GUIDELINES FOR DRONE USE:

INFRASTRUCTURE INSPECTIONS

by

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Abstract

The application of Unoccupied Aerial Vehicles (UAVs) is becoming essential in many industries. The potential benefits of UAVs for inspecting inaccessible infrastructure is beginning to emerge as current methods are limited in their practicality, cost effectiveness, and lack the ability to provide a comprehensive status of infrastructure. Identifying the circumstances in which to utilize a UAV as an inspection method is unclear and therefore this research aims to identify the circumstances in which to utilize aerial technologies as an inspection tool for currently inaccessible infrastructure by capturing high-resolution images from a small-scale UAV and delivering those images through a web-based interface.

A notable increase in research on the application of UAVs within civil engineering was identified from 2011 onward. The increase in literature includes the use of UAVs as inspection tools, which is an advancement of current inspection procedures. A large number of UAVs are commercially available and users must determine the necessary features for their application. However, upon use of a UAV, the Transport Canada regulations must be met, including the application for a Special Flight Operation Certificate. The four-part case study completed provides an example of the value a UAV inspection method and as a result the requirement to develop guideline material. With the use of the guideline materials, including a selection flowchart, users have the ability to understand the conditions and constraints of a UAV inspection, along with the advantages of UAV and traditional inspection methods. The validation of this material by several industry experts demonstrates that engineers and inspectors value the necessary material for the decision making process of a preferred inspection method.
Dedication

To my late grandfather, Henry Albert Ferguson
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List of Acronyms

AEC: Architect, Engineering, and Construction

AR: Augmented Reality

CEM: Construction, Engineering, and Management Group

DTM: Digital Terrain Models

FPV: First Person View

GPS: Global Positioning System

GSD: Ground Sampling Distance

P3P: Phantom 3 Professional

MSE: Mechanically Stabilized Earth

NBDTI: New Brunswick Department of Transportation & Infrastructure

NSTIE: Nova Scotia Department of Transportation and Infrastructure Renewal

PEITIE: Prince Edward Island Department of Transportation, Infrastructure and Energy

SFOC: Special Flight Operation Certificate

TLS: Terrestrial Laser Scanner

UAV: Unoccupied Aerial Vehicle

UBI: Underwater Bridge Inspection

UNB: University of New Brunswick

VR: Virtual Reality
1 Introduction

This chapter introduces the author’s research through the necessary background material, research mission, pilot sites, and the deliverables. The background material in section 1.1 presents the overall frame of the research, which is then narrowed in the research mission, section 1.2. The pilot sites are first introduced in section 1.3 with further details in the following chapters. The intended deliverable of this research are outlined in section 1.4.

1.1 Background

1.1.1 Context

North America is faced with an infrastructure deficit and major investment is required to reach the serviceability of the post-war era. This research addresses the lack of a comprehensive method for inspecting inaccessible infrastructure, which has contributed to a lack of knowledge about the status of the deterioration of infrastructure. Current inspection methods for inaccessible infrastructure are not always practical and cost effective.

The increased use of Unoccupied Aerial Vehicles (UAVs) is apparent from the increase in retail sales. A large number of commercial UAVs are equipped with a camera that provides a real time, first person view (FPV), that gives users the ability to go beyond standard recording capabilities. However, the increased use of UAVs has also seen widespread misuse, as a result regulatory measures have been enacted. The potential of UAVs to capture high-quality images is matched with an increasing list of applications, including use as an engineering inspection and mapping tool.
With the prospect of UAVs to capture high-quality images, this potential can be combined with the benefits of augmented reality (AR) and virtual reality (VR) technology. The use of AR and VR technologies as a delivery mechanism for aerial data could prove to be beneficial to the industry for inspections and therefore provide a better understanding of the current status of infrastructure. This can be achieved through the use of aerial images that are captured with a small-scale UAV and delivered through a web-based, virtual reality, information management system.

1.1.2 Interested Participants

A range of industry participants would find this research valuable, including design teams, inspectors, safety officers, and engineers (Rankohi & Waugh, 2014). These participants would be interested in the practicality of a UAV as an inspection tool and the cost effectiveness when compared to traditional approaches.

1.1.3 Problem Statement

The current inspection process for inaccessible infrastructure is limited in its practicality, is not always a cost-effective approach, and lacks the ability to provide a comprehensive report on the status of infrastructure.

1.1.4 Research Question and Hypothesis

Industry practitioners require a method to determine if a UAV is an appropriate inspection method. This method could include understanding the advantages of select methods and the development of a selection flowchart. However, is it possible to develop useful guideline material for industry practitioners?
To address this question, research will be conducted on the following hypothesis: The proposed guideline materials are valuable for industry practitioners when selecting a cost-effective and practical inspection method. Industry experts will be asked to respond to this hypothesis regarding inaccessible infrastructure.

1.2 Research Mission

1.2.1 Goal

The goal of the research is to identify the circumstances in which to utilize aerial technologies as an inspection tool for currently inaccessible infrastructure by capturing high-resolution images from a small-scale UAV and delivering these images through a web-based interface.

1.2.2 Objectives

To achieve the goal, the following objectives have been identified:

1. To conduct a review of UAV and VR technologies along with a review of current inspection methods to identify the prominent traditional methods.

2. To develop a new inspection process with the use of a small-scale UAV that delivers high-resolution images through a web-based interface.

3. To perform four case studies on New Brunswick Infrastructure to test the practicality of aerial images as an inspection tool. The case studies are as follows:
   a. Robinsonville Mechanically Stabilized Earth (MSE) Wall,
   b. Longs Creek Bridge,
   c. Hawkshaw Bridge,
d. Reversing Falls Bridge.

4. To analyze and compare the results by
   a. determining the circumstances in which to utilize aerial technologies as an inspection tool;
   b. comparing similar traditional inspection methods.

5. To develop guidelines that will assist in the selection of a UAV inspection method.

6. To assess the inspection process in terms of practicality and cost effectiveness.

1.2.3 Assumptions

The technical assumptions were that a UAV would be capable of capturing quality images at each location in its respective environment and that the selected web-based interface would be an appropriate platform to act as an inspection delivery mechanism. The regulatory assumption was that a Special Flight Operation Certificate (SFOC) would be granted by Transport Canada. It was also assumed that the appropriate weather conditions would allow the UAV to operate throughout all four case studies.

1.2.4 Scope

The research only included the above four case studies at the specific areas of concern. At the Robinsonville MSE Wall, an aerial inspection was conducted on the primary wall with significant deterioration. The Longs Creek and Hawkshaw Bridge studies would only include an aerial inspection of the bridge towers and spacers. At the Reversing Falls Bridge, an aerial inspection would only be completed on three bridge footings and abutment walls.
The study only focused on provincial infrastructure during the maintenance and rehabilitation phase. According to the Rankohi & Waugh (2014) classifications, the target audience was inspectors and engineers and the maturity of the technology was identified as a ‘system application’ phase because it has shown potential benefits and industry is currently motivated to conduct pilot projects on the application of the technology. As it was possible to continue to try to improve the quality of the images captured, the number of site inspections was limited to two visits per location. Analysis and development of guideline material was limited to the UAV inspection method. A basic comparison was made to traditional inspection methods; however, details of select traditional inspection methods were not presented.

1.3 Pilot Sites

Four assets owned by the New Brunswick Department of Transportation & Infrastructure (NBDTI) have been selected that require an inspection on critical sections. One MSE wall, two cable-stayed bridges, and one arch bridge have been selected through collaboration with NBDTI engineers.

The Robinsonville MSE Wall is located along Route 17 in Squaw Cap, NB. The retaining wall is slowly deteriorating. NBDTI is concerned about the long-term status of the wall and need a record that can be used to compare future inspections. There have been previous repairs to the wall to mitigate erosion; however, these repairs were expensive and are not a practical solution for the entire wall. A UAV was used to capture aerial images of the wall and to create a 3D model that can be used for future comparisons. These images are expected to provide a better understanding of the severity of the erosion.
The Longs Creek and Hawkshaw Bridges are similar structures with similar site characteristics. The Longs Creek Bridge is located in Upper Kingsclear, NB on Route 102 where it crosses the Saint John River at the Scoodawabscook Bend. The Hawkshaw Bridge crosses the Saint John River at the Pokiok Bend in Southhampton, NB on the Hawkshaw Bridge Rd. NBDTI employees are concerned about the top of the bridge towers where the cables are connected. Previous inspections were completed with access along the side of the towers; however, due to new safety regulations it is not possible to safely access the top of the towers.

The Reversing Falls Bridge is located in Saint John, NB on Route 100 crossing over the Saint John River as the river enters into the Bay of Fundy. This bridge was selected for inspection of the footings because of concerns about erosion and rock fractures. Previous inspections of the footings were completed by contracting a remote access team that had the capacity and expertise to rappel down from the top of the bridge abutment via rope access and capture images of the bridge footings.

1.3.1 Analysis

To gain a better understanding of the benefits of completing infrastructure inspections using aerial technology, a comparison was completed between a UAV inspection method and traditional inspection methods. The analysis focuses on the comparison of similar traditional inspection methods that could be completed at the selected pilot sites. The analysis includes identifying the conditions and constraints of both methods, identifying the required resources for a UAV method, development of a selection flowchart, a cost breakdown, and the advantages of each method.
The conditions and constraints are presented to demonstrate that a UAV inspection is limited, as select parameters must exist. The resources necessary to complete an adequate inspection are presented. A selection flowchart has been developed to assist in the selection of an inspection method by inspectors and engineers. The cost breakdown and advantages of both methods are presented for comparison of the alternatives. This information is intended to provide inspectors and engineers with a basis to make an informed decision on an inspection method.

1.4 Deliverables

Through this research, industry will gain an understanding of the use of UAVs and will better understand when a UAV is an optimal choice for the inspection of inaccessible infrastructure. Through the use of a UAV as an inspection tool on the proposed infrastructure, NBDTI will gain a practical understanding of a new inspection method.
2 Literature Review

2.1 Introduction

This chapter is a literature review focused on UAVs in combination with augmented or virtual reality technologies in civil engineering. The literature review presents a framework for augmented and virtual reality literature in the architecture, engineering, construction (AEC) industry in section 2.2. Section 2.3 presents the state of the art applications of UAVs in civil engineering, section 2.4 describes various interfaces of augmented and virtual reality, and finally the traditional methods of inspection are presented in section 2.5.

2.2 Framework

This section presents a current framework of augmented and virtual reality literature in the AEC industry that was developed by a recent graduate of the UNB Construction Engineering Management (CEM) group and has been accepted by the author. Similarly a VR roadmap developed by Dawood (2009) on the future of virtual reality was also reviewed, but was not considered as a foundation for this research. Throughout this section, items of interest are stated that relate to the author’s research on inspection of inaccessible infrastructure.

AR provides users the ability to gain an in-depth understanding of AEC projects by combining 3D virtual models with real world images. Rankouhi and Waugh (2012) completed a literature review on AR technology in AEC projects and categorized the literature in the following categories: target audience, project phase, state of technology maturity, application area, and hardware. Of particular interest for this research is that
workers were found to be the largest target audience instead of the design team. The project phase has a higher research focus on the construction phase with limited articles of the maintenance phase. With respect to an application area visualization or simulation was found to be the top research focus and information access or evaluation only being a secondary area of interest.

Rankohi and Waugh (2014) stated in their literature review of virtual reality in the AEC industry that virtual reality provides users the ability to interact within a computer generated environment and real world scenes with three-dimensional objects and locations. Similar to their literature review on AR, the VR literature was categorized into the following categories: improvement focus, industry sector, project phase, target audience, technology maturity, technology role, and technology type. Of interest is that the industry sector research has a high emphasis on buildings/commercial with heavy/highway having a secondary focus, which is followed by infrastructure. Research related to project phase has a concentration towards construction, with maintenance and renovation in comparison having fewer publications. Literature on Inspectors/safety officers was not the main focus in respect to a target audience. Finally, research on the technology role is centred on visualization/simulation, with inspections/safety and progress monitoring having a limited focus.

With the above understanding of the current research in augmented and virtual reality, the author’s research will focus on utilizing technology for inspections during the maintenance phase of public infrastructure; therefore, the target audience of this research is focused on inspectors and engineers. The next section will discuss the literature found
by the author with respect to UAV technology applications and will present a brief analysis of the literature followed by a breakdown of the literature.

2.3 UAV Technology

Until recently UAVs have primarily been used for military applications and were considered too costly a device to own or operate; however, in recent years the commercialization of UAVs have made them a reasonably affordable way to capture aerial images. Select disciplines have tested the application of UAVs for aerial documentation; as early as 2006 the wildlife management discipline began to publish articles on the use of UAVs for wildlife research (Jones et al., 2006). In archaeology there has been the use of low altitude flying platforms to create digital surface models for accurate topographic data according to Martinez-del-Pozo et al. (2013). With a range of disciplines researching the use of UAVs, it is understandable that the civil engineering discipline is exploring the application and benefits of UAVs.

2.3.1 UAV Application Literature Analysis

A total of 31 articles that were related to the application of UAVs were found in 11 conference proceedings, 7 journal articles, and two reports from select transportation departments. The search criterion was articulated between January 2004 and December 2015 using the following keywords: unmanned aerial vehicles, micro unmanned aerial vehicles, and drones. The selected articles related to the application of UAVs weighing under 25kg. Figure 1 depicts the range in the publication years and shows articles began to appear in 2006; however, there was an increase in research from 2011 onward. Figure 2 shows the range of primary topics with the largest frequency on construction
management, structural, and transportation. Other related fields are surveying, post-disaster, flight planning, and research overview.

![Publication Date](image1)

**Figure 1: Publication Date**

![Primary Topic](image2)

**Figure 2: Primary Topic**

The purpose of this analysis was to provide a better understanding of the research publications and to understand the relevance of the information; along with identifying the primary focus of the research. With an increase in the number of articles published from 2011 onward, it is clear that the number of publications is growing and therefore...
research is on an upward trend. The following sections, 2.3.2 through 2.3.6 describe select articles from the disciplines identified in Figure 2. Articles of interest to the author and that provide insights into the current research area are described below.

2.3.2 Construction Management

Construction management is the main research focus with respect to the application of UAVs in the current research. Irizarry et al. (2012) and Gheisari et al. (2014) used the Parrot AR Drone to study the potential benefits of UAVs for safety managers. A two-part case study was conducted, first studying the flight operation interface to identify benefits and deficiencies. The second part was to determine the best viewing platforms by studying three different image-viewing options. As a result, it was found that the iPad was the best platform to utilize the technology for capturing and detecting safety management data.

Elhassan et al. (2015) compared two point cloud models created of an indoor building. One point cloud was created by collecting images with a handheld camera and the other method captured images with a UAV. The resulting point clouds were similar and it was therefore concluded that it would be beneficial to use a UAV to collect images of inaccessible areas in buildings, such as for power or nuclear plants. Wen et al. (2014a) used aerial images captured from a UAV to create AR scenes for planning and practice tools. A field test was completed by capturing a photo at approximately 150-200m altitude and integrating the image into an AR scene in combination with 3D construction plans. Wen et al. (2014b) completed a case study to determine if a UAV could be utilized to construct Digital Terrain Models (DTM) and found it to be more efficient and also valuable for DTM reconstruction. Zollmann et al. (2013) also completed a study using a
UAV in combination with AR technology. Through the use of aerial 3D reconstruction and AR technology, various interface methods were found for presenting the aerial data and information.

2.3.3 Structural

Khan et al. (2015) verified the feasibility of using infrared and red, green, blue cameras with a UAV by comparing experimental UAV tests with airborne (i.e. helicopter) and ground inspections. The authors predict that a UAV-based system could result in periodic rapid assessments of bridge decks and provide further details of select areas of interest. Ellenberg et al. (2014) compared human inspections to inspections conducted with a UAV and found that the result with a UAV can provide better quantitative results than that of a human inspection.

Zink and Lovelace (2015) prepared a report for the Minnesota Department of Transportation on the use of UAVs for bridge inspections. Four bridges of various sizes were selected as a pilot project and it was found that UAVs can be used as a tool for bridge inspections and should be considered for routine bridge inspections because they can minimize associated safety risks and reduce costs. Defects can be identified and measurements estimated; however, a UAV cannot replace hands-on functions (i.e., cleaning, sounding, testing, etc).

2.3.4 Transportation

Various transportation groups are studying the use of UAVs to collect data or to create applicable 3D models. Liu et al. (2013) completed a study to determine the usefulness of UAVs for traffic surveillance of sparse road networks in China. The authors
developed a framework for UAV deployment, route planning, and monitoring. Two case studies were performed and it was found to be beneficial; however, more UAVs were required to increase the response time. Liu et al. (2015) later conducted further studies on traffic surveillance and proposed new route planning algorithms to efficiently plan UAV routes; however, several other problems were identified that need solutions to optimize the use of UAVs for traffic surveillance.

Hart & Gharaibeh (2011) used UAVs to collect data for roadside condition assessments. A level of service field test was performed on 10 road samples using both aerial video and photographs, along with on-site inspectors. The authors found that the results between the on-site data and the data collected from the UAV matched 81% of the time. Zhang & Elaksher (2012) did further research on road conditions to create 3D models of a road surface. A field test was performed with the developed 3D model being compared to ground truth data and a 0.5 cm accuracy was found.

### 2.3.5 Surveying

Hugenholtz et al. (2014) used a UAV as a surveying tool to determine stockpile estimates. It was determined through proper aerial images and Photogrammetry that the accuracy of volumetric estimations could be better than that of LIDAR. Another surveying application was completed by Gonzalez-Jorge et al. (2014) to test the potential of UAVs to complete aerial surveys to monitor shoreline rubble mound breakwaters. Images were captured with a 75% overlap and processed using an algorithm that detected the characteristic change and as a result the authors were able to detect a 1°-rotation change in the breakwater rubble mound cubes. Similarly, Rodriques-Gonzalvez et al. (2014) used aerial images acquired from UAVs to create 3D imagery of electrical
substations, which eliminated problems of shadows, physical limitations, and safety concerns.

2.3.6 Other Research Areas

Other applications of UAVs are being explored for post-disaster scenarios because of their manoeuvrability and rapid response rate to complete post-disaster studies. Adams et al. (2012) completed a study using a UAV to capture images of individual buildings and the overall neighbourhood after a tornado. Yamamoto et al. (2014) also performed two case studies on disaster sites. The first case study was to use aerial images to create 3D data and resulted in an accuracy of 10-34 mm. The second case study was to study the use of aerial images to develop post-disaster plans and develop approximate construction costs. Along with application in post-disaster scenarios, UAV researchers have created various flight planning algorithms such as the ones completed by Siebert & Teizer (2014) for the creation of 3D point clouds and Metni and Hamel (2006) who presented an algorithm for bridge monitoring.

2.4 AR & VR Interfaces

Augmented and virtual reality technologies are not new to the AEC industry; however, the popularity of the technologies has increased. With an increasing trend in research showing the benefits of 4D (3D + time) modelling and specifically the benefits of AR and VR technology, the applications are now widespread. The following provides a brief summary of three AR and VR interfaces. The VRDoc interface is being summarized because it was developed by the UNB CEM group and is the interface of choice for the current research. The D^4AR and the VIRCON systems were also studied
and were found through typical research methods. These systems were determined to either be comparable to VRDoc or it was believed that these interfaces could be adopted in the current research.

2.4.1 VRDoc (Virtual Reality Documentation)

VRDoc is a virtual reality documentation interface that was developed by the Construction, Engineering, and Management group at the University of New Brunswick. VRDoc was initially utilized to follow the progress of construction projects through web-based virtual reality panoramas. With the use of VRDoc, users have the ability to: conduct virtual site visits, obtain detailed as-built photographic documentation of a project, resolve project conflicts, and provide training opportunities for future project managers (UNB-CEM, 2015).

VRDoc is used for projects located in remote areas, such as the Arctic. Waugh et al. (2012) conducted a case study using VRDoc on the construction of a new school located in the Canadian Arctic (Inuvik, NT). Various challenges were faced, including the time required to capture the images. Full and free access was granted to all major participants of the project and as a result, an approach of “information sharing” developed between participants rather than information being held back and secured by individual organizations.

Rankohi et al. (2014) performed a case study using VRDoc with a group of fourth year civil engineering students to test the capabilities of VRDoc for visualizing, detecting, monitoring, and documenting construction progress. The result was that students on-site found more changes; however, the students that used VRDoc spent less time. Rankohi therefore, found that VR technologies can reduce the time spent for
monitoring project status and detecting project changes, but in this study did not replicate the accuracy of traditional methods.

### 2.4.2 D⁴AR (4-Dimensional Augmented Reality)

Research conducted by Golparvar-Fard et al. (2009) resulted in the development of a 4-dimensional augmented reality (D⁴AR) model. D⁴AR uses unsorted construction photos as a data collection technique to extract data and develop a reconstructed scene over as-planned 4D models. D⁴AR was initially understood to provide the user with the ability to complete: a virtual walk through as-built scenes, visual detection of progress, interior and exterior progress monitoring, daily updates with construction photographs, and the correction of augmented reality occlusion, which is when the perspective of the model is changed in comparison to the real world.

Golparvar-Fard completed further research on D⁴AR and other capabilities were observed or perceived and are described in Golparvar-Fard et al. (2011) as: progress monitoring and revisions of work schedule, quality assurance and control, safety management and education, site layout and analysis of construction operations, and remote decision making and contractor coordination meetings. Recently D⁰AR (similar to the D⁴AR model) has been explored as a tool for benchmarking, monitoring, and visualization of the carbon footprint on a construction project. Future work will be conducted to integrate the D⁰AR and the D⁴AR model (Memarzadeh and Golparvar-Fard, 2012).
2.4.3 VIRCON

VIRCON is a virtual construction site that provides a range of tools for construction planners. To demonstrate the VIRCON database and visualization tools, it was utilized on a 1,600 square metre school in the United Kingdom (Dawood et al. 2004). The VIRCON tools include setting up project data, space planning, analysis and optimization, and visualization. The authors conducted an evaluation with ten industry collaborators through a case study and as a result it was found that the planning and visualization features that were developed were practical. Along with the features identified as useful, the industrial evaluator’s also identified the limitations and possible improvements (Dawood et al., 2005). (Note: According to VIRCON Issue 3, the author had planned to commercialize the product, therefore, no subsequent publications are available).

2.5 Traditional Inspection Methods

The traditional inspection processes for bridges and retaining walls involves many standards and guidelines and are primarily conducted with a 100% hands-on approach. These standards and guidelines describe the type of inspections, interval of inspections, and different techniques of completing inspections, which are identified in the following section. The inspection process is being reviewed to gain an understanding of the traditional inspection procedures because the current research is focused on inspections of inaccessible infrastructure.
2.5.1  Bridge Inspections

Bridge inspections are reviewed here because three of the four infrastructure inspections are conducted on NBDTI bridges. Two of these bridge inspections will focus on the bridge cable connection at the top of the bridge towers. The third bridge inspection is focused on the bridge footings.

2.5.1.1  Inspection Intervals

According to Yanev (2007) regular or biennial inspections are standard procedure and entail three main functions: identifies hazards, rating the condition, and updating the inventory. Regular inspections provide a technical report of the infrastructure; however, as with all inspections it is important to state all limitations. It is typical for inaccessible and critical structural locations to be identified and special inspections coordinated. Special inspections typically do not meet the requirements of a full inspection, but are conducted due to a special condition and therefore the scope varies. It is important that a special inspection be recorded and submitted with all other inspections. Based on an inspector’s evaluation, interim inspections may also be required on some infrastructure between regular inspections. Along with regular, special, and interim inspections, there also exist monitoring inspections and in-depth inspections.

2.5.1.2  Inspection Procedure

According to Mayrbaurl and Camo (2004), prior to conducting a major inspection an inspector should take several steps including: reviewing available documents, performing preliminary field observations, interviewing maintenance personnel, preparing inspection forms, assembling a tool kit, developing an inspection QA plan, and
selecting inspection locations. A comprehensive inspection involves various destructive tests, non-destructive evaluation techniques, and monitoring devices. In particular for cable stay bridges, Tabatabai (2005) state that inspection and maintenance for short-term evaluations and monitoring techniques can include conventional visual/manual, magnetic, ultrasonic, X-ray, laser, acoustic, and remote or contact vibration-based techniques. Long-term evaluation and monitoring techniques include the use of acoustic monitoring and installing long-term sensors.

**2.5.1.3 Inspection Access**

For the majority of bridge inspections, Cardini and Sohn (2013) state five different types of access for bridge inspections and define the advantages and disadvantages. Table 1 summarizes the advantages and disadvantages of five different modes of inspection. Rope and Mast climbers along with Aerial Work Platforms (hydraulic lifts) are considered to be the primary alternative to a UAV inspection.

**2.5.2 Traditional Retaining Wall Inspections**

Typical MSE walls follow a similar inspection process as bridges; according to Gerber (2012) some agencies have adopted similar bridge inspection practices for retaining walls. However, in some U.S. states a five or ten year inspection interval is standard for retaining walls. Special inspections are performed after an extreme event such as a collision, weather, or signs of movement. Typically, retaining wall assessments are concerned with the reinforcement of the wall, along with the effect of corrosion. Inspections are defined to be a “close visual and hands on examination”; however, if it
cannot be safely accessed from the roadside, then the use of binoculars and/or a digital camera are said to be used as an inspection tool.

Table 1: Advantages and Disadvantages for Inspection Modes

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supported Scaffolding</td>
<td>- Configurable in different arrangements</td>
<td>- Labour intensive set-up</td>
</tr>
<tr>
<td></td>
<td>- Support large loads</td>
<td>- Requires semi-level structure for installation</td>
</tr>
<tr>
<td></td>
<td>- Minimal safety training</td>
<td></td>
</tr>
<tr>
<td>Suspended Scaffolding</td>
<td>- Access to high loads</td>
<td>- Low live load capacity</td>
</tr>
<tr>
<td></td>
<td>- Easy to relocate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Efficient and effective</td>
<td></td>
</tr>
<tr>
<td>Aerial Work Platforms</td>
<td>- Direct and efficient to required locations</td>
<td>- Requires significant training</td>
</tr>
<tr>
<td></td>
<td>- Inexpensive for short term rental</td>
<td>- Limited to location set-up</td>
</tr>
<tr>
<td>Mast Climbers</td>
<td>- Efficient to carry personnel and heavy material</td>
<td>- Limited to imitated mask location</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Requires significant training</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Safety is dependent on attached structure</td>
</tr>
<tr>
<td>Rope Climbers</td>
<td>- Quick and easy</td>
<td>- Limited to reliable anchor points</td>
</tr>
<tr>
<td></td>
<td>- Simple to move around</td>
<td>- Significant amount of training</td>
</tr>
<tr>
<td></td>
<td>- Low operation impact</td>
<td>- Limited by weight of tools and materials</td>
</tr>
<tr>
<td></td>
<td>- More access on irregular structures</td>
<td></td>
</tr>
</tbody>
</table>

2.6 NBDTI Inspection Procedure

NBDTI is responsible for inspecting a large number of NB’s public infrastructure, including various bridges and retaining walls. Through personal communication with the NBDTI Bridge Maintenance Technicians (2015) a general understanding of their inspection procedures for large assets were summarized. A visual inspection is completed on a routine schedule of 1, 2, or 4 years with more in-depth inspections completed as required. Visual inspections consist of inspectors investigating all accessible components; the guideline is to inspect a bridge within arm’s length (1m). However, it was stated this
may not always be practical and if an arm length visual inspection is not practical, inspectors will use binoculars to gain a better view of an area of interest and this is understood to cover 90% of above deck areas. For underneath a bridge, an Under Bridge Inspection (UBI) Unit in rented from out of provinces for a 3-6 week period and is used for multiple bridges. Unlike the visual inspection schedule, a UBI unit schedule is on a 30-year rotation. The UBI unit requires three operators and a one-lane traffic closure during the operation; it is also not a practical solution for all bridges, such as an arch bridge. Other inspection methods include a Boat Inspection if the bridge is close enough to the water, as well as non-destructive testing when more in-depth analysis is required.

It was also understood from the Bridge Maintenance Technicians (2015) how similar inspections would be completed for the case studies of this research. The Robinsonville MSE Wall would be visually inspected with a walk around the site, but staying a safe distance away from the edge of the wall. If more in-depth analysis were required, a rock scaling team would be contracted. For the inspection of the Longs Creek and Hawkshaw Bridge a visual inspection would be completed, if the towers were identified as an area of interest a boom truck would be rented. On the Reversing Falls Bridge a visual inspection would be completed to cover all accessible areas and a Remote Access (i.e. rope access) Team would be contracted to rappel to inaccessible areas of interest to capture images.
3 Methodology

3.1 Introduction

This chapter describes the selected UAV in section 3.2, the regulations set by Transport Canada and the application procedures for a Special Flight Operation Certificate (SFOC) in section 3.3, the developed general and site-specific methodology in section 3.4, the proposed research analysis in section 3.5, and the flight operation procedures that were prepared for executing each flight operation in section 3.6.

3.2 UAV Selection and Details

The selection of a UAV was focused on a multicopter flight system because of the advantages that these flight systems provide. According to Siebert and Teizer (2014) multicopters are easy to operate, highly flexible and manoeuvrable, relatively weather dependent, require low setup time, and are reasonably cost effective when compared to other flight systems and therefore, a quadcopter flight system was selected. According to the Oxford Dictionary (2015) a quadcopter is “an unmanned helicopter having four rotors.” It was decided that the system would be purchased ‘off the shelf’ and ‘ready to fly’ and that a custom designed and built system was not necessary.

After the selection of a multicopter flight system the following functions were determined to be important: camera resolution, adjustable camera settings, camera gimbal, first person view (FPV), Global Positioning System (GPS), flight time, and cost. A table was developed to compare select multicopters with the above features, as well as with secondary features. This table resulted in four multicopters of interest, DJI Phantom 3 Professional (P3P), DJI Inspire 1 (I1), DJI Spreading Wings 1000+ (SW), and the
Blade 350 QX3 (QX3); see Table 2. All of the multicopters in Table 2 are equipped with a GPS system, a 3-axis gimbal, and are capable of FPV. After reviewing these models with consumers, sales, and industry professionals, the DJI Phantom 3 Professional quadcopter was selected; see Figure 3: DJI Phantom 3 Professional.

Table 2: UAV Selection Specifications

<table>
<thead>
<tr>
<th>Type</th>
<th>DJI</th>
<th>Blade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>P3P</td>
<td>I1</td>
</tr>
<tr>
<td>Aircraft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>1280g</td>
<td>2935g</td>
</tr>
<tr>
<td>Vertical hover accuracy</td>
<td>+/- 0.5m</td>
<td>0.5m</td>
</tr>
<tr>
<td>Horizontal hover accuracy</td>
<td>+/- 1.5m</td>
<td>2.5m</td>
</tr>
<tr>
<td>Wind resistance</td>
<td>NR</td>
<td>10 m/s</td>
</tr>
<tr>
<td>Aircraft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind resistance</td>
<td>NR</td>
<td>10 m/s</td>
</tr>
<tr>
<td>Camera</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photo</td>
<td>12.4 MP</td>
<td>12.4 MP</td>
</tr>
<tr>
<td>Recording</td>
<td>4000p</td>
<td>4000p</td>
</tr>
<tr>
<td>Lens (FOV)</td>
<td>94°</td>
<td>94°</td>
</tr>
<tr>
<td>ISO range</td>
<td>100-1600</td>
<td>100-1600</td>
</tr>
<tr>
<td>Shutter speed</td>
<td>8s-1/8000s</td>
<td>8s-1/8000s</td>
</tr>
<tr>
<td>Gimbal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controllable pitch range</td>
<td>-90° to +30°</td>
<td>-90° to +30°</td>
</tr>
<tr>
<td>Battery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight time</td>
<td>23 min</td>
<td>18 min</td>
</tr>
<tr>
<td>Cost</td>
<td>$1,259</td>
<td>$2,899</td>
</tr>
</tbody>
</table>

Note: Specifications were retrieved from their respective manufacturer website and costing was found at http://www.bhphotovideo.com.

¹WooKong: DJI flight controller system.
²NR: Not recorded – No value was provided.
³NA: Not applicable – Function does not exist on the platform.
The P3P was selected because it was a high-end, introductory level, and state of the art quadcopter that had all the required functions. A high-end professional level multicopter was not selected because it was determined that due to the cost and associated risk, it would be appropriate to begin the research with a high-end, introductory level multicopter. It was concluded at the time that if further research were to be completed, an advanced multicopter might be recommended. The P3P has a 12MP camera with adjustable ISO and shutter speed settings; the camera is mounted on an adjustable (manual/auto) 3-axis gimbal, with a live 720p HD camera stream, and 4000p camera recording. The P3P is also equipped with a GPS and a vision position system. The battery is rated for approximately 23 minutes of flight time and the unit was priced at US $1,259 + taxes at the time of purchase. The P3P has many features that are suited for beginner pilots, including the ability to set flight parameters, auto take-off, auto landing,
and a return home feature. A complete list of the P3P specifications can be found in Appendix A.

3.3 Transport Canada

Transport Canada is the Federal government department that is responsible for Civil Aviation Services and regulates the use of UAVs in the Canadian Airspace. Transport Canada has produced a flowchart to assist in determining if permission for a UAV operation is required and can be found in Appendix B. For this research it was determined that the following exemption requirement for a UAV 2kg or less could not be maintained, “Stay at least 30 metres away from people, animals, buildings, structures, and vehicles not involved in the operation.” An SFOC application was therefore required.

According to Transport Canada (2014) there exist two main types of applications, a Compliant Operation Application and a Restricted Operator Application which has three sub methodologies: Complex Application, Simplified Application, and a MAAC/AMA Application. A Restricted Operation – Simplified Application was determined to be the appropriate application type after discussion with the Atlantic Regional Civil Aviation Safety Inspector. The final version of the submitted application, excluding the appendices can be found in Appendix C.

A Restricted Operator Application is described by Transport Canada (2014) as:

Restricted Operator Application: These certificate applicants are either unable or unwilling to meet the criteria to become a Compliant Operator or compliance with these criteria is not required based on the scope and complexity of the operation. Again, these operators will be granted fewer privileges than those extended to Compliant Operators.
A Simplified Application is described by Transport Canada (2014) as:

Simplified Application: Applies to small UAVs, operated within Visual Line of Sight (VLOS) where the scope of operation is limited. See specific eligibility requirements and the SFOC application process in Section 11 of this Staff Instruction (SI).

To complete the application, two sections from the Transport Canada (2014) Staff Instruction Report were used, Section 8.0 – Reviewing The Application and Section 11.0 – Restricted Operator – Simplified Application Process. The format of the application mirrored the outline of Section 8.0 – Reviewing The Application, and is as follows:

1. Applicant Main Contact
2. Operation Manager Main Contact
3. Operation Manager Flight Contact
4. Operation Type & Purpose
5. Operation Dates
6. UAV Specifications
7. Security Plan
8. Emergency Plan
9. Ground Supervisor Contact
10. Flight Plan
11. Pilot Qualifications
12. Inspections & Operations

Section 11 - Pilot Qualifications and section 12 - Inspections & Operations were added as additional sections because it was stated to be of significant importance in Section 11 – Restricted Operator – Simplified Application Process, but was not directly outlined in the Section 8.0 – Reviewing The Application.

The application was first submitted to the Transport Canada Regional office on May 11, 2015 and on June 9, 2015 a request was received for further information. The application was revised and re-submitted on June 10, 2015. On June 11, 2015 approval was issued by Transport Canada for all operations and a copy of the certificate can be found in Appendix D.
3.4 Project Methodology

The research studied the use of a UAV as an inspection tool on four pieces of infrastructure: Robinsonville MSE Wall, Longs Creek Bridge, Hawkshaw Bridge, and Reversing Falls Bridge. The following section presents the procedures that were followed for each operation.

3.4.1 General Methodology

The following steps were completed for each case study, along with continued communication between all parties during individual steps.

1. Site assessment – A complete site assessment of the Robinsonville MSE Wall, Longs Creek Bridge, and the Reversing Falls Bridge. A site assessment was not completed at the Hawkshaw Bridge because both the Hawkshaw and Longs Creek Bridge sites were deemed to have similar characteristics.

2. Regulatory exemption – Submitted an SFOC application to Transport Canada for regulatory exemption.

3. Site plan – Collaborated with NBDTI and identified specific areas of concern for documentation at each case study.

4. Data collection – Captured aerial images of all concerned areas.

5. Processing – Processed select images of the Robinsonville MSE Wall to create a 3D model. All other images were organized and delivered to NBDTI.

6. Create interface – Created a site-specific interface on VRDoc for each case study.

7. Upload images – Uploaded images to each site-specific interface.
3.4.2  Pilot Locations

Four pilot sites were selected including the Robinsonville MSE Wall, Longs Creek Bridge, Hawkshaw Bridge, and the Reversing Falls Bridge. At each site the operation was conducted during daylight hours, with wind speeds less than 20 km/hr and zero precipitation. The following figures depict the site location and flight area, Figure 4: Robinsonville MSE Wall, Figure 5: Longs Creek Bridge, Figure 6: Hawkshaw Bridge, and Figure 7: Reversing Falls Bridge. Table 3 presents the site location, areas of interest, and notes if traffic closure was required.

Figure 4: Robinsonville MSE Wall
Figure 5: Longs Creek Bridge

Figure 6: Hawkshaw Bridge
Table 3: Pilot Site Characteristics

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Area of Interest</th>
<th>Traffic Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robinsonville MSE Wall</td>
<td>Robinsonville, NB Route 17</td>
<td>Face and top of MSE walls</td>
<td>Yes</td>
</tr>
<tr>
<td>Longs Creek Bridge</td>
<td>Upper Kingsclear, NB Route 102 crossing over Scoodawabscook Bend</td>
<td>Top of tower and spacers</td>
<td>Yes</td>
</tr>
<tr>
<td>Hawkshaw Bridge</td>
<td>Southampton, NB Hawkshaw Bridge Rd over the Pokiok Reach</td>
<td>Top of tower and spacers</td>
<td>Yes</td>
</tr>
<tr>
<td>Reversing Falls Bridge</td>
<td>Saint John, NB Route 100 crossing Saint John River</td>
<td>3 of the 4 bridge footings</td>
<td>No</td>
</tr>
</tbody>
</table>

Each operation was coordinated with NBDTI who was responsible for the necessary traffic closure arrangements. All reasonable measures were taken to ensure the safety of the public, including landing the UAV if a manned aircraft entered the airspace.
For further details concerning the flight plan, refer to the SFOC application found in the Appendix C.

3.5 Analysis

Contracting a remote access (i.e. rope access, mast climber, etc) team with the capacity to capture high-resolution images of a concerned area is a traditional method for inspection of inaccessible infrastructure for NBDTI. This procedure was completed on the Reversing Falls Bridge and would also be feasible for future inspections if a UAV were unavailable or impractical. Similar traditional methods could also be utilized at all other sites. The following analysis was completed to gain an understanding of the use of a UAV as an inspection tool for inaccessible infrastructure when compared to other traditional methods.

The first step was to determine the conditions and constraints that would make a particular method practical. General conditions included weather, regulations, traffic, and site characteristics, as these conditions are constraints on an inspection method selection. Once these factors were identified a selection flowchart was developed that can be utilized to determine if a UAV inspection is a preferred inspection method.

A cost analysis was performed to determine the cost effectiveness of a UAV method when compared to traditional approaches. The cost to complete each case study was determined, as well as the cost to complete additional UAV inspections assuming amortization of the equipment cost. For comparison purposes, the cost to complete similar traditional inspections for each case study locations are presented. Finally, the advantages of both methods were also determined. This material is intended to provide an
inspector or engineer with the necessary material to determine if a UAV inspection is a preferred method for an operation.

3.6 UAV Operation

Proper operation of a UAV is important to ensure the safety of all participants and the general public, as well as to ensure that quality results are collected. The following procedures have been developed to ensure flight success, including a pre-site checklist, pre-flight checklist, flight operation, and manual and records.

3.6.1 Pre-Site Checklist

Prior to site departure, the following checklist of the necessary equipment has been developed. The items on this list may not be required for every operation, but they do supplement an operation. The list is broken down into UAV case (UAV related items) and backpack (additional items).

- **UAV Case**
  - Phantom 3
  - Remote controller (full charge)
  - Propellers
  - UAV batteries (full charge)
  - UAV spare parts
  - Flight forms

- **Backpack**
  - iPhone & charger (full charge)
  - Laptop & charger (full charge)
  - Power converter
  - Card reader
  - Notebook & pen
  - Sunglasses
3.6.2 Pre-Flight Checklist

Prior to each operation the following was completed to ensure proper functionality of the UAV:

1. Develop and review flight plan.

2. Inspect the UAV for:
   - proper fitting of all components
   - cracks
   - debris accumulation
   - general damage

3. Inspect remote controller and ensure proper communication between controller and UAV.

4. Conduct a test flight in an open and un-restricted area to ensure all UAV functions work properly.

   In addition to the above steps, all of the manufacturer’s inspections and maintenance schedules were followed. A complete record of all inspections have been recorded and archived with the UAV.

3.6.3 Flight Operation

Prior to any flight, the pilot must assess the flight conditions and ensure that all conditions meet the minimum flying standards including:

- Wind < 20km/hr
- Zero precipitation
- Temperature > 0°C
- Adequate visibility
- Zero airspace traffic
- General hazards

During all flight operations, the pilot must continually assess the flight conditions.
3.6.4 **Manual and Records**

To adequately adhere to Transport Canada regulations, a UAV Inspection Form, UAV Flight Form, and a Pilot Logbook have been created and are found in Appendix E. A copy of the UAV manual and all other documents have been kept with the UAV, along with up to date inspections and flight plans.
4 Results

4.1 Introduction

This chapter first presents a summary of the data collected in section 4.2, then the site specific results for the Robinsonville MSE Wall in section 4.2.1, Longs Creek Bridge in section 4.2.2, Hawkshaw Bridge in section 4.2.3, and the Reversing Falls Bridge in section 4.2.4. For each site this chapter includes: a procedure on how the data was collected, what was collected, when it was collected, and who was present during the data collection. The results from the VRDoc interface are found in section 4.3 and lessons learned are presented in section 4.4.

4.2 Data

All locations with the exception of the Reversing Falls Bridge had traffic control. Traffic was stopped in both directions while the UAV was in flight and after a maximum of five minutes the UAV was landed and traffic would flow in one lane at a time and then the cycle was repeated. Traffic control was not required at the Reversing Falls Bridge because when the UAV was in-flight, it was always below the bridge deck. For all operations there were only three UAV batteries and therefore a 12V power converter was used to charge depleted batteries in a running vehicle immediately following the depletion of the first battery. Table 4 presents a summary of all the operation details including: date, quantity of data, and duration.
### Table 4: Operation Summary

<table>
<thead>
<tr>
<th>Site</th>
<th>Date (2015)</th>
<th>Data</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Robinsonville MSE Wall</strong></td>
<td>July 9</td>
<td>Aerial Images: 3</td>
<td>2hrs, 20mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Video:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Original – 21mins, 11s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Edited – 7mins, 37s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Panoramas: 21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>July 29/30</td>
<td>Aerial Images: 719</td>
<td>4hrs, 34mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Video:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Original – 3mins, 31s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Edited – 3mins, 22s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Panoramas: 39</td>
<td></td>
</tr>
<tr>
<td><strong>Longs Creek Bridge</strong></td>
<td>August 7</td>
<td>Aerial Images: 126</td>
<td>2hr, 11mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground Images: 26</td>
<td></td>
</tr>
<tr>
<td><strong>Hawkshaw Bridge</strong></td>
<td>August 10</td>
<td>Aerial Images: 98</td>
<td>1hr, 42mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground Images: 17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Panoramas: 3</td>
<td></td>
</tr>
<tr>
<td><strong>Reversing Falls Bridge</strong></td>
<td>August 19</td>
<td>Aerial Images: 191</td>
<td>2hrs, 2mins</td>
</tr>
</tbody>
</table>

#### 4.2.1 Robinsonville MSE Wall

The Robinsonville MSE Wall was the first case study to be completed and included a preliminary site visit along with a two-day site visit. The purpose of the first visit was to gain an understanding of the site details and determine the approach for the full documentation. Both NBDTI and UNB representatives on-site for both site visits. To achieve a site overview, aerial video was captured of the entire wall, as well as overview images that were taken at the maximum altitude of 120m. Traffic control was coordinated with one person stationed at either end of the wall and were responsible to inform the pilot when there was no traffic and if it was safe to fly; the UAV would then take-off and subsequently land when traffic was approaching. This resulted in 20 video clips that were compressed into a 3mins-22s clip; along with the three aerial images. A minor UAV error was encountered, a ‘gimbal overload’ error appeared on the interface; however, this only
caused a short delay in the operation until the issue was resolved. It was later determined to be due to a broken gimbal vibration damper that was replaced before the next site visit.

The full operation was conducted during the second site visit with the purpose of fully documenting the wall and creating a 3D model. NBDTI and UNB representatives were on-site along with a private traffic control company who provided traffic control for the entire two-day operation. The following four flight plans were executed with vertical images captured directly below the UAV towards the ground and oblique (nadir) images captured in the horizontal direction of the UAV:

1. Vertical 100m – vertical grid image acquisition flight plan with 75% front and side overlap at 100m altitude (relative to the take-off elevation).
2. Vertical 75m – vertical grid image acquisition flight plan with 75% front and side overlap at 75m altitude (relative to the take-off elevation).
3. Oblique/Vertical – a combination of oblique images taken along the face of the wall at 10m spacing along the wall and 4m altitude (relative to the road surface) spacing and vertical images taken at 35m altitude with 75% front overlap.
4. Video – 4K video taken along the entire wall (to be used to extract still images if required).

Aerial images were captured in JPEG format for the initial site visit; however, during the second visit images were captured in DNG (RAW) and JPEG format. DNG images were captured in case any image corrections were required. Panoramas were captured during both site visits that documented the wall at the ground level. During the first site visit, panoramas were captured on the opposite side of the road for both the primary and secondary walls; during the second site visit, panoramas were captured on
both sides of the road, but only for the primary wall. The duration in Table 4 does not include the time that was required to charge batteries, this was decided because with extra batteries and chargers it would be possible to continuously fly without any interruptions due to UAV battery life, making the battery life of the interface (iPhone for this operation) the limiting factor. The durations do include a 10-minute set-up time each day and 5-minute take-down time. To keep all photos organized with their respective flight plans the images on the UAV’s SD card were transferred to a laptop and the SD card was cleared between flight plans. This was not necessary, but was completed while waiting for batteries to charge.

During the 100m and 75m flight plans it was determined that a spotter was not required and the pilot conducted the flight operation alone. For this flight plan the pilot primarily used the map view on the UAV interface to fly a grid pattern to capture images with the necessary overlap. At all times the pilot was able to keep the UAV within direct line of sight. When capturing images and video of the face of the wall, there was always a spotter who assisted in the positioning of the UAV over the edge of the road, as well identified potential hazards.

To increase the accuracy of the model and reference the model to a coordinate system, 3D ground control points (GCP) were surveyed by a NBDTI survey crew prior to the site visit. Points were staked out with a nail at 12.5m chainage. It was not possible to see the head of the nail from the aerial images; however, each nail head could be located with a painted triangle around the centre of the nail.

A Trimble TX5 3D Terrestrial Laser Scanner (TLS) was utilized by the UNB Department of Geodesy and Geomatics to create a high-resolution scan of the wall. A
total of 11 setups were completed to capture the entire wall. Each setup consisted of two
scans per setup, a quick (10min) scan that resulted in half the resolution and a full high-
resolution (40min) scan. Each scan captured a windowed section of the wall; spherical
targets within overlapping zones were used to connect each scan. The quick scan was
primarily used for analysis because of the ease to manipulate the data; the high-resolution
scan was only used if in-depth detail was required of a particular section. A comparison
of the distance between the GCPs and the TLS resulted in a mean difference of 0.002m
with a standard deviation of 0.016m.

4.2.1.1 Pix4D

Image processing software for aerial photogrammetry was used to create a 3D
model of the retaining wall. Pix4D (2015a) software was selected for this project, which
has both a free version – Pix4D Discovery Mapper and a paid version – Pix4D Pro
Mapper. A 7-day trial version and a 1-month license were obtained of Pix4D Mapper Pro.
Table 5 provides information on the characteristics of the utilized templates offered by
Pix4D. These templates were used in various combinations with different flight plans and
are summarized in Table 6.

The first step for the model creation is to upload all images into the software,
images are aligned using the latitude, longitude, and altitude of each image and then
aligned with reference to all other images. Similar points are then detected between
images for the creation of individual points. The GCPs are inputted into the software and
each location is initially estimated. An iterative process is then completed by the user to
correct the location of each GCP using the individual images. After any necessary
corrections, the final processing step is to create the digital surface model, orthomosaic, and index maps if required.

Table 5: Template Characteristics Pix4D (2015b)

<table>
<thead>
<tr>
<th>Processing templates</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Default</td>
<td>Generates a 3D Model Point Cloud with mid level density, Digital Surface Model (DSM), and Orthomosaic.</td>
</tr>
<tr>
<td>3D Maps</td>
<td>Generates a 3D Model (Point Cloud, 3D Mesh, mid level density) as well as a DSM and an Orthomosaic. Applications: quarries, cadaster, etc</td>
</tr>
<tr>
<td>3D Model</td>
<td>Generates a 3D Model (Point Cloud, 3D Mesh, mid level density). Applications: buildings, objects, ground imagery, indoor imagery, inspections, etc.</td>
</tr>
<tr>
<td>Custom</td>
<td>Generates a 3D Model (Point Cloud, 3D Mesh), DSM, and Orthomosaic with high density and outputs of all formats including: LAZ, DXF, and 3D PDF. Application: A trial of a high-density point-cloud that could be exported to other software.</td>
</tr>
</tbody>
</table>

Table 6: Model Template Summary

<table>
<thead>
<tr>
<th>Flight Plan</th>
<th>Pix4D Templates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Default</td>
</tr>
<tr>
<td>Vertical 75m</td>
<td>✔️</td>
</tr>
<tr>
<td>Oblique/Vertical</td>
<td>✔️</td>
</tr>
<tr>
<td>Vertical 75m &amp; Oblique/Vertical</td>
<td>✔️</td>
</tr>
</tbody>
</table>

The flight pattern that resulted in the best visual model was the vertical 75m flight plan. The images taken as part of the vertical 100m flight plan were not used as time did not permit for processing within the 30-day license. The vertical 75m acquisition provided a high quality representation of the site. The point cloud and 3D mesh in the custom template was marginally better than that of the other templates. This was expected as the point generation density was set higher compared to other templates. The flight pattern that resulted in the highest accuracy was with a combination of the vertical 75m flight plan and the oblique/vertical flight plan.
Checkpoints are similar to GCPs, but are not used in the model for processing or calibration, but are only used to verify the accuracy. Checkpoints represent the accuracy of the GCPs by using three GCPs as reference points. The accuracy provided by the checkpoints is only the accuracy for the GCPs. The relative and absolute accuracy are defined by Pix4D (2015c) as:

Relative Accuracy: It is the accuracy that is defined by comparing individual features on a map / reconstructed model / orthomosaic with other features on the same model. For example two points of the model can be 2 meters away from their real position on the earth but if their relative accuracy is high, then the distance measured between these points will be very accurate as it is related with the relative position of the points and not the real one.

Absolute Accuracy: It is the accuracy that is defined by the difference between the location of features on a map or reconstructed model or orthomosaic and their true position on the Earth.

The relative and absolute accuracy is reported in Table 7 for two flight plans using the custom template. From the Pix4D (2015c) definitions, the relative accuracy is understood to be the accuracy of the images relative to all the other images within the same model and therefore the absolute accuracy of the images is with respect to their true position on earth. The absolute Z[m] values for both flight plans show a significant error in Table 7 and is understood to be the result of the image altitude being recorded as the height above ground level, instead of the height above sea level. The Ground Sampling Distance (GSD) is the primary indicator to determine the accuracy of the overall model. Pix4D (2015a) states that a project with a GSD of about 2 cm will have an approximate horizontal accuracy of 2-4 cm and a vertical accuracy of 2-6 cm. As a result, measurements made within the model are accurate within 2-6 cm.
Table 7: Pix4D Model Accuracy

<table>
<thead>
<tr>
<th></th>
<th>75 m Grid Flight</th>
<th>75 m Grid &amp; Oblique/Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Error</td>
<td>X[m]</td>
<td>Y [m]</td>
</tr>
<tr>
<td>Check Points</td>
<td>0.027</td>
<td>0.023</td>
</tr>
<tr>
<td>Absolute</td>
<td>1.90</td>
<td>3.03</td>
</tr>
<tr>
<td>Relative</td>
<td>X[%]</td>
<td>Y[%]</td>
</tr>
<tr>
<td>[-1.00, 1.00]</td>
<td>60.9</td>
<td>44.4</td>
</tr>
<tr>
<td>[-2.00, 2.00]</td>
<td>88.9</td>
<td>70.4</td>
</tr>
<tr>
<td>[-3.00, 3.00]</td>
<td>98.4</td>
<td>84.7</td>
</tr>
<tr>
<td>GSD [cm]</td>
<td>2.94</td>
<td></td>
</tr>
</tbody>
</table>

4.2.2 Longs Creek Bridge

The Longs Creek Bridge was the first case study completed of the three bridges. A preliminary site visit was conducted in mid May during discussion with the NBDTI on the use of UAVs to conduct inspections. The operation was conducted during the morning of August 7, 2015 beginning at 9:30am during low levels of traffic. On-site personnel included UNB personnel and NBDTI representatives. NBDTI personnel were responsible for conducting traffic control. The operation objectives were to capture aerial images of the bridge tower, cross member gusset plates, and the suspension cable spacers. The following images were captured for each concerned area:

- towers
  - four oblique views of each side
  - one vertical view of the top
- spacers
  - one vertical view of the top
  - two oblique views of each side
- gussets plates
  - one oblique view of each side

In some instances several images were taken from one view to obtain quality results. Images at the 120m maximum altitude were captured directly above the bridge as an overview of the structure. In addition to the tower images, additional images on one side of the tower were captured in an attempt to create a 3D model of the tower. However,
after processing these images it was determined that the resolution was too low and impractical for use and therefore was not attempted on the Hawkshaw Bridge.

The wind during the operation was a hindering factor. The wind speed was approximately 15km/hr and was gusting and therefore resulted in difficulty to operate the UAV in close proximity to the bridge structure. The UAV was also having difficulty maintaining a reliable GPS signal; a ‘metallic interference’ error would intermittently occur. The operation was completed despite this error. A spotter was stationed away from the pilot to provide assistance in determining how close the UAV was to the structure. The spotter was primarily beneficial when capturing images of the gusset plates.

4.2.3 Hawkshaw Bridge

The Hawkshaw Bridge was the second of the three bridges to be completed and was done immediately following the Longs Creek Bridge. No preliminary site visit was conducted because of its similarity to the Longs Creek Bridge. The operation details were similar to the Longs Creek Bridge with the operation conducted during the morning of August 10, 2015, at approximately 9:15am. NBDTI representatives were on-site to conduct traffic control along with UNB personnel documenting the bridge status. The operation followed a similar format, with the objective of capturing aerial images of the towers, gusset plates, as well as the cable spacers; however, there was only one spacer installed.

The difference between the Longs Creek and Hawkshaw Bridge case studies included: pre-planning the order that the images would be taken, additional images taken of the towers, and panoramas taken on the bridge deck. Prior to beginning the operation a detailed flight plan was developed to determine the order that the images would be taken.
This was done to better organize the images after the operation. Instead of four images taken at the four corners of each side of the tower, six images were taken, four images at each corner and one additional images of each cable side. In addition to the aerial images, three panoramas were taken, one at each end and one in the middle of the bridge.

4.2.4 Reversing Falls Bridge

The Reversing Falls Bridge was the final operation to be completed and had various differences when compared to the other operations. The focus of the Reversing Falls Bridge data collection was three of the four bridge footings. The bridge footings are inaccessible, but also have increased flying hazards. The other difference was traffic control was not required as all flights were under the bridge deck.

It was determined that a spotter would be required at all times when the UAV was in flight because of the flight difficulty due to the close proximity to the water and unpredictable wind. To achieve the optimal location, the spotter was stationed at a right angle of the pilot. Communication between the pilot and the spotter was tested by use of hand signals; however, this proved to be ineffective and the best communication was achieved by a third individual located beside the pilot who communicated with the spotter via a cell phone and relayed the details to the pilot. The spotter’s primary task was to communicate the depth dimension of the UAV to an object or the water. With a clear line of communication between the spotter and the UAV pilot, the operation was successfully completed.
4.3 VR Doc

The VRDoc interface was updated to present the inspection results through use of various icons to represent panoramas, aerial images, and video. As seen in Figure 8 (showing the Robinsonville MSE Wall interface) there are three map names at the top of the screen. These maps depict the panoramas for the primary wall (RW#2), aerial images and video of the primary wall, and the panoramas of both the primary and secondary wall (RW#1 and RW#2). Each panorama and still image icon are placed on the map to indicate the relative camera location. The video icon is placed in the middle of the map, but displays the entire wall.

![Image of VR Doc interface]

Figure 8: VR Doc - Robinsonville MSE Wall

For each of the three bridge sites, the VR Doc interface was set up using hotspots that linked the different maps of the bridge to specific areas of concern. When the mouse...
is placed over a hotspot a title will appear, providing the user with a description of the area that the hotspot will represent.

Figure 9: VRDoc - Hawkshaw Bridge (1)

If a user is interested in a particular area, by clicking on a hotspot they will automatically be redirected to a new map, for example Figure 10. The arrow icons indicate an image perpendicular to the current view and point in the direction that the image represents. To zoom into a still image, the user may simply right-click to bring up the interface options and is then able to zoom in and out. To return to the overall map the user may simply click the return button on the top left corner of their web browser. It is also possible to click the desired map at the top of the image, which is represented with a green background as seen in Figure 8, Figure 9, and Figure 10.
Lessons Learned

The lessons learned are presented in Table 8 with the identified problem and solutions. Problems for this research were solved with a new procedure, but for future research could be eliminated with new equipment. The live feed disruption was a reoccurring issue during the initial practice phase with the UAV, but after updating the firmware, the issue was resolved.
Table 8: Problem Breakdown

<table>
<thead>
<tr>
<th>Problem</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic interference</td>
<td>Take-off away from metal structures or purchase a UAV that is independent of environment.</td>
</tr>
<tr>
<td>Wind gusts</td>
<td>Stay further away from structures or purchase UAV with higher wind resistant.</td>
</tr>
<tr>
<td>Sun glare on interface</td>
<td>The pilot is oriented with the sun to their back or purchase a screen hood to block sun.</td>
</tr>
<tr>
<td>Picture ordering</td>
<td>Complete a detailed flight plan or create an interface to sort photos in-flight.</td>
</tr>
<tr>
<td>Battery depletion and charging</td>
<td>Charge batteries in a running vehicle or purchase additional batteries.</td>
</tr>
<tr>
<td>Spotter location &amp; communication</td>
<td>Station spotter at a right angle to the pilot and communicate via mobile phone or radio.</td>
</tr>
<tr>
<td>Live feed disruption</td>
<td>Updated firmware (no longer an issue).</td>
</tr>
</tbody>
</table>
5 Guideline Development

5.1 Introduction

This chapter presents guideline material to determine if a UAV inspection method should be selected for a project. Comparisons are made with traditional inspection methods, which are considered to be any type of inspection method or procedure currently used, including those listed in section 2.5. The guideline material is structured to present the conditions and constraints for UAV and traditional methods in section 5.2, the required resources for a UAV method in section 5.3, a selection flowchart to determine a preferred method in section 5.4, example of costs are presented in section 5.5, and the advantages of each method are provided in section 5.6. The selection procedure is outlined in Figure 11 and the material is intended to provide an inspector or engineer with the necessary information to make an informed decision about an inspection method.

![Figure 11: Selection Procedure](image)

5.2 Conditions and Constraints

An inspection conducted with a UAV or by a traditional method are both restricted by various conditions and constraints. The following presents the conditions and constraints for a UAV inspection that were followed in this research: the general flight requirements, weather conditions, regulations set by Transport Canada, traffic closure interaction, as well as how the structure can affect an operation. Similarly,
weather, traffic, mobilization, and structural conditions and constraints are presented for traditional inspection methods.

The general flight requirements will vary depending on the UAV; however, the requirements set out by DJI (2015) for the P3P are used:

1. Do not use the aircraft in severe weather conditions. These include wind speeds exceeding 10 m/s, snow, rain and fog.
2. Only fly in open areas. Tall structures and large metal structures may affect the accuracy of the on-board compass and GPS system.
3. Avoid obstacles, crowds, high voltage power lines, trees, and bodies of water.
4. Minimize interference by avoiding areas with high levels of electromagnetism, including base stations and radio transmission towers.
5. Aircraft and battery performance is subject to environmental factors such as air density and temperature. Be very careful when flying at altitudes greater than 19,685 feet (6000 meters) above sea level, as the performance of the battery and aircraft may be affected.
6. The Phantom 3 Professional cannot operate within the polar areas.

For all operations of this research the UAV was not operated if the wind speed was above 20 km/hr; wind speeds below 10km/hr were preferred. An overcast day was preferable to a sunny day because it resulted in less time adjusting the exposure settings on the camera. Temperature was not an issue during these operations because all operations were conducted during the summer months; the specifications state that the operating temperature must be between 0°C and 40°C. It should be noted that the weather conditions could be overcome with high-end professional UAVs that are capable of flying in precipitation, low temperatures, and high wind speeds.

The Canadian regulations that affect the operation of a UAV are set by Transport Canada as described in section 3.3. If an SFOC is required, a submission should be made at least eight weeks prior to the expected operation to ensure approval is obtained (Note: A 2016 SFOC application was approved 24 hrs after submission to Transport Canada).
Through personal communication with the Civil Aviation Safety Inspector (2015) blanket approval for a geographical area can be obtained that would certify a pilot to conduct specific operations within a geographical area for an approved period. However, if the operation is to take place more than 30m away from traffic, buildings, and structures not involved in the operation and the flight will be below 90m, an SFOC may not be required. Prior to any operation, a pilot should ensure that there do not exist any additional constraining local or provincial regulations.

Traffic closure is another constraint for a UAV inspection method. Traffic closure may be required for the safety of the general public if there is the potential of the UAV to distract drivers or if the UAV would be in-flight over traffic. Three of the four case studies for this research did require traffic closure, traffic was held for approximately five-minute intervals in both directions while the UAV was in-flight. On the Reversing Falls Bridge, traffic closure was not required because the flight was below the bridge deck. The application for the SFOC included traffic closure for the appropriate sites; however, for an operation separate from this research the author operated a UAV over a roundabout to record driver behaviour. The developed and approved flight plan stated the UAV would fly at an operating altitude of 150m over the centre of the roundabout until the battery level was low, the UAV would then land, a new battery would be installed, and the flight would be resumed. This demonstrates that the current regulations allow for users to demonstrate experience and gain approval for higher risk operations.

Another constraint is the structure, building, or land feature of interest for an operation. The operation area must be analyzed to determine if it is possible to safely fly a UAV. This constraint is a judgment that must be made by the pilot and depends on
factors such as the pilot experience, UAV accuracy, predicted flight conditions, and the area of interest. A general guideline of the required clearance is to maintain at least 2m of clearance all around the UAV when flying in a confined space. The following questions should also be reviewed when deciding if an operation is suited for a UAV operation:

- Will a visual line of sight be maintained throughout the flight?
- Does the pilot need to change his/her location during the flight?
- Is a spotter required?
- Is the accuracy of the UAV sufficient to fly the area (i.e. will the UAV drift, loose signal, etc)?
- What weather conditions would make the operation no longer feasible?
- Is the pilot confident in his or her ability to successfully complete the operation?

It is important that a flight plan be developed before an operation to understand all the components of the flight and to communicate the flight plan with all parties.

The conditions and constraints for traditional inspections are dependent on the specific method. The main constraint for a traditional visual inspection is the absence of snow; otherwise a visual inspection can be conducted in most weather conditions. However, a visual inspection is also constrained by what an inspector can see, even with the use of binoculars an inspector is constrained by the direction of sight and may not always be able to gain a 360° view of an area of interest.

Traditional inspections such as remote access (i.e., rope climbers), hydraulic lifts (aerial work platforms), UBI units, and constructed work platforms have conditions and constraints that are similar to a UAV inspection method. Weather, traffic closure,
mobilization, and the structure influence the inspection method. Weather conditions must be met; high winds can result in unsafe conditions for rope climbers and workers on hydraulic lifts and UBI units, as well constructed work platforms are limited by the design of the platform.

Traffic closure is also required for traditional methods; a UBI unit requires at least a partial lane closure and depending on the scope a full closure may be required for select traditional methods. Mobilization of traditional methods compared to a UAV method is significant, if a constructed platform is required, the design and construction must be completed before an inspection and if large equipment is required to gain access to an area of interest, the equipment must be transported to the site.

The structure can also constrain access to required areas when using a traditional method. This can include required tie off points for a rope access inspection, which then limit the scope of an inspection. Hydraulic lift and UBI units require significant space to gain access to an area and must be located in a semi-level area to operate. Also, if a platform is to be constructed, it is limited to areas of the structure that allow for its construction.

5.3 **Required UAV Resources**

The required resources to complete a UAV inspection are shown in Table 9. This table should be reviewed to understand the required resources for the collection of aerial images and the development of a 3D model. If a 3D model will not be created, the model development resources are not necessary.
Table 9: UAV Resources

<table>
<thead>
<tr>
<th>Data Acquisition</th>
<th>Model Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAV &amp; accessories</td>
<td>Software license</td>
</tr>
<tr>
<td>Experienced pilot</td>
<td>Computer meeting software specifications</td>
</tr>
<tr>
<td>Working knowledge of required Transport Canada materials (policies, guidance material, airspace, aeronautical charts, air traffic control, etc)</td>
<td>Ability to manipulate data (i.e. point clouds)</td>
</tr>
<tr>
<td></td>
<td>Storage of data (~10GB per project)</td>
</tr>
<tr>
<td></td>
<td>Capacity to survey ground control points</td>
</tr>
</tbody>
</table>

5.4 Selection Flowchart

A UAV inspection method may be an optimal choice for an operation, but it is not the best method for every operation. To determine if a UAV inspection method would be appropriate for a project, the list of statements in Table 10 was developed. Figure 12 (a selection flowchart) was created from Table 10 to assist in the decision making process.

Table 10 is broken down into two categories of statements that either exclude or make possible a UAV inspection. The selection chart is structured to determine if a UAV inspection is possible and if it would be an optimal selection or if a traditional method would be better suited. Figure 12 begins with what type of information is required and then filters through a series of questions to determine an inspection method.

The first step in Figure 12 is to determine what type of information or data is required. If any type of physical testing is required, a traditional method is likely to be better suited. If visual information is required, several questions must be answered first to determine if a UAV inspection method is optimal. Spatial information can be gathered with a UAV, but with the current technology the accuracy is limited, therefore if mm accuracy is required, a traditional approach is better suited.
Table 10: UAV Selection

<table>
<thead>
<tr>
<th>Statement</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Excludes a UAV Tool</strong></td>
<td></td>
</tr>
<tr>
<td>Requires physical testing</td>
<td>Not possible with current technology</td>
</tr>
<tr>
<td>Only need visual data and foot access is available</td>
<td>If the area of interest is easy to access a UAV may not be optimal</td>
</tr>
<tr>
<td>Not possible to successfully fly the area of interest</td>
<td>If a UAV would not have clearance</td>
</tr>
<tr>
<td>No time to apply for an SFOC</td>
<td>If you do not currently have an SFOC that would cover the operation</td>
</tr>
<tr>
<td>Requires spatial data with mm accuracy</td>
<td>Not possible with current technology</td>
</tr>
<tr>
<td><strong>Possibility of a UAV Tool</strong></td>
<td></td>
</tr>
<tr>
<td>Do not need an SFOC</td>
<td>If the operation is exempt from Transport Canada requirement for an SFOC</td>
</tr>
<tr>
<td>Already have an SFOC that would cover the operation</td>
<td>If you already have an SFOC that would cover this operation (blanket SFOC) and can meet the required conditions</td>
</tr>
<tr>
<td>Applied and received an SFOC</td>
<td>If there was time apply for an SFOC and meet the required conditions</td>
</tr>
</tbody>
</table>

If visual information is required and an inspector is able to access the area of interest relatively easily and safely on the ground, a UAV may not be required. Second, is a UAV capable of flying the particular structure or area of interest? Is there space to fly a UAV, will the UAV be able to maintain a signal when flying the structure, and is the pilot comfortable flying the structure? If the pilot determines that it is possible to fly the structure, the remaining questions are related to the regulatory requirements. If an SFOC is required, first review any current SFOCs that may cover this operation. If an SFOC application needs to be submitted, it should be understood that the application period could range from hours to several weeks.
Figure 12: Selection Flowchart
If a UAV method is selected, it is important to understand the limitations and specifications of the UAV that will be used in the operation. Weather is a significant factor to consider when using a UAV; different UAVs will have varying limitations with regard to wind, precipitation and temperature. The pilot must also be comfortable completing the operation successfully, but most importantly safely. The selection chart does not indicate what type of traditional method or tool should be used, instead it indicates whether a UAV or traditional method is preferred. It is also possible that a combination of a traditional inspection and UAV inspection method may be required to fulfill the requirements of an operation, which is not included in the selection flow chart.

5.5 Cost Breakdown

The cost breakdown found in the subsections below presents the initial cost to complete all operations in this research, the estimated cost for future UAV inspection and mapping operations, and sample costs from select traditional inspection that were obtained from NBDTI and presented for a basic comparison with the UAV costs. Only direct costs presented, which are provided as sample costs only. Economic and social cost were not calculated, but should be considered when determining an inspection method.

5.5.1 Initial UAV Operation Cost

The cost to conduct the site inspection for each case study of this research was determined as a means to provide a quantitative measure for comparison. The cost was found by determining the equipment/software cost, labour costs, and the cost for traffic control. The final total project cost was found by dividing the total equipment cost among all four projects and adding each associated labour cost, using a rate of $100/hr. The
Robinsonville MSE Wall was the only location that utilized the Pix 4D software and therefore the software cost was not included for any other project totals. Post-processing includes the time to develop the 3D models and the time to create the VRDoc interfaces. Traffic control cost of the Robinsonville MSE Wall was extracted from the subcontractor invoice. For the Longs Creek and Hawkshaw Bridge, an estimate of $340 was made for NBDTI traffic control costs. Similarly the cost for a NBDTI survey crew to survey GCPs on-site was estimated at $1,000. Travel cost and the required training time to become familiar with the UAV were not included; however, a first time UAV pilot should spend a minimum of 40 hours of practice flights before conducting a low risk operation. The cost breakdown and total costs for each location can be found in Table 11.

Table 11: UAV Inspection Project Cost

<table>
<thead>
<tr>
<th></th>
<th>Robin.</th>
<th>Longs.</th>
<th>Hawk.</th>
<th>Reverse.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equip. &amp; Software</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DJI Phantom 3 Pro</td>
<td>$425</td>
<td>$425</td>
<td>$425</td>
<td>$425</td>
<td>$1,700</td>
</tr>
<tr>
<td>2xPhantom 3 battrs.</td>
<td>$101</td>
<td>$101</td>
<td>$101</td>
<td>$101</td>
<td>$404</td>
</tr>
<tr>
<td>Phantom 3 case</td>
<td>$51</td>
<td>$51</td>
<td>$51</td>
<td>$51</td>
<td>$204</td>
</tr>
<tr>
<td>Mobile power inverter</td>
<td>$38</td>
<td>$38</td>
<td>$38</td>
<td>$38</td>
<td>$152</td>
</tr>
<tr>
<td>Pix 4D - 1-month</td>
<td>$455</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$455</td>
</tr>
<tr>
<td><strong>Total Equip. &amp; Soft.</strong></td>
<td>$1,070</td>
<td>$615</td>
<td>$615</td>
<td>$615</td>
<td>$2,915</td>
</tr>
<tr>
<td><strong>Labour (hrs)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onsite</td>
<td>7</td>
<td>2.5</td>
<td>2</td>
<td>2</td>
<td>13.5</td>
</tr>
<tr>
<td>SFOC Application</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Post Processing</td>
<td>40</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td><strong>Total Hrs</strong></td>
<td>57</td>
<td>20.5</td>
<td>20</td>
<td>20</td>
<td>117.5</td>
</tr>
<tr>
<td><strong>@ $100/hr</strong></td>
<td>$5,700</td>
<td>$2,050</td>
<td>$2,000</td>
<td>$2,000</td>
<td>$11,750</td>
</tr>
<tr>
<td>Traffic control</td>
<td>$2,684</td>
<td>$340</td>
<td>$340</td>
<td>$0</td>
<td>$3,364</td>
</tr>
<tr>
<td>GCP Survey</td>
<td>$1,000</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$1,000</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td>$10,500</td>
<td>$3,000</td>
<td>$3,000</td>
<td>$2,700</td>
<td>$19,200</td>
</tr>
</tbody>
</table>

5.5.2 Estimated Additional UAV Cost

The cost to complete additional UAV inspections is shown in Table 12. With the assumption that the equipment cost can be amortized over a minimum of 10 inspections before the equipment becomes outdated or damaged and requires replacement. On this
basis, the equipment cost for each inspection would be approximately $250 ($1,700 + $404 + $204 + $152 = $2,460/2 ~ $250). The time required to complete each inspection would be reduced as the pilot becomes familiar with the operation of the UAV. The time required to complete further SFOC applications is estimated to take approximately 4 hours, but is dependent on the complexity of the application and whether blanket approval is obtained, as an application would not be required for each operation. The ‘Inspection’ cost is an estimate to complete further bridge inspections similar to the Longs Creek, Hawkshaw, and Reversing Falls Bridge including the creation of a virtual reality interface. The ‘Inspection & Mapping’ cost is an estimate to complete an inspection similar to the Robinsonville MSE Wall along with a virtual reality interface. It should be noted that Table 12 does not include any travel cost and the equipment was assumed to be a P3P.

### Table 12: Additional UAV Inspections/Mapping Costs

<table>
<thead>
<tr>
<th></th>
<th>Inspection</th>
<th>Inspection &amp; Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td>$250</td>
<td>$250</td>
</tr>
<tr>
<td><strong>Software</strong></td>
<td>$0</td>
<td>$455</td>
</tr>
<tr>
<td><strong>Labour</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning (SFOC, etc)</td>
<td>$400</td>
<td>$400</td>
</tr>
<tr>
<td>Onsite</td>
<td>$200</td>
<td>$300</td>
</tr>
<tr>
<td>Processing</td>
<td>$800</td>
<td>$1,000</td>
</tr>
<tr>
<td><strong>GCP Survey</strong></td>
<td>$0</td>
<td>$1,000</td>
</tr>
<tr>
<td><strong>Total $</strong></td>
<td>$1,650</td>
<td>$3,405</td>
</tr>
</tbody>
</table>

#### 5.5.3 Sample Traditional Inspection Cost

To understand and relate the cost of the UAV inspections, similar inspection costs were obtained through personal communication with NBDTI (2015) for projects similar to those completed for this research. Table 13 provides the cost to complete an inspection using three different methods. Rock scaling is a procedure that would be required at the Robinsonville MSE Wall to safely conduct an inspection. Rock Scaling is a procedure to
remove loose rock to ensure the safety of the climbers. The cost breakdown for rock scaling shows the required set-up/take-down cost which includes signs, barricades and sand to protect the road surface.

The Hydraulic lift cost would apply to the Longs Creek and Hawkshaw Bridge. These costs include rental and labour. It should be noted that heavy equipment is typically rented on a per month basis, which results in this section of Table 13 providing an overestimate due to the use of a daily rate. The Remote Access quote is the cost for previous rope access work completed on the Reversing Falls Bridge and therefore is used for the comparison with the UAV inspection that was completed on the Reversing Falls Bridge.

<table>
<thead>
<tr>
<th>Rock scaling</th>
<th>Set-up &amp; take-down 1</th>
<th>$5,300</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Execute 2</td>
<td>$4,700</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$10,000</strong></td>
</tr>
<tr>
<td>Hydraulic lift</td>
<td>Rental 3</td>
<td>$1,900</td>
</tr>
<tr>
<td></td>
<td>Labour 4</td>
<td>$1,600</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$3,500</strong></td>
</tr>
<tr>
<td>Remote Access</td>
<td>Field work 5</td>
<td>$3,000</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$3,000</strong></td>
</tr>
</tbody>
</table>

1 Original quote = $21,244.66 for 4 - 60m sections, broken down to represent single 60m section.
2 Original quote = $21,425 for four person crew over 5 days, broken down to represent a two person crew for two days.
3 Estimated daily rate = 1200+1500/2 = 1350 plus delivery both ways to Nackawic area.
4 Calculated as a two-person crew at a $100/hr rate for an 8-hour day.
5 Original quote included field work and a report, used half of quote to only represent field work.

5.6 Advantages

The advantages of each inspection method are summarized in Table 14. The advantages of UAV methods are that it is an accessible approach, it is easy to capture an overview of an area of interest, but also capable of capturing details of an area of concern. It is also time effective because it can quickly capture an overview area, which can then be used to identify areas of concern. It currently does not require any formal
training and there are no significant safety issues for inspectors. A UAV inspection also provides a comprehensive record by capturing areas that are not accessible. This record can be used as a benchmark for future inspections or be used to effectively communicate the current status to other interested parties.

The advantages of a traditional inspection method are that it provides the ability to conduct physical tests, either non-destructive or destructive testing. It is also a hands-on approach that is well understood and the knowledge base has been well developed. A traditional approach may also be an advantage because it may be completed urgently due to different regulatory requirements; however, if regulatory requirements are not a factor and a UAV is available, a UAV inspection may be completed on an urgent timeline, but it is also more dependent on weather conditions. Therefore, urgency can be considered to be an advantage for either method depending on the operation.

Table 14: Advantages of UAV & Traditional Inspections

<table>
<thead>
<tr>
<th>The advantage of UAV inspection is that:</th>
<th>The advantage of traditional inspection is that:</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is an accessible approach</td>
<td>It allows for physical testing capabilities</td>
</tr>
<tr>
<td>It is time effective</td>
<td>It is a hands-on approach</td>
</tr>
<tr>
<td>No formal training is required</td>
<td>The procedure is well understood</td>
</tr>
<tr>
<td>There is limited safety concerns</td>
<td></td>
</tr>
<tr>
<td>Comprehensive status record</td>
<td></td>
</tr>
</tbody>
</table>

By reviewing the conditions and constraints, required resources, selection flowchart, sample costs, and the advantages of each method, an inspector or engineer has the ability to identify the circumstances in which to utilize aerial technologies. The comparison of both methods demonstrates that a UAV inspection method is a practical and cost-effective tool that can be enhanced when the information is delivered through virtual reality technologies.
The material presented in this chapter is to be used as guideline material by inspectors and engineers to determine if a UAV should be selected as an inspection method or if a traditional inspection method would be a preferred approached. It is assumed that if a traditional inspection method is determined to be the preferred method, that further information will be available to make a final decision. Also, a combination of a UAV and traditional inspection method may be necessary to complete a full inspection of a particular asset.
6 Validation

To validate the research and determine if the developed guideline material is useful and applicable for industry, interviews were conducted with industry experts from the local provincial transportation departments. These were completed by synthesizing the material in chapter 5 into a four page document that was sent to interviewees prior to individual interviews. NBDTI employees were first approached; interviews with NBDTI employees were completed one per day to provide an opportunity to make adjustments per individual feedback. After the interviews with NBDTI employees, the Prince Edward Island Department of Transportation, Infrastructure and Energy (PEITIE), and the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) were approached to gain their feedback. Section 6.1 presents the results of the NBDTI interviews and section 6.2 presents the results of the PEITIE and NSTIR interviews. Four versions of the validation survey were developed as feedback was received; a copy of the original survey can be found in Appendix F and a copy of the final version in Appendix G.

6.1 NBDTI Feedback

Interviewees were selected from NBDTI employees that were knowledgeable about the research conducted within their department. Table 15 summarizes the feedback, along with a reference of the action that was implemented. Significant feedback included outlining the necessary resources for a UAV inspection and as a result, section 5.3 Required UAV Resources was added to the guideline development material. Along with specific feedback, interviewees also provided suggestions about the phrasing
and wording in select sections. As NBDTI employees were familiar with the research on the application of a UAV inspection, their feedback on how they will make future decisions about the selection of a UAV inspection method was valuable. However, because they were involved with the research they had a greater understanding of the parameters that exist for a UAV inspection than other interviewees.

<table>
<thead>
<tr>
<th>Feedback</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition &amp; constraint clarification</td>
<td>Outline decision procedure and inform survey is apart of thesis</td>
</tr>
<tr>
<td>Flowchart: SFOC application rejection</td>
<td>Adjusted flowchart to depict a rejected SFOC application</td>
</tr>
<tr>
<td>Cost adjustments</td>
<td>Rounded cost values</td>
</tr>
<tr>
<td>Technical support requirement</td>
<td>Added required resources table: Data acquisition</td>
</tr>
<tr>
<td>Transport Canada requirements within selection flowchart</td>
<td>Added a note referencing the Transport Canada flowchart</td>
</tr>
<tr>
<td>SFOC application waiting period</td>
<td>Note added about SFOC application period</td>
</tr>
<tr>
<td>Required resources to create 3D models</td>
<td>Added to resource table requirement for Model development</td>
</tr>
</tbody>
</table>

### 6.2 PEITIE & NSTIR Feedback

After the initial interviews with the NBDTI, the PEITIE was approached to complete the survey validation and obtain their feedback. The capital division of PEITIE was approached, as they are responsible for all capital projects within the province of PEI. Bridge design, construction, and maintenance are considered to be the majority of the work within the division. Three levels of management were interviewed, which provided insight from all levels of decision-makers. Their feedback reiterated that the material provided was useful to determine if a UAV would be appropriate for a particular inspection operation. The interviews with PEITIE were completed consecutively and
only one, final revision of the survey validation was completed after the interviews and was used for the NSTIR interviews.

Three employees of the NSTIR Structures department who are responsible for bridge design and maintenance were interviewed. Their feedback outlined the need for a general guideline of the required clearance for a UAV, which has been included in the section 5.2 Conditions and Constraints. NSTIR employees also raised questions about the regulatory requirements in terms of the operation of a UAV over railways and watercourses. These regulatory parameters are covered when an SFOC application is made through Transport Canada.

In general, all sets of interviews with the local transportation departments resulted in positive feedback on the use of the guideline material. Along with validating the use of the guideline material, interviewees reiterated that a UAV is a useful tool for inspection work, as it provides advantages that traditional methods do not offer.
7 Conclusion & Recommendations

7.1 Goal & Hypothesis

The goal of this research was to identify the circumstances in which to utilize aerial technologies as an inspection tool for currently inaccessible infrastructure by capturing high-resolution images from a small-scale UAV and delivering those images with a web-based interface.

To achieve this goal, the following four case studies were completed: Robinsonville MSE Wall, Longs Creek Bridge, Hawkshaw Bridge, and the Reversing Falls Bridge. It was hypothesized that the proposed guideline materials would be valuable for industry practitioners when selecting a cost-effective and practical inspection method. Industry experts were asked to respond to this hypothesis regarding inaccessible infrastructure.

7.2 Completed Work

The Robinsonville MSE Wall case study resulted in a 3D model that was created from aerial images and traditional GCPs that were processed using Pix4D modelling software. The model provided NBDTI with a baseline that can be used for comparison of future inspections. The Longs Creek and Hawkshaw Bridge case studies provided images of inaccessible areas that required a status update. These images provided NBDTI with the ability to better determine the status of the infrastructure in the areas of concern. The Reversing Falls Bridge project also provided images of inaccessible areas to provide a status update. However, from this inspection NBDTI was able to determine that further analysis was required and is planning to contract specialist consultants to gain more
specific information. Delivering the collected information on the VRDoc interface provided NBDTI with an accessible and user-friendly interface. The simple access to VRDoc for all NBDTI employees resulted in an efficient delivery mechanism. The UAV inspection method resulted in a new tool for NBDTI to collect information on their assets and be able to make informed decisions.

7.3 Contribution

The research resulted in guideline material for engineers and inspectors to identify the circumstances in which a UAV inspection is a preferred method. This material includes the conditions and constraints, required UAV resources, a selection flowchart, sample costs, and the advantages of both a UAV inspection and a traditional inspection method. If an engineer or inspector is attempting to determine what type of inspection method to utilize, this material may guide the decision-maker; however, the decision-maker ultimately must make a final decision based on the information provided, but most importantly on their expertise. This research demonstrates that a UAV inspection is a practical and cost-effective inspection tool when delivered through VR technology.

7.4 Recommendations

Research on the application of UAVs has recently accelerated and future developments will emerge quickly. Future developments will include improvements in UAV technology and the application of the technology. These two categories are both integrated and should be developed together and therefore industry and research partnerships should be developed. Research-industry partnerships should also be created
for the application of UAVs, with industry driving the application and the research field integrating UAVs with other non-UAV technology or practices.

New technology advancements will move quickly and will likely develop independently. The DJI Phantom 4 was released in the spring of 2016 and is equipped with an obstacle sensing system that detects oncoming obstacles to avoid a potential collision (DJI, 2016). Other technological improvements have been identified that would benefit users in an engineering application and include

- Increased GPS accuracy
- Higher resolution camera payload
- High accuracy laser scanner payload
- Weather independence
- Compass independence of surrounding environment

The integration of new UAV technology with other technology or practices would expand the current opportunities and provide unforeseen benefits. Possible areas of integration could include

- Virtual & augmented reality
- Structural health monitoring
- Visual change detection
- Asset management plans
- Building information models
- Project status monitoring & updates

This research to explored the application of UAVs and determined the circumstances in which to utilize a UAV and when a UAV was a practical and cost-
effective inspection method when combined with VR technology. Future research must continue to integrate new and improved technology to efficiently inspect our current deteriorating infrastructure and address the lack of a comprehensive guide of inspection technologies. New and improved inspection methods are required to prepare for the next generation of infrastructure and actively monitor and inspect those assets to eliminate the current infrastructure deficit.
References


Bridge Maintenance Technicians (personal communication). 2015.


Civil Aviation Safety Inspector (personal communication). 2015.


Appendices
Appendix A – DJI Phantom 3 Professional Specifications
<table>
<thead>
<tr>
<th>DJI Phantom 3 Professional Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aircraft</strong></td>
</tr>
<tr>
<td>Weight (Incl. Battery &amp; Weight)</td>
</tr>
<tr>
<td>Diagonal Size (Incl. Propellers)</td>
</tr>
<tr>
<td>Max Ascent Speed</td>
</tr>
<tr>
<td>Max Descent Speed</td>
</tr>
<tr>
<td>Hover Accuracy</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Max Speed</td>
</tr>
<tr>
<td>Max Altitude Above Sea Level</td>
</tr>
<tr>
<td>Operation Temperature</td>
</tr>
<tr>
<td><strong>Camera</strong></td>
</tr>
<tr>
<td>Sensor</td>
</tr>
<tr>
<td>Lens</td>
</tr>
<tr>
<td>ISO Range</td>
</tr>
<tr>
<td>Shutter Speed</td>
</tr>
<tr>
<td>Image Max Size</td>
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<tr>
<td>Still Photography Modes</td>
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</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
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<tr>
<td>Video Recording Modes</td>
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<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Supported SD Card Types</td>
</tr>
<tr>
<td></td>
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<tr>
<td>Max Video Bitrate</td>
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<tr>
<td>Supported File Formats</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Operating Temperature</td>
</tr>
<tr>
<td><strong>Gimbal</strong></td>
</tr>
<tr>
<td>Controllable Range</td>
</tr>
<tr>
<td>Stabilization</td>
</tr>
<tr>
<td><strong>Vision Positioning</strong></td>
</tr>
<tr>
<td>Max Velocity</td>
</tr>
<tr>
<td>Altitude Range</td>
</tr>
<tr>
<td>Operating Range</td>
</tr>
<tr>
<td>Operating</td>
</tr>
<tr>
<td>Environment</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td><strong>Remote Controller</strong></td>
</tr>
<tr>
<td>Operating Frequency</td>
</tr>
<tr>
<td>Max Distance</td>
</tr>
<tr>
<td>Video Output Port</td>
</tr>
<tr>
<td>Operating Temperature</td>
</tr>
<tr>
<td>Battery</td>
</tr>
<tr>
<td>Mobile Device Holder</td>
</tr>
<tr>
<td>Receiver Sensitivity (1%PER)</td>
</tr>
<tr>
<td>Transmitter Power (EIRP)</td>
</tr>
<tr>
<td>Working Voltage</td>
</tr>
<tr>
<td><strong>Battery Charger</strong></td>
</tr>
<tr>
<td>Voltage</td>
</tr>
<tr>
<td>Rated Power</td>
</tr>
<tr>
<td><strong>Intelligent Flight Battery</strong></td>
</tr>
<tr>
<td>Capacity</td>
</tr>
<tr>
<td>Voltage</td>
</tr>
<tr>
<td>Battery Type</td>
</tr>
<tr>
<td>Energy</td>
</tr>
<tr>
<td>Net weight</td>
</tr>
<tr>
<td>Max Flight Time</td>
</tr>
<tr>
<td>Operating Temperature</td>
</tr>
<tr>
<td>Net Charging Power</td>
</tr>
<tr>
<td><strong>App/Live View</strong></td>
</tr>
<tr>
<td>Mobile App</td>
</tr>
<tr>
<td>EIRP</td>
</tr>
<tr>
<td>Live View Working Frequency</td>
</tr>
<tr>
<td>Live View Quality</td>
</tr>
<tr>
<td>Latency</td>
</tr>
<tr>
<td>Required Operating Systems</td>
</tr>
<tr>
<td>Recommended Devices</td>
</tr>
<tr>
<td><strong>Operating Systems</strong></td>
</tr>
<tr>
<td>Required Operating Systems</td>
</tr>
<tr>
<td>Recommended Devices</td>
</tr>
<tr>
<td>Recommended Devices</td>
</tr>
<tr>
<td>Z7 mini</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>*Support for additional Android devices available as testing and development continues</td>
</tr>
</tbody>
</table>
Appendix B – Transport Canada Flowchart
Flying an unmanned aircraft?
You may need permission from Transport Canada

I use my aircraft for work or research

No
Yes

It weighs more than 35 kg

No
Yes

It weighs more than 25 kg

Yes
No

It weighs 2 kg or less

Yes
No

You don’t need permission, but you must meet the exemption requirements

I can meet the exemption requirements for UAVs 2 kg or less

No
Yes

I can meet the exemption requirements for UAVs between 2.1 kg and 25 kg

No
Yes

You don’t need permission, but you must meet the exemption requirements

You must apply for a Special Flight Operations Certificate

No
Yes

You don’t need permission, but you must meet the exemption requirements

You don’t need permission, but you must meet the exemption requirements and give Transport Canada:
1. Contact information
2. UAV model
3. Description of operation
4. Geographical boundaries of operation

Tips to fly safely

• Fly during daylight and in good weather
• Always keep your aircraft in sight
• Respect the privacy of others
• Don’t fly close to airports, in populated areas, near moving vehicles, or higher than 90 metres

tc.gc.ca/safetyfirst
Exemption requirements for operating UAVs without permission

THIS INFOGRAPHIC IS FOR EASE OF REFERENCE ONLY. YOU MUST CONSULT THE OFFICIAL EXEMPTIONS.

UAVs 2 kg or less

- Be safe, well trained and know the rules of the sky
- Be 18 years old, or at least 16 years old to conduct research under academic supervision
- Have at least $100,000 liability insurance
- Be alert—not tired or under the influence of alcohol or drugs
- Inspect your UAV and site before flight to ensure they are safe
- Get permission before you go onto private property
- Inform Air Traffic Services if your UAV enters controlled airspace
- Give right-of-way to manned aircraft
- Fly during daylight and in good weather
- Keep your aircraft in direct line of sight and always be able to see it with your own eyes
- Verify that radio frequencies/transmissions won’t affect control of your UAV
- Have an emergency plan ahead of time
- Carry a copy of your UAV exemption, proof of liability insurance, contact information, and aircraft system limitations
- Respect laws from all levels of government
- Keep your UAV in direct line of sight and always be able to see it with your own eyes
- Operate only one UAV at a time, with a single remote control
- Give right-of-way to manned aircraft
- Fly during daylight and in good weather (no clouds, snow or icy conditions)
- Create and follow procedures for landing and recovering your UAV and for contacting emergency responders and air traffic control.
- Have an emergency plan ahead of time
- Follow the manufacturer’s operating and emergency procedures, including those if the remote control loses contact with the aircraft
- Respect laws from all levels of government
- Operate only one UAV at a time, with a single remote control
- Immediately stop all operations if you can no longer meet the exemption requirements or if the safety of a person, property or other aircraft is at risk
- Stay at least 30 metres away from people, animals, buildings, structures, and vehicles not involved in the operation

UAVs between 2.1 kg and 25 kg

- Be safe, well trained and know the rules of the sky
- Be 18 years old
- Have at least $100,000 liability insurance
- Be alert—not tired or under the influence of alcohol or drugs
- Inspect your UAV and site before flight to ensure they are safe
- Get permission before you go onto private property
- Carry a copy of your UAV exemption, proof of liability insurance, contact information, and UAV system limitations
- Respect laws from all levels of government
- Keep your UAV in direct line of sight and always be able to see it with your own eyes
- Operate only one UAV at a time, with a single remote control
- Give right-of-way to manned aircraft
- Fly during daylight and in good weather (no clouds, snow or icy conditions)
- Create and follow procedures for landing and recovering your UAV and for contacting emergency responders and air traffic control.
- Have an emergency plan ahead of time
- Follow the manufacturer’s operating and emergency procedures, including those if the remote control loses contact with the aircraft
- Verify that radio frequencies/transmission and electronic devices won’t affect control of your UAV
- Assess the risk of losing connection with the UAV and decide when to use the flight termination setting
- Have a fire extinguisher on site
- Inform Air Traffic Services if your UAV enters controlled airspace
- Follow the manufacturer’s maintenance/assembly instructions
- Ensure the UAV does not have an emergency locator transmitter
- Report accidents to Transport Canada and stop operations until you have addressed the risks
- Immediately stop all operations if you can no longer respect the exemption requirements or if the safety of a person, property or other aircraft is at risk
- Stay at least 150 metres away from people, animals, buildings, structures, and vehicles not involved in the operation

DO NOT:

- Fly closer than 9 km from forest fires, airports, heliports, aerodromes, or built-up areas
- Fly over military bases, prisons or in controlled or restricted airspace
- Fly over crowds or higher than 90 metres
- Participate in special aviation events, air shows or system demonstrations
- Carry dangerous goods or lasers
Appendix C – SF0OC Application
A SIMPLIFIED
SPECIAL FLIGHT OPERATION CERTIFICATE
APPLICATION

FOR
REVERSING FALLS BRIDGE, LONGS CREEK BRIDGE, HAWKSHAW BRIDGE, & ROUTE
17 RETAINING WALL

2015 June 1 to 2015 August 31

BY
THE UNIVERSITY OF NEW BRUNSWICK
CONSTRUCTION ENGINEERING AND MANAGEMENT GROUP
L.M. WAUGH, AND, L.D. FERGUSON
lmw/ldf

2015 June 10
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1.0 Applicant Main Contact
University of New Brunswick (UNB) - Department of Civil Engineering - Construction Engineering Management (CEM) Group
H-124 Head Hall, 17 Dineen Drive
P.O. Box 4400
Fredericton, N.B., Canada E3B 5A3
Tel: [redacted]

2.0 Operation Manager Main Contact
Laird Ferguson
H-229 Head Hall, 17 Dineen Drive
P.O. Box 4400
Fredericton, N.B., Canada E3B 5A3
Tel: [redacted]
Cell: [redacted]

3.0 Operation Manager Flight Contact
The main contact for the operation manager during operation will be through the listed cell number.

4.0 Operation Type & Purpose
The UNB CEM group has developed the technology to document the progress of construction projects using virtual reality (VR) panoramas and is beginning research on the use of an Unmanned Aerial Vehicle (UAV) to capture images of on-going projects, completed projects, and infrastructure in need of inspections. These records can be accessed by means of an intuitive, web-based interface referred to as VR Doc. The interface enables project participants to examine progress or current status without travelling to the site; furthermore, the record may be used as an as-built record, benchmark for future inspections, and as a training tool for future projects. These technologies were originally used on the construction of the K-12 school in Hartland, NB in 2007, subsequently on the $1.4 billion refurbishment of the Point Lepreau Nuclear Generating Station (NB), on the construction of a Super-School in Inuvik (NWT) from 2009 through 2011, on the One Mile House Interchange in Saint John (NB) from 2009 to 2013, on the Saint John Law Courts, among many other projects.

The current research project on the use of UAVs is being conducted in collaboration with the New Brunswick (NB) Department of Transportation and Infrastructure (DTI). DTI is interested in the daytime use of UAVs for the inspection of inaccessible infrastructure to capture high-resolution images in areas that are either difficult to access, not safe to access, or not cost effective to access. Currently we anticipate on utilizing UAV aerial images on four projects: Reversing Falls Bridge, Longs Creek
Bridge, Hawkshaw Bridge, and the Route 17 Retaining Wall. All four locations are located in New Brunswick and are within the Transport Canada requirement to be at least 30 m away from all traffic and as result we are submitting this SFOC application. Please refer to the below sections on how we plan conduct of four operations in a safe manner.

5.0 Operation Dates
All operations are being requested to be conducted between June 1, 2015 and August 31, 2015. The three month time frame is being requested to allow time to coordinate between UNB and DTI and to ensure that an actual selected date of operation has the appropriate flying conditions.

6.0 UAV Specifications
The UAV that will be utilized is the new Phantom 3 manufactured by DJI. See below figures of the UAV and Appendix A – UAV Manufacture Specifications for the DJI Phantom 3 manufacture specifications.
7.0 Security Plans

7.1 Reversing Falls Bridge
The Reversing Falls Bridge is located on Route 100 in Saint John, NB crossing the Saint John River. The point of interest is the bridge abutments located significantly below the bridge deck. To ensure that there is no danger to the traffic and the general public the UAV will not be flown above the bridge deck. This will eliminate potential hazards of driver distraction or collision because the UAV will be out of sight of all traffic, never above traffic, and the bridge will act as a barrier to all traffic.

7.2 Longs Creek Bridge
The Longs Creek Bridge is located on Route 102 in Upper Kingsclear, NB over the Scoodawabscook Bend. The point of interest is the top of the towers of the bridge and therefore to ensure proper safety, a traffic closure will be conducted with DTI representatives while the UAV will be flying above the bridge deck. This will eliminate potential hazards of driver distraction or collision because the UAV will only be within sight of stopped traffic.

7.3 Hawkshaw Bridge
The Hawkshaw Bridge is located on Hawkshaw Bridge Rd in Southampton, NB over the Pokiok Reach. The point of interest is again top of the towers of the bridge and therefore to ensure proper safety, a traffic closure will be conducted with DTI representatives while the UAV will be flying above the bridge deck. This will eliminate potential hazards of driver distraction or collision because the UAV will be out of sight of all traffic.

7.4 Route 17 Retaining Wall
The Retaining Wall is located on Route 17 in Robinsonville, NB. The point of interest is the front face, and the top of the retaining wall which would be a safety hazard.
were it to fail since the slope would slide on to the roadway. To ensure proper safety, a traffic closure will be conducted with DTI representatives while the UAV will be flying above the road. This will eliminate potential hazards of driver distraction or collision because the UAV will only be within sight of stopped traffic.

8.0 Emergency Plan

If at any time another aerial vehiciles enters the airspace the UAV will immediately, be safely grounded. If any wildlife enters the airspace then a judgment will be made to determine if it is safe to continue the operation or if the UAV should be safely grounded. If at any time the UAV or flight controller experiences technical difficulty then the UAV will be safely grounded.

To ensure the safety of all personnel in the operation, there will be a First Aid certified person with immediate access to a fully supplied First Aid kit. If additional medical attention is required, all personnel will carry a cellular device capable of contacting all first responders including the Fredericton, Saint John, and Charlo Airport if the UAV inadvertently enters a controlled airspace. All personnel will be briefed on all operation plans for ease of execution and proper safety.

9.0 Ground Supervisor Contact

The Ground Supervisor will be the same as the Operation Manager due to the simplicity of the operations.

10.0 Flight Plan

10.1. Reversing Falls Bridge

At this site, DTI is interested in obtaining high-resolution images of the abutments. To obtain these images the UAV will only be flown underneath the bridge and the UAV altitude will not rise above to the height of the bridge deck. The operator will be located in several different spots under the bridge and on either side of the bridge, at no time will the operator be located on the bridge deck near traffic. To ensure that the operator has full control of the UAV, the operator will always have a clear line of sight of the UAV. The UAV will only be flown during daylight hours, in winds speeds below 20km/hrs, and during zero precipitation. See Figure 4 for site location and distance to the Saint John Airport. Figure 5 depicts approximate flight boundaries of the operation.
10.2. **Longs Creek Bridge**

At this site, DTI is interested in the top of the bridge tower for the suspension cables. The operator will be located in close proximity to the bridge towers and will always have a clear line of sight of the UAV to ensure that full control of the UAV is attained at all times. The UAV will only be flown during daylight hours, in winds speeds below 20km/hrs, and during zero precipitation. See Figure 6 for site location and the distance to the Fredericton Airport. Figure 7 depicts the flight boundaries of the operation.

![Figure 6: Longs Creek Bridge - Overview](image-url)
10.3. Hawkshaw Bridge
At this site, DTI is interested in the top of the bridge tower for the suspension cables. The operator will be located in close proximity to the bridge towers and will always have a clear line of sight of the UAV to ensure that full control of the UAV is attained at all times. The UAV will only be flown during daylight hours, in winds speeds below 20km/hrs, and during zero precipitation. See Figure 8 for site location and the distance to the Fredericton Airport. Figure 9 depicts the flight boundaries of the operation.
Figure 8: Hawkshaw Bridge - Overview

Figure 9: Hawkshaw Bridge - Flight Area
10.4. Route 17 Retaining Wall

The UAV will be flown around the face of the retaining wall and over the top of the retaining, located on the shoulder of Route 17. The operator will always have a clear line of sight of the UAV to ensure that full control of the UAV is held at all times. The UAV will only be flown during daylight hours, in winds speeds below 20km/hrs, and during zero precipitation. See Figure 10 for site location and proximity to the Charlo Airport. Figure 11 depicts the flight boundaries of the operation.

Figure 10: Route 17 Retaining Wall - Overview
**11.0 Pilot Qualifications**

The following are the pilot, Laird Ferguson’s qualifications for all operations:

i. Born March 9, 1992, 23 years of age

ii. Good standing medical condition and is not prone to losing consciousness or becoming disorientated

iii. Has an understanding of:
   A. Transport Canada policies, guidance material, and related regulations
   B. Local airspaces and the Designated Airspace Handbook
   C. The pilot is aware of aeronautical charts and the Canada Flight Supplement, however use of these documents is not necessary for these operations and Google Earth will be sufficient to identity topographic features
   D. The operation will not be conducted in an area in or near a controlled airspace
   E. The pilot is aware how the weather can affect a flight and will only operate the UAV during daylight hours, low wind speeds, with zero precipitation
   F. The pilot is experienced in identifying potential hazards prior to take-off and performing on-going hazard assessment during the flight
   G. Aware of the UAV limitations and has the ability to quickly react in emergency situations
iv. Experience flying two different small UAVs, the Blade 180QX and the Parrot AR. Drone 2.0. Prior to conducting operations with the DJI Phantom 3, various simulation operations will be conducted to gain experience using the Phantom 3 and to ensure a proper experience level is obtained.

v. The pilot will maintain proper currency to stay up to date on the UAV technology and will re-apply for SFOC applications for future projects

vi. The pilot will not seek to operate in a protected aviation band.

12.0 Inspections & Operation

12.1 UAV System Airworthiness

The UAV that will be utilized for this operation is deemed to be airworthy because the interface provides a live feed of the flight status inclusive of the altitude, speed, and battery life; as well the UAV is equipped with a Vision Positioning System (VPS) and Global Positioning System (GPS). The interface flight details will provide the pilot will the information needed to ensure that full control over the aircraft is maintained at all times.

To ensure that the UAV does not go beyond its flight boundaries an altitude limit will be set to limit the elevation that the UAV can reach and the UAV will always be flown within VLOS. The UAV is also equipped with a “Return Home” feature which when activated will automatically return the UAV to its takeoff location. The “Return Home” feature will be activated if the VLOS of the UAV is lost, or if the pilot loses control of the UAV for any reason. The UAV described for this application has only recently been released and therefore the history of the UAV is limited, however it is understood that the manufacturers previous models were not prone to system failures and are considered reliable UAVs.

12.2 Pre-Flight Inspection

Prior to each operation the following check list will be completed to ensure that the UAV will function properly:

- Conduct a test flight in open un-restricted area to ensure all UAV functions work properly
- Inspect the UAV: proper fitting of all components, cracks, debris accumulation, and general damage
- Inspect controller and ensure proper communication between flight controller and UAV
- Check batteries for a full charge
- Review flight operation

Inclusive of the above inspection, all of the manufacturer’s inspection and maintenance schedules will be followed that are included with the UAV. A complete record of all inspections and repairs will be recorded. See Appendix B – Forms for a template of inspection and flight forms.
12.3. Flight Operation
During the flight operation the pilot will continuously assess the flight conditions and operation including:
- Wind
- Precipitation
- Visibility
- Airspace traffic
- General hazards

12.4. Manual and Records
Based on the complexity of this operation a UAV Inspection Form, UAV Flight Form, and a Pilot Logbook have been created and can be found in Appendix B - Forms. These documents will be achieved along with the UAV manufacture manual. A copy of the UAV manual and documents can accessed through the manufacturers website at http://www.dji.com/product/phantom-3/download, as well a copy will be achieved along with the up to date inspections and flight documents.
Appendix D – Approved SFOC
June 11, 2015

University of New Brunswick
Department of Civil Engineering
Construction Engineering and Management Group
H – 124 Head Hall, 17 Dineen Drive
P.O. Box 4400
Fredericton, NB E3B 5A3

Attention: Laird Ferguson

Dear Sir:

Please find attached the requested Special Flight Operations Certificate (SFOC) in accordance with your SFOC application dated June 10, 2015.

Nothing in this SFOC relieves you, the unmanned air vehicle (UAV) operator, from complying with the provisions of any other relevant Acts, Regulations or laws from any level of government.

Should you have any questions or concerns, please do not hesitate to communicate with the undersigned.

Yours truly,

Christian Allain
Civil Aviation Safety Inspector, Flight Operations/
Inspecteur de la sécurité de l’Aviation civile, Opérations aériennes
Atlantic Region/Région de l’Atlantique
CA/js

Enclosure

cc: Rob Gladney
SPECIAL FLIGHT OPERATIONS CERTIFICATE # 15034

Pursuant to section 603.67 of the Canadian Aviation Regulations, this constitutes your Special Flight Operations Certificate (SFOC), for the operation of unmanned air vehicle (UAV) systems, issued under the authority of the Minister pursuant to the Aeronautics Act.

Approval of this Certificate is based on the information provided in your SFOC application dated June 10, 2015 and any accompanying documentation.

Nothing in this Certificate shall be held to relieve the UAV operator from requirements to comply with the provisions of such Canadian Aviation Documents as may have been issued pursuant to the Aeronautics Act or the Canadian Aviation Regulations.

Pursuant to Section 6.71 of the Aeronautics Act, this Certificate may be suspended or cancelled at any time by the Minister for cause, including failure on the part of the UAV operator, its servants or agents to comply with the provisions of the Aeronautics Act and the Canadian Aviation Regulations.

This Certificate is not transferable.

Legal Name and Address of the UAV System Operator

This Certificate is issued to University of New Brunswick – Department of Civil Engineering – Construction Engineering Management Group, H – 124 Head Hall, 17 Dineen Drive, Fredericton, NB, E3B 5A3, hereafter referred to as the UAV operator.

Validity Period of this Certificate

This Certificate is valid from June 12, 2015 until August 31, 2015 or until it is suspended or cancelled.

Type and Purpose of the Operation Authorized

This Certificate is valid for the operation of the DJI Phantom 3 UAV system for the purpose of capturing aerial imagery at the Reversing Falls Bridge, Longs Creek Bridge, Hawkshaw Bridge and the Route 17 Retaining Wall, as described in the application, subject to the conditions of this Certificate.

Specific Conditions

(1) The UAV shall only be operated within visual line-of-sight.
(2) The pilot of the UAV shall give way to manned aircraft at all times.
(3) The pilot shall only operate the UAV in visual meteorological conditions.
(4) The UAV shall only be operated during the day.
(5) Operations within Class F Restricted airspace dedicated for UAV testing and development are prohibited under this Certificate.
(6) Operations in restricted or Class F Restricted airspace are prohibited unless specifically authorized under this certificate.
(7) Operations within Class A and Class B airspace are prohibited.

(8) No pilot shall operate the UAV above 400 feet above ground level (AGL).

(9) The UAV operator shall conduct a site survey in accordance with the procedures outlined in the SFOC application prior to commencing operations at each location.

(10) The UAV shall not be operated in any special aviation event requiring an SFOC under Part VI, Subpart 3, Division 1 of the Canadian Aviation Regulations.

**General Operating Conditions**

(11) A copy of this Certificate shall be on site any time the UAV is in operation.

(12) The UAV operator shall notify this office within 10 working days after:

   (a) changing its legal name, trade name, main base, any contact information, and
   (b) ceasing to operate models of UAV systems authorized under this Certificate.

(13) The UAV operator shall not require any pilot to operate the controls of the UAV if either the pilot or the UAV operator has any reason to believe that the pilot is suffering or is likely to suffer from fatigue so that they are unfit to perform their duties.

(14) No pilot shall operate the UAV system within eight hours after consuming an alcoholic beverage or while under the influence of alcohol or while using any drug that impairs the person’s faculties to the extent that the safety of the operation is endangered in any way.

(15) Every crewmember engaged in the operation of the UAV system shall, during flight time, comply with the instructions of the pilot-in-command.

(16) Only one UAV shall be operated in-flight by a single pilot at any one time.

(17) No pilot shall operate the UAV unless it is operated in accordance with the operating limitations specified in the SFOC application.

(18) The UAV operator shall not permit the use of a portable electronic device at the control station of a UAV system where the device may impair the functioning of the systems or equipment.

(19) No pilot shall create a hazard to persons or property on the surface by dropping an object from the UAV in flight.

(20) The UAV operator shall not operate the UAV system, where visual observers are used as part of the sense and avoid function unless reliable communication is established and maintained between the visual observer and the pilot and standard operating procedures are followed.

(21) The UAV operator shall ensure that visual observers perform observation duties for only one UAV.

(22) The UAV operator shall not permit visual observer functions to be performed from a moving surface vehicle.

(23) Prior to conducting flight, the pilot shall ensure that the UAV System is in an airworthy condition.
(24) The UAV shall not be equipped with an ELT.

(25) The UAV operator shall ensure that the UAV is not flown if it has been subjected to any abnormal occurrence unless it has been inspected for damage.

(26) The UAV operator shall not permit UAV operations to be conducted unless the following operational and emergency equipment is immediately available to the appropriate crew member(s):

(a) checklists or placards that enable the UAV system to be operated in accordance with the limitations specified in the SFOC application or UAV system flight manual; and

(b) a hand-held fire extinguisher of a type suitable for extinguishing fires that are likely to occur.

(27) No pilot shall conduct a take-off/launch of the UAV unless there is a means of:

(a) Controlling the flight of the UAV;

(b) Monitoring the UAV system;

(c) Navigating;

(d) Communication, as required by the Class of airspace or regulation;

(e) Detecting hazardous environmental flight conditions;

(f) Mitigating the risk of loss of control of the UAV trajectory, where applicable;

(g) Sensing and avoiding other aircraft;

(h) Avoiding flight into obstacles and terrain;

(i) Aircraft lighting or illumination, for operations between sunset and sunrise, sufficient to maintain safe visual line-of-sight operations; and

(j) Remaining clear of cloud to the distance required for the airspace and operation.

(28) The UAV operator shall maintain records of their flight operations to include the following information:

(a) Location, date, times, crew, and aircraft type for each flight;

(b) Flight hours accumulated per aircraft; and

(c) Pilot(s) flight hours per day, month and year.

(29) The UAV operator shall maintain the records indentified in the condition above for a period of time equal to the validity period of this Certificate plus one (1) year beyond the expiry date.

(30) The UAV operator shall have subscribed for adequate liability insurance covering risks of public liability at the appropriate level, as described in section 606.02(8) of the Canadian Aviation Regulations.

(31) The UAV operator shall adhere to the security plan in accordance with the information provided in the SFOC application.

(32) The UAV operator shall adhere to the emergency contingency plan in accordance with the information provided in the SFOC application.
(33) The UAV operator shall maintain an adequate management organization that is capable of exercising supervision and operational control over persons participating in the operation.

(34) The UAV operator shall maintain UAV systems that are properly equipped for the area of operation and the type of operation.

(35) The UAV operator shall conduct a safe operation.

(36) The UAV operator shall cease operations if at any time the safety of other airspace users or persons or property on the ground is in jeopardy or if unable to comply with the conditions of this Certificate.

(37) The UAV operator is responsible for obtaining permission from the owner(s) of the property on which the UAV intends to take-off from and/or land on.

**General Flight Conditions**

(38) No pilot shall operate the UAV system in such a reckless or negligent manner as to endanger or be likely to endanger the life or property of any person.

(39) The pilot shall follow the normal and emergency procedures in accordance with the information provided in the SFOC application.

(40) The pilot shall follow the lost link procedures in accordance with the information provided in the SFOC application.

(41) No pilot shall conduct a take-off/launch of the UAV unless the risk involved with lost link circumstances has been assessed and a determination has been made as to when auto-recovery manoeuvres or flight termination shall be initiated.

(42) No pilot shall activate a flight termination system, if the UAV is so equipped, in such a manner as to endanger other airspace users or persons or property on the ground.

(43) No pilot shall conduct a take-off/launch of the UAV that has frost, ice or snow adhering to the any of its critical surfaces.

(44) No pilot shall conduct a take-off/launch of the UAV if explosive, corrosive or bio-hazard payloads are carried onboard.

(45) The pilot shall confirm that no unacceptable radio frequency interference is present prior to flight, nor is likely to be present during flight.

(46) The pilot-in-command of the UAV shall be familiar with the available information that is appropriate to the intended flight, before commencing a flight.

(47) No pilot shall operate the UAV in known or forecast icing conditions.

(48) Where the UAV is operated at or in the vicinity of an aerodrome, the pilot shall ensure that the UAV is flown in a manner so as to remain clear of the take-off, approach and landing routes and the pattern of traffic formed by manned aircraft operating at the aerodrome.

(49) The pilot shall comply with sections 602.97 through 602.101 of the *Canadian Aviation Regulations* if operating in the vicinity of an uncontrolled aerodrome.
The pilot shall ensure that the appropriate frequency is continuously monitored throughout the duration of the flight, whenever two-way radio communications is required.

The pilot shall ensure that the appropriate air traffic service unit(s) is advised immediately anytime the flight of the UAV is no longer under the control of the pilot and inadvertent entry into controlled airspace occurs or is likely to occur.

No pilot shall operate the UAV at a lateral distance of less than 100 feet of a building, vehicle, vessel or persons, unless;

(a) the building, vehicle or vessel is the subject of the aerial work, and
(b) only persons inherent to the operation are present.

No pilot shall operate the UAV at a lateral distance of less than 100 feet from the general public, spectators, bystanders or any person not associated with the operation.

No pilot shall operate the UAV over a built-up area or over an open-air assembly of persons.

The pilot or visual observer(s) must maintain continuous unaided visual contact with the UAV sufficient to be able to maintain operational control of the aircraft, know its location and be able to scan the airspace in which it is operating to decisively see and avoid other air traffic or objects.

No pilot shall operate the UAV over a forest fire area, or over any area that is located within five nautical miles of a forest fire area.

**Personnel Conditions**

The UAV operator shall ensure that all personnel are appropriately trained and qualified for the area of operation and the type of operation.

The UAV operator shall ensure that all pilots, visual observers, maintainers, payload operators are a minimum of 18 years of age.

No pilot shall operate the UAV unless they are medically fit to conduct their required duties.

All persons connected with this operation shall be familiar with the contents of this Certificate.

**UAV System Conditions**

The UAV operator shall ensure that all maintenance, servicing and disassembly-assembly of the UAV and associated components are performed in accordance with procedures described in the SFOC application.

The UAV operator shall ensure that the requirements of any airworthiness directives, or equivalent, issued by the manufacturer have been completed.

The UAV operator shall ensure that all UAV system equipment required for safe flight operations is serviceable.
Incident/Accident Reporting

(64) The UAV operator shall report to this office, as soon as possible, details of any of the following aviation occurrences during the operation of the UAV:

(a) Injuries to any person requiring medical attention;
(b) Unintended contact between the UAV and persons, livestock, vehicles, vessels or other structures;
(c) Unanticipated damage incurred to the airframe, control station, payload or command and control links that adversely affects the performance or flight characteristics of the UAV;
(d) Anytime the UAV is not kept within the geographic boundaries and/or altitude limits as outlined in this Certificate;
(e) Any collision or risk of collision with another aircraft;
(f) Anytime the UAV becomes uncontrollable, experiences a fly-away or is missing; and
(g) Any other incident that results in a Canadian Aviation Daily Occurrence Report (CADORS).

(65) The UAV operator shall not operate the UAV following any of the aviation occurrences listed in the condition above, until such time as this office approves its further operation. Any such approval for resumption of operations shall be documented.

Dated at Moncton, New Brunswick, Canada, this 11th day of June, 2015.

R. L. Gladney
Technical Team Lead, Flight Operations/
Chef d'équipe technique, Opérations aériennes
Civil Aviation/Aviation civile
Atlantic Region/Region de l'Atlantique
For the MINISTER OF TRANSPORT/Pour le MINISTRE DES TRANSPORTS
Appendix E – UAV Flight Forms
# UAV Inspection Form

**Inspector:**

**University of New Brunswick**  
**Dept of Civil Engineering**

**Visibility:**  
**Wind:**

**Temperature:**  
**Pressure:**

**Type:**  
**ID:**

**Model:**

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**Conduct a test flight and provide a brief description**

**Name**  
**Signature**

**Date:**
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<th>Pilot:</th>
<th>University of New Brunswick</th>
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Provide a description of operation location, site specific details, airspace, and all potential hazards

Provide a description of operation flight plan and expected outcome

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# Pilot Logbook

**University of New Brunswick**  
**Department of Civil Engineering**

## Flight Details

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## Name

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Appendix F – Original Validation Survey
Validation Survey

Laird Ferguson is conducting research with the Construction, Engineering, & Management group at the University of New Brunswick on the use of Unmanned Aerial Vehicles for inspecting inaccessible infrastructure. The goal of the research is to identify the circumstances in which to utilize aerial technologies as an inspection tool for currently inaccessible infrastructure by capturing high-resolution images from a small-scaled UAV and delivering the images through the VRDoc interface. The research is being completed in collaboration with the New Brunswick Department of Transportation & Infrastructure and was tested on the Robinsonville MSE Wall, Longs Creek Bridge, Hawkshaw Bridge, and the Reversing Falls Bridge. The results have showed to be valuable and further applications were explored including the use for post disaster scenario.

To complete the research goal, a UAV inspection method was compared to traditional inspection methods. Traditional inspection methods are considered to be previous inspection methods utilized to inspect infrastructure and range from a visual inspection, hydraulic lifts, including an underwater bridge inspection unit, constructed inspection platforms, and rope access.

As validation it is being requested from engineers and inspectors in select departments of transportations to evaluate the selection guideline that has been developed and provide comments on its usefulness and the applicability of the information presented.

Procedure

The first step is to review the conditions and constraints of both methods to gain an understanding when each method can be considered as an option. The next step is to use the flowchart as a guideline to determine what method is a preferred option. The final step is to then review the advantages and approximate costs of various alternatives to make a final decision as to what the best method is for an operation.

It is assumed that all methods and alternatives are available in the local area. That if a traditional method is determined as a preferred option then other information is available for a further breakdown.
Conditions & Constraints

The following is a list of the conditions and constraints for a UAV inspection and traditional inspection method.

<table>
<thead>
<tr>
<th>Condition/Constraint</th>
<th>UAV Inspection</th>
<th>Traditional Inspection</th>
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</table>
| **Weather**          | Dependent on UAV, but a guideline is:  
  • Wind > 20km/hr  
  • Temperature < 0°C  
  • Precipitation = 0 | Typically completed in summer months with:  
  • Wind > 50km/hr  
  • Low precipitation |
| **Regulations & Traffic** | Special Flight Operation Certificate typically required:  
  • Blanket or individual approval  
  • Traffic restrictions | Depending on the scope of the operation:  
  • Safety regulations  
  • Traffic restrictions |
| **Structure**        | Ability to fly the area of interest:  
  • Visual line of sight  
  • Spotter requirement  
  • UAV capabilities (GPS, signal strength, etc) | Varies for each method, but may need:  
  • Tie-off points  
  • Access for lifts  
  • Access to construct platforms |
| **Mobilization**     | Transportation  
  • Light equipment | Transportation  
  • Typically need heavy equipment and requires coordination |

Selection Chart

The selection flowchart is a guideline to determine what type of inspection method may be a preferred option. See attached flowchart.
Figure 1: Selection flowchart
Advantages

After a selection has been made with the flowchart the advantages in Table 2 and sample costs in Table 3 of both methods must be reviewed to make a final decision on the method that best suites an operation.

<table>
<thead>
<tr>
<th>Table 2: Advantages</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The advantage of UAV inspection is that:</td>
<td>The advantage of traditional inspection is that:</td>
</tr>
<tr>
<td>It is an accessible approach</td>
<td>It allows for physical testing capabilities</td>
</tr>
<tr>
<td>It is time effective</td>
<td>It is a hands-on approach</td>
</tr>
<tr>
<td>No formal training is required</td>
<td>The procedure is well understood</td>
</tr>
<tr>
<td>There is limited safety concerns</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3: Cost Estimates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Type</td>
</tr>
<tr>
<td>UAV Inspection</td>
<td>Inspection</td>
</tr>
<tr>
<td></td>
<td>Inspection &amp; Mapping</td>
</tr>
<tr>
<td>Traditional Inspection</td>
<td>Rock Scaling</td>
</tr>
<tr>
<td></td>
<td>Boom Lift</td>
</tr>
<tr>
<td></td>
<td>Rope Access</td>
</tr>
</tbody>
</table>

Comments

Please provide any comments on the information presented and if you would find the information useful in determining if a UAV was an appropriate inspection method.
Appendix G – Final Validation Survey
Research Validation

Laird Ferguson is conducting research with the Construction, Engineering, & Management group at the University of New Brunswick on the use of Unmanned Aerial Vehicles (UAV) for inspecting inaccessible infrastructure. The goal of the research is to identify the circumstances in which to utilize aerial technologies as an inspection tool for currently inaccessible infrastructure by capturing high-resolution images from a small-scaled UAV and delivering the images through a virtual reality interface (vrdoc.ca). The research is being completed in collaboration with the New Brunswick Department of Transportation & Infrastructure (NBTDI) and was tested on the Robinsonville MSE Wall, Longs Creek Bridge, Hawkshaw Bridge, and the Reversing Falls Bridge. The results have showed to be valuable and further applications were explored including use after a severe storm event.

The results provided NBTDI with overview images of the infrastructure and detail images of areas of concern. This provided engineers with a new tool to further assess their infrastructure. For the Robinsonville MSE Wall the images were processed to create a 3D model that included a 3D point cloud, 3D mesh, and an orthomosaic. The images collected of the three bridges provided NBTDI with high-resolution images of concerned areas.

To complete the research goal, a UAV inspection method was compared to traditional inspection methods. Traditional inspection methods range from visual inspection, to hydraulic lifts including an under bridge inspection unit, constructed inspection platforms, and rope access. As validation, it is being requested from engineers and inspectors in select departments of transportations to evaluate the selection guideline that has been developed and provide comments on its usefulness and the applicability of the information presented.

Procedure

Several tables and figures have been created as a guideline to determine if a UAV inspection method is appropriate for an operation. To be completed in the following order:

1. Review Table 1: Conditions & Constraints
2. Review Table 2: UAV Resources
3. Complete Figure 1: Selection flowchart
4. Review Table 3: Method Advantages
5. Review Table 4: Costs per Sites

It is assumed that all methods and alternatives are available in the local area. That if a traditional method is determined as a preferred option that other information is available for a further breakdown.
Conditions & Constraints

The following is a list of the conditions and constraints for a UAV inspection and traditional inspection method.

<table>
<thead>
<tr>
<th>Condition/Constraint</th>
<th>UAV Inspection</th>
<th>Traditional Inspection</th>
</tr>
</thead>
</table>
| **Weather**          | Dependent on UAV, but a guideline is:  
• Wind < 20km/hr  
• Temperature > 0°C  
• Precipitation = 0 | Typically completed in summer months with:  
• Wind < 50km/hr  
• Low precipitation |
| **Regulations & Traffic** | Special Flight Operation Certificate (SFOC) typically required:  
• Blanket or individual approval  
• Traffic restrictions | Depending on the scope of the operation:  
• Safety regulations  
• Traffic restrictions |
| **Structure** | Ability to fly the area of interest:  
• Visual line of sight  
• Spotter requirement  
• UAV operation abilities (GPS, signal strength, etc) | Varies for each method, but may need:  
• Tie-off points  
• Access for lifts  
• Access to construct platforms |
| **Mobilization** | Transportation  
• Light equipment | Transportation  
• Typically need heavy equipment and requires coordination |

Resources

Table 2 provides the required resources to complete a UAV inspection. If a 3D model will not be created, the model development resources would not be required, otherwise the client should be aware of the required storage requirements and be able to manipulate the delivered data.

<table>
<thead>
<tr>
<th>Data Acquisition</th>
<th>Model Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAV &amp; accessories</td>
<td>Software license</td>
</tr>
<tr>
<td>Experienced pilot</td>
<td>Computer meeting software specifications</td>
</tr>
<tr>
<td>Working knowledge of required Transport Canada materials (policies, guidance material, airspace, aeronautical charts, air traffic control, etc)</td>
<td>Ability to manipulate 3D model data (i.e. point clouds)</td>
</tr>
<tr>
<td></td>
<td>Storage of data (~10GB per project)</td>
</tr>
<tr>
<td></td>
<td>Capacity to survey ground control points</td>
</tr>
</tbody>
</table>

Selection Flowchart

The selection flowchart is a guideline to determine what type of inspection method may be a preferred option, see Figure 1.
Figure 1: Selection Flowchart
Advantages

After a selection has been made with the flowchart the advantages in Table 3 and sample costs in Table 4 of both methods should be reviewed prior to making a final decision on the method that best suites an operation. The sample costs are based on similar projects as completed for the research and are the cost per site.

Table 3: Method Advantages

<table>
<thead>
<tr>
<th>The advantage of UAV inspection is that:</th>
<th>The advantage of traditional inspection is that:</th>
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</tr>
<tr>
<td>There is limited safety concerns</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Costs per Sites

<table>
<thead>
<tr>
<th>Mode</th>
<th>Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAV Inspection</td>
<td>Inspection</td>
<td>$1,500</td>
</tr>
<tr>
<td></td>
<td>Inspection &amp; Mapping</td>
<td>$3,500</td>
</tr>
<tr>
<td>Sample Traditional Inspection</td>
<td>Rock Scaling</td>
<td>$10,000</td>
</tr>
<tr>
<td></td>
<td>Boom Lift</td>
<td>$3,500</td>
</tr>
<tr>
<td></td>
<td>Rope Access</td>
<td>$3,000</td>
</tr>
</tbody>
</table>

Comments

Please provide any comments on the information presented and if you would find the information useful in determining if a UAV was an appropriate inspection method.
Curriculum Vitae

Candidate’s full name: Laird Dalvay Ferguson

Universities attended:

University of New Brunswick, BScE, 2014

Publications:


Conference Presentations:
