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Evaluation of Bridge Decks Using Non-Destructive Evaluation (NDE) at Near Highway Speeds for Effective Asset Management – Implementation for Routine Inspection (Phase III)

Element Level Condition State Assessment, Comparison to Traditional Methods, and Cost and Time Comparison Analysis mini reports

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16. Abstract

This project focused on implementing the 3DOBS technology (developed under Phase I and Phase II) for successful detection, quantification, and visualization of concrete bridge deck distress features at near-highway speeds for routine MDOT inspections. The integration and further re-defining of the 3DOBS methods into MDOT practices was accomplished by assessing 11 bridge decks with an average size of 10,350 ft^2. Distress features were categorized according to the Bridge Element Inspection Manual and compared to traditional (visual) element level inspection results. The Great Lakes Engineering Group, LLC worked with the research team to inspect, interpret, report results, and advise on current condition state reporting requirements. The project team also trained MDOT bridge inspectors in the use of the remote sensing equipment, data collection, data processing, and reporting through multiple different training sessions. A cost comparison between 3DOBS and traditional inspection methods was conducted, with 3DOBS costing an average of $92 per bridge, as compared to $39 for traditional methods. For producing standard element level condition state tables, 3DOBS cost more than a traditional inspector, but is still estimated to be less than $100 for an average bridge in this study.

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1.1 Introduction

Knowing the condition of the bridge deck plays a key role in understanding the overall condition and safety of a bridge structure. Through the use of the 3D Optical Bridge-evaluation System (3DOBS), MDOT can gain a better understanding of the bridge deck without having to close lanes to traffic or place inspectors on a bridge. The 3DOBS system consisting of a high-tech camera, global positioning system, and inertial measurement unit (IMU) can collect bridge deck imagery at near-highway speeds. Once 3DOBS collects the imagery, which is processed through Agisoft PhotoScan, a 3D modeling software or 2D mosaicking software, it is analyzed to detect distress features such as spalls. After the features are detected, having the ability to quantify each into a condition state can provide further understanding of the overall condition of the structure. The Bridge Deck Condition State (BDCS) algorithm can be used to quickly quantify the distresses and place them into the respective condition state. The condition state definitions are based on the Michigan Bridge Element Inspection Manual's (MBEIM) CS Table 1 - Reinforce Concrete (Figure 1).

Defect	Condition State 1 GOOD	Condition State 2 FAIR	Condition State 3 POOR	Condition State 4 SEVERE
Spalls/ Delaminations/ Patch Areas (1080)	None.	Delaminated. Spall 1 in. or less deep or less than 6 in. diameter. Patched area is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None.	Present without section loss.	Present with section loss that does not warrant structural review.	
Efflorescence / Rust Staining (1120)	None.	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking (1) Reinforced Concrete and Other (1130)	Insignificant cracks or moderate-width cracks that have been sealed.	Unsealed moderate-width cracks or unsealed moderate pattern (map) cracking.	Wide cracks or heavy pattern (map) cracking.	
Abrasion /Wear (1190)	No Abrasion of wearing	Abrasion or wearing has exposed coarse aggregate	Coarse aggregate is loose or has popped out of the concrete matrix due to abrasion or wear.	
Distortion – Culvert (1900)	None.	Distortion not requiring mitigation or mitigated distortion.	Distortion that requires mitigation but does not require structural review.	
Settlement – Substructure Elements (4000)	None.	Exists within tolerable limits or arrested with effective actions taken to mitigate.	Exceeds tolerable limits but does not warrant structural review.	

Figure 1: Condition State table for Reinforced Concrete

Spalls - the condition state of spalls were assigned by determining the depth and diameter. Following MBEIM's definitions, if a detected spall is less than one inch in depth or less than six inches in diameter, it was assigned a rating of "Condition State 2 - Fair". Likewise, if the detected spall is greater than one inch in depth or greater than six inches in diameter, it was assigned a rating of "Condition State 3 - Poor".

Bitpatch - Through discussion with project partner, Great Lakes Engineering Group (GLEG), it was determined that bitpatch should be automatically considered poor condition. Therefore, all instances of bitpatch were assigned a rating of "Condition State 3 - Poor".

Concrete Patch - Through discussion GLEG, it was determined that concrete patching is assigned a condition rating based on if it is sound or not. If a patch is showing signs of cracking or deterioration (delamination forming underneath), including the presence of a spall inside of the patch, it is considered unsound and assigned a rating of "Condition State 3 - Poor". Since this analysis did not include thermal remote sensing, the presence or absence of a delamination could not be determined. Therefore, for this analysis, all concrete patches were assigned a rating of "Condition State 2 – Fair".

Cracking - the condition state of cracks was assigned by determining if the distresses were sealed and the crack's thickness. Following MBEIM, if the cracks were insignificant or sealed, it was assigned a rating of "Condition State 1 - Good". However, if the cracks are not sealed and are moderate in width or pattern (map cracking), the distress was assigned a rating of "Condition State 2 - Fair". Lastly, if the cracks are not sealed and are wide with a heavy pattern, the rating was assigned as "Condition State 3 - Poor".

1.2 Condition State Assessment

1.2.1 Python Algorithm / Toolbox

The BDCS algorithm was written in Python 2.7 and is used to automatically calculate the quantity and condition state of distresses found on a bridge deck. User-defined inputs include the inspected bridge structure number, shapefiles of the distress features, and a digital elevation model (DEM) of the bridge deck. The algorithm was designed to run with the presence or absence of any of the distress types described above. As the algorithm is processing, two background files are created including a zonal statistics table and spalls bounding box shapefile. However, at the end of the algorithm, both files are deleted. A final comma separated value (csv) is created, summing the values for each condition state.

To assist in using the BDCS algorithm, the Python script was converted into an ESRI ArcMap Toolbox / graphical user interface (GUI). This promotes users without programming experience to easily use the algorithm. Using the tool only requires the user to enter the structure identification number, input files' path locations, and the output locations.

1.2.2 Results – Metro Region

Harper

The Harper Road bridge (Str 11223) is located in Detroit, Michigan and passes over Interstate 94. The total area of the bridge deck is approximately 6,836 sq. ft. and has two spans. After processing the optical imagery, analysts were able to identify spalls, bitpatch, and cracks (Figure 2). The total area of the distresses are as follows:

- Spalls - 11 sq. ft
- Bitpatch - 379 sq. ft
- Concrete Patching - 0 sq. ft
- Cracks - 2,454 sq. ft

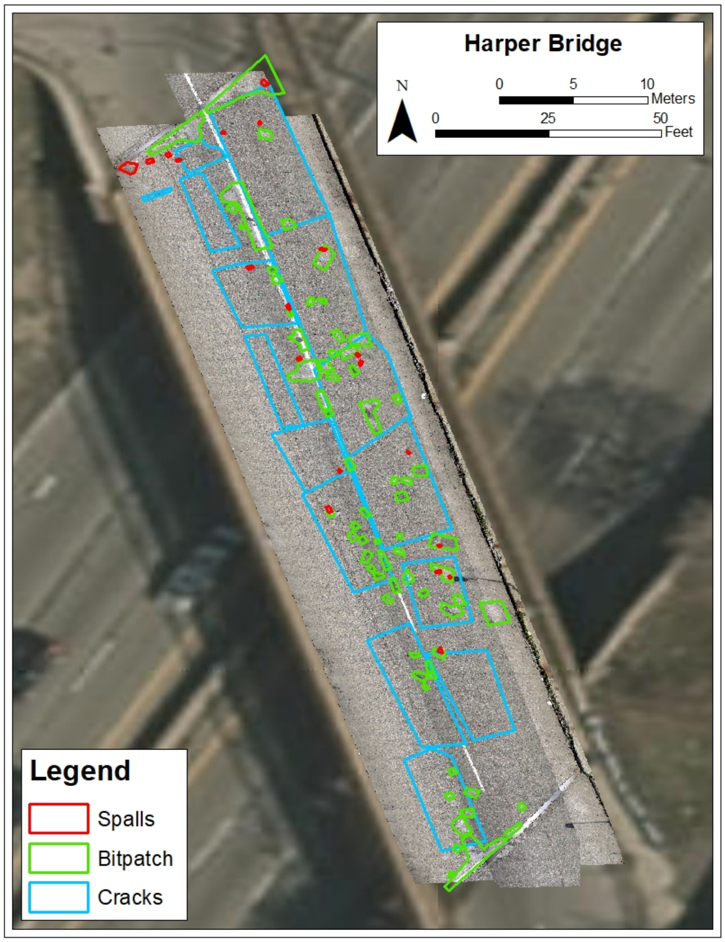


Figure 2. Identified distresses on the Harper Road bridge.

Since a DEM could not be created for the Harper Road bridge, visual inspection of the merged output was conducted to determine if any rebar could be detected within each of the spalls. If there was rebar, the spall was classified as "Condition State 3 - Poor". However, if rebar could not be detected and the spall was smaller than six inches in diameter, the spall was classified as "Condition State 2 - Fair".

Table 1 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls and bitpatch), there was one spall that had visible rebar, placing it into the "poor" category. Otherwise, the other spalls were classified as "fair". Bitpatch distresses were also classified as "poor" condition. For Elem. Key 1130 (cracks), some of the crack detected regions were classified as "insignificant" and therefore rated as "good". The cracked regions that were classified as "unsealed - moderate" were rated as "fair" and lastly, those classified as "unsealed - wide/heavy" were rated as "poor". Overall, the condition of the bridge deck was rated "Good" at 67%, "Fair" at 11%, and "Poor" at 23%.

Table 1. Condition State Table for the Harper Road bridge

Structure ID: 11223								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	6,836	sq.ft	4,561	719	1,556	0
					67%	10%	23%	0%
1080	Spalls/Delaminations/Patch Areas	4	391	sq.ft	0	9	382	0
1130	Cracking	4	2,453	sq.ft	569	710	1,174	0

Miller

The Miller Road bridge (Str 11334) is located in Dearborn, Michigan and passes over M-153 (Ford Road). The total area of the bridge deck is approximately 6,000 sq. ft. and has two spans. After processing the optical imagery, analysts were able to identify bitpatch and cracks (Figure 3). The total area of the distresses are as follows:

- Spalls - 0 sq. ft
- Bitpatch - 14 sq. ft
- Concrete Patching - 0 sq. ft
- Cracks - 1,286 sq. ft

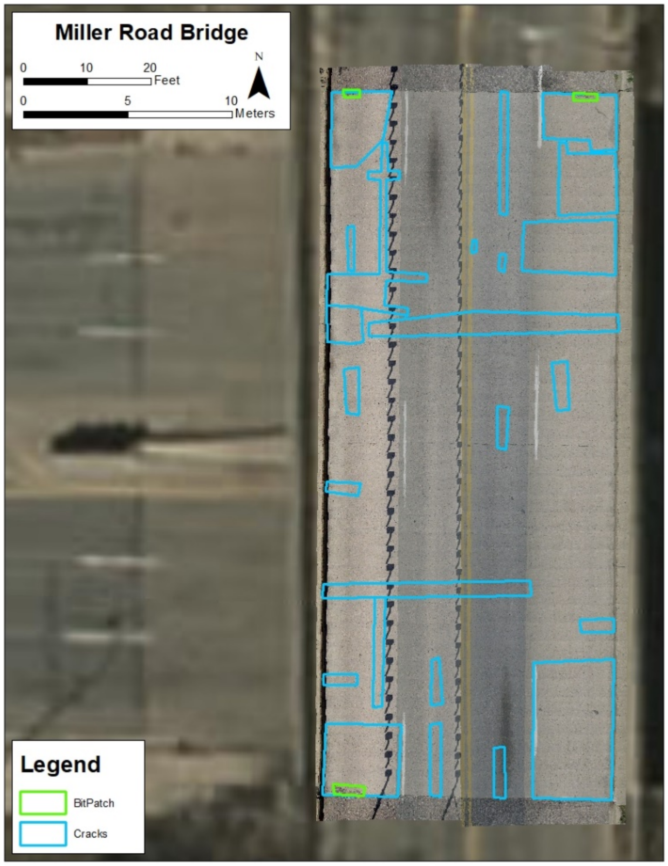


Figure 3. Identified distresses on the Miller Road bridge.

Table 2 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (bitpatch), the bitpatch areas were all placed into the "poor" category. All of the identified cracks were classified as "unsealed - moderate", which were placed in condition state "fair". Although there is a large area of the bridge deck that is cracked, none of the cracks appear to be in a "poor" condition. Overall, the condition of the bridge deck was rated "Good" at 78% and "Fair" at 21%.

Table 2. Condition State Table for the Miller Road Bridge

Structure ID: 11334								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	6,000	sq.ft	4,699	1,287	14	0
					78%	22%	0%	0%
1080	Spalls/Delaminations/Patch Areas	4	14	sq.ft	0	0	14	0
1130	Cracking	4	1,287	sq.ft	0	1,287	0	0

Mt. Vernon

The Mt. Vernon bridge (Str 7882) is located in Southfield, Michigan and passes over M-10, the Lodge. The total area of the bridge deck is approximately 4,685 sq. ft. and has two spans. After processing the optical imagery, analysts were able to identify spalls, bitpatch, and cracks (Figure 4). The total area of the distresses are as follows:

- Spalls - 94 sq. ft
- Bitpatch - 51 sq. ft
- Concrete Patching - 0 sq. ft
- Cracks - 9 sq. ft

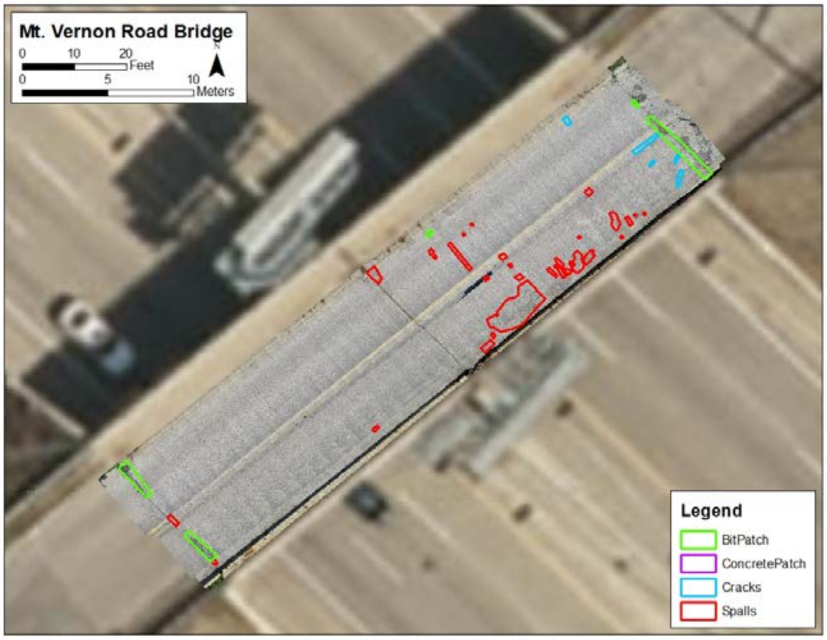


Figure 4. Identified distresses on the Mt. Vernon Road bridge.

Table 3 shows the results from processing the distresses through the BDCS algorithm. None of the identified spalls had rebar showing, placing each of the spalls into a "fair" category. All of the bitpatch distresses were classified as "poor" condition. Lastly, the cracks on the deck were all rated as "insignificant", resulting in a classification of "fair". Overall, the condition of the bridge deck was rated "Good" at 97%, "Fair" at 2%, and "Poor" at 1%

Table 3. Condition State Table for the Mt. Vernon Road bridge

Structure ID: 7882								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	4,685	sq.ft	4,541	93	51	0
					97%	2%	1%	0%
1080	Spalls/Delaminations/Patch Areas	4	144	sq.ft	0	93	51	0
1130	Cracking	4	10	sq.ft	10	0	0	0

Pennsylvania

The Pennsylvania bridge (Str 11902) is located in Romulus, Michigan and passes over I-275. The total area of the bridge deck is approximately 13,939 sq. ft. and has two spans. After processing the optical imagery, analysts were able to identify spalls, bitpatch, concrete patches, and cracks (Figure 5). The total area of the distresses are as follows:

- Spalls - 11 sq. ft
- Bitpatch - 11 sq. ft
- Concrete Patching - 402 sq. ft
- Cracks - 135 sq. ft

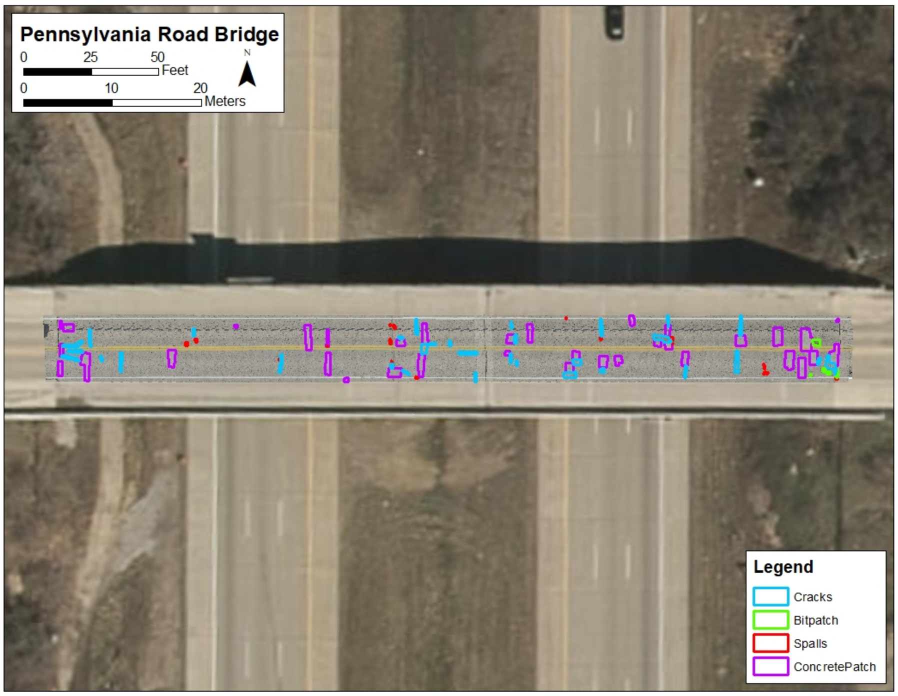


Figure 5. Identified distresses on the Pennsylvania Road bridge.

Table 4 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls, bitpatch, and concrete patches), the bitpatch areas were all placed into the “poor” category. None of the identified spalls had rebar showing, placing each of the spalls into a “fair” category. All concrete patches were assigned a “fair” category. For Elem. Key 1130 (cracks), most of the cracked areas were dectermined to be insignificant / “good”. However, some cracks were moderate or heavy, resulting in ratings of “fair” or “poor”. Overall, the condition of the bridge deck was rated “Good” at 97% and “Fair” at 3%.

Table 4. Condition State Table for the Pennsylvania Road bridge

Structure ID: 11902								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	13,939	sq.ft	13,467	449	23	0
					97%	3%	0%	0%
1080	Spalls/Delaminations/Patch Areas	4	418	sq.ft	0	407	11	0
1130	Cracking	4	135	sq.ft	81	42	12	0

Virgil

The Virgil Road bridge (Str 11508) is located in Detroit, Michigan and passes over I-96. The total area of the bridge deck is approximately 14,185 sq. ft. and has two spans. After processing the optical imagery, analysts were able to identify spalls, bitpatch, concrete patches, and cracks (Figure 6). The total area of the distresses are as follows:

- Spalls - 38 sq. ft
- Bitpatch - 201 sq. ft
- Concrete Patching - 11 sq. ft
- Cracks - 193 sq. ft

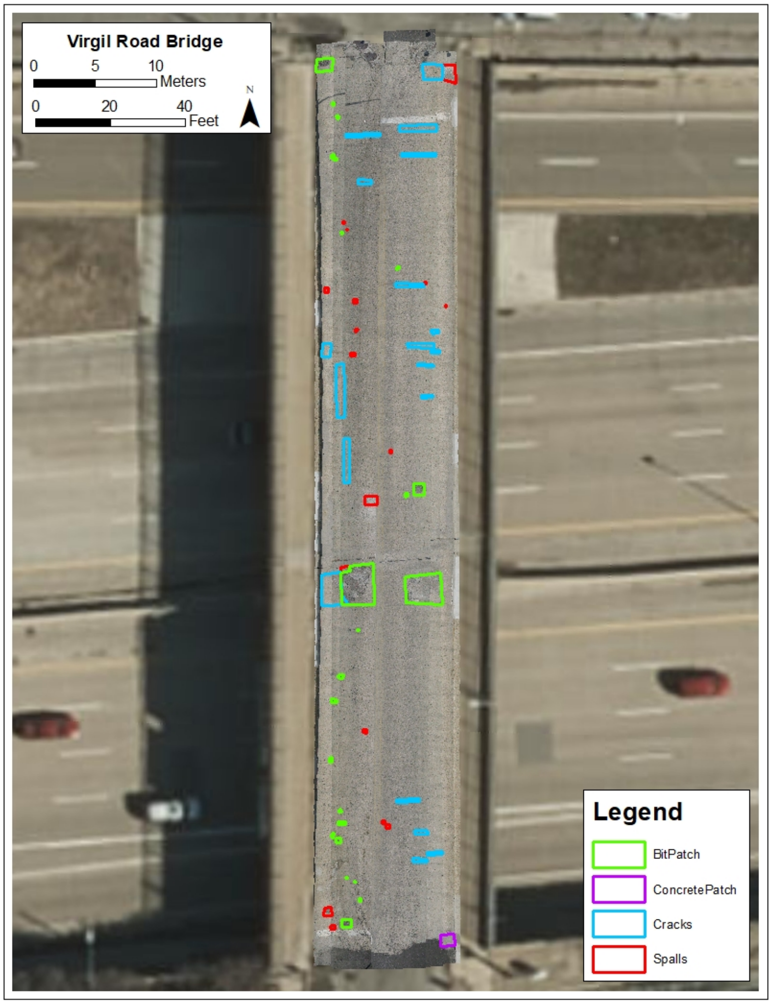


Figure 6. Identified distresses on the Virgil Road bridge.

Table 5 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls, bitpatch, and concrete patches), the bitpatch areas were all placed into the "poor" category. None of the identified spalls had rebar showing, placing each of the spalls into a "fair" category. All of the concrete patches were assigned a category of "fair". For Elem. Key 1130 (cracks), most of the cracked areas were determined to be insignificant / "good". However, some cracks were moderate or heavy, resulting in ratings of "fair" or "poor". Overall, the condition of the bridge deck was rated "Good" at 97%, "Fair" at 1%, and "Poor" at 2%.

Table 5. Condition State Table for the Virgil Road Bridge

Structure ID: 11508								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	14,185	sq.ft	13,846	96	243	0
					97%	1%	2%	0%
1080	Spalls/Delaminations/Patch Areas	4	247	sq.ft	0	48	199	0
1130	Cracking	4	193	sq.ft	101	48	44	0

1.2.3 Results – Southwest Region

Jackson

The Jackson bridge (Str 1224) is located in Tekonsha, Michigan and passes over I-69. The total area of the bridge deck is approximately 8,261 sq. ft. and has four spans. After processing the optical imagery, analysts were able to identify spalls, bitpatch, concrete patches, and cracks (Figure 7). The total area of the distresses are as follows:

- Spalls - 66 sq. ft
- Bitpatch - 18 sq. ft
- Concrete Patching - 574 sq. ft
- Cracks - 318 sq. ft

Figure 7. Identified distresses on the Jackson Road bridge.

Table 6 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls, bitpatch, and concrete patches), the bitpatch areas were all placed into the "poor" category. Two spalls had rebar showing and were therefore assigned a "poor" condition. The remaining spalls were assigned a "fair" condition. All concrete patches were assigned a "fair" category. For Elem. Key 1130 (cracks), most of the cracked areas were determined to be insignificant / in "good" condition. However, some cracks were moderate or heavy, resulting in a "fair" category. Overall, the condition of the bridge deck was rated "Good" at 92% and "Fair" at 8%.

Table 6. Condition State Table for the Jackson Road bridge

Structure ID: 1224								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	8,261	sq.ft	7,592	651	18	0
					92%	8%	0%	0%
1080	Spalls/Delaminations/Patch Areas	4	623	sq.ft	0	605	18	0
1130	Cracking	4	316	sq.ft	270	46	0	0

J Drive

The J-Drive bridge (Str 1241) is located in Marshall, Michigan and passes over I-69. The total area of the bridge deck is approximately 10,127 sq. ft. and has two spans. After processing the optical imagery, analysts were able to identify spalls and bitpatch (Figure 8). The total area of the distresses are as follows:

- Spalls - 38 sq. ft
- Bitpatch - 500 sq. ft
- Concrete Patching - 0 sq. ft
- Cracks – 146 sq. ft

Figure 8. Identified distresses on the J Drive Road bridge.

Table 7 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls and bitpatch), the bitpatch areas were all placed into the "poor" category. Four spalls had rebar showing and were therefore placed assigned a "poor" condition. The remaining spalls were assigned a "fair" condition. For Elem. Key 1130 (cracks), most of the cracked areas were determined to be insignificant / in "good" condition. However, some cracks were moderate or heavy, resulting in a "fair" category. Overall, the condition of the bridge deck was rated "Good" at 94%, "Fair" at 1%, and "Poor" at 5%.

Table 7. Condition State Table for the J Drive Road bridge

Structure ID: 1241								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	10,127	sq.ft	9,556	58	513	0
					94%	1%	5%	0%
1080	Spalls/Delaminations/Patch Areas	4	538	sq.ft	0	25	513	0
1130	Cracking	4	148	sq.ft	115	33	0	0

N Drive

The N-Drive bridge (Str 1243) is located in Marshall, Michigan and passes over I-69. The total area of the bridge deck is approximately 15,441 sq. ft. and has five spans. After processing the optical imagery, analysts were able to identify spalls, bitpatch, concrete patching, and cracks (Figure 9). The total area of the distresses are as follows:

- Spalls - 56 sq. ft
- Bitpatch - 413 sq. ft
- Concrete Patching - 17 sq. ft
- Cracks - 46 sq. ft

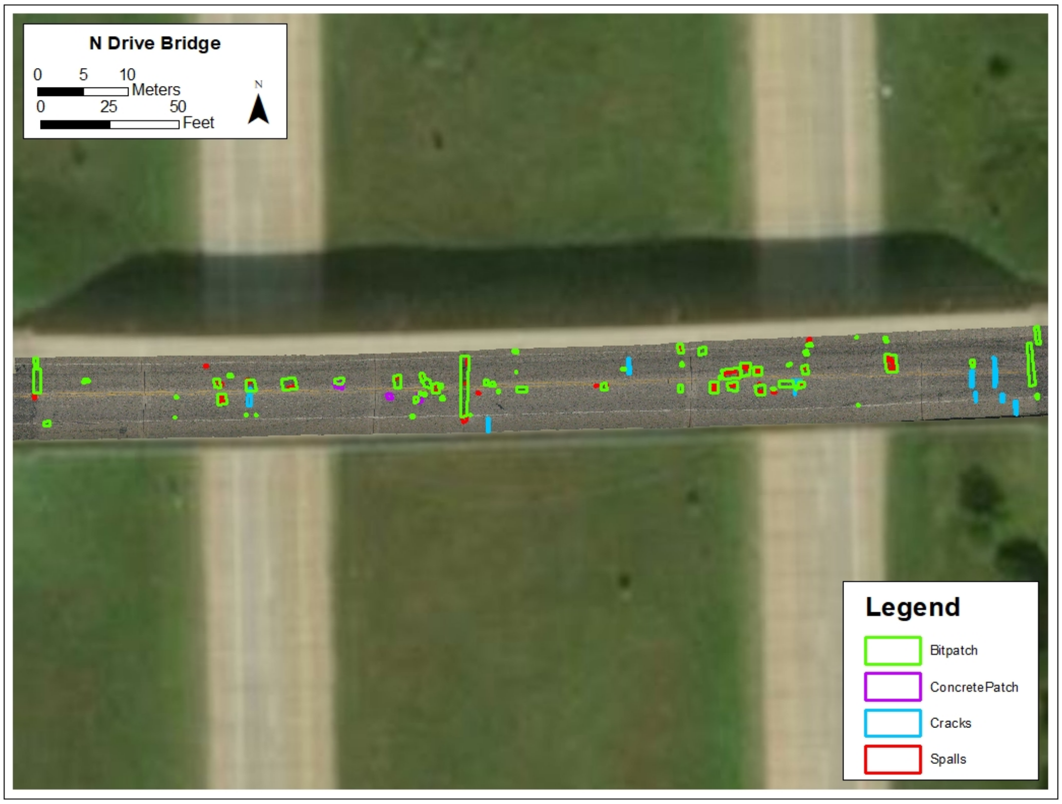


Figure 9. Identified distresses on the N Drive Road bridge.

Table 8 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls, bitpatch, and concrete patches), the bitpatch areas were all placed into the "poor" category. None of the spalls had any rebar showing and were therefore assigned a "fair" condition. Since concrete patches were identified on the bridge, all were assigned a "fair" rating. For Elem. Key 1130 (cracks), half the cracked areas were determined to be insignificant / in "good" condition. However, the other half of the cracked areas were moderate or heavy, resulting in both "fair" and "poor" ratings. Overall, the condition of the bridge deck was rated "Good" at 97% and "Poor" at 3%.

Table 8. Condition State Table for the N Drive bridge

Structure ID: 1243								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	15,541	sq.ft	15,086	40	415	0
					97%	0%	3%	0%
1080	Spalls/Delaminations/Patch Areas	4	432	sq.ft	0	19	413	0
1130	Cracking	4	45	sq.ft	22	21	2	0

Garfield

The Garfield bridge (Str 1244) is located in Marshall, Michigan and passes over I-69. The total area of the bridge deck is approximately 23,129 sq. ft. and has six spans. After processing the optical imagery, analysts were able to identify spalls, bitpatch, concrete patching, and cracks (Figure 10). The total area of the distresses are as follows:

- Spalls - 10 sq. ft
- Bitpatch - 2,341 sq. ft
- Concrete Patching - 6 sq. ft
- Cracks - 438 sq. ft

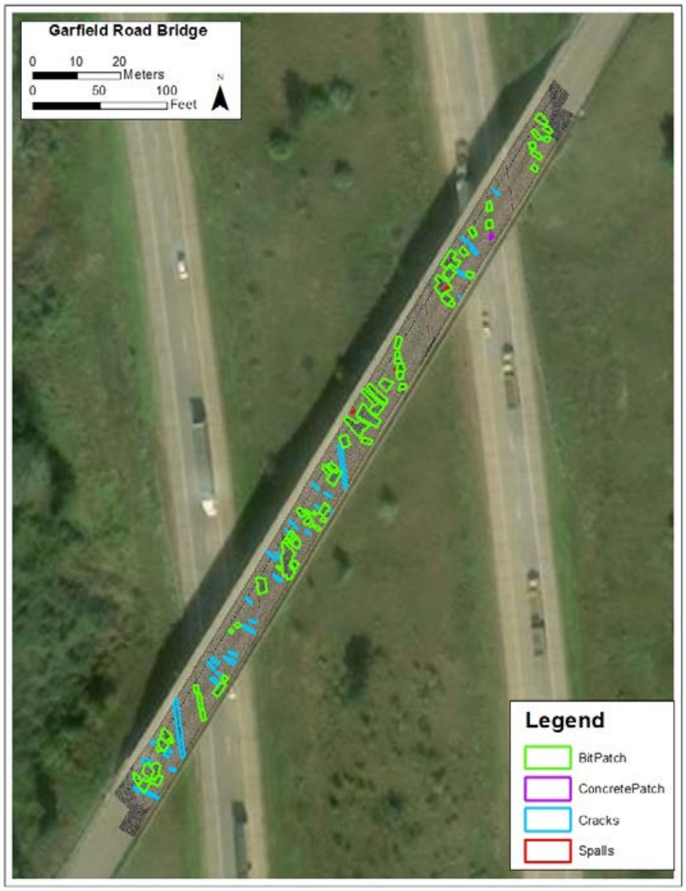


Figure 10. Identified distresses on the Garfield Road bridge.

Table 9 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls, bitpatch, and concrete patches), the bitpatch areas were all placed into the "poor" category. One spall had rebar showing and were therefore placed assigned a "poor" condition. The remaining spalls were assigned a "fair" condition. All of the concrete patches were assigned a "fair" category. For Elem. Key 1130 (cracking), most of the cracked areas were determined to be insignificant / in "good" condition. However, some cracks were moderate, resulting in ratings of "fair". Overall, the condition of the bridge deck was rated "Good" at 89%, "Fair" at 1%, and "Poor" at 10%.

Table 9. Condition State Table for the Garfield Road bridge

Structure ID: 1244								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	23,129	sq.ft	20,540	237	2,352	0
					89%	1%	10%	0%
1080	Spalls/Delaminations/Patch Areas	4	2,361	sq.ft	0	9	2,352	0
1130	Cracking	4	435	sq.ft	207	228	0	0

I-69 North

The I-69 North bridge (Str 1215) is located in Tekonsha, Michigan and passes over the St. Joseph River. The total area of the bridge deck is approximately 5,494 sq. ft. and has three spans. After processing the optical imagery, analysts were able to identify spalls, concrete patching, and cracks (Figure 11). The total area of the distresses are as follows:

- Spalls - 48 sq. ft
- Bitpatch - 0 sq. ft
- Concrete Patching - 585 sq. ft
- Cracks - 16 sq. ft

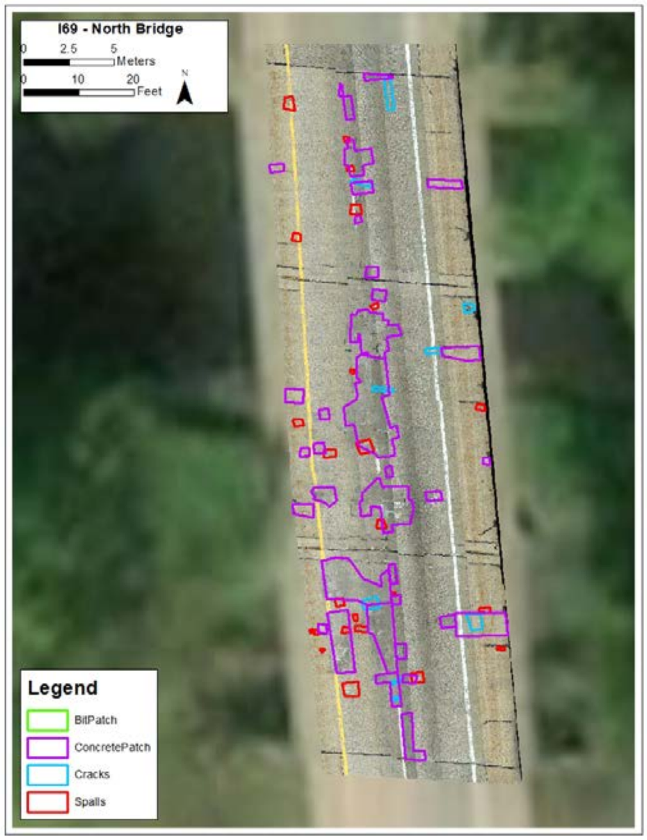


Figure 11. Identified distresses on the I-69 North bridge.

Table 10 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls and concrete patches), two spalls had rebar showing and were therefore placed assigned a “poor” condition. The remaining spalls were assigned a “fair” condition. All concrete patches were assigned a “fair” condition. For Elem. Key 1130 (cracking), most of the cracked areas were determined to be insignificant / in “good” condition. However, one area of cracking was moderate, resulting in a rating of “fair”. Overall, the condition of the bridge deck was rated “Good” at 89% and “Fair” at 11%.

Table 10. Condition State Table for the I69 North bridge

Structure ID: 1215								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	5,494	sq.ft	4,862	621	11	0
					89%	11%	0%	0%
1080	Spalls/Delaminations/Patch Areas	4	564	sq.ft	0	619	11	0
1130	Cracking	4	16	sq.ft	14	2	0	0

I-69 South

The I-69 South bridge (Str 1213) is located in Tekonsha, Michigan and passes over the St. Joseph River. The total area of the bridge deck is approximately 5,625 sq. ft. and has three spans. After processing the optical imagery, analysts were able to identify spalls, bitpatch, concrete patching, and cracks (Figure 12). The total area of the distresses are as follows:

- Spalls - 63 sq. ft
- Bitpatch - 125 sq. ft
- Concrete Patching - 488 sq. ft
- Cracks - 18 sq. ft

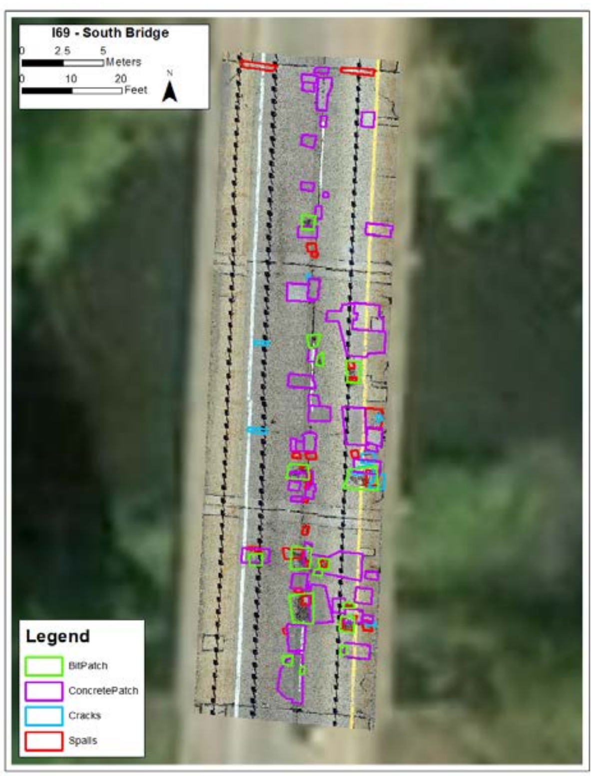


Figure 12. Identified distresses on the I-69 South bridge.

Table 11 shows the results from processing the distresses through the BDCS algorithm. For Elem. Key 1080 (spalls, bitpatch, and cracking), the bitpatch areas were all placed into the "poor" category. Three spalls had rebar showing and were therefore placed assigned a "poor" condition. The remaining spalls were assigned a "fair" condition. All concrete patches were assigned a rating of "fair". For Elem. Key 1130 (cracking), half of the cracked areas were determined to be insignificant / in "good" condition. However, some cracks were moderate or heavy, resulting in "poor" and "fair" ratings. Overall, the condition of the bridge deck was rated "Good" at 88%, "Fair" at 10%, and "Poor" at 3%.

Table 11. Condition State Table for the I-69 South bridge

Structure ID: 1213								
Elem. Key	**Element**	**Env.**	**Quantity**	**Unit**	**GOOD CS1**	**FAIR CS2**	**POOR CS3**	**SEVERE CS4**
810	Reinforced Concrete Deck Top Surface	2	5,625	sq.ft	4,936	538	151	0
					88%	10%	3%	0%
1080	Spalls/Delaminations/Patch Areas	4	677	sq.ft	0	536	141	0
1130	Cracking	4	19	sq.ft	7	2	10	0

1.2.4 Conclusions

By collecting 3DOBS data at 11 different bridges across the state and processing it through 2D and 3D modeling software, each bridge deck model is able to be assessed for distress features such as spalls, bitpatch, concrete patches, and cracks. GIS software can be used to digitize the different types of distress features without the need to send and place an inspector on the site. Once digitized, the distress features can be categorized into their respective condition states using the definitions found in MBEIM. This analysis has shown that is possible to identify specific distress features and quantify condition states from 3DOBS imagery.

2. Comparison of 3DOBS to Traditional Methods

2.1 Introduction

The main goal of both traditional visual bridge deck inspections and 3DOBS is to generate an element level condition state table for reporting. Over the past three phases of research of MDOT sponsored research, 3DOBS has been transformed from a slow moving (< 5mph) vehicle based camera system requiring the use of ground control to provide mosaics and 3D models to a near-highway speed (45 mph) system which does not require anything to be placed on the bridge deck or lane closures. This fits directly into MDOT's current reporting standards while increasing the safety of bridge inspectors and eliminating the need for lane closures for detailed bridge deck surface assessments.

2.2 Field Data Collection

Traditional visual inspections are conducted by an inspector who walks across the bridge deck and estimates the quantities of the defects present. This method is subjective as the inspector quickly estimates the quantities of each defect and adds them at the end of the inspection. While the inspector is assessing the bridge deck they are also exposed to traffic without a protective barrier. With 3DOBS, the inspectors are in a vehicle which keeps them away from the traffic while collecting data for a bridge deck assessment (Figure 13).

Figure 13. 3DOBS about to collect data over the I-69N bridge over St. Joseph River in MDOT's Southwest Region.

With the ability of the vehicle to drive up to 45 mph, there is little or no disruption of traffic on most bridges. On freeway bridges with higher speed limits, a shadow vehicle was used for the collects for safety. The collection vehicle only needs to reduce its speed down to 45 mph during the collection of data and is able to drive back up to the speed limit after the target bridge. This minimizes the impact of traffic to less than 10 seconds per pass over the average sized bridges used in the study. The collection of the I-69 freeway bridges took longer than the non-freeway bridges as the availability of places to turn around for each pass and traffic patterns slowed the process. For the bridges collected in the Metro region, three passes were made per lane and then one pass for each shoulder. This method was used as it was necessary to determine the amount of overlap required to create 3D models of the bridges. For the collections in the Southwest Region, the system was optimized for a collection style of one pass per lane plus one pass over each shoulder. The Southwest Region collections replicate the final implementation collection style.

The data collected for 3DOBS was processed into high resolution mosaicked images of bridges decks (~ $1/64^{th}$ in) and a high resolution DEM (~ $1/16^{th}$ in) which can be used for detailed assessments similar to a bridge scoping (Figure 14). This is a significant advantage for inspectors to track defect changes over time for asset management as objective measurements can be taken of cracks, spall, and patching. Another advantage is not having to close lanes on the bridge to collect this data which reduces the impact to motorists.

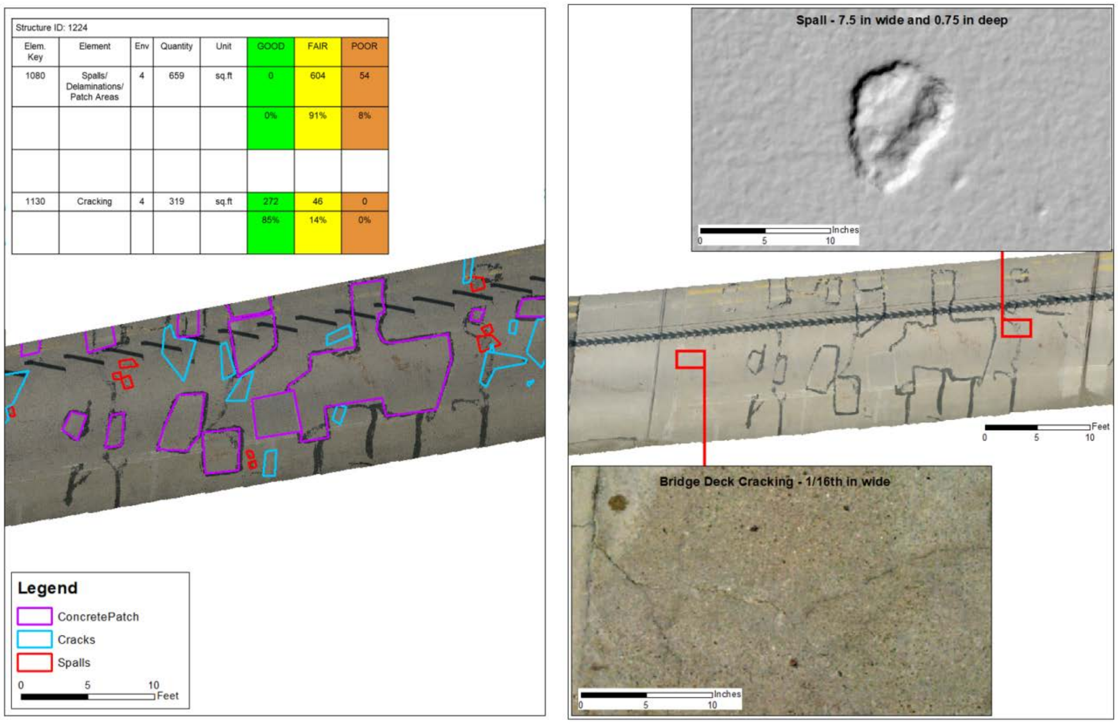


Figure 14. An example of the high resolution image mosaic and DEM resulting from 3DBOS (Right). The left side of the figure shows the results of the defect digitizing of the image mosaic along with the resulting element level condition state table.

2.3 Analysis and Reporting

Table 12, Table 13, and Table 14 quantify the percentage of distress per condition states for each bridge based on MDOT, 3DOBS, and traditional visual GLEG inspections, respectively. For each of the bridges, MDOT inspections reported larger areas of distress features in condition state 2. However, for condition state 3, MDOT reported smaller pecentages as compared to 3DOBS except for the Jackson bridge deck. As for condition state 3, 3DOBS may have the higher quantification of spalls due to its ability to detect smaller spalls based on settings in the Spallgorithm. The higher areas of bitpatch in the 3DOBS inspection is likely due to the boundaries drawn by imagery analysts.

As for the comparison between 3DOBS and GLEG, condition state 2 areas were very similar for I-69N and I-69S. However, the percentages differed for the remaining four bridges. While the exact reasons behind the differences is unknown, it may be dependent on what features are placed in into GLEG's condition states as compared to 3DOBS and the visual versus automated detection methods. The comparison between condition state 3 shows that generally GLEG quantified a lower total area of distress features, except for Jackson Road.

Table 12. MDOT Inspection Condition State Reporting

Structure ID	Deck Area (sft)	State 2	State 3
I-69S	5,625	12%	2%
I-69N	5,494	12%	1%
Jackson	8,261	16%	2%
J-Drive	10,127	2%	3%
N-Drive	15,441	1%	1%
Garfield	23,129	3%	4%

Table 13. 3DOBS Condition State Reporting

Structure ID	Deck Area (sft)	State 2	State 3
I-69S	5,625	9%	4%
I-69N	5,494	11%	1%
Jackson	8,261	8%	1%
J-Drive	10,127	0%	5%
N-Drive	15,441	0%	3%
Garfield	23,129	1%	10%

Notes: All concrete patches that 3DOBS detected are placed into State 2 for the comparison.
All spalls that 3DOBS detected are placed into State 3 for the comparison.
All bit patch that 3DOBS detected are placed into State 3.
All “unsealed-moderate” and all “unsealed-heavy” cracks that 3DOBS detected are placed into State 2 and State 3, respectively.

Table 14. GLEG Condition State Reporting

Structure ID	Deck Area (sft)	State 2	State 3
I-69S	5,625	9%	1%
I-69N	5,494	10%	1%
Jackson	8,261	43%	49%
J-Drive	10,127	6%	4%
N-Drive	15,441	3%	1%

3. Cost and Time Comparison Analysis

3.1 Introduction

Utilizing traditional methods and 3DOBS would enable MDOT to perform the Element Level Condition State analysis shown in the previous section. One difference between the two methods is the amount of time required to perform both methods and the cost, with most of the time required for 3DOBS being computer time with minimal human intervention. This allows for the user to prepare the datasets after collection and allows the processing to run overnight.

3.2 Time Analysis

When compared to traditional methods, 3DOBS has the ability to collect data over a bridge faster than traditional inspection methods. Table 15 shows the amount of time required to collect each of the eleven bridges as it relates to vehicle speed and bridge deck area. Most of the time required for collecting data on bridges is due to turning the vehicle around after a pass and driving back for another. Each pass across a bridge takes less than 30 seconds, with the overall time to collect imagery over a whole bridge typically requiring less than 20 minutes. The first set of five bridges for the Metro Region (Harper, Miller, Mt. Vernon, Pennsylvania, and Virgil) on average took longer to collect than the six bridges from the Southwest Region (Jackson, J-Drive, N-Drive, Garfield, I-69N and I-69S). This is due to a change in collection procedures. 3DOBS made two passes for each lane, one pass over the shoulder and one pass over the centerline for the bridges in the Metro Region which required seven passes over a two lane bridge. The collection procedure was updated for the bridges in the Southwest Region by increasing the height of the camera. This increases the field of view of the camera to require only a single pass over each lane and shoulder, resulting in four passes over a two lane bridge.

Table 15. Time for collecting data

Bridge	Number of Lanes	Bridge Length (ft)	Deck Area (sft)	Average Time per Pass (s)	Average Collect Speed (mph)	Total Collection Time (min)
Harper	2	288	13,939	8	24	13.4
Miller	4	111	6,000	6	40	14.2
Mt. Vernon	2	122	4,685	6	26	13.8
Pennsylvania	2	171	6,836	8	45	6.4
Virgil	2	239	14,341	10	21	14.4
Jackson	2	240	8,261	20	25	5
J-Drive	2	264	10,127	8	25	5.6
N-Drive	2	364	15,441	11	25	6.7
Garfield	2	602	23,129	18	25	8.1
I-69N	2	130	5,497	7	45	25.8*
I-69S	2	133	5,625	7	45	
* Freeway bridges were collected together						

The bridges which required the most amount of time were the freeway bridges (I-69 North and South). Both bridges were collected even though I-69 North was the intended target. I-69 South was collected because the collection vehicle had to cross over it to get back to I-69 North for another pass. The freeway turnarounds were also approximately one-mile north and south of the bridges which added to the time required for collection. The time listed on the table is the total time required for 3DOBS to collect imagery over both I-69 bridges.

After imagery is collected from the bridges, the individual frames must be exported to produce the mosaicked image and DEM. This is done using RED Cinema's REDCINE-X Pro software which can batch process the video frames with very little user intervention. The number of frames extracted from a RED video is directly related to the length of the video and the frame rate. A ten second video collected at 48 frames per second (fps) will have 480 frames while a video collected at 60 fps will have 600 frames to export. Table 16 shows the amount of time required to extract video frames for each of the bridges. The first five bridges are from the Metro Region and were collected at 60 fps and each bridge lane was collected twice, which required a total frame extraction time of an hour or more for each bridge. With the advancement of collection techniques (video collected at 48 fps and only one pass per lane) the frame extraction time for the last six bridges was a half hour or less. The one exception was Garfield Road which required 80.1 minutes to extract all the frames due to the bridge being more than twice the length and deck area as most of the other bridges.

Table 16. Time required for exporting imagery compared to number of frames per bridge.

Bridge	Average Time to Extract Frames per Pass (min)	Average Number of Frames	Total Frame Extraction Time (min)	Total Frames
Harper	11.3	784	67.7	2,902
Miller	7.4	319	89.3	3,828
Mt. Vernon	9.1	390	54.5	2,337
Pennsylvania	10.5	450	52.9	2,697
Virgil	13.8	593	83.0	2,556
Jackson	13.4	978	82.4	5,865
J-Drive	3.5	367	14.0	1,467
N-Drive	8.0	518	32.0	2,073
Garfield	20.0	859	80.1	3,434
I-69N	7.0	357	28.0	1,428
I-69S	6.8	403	27.0	1,612

Creating the GPS, IMU, and Frame Sync text file was required for producing spatially referenced 2D mosaics and DEMs and orthomosaics from Agisoft. The software necessary to complete this task was developed at MTRI and requires the user to determine the time offset between the GPS/IMU box and the RED camera. A time difference between the datasets originates from the RED camera's internal time not being synced to GPS time and a difference in when the two systems start collecting data when the 3DOBS is remotely triggered. This first step is the most time consuming as it is a manual task (Table 17). This step averages about three minutes per pass over a bridge. The next step is working through the steps of syncing software. This step is also mostly personnel time as the user must import the raw data and specifying the time offset previously determined. This requires a minute or less per pass while the time required for computer processing is less than 20 seconds for an entire bridge.

Table 17. Time to sync GPS, IMU, and extracted RED frames data

Bridge	Setting Time Offset for Passes (min)	Setting up GPS, IMU, and Frame Sync Program (min)	Total Time
Harper	18	6.2	24.2
Miller	36	12.3	48.3
Mt. Vernon	18	6.2	24.2
Pennsylvania	18	6.2	24.2
Virgil	18	6.2	24.2
Jackson	18	6.4	24.4
J-Drive	12	4.1	16.1
N-Drive	12	4.1	16.1
Garfield	12	4.2	16.2
I-69N	12	4.1	16.1
I-69S	12	4.1	16.1

There are two methods developed for 3DOBS to produce imagery products for Element Level Condition State analysis; producing a 2D mosaic of the entire bridge deck by using an MTRI developed program and a 3D (DEM) of the bridge deck using Agisoft Photoscan Pro commercial software. The 2D mosaic program requires some setup time for each pass and is dependent on the number of frames required for recreating an entire pass. While the 2D mosaic program requires fewer images than Agisoft PhotoScan (60% image overlap as opposed to 90% or more), the program can only process a maximum of 60 frames at time due to constraints on computer memory and processing ability. That translates into requiring two smaller segments to be processed for a 200 ft bridge and more for longer bridges.

Table 18 shows a breakdown of the time required for the setup and computer processing time for each bridge evaluated. The “Total Setup Time” column documents the amount of time required for preparing all of the smaller segments for a bridge. After the segments are created, the user is required to georeference the segments together to resolve any alignment or geographic placement issues. This additional time is displayed in the “Total Personnel Time” column which includes setup time and georeferencing for each bridge.

Table 18. Time required to complete 2D mosaic of bridges.

Bridge	Average Setup Time per Pass (min)	Total Setup Time (min)	Total Personnel Time (min)	Average Processing Time per Pass (min)	Total Processing Time (min)	Total 2D Processing Time (hour)
Harper	8	48	168	160	960	18.8
Miller	8	96	336	160	1,920	37.6
Mt. Vernon	8	48	168	160	960	18.8
Pennsylvania	12	72	252	240	1,440	28.2
Virgil	8	48	168	160	960	18.8
Jackson	8	48	168	80	480	10.8
J-Drive	16	80	280	160	800	18.0
N-Drive	14	70	245	140	700	15.8
Garfield	18	90	315	180	900	20.3
I-69N	16	80	280	160	800	18.0
I-69S	16	80	280	160	800	18.0

3D processing of bridges was completed for the second set of five bridges assessed in the Southwest Region (Appendix A). The first set of five bridges were unable to be processed through this method due to poor GPS and IMU data recorded by the Reach RTK used early in the project. During the second part of the project, the MTRI built GPS/IMU system provided significantly improved GPS and IMU data which allowed for 3D model building. The final result from Agisoft PhotoScan was an orthoimage with a resolution of 0.02in (0.5 mm) and a DEM with a resolution of 0.09 in (2.25 mm).

Setting up Agisoft PhotoScan is quicker than the 2D mosaicking software and only requires, at most, two minutes for the user to setup. With a batch processing file already created and saved, the user does not need to provide input to start each step of the processing. As shown in Table 19, the typical setup time required for each pass is less than five minutes. Total computer processing time for bridges with a 250 ft span and 10,000 ft^2 deck is roughly 10 hours (i.e. Jackson, J-Drive, and N-Drive). Garfield is significantly larger with a 602 ft span and 23,129 ft2 deck and required 46.4 hours to process all passes.

The first four bridge models were built using the “Medium” setting for the point cloud densification step in Agisoft Photoscan. For faster model generation, this setting can be reduced to “Lowest” at the cost of DEM resolution. This setting was used for the I-69 North bridge and resulted in the processing being completed in only two hours for the full bridge. Resolution of the resulting DEM was reduced to 0.4 in (9.4 mm) and there was some reduction in the ability to characterize spalls which were less than a 0.5 in deep.

Table 19. Time required to complete 3D reconstruction of bridges.

Bridge	Average Setup Time per Pass (min)	Total Setup Time (min)	Average Agisoft Processing Time per Pass (hour)	Total Agisoft Processing Time (hour)	Total 3D Processing Time (hour)
Jackson	5	20	2.8	11.2	11.5
J-Drive	4.5	18	3.1	12.4	12.7
N-Drive	5	20	2.5	10.0	10.3
Garfield	3	12	11.6	46.4	46.6
I-69N	2	8	0.5*	2.0	2.1
* The point cloud densification step in Agisoft was reduced from "Medium" to "Lowest" to improve processing time.					

Once the reconstructions were made (2D mosaic or 3D) they were brought into ArcGIS for analysis. If only a 2D mosaic was available, all of the defects were manually digitized. The defect categories mirror MBEIM and for 3DOBS imagery products included spalls, bitpatch, concrete patches, and cracks. Table 20 displays the times required for a user to digitize each of the defects for the bridges in the study. This time ranged between 20 and 60 minutes depending on the size of the bridge and the quantity of defects. The time required for digitizing spalls can be reduced if a DEM was generated of the bridge. MTRI's Spallgorithm can automatically detect, digitize, and characterize spalls in less than five minutes. For larger bridges with more scattered spalls, this process can take up to 20 minutes of a user's time. The second column displays the amount of time required for an inspector to create similar drawings of the bridge deck during an inspection

Table 20. Amount of time required to record defect quantities between 3DOBS and traditional methods.

Bridge Name	3DOBS – Time to Complete Analysis	Manual – Time to Complete Analysis
Harper	65 minutes *Spalls - 20 minutes* *Bitpatch - 35 minutes* *Conc. Patches - 0 minutes* *Cracks - 10 minutes*	20 minutes
Miller	18 minutes *Spalls - 0 minutes* *Bitpatch - 3 minutes* *Conc. Patches - 0 minutes* *Cracks - 15 minutes*	20 minutes
Mt. Vernon	26 minutes *Spalls - 18 minutes* *Bitpatch - 2 minutes* *Conc. Patches - 0 minutes* *Cracks - 6 minutes*	20 minutes
Pennsylvania	37 minutes *Spalls - 8 minutes* *Bitpatch - 1 minutes* *Conc. Patches - 11 minutes* *Cracks - 17 minutes*	1 hr 5 minutes

Virgil	47 minutes *Spalls - 8 minutes* *Bitpatch - 15 minutes* *Conc. Patches - 0 minutes* *Cracks - 24 minutes*	45 minutes
Jackson	61 minutes *Spalls - 17 minutes* *Bitpatch - 3 minutes* *Conc. Patches - 0 minutes* *Cracks - 41 minutes*	29 minutes
J-Drive	47 minutes *Spalls - 18 minutes* *Bitpatch - 29 minutes* *Conc. Patches - 0 minutes* *Cracks - 0 minutes*	20 minutes
N-Drive	50 minutes *Spalls - 15 minutes* *Bitpatch - 16 minutes* *Conc. Patches - 3 minutes* *Cracks - 16 minutes*	29 minutes
Garfield	54 minutes *Spalls - 2 minutes* *Bitpatch - 34 minutes* *Conc. Patches - 2 minutes* *Cracks - 22 minutes*	1 hr 2 minutes
I-69N	51 minutes *Spalls - 13 minutes* *Bitpatch - 2 minutes* *Conc. Patches - 26 minutes* *Cracks - 10 minutes*	25 minutes
I-69S	38 minutes *Spalls - 10 minutes* *Bitpatch - 3 minutes* *Conc. Patches - 9 minutes* *Cracks - 16 minutes*	23 minutes

After the defects are digitized, they are processed through the BDCS algorithm to generate element level condition state tables for reporting. The overall time it takes to process a bridge deck through the BDCS is less than five minutes, including the time it takes to enter the datasets into the BDCS GUI and processing.

The total time required to collect, process, and analyze each bridge deck is summarized in Table 21 and Table 22. This time is separated into personnel and computer time. Both the 2D and 3D methods require the same collection and data setups. Therefore, for both tables, the collection times, frame extraction, and GPS/IMU/Frame sync columns are the same. These methods are only with respect to the software used to generate the 2D mosaic and/or 3D models. This places different demands on the amount of user intervention is required to create a bridge mosaic. For the 2D mosaic method (Table 21), each of the passes were required to be broken into smaller segments and then georeferenced together. This increased the amount of personnel time required for processing as the user is required to setup the mosaicking algorithm two to four time per pass depending on the length of the bridge. An average sized bridge of approximately 200 ft in length and 10,000 ft2 requires ~23 hours to produce a 2D mosaic. Approximately 5 hours, or 20% of the total time, is personnel time. On average, the 2D mosaicking method requires approximately 8.3 seconds per ft^2 of bridge deck.

Table 21. Total amount of time required to complete 2D mosaic products. Personnel and computer time are separated.

Bridge	Deck Area (sft)	Total Collection Time (min)	Extract Frames (min)	GPS, IMU, and Frame Sync (min)	2D Processing Software (hour)	Total Time (hours)
Personnel Time						
Harper	13,939	13.4	6	24.2	2.8	3.5
Miller	6,000	14.2	12	48.3	5.6	6.8
Mt. Vernon	4,685	13.8	6	24.2	2.8	3.5
Pennsylvania	6,836	6.4	6	24.2	4.2	4.8
Virgil	14,340	14.4	6	24.2	2.8	3.5
Jackson	8,261	5	6	24.4	2.8	3.4
J-Drive	10,127	5.6	4	16.1	4.7	5.1
N-Drive	15,441	6.7	4	16.1	4.1	4.5
Garfield	23,129	8.1	4	16.2	5.3	5.7
I-69 Bridges	11,122	25.8	8	32.2	9.3	10.4
Computing Time						
Harper	13,939		62		18.8	19.8
Miller	6,000		77		37.6	38.9
Mt. Vernon	4,685		49		18.8	19.6
Pennsylvania	6,836		57		28.2	29.1
Virgil	14,340		77		18.8	20.1
Jackson	8,261		76		10.8	12.1
J-Drive	10,127		10		18.0	18.2
N-Drive	15,441		28		15.8	16.2
Garfield	23,129		76		20.3	21.5
I-69 Bridges	11,122		47		36.0	36.8

Using the 3D modeling method with Agisoft PhotoScan requires less personnel time than the 2D mosaic method. Table 22 shows that it required less than a half an hour of personnel time to process a full bridge with this method. The same bridges required 2-5 hours of personnel time for the 2D mosaic method. The computer processing time is also generally less for the 3D method than the 2D mosaic. The I-69 North bridge was processed in only 2.4 hours using a reduced 3D resolution processing setting. This could be an option to reduce computer processing time and only characterizing spalls which are at least an inch deep. An average sized bridge of approximately 200 ft in length and 10,000 ft2 requires ~15 hours to produce a 3D model. Approximately 0.5 hours, or less than 1% of the total time, is personnel time. On average, the 3D modeling method requires approximately 5.5 seconds per ft^2 of bridge deck.

Table 22. Total amount of time required to complete 3D products. Personnel and computer time are separated.

Bridge	Deck Area (sft)	Total Collection Time (min)	Extract Frames (min)	GPS, IMU, and Frame Sync (min)	3D Processing Setup (min)	3D Processing Software (hour)	Total Time (hours)
Personnel Time							
Jackson	8,261	5	6	24.4	20		0.9
J-Drive	10,127	5.6	4	16.1	18		0.7
N-Drive	15,441	6.7	4	16.1	20		0.8
Garfield	23,129	8.1	4	16.2	12		0.7
I-69N	5,497	12.9	4	16.1	8		0.7
Computing Time							
Jackson	8,261		76.4			11.2	12.5
J-Drive	10,127		10.0			12.4	12.6
N-Drive	15,441		28.0			10	10.5
Garfield	23,129		76.1			46.4	47.7
I-69N	5,497		24.0			2	2.4

3.3 Cost Analysis

For comparing the cost using traditional methods and 3DOBS, an hourly rate $60/hour was used from the previous Phase II final report. The amount of time for MDOT's traditional methods was compared to both the 2D mosaic and 3D methods of 3DOBS. The time requirements used to generate cost includes the collection time through the generation of element level condition state tables. The cost for traditional methods is separated between a standard visual inspection and creating drawings similar to the maps generated from 3DOBS methods. Table 23 shows a breakdown of the associated cost for personnel time for each method. The estimated costs for each method does not include drive time to and from a bridge and assumes 3DOBS was setup before leaving the office. For both sets of bridges in each region, 3DOBS was able to collect all five bridge within a single day in the field and the vehicle mount and camera were not removed from the truck.

Table 23. A breakdown of the estimated cost between the 3DOBS 2D mosaic and 3D methods along with the traditional bridge deck inspection technique.

Bridge	Personnel Time (hr)	Cost (at $60/hr)
2D Mosaic		
Harper	4.6	277
Miller	7.9	476
Mt. Vernon	4.6	277
Pennsylvania	5.9	354
Virgil	4.6	278
Jackson	4.5	268
J-Drive	6.2	371
N-Drive	5.6	337
Garfield	6.8	408
I-69N	6.5	390
3D Method		
Jackson	1.7	104
J-Drive	1.3	78
N-Drive	1.4	87
Garfield	1.6	94
I-69N	1.6	97
Inspector Using Traditional Methods		
Harper	0.3	18
Miller	0.3	18
Mt. Vernon	0.3	18
Pennsylvania	1.1	66
Virgil	0.8	48
Jackson	0.5	30
J-Drive	0.3	18
N-Drive	0.5	30
Garfield	1.0	60
I-69N	1.4	84

The average cost to generate element level condition state results using the 3DOBS 2D mosaic method is $343 per bridge. This time includes all of the personnel time required from collecting the imagery of a bridge though producing the condition state tables. With the advancements made in developing the MTRI built GPS/IMU, this cost was reduced to an average of $92 per bridge. The cost savings is due to the reduction of personnel intervention needed to complete each pass of a bridge when compared to the 2D mosaic method. The average cost for an inspector over the same bridges is $39.

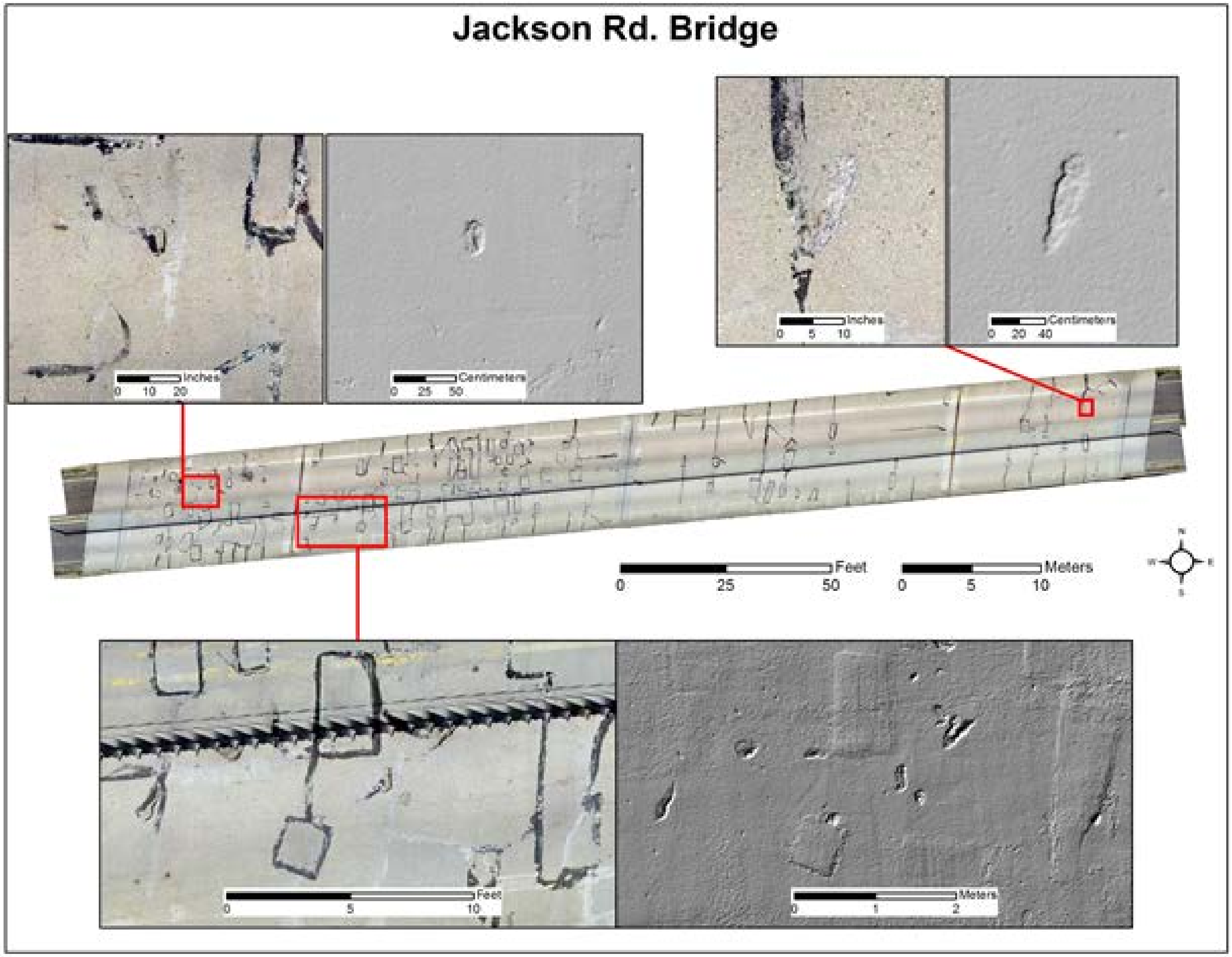
For producing standard element level condition state tables, 3DOBS cost more than a traditional inspector, but is still estimated to be less than $100 for an average bridge in this study. 3DOBS is capable of delivering detailed results which are similar to those of bridge scoping without the need to close lanes on a bridge. When the use case of 3DOBS is to replace the visual inspection portion of a bridge deck scoping, it is significantly cheaper than current methods, in which a simple lane closure cost approximately $1,600/day for a contractor to place barricades for the inspectors to conduct an inspection, as compared to where 3DOBS does not require the need for any lane closures. The amount of time required for an inspector is also increased due to the need for drawing detailed maps of surface defects and requiring a cherry picker to get an inspector elevated to take pictures of a bridge deck.

With the implementation of 3DOBS the bridge deck would only need to be closed long enough to do a sounding and mark areas of potential delaminations. Once that work is completed, 3DOBS would be used to collect high resolution imagery of the entire bridge deck without additional lane closures within a half hour of total collection time for an average sized bridge deck. The mosaicked imagery produced by 3DOBS would enable the inspectors to not only digitize the surface defects but also the outlines of the potentially delaminated areas as well.

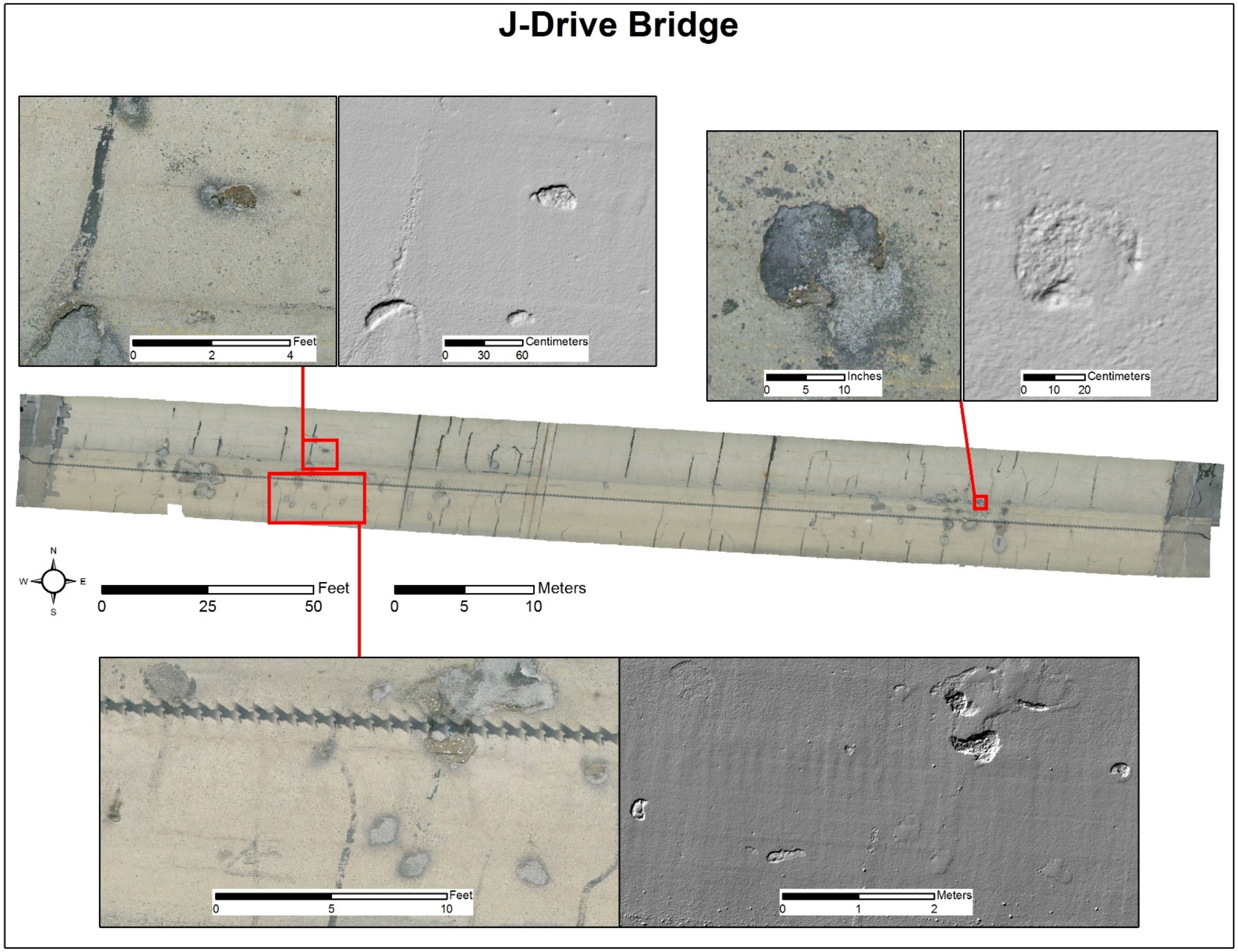
A potential upgrade for 3DOBS is to add a thermal camera to the vehicle setup. As shown in the previous phase the two cameras have the capability to produce a detailed assessment of surface and subsurface defects of a bridge deck. Currently, the thermal imagery needs to be manually mosaicked and georeferenced over the high resolution mosaic currently generated by 3DOBS. This process could also be automated in the future to produce referenced thermal mosaics of bridge decks to digitize potential delaminations.

Appendix A - 3DOBS 3D Bridge Reconstructions

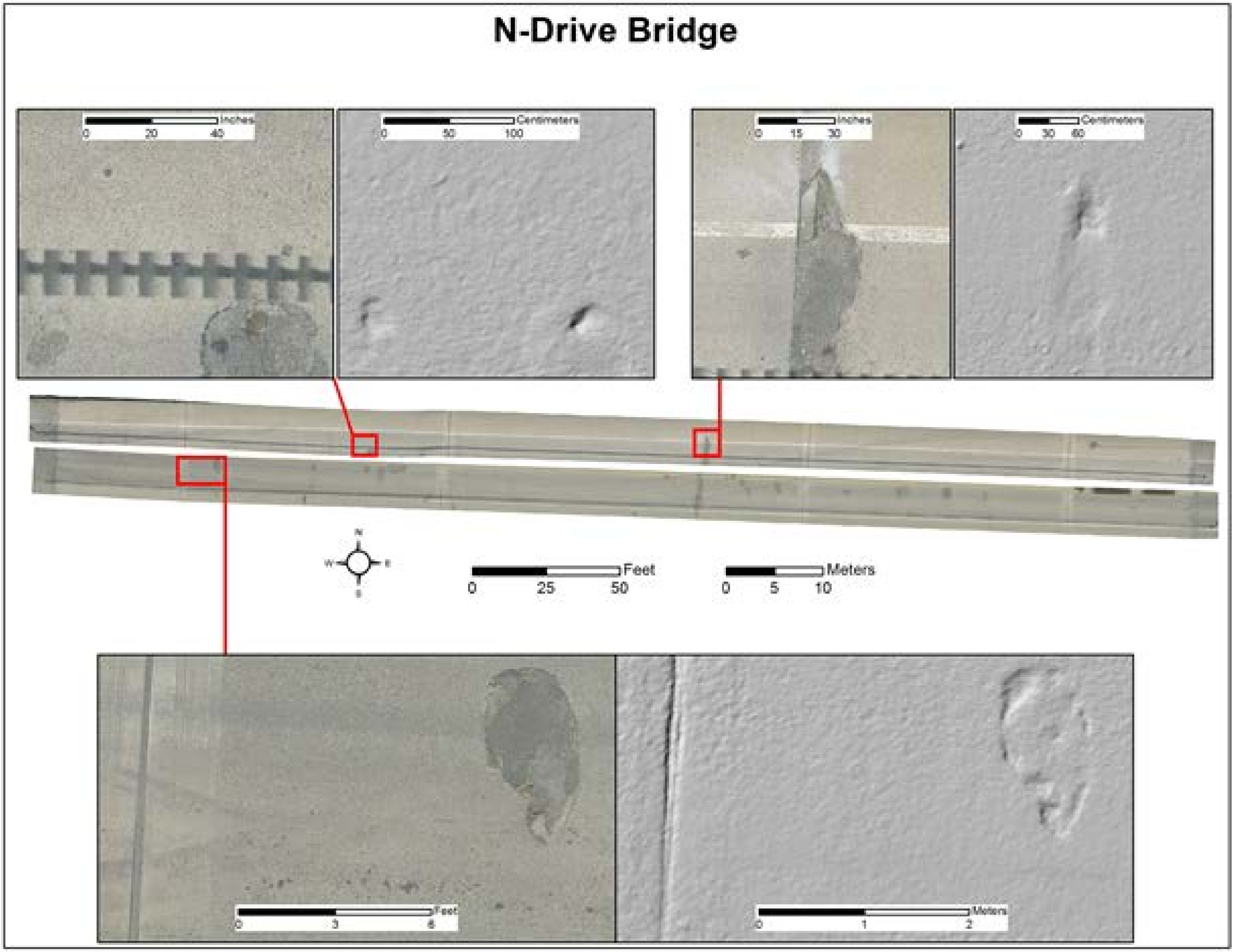
Jackson



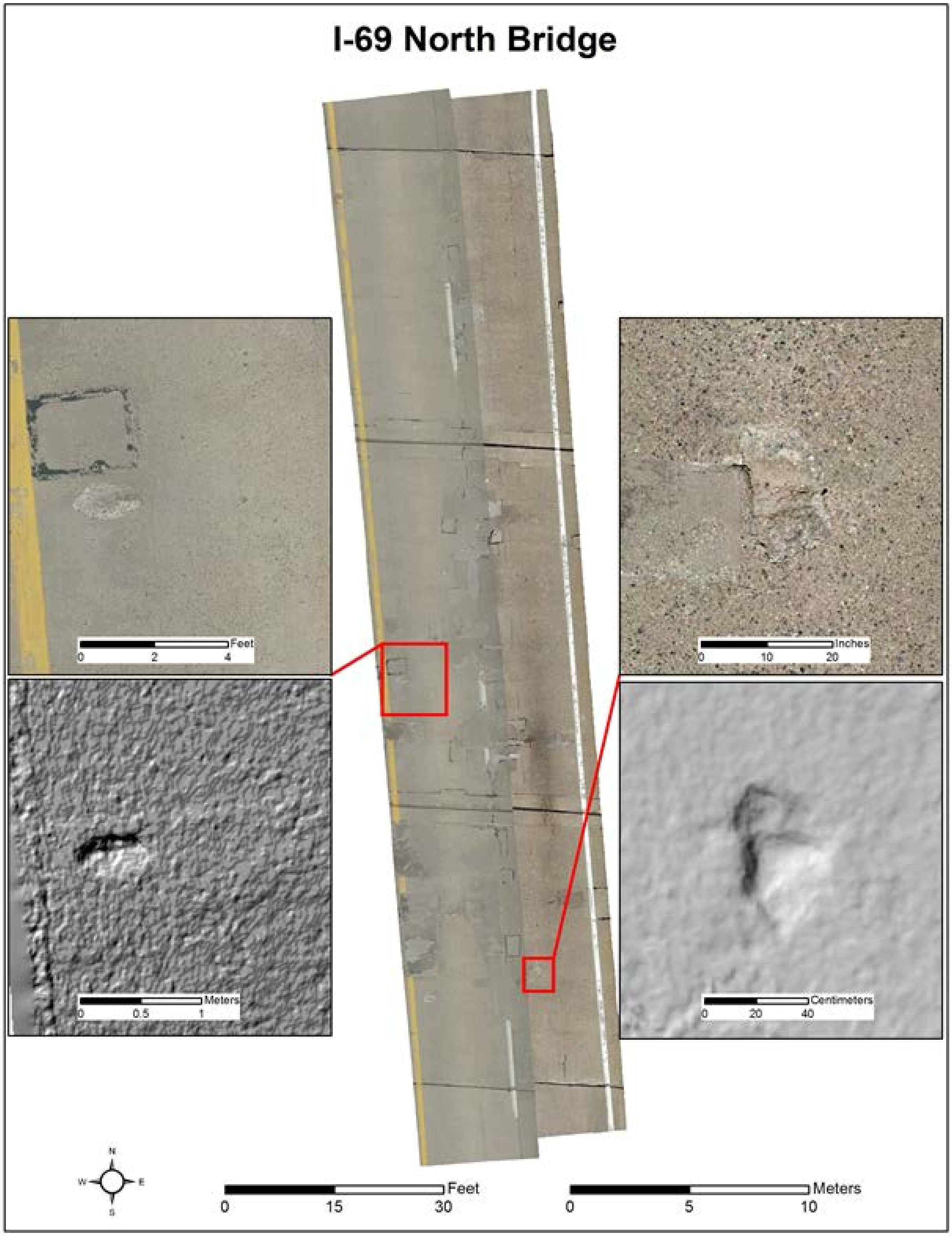
J-Drive


J-Drive Bridge
Feet
0 2 4
Centimeters
0 30 60
Inches
0 5 10
Centimeters
0 10 20
N
W
E
S
Feet
0 25 50
Meters
0 5 10
Feet
0 5 10
Meters
0 1 2

N-Drive


N-Drive Bridge
Inches
0 20 40
Centimeters
0 50 100
Inches
0 15 30
Centimeters
0 30 60
Feet
0 25 50
Meters
0 5 10
Feet
0 3 6
Meters
0 1 2

I-69N


I-69 North Bridge
Feet
0 2 4
Meters
0 0.5 1
Inches
0 10 20
Centimeters
0 20 40
N
W E
S
Feet
0 15 30
Meters
0 5 10