TECHBRIEF

Effective Practices for Managing Bridge Inspection Data Captured by UAS

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This document is one in a series of technical summaries that accompany the forthcoming Federal Highway Administration report *Collection of Data with Unmanned Aerial Systems (UAS) for Bridge Inspection and Construction Inspection*.

INTRODUCTION

The first bridge owners to integrate unmanned aerial systems (UAS) into bridge inspection processes have found that managing the data collected using this emerging technology requires dedicated attention to detail, forethought, and planning. The effective data-management practices discussed in this TechBrief address how early adopting State departments of transportation (DOTs)—among them Maine, Minnesota, and Utah—are using specific techniques to collect, store, and archive UAS data that allow the information to be recalled, analyzed, used for reporting purposes, and shared with others. The data-management practices used by these and other early adopting States have evolved as their experience with UAS has grown. These practices help improve an agency's ability to capture, review, and store field-collected UAS data; archive and present UAS data through bridge modeling; expand methods and media to store and archive data for future recall and use; and integrate UAS data within a bridge management system (BMS).

BACKGROUND

A significant aspect of incorporating UAS into a bridge inspection program is dealing with the amount of data that can be collected on every bridge inspected. Unlike the data collected on a bridge when using traditional inspection techniques and procedures, all data captured by a UAS is digital, with the vast majority of the information in the form of high-definition images and video. When introducing UAS as a tool for inspections, the bridge owner will need to decide the methods and means of handling UAS data both in the field and in the office. This TechBrief presents practices developed through the experience of early adopting State DOTs that can serve as lessons for new users of UAS technologies for bridge inspections.

As has been demonstrated by the early adopting States, UAS can serve as a powerful tool to augment and enhance the bridge-inspection process. While a UAS *can* collect massive amounts of data, no current requirements are in place that demand the inspector capture and then save all the images and video collected. The effective practices

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discussed in this document begin with proper planning and field-collection techniques, which are the first steps for managing UAS inspection data.

For long, complex bridges where the inspection team is tasked with capturing video of the entire structure, collecting and storing 30 gigabytes (GB) of data or more while in the field is not uncommon. Storing such large amounts of data can become burdensome to a bridge owner, and the time and effort required to analyze images and extract the data needed to illustrate bridge defects can greatly increase labor hours on the back end of the inspection, thus reducing the efficiencies achieved when employing UAS.

Effective techniques and processes to manage the large amount of data collected for an individual project and to catalogue and archive the data for later recall are important components of any inspection program that incorporates UAS for data capture. The practices addressed in this document include focusing the UAS image-collection efforts on defects, thus limiting data collected in the field to needed images only; creating three-dimensional (3D) models to catalog, present, and archive data; using different data storage methods; and integrating collected data with an existing BMS.

MANAGING UAS DATA IN THE FIELD

One challenge that comes with the ability to collect large volumes of data is the storage requirement. Storing data is not complicated; what creates issues is collecting too much of the wrong data. If an organization lacks the capacity or desires not to store large amounts of UAS data on its internal network, a means must exist whereby the inspection team can effectively manage inspection data while in the field.

Preplanning

Effective management of UAS data starts prior to arrival at the bridge site. Determining what data are needed begins with a thorough examination of the bridge prior to inspection by reviewing available photographs and past inspection results. During initial planning, the inspection team will determine whether the entire bridge will be imaged (a requirement if a 3D model of the bridge is to be created) or only certain bridge elements, perhaps those with known defects.

The inspection team should create a flight plan that details the order in which the bridge will be recorded. Crafting a plan to cover areas of concern the inspector wishes to film, while also reexamining previously identified defects and searching for new defects in an efficient manner, will go a long way toward limiting the number of flights needed and thus the number of images collected.

Field Review

By performing an effective review of the UAS imagery while onsite, an inspector can ensure all the necessary data has been collected as well as delete any unnecessary images or video, thus limiting the amount of data stored for transport back to the office. Inspectors working for the Maine DOT take two opportunities to review and select the best images to tell the story of the inspection while in the field. The first is an in-flight review, and the second is a post-flight review conducted in a mobile field office.

The agency uses a two-person UAS operating team: a certified UAS pilot who operates the UAS and a qualified bridge inspector who operates the primary UAS sensor. The pilot's responsibility is focused solely on flying the UAS safely and in accordance with the flight plan. The inspector observes the video feed from the primary UAS sensor and directs the pilot to position the platform so the bridge structure can be examined more closely when defects are detected.

In Maine, the inspector typically uses a separate controller to direct one of two sensors on the UAS. The inspector views the bridge with a dedicated monitor and can designate still images with a separate sensor controller. In lieu of the separate monitor, first-person view (FPV) goggles can also be used when working within this two-person operating team. The use of FPV may allow the inspector to better focus on bridge components and more precisely direct the main sensor toward areas of interest.

Using a Mobile Field Office

Managing data in the field comes down to a straightforward series of activities: capturing bridge images; reviewing the images to determine usability; selecting the images that best supplement the inspector's narrative, notes, sketches, and recommendations; deleting images or video not useable or necessary for inspection reporting purposes; and storing the images selected for retention on a temporary storage medium.

During flight, the inspector views and selects images deemed important to the inspection in real time. However, the fidelity and resolution of the data feed from the UAS is limited by the downlink from the sensor to the inspector's controller and monitor, which offers less than optimum image resolution for the inspector during UAS flight. The Maine DOT process involves a second review of the recorded imagery between flights to mitigate this issue.

For an optimum view of the images, inspection teams in Maine configure a mobile field office, which provides an additional quality review of the UAS imagery. The field office is typically the team's vehicle, often a van or towed trailer equipped with a computer, a high-definition monitor, and screens or blinds to darken the cabin for better viewing of the imagery. The storage device in the platform's sensor is removed and inserted into the computer, thus the highest quality imagery is viewed in the field in high definition.

This setup allows the inspector to ensure that the images captured adequately show the condition of the bridge and properly identify defects. It also enables the inspector to select the best images to use for reporting purposes. Should the images captured lack the desired quality or content, the operating team can repeat the flight since it is still onsite.

FULL BRIDGE IMAGING AND 3D MODELING

Another method for managing bridge imagery and other data captured by UAS is in the creation of a 3D bridge model after recording the entire bridge. While this method creates the most data possible, there are advantages to this method being explored by the Minnesota DOT (MnDOT) and its contracted consultant.

Archiving Full-Bridge-Structure Conditions

Modeling in 3D offers a novel method of displaying, comparing, and archiving bridge condition data. MnDOT has been experimenting with cloud-based 3D modeling (figure 1 and figure 2), also referred to as structure-from-motion (SfM) or reality modeling, as a tool for data presentation and storage (Wells and Lovelace 2018). This method creates efficiencies in digital storage by removing the need for local servers and allows the user to examine defects on a scaled virtual representation of the structure.

These models can be shared with interested parties and stakeholders by sending other users a link to access a particular model via the internet.

Figure 1. Graphic. MnDOT 3D bridge model.

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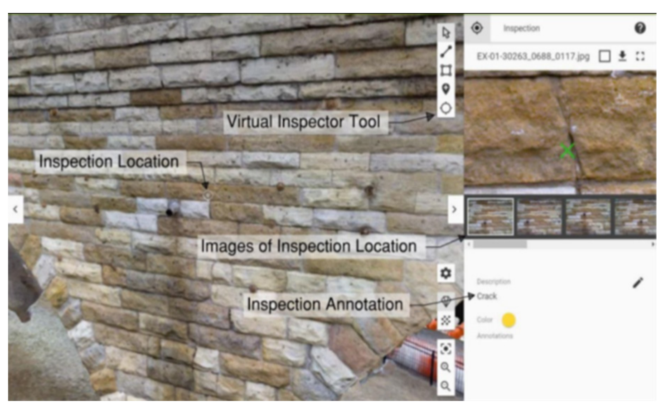
Managing data with this method requires collection of multiple georeferenced images to create an accurate model that typically ranges from 10 to 100 GB in total data depending on the size and complexity of the bridge structure. Capturing this amount of data for several bridges could cause issues for, or even overwhelm, the storage space on local network servers. The platform for the MnDOT 3D-storage model is cloud based, thus enabling the agency to avoid this potential issue.

In the case of the models created for MnDOT's UAS bridge-inspection research efforts, georeferenced JPEGs are taken using a 38-megapixel camera. With this high-resolution sensor, each JPEG is approximately 15 megabytes. The bridge model in figure 1 shows bridge number 27004 in Minneapolis, MN. This model was created using more than 720 images of the fascia and top of the bridge, resulting in a model size of nearly 11 GB.

While 3D models offer a means to store and display high-resolution images, they currently cannot be updated by capturing a specific image and inserting it into the existing model when a new defect is discovered. As a result, if an organization wants to continue using 3D models, and comparing one inspection image to another, a new model must be created during each subsequent inspection, requiring that the entire bridge be recorded again.

For reporting purposes, 3D models can be used as a supplemental means of inspecting delivered products, providing additional visual information along with the traditional inspection report. This complementary step is done by sharing the model over the internet with other stakeholders. While producing and sharing a 3D model does not satisfy current reporting requirements, it can be useful in communicating inspection findings when planning bridge maintenance and repairs.

Figure 2. Graphic. Selectable recall of images used in a 3D bridge model.



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Even though 3D modeling is an effective means of cataloging, sharing, and archiving data from an inspection, some consideration needs to be given to the bridge structure and the imagery capture process. While MnDOT has had success with 3D modeling, this process may not be ideal for all types of bridges. For example, Colorado DOT (CDOT) conducted a pilot project using a bridge in Glenwood Springs, CO, (figure 3 and figure 4) to assess the feasibility of employing 3D models to supplement numeric condition data with a visual representation of the condition of the entire structure. The agency believed such a process would be useful for reviewing the accuracy of numeric condition data, establishing the specific locations of defects, comparing condition changes across inspections, and assessing repair needs.

However, the team conducting the pilot project found that, due to the intricate nature of the structure and the poor quality of the Global Positioning System (GPS) signal available at the bridge location, it was unable to create a usable model. A 3D bridge model requires several accurately georeferenced images that overlap by approximately 80 percent for the program to stitch the images together correctly. CDOT was unable to obtain the needed imagery largely due to the lack of georeferenced images resulting from the lack of a consistent GPS signal.

Figure 3. Photo. UAS photo of the Glenwood Springs Bridge.

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Figure 4. Photo. Glenwood Springs Bridge structure with UAS capturing imagery.

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STORAGE METHODS

Even with effective review and management of data in the field, a large amount of data will still be retained by the bridge owner for archiving and future recall. Agencies have several options for storing this data: local storage on the responsible organization's servers, removable storage, and cloud storage. Each of these methods has pros and cons.

Local Server Storage

Local storage leveraging existing organizational information technology (IT) infrastructure and support personnel allows the bridge owner to access and manage data directly without adding to their IT footprint.

This can present a problem with long-term storage as the organization moves forward with incorporating more UAS-capable teams into their inspection process. The sheer volume of data can overwhelm local-network-storage capacity and present global data-management issues across the organization, thus necessitating additional storage space within the existing IT infrastructure.

Removable Media

An option to minimize the impact of storing such large volumes of data on organizational networks is using removable hard drives to augment storage. Removable hard drives allow the inspector to store, transport, and archive inspection data while in the field and to provide a simple means of transporting and transferring the data to the bridge owner without impacting the organization's local server capacity.

While both methods are sufficient for storage, each has drawbacks. Local server networks can be costly and often require IT personnel to maintain. Local networks can also be subject to cyberattack and data breach as well as loss of data though catastrophic events or data corruption. Removable hard drives, while having the benefit of being inexpensive and portable, carry the risk of data corruption, loss of the physical asset, and technology obsolescence, which may require the user to back up the data on another platform to ensure continued accessibility.

Cloud Storage Solutions

Some early UAS adopters are moving to the use of cloud services to store UAS inspection imagery and data. For example, Maine DOT, MnDOT, and

Utah DOT (UDOT) have all concluded that cloud storage offers definite advantages as a primary data-management approach. Cloud storage provides several service options, including backup, storage and file sharing, file hosting, file synching, and cloud computing. For this TechBrief, the focus is on storage and file sharing.

Cloud storage is a relatively low-cost means of storing large volumes of data without the need for expensive internal information technology (IT) infrastructure. The cost can be roughly $50 or $60 per year for a terabyte or more of storage space (Laporte 2015). This can appear to be a higher-cost solution than just buying an external hard drive in the terabyte range; however, unlike a local external hard drive, the service provider is responsible for maintaining and upgrading the hardware, not the bridge owner. Another benefit of cloud storage is that data are always accessible provided a network connection is available.

At the time of writing, Maine DOT planned to continue using a consultant to provide its UAS inspection services while contracting out for its cloud services. Following an inspection, the consultant uploads the inspection imagery to the cloud via the Maine DOT inspection report software suite. This suite is used to generate the inspection report and to archive the UAS data. The consultant also provides all the data captured by the UAS (images and video) to Maine DOT on portable media as another means of archiving the information.

MnDOT currently relies upon its supporting consultant to archive UAS data using the consultant's cloud services. MnDOT does envision having each county manage its own UAS program for bridge inspections, but this plan is in the early stages of implementation.

UDOT is developing its UAS program internally, using State resources and personnel for inspection activities. As a result, the agency is using the State's enterprise cloud services to store its UAS data. The State does use consultants on an as-needed basis to augment its inspections, and using the governmental cloud can limit the contractor's ability to access this storage solution fully. While there are issues to be resolved, the advantages of using the cloud are driving the State's ongoing transition to a cloud-storage solution.

Each of these three States has learned through early experience that the data needs resulting from incorporating UAS-based data collection into their inspection processes overwhelms their internal IT infrastructure, and as a result, all have migrated to a cloud-based solution as their UAS programs have matured.

Like large-volume storage, file sharing is another benefit of cloud-based storage. It provides a means to transfer large volumes of data that may otherwise be too large to be sent by other means.

Cloud-based solutions, however, are not without drawbacks. A primary concern for users is security. While most systems have security protocols in place, this does not mean that they are invulnerable. In recent years, a number of high-profile companies have suffered data breaches that compromised private information (Swinhoe 2020). A similar catastrophic event such as a fire, natural disaster, or a malicious attack could also jeopardize the bridge owner's information. Thus, it is important to research the service to be used to ensure it satisfies the needs of the data owner, including providing sufficient redundancy.

INTEGRATING UAS DATA INTO A BMS

Currently, data collected from UAS flights in the form of high-resolution color images are included in an inspection report in the same way as images captured with handheld cameras. The inspection reports and data are then uploaded to a BMS. At present, providing images for inclusion in a bridge inspection report is the sole means of supporting a BMS with UAS, as exemplified by Maine DOT, MnDOT, and UDOT.

While currently limited to imagery, bridge owners are envisioning additional ways that UAS data can support a BMS. Maine DOT foresees UAS images being used as examples in inspection guidance or manuals to illustrate condition states for bridge components that are difficult to access. Bearings are one such component. Images of the entire bearing can be taken from a UAS and included in a BMS to show examples of each condition state, enabling other users to examine and compare them.

Additionally, Maine DOT envisions UAS imagery being used to better quantify condition states and estimate repair costs, which can then be used in a BMS to better analyze and compare bridge needs, costs, and the benefits of performing repairs.

UDOT sees similar BMS applications on the horizon. With the incorporation of artificial intelligence applications, systems may be able to use UAS data to detect the quantity of bridge cracks more effectively and assign a condition state to the bridge component automatically. UAS data are enabling the bridge owner to collect better, more comprehensive information on the quality of defects found on high-use and large bridges. As processes and techniques advance, the value and application of UAS have the potential to provide more and better data for use in a BMS. UAS-collected data may also bring about changes to BMS features, processes, and computations that use refined data or metadata that better identify the location of defects, as can be afforded by 2D and 3D imagery and models.

Several products can be created using the data obtained from a UAS to enable engineers and inspectors to conduct detailed planning for maintenance, repairs, and inspection. Among these are the previously discussed 3D images as well as infrared images, which can be used to create detailed orthographics for mapping delaminations in concrete decks. These products could be attached to an inspection report in the form of a weblink and would serve to enhance and augment the overall information contained in an inspection report. A 3D model would enable the person reviewing the inspection report to view the defects in relation to the entire structure.

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