily determine if any maintenance has occurred and, most importantly, remedy the stored settings is necessary for future operations. To remedy misalignments between stored settings and desired views relies on a database of definitions of particular objects or points that are presumed to be fixed, called benchmarks. Benchmarks do not necessarily have a valuable image concerning TIM processes but serve to maintain the functionality of those processes.

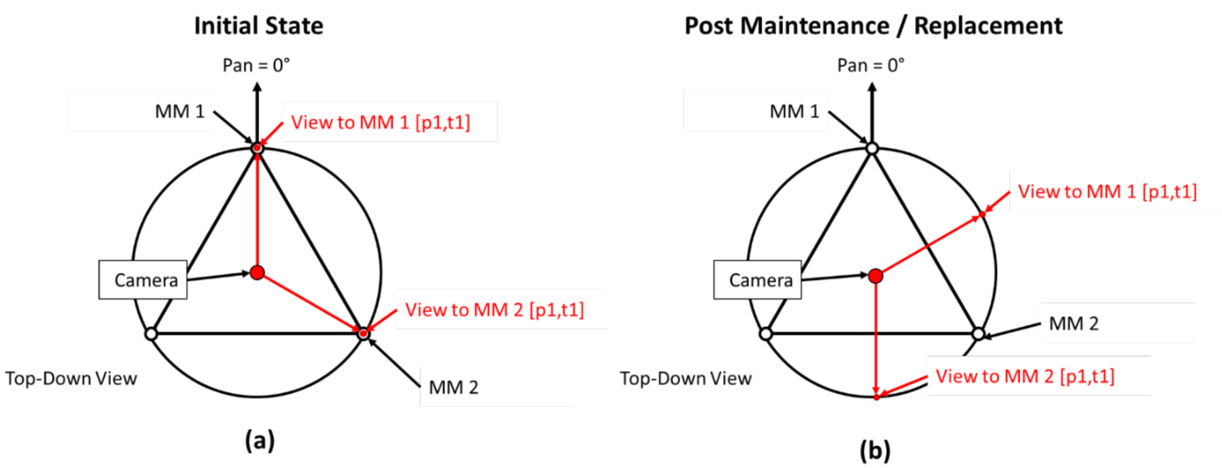
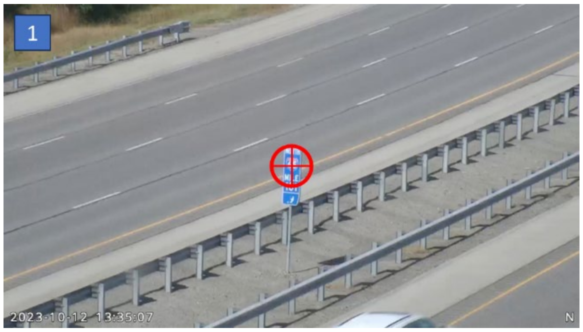


Figure C.1 Benchmarking overview (a) correct alignment, and (b) misaligned settings and feature.

Benchmarking involves locating desirable features from each camera, storing PTZ settings, and capturing an image of the benchmark. Desirable features follow a hierarchy of common road-side elements, notably mile-marker posts, bridge abutments, and drains, as these features are easily recognizable and semi/fully permanent. Once this network is established for each camera, a simple rotation is applied to the stored settings by calculating a correction from the old position of a given benchmark to the position after a camera undergoes maintenance.

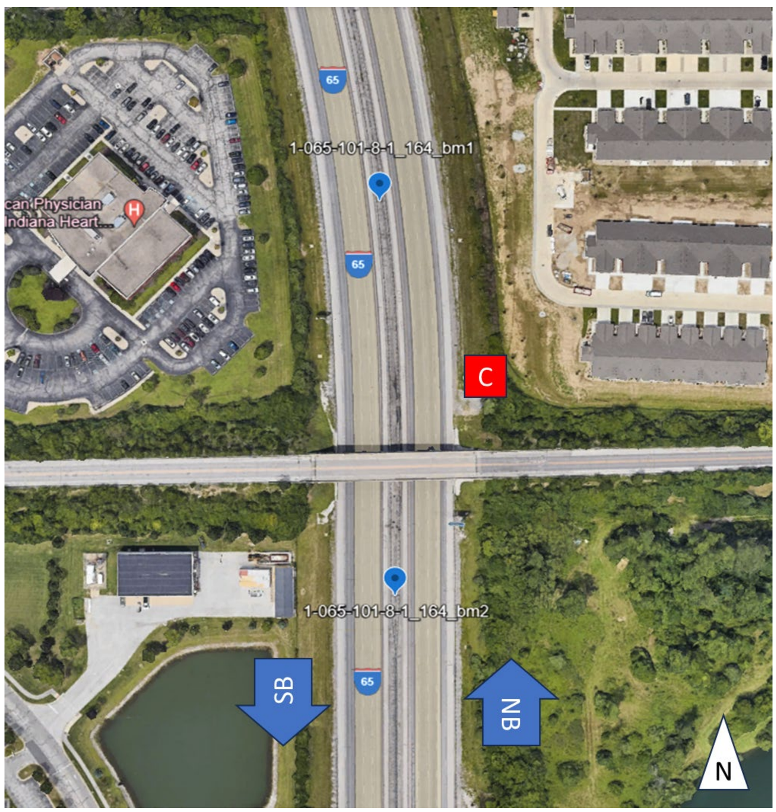
To aid in future realignment efforts, picture books, like Figure C.2, are created for each camera for all benchmarks, showing where the cameras should point to realign stored settings using benchmarks properly. Figure C.2 shows an example for camera number 164 (callout C on Figure

C.2c) on I-65. Two benchmarks are recorded for this camera—mile marker sign 101.9 (Figure C.2a) and mile marker sign 101.8 (Figure C.2b).



(a) Benchmark 1 – MM 101.9

(b) Benchmark 2 – MM 101.8



(c) Site Map

Figure C.2 Sample picture book.

APPENDIX D. CAMERA TOUR USING LiDAR DATA

Once the cameras are all calibrated, the extents of the highway that each camera can see can be quickly determined. From the calibration settings and the LiDAR data of the centerline of the highway, the camera can be programed to move along, or "sweep" the route to determine the view extents of every camera. This can also be used for TMC operators to quickly detect incidents without having to manually control the camera. Table 5 below shows sample camera tours for cameras along I-465.

Table D.1 I-465 camera tours

Camera Location	Camera Number	Visible Mile Markers	YouTube Link
I-465	4	0.4–2.0	https://youtu.be/G4IpAlqSprE
I-465	9	9.4–10.0	https://youtu.be/jPxaSgLFyDM
I-465	19	17.9–19.2	https://youtu.be/zJ3psvDbsls
I-465	21	20.4–22.1	https://youtu.be/2nUfycS9NDs
I-465	23	21.9–24.0	https://youtu.be/Ouoy2qq-TMQ
I-465	24	31.5–32.6	https://youtu.be/59wl6uJlV7A
I-465	32	32.9–34.6	https://youtu.be/P3fcv_3M09A
I-465	42	42.1–43.1	https://youtu.be/qzeosTi1E9c
I-465	43	42.1–43.1	https://youtu.be/ZTtWlCSDWjw
I-465	132	29.9–31.6	https://youtu.be/76TmBDwZzas
I-465	231	3.6–4.4	https://youtu.be/BR3yKR1-exE
I-465	733	48.2–48.7	https://youtu.be/zXnjXiU6GHM

APPENDIX E. REAL-TIME DETECTION OF HOOSIER HELPERS ON SCENE

One of the applications developed using the methodologies highlighted in this report is the automatic positioning of cameras on Hoosier Helpers and other INDOT vehicles actively attending a scene. These vehicles are retrofitted with digital alerts that broadcast their position while attending a scene. The application automatically finds the nearest camera to this geolocation and using the methodologies highlighted in Appendix A, positions the camera view on this location.

Figure E.1 shows a snapshot of this application where camera number 42 automatically position its view on a vehicle attending a scene on I-465 near mile marker 42.6. A YouTube video illustrating this application can be found at: https://youtu.be/CU1tn0RywoA

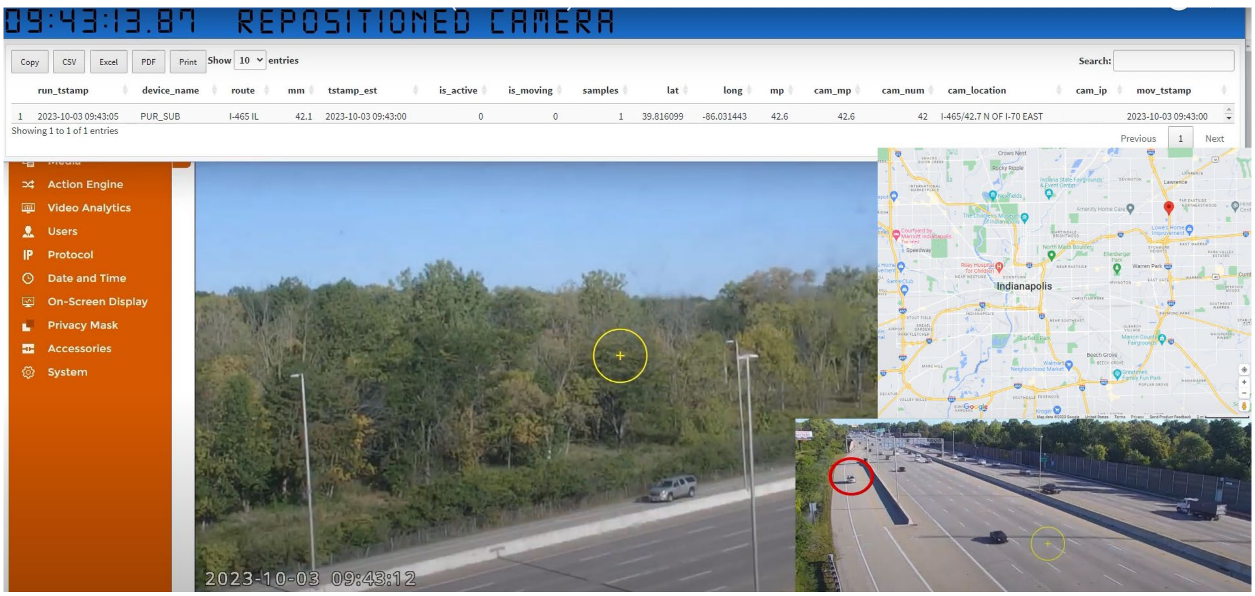


Figure E.1 Real-time positioning of cameras on Hoosier Helpers.

APPENDIX F. MANUAL MAPPINGS USING INTERPOLATION

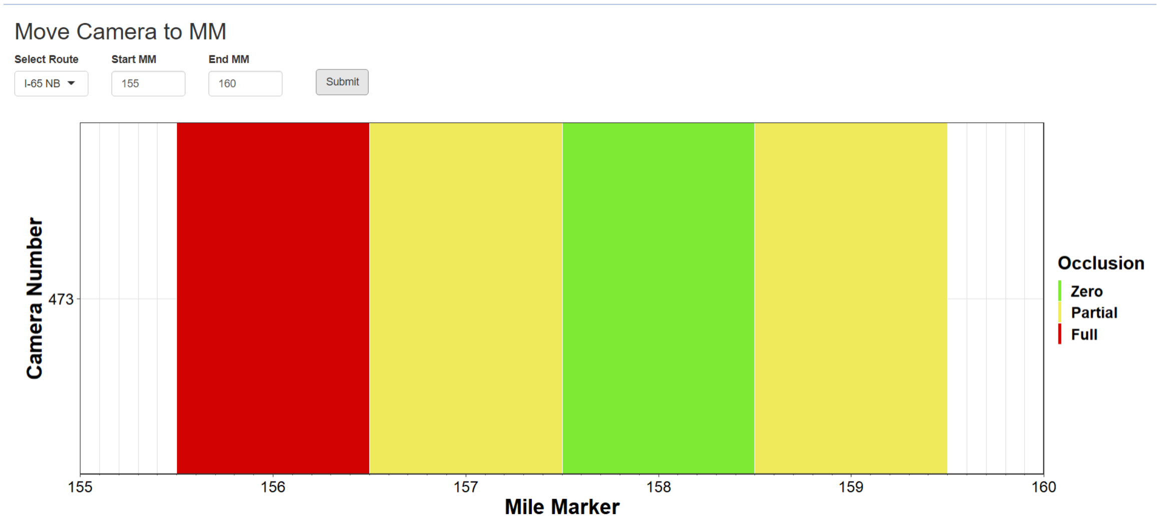
During the manual mapping of each camera, the benchmarks for each camera position was based on the physical mile marker signs on the interstate. For I-465, there is good coverage at about every 500 ft because there is a mile marker post every 0.1 miles. However, in many locations throughout the state there are only signs every half mile or mile. This is not precise enough for quickly locating camera incidents based on the GPS trajectory data as described in Appendix A. Before the LiDAR point cloud was processed, manual interpolation of the distance in between 1.0-mile marker posts were done to show the proof of concept of the advantages of the LiDAR dataset. To interpolate, each mile marker location was found in Google Earth, and then measured 1,500 ft to simulate 0.2 miles. Figure F.1 shows the comparison of Google maps street view compared to the PTZ camera view for Camera 473 at mile marker 157.2. Callout i shows the common green sign that is used to reference the two images together.

157.2

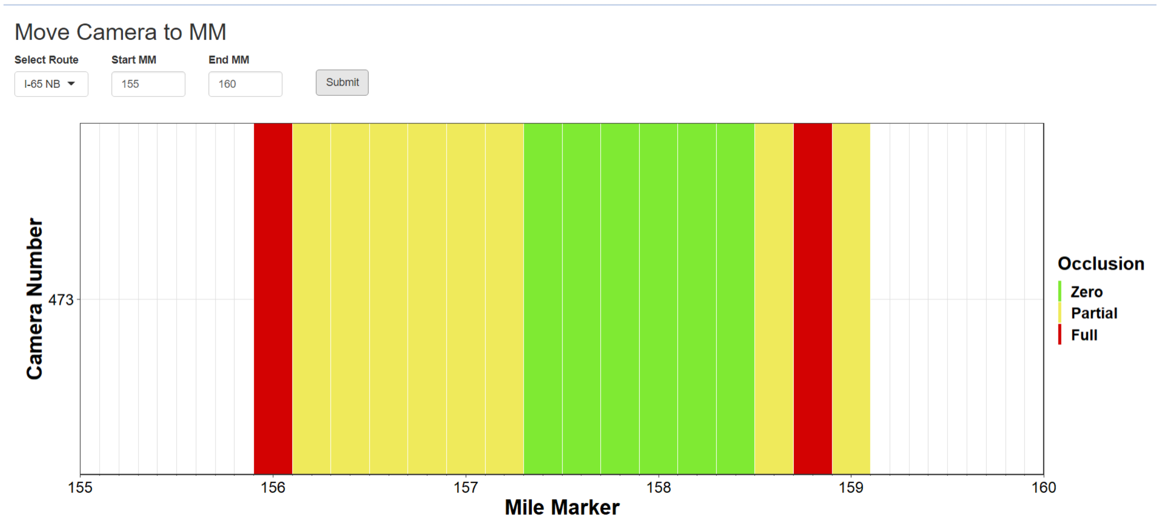
9	I-65 NB	157.2	1-065-157-9	473	SR 28	1	2	02 00 00 C4	02 00 8C 99	02 00 9B 5C	02 00 4C 90

Figure F.1 Camera 473 Google Maps Interpolation—MM 157.2.

This location was then found on the PTZ cameras and logged as the decimal mile marker location. Figure F.2 shows the results of the camera view to mile marker application interface for camera number 473 located near I-65 NB mile marker 158. Figure F.2a is based on the physical mile marker signs on the roadway, and Figure F.2b is after manual interpolation to decimal mile marker locations. The advantage of the LiDAR point cloud is the system can automatically interpolate down to every 0.01 miles.



(a) Camera view to mile marker application for camera 473 based on physical mile post.



(b) Camera view to mile marker application for camera 473 based on 0.2-mile interpolation.

Figure F.2 I-65 MM 156-159 interpolation results.

APPENDIX G. OCCLUSIONS

The camera tours outlined in Appendix D are not only helpful for the extents of which the cameras can see, but additionally can be used to quickly identify obstructions of camera visibility on the roadway. For example, where there are bridges going across the highway, there is immovable obstruction. However, there are occlusions from trees that we see when they are full of leaves but may not be there during the fall and winter months. These can now be quickly accessed with a click of the button to make the camera tour, and any obstructions can be quickly identified.

In terms of investment, if there is a blind spot on the interstate, operators and decision makers can take a quick look at the tours of nearby camera to determine the need for capital investment, tree clearing, or acceptable blind spot. Figure G.1 is an example where cutting a tree would increase the visibility of camera 19. A small investment to trim the tree back would add visibility for an additional half mile of interstate. It is recommended that this is evaluated when the trees are full of foliage and again when the tress are bare to determine the best course of action.

Figure G.1 Camera 19 occlusion due to tree branch in camera field of view.

APPENDIX H. STATEWIDE MILE MARKER VISIBILITY

As discussed in Section 9 of the body of the report, visibility analysis is important for future investments in the ITS infrastructure. This appendix is a compilation of figures similar to Figure 9.1 showing the visibility and occlusion for all mile markers for all of the Indiana interstates.

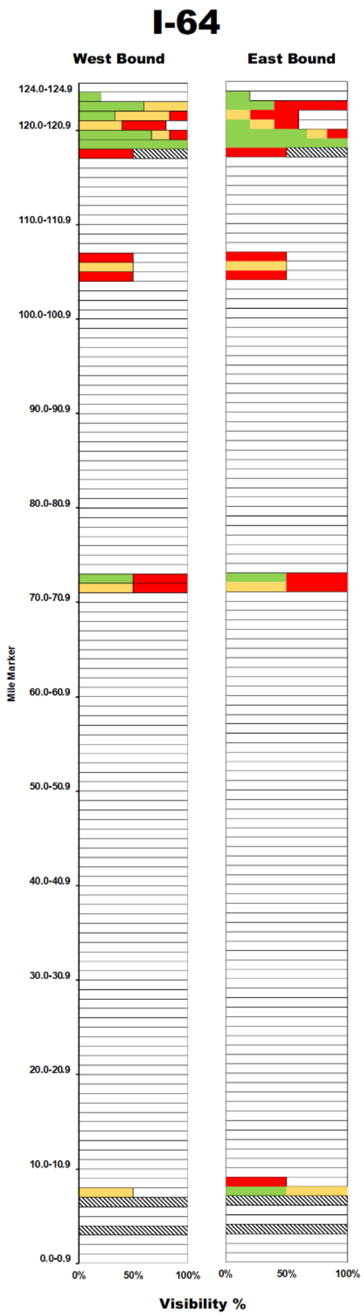
Percent of MM with No Occlusion

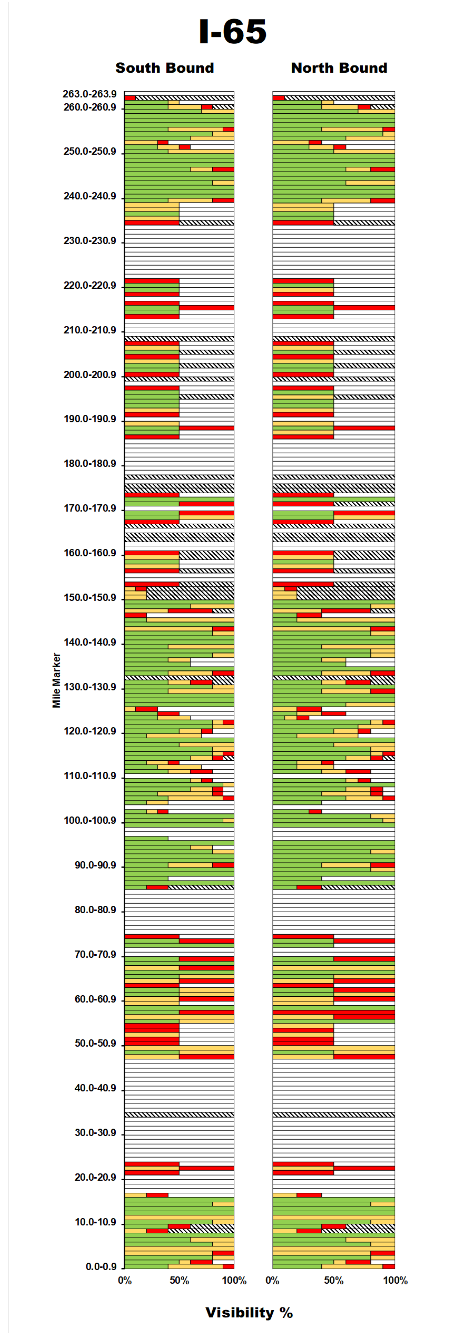
Percent of MM with Partical Occlusion

Percent of MM with Full Occlusion

Percent of MM with No Visibility

MM with Inaccessible Camera





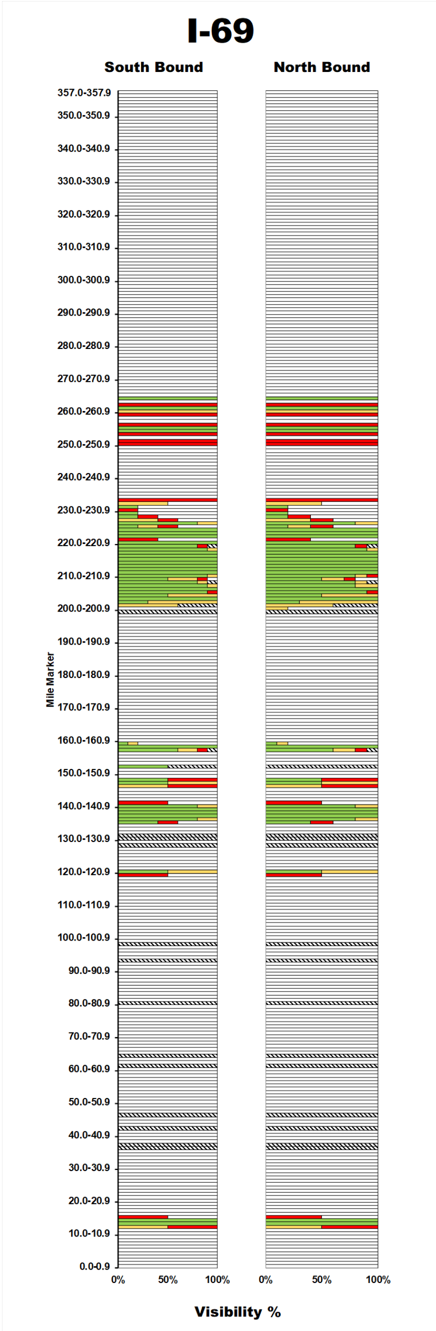
Percent of MM with No Occlusion

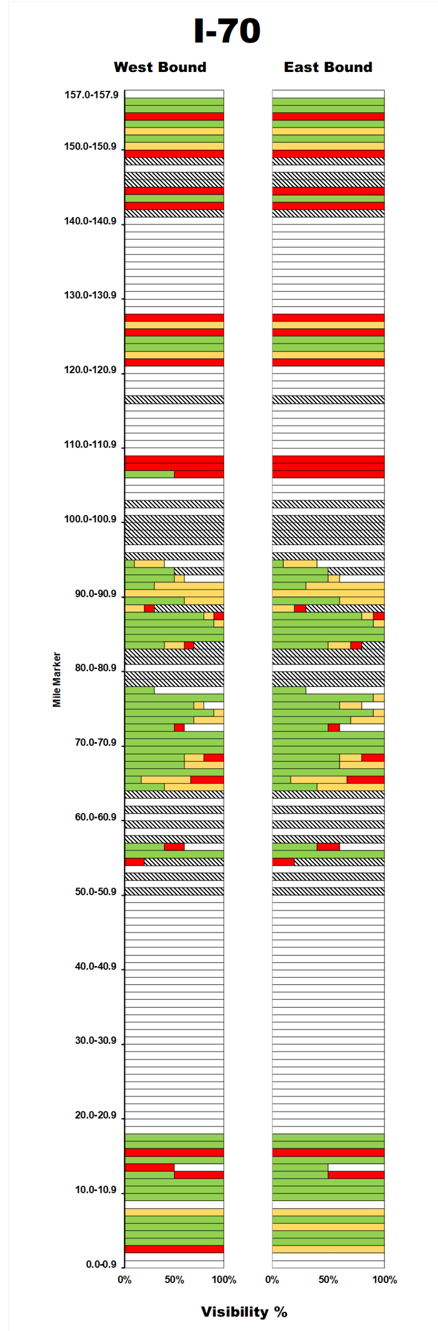
Percent of MM with Partical Occlusion

Percent of MM with Full Occlusion

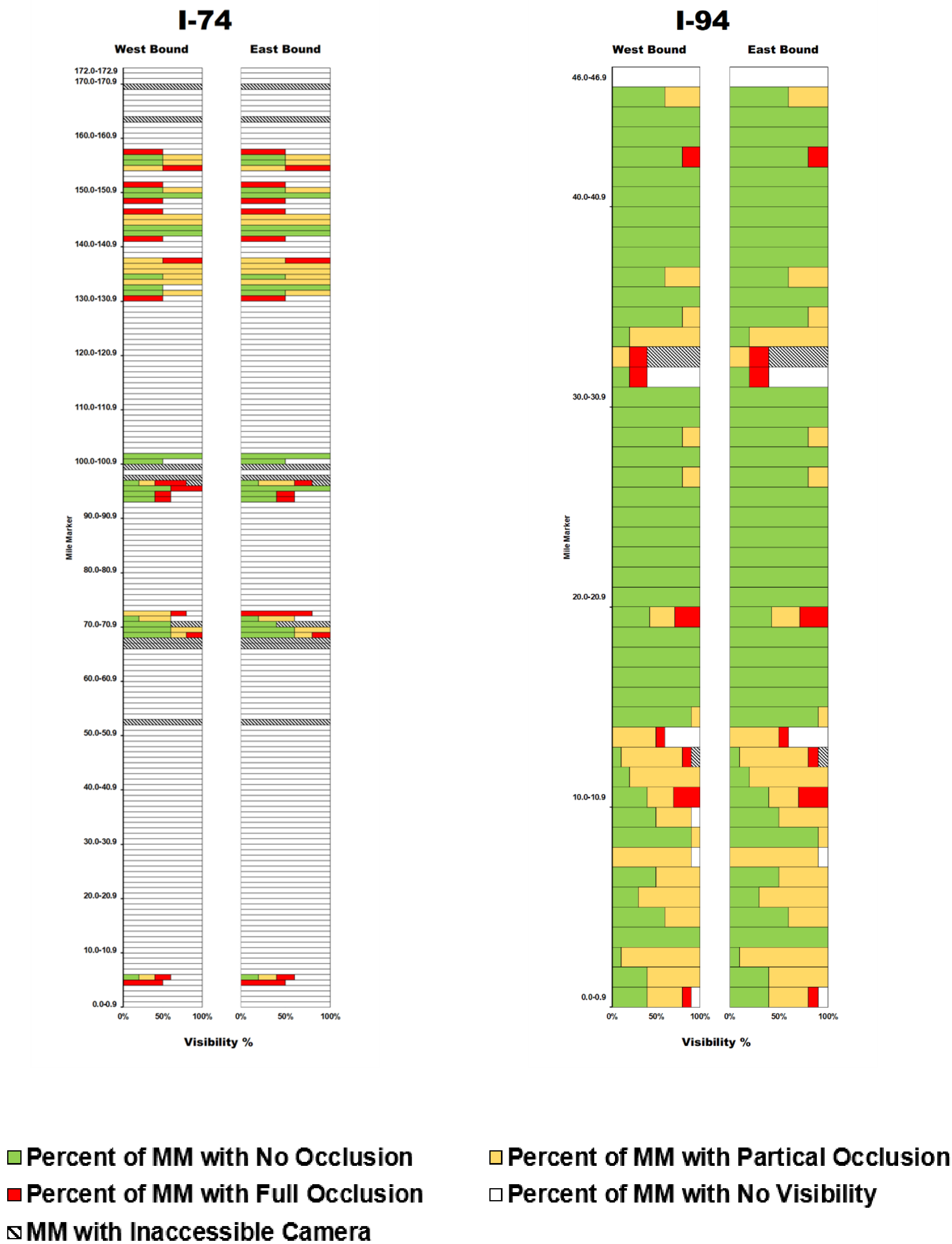
Percent of MM with No Visibility

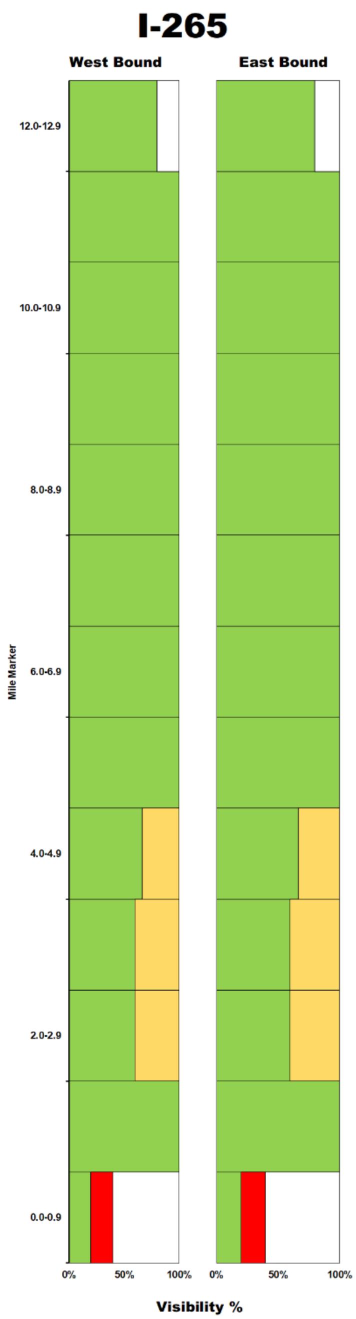
MM with Inaccessible Camera





Percent of MM with No Occlusion
Percent of MM with Partical Occlusion
Percent of MM with Full Occlusion
Percent of MM with No Visibility
MM with Inaccessible Camera


I-74
West Bound
East Bound
Mile Marker
Visibility %
I-94
West Bound
East Bound
Mile Marker
Visibility %
Percent of MM with No Occlusion
Percent of MM with Partical Occlusion
Percent of MM with Full Occlusion
Percent of MM with No Visibility
MM with Inaccessible Camera



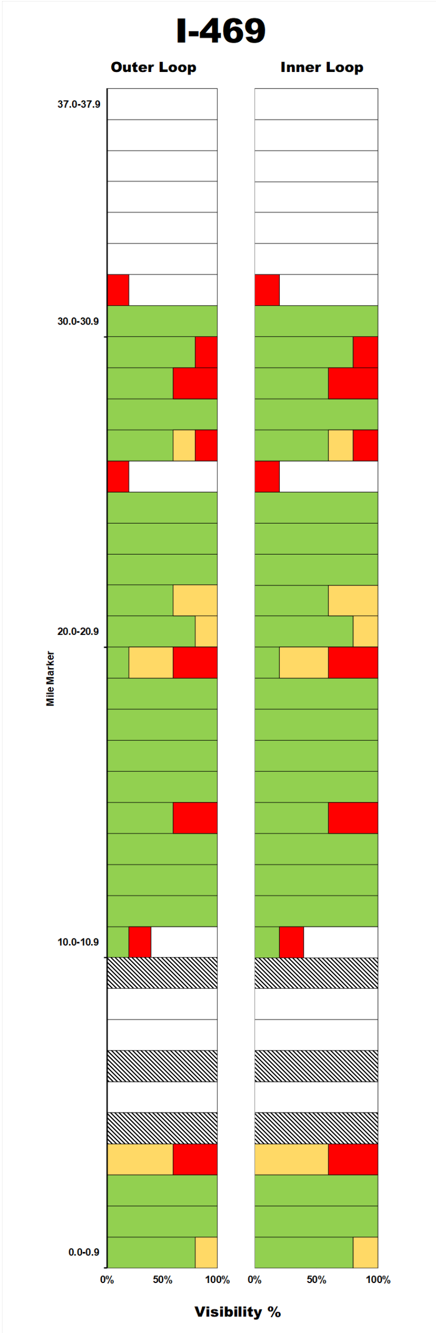
Percent of MM with No Occlusion

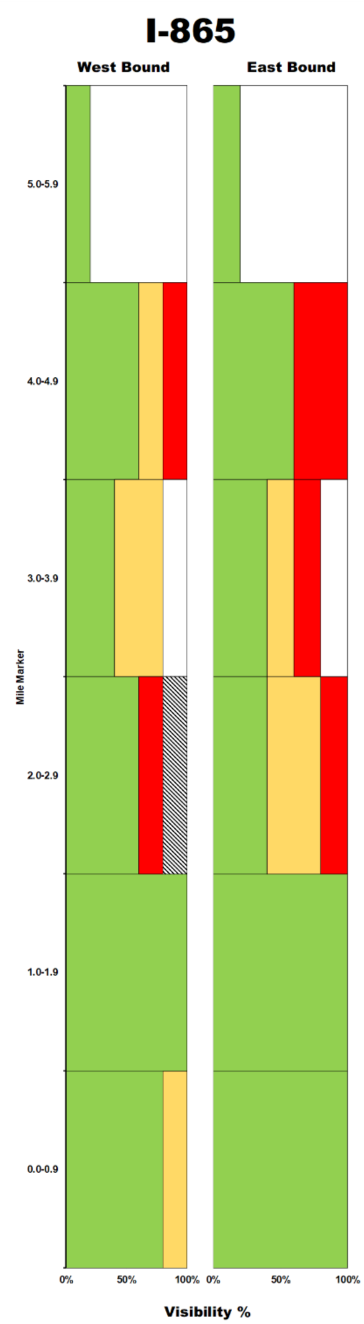
Percent of MM with Partical Occlusion

Percent of MM with Full Occlusion

Percent of MM with No Visibility

MM with Inaccessible Camera


I-469
Outer Loop
Inner Loop
37.0-37.9
30.0-30.9
20.0-20.9
10.0-10.9
0.0-0.9
Mile Marker
0%
50%
100%
Visibility %


I-865
West Bound
East Bound
5.0-5.9
4.0-4.9
3.0-3.9
2.0-2.9
1.0-1.9
0.0-0.9
Mile Marker
0%
50%
100%
Visibility %

APPENDIX I. I-465 TRUE MILE MARKER LOCATIONS

MM	Latitude	Longitude
0.1	39.70342	-86.1096
0.2	39.70254	-86.1118
0.3	39.70239	-86.114
0.4	39.70215	-86.1155
0.5	39.70186	-86.1173
0.6	39.70156	-86.1191
0.8	39.70096	-86.1228
0.9	39.7007	-86.1244
1	39.70039	-86.1263
1.1	39.70009	-86.1282
1.2	39.69977	-86.1301
1.3	39.69948	-86.1319
1.4	39.69918	-86.1338
1.5	39.6989	-86.1355
1.6	39.69858	-86.1374
1.8	39.69826	-86.1411
1.9	39.69784	-86.1435
2	39.69863	-86.1457
2.1	39.69848	-86.1473
2.2	39.69872	-86.1483
2.3	39.69943	-86.1499
2.4	39.69946	-86.1521
2.5	39.69983	-86.1539
2.6	39.70021	-86.1557
2.7	39.7006	-86.1576
2.8	39.70097	-86.1593
2.9	39.70137	-86.1615
3	39.70166	-86.1636
3.1	39.70128	-86.1652
3.2	39.70109	-86.1667
3.3	39.70056	-86.1685
3.4	39.70014	-86.1703
3.5	39.69959	-86.1719
3.6	39.69925	-86.1738
3.7	39.69864	-86.1755
3.8	39.69836	-86.1773
3.9	39.69781	-86.1796
4	39.69719	-86.1814
4.1	39.69695	-86.183

MM	Latitude	Longitude
4.2	39.69648	-86.1844
4.3	39.69615	-86.1862
4.4	39.69557	-86.1879
4.5	39.69523	-86.1898
4.6	39.69463	-86.1915
4.7	39.69436	-86.1934
4.8	39.69383	-86.1951
4.9	39.69359	-86.1972
5	39.69317	-86.1991
5.1	39.69293	-86.2007
5.3	39.69252	-86.2043
5.4	39.6925	-86.2061
5.5	39.69227	-86.208
5.6	39.69232	-86.2099
5.7	39.69217	-86.2117
5.8	39.69228	-86.2136
5.9	39.69216	-86.2157
6.1	39.69216	-86.2197
6.2	39.69216	-86.2209
6.3	39.69215	-86.2229
6.4	39.69226	-86.2248
6.5	39.69211	-86.2266
6.7	39.69214	-86.2304
6.8	39.69213	-86.2322
7	39.69224	-86.2367
7.2	39.69233	-86.2397
7.3	39.69244	-86.2415
7.5	39.6931	-86.2452
7.6	39.69358	-86.2469
7.7	39.69415	-86.2487
7.8	39.6948	-86.2503
7.9	39.69592	-86.2526
8	39.69592	-86.2526
8.1	39.69723	-86.2548
8.2	39.69783	-86.2557
8.3	39.69927	-86.2576
8.4	39.70027	-86.2589
8.5	39.70134	-86.2603
8.6	39.70231	-86.2616

8.7	39.70345	-86.2629
8.8	39.7046	-86.2638
8.9	39.706	-86.2643
9	39.70735	-86.2644
9.1	39.70895	-86.2644
9.2	39.71046	-86.2644
9.3	39.71191	-86.2645
9.4	39.71343	-86.2645
9.5	39.71483	-86.2645
9.6	39.71622	-86.2645
9.7	39.71773	-86.2645
9.8	39.71916	-86.2645
9.9	39.72065	-86.2645
10	39.7222	-86.2645
10.1	39.72345	-86.2645
10.2	39.72489	-86.2645
10.3	39.72635	-86.2645
10.4	39.72781	-86.2645
10.5	39.72926	-86.2645
10.6	39.73128	-86.2645
10.7	39.73272	-86.2645
10.8	39.73419	-86.2645
10.9	39.73564	-86.2645
11	39.73708	-86.2645
11.1	39.73853	-86.2645
11.2	39.73998	-86.2646
11.3	39.74142	-86.2646
11.4	39.74287	-86.2646
11.5	39.74446	-86.2646
11.6	39.74582	-86.2646
11.7	39.74726	-86.2646
11.8	39.7487	-86.2646
13.1	39.76718	-86.2678
13.2	39.76854	-86.2683
13.3	39.76994	-86.2689
13.4	39.77133	-86.2694
13.5	39.77275	-86.2698
13.6	39.77419	-86.2701
13.7	39.77563	-86.2703
13.8	39.77708	-86.2703
13.9	39.77852	-86.2703

14	39.77997	-86.2703
14.1	39.78143	-86.2704
14.2	39.78287	-86.2704
14.3	39.78432	-86.2705
14.4	39.78535	-86.2706
14.5	39.78716	-86.271
14.6	39.78843	-86.2713
14.7	39.78967	-86.2718
14.8	39.7909	-86.2723
14.9	39.79271	-86.2732
15	39.79407	-86.2739
15.1	39.79546	-86.2744
15.2	39.79688	-86.2748
15.3	39.79832	-86.2751
15.4	39.79976	-86.2752
15.5	39.80122	-86.2753
15.6	39.80267	-86.2753
15.7	39.80411	-86.2753
15.8	39.80556	-86.2753
15.9	39.80702	-86.2754
16	39.80847	-86.2754
16.1	39.80991	-86.2754
16.2	39.81135	-86.2755
16.3	39.8128	-86.2755
16.4	39.81424	-86.2755
16.5	39.81569	-86.2755
16.6	39.81714	-86.2756
16.7	39.81859	-86.2756
16.8	39.82005	-86.2756
18.2	39.84033	-86.276
18.3	39.84177	-86.2761
18.4	39.84323	-86.2761
18.5	39.84468	-86.2761
18.6	39.84612	-86.2761
18.7	39.84757	-86.2762
18.8	39.849	-86.2762
18.9	39.8505	-86.2762
19	39.85195	-86.2763
19.1	39.85339	-86.2763
19.2	39.8548	-86.2763
19.3	39.85626	-86.2763

19.4	39.85763	-86.2764
19.5	39.85925	-86.2764
19.6	39.86076	-86.2764
19.7	39.86199	-86.2759
19.8	39.86326	-86.2749
20	39.86428	-86.2738
20.1	39.86535	-86.2725
20.2	39.86645	-86.2713
20.3	39.86756	-86.2701
20.4	39.86883	-86.2692
20.6	39.87167	-86.2686
20.7	39.87403	-86.2688
20.8	39.87637	-86.2689
20.9	39.87791	-86.2689
21	39.87926	-86.269
21.1	39.88075	-86.2691
21.2	39.88217	-86.2691
21.3	39.88366	-86.2692
21.4	39.88509	-86.2693
21.5	39.88654	-86.2693
21.6	39.88799	-86.2694
21.7	39.88939	-86.2694
21.8	39.89085	-86.2695
21.9	39.89229	-86.2696
22	39.89378	-86.2696
22.1	39.89523	-86.2697
22.2	39.89668	-86.2697
22.3	39.89818	-86.2697
22.4	39.89957	-86.2697
22.5	39.90103	-86.2697
22.6	39.90247	-86.2697
22.7	39.90393	-86.2697
22.8	39.90537	-86.2697
22.9	39.9068	-86.2697
23	39.90823	-86.2697
23.1	39.90968	-86.2697
23.2	39.91116	-86.2697
23.3	39.91258	-86.2697
23.4	39.91402	-86.2697
23.5	39.91551	-86.2697
23.6	39.91698	-86.2697

23.7	39.91841	-86.2697
23.8	39.91982	-86.2695
23.9	39.92128	-86.2691
24	39.92275	-86.2687
24.1	39.92359	-86.2684
24.2	39.92439	-86.2682
24.3	39.92592	-86.2683
24.4	39.9276	-86.2688
24.6	39.92766	-86.2663
24.7	39.92817	-86.2652
24.8	39.92834	-86.2646
25.2	39.92749	-86.2585
25.4	39.92675	-86.2556
25.5	39.92628	-86.2538
25.6	39.92585	-86.252
25.8	39.9249	-86.2484
25.9	39.92436	-86.2463
26	39.92382	-86.2442
26.1	39.92358	-86.2427
26.2	39.9235	-86.2411
26.3	39.92353	-86.2393
26.4	39.92357	-86.2374
26.5	39.9236	-86.2355
26.6	39.92363	-86.2336
26.7	39.92367	-86.2317
26.8	39.9237	-86.2298
26.9	39.92375	-86.2278
27	39.92377	-86.2258
27.1	39.9238	-86.224
27.2	39.92383	-86.2223
27.3	39.92386	-86.2204
27.4	39.9239	-86.2185
27.5	39.92393	-86.2166
27.6	39.92396	-86.2148
27.7	39.92399	-86.2129
27.8	39.92403	-86.211
27.9	39.92406	-86.2088
28	39.9241	-86.2066
28.1	39.92413	-86.205
28.2	39.92415	-86.2034
28.4	39.92422	-86.1997

28.5	39.92425	-86.1978
28.6	39.92428	-86.1959
28.7	39.92432	-86.1938
28.8	39.92435	-86.1921
28.9	39.92439	-86.19
29	39.92442	-86.1878
29.1	39.92445	-86.1863
29.2	39.92448	-86.1846
29.3	39.92473	-86.1827
29.4	39.9253	-86.181
29.5	39.92616	-86.1795
29.6	39.92715	-86.1782
29.7	39.92825	-86.1769
29.8	39.92918	-86.1754
29.9	39.92975	-86.1739
30	39.93017	-86.1713
30.1	39.93016	-86.1697
30.2	39.93018	-86.1681
30.3	39.9302	-86.1662
30.4	39.93022	-86.1643
30.5	39.93025	-86.1624
30.6	39.93027	-86.1605
30.7	39.93027	-86.1587
30.8	39.93031	-86.1568
31	39.93033	-86.1545
31.1	39.93038	-86.1504
31.2	39.9304	-86.1488
31.3	39.93042	-86.1469
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31.5	39.93015	-86.1432
31.6	39.92982	-86.1413
31.7	39.92937	-86.1396
31.8	39.92886	-86.1378
31.9	39.92834	-86.136
32	39.9278	-86.1342
32.1	39.9273	-86.1325
32.2	39.92682	-86.1308
32.3	39.92629	-86.129
32.4	39.92578	-86.1272
32.5	39.92526	-86.1255
32.6	39.92475	-86.1237

32.7	39.92422	-86.1219
32.8	39.9237	-86.1201
32.9	39.92319	-86.1184
33	39.92267	-86.1166
33.1	39.92214	-86.1148
33.2	39.92165	-86.1131
33.3	39.92112	-86.1113
33.4	39.9206	-86.1095
33.5	39.92008	-86.1077
33.6	39.91958	-86.106
33.7	39.91909	-86.1043
33.8	39.91857	-86.1025
33.9	39.91805	-86.1007
34	39.91754	-86.099
34.1	39.91702	-86.0972
34.2	39.91652	-86.0955
34.5	39.91497	-86.0902
34.8	39.91317	-86.084
34.9	39.91269	-86.0825
35	39.91204	-86.081
35.1	39.91115	-86.0795
35.2	39.91022	-86.0781
35.5	39.90746	-86.0738
35.6	39.90653	-86.0723
35.7	39.90562	-86.0709
35.8	39.90469	-86.0695
35.9	39.90377	-86.068
36	39.90285	-86.0666
36.3	39.90008	-86.0622
36.6	39.89732	-86.0579
36.7	39.89641	-86.0565
36.8	39.89547	-86.055
36.9	39.89436	-86.0533
37	39.89314	-86.0517
37.1	39.89225	-86.0507
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37.8	39.8828	-86.0474

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38	39.88015	-86.0474
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38.3	39.87574	-86.0473
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38.5	39.87293	-86.0473
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38.7	39.87016	-86.0472
38.8	39.86873	-86.0472
39.2	39.86292	-86.0471
39.3	39.86146	-86.0471
39.4	39.86002	-86.0471
39.5	39.85852	-86.0471
39.6	39.85712	-86.047
39.7	39.85568	-86.047
39.8	39.85423	-86.047
39.9	39.85276	-86.047
40	39.85134	-86.0466
40.1	39.85	-86.0459
40.2	39.84867	-86.0452
40.3	39.84721	-86.0443
40.4	39.84587	-86.0436
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40.6	39.84337	-86.0421
40.7	39.84197	-86.0413
40.8	39.84072	-86.0406
40.9	39.83945	-86.0399
41	39.83818	-86.0392
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41.2	39.83557	-86.0377
41.3	39.83417	-86.0369
41.4	39.83276	-86.0361
41.5	39.83121	-86.0352
41.6	39.82967	-86.0343
41.7	39.82833	-86.0336
41.8	39.82698	-86.0328
41.9	39.82599	-86.0322
42	39.82483	-86.0317
42.1	39.82338	-86.0312
42.2	39.82189	-86.0311

42.3	39.81997	-86.031
42.4	39.81808	-86.031
42.5	39.81711	-86.031
42.6	39.81623	-86.031
42.7	39.81479	-86.031
42.8	39.81334	-86.031
42.9	39.81179	-86.0309
43	39.81024	-86.0309
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43.2	39.8076	-86.0309
43.3	39.80635	-86.0311
43.4	39.8051	-86.0313
43.5	39.80352	-86.0319
43.6	39.80203	-86.0328
43.7	39.8008	-86.0337
43.8	39.79952	-86.0345
43.9	39.79787	-86.0351
44	39.79614	-86.0354
44.1	39.79428	-86.0356
44.3	39.79169	-86.0351
44.4	39.79098	-86.0347
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44.7	39.78696	-86.0327
44.8	39.78554	-86.0323
44.9	39.78389	-86.032
45	39.78249	-86.0318
45.1	39.78105	-86.0316
45.2	39.77963	-86.0314
45.3	39.77825	-86.0312
45.4	39.7769	-86.0309
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45.7	39.77261	-86.0303
45.8	39.77116	-86.03
45.9	39.76961	-86.0298
46	39.76806	-86.0295
46.1	39.76665	-86.0293
46.2	39.76525	-86.0291
46.3	39.76385	-86.0289
46.4	39.76244	-86.0287

46.5	39.76091	-86.0285
46.6	39.75939	-86.0286
46.7	39.75797	-86.029
46.8	39.7566	-86.0296
46.9	39.75528	-86.0305
47	39.75397	-86.0315
47.1	39.75286	-86.0323
47.2	39.75176	-86.0332
47.3	39.7504	-86.0342
47.4	39.74905	-86.0352
47.5	39.74777	-86.0362
47.6	39.74649	-86.0372
47.7	39.745	-86.0383
47.8	39.74388	-86.0392
47.9	39.74284	-86.04
48	39.7418	-86.0408
48.1	39.74041	-86.0418
48.2	39.73893	-86.0425
48.3	39.73798	-86.0429
48.4	39.737	-86.0432
48.5	39.73558	-86.0436
48.6	39.73419	-86.0441
48.7	39.73278	-86.0446
48.8	39.73138	-86.045
48.9	39.73004	-86.0454
49	39.72872	-86.0459
49.1	39.72734	-86.0463
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49.3	39.72459	-86.0475
49.4	39.72323	-86.0482
49.5	39.72191	-86.0489
49.6	39.72058	-86.0497
49.7	39.71933	-86.0506
50	39.71532	-86.054
50.1	39.71418	-86.0552
50.2	39.71304	-86.0563
50.3	39.71191	-86.0575
50.4	39.71076	-86.0587
50.5	39.7097	-86.0599
50.6	39.70866	-86.0613
50.7	39.70772	-86.0627

50.8	39.70687	-86.0642
50.9	39.70611	-86.0658
51	39.70544	-86.0675
51.1	39.70492	-86.069
51.2	39.70448	-86.0706
51.3	39.70409	-86.0724
51.4	39.7038	-86.0743
51.5	39.70362	-86.0762
51.6	39.70355	-86.0781
51.7	39.70357	-86.0799
51.8	39.70363	-86.0818
51.9	39.70368	-86.0837
52	39.70373	-86.0856
52.1	39.70378	-86.0876
52.2	39.70383	-86.0896
52.3	39.70388	-86.0914
52.5	39.70398	-86.0952
52.6	39.70403	-86.097
52.7	39.70408	-86.0989
52.8	39.70413	-86.1008
52.9	39.70417	-86.1027

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

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