TECHNOLOGY SOLUTIONS FOR STRATEGIC BRIDGE INSPECTIONS IN SOUTH AFRICA

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ABSTRACT

Principal bridge inspections for strategic bridges require an Under-bridge Inspection Unit (UBIU). Strategic bridges have restricted access due to the height and size of the structures or when the structure is located over a perennial river. The cost associated with strategic bridge inspections can be substantial depending on the size of the structure and duration of inspection. The Council for Scientific and Industrial Research (CSIR) has been investigating the application of new technologies such as Unmanned Arial Vehicles (UAVs) to capture image data and photogrammetry software to process images and creating point cloud models, to enhance the current bridge inspection methodology in accordance with Technical Methods for Highways (TMH) 19. Research to date indicates that bridge inspections can be performed off-site using only point cloud models and captured images, to identify defects and complete inspection forms as an alternative bridge inspection methodology. This paper investigates the practicality of replacing the use of an UBIU for strategic bridges and alternatively capture image data with an UAV and performing inspections using the new proposed inspection methodology. The paper also includes the comparison of the cost and time components of the new inspection methodology versus traditional TMH19 visual inspections. This study aims to reduce the cost of bridge inspections and to improve the safety of bridge inspectors.

1 INTRODUCTION

1.1 Background

The proposed new inspection methodology utilises Unmanned Aerial Vehicles (UAVs), photogrammetry, computer vision and deep learning techniques, aiming to improve the overall quality and consistency of bridge inspections, while considering the cost and time components.

UAVs have the ability to capture image data of bridge structures where human accessibility is limited. By processing the captured images using photogrammetry software, a point cloud model can be developed. These models and images could then be used as a reference for inspections and reduce physical site visits where possible. It is important to consider all the cost and time components of the new proposed inspection methodology to determine if the enhancements and utilisation of technologies are beneficial to all users.

The CSIR has been investigating the application of new technologies such as UAVs to capture image data and photogrammetry software to process images and create point cloud models, to enhance the current TMH19 bridge inspection methodology (COTO, 2020a); (COTO, 2020b).

Research conducted by the CSIR to date indicates that bridge inspections can be performed off-site using only point cloud models and captured images, to identify defects and complete inspection forms as an alternative bridge inspection methodology or to use as a screening process (Kemp, et al., 2021); (Kemp, et al., 2022). International studies have indicated success in this field of study and the need to adopt these technologies in a South African context has been identified (Wells & Lovelace, 2018); (Ciampa, et al., 2019); (Jahanshahi, et al., 2009); (Perry, et al., 2020); (Hallermann, et al., 2018); (PIARC, 2018).

A three-phased study conducted by the Minnesota Department of Transport together with industry stakeholders, investigated the use of UAVs for bridge inspections. The study focussed on rules and regulations, UAV hardware and the ability of UAVs to collect quality inspection data. The ability of UAV technology to conduct bridge inspections was confirmed by the Minnesota study, but the practicality to conduct network inspections of thousands of structures is yet to be determined and specific use cases need to be identified (Wells & Lovelace, 2018).

A study by the Purdue University School of Aviation and Transportation Technology, West Lafayette, focussed on using UAVs to remove bridge inspection workers from potential harm. This paper investigated in greater detail the potential use for UAVs to increase the safety of bridge inspection and includes the results of a survey of bridge inspectors, as well as a benefit cost methodology that utilised worker compensation rates to quantify the safety benefits of UAVs; the methodology was demonstrated using a case study for the Indiana State Department of Transport (Hubbard & Hubbard, 2020).

Bridge inspections for strategic bridges require an Under Bridge Inspection Unit (UBIU) as shown in Figure 1-1. Strategic bridges have restricted access due to the height and size of the structure or when located over a perennial river. The new methodology could replace the use of an UBIU and capture images with an UAV, reducing the cost of strategic inspections and ensure the safety of bridge inspectors.

Figure 1-1: The Under Bridge Inspection Unit being used on the bridge across the Orange River at the Vioolsdrif border post between South Africa and Namibia (Source: SANRAL)

1.2 Aim & Scope

The objective of this study is to compare cost and time components of traditional TMH19 inspections and the new inspection methodology. The paper also intends to investigate the practicality of replacing the use of an UBIU for strategic bridge inspections and alternatively capture image data with an UAV and perform inspections using the new proposed inspection methodology. This study aims to reduce the cost of strategic bridge inspections and to improve the safety of bridge inspectors.

2 METHODOLOGY

2.1 Calculation of cost and time components

To determine if the new inspection methodology has cost and time saving benefits, the cost and time components of traditional TMH19 bridge inspections and inspections using only point cloud models and images, were compared.

Data were collected from a consulting engineering company conducting routine visual inspections of structures on a provincial road network. The inspections took place in 2019 over a period of 11 days and included the visual inspections of 121 bridges and culverts. The data collected included the actual time spent on inspections, the total duration of inspections and the cost associated with each inspection. Each of the structures were inspected by either a COTO accredited senior bridge inspector or culvert inspector accompanied by a technical assistant. The team consisted of three inspectors and three technical assistants who conducted inspections simultaneously.

The cost and time components of the new inspection methodology were estimated based on the data recorded for capturing the image data, processing the images and the inspections of the selected structures. The cost of capturing and processing the images were based on the actual quotation. The cost of new inspections was based on the professional fees supplied by the consulting engineering company.

The cost and time components for travelling to site and between the structures would be the same using either the traditional TMH19 inspection methodology or the new inspection methodology. For this study the travel components were thus omitted.

2.2 Strategic bridge inspections

A specific use case for the new methodology was identified. Replacing the use of an UBIU for strategic bridge inspections with capturing images with an UAV was investigated. Image data for a strategic bridge (P155_01N_B3886) located over the Vaal River in Vereeniging was captured in collaboration with Zutari.

Images of the bridge were captured using the Mavic 2 Pro and a Zenmuse x4S camera, mounted on the bottom of the UAV. As shown in Figure 2-1, the UAV was fitted with a protective cage which enabled the UAV to fly closer to the structure. The captured images were processed using photogrammetry software to create the point cloud model presented in Figure 2-2.

The quality of the point cloud model was considered to determine if a principal bridge inspector would be able to inspect the bearings and the bottom of the deck slab of the structure.

The cost of hiring and using an UBIU for one day to inspect the strategic bridge was obtained from the company managing the UBIU on behalf of SANRAL. The UBIU hiring cost was compared to the cost of capturing and processing image data.

Figure 2-1: Mavic 2 Pro UAV with a protective cage

Figure 2-2: Point cloud model of strategic bridge P155_01N_B3886

3 RESULTS

3.1 Cost and time components of traditional TMH19 inspections

The data collected from the consulting engineering company was analysed and the average time and cost of the inspections for the different structure asset classes were calculated.

The cost of each inspected structure was calculated based on the actual time spent on the inspection and the inspector's and technical assistant's professional fees. The inspections were in close proximity of the consulting engineering company's offices and travel was charged as a lump sum and not included in the cost calculation.

Although the cost for each structure was calculated based on the actual time spent on each inspection, the total duration of the inspection was of interest to this study as it includes the preparation time on site. The cost and time calculations included the completion of inspection sheets on site. The inspection sheets were then manually captured in the BMS on return to the office.

3.2 Cost and time components of new inspection methodology

The new inspection methodology included additional components compared to traditional TMH19 inspections. The new inspection methodology consists of three main tasks: capturing of images, processing of images, and the inspection of structures using the point cloud model and images.

For this study, the duration of processing the images only considers the manual input required to create point cloud models and excludes the computation time. The duration of processing the captured images to create point cloud models included the following:

- Initial setup - 30 minutes of manual processing and two and a half hours computation time, and
- Addition of control - one hour of manual processing and four to five hours computation time.

The manual processing required to create the point cloud models was estimated to be one and a half hours per structure.

Two senior bridge inspectors were approached to perform inspections using only the point cloud models and captured images of two bridge structures. Culverts were not inspected as part of this study but a conservative estimate of 30 minutes for a large culvert inspection was used based on the duration of the bridge inspections.

The cost of capturing and processing the images was calculated based on the actual quoted amount. The cost was not calculated per hour but as a unit cost per structure. The cost included capturing the images, processing the images and the use of equipment. The cost per structure was R 12 000.

The cost of each new inspection and completing inspection sheets were calculated using the same professional hourly fees provided by the consulting engineering company.

The duration and cost involving the new inspection methodology and traditional TMH19 inspections were compiled for comparison. Image data were captured for only large and medium bridges and major culverts. The cost and time components for the three structure asset classes are summarised in

Table 3-1 and Table 3-2.

Table 3-1: Summary of inspection time components

Time components	Culverts	Bridges	
	Major	Medium	Large
New Inspection Methodology			
Preparation for capturing images	0.30	0:35	0.45
Duration of capturing images			
Image processing	1:30	1:30	1:30
Preparation of inspection	0:30	0:35	1:15
Duration of inspection			
Completion of inspection sheet			
Total Duration	**2:30**	**2:40**	**3:30**
Traditional TMH 19 Inspections			
Preparation of inspection	0:45	1:00	1:10
Duration of inspection			
Completion of inspection sheet			
Total Duration	**0:46**	**1:02**	**1:10**

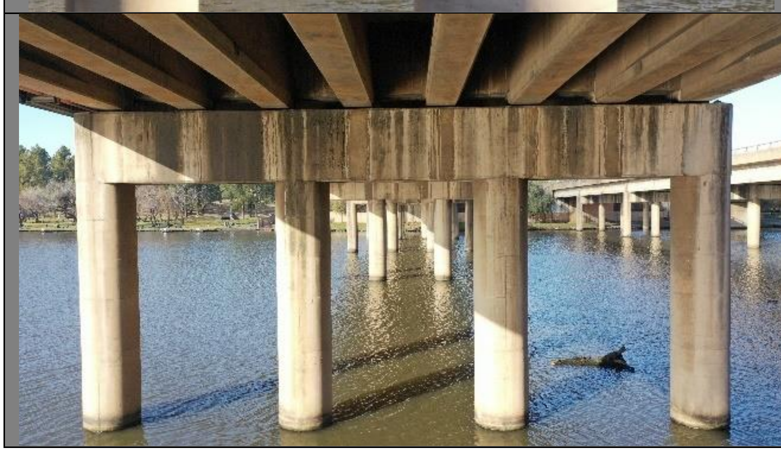
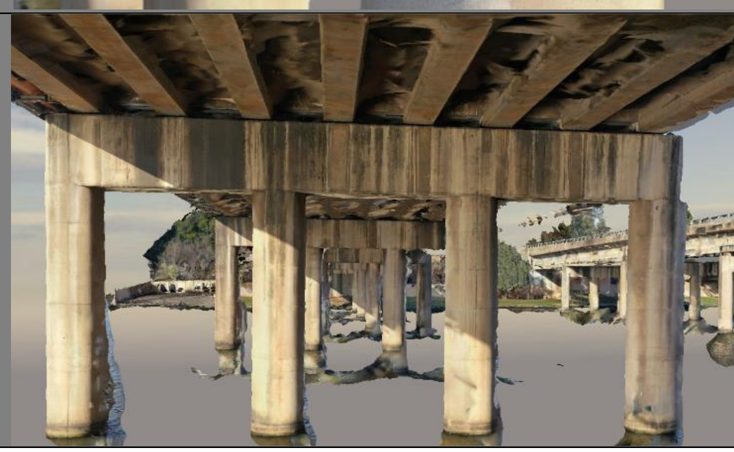
Table 3-2: Summary of inspection cost components

Cost components	Culverts	Bridges	
	Major	Medium	Large
New Inspection Methodology			
Preparation for capturing images Cost of capturing images Image processing	R 12 000	R 12 000	R 12 000
Preparation of inspection Cost of inspection Completion of inspection sheet	R 406	R 892	R 1 925
Total Cost	**R 12 406**	**R 12 892**	**R 13 925**
Traditional TMH 19 Inspections			
Preparation of inspection Cost of inspection Completion of inspection sheet	R 3 625	R 5 476	R 5 786
Total Cost	**R 3 625**	**R 5 476**	**R 5 786**

3.3 Strategic bridge inspections

The cost of capturing the images, processing the image data, and creating the point cloud model of the strategic bridge was R29 398.60. A quotation was obtained from SQS INDUSTRIAL SOLUTIONS (PTY) LTD (the company managing the UBIU on behalf of SANRAL) for the hire and use of an UBIU for the inspection of the Vaal River bridge for one day. The quoted amount was R76 261.10 and included the transport of the unit. Surveying the entire structure and capturing the images and reference points took approximately three hours to complete.

The quality of the point cloud model has improved compared to the initial CSIR study in 2019. The bearings and deck slab underneath the bridge are more visible and illuminated. Figure 3-1Table 4-1 presents the captured images versus point cloud model.

Captured Image	Point Cloud Model
	
	

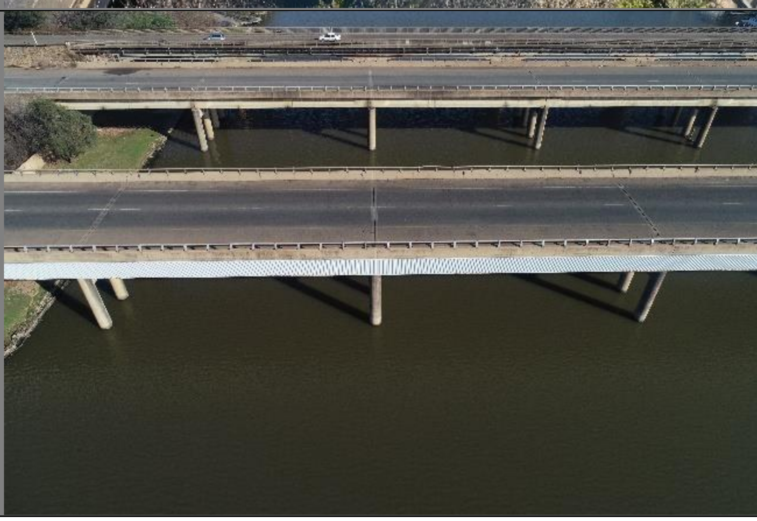
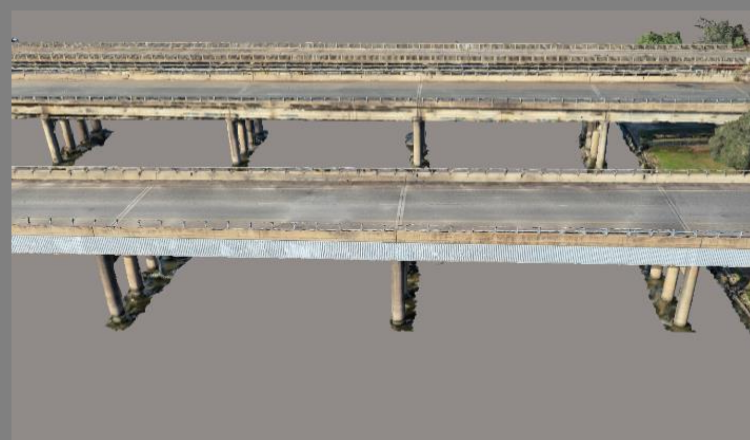
Captured Image	Point Cloud Model
	
	

Figure 3-1: Original captured image versus point cloud model

4 DISCUSSION OF RESULTS

The cost and time components of the new inspection methodology and the traditional TMH19 inspections were compared to determine if the new inspection methodology have cost or time saving benefits. The structure classes used for comparison were major culverts, medium bridges, large bridges and strategic bridges. The total cost and duration of inspections for each structure type are summarised in

Table 4-1.

Table 4-1: Summary of the total cost and duration of inspections

	Culvert	Bridges		
	Major	Medium	Large	Strategic
New Inspection Methodology				
Cost	R 12 406	R 12 892	R 13 925	R 29 400
Duration	2:30	2:40	3:30	-
Traditional TMH 19 Inspections				
Cost	R 3 625	R 5 476	R 5 786	R 76 261
Duration	0:46	1:02	1:10	-
Comparison (Percentage)				
Cost	242%	135%	141%	- 159%
Duration	226%	158%	200%	

The total duration of the new inspection methodology was 226% longer than the duration of traditional TMH19 inspections for major culverts, 158% longer for medium bridges and 200% longer for large bridges. Considering only the inspection components of the new inspection methodology, the duration of inspections using point cloud models and images was shorter for large culverts and medium bridges.

The overall cost calculated for the new inspection methodology is considerably higher compared to the traditional TMH19 inspections. The cost for major culverts is 242% higher, 135% higher for medium bridges and 141% higher for large bridges. Capturing and processing the images were the largest cost component. The cost of the inspection components for the new methodology was significantly lower for all asset classes compared to the traditional TMH19 inspections. The inspectors did not require a technical assistant for the new inspections and the duration of inspections was shorter for the large culvert and medium bridge.

The cost of capturing the images, processing the image data, and creating a point cloud model was 159% less than the cost to hire and use a UBIU for one day to inspect the same structure. The costs only include the hiring and use of equipment and not the cost of appointing a principal bridge inspector to conduct the inspection.

5 CONCLUSIONS

The new inspection methodology did not have cost or time saving benefits considering the total cost and duration, compared to traditional TMH19 inspections. However, the inspection component of the new inspection methodology has potential cost and time saving benefits. Inspections from point cloud models and images could be performed faster compared to the traditional TMH19 inspections if the inspector is comfortable and accustomed to the new inspection methodology. The new inspection methodology does not require a technical assistant and inspections could be performed off-site. Bridge inspectors do not have to travel between structures and could inspect more structures per day.

Bridge inspection is still a relatively new application for UAVs in South Africa and as the demand increases to capture images of bridge structures for an entire road network, the cost could be reduced. Consulting engineering companies conducting bridge inspections could build internal capacity to capture and process images. Images could be preselected for processing to create point cloud models with fewer images and reduce the computation time.

Bridge inspections for strategic bridges require an Under Bridge Inspection Unit (UBIU). Strategic bridges have restricted access due to the height and size of the structure or when located over a perennial river. The new methodology could replace the use of an UBIU and capture images with an UAV, reducing the cost of strategic inspections and ensure the safety of bridge inspectors.

Additional components to consider for strategic bridge inspections using an UBIU for future studies include:

- The duration to inspect the bridge decks, piers, abutments, and bearings. The UBIU’s platform has to be lifted and then lowered before and after each pier when inspecting these sub-structure elements;
- The cost of the principal bridge inspector to inspect a strategic bridge;
- Traffic accommodation costs. The use of the UBIU could require the closure of lanes of the road crossing the bridge;
- Road users time to cross the bridge if a lane is closed and a stop-go control is implemented;
- The availability and transport of the unit. Currently there is only one UBIU (owned by SANRAL) available in South Africa, and
- The physical restrictions of the unit. If the sidewalk of a bridge is too wide the UBIU’s arm will be too short to reach underneath the structure.

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