EFFECTIVENESS OF VIDEO CAMERA-BASED REMOTE ROADWAY CONDITION MONITORING ON SNOW REMOVAL-RELATED MAINTENANCE OPERATIONS

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Remote monitoring through the use of cameras is widely utilized for traffic operation, but has not been utilized widely for roadway maintenance operations. The Utah Department of Transportation has implemented a new remote monitoring system, referred to as a Cloud-enabled Remote Video Streaming (CRVS) camera system for snow removal-related maintenance operations. This study evaluated the effectiveness of the use of the CRVS camera system in snow removal-related maintenance operations and was conducted in two parts: opinion surveys of maintenance station supervisors and an analysis on snow removal-related maintenance costs. On a scale of 1 (least effective) to 5 (most effective), the average overall effectiveness given by the station supervisors was 4.3 for both direct interviews and online questionnaire. The average reduction in expedition trips after the installation of the camera was estimated to be about 33 percent. An expedition cost comparison was performed for 10 sets of maintenance stations within Utah. It was difficult to make any definitive inferences from the comparison of expedition costs; hence, a statistical analysis was performed using the Mixed Model ANOVA, resulting in an average of 14% higher ratio of expedition costs at maintenance stations with a CRVS camera before the installation. This difference was not proven to be statistically significant at the 95% confident level, but indicated that the CRVS cameras were on the average helpful in reducing expedition costs and may be considered practically significant.
INTRODUCTION
For a State Department of Transportation (DOT) in a cold region, snow removal-related roadway maintenance is a major and important part of the tasks maintenance crews are responsible for. DOTs are responsible to provide safety in travel for the public by clearing roadways of snow and ice. With limited resources, it is difficult to maintain all roadways within the state during winter conditions. Remote monitoring is a method used to help DOT maintenance crews efficiently maintain certain roadways that require attention in a timely manner.

Remote monitoring through the use of cameras is already widely utilized for traffic operation, control, and management. However, the use of video-based highway monitoring for maintenance operations has not been utilized widely by maintenance station employees.

This report presents the findings of a study on the effect of the use of video camera-based remote roadway condition monitoring on snow removal-related maintenance operations, consisting of the results of the two opinion surveys and two statistical analyses.

BACKGROUND
There is a massive network of roads and highways in the U.S. As of 2008, there are about 2.7 million miles of paved public roads in the U.S. (1). It becomes a challenge for public agencies to monitor the conditions of each road. Conditions of the road affect driver behaviors and performances. Poor roadway conditions could lead to injuries and fatalities, traffic delay and congestion, and high operational and maintenance costs.

Weather conditions have a significant effect on poor road conditions. This presents a challenge to public agencies in that they cannot control the natural occurrence of severe weather. Over 10 percent of all passenger vehicle crashes occur in rain, snow, or sleet each year. 18 percent of fatal passenger vehicle crashes (over 6,600) and 22 percent of injury crashes (over 470,000) occur under poor weather or pavement conditions each year (2). To prevent such disasters from happening, timely recognition of such road conditions is necessary, and early detection of the commencement of freezing of a road surface and the application of freezing inhibitors is important. However, early detection of problems requires constant monitoring, which can be costly and entails significant workload (3). Therefore, there is a necessity for effective remote road condition monitoring to carry out efficient and effective maintenance work.

Not only does the failure to act and deice and remove snow from the roads create general threats to the health and safety to the public, it also has immediate consequences on traffic delay, traffic volumes, traffic congestion, and the public’s image of public agencies (4). The Oak Ridge National Laboratory has estimated that in 1999, capacity of U.S. freeways and principle arterials was reduced by more than 11 percent due to fog, snow, and ice. Also, the Lab projected that nearly 544 million vehicle-hours of delay or 23 percent of total delay was caused by weather conditions, with snow accounting for 90 percent of delay (2).

Other than the externality costs introduced such as injuries and fatalities from crashes, traffic delay, and traffic congestion, there are direct costs of road maintenance. Winter road maintenance accounts for 24 percent of road operating costs. Each year, over 2 billion dollars are spent on snow and ice control operations and over 5 billion dollars are spent for repairing roadway infrastructure damaged by snow and ice by state and local agencies. In 1999, state DOTs spent an average of $2,800 per route mile on winter road maintenance (2).
Safety in winter driving conditions must be provided to the public at minimum expenditures, since winter road maintenance operations do not provide permanent improvements to the highway system. Managing winter roads is a continuous process, and labor represents the largest class of expenditure in highway maintenance activities (4). In many cases, road conditions are currently inspected by patrolling employees. There exists a challenge in this current situation in which the constantly changing winter road surface conditions are examined only by a few patrol employees dispatched a day (5). This presents a need for remote road condition monitoring utilizing cameras.

**Use of CCTV Cameras in Roadway Condition Monitoring**

Public agencies utilize different methods and devices to fulfill the responsibility of providing a high level of service by proper maintenance of roadways. Among these methods and devices is the use of Closed-Circuit Television (CCTV) cameras in remote road condition monitoring. CCTV cameras are becoming more affordable and accessible. Also, in many areas, CCTV cameras are already installed for other purposes, such as traffic monitoring (3). Therefore, there is potential to make the decision to utilize CCTV cameras for road condition monitoring purposes with low installation costs. This section will examine the use of CCTV cameras for road monitoring purposes as demonstrated by the systems used in Washington State, New York, Idaho, and Japan as examples.

**Washington State**

Many public agencies, such as the Washington State DOT, have invested in advanced technology designed to monitor, report and forecast road related weather conditions, referred to as Road Weather Information Systems (RWIS). The Federal Highway Administration (FHWA) has invested in research and development for more sophisticated use of RWIS capabilities, referred to as Winter Maintenance Decision Support Systems (MDSS). The objective of the MDSS is to take advantage of recent advances in weather forecasting and understanding of pavement information designed to support proactive decision-making by winter road maintenance managers (6). In Washington State, there are more than 50 RWIS stations located along roadway right-of-way at locations that typically experience the most severe weather-related road conditions. All of the RWIS stations provide air temperature, wind speed and direction detection; many provide road surface and subsurface temperatures. Many also have cameras providing a visual image of the conditions (6).

**New York**

In New York, the New York State DOT has developed a fixed anti-icing system prototype for a portion of the Brooklyn Bridge. In this system, operators review weather forecasts and view CCTV video images to monitor pavement conditions. Maintenance crews are mobilized to supplement anti-icing operations with plowing to remove snow and ice if there is a 60 percent or greater chance of precipitation and when pavement temperatures are predicted to be lower than air temperature. The New York State DOT is hoping to expand the anti-icing system by integrating a RWIS with the control system, CCTV camera, and a Dynamic Message Sign (DMS), which warns motorists during spray operations, to improve treatment decision-making (7).
Idaho

The Idaho DOT utilized visibility sensors with forward-scatter detection technology in monitoring road conditions. A CCTV surveillance system was then used to evaluate visibility sensors. A CCTV camera was pointed at roadside target signs equipped with flashing lights, confirming actual roadway conditions. The data collected by the sensor systems were transmitted to a central computer. Then, warnings of adverse conditions were informed to drivers on four roadside DMSs. This advisory information prompted changes in driver behavior and improved safety and mobility (7).

Japan

In Japan, CCTV cameras are used widely in various applications. Japanese public agencies have not missed seizing the opportunity to utilize CCTV cameras for road monitoring purposes. Sapporo is a city with nearly 2 million people in northern Japan. Having snowy winter weather, studies of roadway maintenance in winter conditions have been performed in Sapporo. In Sapporo, CCTV cameras are already widely installed, so road visibility data can be gathered over wide areas at low cost. Road administrators in Sapporo use CCTV cameras and visibility meters to obtain visibility information. A road visibility information system (RVIS) was developed for calculating the road visibility index (RVI), which categorizes visibility information in four ranks based on a visibility scale, in real time from daytime images obtained from the CCTV cameras along roads. The RVIS can change these still images into quantitative data (8).

Effectiveness of CCTV Cameras in Roadway Condition Monitoring

From the examples of public agencies in various areas introduced in the previous section, it can be seen that several agencies are investing in utilizing CCTV cameras for road condition monitoring purposes. Agencies assess the advantages and disadvantages of CCTV cameras and estimate their effectiveness.

Advantages of CCTV Cameras in Roadway Monitoring

When implementing technology into any task planning scheme, the benefit-cost ratio is an important indicator to whether the technology is worth investing in or not. “All current studies indicate that the benefits of RWIS far outweigh its costs, with an estimated benefit-cost ratio of between 2:1 and 10:1” (9). RWIS equipment has evolved from simple air and road temperature measurements to complete roadside weather stations with cameras. Maintenance authorities can recover the cost of implementing RWIS by using more efficient and timely salting procedures for instance, reducing the cost of road maintenance (10). CCTV cameras have become inexpensive, and as discussed before, there are large numbers of cameras that have already been set up on roads for use in road management (3). Therefore, there is potential to install new cameras or utilize existing cameras at low costs.

The most significant advantage of utilizing CCTV cameras in road condition monitoring is the reduced cost in labor. The RVIS that is utilized in Sapporo has the capability to judge visibility from road images and functions in place of the road administrator’s eyes (8). The use of CCTV cameras in accurate and timely weather observations from RWIS sensor stations can reduce routine patrols, as the cameras become the eyes of supervisors, allowing them to mobilize the right amount of personnel and equipment at the right time in the right place. The result is lower equipment use costs and improved labor productivity, particularly in large geographic

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areas (6). In the state of Washington, the implementation of RWIS has allowed the DOT to eliminate weekend and night shift work because of forecasts that make it possible to staff night and weekend shifts only when necessary. In Utah, using RWIS-supported forecasts has saved the DOT $2.2 million per year in labor and material costs for snow and ice control activities, which accounts for 18 percent of the annual winter maintenance budget (9).

Another advantage that CCTV cameras can provide is awareness to the public, particularly the motorists that will use the road facilities. The assumption is that more informed travelers will make better decisions about where, when, and how to travel, resulting in a safer driving environment during severe weather conditions (Boon and Cluett 2002). The Environmental Sensor Station (ESS) is the primary field component of the RWIS that collects and sends information to maintenance managers, DMSs, and the public, as shown in Figure 1. A CCTV camera could be installed to the ESS.

\[ \text{FIGURE 1. Operational applications of environmental sensor station (9).} \]

**Disadvantages of CCTV Cameras in Roadway Monitoring**

While CCTV cameras are becoming affordable, the cost of installing many of these cameras could be substantial, especially when installing new cameras at locations that do not have existing cameras. In Washington, the North Central Region Winter Maintenance Plan called for installation of up to 20 additional RWIS sensor stations at a total cost of $1.4 million (6). Also, as with any other technological device, there are costs associated with maintenance in order to guarantee expected performance.
While labor costs can be reduced by replacing labor with technology, there is a danger in the tendency of over-dependence on such options. CCTV cameras and various technologies can never replace the judgments that the wisdom of experienced maintenance managers can provide. Agencies must be attentive in each different scenario to ensure safety and a high level of service for the public.

Overall Effectiveness of CCTV Cameras in Roadway Monitoring

From the observed advantages, it can be seen that there is a significant potential in utilizing CCTV cameras to monitor and maintain roads more effectively. Although CCTV cameras have the capability to provide the benefits discussed above, the benefits result only when winter maintenance practices are significantly changed by taking advantage of RWIS capabilities (6). If utilized to take advantage of RWIS capabilities, CCTV cameras could be utilized effectively in road condition monitoring.

DESCRIPTION OF REMOTE MONITORING SYSTEM

The Utah DOT (UDOT) has implemented the use of video camera-based highway monitoring for maintenance operations, mainly for snow removal-related maintenance operations in the winter. The remote monitoring system implemented by UDOT does not use conventional CCTV cameras, but rather a new system provided by Live View Technologies. This video camera-based remote monitoring system is referred to as a Cloud-enabled Remote Video Streaming (CRVS) camera system in this report. The CRVS cameras are different from CCTV cameras because they are accessible from various devices via the internet and the maintenance station supervisors and workers can zoom, pan, and tilt the cameras from various devices. The devices include computers, smartphones, and tablets. This system is described visually in Figure 2-(a). The CRVS cameras are independent from the CCTV camera grid owned by UDOT. They run on power independent from UDOT’s CCTV cameras, and are backed up by a solar-powered battery, as shown in Figure 2-(b).
(a) CRVS Camera System Overview (Provided by Live View Technologies)

(b) CRVS Camera

FIGURE 2. CRVS camera system.
ANALYSIS RESULTS

The purpose of this research was to evaluate the effectiveness of the use of the CRVS camera system in remote roadway condition monitoring for snow removal-related maintenance operations at UDOT’s roadway maintenance stations by conducting both qualitative and quantitative analyses. The research was conducted in two parts. The first part involved interviews and a survey with selected maintenance station supervisors to understand opinions. The second part involved a quantitative analysis of snow removal-related maintenance costs.

Results of Opinion Surveys

Supervisors of several maintenance stations that received CRVS cameras were contacted for the first part of this study. This was done in two methods. The first method was in-person interviews with the supervisors. Six maintenance stations that received their first camera for the winter of 2012-2013, the most recent winter, were selected and visited for an interview. The second method was through an online questionnaire created using Qualtrics, an online service to create surveys, sent to nine supervisors of maintenance stations that received their first camera for the winter of 2011-2012. Eight supervisors responded to the online questionnaire. The questions asked to the supervisors were aimed to collect opinions of maintenance station supervisors who have experienced the use of the cameras first-hand.

Responses varied with each station supervisor, but mostly displayed positive reviews. In the opinion surveys, all supervisors were asked to evaluate the overall effectiveness of camera use in snow removal-related maintenance operations on a scale of one to five. The definitions of each scale were described as the following: 1 = not effective at all, 2 = less effective, 3 = no change, 4 = more effective than before, and 5 = definitely more effective.

A common response from the majority of the supervisors was how trips sent out to check the roads could be reduced with a camera in the area. One supervisor referred to this type of trip as an “expedition.” Supervisors were also asked to give a rough estimate of how much reduction in expedition trips they saw after the installation of the cameras. A summary of the pertinent findings from the opinion surveys is presented in Table 1.

<table>
<thead>
<tr>
<th>Question</th>
<th>In-Person Interviews</th>
<th>Online Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera Usage Frequency</td>
<td>Multiple times a day</td>
<td>Multiple times a day</td>
</tr>
<tr>
<td>Change in Snow Removal Dispatch Protocol</td>
<td>Yes (4 responses)</td>
<td>Yes (2 responses)</td>
</tr>
<tr>
<td>Not totally changed (2 responses)</td>
<td>4.3 (average of 6 responses)</td>
<td>4.3 (average of 8 responses)</td>
</tr>
<tr>
<td>Overall Effectiveness</td>
<td>23% (average of 2 responses)</td>
<td>33% (average of 8 responses)</td>
</tr>
</tbody>
</table>

Snow Removal-Related Maintenance Cost Analysis

It was observed from the opinions of maintenance station supervisors that the CRVS cameras are effective in roadway maintenance operations in the winter though the level of effectiveness reported was varied. A common response from the majority of the supervisors was how expedition trips were reduced with a camera in the area. In the opinion surveys, a few supervisors mentioned that on expedition trips, labor and equipment costs would be used but
usually no material costs were required. For the second part of this study, an analysis was performed on snow removal-related maintenance costs to see if the station supervisor opinions could be supported quantitatively.

To perform a quantitative analysis on whether the installation of a camera affected the costs of snow removal-related maintenance operations, the following hypothesis was set: the installation of the camera reduces the number of trips that do not require material costs. To test this hypothesis, an assumption was made that work orders that did not include material costs were possible expeditions made to check roadways for snow-removal work. Data on statewide snow removal-related maintenance costs for the years of 2009 to 2013 were provided by UDOT. The data were separated into three types of cost: labor, equipment, and material.

For this study, 10 maintenance stations in Utah that have received a CRVS camera were selected for analysis on snow removal-related maintenance costs. The 10 stations were selected because of the availability of a maintenance station nearby that has not received a CRVS camera for snow removal-related expedition cost comparison. The list of the set of maintenance stations selected for analysis is presented in Table 2. A map showing the stations selected for comparison and camera locations is presented in Figure 3.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Station with Camera</th>
<th>Adjacent Station without Camera</th>
<th>Installation of First Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clearfield</td>
<td>Clinton</td>
<td>2010-2011</td>
</tr>
<tr>
<td>2</td>
<td>Wellsville</td>
<td>Sardine Summit</td>
<td>2010-2011</td>
</tr>
<tr>
<td>3</td>
<td>Salt Lake West</td>
<td>Salt Lake Metro</td>
<td>2012-2013</td>
</tr>
<tr>
<td>4</td>
<td>Silver Summit</td>
<td>Parley's Canyon</td>
<td>2012-2013</td>
</tr>
<tr>
<td>5</td>
<td>Lehi</td>
<td>Provo Canyon</td>
<td>2011-2012</td>
</tr>
<tr>
<td>6</td>
<td>Tabiona</td>
<td>Kamas</td>
<td>2012-2013</td>
</tr>
<tr>
<td>7</td>
<td>Monticello</td>
<td>Blanding</td>
<td>2011-2012</td>
</tr>
<tr>
<td>8</td>
<td>Huntington</td>
<td>Emery</td>
<td>2012-2013</td>
</tr>
<tr>
<td>9</td>
<td>Long Valley Junction</td>
<td>Kanab</td>
<td>2010-2011</td>
</tr>
<tr>
<td>10</td>
<td>Beryl Junction</td>
<td>Cedar City</td>
<td>2012-2013</td>
</tr>
</tbody>
</table>
FIGURE 3. Map of maintenance stations for analysis and camera locations.
Before performing the expedition cost comparisons, precipitation data were collected from the archived data provided by MesoWest (12) to check if there was a correlation between snow removal-related costs and precipitation. If there was a correlation, the comparison of expedition costs between the adjacent maintenance stations could be valid and the subsequent analysis would be meaningful. The precipitation data used for this study were limited to data provided by the UDOT’s RWIS stations, which included both snow and rain. Precipitation data were available for five of the ten maintenance station comparison pairs selected for analysis. All five locations showed a strong correlation between precipitation and snow removal-related costs and the cost trends between the adjacent stations were similar. Therefore, it was assumed that the other five sets of stations would experience similar precipitation patterns between the station pairs, thus allowing a comparison of expedition costs of two adjacent maintenance stations. An example of the relation of the Tabiona and Kamas station pair in the winter of 2012-2013 is shown in Figure 4, where the precipitation is shown in levels of 0, 1, 2, and 3, corresponding to data presented by UDOT RWIS stations as “no precipitation”, “light precipitation”, “moderate precipitation”, and “heavy precipitation” respectively.

It was found that the cost records between the two adjacent station pairs correlate with precipitation patterns obtained from precipitation data. The snow removal-related cost data for the 10 sets of maintenance stations with a camera and the maintenance stations without a camera were reduced from the data provided by UDOT. For each maintenance station, the total snow removal-related costs and assumed expedition costs that did not require material costs were compiled for the four winters from 2009 to 2013. The total amount of expedition costs were then compared between the two adjacent maintenance stations with and without a CRVS camera.

When comparing snow removal-related costs of the maintenance station with a camera and the station without a camera, there is an issue of differences in coverage area. Due to geographical reasons, some stations hold maintenance responsibilities over larger areas than other stations. Also, some roadways experience more usage than others and might require more attention. Maintenance stations responsible over such roadways will experience more costs than other stations. To accommodate for this issue and make the analysis valid, the expedition costs of the maintenance stations without a camera was standardized using the relationship outlined in Equation 1:

\[
\text{Standardized Expedition Cost of Station Without Camera} = (\text{Expedition Cost of Station Without Camera}) \times \frac{(\text{Total Cost of Station With Camera})}{(\text{Total Cost of Station Without Camera})} \quad \text{(Equation 1)}
\]

The ratio of the expedition costs of the station with a camera and the station without a camera was then determined using Equation 2:

\[
\text{Ratio of Expedition Costs} = \frac{\text{Expedition Cost of Station With Camera}}{\text{Standardized Expedition Cost of Station Without Camera}} \quad \text{(Equation 2)}
\]
From this equation, a lower ratio implies more savings of expedition costs at the station with a camera than the station without a camera. This analysis was completed for the 10 selected sets of maintenance stations. The summary of the expedition cost comparison for Tabiona (station with camera) and Kamas (station without camera) is presented in Table 3 as an example. The years and ratios in bold font indicate the years that a camera was installed.

**TABLE 3. Expedition Cost Comparison Summary for Tabiona and Kamas Station Pair**

<table>
<thead>
<tr>
<th>Year</th>
<th>Maintenance Station</th>
<th>Camera Installed</th>
<th>Total Snow-Related Cost</th>
<th>Expedition Costs</th>
<th>Standardized Expedition Costs (Without CRVS)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009-2010</td>
<td>Tabiona</td>
<td>No</td>
<td>$137,002.29</td>
<td>$8,751.57</td>
<td>$13,583.24</td>
<td>0.644</td>
</tr>
<tr>
<td></td>
<td>Kamas</td>
<td>No</td>
<td>$326,131.35</td>
<td>$32,334.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010-2011</td>
<td>Tabiona</td>
<td>No</td>
<td>$179,017.16</td>
<td>$21,950.73</td>
<td></td>
<td>1.311</td>
</tr>
<tr>
<td></td>
<td>Kamas</td>
<td>No</td>
<td>$430,135.62</td>
<td>$40,224.16</td>
<td>$16,740.80</td>
<td></td>
</tr>
<tr>
<td>2011-2012</td>
<td>Tabiona</td>
<td>No</td>
<td>$113,628.33</td>
<td>$974.55</td>
<td></td>
<td>0.193</td>
</tr>
<tr>
<td></td>
<td>Kamas</td>
<td>No</td>
<td>$236,642.21</td>
<td>$10,499.92</td>
<td>$5,041.74</td>
<td></td>
</tr>
<tr>
<td>2012-2013</td>
<td>Tabiona</td>
<td>Yes</td>
<td>$143,695.82</td>
<td>$8,088.16</td>
<td></td>
<td><strong>0.739</strong></td>
</tr>
<tr>
<td></td>
<td>Kamas</td>
<td>No</td>
<td>$276,495.08</td>
<td>$21,058.88</td>
<td>$10,944.40</td>
<td></td>
</tr>
</tbody>
</table>

For this comparison pair, it was difficult to observe an apparent trend. The ratio was lower than one for the year with a camera installed (year 2012-2013), meaning that the expedition costs for the station with a camera was lower than the station without a camera for that year. However, the ratio was higher for two of the three years before the camera was installed. With the data available, it was difficult to explain why such lower rates resulted. The trend is shown in Figure 5.

![FIGURE 5. Trend in expedition cost ratio for Tabiona and Kamas station pair.](image-url)
Some comparison pairs showed apparent trends in reduction in expedition cost ratio, while others showed unclear trends as in the presented example of the comparison of Tabiona and Kamas. The results did not seem definitive, and it was difficult to infer whether the hypothesis that the cameras reduce trips that do not require material costs was true or not. To help with this analysis on expedition costs, a statistical analysis was performed to make an inference.

For this study, a Mixed Model Analysis of Variance (ANOVA) with blocking on the maintenance station was selected. The analysis was performed by the Statistical Analysis System (SAS) software (13) to compare the two conditions of whether a camera was installed or not on the dependent variable, which is the expedition cost ratio. The mean, standard deviation, minimum value, and maximum value for the ten stations are presented in Table 4-(a).

The standard deviation was rather large, showing a wide variability in the “No” dataset. The difference in standard deviations between the two datasets was very large too. The maximum value of 145.25 stands out as an outlier and controls the wide variance. In order to meet the condition for an ANOVA and reduce the variance, the ratios were transformed into natural logs for analysis. Some ratios presented a value of zero. A log transformation of zero is not defined. This issue was resolved by adding one to all ratios before being transformed into natural logs. The result of this ANOVA on natural log-transformed data is shown in Table 4-(b).

The difference between standard deviations was now significantly reduced and viable for analysis. The data available for analysis were observed to be sufficient for an ANOVA and a normality check was not necessary. For the subsequent analysis, two outliers were excluded by limiting the log ratios to values less than 2.0 in the log-transformed dataset because having values greater than 2.0 may not be realistic. The least squares means were then taken for the dataset. The results of this are shown in Table 4-(c).

The difference of least square means of the mixed model ANOVA test for the block locations of without and with a camera was then computed. When two outliers were removed, two station pairs were also removed from the subsequent analysis, leaving eight station pairs in the data set. The result of this ANOVA test is presented in Table 4-(d). The difference is defined as the natural log transformation of the ratio of expedition costs for the period with no camera for the maintenance station that has a camera minus the natural log transformation of the ratio of expedition costs for the period with camera for the maintenance shed that has a camera. Due to the nature of natural logarithm, when the difference in natural log transformation is converted back to the normal value from the logarithm, the normal value shows the ratio of the ratios of expedition cost before and after the camera installation at the maintenance stations with a camera.

The estimated difference of Least Square Means of 0.1329 transformed back into a normal value is 1.142, which means the average ratio of the ratios of expedition costs before and after the camera installation was 1.142. The 95 percent confidence is transformed to 0.907 to 1.438. This suggests that before the installation of cameras, the ratio of expedition costs is estimated to be about 14 percent higher, with a 95 percent confidence interval of about 9 percent lower to 44 percent higher than the ratio of expedition costs after the camera installation. The probability of 0.2142 of the t-value is much higher than 0.05. This suggests that the estimate of 14 percent higher expedition costs before the installation of cameras is not statistically significant at the 95 percent confidence level. It is significant at about a 75 percent confidence
level. Nevertheless, for practical purposes, the difference may be considered practically significant.

**TABLE 4. Results of Mixed Model ANOVA Analysis**

(a) Mean Procedure Statistics for Expedition Cost Ratios with Raw Data

<table>
<thead>
<tr>
<th>Camera Installed</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>7.764</td>
<td>30.736</td>
<td>0.061</td>
<td>145.250</td>
</tr>
<tr>
<td>Yes</td>
<td>1.864</td>
<td>3.520</td>
<td>0.000</td>
<td>13.467</td>
</tr>
</tbody>
</table>

(b) Mean Procedure Statistics for Expedition Cost Ratios after Natural Log Transportation

<table>
<thead>
<tr>
<th>Camera Installed</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>0.856</td>
<td>1.048</td>
<td>0.059</td>
<td>4.985</td>
</tr>
<tr>
<td>Yes</td>
<td>0.678</td>
<td>0.760</td>
<td>0.000</td>
<td>2.672</td>
</tr>
</tbody>
</table>

(c) Least Squares Means for Expedition Cost Ratios in Natural Log without Outliers

<table>
<thead>
<tr>
<th>Camera Installed</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>Degrees of Freedom</th>
<th>t Value</th>
<th>Pr &gt;</th>
<th>Alpha</th>
<th>Lower Confidence Interval</th>
<th>Upper Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>0.4754</td>
<td>0.07266</td>
<td>7</td>
<td>6.54</td>
<td>0.0003</td>
<td>0.05</td>
<td>0.3036</td>
<td>0.6472</td>
</tr>
<tr>
<td>Yes</td>
<td>0.3425</td>
<td>0.08094</td>
<td>7</td>
<td>4.23</td>
<td>0.0039</td>
<td>0.05</td>
<td>0.1511</td>
<td>0.5339</td>
</tr>
</tbody>
</table>

(d) Differences of Least Squares Means

<table>
<thead>
<tr>
<th>Estimate</th>
<th>Standard Error</th>
<th>Degrees of Freedom</th>
<th>t Value</th>
<th>Pr &gt;</th>
<th>Alpha</th>
<th>Lower Confidence Interval</th>
<th>Upper Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1329</td>
<td>0.0973</td>
<td>7</td>
<td>1.37</td>
<td>0.2142</td>
<td>0.05</td>
<td>-0.0972</td>
<td>0.3630</td>
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</table>

In the quantitative analysis of snow removal-related maintenance costs, the following study limitations were identified.

- The assumptions made that all work orders that did not include material costs were possible expeditions made to check roadways for snow-removal work may not be exactly reflecting the reality.
- The existing maintenance cost records did not include details of the location and nature of work, so there could be uncertainty in data reduction.
- The number of maintenance stations with a CRVS camera located next to a station without a CRVS camera was limited at the time of study, thus causing a small sample size for the statistical analysis.

CONCLUSIONS AND RECOMMENDATIONS

UDOT has implemented the new concept of using video camera-based remote monitoring for maintenance operations using CRVS cameras provided by Live View Technologies. The purpose of this study was to evaluate the effectiveness of the use of the CRVS camera system in snow removal-related maintenance operations in the state of Utah.

The opinion surveys displayed mostly positive reviews of the use of CRVS cameras. The quantitative analysis showed 14 percent higher expedition cost ratio before the installation of the cameras with practical significance. This implied a reduction in expedition costs after the installation of the cameras.

The results of this study were not statistically conclusive regarding the effectiveness of video camera-based remote roadway condition monitoring on snow removal-related maintenance operations when evaluated quantitatively due to several study limitations. To perform a similar analysis done in this study, it is recommended that the analysis be performed in early stages of camera installation to have a larger sample size of expedition cost comparisons. It is also recommended that more detailed and consistent maintenance cost records be prepared to enable accurate analysis of cost records for this type of analysis and any other cost-related analyses that may be performed in the future.

Overall, the installation of the CRVS cameras did display positive results and added benefits to UDOT. The maintenance station supervisors who utilize the cameras generally gave positive feedback, and there was a difference in expedition costs after the installation of the cameras with a practical significance. There are several added values from the installation of the CRVS cameras that were not examined in this study. The results of this study and the added values that were not examined in this study suggest that there are benefits to UDOT by implementing the CRVS cameras. Therefore, it is recommended that UDOT considers the installation of more CRVS cameras within the state.

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REFERENCES


