VERMONT AGENCY OF TRANSPORTATION'S TECHNICAL TRANSFER ADAPTATION OF MNDOT'S HYDRAULIC INSPECTION VEHICLE EXPLORER (HIVE)

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The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

ABSTRACT
The Vermont Agency of Transportation owns 47,873 small culverts. Each year culvert failures occur which can result in unplanned roadway closures which are costly to both the Agency and its customers. The Agency has recognized the risk this population of culverts pose and recognized the need to collect more accurate information on culvert condition to improve decision making. Commercially available video culvert inspection tools cost approximately $80,000 and there is a lot of risk in using these when culverts are underwater or full of debris. Spending $1500 to adapt MinnDOT's HIVE (Hydraulic Inspection Vehicle Explorer) for use in Vermont is a much more attractive option. This paper describes the technical transfer process of deciding to use HIVE, adapting it to Vermont, and several lessons learned from a pilot demonstration of Vermont's HIVE in 141 culverts.

Keywords: Culverts, Field Inspection, Robot, HIVE, Technical Transfer

INTRODUCTION

This paper is an example of technical transfer of a tool developed by one state's department of transportation and the technology's implementation and use by another state department of transportation. An asset management engineer at the Vermont Agency of Transportation (VTrans) recognized the need for a lower cost inspection tool to determine the condition of the Agency's small culverts. A literature review revealed the Minnesota Department of Transportation (MinnDOT) HIVE: Hydraulic Inspection Vehicle Explorer. This paper describes VTrans' small culverts and inspection needs, initial implementation of a HIVE, adaptation to Vermont conditions, lessons learned, and some suggestions for future HIVE implementers.

BACKGROUND/NEED FOR CULVERT INSPECTIONS

The Vermont Agency of Transportation owns 47,873 small culverts. Of those 28,203 are defined as a "cross pipe" which means the culvert crosses beneath the roadway. 33% of all Cross Pipes (9,358) have a barrel condition that is either Critical, Poor, or Unknown. Each year culvert failures occur which can result in unplanned roadway closures which are costly to both the Agency and its customers. The Agency has recognized the risk this population of culverts pose and recognized the need to collect more accurate information on culvert condition to improve decision making.

The Agency currently has a policy which requires all culverts to be inspected every 5 years, this requires almost 9,600 culverts to be inspected annually. Video inspection was recognized as one method for improving the data quality collected during culvert inspections. Commercial video inspection equipment is very expensive and cost prohibitive for such a large population. VTrans recognized the need to augment its video inspection capabilities to include other methods which are lower tech and do not require specialty training. By implementing a technology such as the "HIVE", or Hydraulic Inspection Vehicle Explorer, the Agency removes the cost and training barriers that restrict use of more robust pipe crawlers and also increases the number of culvert inspection vehicles.

Figure 1 shows a Vermont culvert in need of repair. This image was captured while performing video inspections in May 2018 using the HIVE and shows how video is needed to fully understand culvert condition.

Figure 1 Photo Showing Vermont Culvert in Need of Repair (Initially Captured by Vermont's HIVE in May 2018)

In order to implement the HIVE pilot program, the Asset Management Engineer needed to justify how implementation of a new technology would benefit the State of Vermont. The strategic goals of the Vermont Agency of Transportation are shown in Figure 2. All Agency efforts should be related to one or more of these goals. Implementation and adaptation of the HIVE was motivated by trying to achieve these goals. The Asset Management Engineer was successful in articulating that deployment of the HIVE addresses Goals 1-4. Investing in the HIVE supports our Agency's Strategic Goal Number 1 by helping the Agency achieve no unplanned road closures or restrictions within our control. It supports Goal Number 2 by helping Asset Management plan and program projects to keep the transportation system in a state of good repair. It supports Goal Number 3 by minimizing travel delays during culvert inspection. Finally, it supports Goal Number 4 which is to cultivate and continually pursue innovation.

Figure 2 Vermont Agency of Transportation Strategic Goals

INITIAL HIVE BUILD

The concept of the HIVE was first introduced to VTrans through our State Hydraulics Engineer through an issue of Hydrolink published by the AASHTO Technical Committee on Hydrology and Hydraulics July of 2016 (*1*) . The VTrans Hydraulics Engineer's responsibility is to perform a hydraulics analysis and to recommend adequate sizing or lining's that comply with State and Federal regulations. All hydraulic requests are made through programs or the VTrans Operations sections which are looking to perform a treatment or replacement of a small culvert. Given the other responsibilities of the Hydraulics Engineer the information regarding the HIVE was shared with agency staff but it was not pursued at that time. In July of 2017 a member of the Hydraulics Engineer's team moved to Asset Management and saw the opportunity for utilizing this technology. At that time, staff was motivated by a one-page description of the HIVE provided by MnDOT (*2*).

After convincing VTrans management about the potential of the HIVE for culvert inspections, the Asset Management Section of the Agency of Transportation purchased the components necessary to construct its first Hydraulic Inspection Vehicle Explorer (HIVE) for use in an Interstate culvert video inspection pilot in early Spring 2018. The cost for all the components required to construct the HIVE were approximately $1,500 (see the Parts List provided by MnDOT (*3*)) including purchasing of a tablet, tablet case, and spare parts that would not be needed if building just a HIVE. Using the Build Instructions (*4*) and Wiring Schematic (*5*) provided by Minnesota DOT, the time to construct the vehicle was approximately 6 hours. The components included in the HIVE inspection explorer cost about $800. Our initial HIVE is shown in Figure 3.

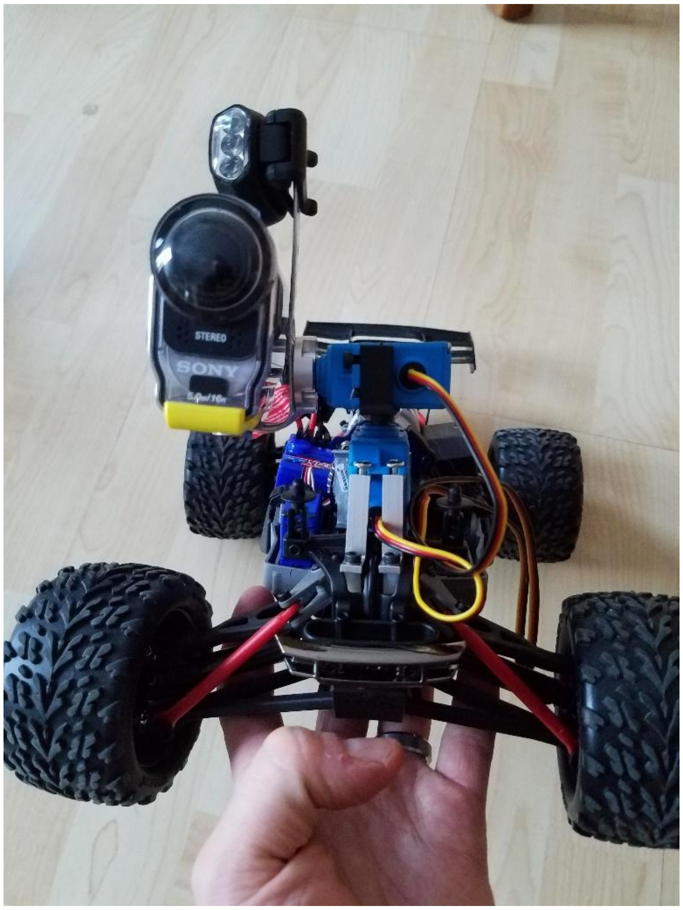

Figure 3 Initial Build of MnDOT's HIVE (March 20, 2018)

ADAPTATION TO VERMONT AGENCY OF TRANSPORTATION

The Vermont Agency of Transportation already has a robust culvert inspection program requiring all small culverts (culverts less than 72" in diameter) to be inspected every 5 years. The 20% annual inspection requirement requires a significant amount of resources to be expended in collecting inventory data. In order to successfully augment the existing effort, inclusion of video inspection should not significantly increase the time required to inspect a culvert or require an inspector to carry an excess of equipment to perform the inspection.

The Agency currently uses ESRI's collector application to collect data in the field. The application is downloaded on a tablet which is used onsite for each culvert inspection. Utilizing the HIVE with a WIFI enabled action camera allows the inspectors to use existing equipment and reduce the number of items that are required to be carried during data collection in the field.

The camera recommended by MNDOT in the build instructions is a Sony HDR action cam. The Sony camera does allow a live stream view from the camera, however it requires the footage to be stored on an SD card in the camera. Data storage and post processing was a concern given the data would have to be transferred from the device to its final storage destination and stored for at least 5 years or until such a time a newer video was collected. The time required to post process was determined to be a logistical challenge that would ultimately make the technology unsuccessful due to the time and cost associated with the additional work.

The Sony Play Memories App (required for live preview) can be installed on the same device as the ESRI Collector App. It was decided that having the inspector record his/her observations during the HIVE-enabled live stream (using the Sony Play Memories App) was acceptable. See Figure 4 below for an example screenshot. During the pilot project data collection, staff realized that screenshots of the live stream could be saved to the device and then uploaded into the collector application to support the inspector comments and rating. This modification to the HIVE and slightly revised inspection process allowed the Agency to utilize existing resources and processes in order to capture culvert barrel condition information that hadn't been captured in the past. See Figures 5 and 6 for examples of the ESRI Collector application.

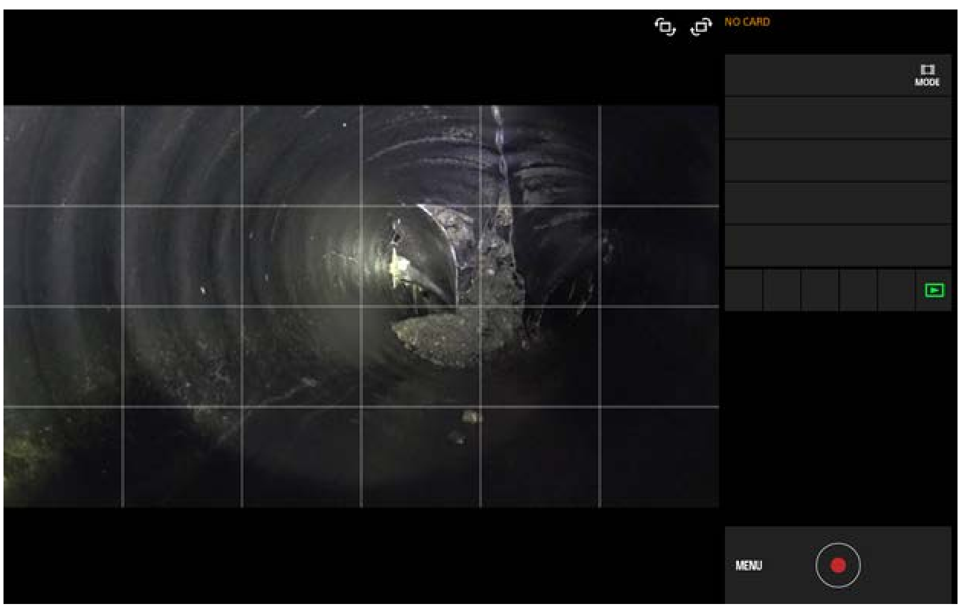

Figure 4 Example of Sony PlayMemories App Screenshot inside a 15" culvert (March 20, 2018)

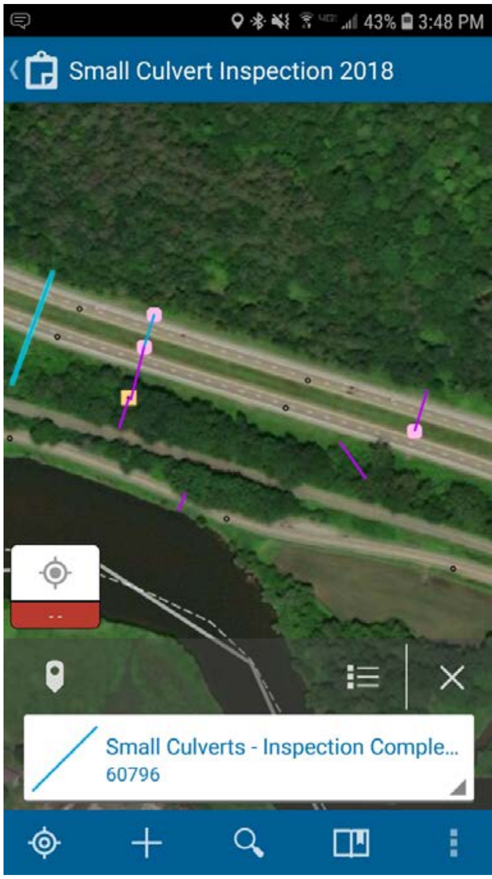

Figure 5 (left) Screen Shot of the ESRI Collector Application Showing a Vermont Culvert
Figure 6 (right) Attachments Uploaded as Part of Culvert Inspection within ESRI App

Prior to full time field work, the HIVE went through several mini trials to demonstrate its capabilities. After the first day of testing it was decided that the HIVE-provided lighting was not adequate inside of the culvert. VTrans developed a new mounting bracket for the camera which included space for mounting a pen light directly above the camera lens vastly improving the visibility during barrel inspections. The new bracket is shown in Figure 7.

Figure 7 Showing New Mounting Bracket Developed by VTrans for Additional Lighting

Since the completion of the pilot project described below the Agency is looking at making additional modifications to HIVE in order to augments its physical capabilities. Currently the HIVE can only be deployed for an end of pipe inspection on open drainage systems. There is a Statewide need to inspect closed drainage systems. To inspect closed systems, a HIVE retrofit is needed for lowering the HIVE into a drop inlet and then retrieving it.

PILOT IMPLEMENTATION AND LESSONS LEARNED

To demonstrate the use of HIVE for small culvert inspections in Vermont, a subset of 141 culverts representing 4,153 Interstate cross culverts was selected. Figure 8 shows the characteristics of the 141 culverts used in the pilot demonstration. The 141 culverts are considered to be the highest risk culverts which are cross pipes that are greater than 30” in diameter, have less than 10’ of fill over top of them, and have a combination of poor, critical, or unknown conditions.

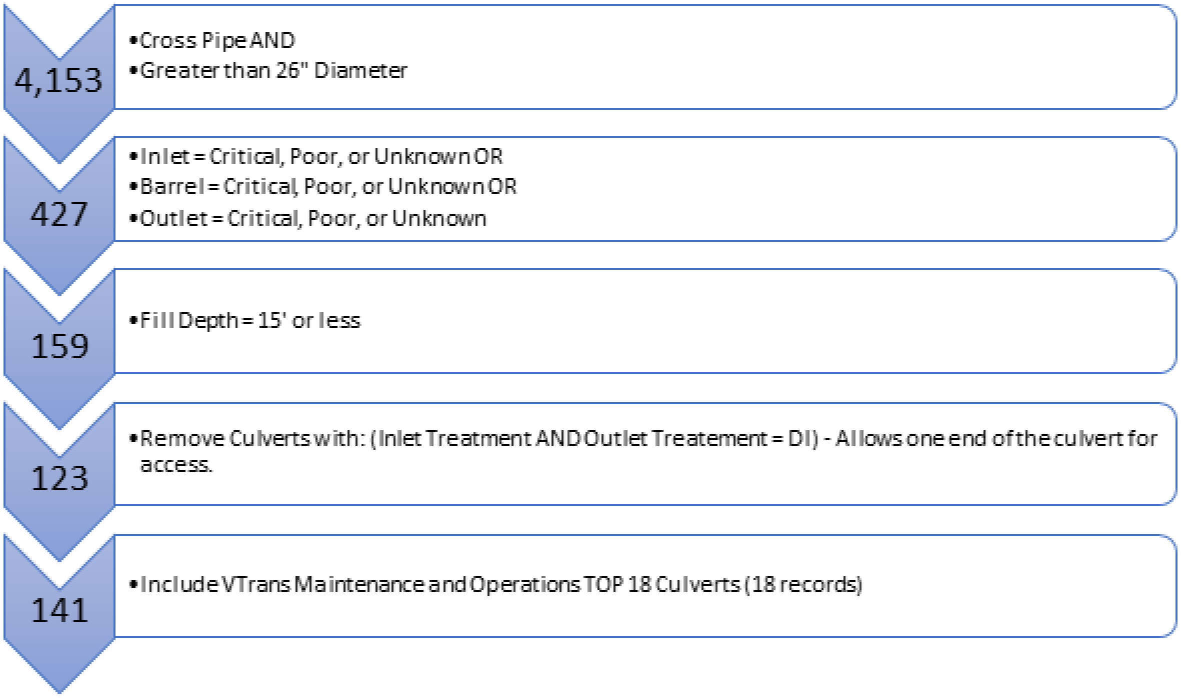

Figure 8 Graphic Showing the Characteristics of the 141 Culverts Used in Vermont's HIVE Pilot Demonstration

One engineer was able to demonstrate the use of the adapted HIVE on the 141 culverts in a three-week period in June 2018. The HIVE inspections revealed four culverts that need repairs in the next 12 months. The HIVE confirmed that the observed inlet and outlet conditions were carried through the culvert barrel. The HIVE analysis revealed additional culvert repair needs that will be authorized when funding is available.

The list of lessons learned include:

- HIVE operation. The HIVE moves really fast so learning to operate it proficiently is a challenge.
- It doesn't perform well in muck, so if a culvert is heavily sedimented it will not be able to go far. More than two inches of muck led to limited success.
- Water depths exceeding 4" will probably give it some difficulty. It can be fully submerged and operate but it will not travel far underwater due to loss of the radio signal.
- HIVE has trouble with debris (sticks, leaf litter, trash)--In pipes where there is a lot of debris, it's difficult to get the HIVE around all of the debris and then you risk getting it hung up and stuck. Once in the 141 deployments the operator struggled to get it free after it was stuck.
- It doesn't work well in culverts where the bottom is decomposed. It tends to get hooked on the corrugations and get stuck.
- Sloped pipes: The HIVE will go up them (or down them) but it does not have brakes so if you drive up, it is really difficult to get it back down because it will come zipping back

down, flip, and then you have to drag it out by the recovery cable (The first HIVE field break occurred during a sloped culvert inspection). If you can go down sloped pipes from the top it works better because then you are reeling the HIVE back up the slope.

Additional observations about the capabilities of the HIVE: The observed range inside of a concrete pipe was significantly less than the HIVE range in a metal pipe of equal diameter. The HIVE was unable to traverse muck and would easily become stuck in more than 2” of sediment inside a pipe. The HIVE was capable of traversing through 3”-4” of standing water in a pipe however when submerged radio transmission limited. Culverts with significant debris such as sticks, leaf litter, or trash were not traversable. The HIVE was capable of maneuvering through, over, or around rocks without getting hung up. The HIVE does not have brakes, therefore inspecting culverts with steep slopes from the bottom was tricky once the culvert reached the top and had to be retrieved (these situations typically resulted in damage and the end of the data collection for the day). It is recommended to start from the highest elevation and drive the HIVE to the lowest elevation such that brakes are not needed for slow recovery. Given the nature of the vehicle, piloting the HIVE was challenging. The controls are very sensitive and without proper operation the vehicle can easily get out of control inside a culvert and flip upside down. In one instance, the camera and servo assembly got stuck in a separation between two concrete pipe sections inside the culvert. Field staff had to pull firmly enough on the recovery cable that the section that was lodged in the pipe broke free of the HIVE. The recovery spool has a diameter of 18” therefore upon detection of an issue inside a culvert the distance from the end of pipe can be estimated based on the number of times the spool was turned during recovery. This allowed for relatively simple and accurate measurements inside of the culvert to observed distresses.

CONCLUSIONS

It is realized that this vehicle is not intended to replace a more capable and robust commercially sold pipe crawler, however it is intended to expand the Agency’s ability to collect credible data and reduce the cost of gathering that data. The risk associated with not authorizing funding to the culverts with observed distresses includes lost efficiency in decision making, higher risk to unplanned road closures, and the risk of potentially unsafe road conditions.

The HIVE is a great inexpensive tool that we can use to get video images of 80-90% of our network. For the last 10-20% of the culverts we can use an expensive video crawler. Given the lower HIVE cost, it is bound to have limitations since it was not made for commercial applications. However all video inspection crawlers can get stuck, and our Agency would prefer to lose an $800 video inspection tool than an $80,000 video inspection tool. The lower risk aspect of the HIVE is attractive.

The technology has the capacity to have multiple uses. It can be leveraged by Operations staff as part of the annual culvert inspection program, by Hydraulics to support data collection, Asset Management to validate pre-candidate lists, and by Design to determine treatment recommendations and support the Engineers' Estimate.

Next steps for VTrans include statewide implementation within our nine Maintenance Districts. District 4 is currently using the initial HIVE and plans to purchase the components and build their own HIVE. Districts 2 and 9 are also interested. Two of these Districts are known to be slow to implement new technologies so it is exciting that they see the value of the HIVE and are eager to deploy.

Without MNDOT's marketing of the HIVE, Vermont may never have been exposed to this technology and as such would not have been able to realize the magnitude of the potential benefits.

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