5. Discussion

5.1 Summary of Collection and Processing Times

5.1.1 Data Collection Times

The collection and processing times were recorded for each of the six large deck bridges and the accuracy assessment bridge. All of the six large deck bridges were collected over the span of four days in the field. Processing of data began shortly after completing fieldwork and is reported as a combination of person hours and computational time. The data collection of 8 Mile in Southfield, MI was completed on the first day. The next two days were devoted to travel and data collection at the two US-131 bridge decks in Grand Rapids, MI. Optical and thermal data were collected for I-75 north and southbound decks in Southgate, MI and I-696 in Hazel Park, MI on the fourth day of data collections. Because the bridges were a half hour drive from each other, data was collected for I-75 in the morning and I-696 in the afternoon. The collection started at 10:30 am on the right lane of I-75 northbound and finished on the left lane of I-696 westbound at 3:30 pm.

The amount of time needed to perform data collection per pilot study bridge is shown in Table 15. A single pass is a single collection between the beginning and end bridge joints. During the data collection on the bridges, two passes were made per lane, one on the right side of the lane and one on the left. The total collection time includes the amount of time to complete all passes, including turning around, for the whole bridge deck. For all bridge decks except for US-131, the collection started with the right side of the right lane of the north or westbound lanes. The next pass collected data from the right side of the right lane of the south or eastbound lanes. The data collection of US-131, unlike the other bridges, took two days in the field to complete. This was due to an accident in the northbound lanes, which occurred after only completing the right lane, and resulted in a backup on the northbound lanes that persisted through the prime collection hours of 9am to 4pm needed for passive thermography. The remainder of the northbound lanes data was collected the following morning. The "Average Pass per Lane" column represents the average amount of time needed to collect one lane of data with one pass over the bridge deck.

Table 15: Data collection time by bridge.

Bridge	Number of Lanes	Bridge Length (ft)	Deck Area (ft^2)	Average Time per Pass (sec)	Total Collection Time (hr)	Comments
M-102 (8 Mile)	6	1,838.40	167,662	34	0.7	
US-131 North	4	1,605.64	115,924	25	3.4	Total for US-131 *Delay due to traffic accident on bridge*
US-131 South	4	1,358.60	98,091	23		
I-75 North	3	1,938.32	95,013	31	1.3	Total for I-75
I-75 South	3	1,992.49	97,401	32		
I-696	8	670.00	102,207	14	1.6	

5.1.2 3DOBS Data Processing Time

RED Epic imagery was processed in three steps: frame extraction, geotagging, and 3D model processing. Frame extraction and model making were done through commercially available software while the frame geotagging was done through automated scripts, which were developed within MTRI. Frame extraction from the RED Epic video was completed using Adobe Premiere and involved locating the starting and ending locations of the bridge deck followed by automated frame extraction. Table 16 shows the breakdown of frame extraction times for each bridge.

Table 16: Frame extractions times by bridge.

Bridge	Average Extract per Pass (min)	Average Number of Frames	Average Size per Pass (GB)	Total Extract Time Frames (hr)	Total Frames	Total Size (GB)
M-102 (8 Mile)	49.8	1,997	10.4	10.0	23,964	124.7
US-131 North	29.1	1,471	7.46	4.9	14,719	74.6
US-131 South	22.4	1,118	5.9	2.6	7,828	41.55
I-75 North	34.8	1,554	8.32	3.5	9,327	49.9
I-75 South	93.2	1,683	9	3.9	10,098	54.07
I-696	17.7	776	4.4	4.7	12,418	70.04

The geotagging scripts greatly improved the efficiency of completing this step. While it took roughly five hours to write the scripts and test, the scripts saved a considerable amount of time during the processing. For each of the six large deck bridges, except I-696, geotagging took just over one half an hour to complete for each lane. I-696 has a shorter bridge deck and, therefore, a shorter processing time of 14 minutes per lane. Table 17 shows the breakdown of the amount of time needed to geotag the frames from the RED Epic. Geotagging times for both US-131 bridges were not processed as the project team did not record this dataset. Based on the results from I-696 and 8 Mile, which had similar deck conditions, geotagging would not have resulted in accurate reconstruction of the bridge deck.

Table 17: RED Epic frame geotagging times by bridge.

Bridge	Separating GPS by Run (min)	GPS Interpolation (min)	Locating Starting Frames and GPS Point (min)	Geotagging Frames (min)	Total Geotagging Time (hr)
M-102 (8 Mile)	60	36	180	123	6.7
I-75 North	30	18	25	35	1.8
I-75 South	30	18	25	53	2.1
I-696	80	48	65	67	4.3

After extraction and geotagging, the frames were mosaicked and georeferenced. Table 18 shows the breakdown in time for creating a mosaic for each bridge. Most of the processing time is computer-processing time. For the Photoshop correction, two hours are needed per bridge for a technician to determine the parameters for the camera orientation since camera orientation (yaw, pitch, and roll) are not recorded in the video. Manual estimations must be processed and verified on a sample set of imagery. Once obtained, parameters are entered into Adobe Photoshop and the frames are automatically corrected. This is required so that extracted frames line up and are correctly orientated to make a more accurate mosaic. The next step is represented in the "Frame Mosaic" column. This is also an automated process through scripts developed at MTRI, which mosaic all of the frames from each pass.

Table 18: Time needed to create an optical mosaic by bridge.

Bridge	Photoshop Correction (hr)	Frame Mosaic (hr)	Georeferencing (hr)	Total Time (hr)
M-102 (8 Mile)	32	3	12	47
US-131 North	24	1	8	33
US-131 South	24	1	8	33
I-75 North	16	2	9	27
I-75 South	16	2	9	27
I-696	18	1	8	27

Table 19 shows the breakdown in processing times for the Lake Nepessing Rd bridge deck. The "GPS Interpolation" and "Correcting Orientation" columns represent analyst- processing time while the other columns represent computer-processing times. The northbound Lake Nepessing lane data took longer to correct the orientation than southbound as it was the first full model to be processed using the orientation input, and resulted in a significant amount of trial and error. Once it was determined how changing the roll, pitch, and yaw values impacted the final model orientation, the amount of time needed for this step was reduced. For future data collections, the use of an Inertial Measurement Unit (IMU) could be integrated into 3DOBS. An IMU would collect roll, pitch, and yaw values as the camera is collecting data and would eliminate the need for a technician to manually estimate and correct the orientation parameters for Agisoft processing.

Table 19: RED Epic processing time for Lake Nepessing Rd. bridge deck.

Bridge Direction	Frames	Frame Extract (min)	GPS Interpolation (min)	Frame Geotag (min)	Correcting Orientation (hr)	Agisoft Processing (hr)	Total Time (hr)
Lake Nepessing North	409	50	15	10	8	2.2	11.5
Lake Nepessing South	440	37	15	10	2	3	6.0

Table 20 displays the total amount of time required to process 3DOBS data and is separated between personnel and computer processing times.

Table 20: Time required to process 3DOBS data for all study bridges split between personnel and computational time

Bridge	Deck Area (ft^2)	Total Collection Time (hr)	Extract Frames (min)	Frame Geotagging (hr)	Mosaic & Georeferencing (hr)	Orientation Correction (hr)	Agisoft Process (hr)	3DOBS Total Time (hr)
Personnel Time								
M-102 (8 Mile)	167,662	0.7	1	4	15	-	-	19.7
US-131 North	115,924	1.7	0.67	-	9	-	-	10.7
US-131 South	98,091	1.7	0.67	-	9	-	-	10.7
I-75 North	95,013	0.65	0.5	0.9	11	-	-	12.6
I-75 South	97,401	0.65	0.5	0.9	11	-	-	12.6
I-696	102,207	1.6	1.3	2.4	9	-	-	13.0
Lake Nepessing	11,721	0.3	20	0.5	-	10	0.2	31.0
Computing Time								
M-102 (8 Mile)	167,662		9	2.7	32	-	-	43.7
US-131 North	115,924		4.2	-	24	-	-	28.2
US-131 South	98,091		1.9	-	24	-	-	25.9
I-75 North	95,013		3	0.9	16	-	-	19.9
I-75 South	97,401		3.4	1.2	16	-	-	20.6
I-696	102,207		3.4	1.9	18	-	-	23.3
Lake Nepessing	11,721		1.1	0.3	-	-	5.2	6.6

5.1.3 BVRCS Processing Time

To process the BVRCS data, the initial M-102 (8 Mile) processing attempts were unsuccessful due to the GoPro Hero 3 camera settings, which were set to the incorrect date and time. Therefore, instead of only having to specify the difference in time settings between the GoPro Hero 3 cameras and Trimble GPS unit, the difference in time setting between the GoPro Hero 3 cameras and actual date and time also had to be taken into account. This was different compared to previous MDOT projects where BVRCS was used for data collection and analysis. The error significantly slowed down processing times as the correct difference in date and time between the GoPro Hero 3 cameras and GPS Trimble unit had to be determined. Once the time difference was determined, processing time was significantly lowered. This time difference also had to be calculated for the other three bridge locations. However, because the process to determine the difference was already figured out, the overall processing time was lower as compared to the M-102 (8 Mile) bridge. These times are reflected in Table 21, along with the expected time it would take if these methods were implemented into MDOT inspection procedures.

Table 21: Processing time for BVRCS

Bridge Location	Average Data Processing Time per Lane	Expected Data Processing Time per Lane if Implemented
M-102 (8 Mile)	90 minutes	25 – 30 minutes
US-131	45 minutes	25 – 30 minutes
I-75	60 minutes	25 – 30 minutes
I-696	35 minutes	25 – 30 minutes

5.1.4 Thermal Infrared Image Processing Time

Data processing for the passive thermography component of this pilot project was conducted by GS Infrastructure. Infrared Thermography images were processed in proprietary software developed by GS Infrastructure personnel. The images are manually inspected by certified ASNT-1 – Level 1 (with Level III oversight) and set-up in three steps: (1) correct configuration and overlap of the bridge elements; (2) inspection and tagging of defects in images; (3) and a separate quality review of the images. The images that are tagged as defects are then put into a client chosen CAD file and a report that is populated with automated scripts developed by the GS Infrastructure personnel. Table 22 shows the breakdown of frame extraction times for each bridge.

Table 22: Thermal IR image review times by bridge

Bridge	Configure images for review	Inspection and tagging of defects	Quality Review of Images	Average # of raw images for each lane	Average # of analyzed images for each lane
M-102 (8 Mile)	2 hr	18 hr	7 hr	250+	100+
US-131 North	1 hr	15 hr	5 hr	250+	100+
US-131 South	1 hr	12.5 hr	6 hr	250+	100+
I-75 North	1.5 hr	17 hr	5 hr	250+	100+
I-75 South	1.5 hr	16 hr	5 hr	250+	100+
I-696	2 hr	18 hr	5 hr	250+	100+
Average of six decks	*1.5 hr*	*16.1 hr*	*5.5 hr*		

5.1.5 Total Time Summary for Pilot Study Bridges

The total time documented to process, analyze, review and report the data associated with each bridge deck studied is summarized in Table 23 based on information found in Tables 15-19. The table is separated between the amount of time required for personnel hours and computer processing hours. Additionally, once the collection time was combined with the time associated to process data from each technology, the total time was divided by the total area of each bridge deck, providing the total time to process and analyze data per square foot of bridge deck. It is important to note that the total time is indicative of the processing time needed to create the optical and thermal mosaic overlays for the six large deck bridges, and does not include processing time needed to create a DEM. Because the project team was unable to process the collected 3DOBS imagery through Agisoft PhotoScan, a DEM was not produced and the imagery was mosaicked instead. Only the 3DOBS imagery collected from the Lake Nepessing bridge was fully processed through Agisoft PhotoScan which generates a DEM along with the orthomosaic layer.

Table 23: Total processing time for each bridge.

Bridge Location	Area of Deck (ft²)	Collection Time (hr)	3DOBS (hr)	BVRCS (hr)	Thermal (hr)	Total Time (hr)	Total time per ft² (sec/ft²)
				Personnel			
M-102 (8 Mile)	167,662	0.70	19.7	1.30	27.0	48.7	1.05
US-131 North	115,924	1.70	9.7*	0.55	21.0	33.0	1.02
US-131 South	98,091	1.70	9.7*	0.55	19.5	31.5	1.15
I-75 North	95,013	0.65	12.4	0.80	23.5	37.4	1.42
I-75 South	97,401	0.65	12.4	0.80	22.5	36.4	1.34
I-696	102,207	1.60	12.7	0.30	25.0	39.6	1.39
Average of six decks	*112,716*	*1.20*	*12.7*	*0.72*	*23.1*	*37.8*	*1.23*
Lake Nepessing	11,721	0.3***	20.5	-	-	20.8	6.39
				Computer			
M-102 (8 Mile)	167,662		43.7	0.20	**	43.9	0.94
US-131 North	115,924		28.2	0.20		28.4	0.88
US-131 South	98,091		25.9	0.20		26.1	0.96
I-75 North	95,013		19.9	0.20		20.1	0.76
I-75 South	97,401		20.6	0.20		20.8	0.77
I-696	102,207		23.3	0.20		23.5	0.83
Average of six decks	*112,716*		*26.9*	*0.20*		*27.1*	*0.86*
Lake Nepessing	11,721		6.6	-	-	6.6	2.03

* Geotagging times for both US-131 bridges were not recorded (see Section 5.1.2)

** Thermal IR used limited computer processing time.

*** Time required when the bridge is closed to traffic and 3DOBS is running at 5 mph

5.2 Estimating Collection and Processing Times for Future Large-deck Bridges

A representative scenario was evaluated considering a large deck bridge with six lanes and a deck length of 1,500 ft, for a total of 108,000 sf. The summary of manual labor in hours per technology and associated costs to conduct a condition assessment of the top surface of the large deck bridge are listed in Table 24. The data collection time is based on two passes per lane due to light spalling and patching similar to I-75, and includes the time needed for each pass followed by five minutes for each turn around to begin collecting data in the opposing lanes. The estimated time for data collection of all three technologies is assumed to take place simultaneously. Estimates (time and costs) related to each individual technology studied are discussed below. A charge rate of $60 per person per hour was used to estimate the total cost of personnel hours per bridge. The table illustrates for MDOT to conduct this type of condition assessment of large deck bridges, total costs are approximately $3,100 per large deck bridge (~108,000 sf) including equipment setup, data collection, processing, analysis, quality assurance and reporting. Not included in this estimate is the cost of equipment, travel to and from the site, computing time costs, and other associated consultant fees.

Table 24: Estimated personnel hours and cost per future large deck bridge condition assessment.

Task	BVRCS Time (hr)	Thermal IR Time (hr)	3DOBS Time (hr)	Total Time (hr)	Cost (at $60/hr)	Comments
Equipment Setup	0.25	0.25	0.25	*0.75 x 2*	$90	Two inspectors
Data Collection	-	-	1.00	*1.00 x 2*	$120	Two inspectors, simultaneous data collection
Data Processing	0.50 (0.20)*	1.50 (**)	3.55 (94.7)*	*5.55*	$334	
Data Analysis	3.0	16.1	8.0	*27.1*	$1,626	
Quality Assurance	1.0	5.5	4.0	*10.5*	$630	
Reporting Results	1.0	2.0	2.0	*5.0*	$300	
Total	5.75	25.25	20.25	*51.65*	**$3,100**	

* value in parentheses indicates computing time (in hours) and is not included in total costs.

** Thermal IR used limited computer processing time.

Each technology was evaluated in Table 24 for personnel hours and computing hours. BVRCS analysis, quality assurance, and reporting results times are similar to the times experienced during these tasks for the six bridge decks studied in this project. BVRCS data processing time from Table 21 is included. Given that the six large deck bridges studied averaged 113,000 sf and the estimated future deck size is 108,000 sf, hours in Table 24 related to Thermal IR are averages for the six decks in Table 22 plus time for set-up and reporting.

Considering the estimates related to the 3DOBS technology in Table 24, the Agisoft processing time is estimated from the data processing method used on Lake Nepessing Rd and is expected to take the analyst less set up time to process 3DOBS data because most of the estimated processing time is computer time. Agisoft processing was completed on a desktop computer with two Intel Xenon 8-core processors, 128 GB of RAM and a NVIDIA Quadro K4000 video card with 2 GB of memory. Table 25 shows the breakdown of the total time needed to process full models of each direction of travel. The total time needed for an analyst is about 3.55 hours which includes setting up the data processing to run as well as separating the GPS by pass data, locating the starting frames and GPS points, and correcting the orientation. This estimated time is down from 12.7 hours averaged for the 6 pilot study bridge. The total amount of time needed for computer processing is 94.7 hours, up from the average of 26.9 hours reported in Table 23. It is therefore estimated that the total processing time for one analyst on a single computer to complete a DEM and orthoimage of each travel direction is approximately five days. However, the project team anticipates that significantly less time would be needed using cloud-based processing, the direction commercial close-range photogrammetry software is heading for more rapid production of processed results.

Table 25: Estimated time to process 3DOBS data from a future bridge data collection.

Extract per Pass (min)	Total Extract Time Frames (hr)	Separating GPS by Run (min)	GPS Interpolation (min)	Location Starting Frames and GPS Point (min)	Frame Geotag (min)	Correcting Orientation (hr)	Agisoft Processing (hr)	Total Processing Time (hr)
27 (C)	5.4 (C)	45 (P)	12 (C)	24 (P)	66 (C)	2 (P)	88.4 (C/P)	98.25

(P) = personnel hours; (C) = computing hours

Also for the 3DOBS technology, almost two full days are needed to generate the full DEM and orthoimage of each travel direction of the bridge using the MTRI computers. Most of the Agisoft processing time is devoted towards the point cloud densification. In this step, Agisoft takes the sparse point cloud model and calculates additional model points based on the image alignment. There are several settings as to how “dense” the point cloud is to be generated. The setting, which is used for Lake Nepessing and this example is the medium setting, which is roughly half the resolution of the input imagery. The highest setting will result in a DEM with the same resolution of the input imagery but it would take significantly longer to process. Using the current 3DOBS setup and the “medium” setting in Agisoft, the resulting DEM will have a resolution of about 1/8 in.

Table 26 shows the estimated time needed to collect the data per technology per lane and for the entire bridge. Also estimated is the file size necessary for data storage for each respective remote sensing technology. The listed times include the time needed for each pass followed by five minutes for each turn around to begin collecting on the opposing lanes.

Table 26: Estimated future data collection time and data storage needs for a future large deck bridge.

System	Time by Lane (sec)	Total Collection Time (hr)	File Size by Lane (GB)	Total File Size (GB)
BVRCS	25	1.0	0.30	3.7
Thermal IR	25	1.0	0.237	2.84
3DOBS	25	1.0	2.70	32.4

5.3 Project Outreach - MDOT General Training Session

MDOT traveled to MTRI in Ann Arbor, Michigan on January 21, 2016 for a demonstration and training session of the 3DOBS and BVRCS systems. Attendance included multiple MDOT personnel and the Michigan Tech / MTRI project team members (Figure 47). The meeting began with a brief PowerPoint presentation overviewing project’s objectives, 3DOBS and BVRCS data collection systems, and sample raw and processed data and imagery collected from the six big bridge decks visited during the Fall 2015 field data collections. The PowerPoint presentation was purposely kept brief as to allow more time for live demonstrations of the data collection platform and technology. Appendix B includes handouts from the training session.

Figure 47: MDOT and Michigan Tech project members in attendance at the demonstration and training session.

After the presentation, MDOT was led to a local Ann Arbor Area Transit Authority (AAATA) "Park and Ride" center, located at intersection of Plymouth Road and US-23, less than one mile away from the MTRI office building. While at the AAATA "Park and Ride" center, MTRI set up 3DOBS and placed the BVRCS GoPro Hero3 cameras on the hood of the data collection vehicle to demonstrate the simplicity of setting up the platform, a process that took about five minutes (Figure 48). After the platform and sensors were assembled, MTRI personnel drove across the Plymouth Road bridge over US-23 (MDOT Structure ID 10873). MTRI drove across the bridge enough times to collect 3DOBS and BVRCS data for each of the bridge's four lanes (Figure 49). During the collection, MDOT personnel stood alongside of the road and observed how quickly bridge condition data was collected using these two systems. After completing the data collection, MTRI disassembled 3DOBS and BVRCS at the AAATA "Park and Ride" while also answering questions that MDOT personnel had after observing the live data collection demonstration.

Figure 48: MTRI setting up 3DOBS and BVRCS at the AAATA “Park and Ride”.

Figure 49: 3DOBS and BVRCS being driven across the Plymouth Road bridge for the data collection demonstration.

Upon returning to MTRI’s office, a live data processing demonstration was given to MDOT in MTRI’s GIS laboratory. During the data processing demonstration, four computers in the GIS lab were set up to demonstrate various data processing techniques and outputs associated with 3DOBS and BVRCS. MDOT personnel were split into two groups, and were given a short five minute presentation at each station, including processing steps required to build a 3DOBS composite image, 3DOBS spall and delamination detection and output, GS Infrastructure thermal delamination GIS output, and BVRCS outputs (Figures 50, 51, and 52). The data used for these demonstrations were a subset of the data collected during the Fall 2015 field data collections which eliminated the processing time necessary to obtain output from data captured minutes earlier during the live demonstration. MDOT personnel were able to ask questions while watching the live data processing procedures, in which MTRI project team members were able to answer through the live data processing demonstrations. Project progress and further questions or concerns were addressed before the conclusion of the meeting.

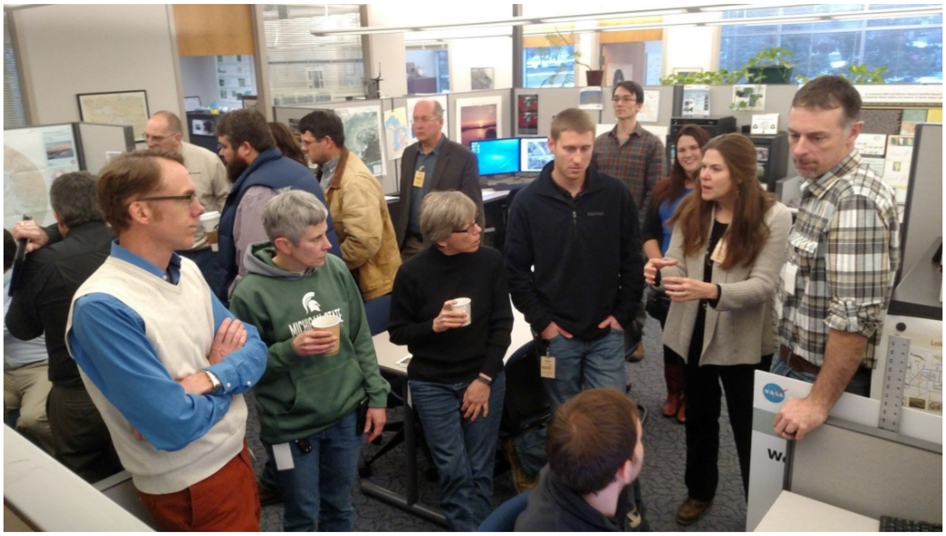

Figure 50: Project Principle Investigator, Professor Tess Ahlborn, providing insight into data processing and outputs.

Figure 51: MTRI project team member, Rick Dobson, providing an overview of 3DOBS imagery processing and output.

Figure 52: MTRI project team member, David Banach, providing an overview of BVRCS imagery processing and output.

6. Conclusions

6.1 Conclusions from the Study

This research project investigated NDE technologies, specifically remote sensing technologies including photogrammetry and thermography, for deployment at near highway speeds to assess the top surface condition of large concrete bridge decks. Several non-destructive technologies validated in previous projects were combined on the same data collection vehicle including 3DOBS, passive infrared thermography, and BVRCS, as an integrated system for condition assessment of the top surface of concrete bridge decks. Integrated data sets can lead to more effective asset management decisions through a more thorough understanding of deck condition.

The 3DOBS system was previously upgraded to a near highway speed version capable of allowing the collection vehicle to travel at speeds up to 45 mph with a high-resolution camera capable of detecting spalls at this speed. The RED Epic was chosen for near highway speed data collections due to its ability to collect 13.8 MP imagery at up to 60 fps. This project successfully demonstrated that distress features such as spalls and delaminations could be detected and quantified at near-highway speeds, on large deck bridges (>95,000 sf) without the need to close traffic lanes. Due to the relatively good condition of the large bridge decks studied (i.e. minimal spalling), full reconstructions of the large-deck bridges were not possible. With enhanced Agisoft processing techniques, sections of the I-75 bridges and the entire Lake Nepessing Road bridge (both of which contained numerous spalls) could be achieved and were demonstrated near the project's end.

When 3DOBS was combined with passive infrared thermography on the same vehicle mount, both surface and subsurface conditions were assessed with a single pass per lane. Optical and thermal datasets were referenced to the same coordinates and viewed in GIS such as ArcMap. The creation and use of separate GIS data layers generated from the collected imagery was successfully demonstrated, including an orthoimage, digital elevation model DEM, Hillshade of the DEM, thermal mosaic, detected spalls layer, and potential delaminations layers. A combination of these layers would enable MDOT to perform change detection analysis on the distresses and provide objective data to generate NBI ratings for the bridge deck (based on deck surface element defect quantification and location information collected).

BVRCS has again proven to be a low cost, valuable tool for collecting a high-resolution photo inventory of bridges providing information to inspectors and agencies. The GeoJot+ software allows for the creation of shapefiles consisting of interpolated points corresponding to the location each photo was captured. Each point was linked to a watermarked version of the collected photo that can be displayed in ArcMap or Google Earth.

Separately, the three technologies demonstrated in this pilot project provide MDOT with a more detailed understanding of bridge deck condition. When combined, these three technologies would ensure MDOT could conduct bridge deck inspections while keeping inspectors safe and are unexposed to traffic (i.e. walking along traffic shoulders), as well as eliminating the need to close down lanes and passing the time savings onto the traveling public.

The total time needed to complete the processing of the large deck bridges during this study was reported in Table 23, and averaged 37.6 personnel hours and 27.1 computing hours. From this analysis, the average amount of personnel time needed to complete a large deck bridge was 1.23 sec/ft^2. Cloud-based processing should significantly shorten this processing time in the future. Future data collections on bridges with spalling similar to the I-75 bridges can be processed through Agisoft PhotoScan to generate an orthoimage and DEM, reducing personnel time while increasing computing time. This supplies the end user with spall depth information and most of the 3DOBS processing time is computer time as opposed to the mostly manual methods used to derive final products for the six large deck bridges.

Considering a representative large deck bridge of 108,000 sf and a condition similar to that of the I-75 bridge decks, an estimate of personnel hours, associated costs, and computing time was determined to be $3100 per large deck bridge (Table 24). The estimate includes equipment setup, data collection, data processing, data analysis, quality assurance review and reporting of results for the three remote sensing technologies considered. The estimate does not include the cost of equipment, travel to and from the site, computing time costs, and other associated consultant fees.

The condition state tables in Section 4.3.6 show the ability to not only identify, spatially locate, and quantify distress features such as spalls and delamination along the bridge deck, but also the ability to separate these features by span and assign condition ratings. By using the Michigan Bridge Element Inspection Manual, which defines the quantitative measurements of distress features by condition state, the analysis was able to indicate the condition state of distress features and spans for the six bridges. Each of the six bridges only had spans that were overall within the “fair” and “poor” states due to the fact that each span had some type of distress feature. “Severe” span condition states were not identified during this analysis due to the lack of severe distress feature damage to any of the bridge decks. Overall, the ability to define the condition state of both the distress features and spans provided visualizations that could potentially help a bridge inspector quickly determine the condition of distress features and spans along a bridge deck. Additionally, through periodic inspections of the bridge deck, the condition states could quickly be updated in the GIS (in which these visualizations are based) to reflect the current condition of the bridge deck.

A general training session was held to provide MDOT inspectors and end users the tools and knowledge to use the presented non-destructive remote sensing technologies for effective asset management. Hands-on equipment demonstrations allowed attendees to have one-on-one discussions with researchers on the use, costs, and benefits of the technologies. Additionally, a live demonstration of data collection procedures was conducted on a sample bridge, allowing MDOT personnel to experience firsthand how quick data collection occurs. The training session confirmed that bridge inspectors are interested in using advanced technologies for routine, detailed and scoping inspections.

6.2 Recommendations for Further Research

Combining remote sensing technologies to assess the condition of a concrete bridge deck has been shown to be very useful to enhance bridge inspection. As the performance of cameras continues to advance, additional health indicators or condition state will be detectable. It is strongly recommended that MDOT keep abreast of changes in technology through additional interactions with the project team, especially as faster, less expensive camera models are released and secure cloud-based imagery processing becomes more practical.

The use of unmanned aerial vehicles (UAVs) for condition assessment has a growing popularity. Remote sensing technologies, including optical, thermal, and LiDAR, have been successfully demonstrated to MDOT through other research opportunities ("Evaluating the Use of Unmanned Aerial Vehicles for Transportation Purposes", 2013-067, No. 1, OR13-008, led by PI C. Brooks). Combining UAVs with the data fusion and common platform for technologies can enhance inspection for bridge decks, superstructures, and other transportation infrastructure. Pilot studies are recommended to demonstrate the optimal use of UAVs for condition assessment of bridge decks, in relation to vehicle-based and manual assessment, building from MDOT's recent research investment in this area. During this project's period of performance, the Michigan Tech Research Institute successfully applied and was selected for Phase II of the "Evaluating the Use of Unmanned Aerial Vehicles for Transportation Purposes" research project. Conclusions and lessons gained from this research project will likely be applied to the Phase II project.

As experts in remote sensing applications for transportation infrastructure, the project team is available to assist MDOT with their future research needs in an area of rapidly changing technology. Data processing techniques for assessment of a variety of health indicators are yet to be developed and can be applied to a host of situations including evaluation of steel and timber superstructures and substructures. Future research could address these additional bridge types and construction materials.

6.3 Recommendations for Implementation

An Implementation and Action Plan (IAP) is based on the IAP developed for the first funded phase of this project, with updates based on an extended phase focused on deploying the integrated vehicle-based sensing tools over six large bridges and detailed accuracy evaluation of 3DOBS. This updated IAP is meant to direct the RAP and other interested MDOT personnel in applying changes within the department's policies and/or practices. Recommendations on how MDOT can incorporate vehicle-based NDE remote sensing technologies for bridge condition assessment are also provided. The plan is included in Appendix D.

BVRCS, a system shown to provide high resolution imagery using GoPro cameras to discern spalls and patchwork on a concrete deck while traveling at 45 mph and above, is near ready for deployment. The system is commercially available and low cost (less than $1000), and can provide an assessment method comparable to visual inspection in a very short time. The system was demonstrated during the demonstration session held at the MTRI in Ann Arbor. It is recommended that MDOT begin with introducing the system into one region for all upcoming inspections. Inspectors will quickly learn the system operation and gain the benefit of having a high-resolution geotagged photo inventory of the bridge deck collected while travelling at highway speed without traffic interruption.

Top of deck evaluation at near highway speed can also include the detection of spalls, cracking, and suspected delaminations by combining 3-D photogrammetry and thermography data collections. By demonstrating and deploying the combined systems at near highways speeds for six large bridges, MDOT now has access to a system that can collect optical and thermal data for assessing the location and size of spalls and potential delaminations at speeds of 45 mph. The 3DOBS technology used for spall detection did encounter a technological challenge where bridge decks in good or excellent condition (with few or no spalls) did not have sufficient surface height diversity to create a 3D model of the entire large bridge decks. However, a mosaicked, georeferenced image map of the bridge could be created, the thermal data could be referenced to it, and a GIS layer of potential delaminations from GS Infrastructure's thermal system could be overlaid on these data. A data processing breakthrough was reached late in the project so that bridge decks that did have significant spall defects could be processed into a 3D data set for automated spall detection. As part of this breakthrough, full 3DOBS assessment (using Agisoft to process 3D models of the bridge deck) should be used for bridge decks with known spalling distresses, which would allow for 3D model reconstruction. For bridges with minimal or no spalling, mosaicking the collected 3DOBS imagery has been shown to be effective in creating base maps for other datasets and manual inspection of the deck surface. It is recommended that these remote sensing technologies be integrated to the bridge inspector's suite of tools for inspection. Capital investment in equipment, training of inspectors, and coordination with the MDOT Design Survey office are necessary for implementation.

Common to the implementation of all these technologies, is the tough question that MDOT must assess thoroughly to fully understand the path to implementation. How will these data be used? Based on this project's results, the project team strongly believes that MDOT can now collect bridge deck condition data without need to close traffic lanes, extended phase findings to understanding if processing time and lack of complete 3D data set for good bridges still meet the agency's condition assessment needs, and use BVRCS to retrieve StreetView-style imagery whenever needed for bridges. MDOT can decide on collecting these data in house, and on making these combined methods an option for their contracted third-party inspection services for spall and delamination data. The value added to MDOT now includes an understanding of the limits of 3D optical technology for large bridge decks, especially those in good condition with few spalls, and big bridges (or essentially any bridge) do not require traffic closures for the collection of data. Traffic escort vehicles may still be a good idea as traveling at near-highway speeds (i.e. 45mph) still disrupts traffic flow patterns. Lastly, MDOT now has access to a professional grade, high resolution, high frame rate camera it can deploy and/or further evaluate, along with other technologies it can implement in daily bridge deck evaluation.

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Appendices

Appendix A: List of Acronyms, Abbreviations, and Symbols

3DOBS – 3-D Optical Bridge-evaluation System

AAATA – Ann Arbor Area Transit Authority

BVRCS – Bridge Viewer Remote Camera System

DEM – Digital Elevation Model

EXIF – Exchangeable Image File format

FLIR – Forward Looking Infrared Radiometer

FPS – Frames per Second

FOV – Field of View

GIS – Geographic Information System

GPS – Global Positioning System

IAP – Implementation Action Plan

IMU – Inertial Measurement Unit

MP – Megapixel

MTRI – Michigan Tech Research Institute

NBI – National Bridge Inventory

NDE – Non-Destructive Evaluation

RAP – Research Advisory Panel

SSD – Solid State Hard Drives

UAV – Unmanned Aerial Vehicles

Appendix B: Training Session Handouts

3-D Optical Bridge Evaluation System (3DOBS) and
Bridge Viewer Remote Camera System (BVRCS)
Live Demonstration and Training Session
Michigan Tech Research Institute (MTRI), 3600 Green Ct., Ste. 100, Ann Arbor, Michigan
Lake Superior Conference Room
Thursday, January 21, 2016; 9am – 11am

9:00am – 9:30am: Introductions and Overview of 3DOBS and BVRCS Equipment (at MTRI)

- Lake Superior Conference Room, MTRI

9:30am – 9:40am: Drive to Demonstration Bridge (Plymouth Road at US-23)

- For the demonstration, we will drive to the nearby Plymouth Road "Park and Ride"

9:40am – 10:00am: Live 3DOBS and BVRCS Demonstration

10:00am – 10:10am: Return to MTRI

10:10am – 10:50am: Live Data Processing and Data Output Demonstration

- MTRI GIS Laboratory

10:50am – 11:00am: Questions and Wrap-up

- Lake Superior Conference Room, MTRI

For further information or assistance, please contact:
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MDOT Project #: OR10-043, Auth. No.7, R1-R4

Evaluation of Bridge Decks using NDE at Near Highway Speeds for Effective Asset Management

Michigan Tech Transportation Institute · Michigan Tech Research Institute · GS Infrastructure

3DOBS Training Session
Thursday, January 21, 2016
Ann Arbor, MI

MDOT Department of Transportation

1

Today's Outline

- Introductions
- Overview of 3DOBS and Equipment
- Data Collection Live Demonstration
- Data Output and Processing Demonstration
- Q & A

2

Project Objectives

- Demonstrate the capabilities of combined thermal and optical imaging at near highway speeds for condition assessment of large deck bridges.
- Demonstrate the accuracy of 3DOBS optical imaging for assessment of spalls and cracking on bridge decks.

Tasks

1. Prep and Data Collection for Large Bridge Decks
2. Data Processing and Condition Assessment
3. Accuracy Assessment for 3DOBS optical imaging
4. Impacting Technology Transfer
5. Final Reporting

3

3DOBS Highway Speed Spall Detection

- Red-EPIC camera system
- 13.8 MP up to 60 frames per second
- $30,000 for the camera and its components

4

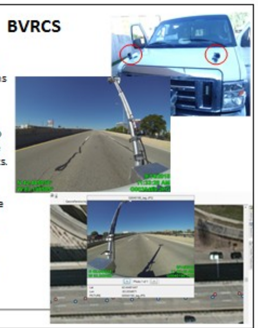
BVRCS

- GoPro HERO3
- 12 Megapixel photo capability
- Lightweight, camera: 74g (2.6 oz) and camera with housing: 136g 4.8 oz)
- Up to 12 frames per second at 8.8 MP
- $300 - $400

5

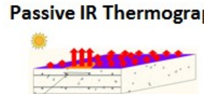
BVRCS

- Low cost (<$1,000) deployable system that provides visual analysis of bridge deck conditions at the time of data collection.
- Consists of two GoPro Hero3 cameras that can be mounted to any vehicle and used at multiple sites without any additional costs.
- Images are processed and geotagged through GeoJot+ Core
- Hyperlinks are set up using both ArcMap and GeoJot+ Core capabilities allowing for visualization of the condition of the bridge deck at defined locations



6

Passive IR Thermography (GS Infrastrucutre)



Delamination

- Sun provides thermal impulse
- Heat transfers from surface to concrete interior
- Delaminations restrict heat transfer and appear as hot spots on thermal images during daytime hours
- Maximum contrast occurs during specific testing time window

7

8 Mile

- Data collected on September 14, 2015

8

I-75 at Goddard

- Data collected on September 17, 2015

I-696 at I-75

- Data collected on September 17, 2015

US-131 at Grandville – Grand Rapids

- Data collected on September 15-16, 2015

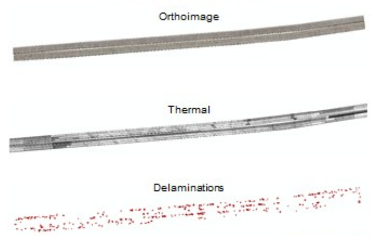
Passive IR Thermal into GIS

- Thermal Infrared data provided by GS Infrastructure
- Using ArcGIS software, MTRI georeferenced and mosaiced these data.
- These data can now be combined with other geospatial datasets (spall detection from 3DOBS).

NDE Technology Integration for Top of Bridge Deck

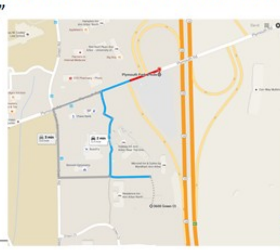
- All collected data and results are either GIS rasters or shapefiles and can be easily displayed and overlaid in a GIS.
- Data and Results Output:
  - Orthoimage
  - Thermal Image Mosaic
  - Detected Spalls Layer
  - Detected Delaminations Layer

8 Mile Datasets



Data Collection Live Demonstration

- Please park at the Plymouth Road "Park and Ride"



Data Output and Processing Demonstration

- MTRI GIS Lab
- Each station in the GIS lab will demonstrate the data processing and output for the following technologies:
  - 3DOBS Composite Image
  - 3DOBS Spall and Delamination Detection and Output
  - GS Infrastructure Thermal Delamination GIS Output
  - BVRCS

Other Questions or Concerns?

Michigan Tech
Create the Future

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Appendix C: Lake Nepessing Field Data Sheets

ID	Feature Type	Length	Width	Depth
JS-1	spall	6.75	4.75	1.00
JS2	spall	2.25	1.25	.75
JS3	spall	6.5	4.25	.75
JS4	patch	32.25	17.5	
JS5	spall – rebar	20.5	12.0	2.25
JS6	spall	6.0	4.25	.75
JS7	spall	7.5	3.25	.75
JS8	spall	2.0	2.0	.5
JS9	patch	11.5	7.0	
JS10	spall	6.25	3.25	.5
JS11	spall	9.5	6.0	.75
JS12	spall	8.25	3.0	.5
JS13	spall	9.25	8.25	1.0
JS14	spall	13.5	29.5	2.25
JS15	SPALL	7.0	2.75	.75
JS16	SPALL	27.0	10.0	2.00
JS17	SPALL	17.0	3.00	.75
JS18	SPALL	17.0	7.25	1.25
JS19	SPALL	10.0	3.75	1.0
JS20	PATCH	16.0	6.75	

ID	Feature Type	Length	Width	Depth
JS21	SPALL	6.50	2.50	.50
JS22	SPALL	3.50	2.00	.50
JS23	PATCH	23.50	13.00	
JS24	SPALL	14.00	6.00	1.25
JS25	SPALL	18.50	10.25	1.50
JS26	SPALL	13.25	4.00	1.00
JS27	SPALL	16.00	5.50	2.25
JS28	SPALL	11.75	5.25	1.25
JS29	SPALL	13.50	7.50	1.75
JS30	SPALL	16.50	10.50	1.50
JS31	SPALL	16.25	4.50	1.50
JS32	SPALL	12.25	4.50	1.00
JS33	SPALL	17.00	6.00	1.50
JS34	SPALL	13.75	4.00	2.00
JS35	SPALL	5.00	2.50	0.50
JS36	SPALL	6.5	2.25	1.0
JS37	Spall	3.75	6.25	1.0
JS38	Spall	5.5	3.25	1.25
JS39	Spall	20.0	12.5	1.75
JS40	Spall	13.0	4.5	1.0
JS41	Spall	10.75	4.5	1.25

ID	Feature Type	Length (cm)	Width (cm)	Depth (cm)
LN1	Spall	11.5	8.2	1.7
LN2	Spall	16.8	13	2.9
LN3	Spall	27.1	11.6	1.6
LN4	Spall	11.6	9.4	2.2
LN5	Spall	35.8	15.2	3.7
LN6	Patch	16.6	12.5	X
LN7	Spall	18.4	7.8	2.1
LN8	Spall	17.2	10.7	2.0
LN9	Spall (w/ patch)	18.0	10.0	1.8
LN10	Spall	26.5	12.3	2.5
LN11	Spall	14.0	11.1	2.2
LN12	Spall	24.2	12.3	2.6
LN13	Spall	21.6	9.7	1.8
LN14	Patch	22.0	16.9	X
NL15	Patch	23.5	7.5	X
LN16	Spall (in patch)	34.4	3.4	1.4
LN17	Spall (in patch)	10.2	10.1	1.0
LN18	Patch	40.3	35.2	X
LN19	Spall	11.6	7.6	1.6
LN20	Spall	29.6	18.1	2.1
LN21	Spall	59.5	33.4	5.8
LN22	Spall	26.5	8.6	1.5

2/23/13 Lake Napising lanes C/D dal IFES/EKS

ID	Feature Type	Length cm	Width cm	Depth cm
LN23	Spall	12.2	9.7	1.4
LN24	Spall (in spall in patch)	38.1	6.9	2.5
LN25	Spall	27.6	7.2	2.5
LN26	Spall	17.3	6.3	1.8
LN27	Spall	32.6	8.2	2.5
LN28	Spall (in patch)	48.6	20.0	1.9
LN29	Spall	10.2	6.5	1.1
LN30	Spall	10.1	9.5	2.0
LN31	Spall (in patch	17.8	9.5	1.9
LN32	Spall (in patch)	19.2	5.7	1.3
LN33	Spall (in patch)	15.2	11.2	1.6
LN34	Spall (in patch)	72.6	30.5	4.5
LN35	Spall	53.1	28.1	4.8
LN36	Spall	19.7	8.5	2.2
LN37	Spall	19.6	11.5	2.7
LN38	Spall in patch	24.8	9.4	2.0
LN39	Spall	17.0	10.4	1.8
LN40	Spall	21.2	9.0	2.7
LN41	Spall	67.0	32.8	4.7
LN42	Spall	32.2	21.6	2.8

2/23/2016 Lake N

Lanes A/B Dal | CESIE KLS

Appendix D: Implementation Action Plan

This implementation action plan (IAP) is based on the IAP developed for the first funded phase of this project, with updates based on an extended phase focused on deploying the integrated vehicle-based sensing tools over six large bridge decks and detailed accuracy evaluation of the 3DOBS technology. This updated IAP is meant to direct the Research Advisory Panel and other interested MDOT personnel in applying changes within the department's policies and/or practices. This guide provides an overview of the extended phase of the project and the problems it focused on changing. The outcomes and potential values to MDOT are reviewed. Recommendations on how MDOT can incorporate vehicle-based NDE remote sensing technologies for bridge condition assessment are also provided.

Project Title: *Evaluation of Bridge Decks using Non-Destructive Evaluation (NDE) at Near Highway Speeds for Effective Asset Management – Pilot Project (RC-1617B)*

Project Number: Contract no. 2010-0295, Auth. No. Z7, Rev. No. R4, Research no. OR10-043

Principal Investigator: Theresa (Tess) M. Ahlborn, Michigan Technological University

Project Manager: Eric Burns, MDOT

Research Manager: Michael Townley, MDOT

Description of Problem

The first phase of this project evaluated mobile (vehicle-based) optical and thermal remote sensing technologies in comparison to traditional bridge assessment techniques, such as coring, chain drag, etc. (Ahlborn and Brooks, 2015). The project demonstrated that optical and thermal sensors combined on a near highway-speed vehicle-based system could be used to collect data on spalls, potential delaminations, and cracking on a practical basis. This phase focused on deploying the combined systems (thermal Infrared and 3DOBS) at near highways speeds for six large concrete bridge decks selected by MDOT (deck area > 90,000 sf), using GS Infrastructure Inc.'s data collection van. MDOT, and their contracting condition assessment companies, now have access to a system that can collect optical and thermal data for assessing the location and size of spalls and delaminations at speeds of 45 mph. The BridgeViewer Remote Camera System (BVRCS) was also deployed to collect location-tagged bridge deck photo inventories with an inexpensive dual camera plus GPS system.

The 3DOBS technology used for spall detection was compared to field hand measurements to evaluate accuracy. A technological challenge was encountered where bridge decks in good or excellent condition (with few or no spalls) did not have sufficient surface height diversity to create a 3D model of the entire large bridge deck. However, a mosaicked, georeferenced image map of the bridge could be created, the thermal data was referenced to it, and a GIS layer of delaminations from GS Infrastructure's thermal system was overlaid on these data. A data processing breakthrough was reached late in the project so that small areas of high-quality bridge data that did have spall defects could be processed into a 3D data set for automated spall detection.

A training session showed a representative 3DOBS data collection process, including GIS lab processing methods, and received positive feedback from MDOT. Included was a depiction of spalling and delamination amounts by condition class and by bridge deck section, showing how these can be depicted graphically within a GIS.

Major Discoveries:

For this second (pilot project) phase (Revision No. R4), results showed that optical and thermal technologies could be deployed for large concrete bridge decks at near highway-speed, with certain technological limitations. These data can be summarized in a map-based and table-based element level summary with percentage and area by condition state and by span.

3DOBS was successful for finding spalling for small areas with defects on otherwise good bridges, but was not able to create a complete 3D surface for entire large bridge decks when used at near-highway speed with the RED Epic camera. However, the team developed an alternative mosaicked, georeferenced GIS output that served as a base map for referencing the thermal output and detected delaminations. Spalls could be manually digitized off this base map if 3D reconstruction was not possible for an area with these distresses. These data could be collected at a near highway speed of 45 mph with the RED Epic camera, with no need to close traffic. Processing time was still significant, but operational use is expected to be lower, especially as computing power continues to increase.

For passive thermography, a GIS output layer of delaminations, as suggested by the GS Infrastructure system, could be created for entire bridge deck and collected at the same time, from the same mount, as the 3D optical data. A thermal infrared combined GIS layer could be created, and these systems, set to a common coordinate system (such as Michigan Georef, or the locally appropriate State Plane system), are available for integrating into CAD software as well.

The combined data of spalls and delaminations could be summarized in condition state tables with areas and percentages, which are data needed for element-level inspection reporting. These data can be represented as either summary tables, or as map-based outputs that show condition state by spans, and/or for each detected spall or delamination.

The BVRCS tool was able to create comprehensive GPS-tagged photo inventories of the large concrete bridge decks, to serve as a "StreetView" style system that can be updated as needed by MDOT, rather than having to rely on Google updates. It is necessary to be aware of the with date/time camera settings on the BVRCS cameras (such as the GoPro units that were used) to easily match to GPS track data needed for geopositioning. A dedicated inexpensive (<$500) GPS unit can be helpful in obtaining the needed track data.

How the Information will be used in MDOT:

These results demonstrate that MDOT can reasonably collect bridge deck condition data without the need to close traffic lanes. Passive thermography data, 3D optical data, plus GPS-tagged and easily updated photo inventories can be created and used as part of bridge inspections. These data track changes over time as well, as future condition inventories can be overlaid on top of previous ones, which is useful for deterioration tracking and modeling. MDOT can use these pilot project findings to understand if processing time and lack of complete 3D data set for good bridge decks still meet the agency's condition assessment needs. As camera technology improves, the answer will go from an "initial" yes to a "firm" yes. For example, the newer RED Dragon camera has a 19 mp sensor capable of 100 fps, versus the older RED Epic system with 13.8 mp at 60 fps; this improves the ability to do 3D reconstructions at faster speeds, while potentially adding crack detection.

As noted in the previous phase final report, BVRCS is ready to use now, with its inexpensive hardware setup. MDOT can get readily updated StreetView-style imagery whenever needed. This can also serve as a location-tagged record of the bridge environment that can be useful to track change over time.

Based on these project results, MDOT can now decide on collecting these data in house, and on making these combined methods an option for third-party companies that provide inspection services on a contractual basis. If MDOT expects these companies will provide numeric data on amount and location of spalls and delaminations, especially as part of element-level inspections, then the combined 3DOBS plus thermal data collection methods are likely to make business sense as a service.

With these technologies, MDOT now has options other than physically sounding a bridge deck with lanes closures to determine delamination areas and spalls. MDOT could use these technologies (thermal infrared, 3DOBS, and BVRCS) to determine bridge deck condition states, defect quantities, and defect locations without adversely impacting traffic. The decision to use these technologies may be made at the MDOT region level or at the MDOT Central Office. The MDOT Region Bridge Engineer may elect to use to all or some of the technologies on a corridor project with high volume interstates routes structures with traffic control restrictions. The Region Bridge Engineer may also elect to use the technology on an “as needed” basis to supplement staffing shortages. MDOT Central Office may elect to use the technology as part of detailed scoping of a big bridge deck project or as part of a detailed scoping of interstate corridor projects as well.

Value Added to MDOT:

The tools, methods, and results described in this report provide several added value options that MDOT can now more easily take advantage of. First and foremost, these systems can provide high-quality data on concrete bridge deck condition at near highway speed without the need to close traffic lanes. The methods are repeatable, providing a valuable data set that can now be used to track location-specific change over time. Because the 3D optical and thermal outputs are location-specific, quantitative data, element level condition states by span can easily be calculated and visualized in tabular and map-based formats. The inexpensive BVRCS tool has a well-defined methodology with location-tagged photos that integrate well with other sources of inspection data. These data have the capability to be visualized on new 3D bridge inspections, such as the 3D BRIDGE app currently undergoing second-phase development.

Through this applied research, MDOT has improved understanding of the strengths and limitations of 3D optical technology. Large bridge decks with few spalls provide a challenge to 3D optical sensing that an active system, such as laser scanning, may not experience when creating complete 3D maps of bridge decks. However, improving fast frame rate cameras with decreasing costs may provide a solution to this issue. 3DOBS provides a georeferenced imagery set even when complete 3D imaging is not technically possible.

MDOT now has access to another way of collecting bridge deck condition data that does not require closure of the bridge. Some traffic control, in the form of an escort vehicle may still be need, if the current deployment speed of 45 mph would cause traffic problems. Newer, faster high-frame-rate cameras should push data collection speeds past 45 mph, with 60mph seeming reasonable with the newest commercially available systems.

It should be noted that as a result of this project, MDOT owns a professional grade, high resolution, high frame rate camera to deploy and/or further evaluate as needed. Transfer of the Red

EPIC camera to MDOT was completed in May of 2016. MDOT should ensure that it exploits the availability of this system to obtain maximum value out of its investment through continued usage on a regular basis.

Implementation Plan Checklist:

The following checklist provides a summary for MDOT on understanding the types of results achieved through this project and the items and actions necessary to implement the results. It is similar to the Phase I report, except that we are concluding this particular research program.

Results achieved through this research (check all that apply)		Items/Actions needed to implement results (check all that apply)	
X	Knowledge to assist MDOT	X	Management decision
	Manual change	X	Funding
	Policy development or change	X	Training
X	Development of software/computer application	X	Information technology deployment
X	Development of new process	X	Information sharing
	Additional research needed		Other (specify)
	Project produced no usable results		
	Other (describe)		

References:

Ahlborn, T.M., and C.N. Brooks, 2015 "*Evaluation of Bridge Decks Using Non-Destructive Evaluation (NDE) at Near-Highway Speeds for Effective Asset Management*," MDOT Research Report RC-1617, Michigan Department of Transportation, Lansing, MI.