ABSTRACT

DHAYA SANKAR, ARVIND SANKAR. Use of Tele-Presence for Real Time Monitoring of Construction Operations. (Under the direction of Dr. Edward Jaselskis).

The research involves the study of a novel approach that can change the paradigm of how construction projects are managed in the field allowing for reduced site-based personnel, the ability to obtain expert opinion without physical site presence, and the potential to completely oversee a project from a remote location. The approach reduces the practical effects and physical presence of professionals at the construction site and enables active real time contribution by participation with on-site construction members. The main objectives of this research study are to:

1. Test the capabilities of virtual project management on different kinds of projects including residential buildings, commercial construction and heavy highway projects.
2. Develop a cost analysis indicating a detailed cost break down of the fixed and variable costs and conduct a survey to understand the benefits and limitations of the virtual project management.
3. Identify the ideal equipment set-up to be used at the site for supporting the harsh construction site environment.

The Tele-Engineering and Management (TEAM) Laboratory was developed at North Carolina State University to serve as a hub for receiving the live streamed video and audio from the jobsite. The Streamer™ is a hardware device provided by Mushroom Networks that can expand the streaming bandwidth and deliver a continuous high-quality video to the users.

The technology uses mobile cameras with zoom capabilities for real time transmission of video and audio to remote participants. Remotely located team members are able to visually instruct and guide the operator of the portable video camera equipment around the site to accomplish their duties in a tele-present or virtual fashion, thereby saving time and cost compared with a physical site visit. Pilot test applications were conducted on projects of varying size and type including single-family dwellings, bridges, roads, and buildings. Use cases for each of these projects included safety inspections, erosion control, progress monitoring, and new employee training. A virtual punch list was developed for a residential project helped the upper management to stay updated on the status of the project. A virtual safety inspection on the building project demonstrated that this approach could be used to replace some of the live jobsite visits. The zoom capability was particularly useful on the heavy/highway projects due to traffic interference.

A detailed cost break down of the fixed and variable costs associated with the functioning of the Streamer™ has been developed. The cost break down was used to establish the running cost associated with every use of the proposed technology. The cost for operating the streaming technology has been compared to the expenses associated with the traditional approach of construction requiring the physical presence of experts at the site. Results show that this approach has promise and with time certain issues related to reliability and cost will be resolved. The technology was studied to understand its application for remote monitoring of construction operations, perform the pilot projects, collect user feedback, analyze the implementation costs, and document the benefits and limitations.

Use of Tele-Presence for Real Time Monitoring of Construction Operations

by
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DEDICATION

To my அம்மா (Mom)

BIOGRAPHY

Arvind is an Engineer Intern (E.I.) who aims to pursue a career in the area of cost control and front end planning. He is a graduate student in Civil Engineering specializing in Construction Engineering and Management. He is a member of the Tau Beta Pi Honor Society and also works part time as a Grade 1 concrete field technician with ACI / DOT at NC State University examining concrete tests. He brings over three years of experience in the construction industry and his work involved project control, estimation, quantity analysis, planning, linear scheduling of resources. An experienced candidate, with a variety of technical and computing software skills such as Primavera, Auto Cad, ArcGIS and MS Project. He aims to work with a progressive construction organization or project development firm where he can excel and contribute to the company's profitability.

ACKNOWLEDGMENTS

I would like to extend deepest gratitude to my advisor, Dr. Edward J. Jaselskis for his valuable guidance and support. I would like to thank my research partners Shitanshu Jain and Ahmad Yousif for their help and contribution. Besides, I also thank Mushroom Networks for their technical support as and when required.

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CHAPTER 1: INTRODUCTION

Modern day construction is a complex operation with many different stakeholders contributing to the welfare of the project, many at different locations. Although, the construction manager is the primary person responsible for the execution of the project a variety of input related to design, construction methods, traffic engineering, structural implications and risk analysis needs to be collected from time to time as the construction advances to crucial stages of the project. Each and every stage of the project is interrelated and therefore a quick, reliable and feasible mode of interaction is necessary to buy input from experts, consultants and owner firms.

The continuous development of tele-communication has made interaction a lot better for participants to discuss the issues and concerns at the site. Use of point and shoot cameras, fixed video cameras, tablets and smart phones have enhanced the ability to send visual information that may not be sufficient and in most cases do not suffice the requirements to bring about a quick solution. As a result contractors and owners have experienced reduced productivity, cost overruns, delays in schedule and misunderstanding between stakeholders. Apart from the direct cost associated with the travel cost and time of these experts from different locations, there is a huge amount of indirect cost that add up as a result of the overhead costs and other home office expenses resulting in cost overruns.

A recent advancement in the field of information technology is the use of tele-presence to enhance the virtual presence of individuals from remote locations. Tele-presence is the use of innovative technology to transfer audio and video data such that the practical efforts of an expert being on-site are achieved without requiring physical presence of that individual at the actual location. The best possible means to achieve tele-presence in construction is the use of mobile cameras to get intricate details of each and every activity and to move around the construction site and provide a better scenario of the project. This research involves the experimentation of innovative techniques in different environments over a variety of projects to prove the benefits of virtual project management.

Virtual Project Management is the use of advanced technologies involving real time interactions enabled by virtual teams from remote locations to guide, manage and improve construction project performance. The approach reduces the practical effects and physical presence of professionals at the actual construction location and enables active real time contribution by participation with on-site construction members. The main objectives of this research study are to:

1. Test the capabilities of the proposed approach in different scenarios at various locations and complete a survey to compare its abilities with the traditional approach of managing construction projects.
2. Develop a cost-benefit analysis indicating a detailed cost break up of the direct and indirect costs involved in performing virtual construction site visits and inspections.
3. Identify the ideal packaging means for the equipment used at the site to support the rugged environment of construction sites.

The primary goal of the research team was to test the technology in different kinds of projects that varied from residential buildings, commercial construction and heavy highway projects. A feasibility study was performed for each of the projects and surveys were conducted with participants to understand the true benefits of using this virtual tool for managing construction projects.

The approach used mobile cameras with zoom capabilities for real time transmission of video and audio to remote participants and also to the Tele-Engineering and Management (TEAM) Laboratory. The Tele-Engineering and Management (TEAM) Laboratory has been developed at North Carolina State University to exchange information about on-site construction, maintenance, and repair activities using online web-conferencing tools such as Collaborate and WebEx. This novel approach is highly interactive and provides immediate feedback and solutions regarding a variety of issues, improves productivity, and reduces the cost of travel.

A Streamer™ is a hardware device provided by Mushroom Networks that can expand the streaming bandwidth and deliver a continuous high-quality video to the users. The live transmission occurs through the Streamer™ that has the capabilities to connect to multiple air cards from different network providers (AT&T, Sprint, T-Mobile etc.). The increased bandwidth helps to broadcast a good quality, continuous video to remote participants. The approach proved to be highly interactive between various participants at the home office, designer firms, consultants, safety inspectors and upper management to learn about the current issues and progress at the site. A survey was carried out to get industry input on the approach, to understand the benefits, and investigate potential improvements to the proposed technology.

A detailed cost break down of the fixed and variable costs associated with the functioning of the streamer has been developed. The cost break down has been used to establish the hourly running cost associated with every single use of the proposed technology. In addition to the proposed concept, another area to look into was to package the available equipment and study better equipment that would support the rugged site conditions.

In the next chapter, "Literature Review," earlier studies, research, and applications related to the area of research has been discussed. Chapter 3 describes the research methodology and approach. Chapter 4 provides more details on the working of the proposed technology, the selection of appropriate devices, and the overall operation. Chapter 5 includes the utilization of the approach on different construction sites, and Chapter 6 includes the cost breakdown for using the proposed technology. This is followed by survey results collected from industry professionals on the virtual tour along with feedback collected from experts to develop a cost benefit analysis in Chapter 7. Alternative equipment that could support the technology has been identified in Chapter 8. Results and evaluation of the various pilot tests performed at various projects has been described in Chapter 9. Chapter 10 provides a summary and conclusion of this research. Recommendations and potential future work in this area has been enlisted in Chapter 11.

CHAPTER 2: LITERATURE REVIEW

Tele-presence is a relatively new field that has been used in other fields apart from construction. One of the most prevailing concepts of tele-presence is the use of fixed web cameras at the job site. The idea behind the use of fixed cameras has been to improve security, calculate productivity and remotely monitor construction activities. A portable camera is required at construction sites to provide an interactive two-way communication between the experts at a remote location and the construction site professionals.

In 2000 (Anumba et al.) performed research on the development of a communication infrastructure that was based on the concept of tele-presence. The idea was to support interaction between project personnel throughout the design and construction phases of projects. The research describes the need for effective communications infrastructure between project team members throughout the construction phases of projects.

In 2008 (Silva et al.), a virtual supervision model was developed by the research team to study the improvement of project management. The model was used to obtain project information by mounting video cameras on tower cranes. The mounted camera provided access to project supervisors for watching construction activities from a remote location. They discovered benefits such as improved operational efficiency, higher quality communication, and improved construction worker satisfaction. A similar approach was performed by the University of Calgary, where a fixed webcam was mounted on five-story office building construction site to conduct virtual supervision. The camera assisted the construction management team in participating proactively and improving the interaction between site management and workers as well as improving safety awareness (Jaselskis et al., 2010).

Jaselskis et al. (2011) has performed additional research studies with promising outcomes making use of satellites to prove the benefits of tele-presence in remote locations. As part of the research, in the summer of 2010, a team of multidisciplinary researchers traveled to Peru to reverse engineer the Inca Road with the objective of identifying sustainable engineering practices. Satellite communication equipment was used to transmit audio and video data that were used to test the functionality of tele-engineering by teleporting information from the Inca location to an expert hydrologists located in the United States. The approach proved to be interactive in which researchers and experts were able to communicate in a two-way process and help better understand Inca road design (Jaselskis et al., 2011). Furthermore, Jaselskis, along with other researchers at Iowa State University, tested the idea of tele-presence by making use of Mifi technology. The research project was to piloted virtual project tours using a wireless MiFi device that was connected to a micro PC, a digital camera, a hands-free headset and microphone. Similar to the satellite technology, real-time video and audio were transmitted from the construction site to students seated in a high-technology classroom over 200 miles away.

Another prospective development in tele-engineering was by the U.S. Army Corps of Engineers (USACE) who have have pioneered research and development in this area. As part of this research program the USACE Reachback Operations Center was established in Vicksburg, Mississippi. The center was developed to enable experts in the United States to provide immediate solutions to the ground personnel through tele-presence. This is achieved by delivering real-time information using video conferencing, digital photos, and other mobile communication technologies (ERDC, 2011).

Tele-medicine has provided significant advantages to the medical industry. The University of Texas Medical Branch (UTMB) Health has significant experience in the area of tele-medicine, tele-communications and wireless and tele-monitoring technologies. The research proved that these approaches had improved the patients' access to specialists, increased patient satisfaction, improved clinical outcomes, reduced emergency room utilization, addressed patient problems before they required major intervention, and resulted in cost savings (Alexander Vo et al., 2011). In Dubai, there is a new center that will enable patients to receive virtual consultations from specialists all over the world (The National, 2011). In Bonsaaso, Ghana, information and communication technologies were used to overcome geographical barriers by reducing the patients' need to travel long or unsafe distances to see medical experts (Novartis Foundation, 2012). Tele-presence has enhanced the efficiency of other industries, and therefore an effective implementation of such a technology in the construction industry is reasonable to consider.

In 2012 Jaselskis proposed the new streaming technology that involved a mobile video system allowing site personnel to broadcast activities from a construction project to participants in remote location situated anywhere around the globe. The idea was tested in a residential environment stating the benefits and limitations of using the approach.

CHAPTER 3: METHODOLOGY

The primary objective of this research team is to determine a solution so as to make construction sites more accessible to project stakeholders. The idea behind the virtual approach is to reduce the unnecessary travel cost and time associated with the experts and to improve productivity at the site by bringing about quicker solutions to problems at the site. The team had to use appropriate combination of hardware and software that is easily available in the industry with high reliability and easy accessibility. Table 1 shows the list of software and hardware used for this purpose with a brief description on the specifications of the equipment.

Table 1: Equipment for the Virtual Approach

Equipment	Features	
Sony® Handycam – DCR-HC62	2.7” LCD Screen 25x Optical Zoom	Live Streaming Manual Focus
Sony Vaio® - P Series Laptop	8” screen 1.5 lb Net Weight	1.60 GHz, 60GB HD 4.8”(W)x9.7”(D)x0.8” (H)
Streamer™	Four USB Ports 1.32 lb Net Weight	5.7”(W)x3.9”(D)x2.0” (H) Operates between 32–113°F
Wireless Internet	Mifi Verizon®	Air Cards AT&T™ , T-Mobile®, and Sprint™

The listed equipment were connected such that they could be packaged in a backpack, as shown in Figure 1, for ease of use at the construction site. A portable battery was used to provide power to the Streamer. The person operating the equipment is called a drone (a non-expert who operates the proposed technology at the construction site) who has all the equipment in the backpack, except for the camera.

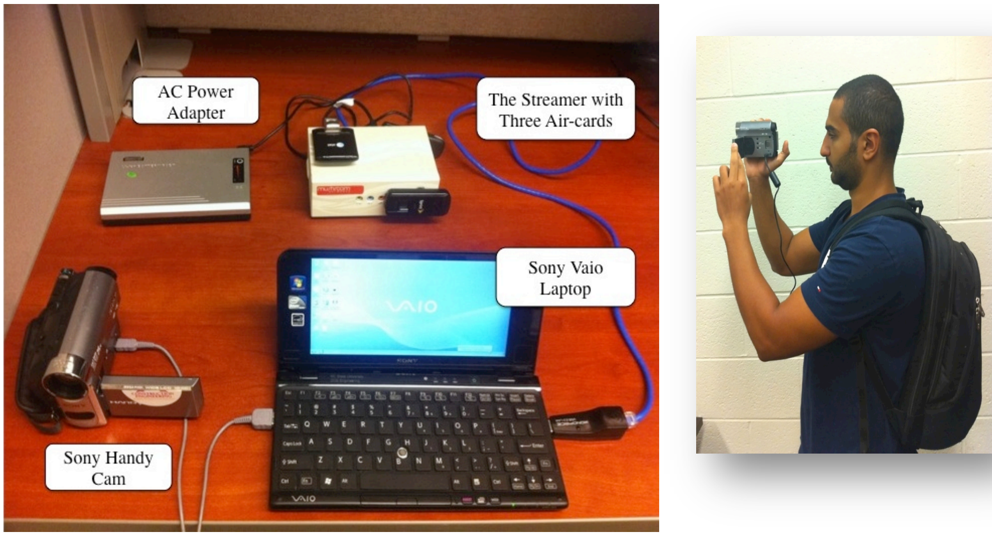


Figure 1: Equipment setup for the Streamer™ technology

Figure 2: Sony Handycam® and Sony VAIO® Laptop

Figure 3: Mushroom Network's Streamer™ With the Three Air-cards

The Tele-Engineering and Management Laboratory (TEAM) laboratory was developed to support the Streamer™ technology and provide an opportunity for distant participants to actively engage themselves in ongoing projects. In order to make this efficient, the equipment in the lab was selected to be of higher configuration that could support multiple software such as AutoCAD, Revit, ArcGIS, Primavera and Navis Works. A total of 6 monitor screens (as seen in Figure 4) were selected in order to make it easier for the user to compare the drawing, schedule and BIM model with the live feed of the project site that comes in from the Streamer™ .

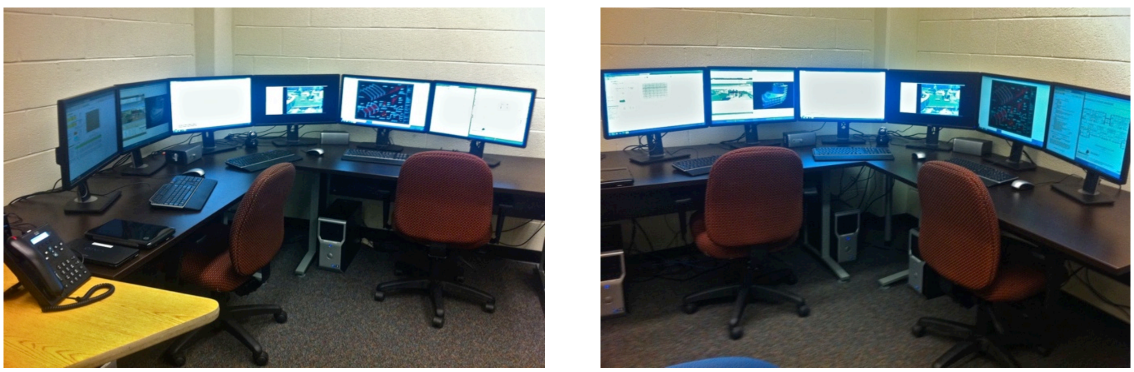


Figure 4: Tele-Engineering and Management (TEAM) Laboratory in Mann 221

The listed software and hardware was used in previous research that included the construction of residential projects. However, the objective of this research was to extend the same to other areas of construction that included commercial and highway projects that were located in different locations. Initially, the idea was to test the approach in multiple areas such as safety inspections, progress reporting and erosion control in nearby commercial projects. The Talley Student Center constructed at North Carolina State University by Rodgers Builders was a project that enabled the team to understand the Streamer™

technology. Based on the results obtained from the commercial projects located locally, the team decided to extend the idea to larger scale projects in bigger cities. There were a couple of reasons for applying the idea on these projects.

- The number of virtual participants increases on larger scale projects which helps to better analyze the approach and understand its feasibility.
- The effectiveness of the Streamer™ could be proved only by proving its reliability in variety of scenarios at different locations.

The larger projects selected for this research were the renovation and extension of the Hamilton Bridge and the Kew Garden highway project. Both of these projects were located in New York City and the tests were performed with the help of the New York Department of Transportation (NYDOT), Long Island City. An evaluation of each of the tests was performed and documentation was performed reporting the feedback that included the suggestions and recommendations of various participants.

The virtual participants were provided a survey at the end of each test, which helped the project team understand the needs and benefits of the proposed concept. The survey helped to develop a cost benefit analysis that was specific to similar category of projects. A detailed cost break down to run the Streamer™ was developed to understand the associated cost impacts.

CHAPTER 4: TECHNOLOGY

An appropriate technology had to be developed to allow construction experts to participate in on-site activities from remote location. The proposed idea had a drone to transmit live data from the site to the experts located in different off-site locations. The devices for this approach were selected to be portable and user friendly. The Sony Handycam had an excellent zooming capability that provides close up details. The Streamer™ is the device that has the ability to connect multiple air cards from various network providers and provide a higher bandwidth for the transmission of live video and audio data. The laptop enables the functioning of the entire setup. It is connected to a Sony Handycam and the Streamer™ through the USB ports. The transmission occurs using

- Adobe flash media live encoder – a free live encoding software
- Amazon Web Services™ (AWS) - a remote computing service

The Adobe flash media live encoder helps to stream the live video using the air cards and webcam connected through the USB port. AWS provides online service for Streamer™'s web based application. The webcam, connected to the Sony Vaio laptop, provides the ability to stream live video using the encoding software. AWS needs to be purchased to get access to the virtual computers that enable the functioning of the tunnel technology protocol associated with the Streamer™. An exclusive flash based video server is used as the broadcasting tool that telecasts the live video from the construction site to remote locations. There is no restriction on the number of users who can access the video server at any particular time.

The TEAM lab is also one of the users to access the live feed from the site. Although Streamer™ allows the broadcast of audio, the technology is designed to provide only one-way audio and video transmission. Hence, a telephone bridge is created to provide a conference call facility for the participants. The video feed is merged with the audio coming out of the telephone bridge. Camtasia Studio is used at the TEAM lab to record the feed and use it as a method of documenting the virtual approach. The video from the Streamer™ has a 5 second lag that requires consideration of the virtual participants. This means that the audio feed is ahead of the video and hence requires coordination of the field participants and the virtual experts. The 5 second delay on the video is the time required by the Streamer™ to combine the bandwidth of the multiple air cards and send out a continuous output to the video server. There are four parameters that define the final output of the live video stream:

- Signal strength on the various air cards at a particular locality
- Bandwidth set on the Flash media encoder
- Delay defined on the webpage of the Streamer™ and
- Number of end users using the video server

The telephone bridge used for audio communication can be replaced by WebEx conferencing tool. This tool not only has the features of any VoIP software (such as Skype) but also has additional features that enhance the interaction between participants. One such feature is the ability of WebEx to share and annotate PDF and MS Office formatted documents. The tool also has the feature to share the desktop that is helpful for the virtual participants. The information on the project in the form of drawings, specifications, schedule and model can be shared real time from the TEAM lab to all other participants.

An overall flow chart of the entire process showing the transmission of information from the construction site to the end users in remote locations has been depicted in Figure 5 and 6. The laptop at the site acts as the input device that combines the technology of the Streamer™ with the Adobe flash media encoder to broadcast the video captured using the handycam. The video server on the other end at the bottom of the chart is the output tool that brings the video to the end users who are the remote participants. Amazon cloud services provide the web-based server connecting the drone at the site to the experts taking part from their desks.

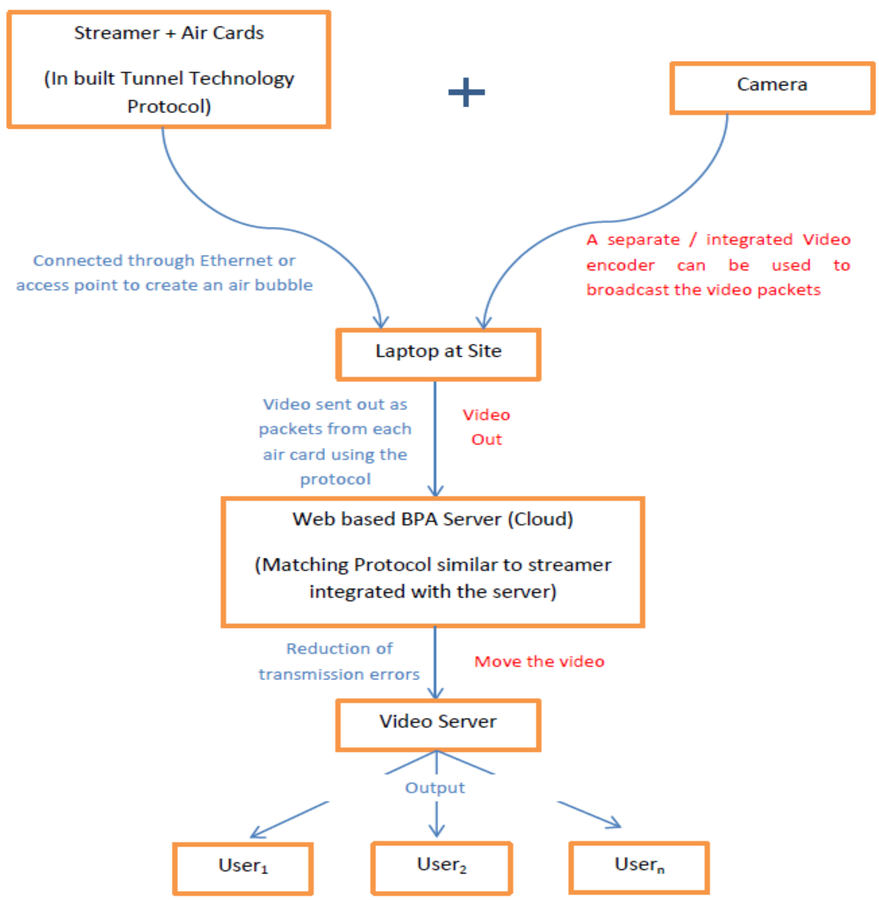


Figure 5: Flow Chart Model of the Proposed Technology

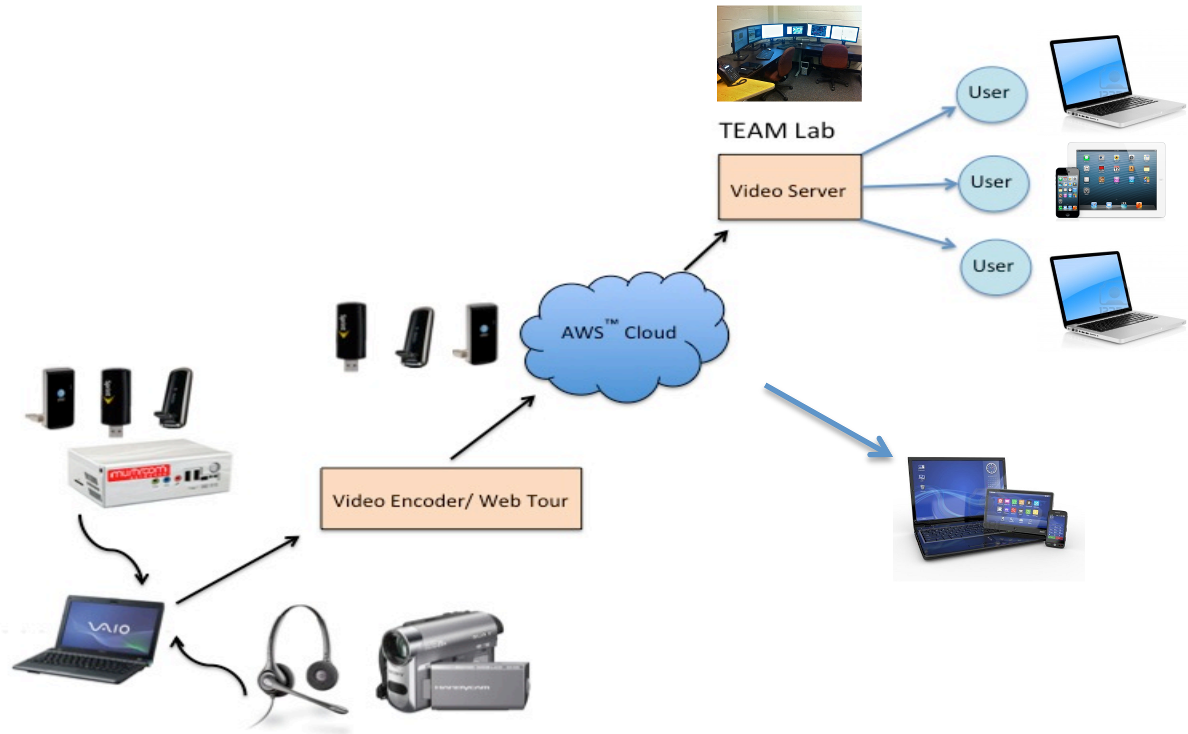


Figure 6: Working of the Proposed Technology

It can be observed from the figures that any electronic device connected to the Internet can directly view the final video server. However, an alternative approach would be to send the server through the TEAM lab as shown in Figure 6. In this approach web conference software such as WebEx can be used to share information between the various stakeholders and it requires a person to monitor the entire virtual tour from the TEAM lab. The advantage of this approach is that the TEAM lab is equipped with software that can record and document the entire session, which can be used as reference or proof of evidence in future.

CHAPTER 5: USE OF STREAMER^{TM} TECHNOLOGY

Several pilot tests were conducted to better understand the effectiveness and capabilities of this novel site monitoring approach. Tests were conducted on private residential, university campus housing, building, and heavy/highway construction projects. Progress monitoring and training was tested for Mungo Homes, a residential development firm. Erosion control and safety inspections were performed on the addition to the Tally Student Center on the North Carolina State University campus. Furthermore, two New York Department of Transportation projects were also used to pilot test this concept. An evaluation for each pilot test was performed along with a discussion of the challenges and improvement suggestions. Feedback and recommendations from the management team and other participants were captured and used for consideration of future work in this area.

RESIDENTIAL

Mungo Homes is a residential company, headquartered in Columbia, South Carolina that has several new housing projects in the Raleigh-Durham area. The research team had obtained access to one of their projects in downtown Raleigh to test the concept. The project scope involved the construction of townhouses. A total of 8 tests were planned as tabulated in Table 2 and the findings on each of the tests have been briefly explained in this section. The author was part of the research team to perform each of these tests that were documented in detail during the summer of 2012 by Ahmad Yousif. A brief overview of the major tests has been provided in this research study.

Table 2: Overview of Virtual tours at Mungo Homes

Test No.	Date	Location	Purpose
Test 1	Saturday, June 16, 2012	Downtown	Virtual Site Inspection, Monitoring, and Percent Complete
Test 2	Tuesday, June 19, 2012	Downtown	Virtual Site Inspection, Monitoring, and Percent Complete
Test 3	Thursday, June 21, 2012	Downtown	Virtual Site Inspection, Monitoring, and Percent Complete—Review Punch List Items
Test 4	Saturday, June 22, 2012	Downtown	Virtual Vs. Traditional Punch List
Test 5	Tuesday, June 26, 2012	Downtown	Virtual Training
Test 6	Saturday, June 30, 2012	Downtown	Virtual Site Inspection, Monitoring, and Percent Complete
Test 7	Tuesday, July 3, 2012	Downtown	Testing Different Setups of Equipment
Test 8	Thursday, July 5, 2012	NCSU	Other

The main goal was to test the effectiveness and capabilities of this VPM system and compare its usefulness to the more conventional construction management methods. The tests performed with Mungo Homes have been documented and discussed based on the feedback received from the participants.

Test 1: Saturday, June 16, 2012

An employee of Mungo Homes was at the construction site to provide an explanation of the status of construction work, the progress, the completion percentage of each activity, and the issues encountered and how they had been corrected. The virtual participant was located in the TEAM Laboratory recording the live video and asking questions to the person at the jobsite.

The progress of each activity at the site could be easily observed by the virtually participant. An example was observing that the roofing in town houses was about 85% complete. The virtual participant was even able to identify that some of the garage roofs had not been shingled and could see that the sidewalk pads were prepared and ready for pouring concrete (see Figure 7).

Figure 7: Virtual tour of the Sidewalk Pad and roofing of town houses

During this test, the video was transmitted through the Streamer™ and the audio through Skype. The drone at the site used an android enabled tablet to access Skype and the internet was provided through the Verizon mi-fi.

Test 2: Tuesday, June 19, 2012

The project managers at Mungo Homes were interested in the virtual approach, but they wanted a reduced delay on the video output. In order to achieve this, they were willing to sacrifice the video quality. The team achieved the shorter delay by reducing the bandwidth on the Adobe Flash Encoder. The video lag time was reduced to 5 seconds. The video was pixelated as compared to 800 kbps bandwidth but was satisfactory to perform the inspection and conduct virtual tours. The bandwidth is a parameter that depends directly on the signal strength of the three air cards at that particular locality. Camtasia was used to record the video and the audio for future reference and documentation purposes. The files were saved online for access to remote participants at a later period of time.

The audio from the Streamer™ was enabled instead of using Skype. The disadvantage of this approach was that

- The audio communication was not two way and hence lacked interaction
- Both the audio and the video had the same delay associated with the protocol on which the streamer worked

Test 3: Thursday, June 21, 2012

During this test, the team visited a unit that was approaching completion and reviewed the punch list items. A person on-site was reviewing the punch list items with the person in the TEAM Laboratory. The person in the laboratory was able to virtually evaluate the following punch list items:

- Ensure that the pilot light is on in the fireplace
- Repair the damaged drywall
- Check installation of ceiling fans
- Check installation of a towel bar in the master bathroom
- Repair the tub in the master bathroom
- Check installation of the cabinets in the laundry room
- Make sure that the trim around the dryer vent in the laundry room is installed
- Check installation of one extra shelf in the second floor bathroom.

The VPM approach also helped the virtual participant to identify that there were some paint imperfections on the walls such as discoloration and spots with extra paint, which needed to be refinished. In addition, there were some scratches on the floor that had to be appropriately marked with green tape for the flooring subcontractor to repair or replace.

Test 4: Saturday, June 22, 2012

In order to compare the effectiveness of VPM with traditional project management, a scenario was created in which two members of the team were in the TEAM Laboratory as project manager and senior project engineer, while one team member was on-site as the project engineer. The project engineer went over the punch list in the traditional way without using the streaming technology. Afterward, the project engineer was asked to go over the same punch list again, but this time with the project manager and senior project engineer for them to see the progress virtually. A total of 16 punch list items were considered for this test. All 16 items were specific to one particular town house that was to be handed over to the client on final completion, due shortly.

It took the project engineer 7 minutes to complete this punch list in the traditional way as compared to the virtual method, which took about 14 minutes. One reason for the additional time was the video delay of 5 seconds, which involved coordination between the person at the site and the participants viewing the project from a remote location.

Another reason for the additional time was the two-way conversation between the project engineers on the site with the people in the TEAM Laboratory. The virtual visit allowed upper management to become more involved in the project. Therefore, more questions were raised while performing the punch list, and thus more time was spent to answer those questions. Such involvement would increase the reliability of the on-site management reports and help develop feasible schedules as well as increase upper management awareness about the exact status of the project.

Test 5: Tuesday, June 26, 2012

A pilot test was also conducted to determine the effectiveness of virtual training for newly employed engineers with no experience in construction. The research team wanted to see how effective it would be to use this technology to connect the people on-site with experts located at a remote location to offer help, guidance, and support. To achieve this goal, one team member who was very familiar with the site was assigned to train and guide another member who had been to the same exact unit before. The researcher in the TEAM Laboratory gave the person on-site directions to walk through the units by viewing the received live video. The person on-site was guided to inspect the roof, ceiling, frames, thermal insulation, electrical work, water piping, windows, columns, and connections. The training went smoothly, without any problems, and the technology proved its effectiveness.

Test 6: Tuesday, July 3, 2012

The objective of the test was to test the efficiency and adaptability of the Streamer™ with a different equipment setup. A Logitech® Web Camera was used to stream the live video instead of the Sony Handy Cam and a Mac Book Pro® replaced the Sony Vaio laptop. A photograph of the setup is shown in Figure 8.

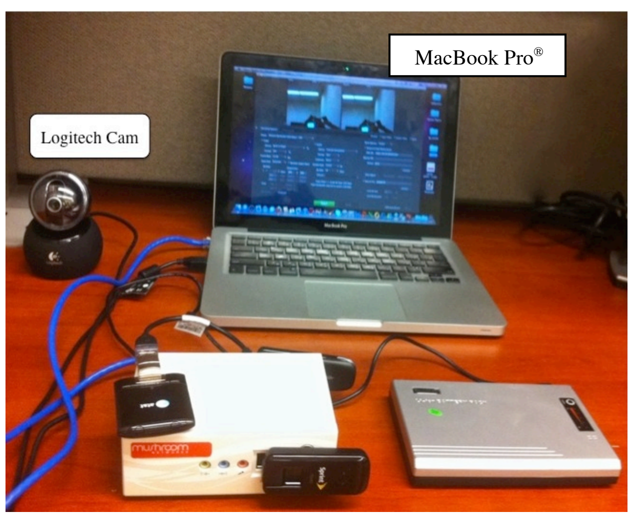


Figure 8: A modified equipment setup to run the Streamer™

The delay on the Streamer™ increased with the modified setup. One major reason for this was the fact that the Logitech Camera was high definition and hence the upload required a higher bandwidth compared to the Sony Handycam. The setup could be used as an alternative in future scenarios with localities that have higher signal strength.

Test 7: Thursday, July 5, 2012

The Streamer™ has four parameters that defined the output data: the delay set on the streamer, signal strength of the air cards, bandwidth set on the encoder and the number of end users. During this test, the team wanted to see if increasing the number of viewers on the web server would increase the video delay. Table 3 shows a summary of the results. The internet signal was very strong, and therefore the video quality was high. The team selected multiple video bandwidths (300 kbps and 800 kbps) and set the Streamer™ for different delay times (1500 ms, 3000 ms, and 6000 ms). As the number of web server viewers increased, the corresponding actual delay was recorded. After reviewing the results from this test, it was concluded that the number of viewers did not have any significant effect on the video delay. For example, in tests 2, 3, and 4, regardless of the increasing number of web viewers from one to five, the video delay kept constant. In test 1, the change was insignificant.

Table 3: Results of Increasing the Number of Web Viewers Vs. Video Delay

Test No.	Bandwidth	Delay Time Set on Streamer	Actual Delay	Remarks	Signal Strength	Location
Test 1	800 kbps	6000 ms	8 s	1 viewer	T-Mobile 45% AT&T 90%	NCSU
			9 s	2 & 3 viewers		
			10 s	4 viewers		
			10 s	5 viewers		
Test 2	800 kbps	1500 ms	6 s	1 viewer		
			6 s	2 & 3 viewers		
			6 s	4 viewers		
			6 s	5 viewers		
Test 3	300 kbps	3000 ms	6 s	1 viewer		
			6 s	2 & 3 viewers		
			6 s	4 viewers		
			6 s	5 viewers		
Test 4	300 kbps	1500 ms	4 s	1 viewer		
			4 s	2 & 3 viewers		
			4 s	4 viewers		
			4 s	5 viewers		

CAMPUS HOUSING PROJECT

Two erosion control inspections were conducted at upcoming projects for North Carolina State University. One was the Housing Project in Centennial Campus and the other was the Talley Student Center in the Central Campus of North Carolina State University. The process was similar for both the projects and hence the virtual tour at the housing project has been documented. Balfour Beatty Construction is constructing the housing project and the participants who were physically present during the test were the Site Supervisor, and a team who were conducting the inspection on behalf of the Owner's representative. Another representative, part of the Owner's construction management team and Dr. Edwards Jaselskis were virtually present at their offices monitoring the inspection.

The inspection was a routine monthly inspection, checking on sediment barriers, inlet barriers, perimeter control, stream crossing and the sediment basin. One other area of inspection was to check the general site conditions that included concrete washout areas, and vehicle tire washing areas that were designated for the project.

The virtual participants were able to clearly view the newly placed clean gravel that was to prevent any deterioration or thinning of the mulches/grasses existing in the project area. The sediment trapping facilities were well maintained by the contractor. The owner CM had questions about the condition of the sediment basin slopes, which were answered by the site supervisor. The virtual tour had no one in the TEAM lab to operate any kind of conferencing software and hence the entire group was connected using a telephone bridge. The live stream that came from the streamer was set to a minimum delay of 5 seconds.

The inspection lasted approximately 90 minutes and the major part of it involved walking around the site under construction since the site was so large. One of the advantages observed by the virtual participants was that during the time that the team travelled around the site, they could multi-task by getting other work done while glancing periodically at the live stream from the construction site on their computer screens.

BUILDING PROJECT

The objective of this virtual tour was to identify the prospects of using the proposed idea for a safety inspection and obtain feedback from the safety coordinator to determine the potential benefits and drawbacks.

Rodgers Builders took part in a virtual safety inspection of the Talley Student Center addition project to better understand the potential value and effectiveness of using an innovative remote site monitoring for conducting construction site safety inspections. The main objective of this test was to identify the prospects of using the proposed virtual management concept on a safety inspection and obtain feedback from the safety coordinator to determine the potential benefits and drawbacks. The company safety coordinator was able to verify many safety aspects related to this project from his off-site location where he was receiving the live video stream from the worksite.

Participants

RODGERS Builders	North Carolina State University
Doug McKelvy, Safety Coordinator	Dr. Edward J. Jaselskis, Professor
Wes Spurlock, Field Superintendent	Arvind Sankar, Graduate Student

Some of the other significant observations that he could make have been listed along with his feedback.

1. *Workers PPE:* Doug was able to see clearly if the workers were tied off with the fall protection system and also tell if they were using their safety harness and personal protective equipment (PPE). The worker seen in Figure 9 was standing 30 feet from the ground level and the zoom capabilities on the camera helped Doug to identify the safety requirements followed by the crew.

Figure 9: Workers wearing PPE

2. *Handrails:* The virtual tour could also give sufficient details to see if the handrails placed for safety protection on the higher levels were in place. However, one concern was additional details of smaller items like nails, which may be sticking out at certain levels.
3. *Column Bolts on the rebar:* The quality on the video was better using the zoom capabilities on the camera, which provided a better and closer picture of the bolts and the workers working on it.
4. *Gauges:* A closer view on the gauges attached to the oxy-acetylene cylinders provided sufficient information to check if they were within the permissible range and another positive aspect was that Doug could make out if the glass panel for the gauge was in place without any damage. In certain cases there is a possibility that these panels are fallen out of place, however Figure 10 shows that they were secured in place without any issues.

Figure 10: Oxy-acetylene cylinders

5. *Ladders:* The job made ladders (seen in Figure 11) were to be secured at the top and bottom as per OSHA requirements--the virtual feed helped the safety coordinator make out if they were set up according to the safety regulations.

Figure 11: Job made ladders

6. *Rebars bent:* The ends of the rebar were to be bent at the edges for protection and the safety coordinator could satisfactorily view that from the incoming live feed.

Figure 12: Rebar bent at the edges

7. *Workers Opinion:* In general, workers tended to be more cautious if the site inspector was physically present at the site during the inspections. This made them aware of

the fact that they were being watched and tended to put the workers on a more heightened state in regards to the use good safety procedures. With this virtual approach, workers are viewed in a more natural state.

8. *Time and Cost:* The idea of virtual presence at the site can be beneficial especially when stakeholders need to travel long distances amidst their busy schedules.

<u>HEAVY/HIGHWAY PROJECTS</u>

The Streamer™ had to be tested for its performance outside the Raleigh area and also on projects on a larger scale. This technology was tested on two large-scale projects executed under the supervision of the New York Department of Transportation (NY DOT). One was the renovation and extension of the Hamilton Bridge and the other was a highway project – Kew Garden. In order to understand the signal strength in the surrounding areas, the Streamer™ was first tested at the construction site and relevant information on the project was collected. The signal strength was adequate in most locations on the site; there were areas where the signal was lost – one area was going into a subway station and another in a tunnel that was under construction.

<u>Hamilton Bridge</u>

At $407 million, the Alexander Hamilton Bridge Rehabilitation Project is the largest single-contracted construction project in the history of the New York State Department of Transportation. This complex highway interchange project where I-95 and I-87 intersect involves many different elements of construction, including a full deck replacement as well as partial replacement and repairs to the superstructure and substructure of the bridge. The bridge that is shown in Figure 13 links I-95 between Manhattan and the Bronx in New York. The purpose of this project is to increase the capacity of this historic bridge by widening lanes and constructing new bridges and ramps. Each of the eight ramps had to undergo repair or replacement and had to be replaced with temporary structures.

Figure 13: Alexander Hamilton Bridge

The area construction supervisor for the NY DOT assisted by providing the virtual tours to colleagues in the regional DOT office, headquarters in Albany, and design office in Manhattan. The purpose of this project is to increase the capacity of this historic bridge by widening lanes and constructing new bridges and ramps. The project was about 75% complete during the site tour.

There were around 15 virtual participants from the Home office of NYDOT in Albany and one viewer from North Carolina State University recording the entire output from the live stream. Initially the viewers at NY DOT had issues accessing the video output from the streamer. One of the reasons for this issue was that the browsers did not have an updated flash to run the video. For the browsers to run the video, it is necessary to update the flash. Flash videos load faster and save on download time, which gives the user a more responsive rich-client like experience.

The virtual tour started from the site office trailer located below Bridge 6 and the stream was not continuous at this location and was attributed to a weak signal amongst all of the steel. There was a jacking tower used to erect and support the piers (Figure 14). The jacks were moved from pier to pier along with the progress in construction. The virtual participants wanted to check the status and quality of this jacking tower as well as the 25x zooming capabilities available on the video camera. Remote participants were satisfied with the results because objects from far away could be brought closer with a good resolution. The site supervisor explained to the virtual audience that the decks were ready for formwork and pouring and also the existence of sheeting under the bridge structure.

Figure 14: Jacking system attached to Bridge 6

The research team then moved on to another location on the Fifth Avenue Bridge (Bronx side of project) to view the site from an elevated perspective. The first area broadcasted to the virtual participants were the gantry cranes that were value engineered by the contractor to place the girders for Stage 4 and Stage 5. A detailed view of the joints and connections were shown to all the participants. A better view of the overall project was provided; it was shown that Ramp B, that had both a temporary and permanent structure, was broadcasted in great clarity. The temporary structure had to be built to support the moving traffic while the actual ramp under construction was currently being poured (see Figure 15).

Figure 15: Ramp B under construction adjacent to temporary ramp

The supervisor at the site talked in detail about the logistics of the traffic movement on the various wings of the bridge, which made the Streamer™ an advantageous tool for people located off-site. There was a ramp, 6A, that was located on the other end of the Hamilton bridge which was about 450 meters away. The zoom capability of the camera helped to provide a closer view of the completed ramp (see Figure 16).

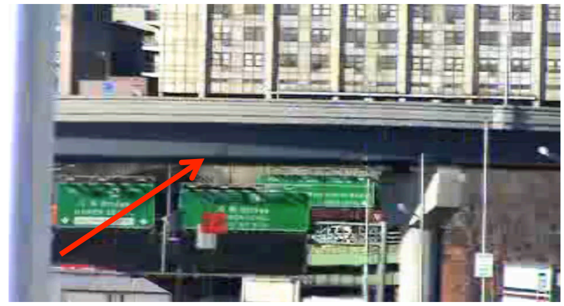


Figure 16: Comparative picture showing the zoom capabilities

The viewers wanted to know the portability and size of the equipment, and hence the details on the dimensions of each of the equipment were shared to the viewers. One major interest to the virtual participants was the clarity of the video output to read overhead signs on the highway. An overhead sign located across the other end of the bridge about 0.28 miles away was focused on and the content on the signboard could be clearly observed.

Figure 17 shows the aerial view of the rehabilitation project and the yellow line in the figure indicates the angle of vision. The distance has also been measured and indicated to prove the zoom capabilities of the virtual setup.

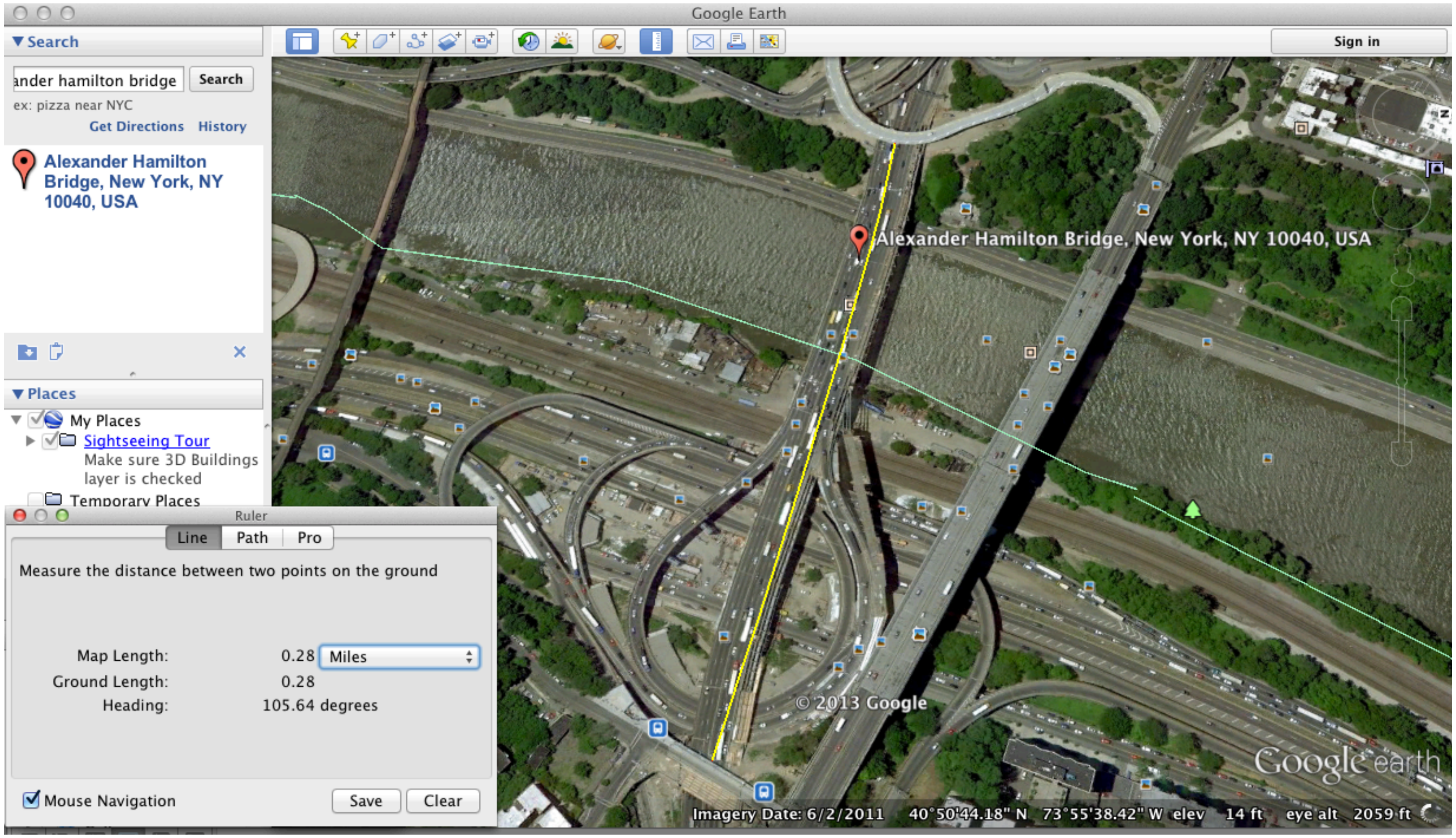


Figure 17: Distance between the virtual equipment at the signboard

Another area that the virtual participants wanted to observe was the area between the bridge and the shield under the bridge that was partially covered by a shadow. The shield could be seen along with the details on how it was suspended from the bridge. The contractor was moving reinforcement bars on the deck under construction using a mobile crane that was observed at a closer view. One of the major challenges in the project was the traffic and so the movement of traffic along each of the ramps and the bridge itself was observed as requested by the virtual participants. Some of the best uses of the technology as discussed by the participants related to performing safety inspections, solving issues that commonly arise on a project that enables a two way conversation between various stake holders, showing accidents and performing investigations at a faster pace, bringing people at distant locations to the project and also perform bridging inspections.

The NY DOT hires consultants to perform the initial inspection followed by site visits by NY DOT inspectors. It was thought that both could be done at once by inviting NY DOT inspectors to the initial inspection using this remote streaming technology. The thought was that the consultant could use this virtual tour concept and eliminate the need for the DOT inspectors to physically go to the bridges.

Kew Gardens Highway Project—Contract 1

The Kew Garden project was another NY DOT project and the virtual tour started at the intersection of the Main Street and Queens Boulevard. A total of around 15 participants were taking part to view this particular project. This project involves ramp widening, road reconfiguration and a new subway station. The first part of the tour was to walk the modified pedestrian walkway to the new subway entrance and to find out if there were any potential hindrances to the public. A picture of the new subway entrance A and the modified subway entrance B is shown in Figure 18. Entrance B was the only access to the subway for the public until the construction of the new subway entrance is complete. The virtual participants could easily observe signage for the temporary entrance.

Figure 18: The Subway entrance A and B

The transit authority had a few issues with the modified entrance to the subway that was shown closer up using the proposed technology. One issue was that the authorities were looking into installing a gutter to the roof and all the participants agreed that a gutter was necessary. The temporary fencing by the side of the walkway was to be replaced by permanent fencing, which was an acceptable requirement. The other area of concern was the handrail (seen in Figure 19) leading to the subway entrance that needed to be extended to the entrance of the pedestrian walkway leading to the subway.

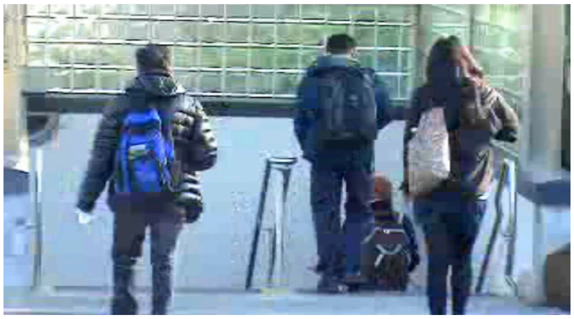


Figure 19: Handrails that need to be extended

The next stop on the virtual tour was to observe the new pedestrian tunnel under construction and the footings for the abutment. A close up of the reinforcing for the foundation was provided to the virtual participants as well as the fiber optic lines that hung across the excavation as shown in the Figure 20. It was pointed out that the cables will eventually need to be relocated.

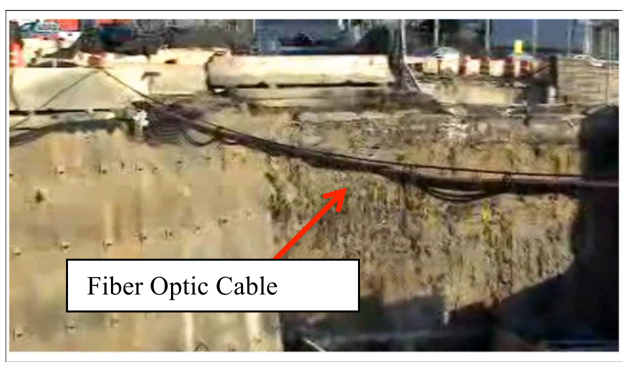


Figure 20: Fiber Optic Cables that needed replacement

The existing tunnel to the subway required some alterations and the contractor had concerns of laying tiles over the existing rough concrete floors, which may not provide a leveled surface and could be a tripping hazard. The virtual participants could clearly see the unlevelled rough surface. Their solution was to lay down a leveling grout layer and then install the tiles. The technology helped the virtual participants interact with on-site officials and discuss these concerns that helped everyone better understand this issue.

The retaining walls under construction for the new ramp that was partially erected beside the old ramp from Northbound Van Wyck to Queens Boulevard was broadcasted as the site team walked through to the new subway tunnel section. The patterns on the wall were shown to the virtual viewers. The new steel for the ramp to Queen's Boulevard which was recently erected and the connections on the steel structure could be seen close up to the satisfaction of the viewers (see Figure 21).

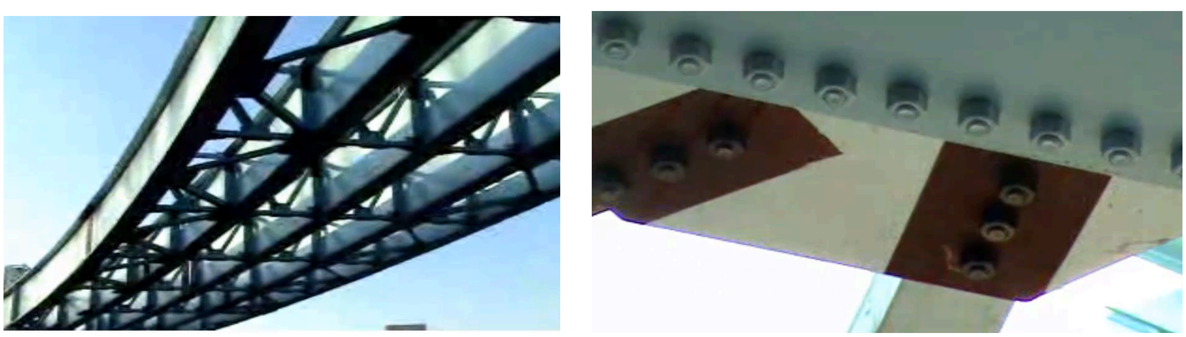


Figure 21: Connections on the Steel Structure

The final part of the virtual tour was the bridge deck under construction at Hoover Avenue. The video showed the gas lines and the utility duct bank that required the fiber optic cables to be pulled at Queen's Boulevard over Van Wyck.

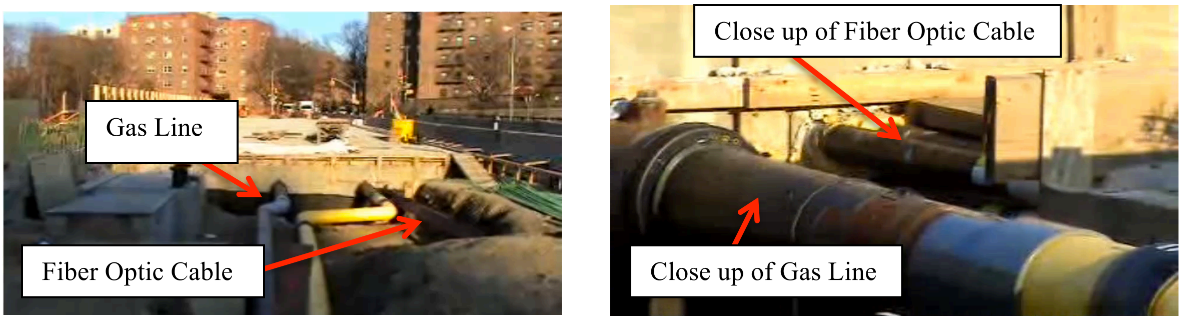
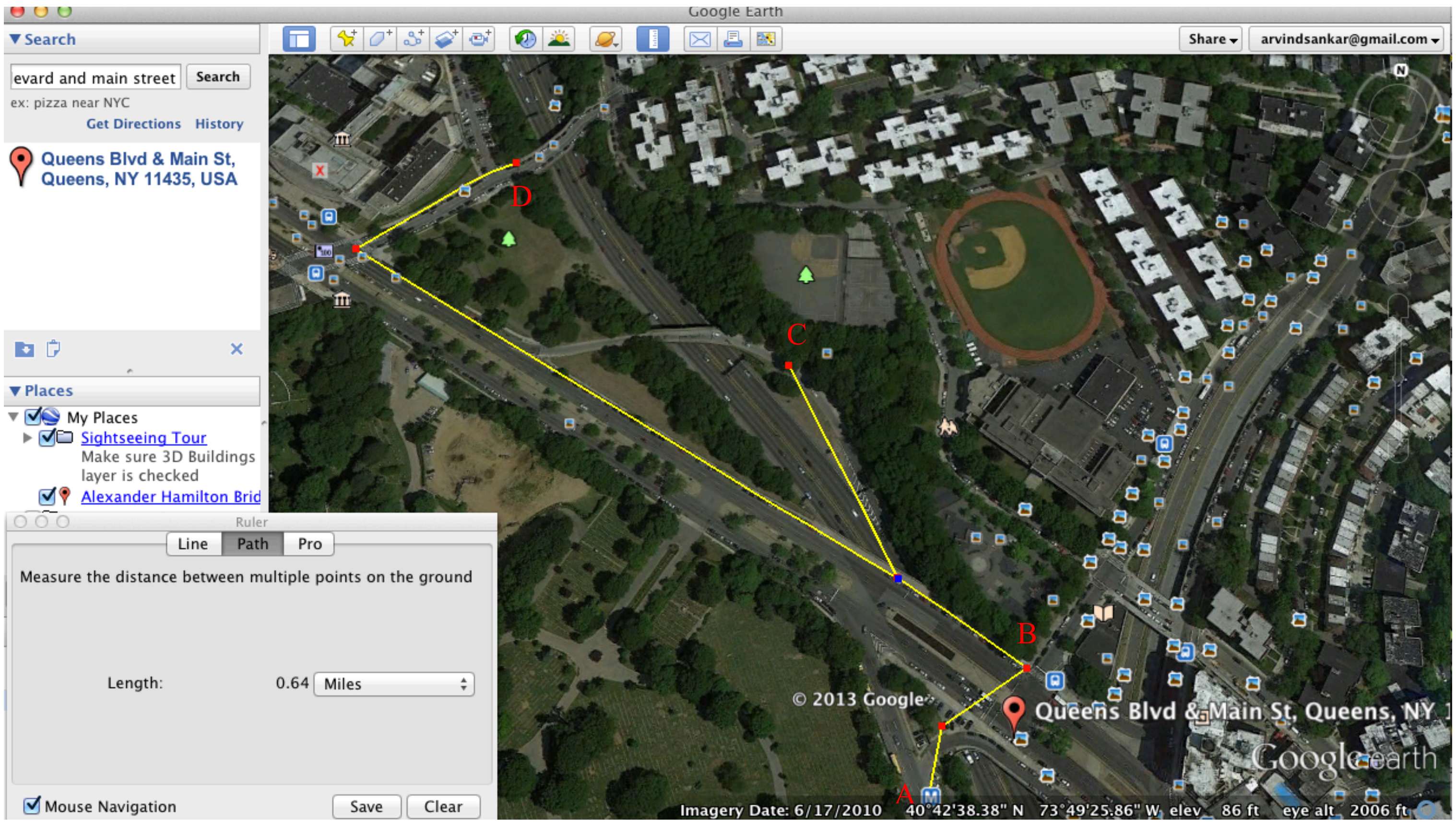


Figure 22: Requirement to remove fiber optic cable

One last view of the retaining walls was shown looking at it from Hoover Avenue before completing the tour. A total of around 15 participants were taking part to view this particular project. There were designers from Manhattan and DOT staff at headquarters in Albany, NY and the field office in Island City, NY.



LEGEND

A- Modified Subway Entrance (Figure 19)	C- New Ramp to Queen's Blvd (Figure 21)
B- New Subway Entrance (Figure 19)	D- Hoover avenue (Figure 22)

Figure 23: Path taken by the virtual team

The path taken during the virtual tour for Contract 1 of the Kew Gardens project has been mapped in Figure 23. The team traversed a distance of 0.64 miles for a total duration of 110 minutes. The tour started at point A which was the modified entrance to the subway and the last point was D in the Figure 23 were the problems related to optical cables were discussed.

Kew Gardens Project—Contract 2

The area construction supervisor provided the virtual tour of Kew Gardens – Contract 2 project. This phase also involves constructing new ramps, bridges and lane widening. The first activity to be observed was the paving work on Union Turnpike about 0.1 miles away from the site team located on the Van Wyck Bridge overlooking Union Turnpike. From the camera perspective, it was easy to see that the paving crew had six workers and the camera could zoom in to see the subcontractor paving this area quite clearly. It was evident that the drainage work for contract 1 was completed. The field crew crossed over the road to observe the demolition of part of the bridge deck and also to view the piling and footing work for the new Ramp KB. One potential issue shown to the virtual participants was the location of one of the footings that was right over a portion of the Grand Central Parkway (see Figure 24).

Figure 24: Location of Footing on Grand Central Parkway

The virtual participants could view the footings marked for which work was supposed to briefly begin. Although, the quality of the video was not high definition, the zoom capability on the camera helped show details of activities at a greater distance. One such instance was a worker removing formwork from one of the piers that could be captured easily as shown in the Figure 25.

Figure 25: Worker working on the formwork

The rebar cages for the columns had been placed at the site and were ready for erection. As the team traversed across the site, the participants found it beneficial to view the video from a remote location and observe the piling activity for the footings. The video made it a lot easier to analyze each of the footings that were in a different state of completion and also other activities like the erection of the sign structure at the West Bound Union turnpike. A few lanes were closed during the day to prevent disturbance to the neighborhood at night. In such cases, this telepresence approach also helped decision makers view traffic at different portions of the project and helped improve decision making related to traffic engineering and logistics.

Figure 26: Work in progress for Erection of Signage

The virtual participants could interact with the field team on various areas of concern and better understand the work progress as the site team moved to different work areas. The next stop was at a lower elevation where soil nail walls had been completed and electrical, water main work and drainage work were in progress. An electrical box for the street lighting is shown being installed (see Figure 27); participants were able to observe the placement of the electrical box from start to finish.

Figure 27: Insertion of Electrical Box

The water mains were observed up close and the contractor could interact with onsite owner representatives and the top management from remote locations. The technology improved the scope for understanding the project as a whole as well as for better understanding the complexities of each individual activity. The site had a location for the wash out of concrete trucks as shown in the Figure 28.

Figure 28: Concrete truck wash out location

Underpass Flooding Issue near Kew Garden Contract 2 Location

One recent area of concern was flooding near the bottom of the ramp on the eastbound side of the Grand Central Parkway. It was explained to the research team that the water level of the adjoining lake has risen and is possibly backing up through the drainage system onto the road. This technology helped by sending in a live feed of the situation and also having the entire video documented for future reference and viewing by management and design teams. The streamer was sending in the live feed while the car was moving from the Kew Garden Contract 2 location to the flooding area. There were no technical issues with the technology (no dropping out and no deterioration of video quality). The video was recorded from the side of the roadway and documented to address the problem and analyze the situation in detail. Figure 29 shows a moving car driving through the water on the roadway and splashing water on the abutment.

Figure 29: Flooding of water on the road

Although the vehicles were travelling at a fast pace, the Streamer™ technology could clearly distinguish the water flooding on the roadway. The tripod helped in providing a video with higher stability and avoided any shakes on the video feed.

CHAPTER 6: COST ANALYSIS FOR USING THE STREAMER^{TM}

The Streamer is a recent innovation in the area of telecommunication, which provides an opportunity to increase the bandwidth by combining multiple air cards. In order to get maximum output from the device it is better to have air cards from multiple network providers (e.g., AT&T, T-mobile and Sprint). Operating the Streamer^{TM} in the field involves both fixed and variable costs. For this analysis, it is assumed that the cost is from the perspective of a university research laboratory performing a service to the industry.

Fixed Costs

The fixed costs include the amortized value of the streamer, the air card service and the Verizon mifi service. The cost of the Streamer^{TM} has been amortized for a period of three years. The final cost per week for the Streamer^{TM} would be $32.05. The air cards have a monthly charge that is under a contract with each of the respective network providers. The Verizon mifi is used at the site to access the internet to use the web conferencing tools.

Apart from the charges on the air card, there are individual charges for broadcasting the video using the Streamer^{TM}. The Amazon cloud service supports the functioning of the streamer and has two kinds of plans to choose from based on the usage requirements.

Table 4: Fixed Costs - Option A

Fixed Costs (Option A: Unlimited Amazon Web Service)	Per year	Per Month	Per Week
Streamer (amortized over 3 years)	$1,667	$138.89	$32.05
Aircard Service for Streamer (3 cards)	$2,028	$169.00	$39.00
Verizon Mifi	$456	$38.00	$8.77
Amazon Web Service (unlimited)	$1,440	$120.00	$27.69
Subtotal	$5,591	$466	$108

The first option (Option A) is a fixed monthly charge (shown in Table 4) to access the cloud computing services in addition to which a minimal variable charge needs to be paid for every hour of streaming. The second option (shown in Table 5) works by paying regularly on an hourly basis. Every time the service is purchased an IP address is obtained to access the service.

Table 5: Fixed Costs - Option B

Fixed Costs (Option B: Hourly Amazon Web Service)	**Per Year**	**Per Month**	**Per Week**
Streamer (amortized over 3 years)	$1,667	$138.89	$32.05
Aircard Service for Streamer (3 cards)	$2,028	$169.00	$39.00
Verizon Mifi	$456	$38.00	$8.77
Subtotal	$4,151	$346	$80

Variable Cost

The variable cost includes the labor charges for the person operating the technology and also the cost related to the transportation from one region to another based on the location of the project. The variable costs for each scenario tend to vary and hence no fixed number can be ascertained on the amount. However, a rough range of the variable cost has been developed assuming the technology would be used in a local environment. Additionally, Option B will have hourly charges of the Amazon Web Services that are variable and the net cost would be based on the number of hours of usage.

The labor mentioned in the tables would ideally be a graduate student who could operate the technology and the hourly salary would be $20 plus allowances. The hourly cost for transportation, inclusive of the fuel and insurance would ideally be \$6 for the virtual team to access different sites. This fare has been considered after looking into hourly rental firms.

A variety of scenarios have been developed to calculate the total cost for operating the Streamer^{TM}. One tour indicates a specific number of hours of streaming as mentioned in the column in addition to which a buffer time of two hours is added for transportation and labor wages. 1-1hour in Table 5 indicates a tour with one hour of streaming in addition to which a buffer time of two hours is added for transportation and labor wages. This is to accommodate the additional time required to access the construction site. Each of the tour tabulated in Table 6 shall correspond to operating the streamer for one month. For instance, a 4-1hour tour indicates the cost associated with a total of four tours a month each comprising of one-hour duration. A brief explanation for each of the scenarios on x-axis of Figure 28 has been tabulated in Table 6.

Table 7 indicates the variable cost associated with Option A that includes a \$2 charge for every hour of streaming in addition to the fixed monthly cost \$120 explained in Table 4. Similarly Table 8 is the variable cost associated with Option B, which includes the hourly amazon service in addition to transportation charges and labor wages. The total cost per month for both the options has been tabulated for various scenarios in each of the tables.

Table 6: Various Scenarios for operating the Streamer

1-1 Hour	One Hour Streaming and Three Hours Labor & Travel time	6-2 Hour	Twelve Hours Streaming and Twenty Four Hours Labor & Travel time
2-1 Hour	Two Hours Streaming and Four Hours Labor & Travel time	6-3 Hour	Eighteen Hours Streaming and Thirty Hours Labor & Travel time
2-2 Hour	Four Hours Streaming and Eight Hours Labor & Travel time	8-2 Hour	Sixteen Hours Streaming and Thirty Two Hours Labor & Travel time
4-1 Hour	Four Hours Streaming and Twelve Hours Labor & Travel time	8-3 Hour	Twenty Four Hours Streaming and Forty Hours Labor & Travel time
4-2 Hour	Eight Hours Streaming and Sixteen Hours Labor & Travel time	10-2 Hour	Twenty Hours Streaming and Forty Hours Labor & Travel time
4-3 Hour	Twelve Hours Streaming and Twenty Hours Labor & Travel time	10-3 Hour	Thirty Hours Streaming and Fifty Hours Labor & Travel time

Table 7: Variable Costs - Option A

Variable Costs (One tour requires 2 additional hours of labor)	**Per Hour**	1 Tour	2- 1Hour	2- 2Hour	4- 1Hour	4- 2Hour	4-3Hour	6- 2Hour	6-3Hour	8-2Hour	8-3Hour	10-2Hour	10-3Hour
Amazon Web Service (unlimited--requires payment of $2/hr)	$ 2	$ 2	$ 4	$ 8	$ 8	$ 16	$ 24	$ 24	$ 36	$ 32	$ 48	$ 40	$ 60
Travel to site (assume ~$6/hr for car rental)	$ 6	$ 18	$ 24	$ 48	$ 72	$ 96	$ 120	$ 144	$ 180	$ 192	$ 240	$ 240	$ 300
Labor @ 1 person with Streamer and Camera	$ 30	$ 90	$ 120	$ 240	$ 360	$ 480	$ 600	$ 720	$ 900	$ 960	$ 1,200	$ 1,200	$ 1,500
Subtotal - Variable Cost Per Month		$ 110	$ 148	$ 296	$ 440	$ 592	$ 744	$ 888	$ 1,116	$ 1,184	$ 1,488	$ 1,480	$ 1,860
Fixed Cost Per Month		$ 466	$ 466	$ 466	$ 466	$ 466	$ 466	$ 466	$ 466	$ 466	$ 466	$ 466	$ 466
Total Cost Per Month		$ 576	$ 614	$ 762	$ 906	$ 1,058	$ 1,210	$ 1,354	$ 1,582	$ 1,650	$ 1,954	$ 1,946	$ 2,326

Table 8: Variable Costs - Option B

Variable Costs (One tour requires 2 additional hours of labor)	**Per Hour**	1 Tour	2- 1Hour	2- 2Hour	4- 1Hour	4- 2Hour	4-3Hour	6- 2Hour	6-3Hour	8-2Hour	8-3Hour	10-2Hour	10-3Hour
Amazon Web Service	$ 10	$ 10	$ 20	$ 40	$ 40	$ 80	$ 120	$ 120	$ 180	$ 160	$ 180	$ 200	$ 300
Travel to site (assume ~$6/hr for car rental)	$ 6	$ 18	$ 24	$ 48	$ 72	$ 96	$ 120	$ 144	$ 180	$ 192	$ 240	$ 240	$ 300
Labor @ 1 person with Streamer and Camera	$ 30	$ 90	$ 120	$ 240	$ 360	$ 480	$ 600	$ 720	$ 900	$ 960	$ 1,200	$ 1,200	$ 1,500
Subtotal - Variable Cost Per Month		$ 118	$ 164	$ 328	$ 472	$ 656	$ 840	$ 984	$ 1,260	$ 1,312	$ 1,620	$ 1,640	$ 2,100
Fixed Cost Per Month		$ 346	$ 346	$ 346	$ 346	$ 346	$ 346	$ 346	$ 346	$ 346	$ 346	$ 346	$ 346
Total Cost Per Month		$ 464	$ 510	$ 674	$ 818	$ 1,002	$ 1,186	$ 1,330	$ 1,606	$ 1,658	$ 1,966	$ 1,986	$ 2,446
Cost / Tour		$ 464	$ 255	$168.47	$204.47	$125.24	$ 98.82	$110.82	$ 89.22	$103.62	$ 81.91	$ 99.29	$ 81.53
Net Cost/Tour		$ 603	$ 331	$ 219	$ 266	$ 163	$ 128	$ 144	$ 116	$ 135	$ 106	$ 129	$ 106
Savings / Tour		$ 139	$ 76	$ 51	$ 61	$ 38	$ 30	$ 33	$ 27	$ 31	$ 25	$ 30	$ 24
ROI		30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
Profit		23%	23%	23%	23%	23%	23%	23%	23%	23%	23%	23%	23%

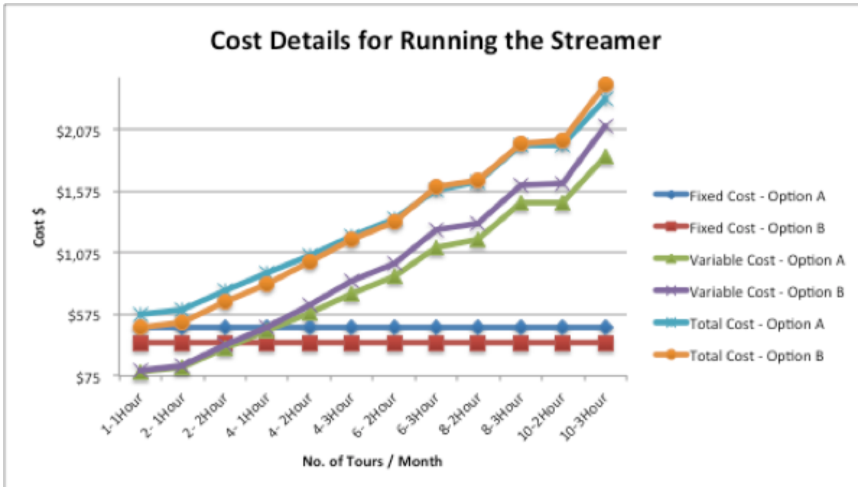


Figure 30: Cost Details for the two options

Figure 30 is a graph showing the comparison of costs for the two options under the different scenarios. The horizontal lines represent the fixed costs, as it remains the same irrespective of the number and duration of tours. It could be observed that option B is a better choice until 15 hours of streaming beyond which option A turns out to be at a lower cost.

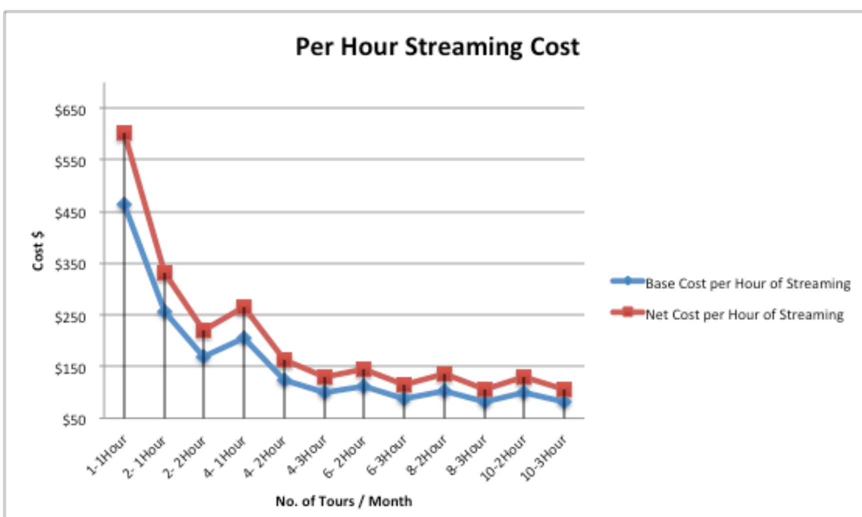


Figure 31: Per Hour Streaming Charges

Figure 31 shows the actual per hour streaming cost for the various scenarios developed earlier. So, from the chart it can be observed that as the number of streaming hours per month increases, per hour charges incurred for operating the technology tends to reduce drastically. To ascertain the amount of profit that could be achieved by using this approach, a thirty percent markup has been done to the base cost to determine a net cost for the virtual technology.

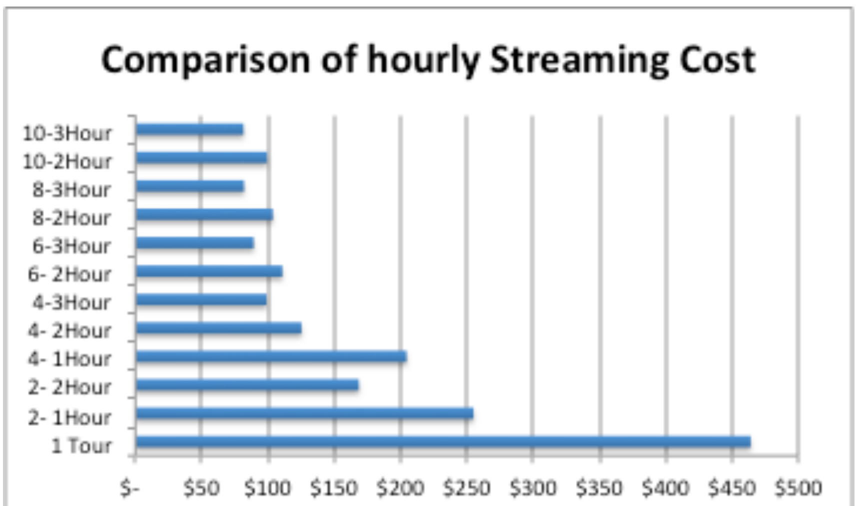


Figure 32: Comparative Chart showing Hourly Cost

Figure 32 shows the same cost comparison as a bar chart. A 55% reduction in cost is observed if the streamer is operated for virtual tours twice a month (2-1Hours) as opposed to using it once a week (1-1Hour). It can be concluded from Figure 32 that with increasing usage of streamer the per hour streaming charges tends to reduce substantially.

CHAPTER 7: INDUSTRIAL FEEDBACK ON THE STREAMER^{TM}

A survey was prepared to receive feedback from all the participants from various types of projects representing the different stakeholders. The survey has been attached in Appendix A and was provided as an online tool to receive their feedback. A majority of the participants represented the heavy/highway project, accompanied by participants working on commercial building projects. The participants had an experience of over 15 years working for the industry and on an average it was determined that each of them worked on a range of 3 to 7 projects.

In order to determine the cost benefits of using the streamer it is necessary to develop a rough estimate of the cost incurred for every accountable site visit performed by the experts. Table 4 shows a rough overview of the cost for one expert who has to travel a distance of two hours to the site for every visit. This is a scenario were the project is located locally and the expert has to travel by road. The metrics in Table 9 have been obtained from the survey. The monthly cost calculated from the metrics would sum up to $1,175. The project cost tends to rise substantially with increasing number of stakeholders travelling from different locations.

Table 9: Average expenses for experts based on Survey Results

Travel Cost / Visit	**No. of Projects**	**Total / Month**
100	5	$500.00
Hourly Overhead Cost	**Total Hours for 5 Projects**	
45	30	$1350.00
		$1,850.00

From Table 9 it can be observed that for the same cost the Streamer^{TM} can be operated for two tours a week comprising of three hours each. An additional advantage to be noted is that the virtual approach is accessible to several virtual participants who can interact and participate in the on-site activities. The cost associated with the Streamer^{TM} would be the same irrespective of the number of users viewing and interacting virtually with the construction professionals at the site. The technology tends to pay for itself with increasing usage and it proves to be more beneficial in bigger projects situated at a distant location for the virtual participants.

The survey respondents felt that the technology would be very helpful for construction site professionals and on-site engineers to discuss issues, concerns, problems with members at the main office and can help consultants to perform inspections on a more regular basis. One other advantage is the fact that architects, design engineers and senior project managers can actively participate and follow the progress at the site on a regular basis and check on the project milestones, without having to travel to the site. One other input was the accessibility provided by the technology, for instance in the Alexander Hamilton Bridge Project the camera could zoom in on details at a farther location and also provided a platform for the main office to interact with the site professionals.

A majority of the experts felt that one of the major challenges of the approach is the reliability of the technology. They were concerned about the technical issues associated with the Streamer^{TM}, and the availability of technical support. Many of the participants felt that cost would be a major issue, but the benefits have been clearly tabulated earlier. The videos could be documented for future reference and be a valuable tool for discussing problems in projects that lead to mitigation or arbitration.

A few of the members believed that the concept has an excellent academic potential where it can be used to bring different types of construction projects to classrooms involving a large group of students. The students could interact with on-site professionals and also have other project stakeholders watch the video to provide their perspective of activities at the site. A majority of the participants felt that project stakeholders (e.g., lenders, investors, company executives, etc.) would participate regularly in monthly contractor progress reviews if remote participation was available using this tele-presence approach.

CHAPTER 8: ALTERNATIVE EQUIPMENT TO PACKAGE THE STREAMER™

The devices used for the approach need to be packaged in such a way that is user friendly for industrial purposes. The current equipment used for the virtual approach is very compact and portable and can be placed easily within a backpack and carried around the construction site. There is however a few concerns associated with the devices:

- The temperature on the streamer tends to rise when it is used in a warmer environment for a longer duration of time
- The tunnel vision on the Sony Handy camera makes it difficult for the viewers to watch the video continuously. This vision makes it difficult for virtual participants to obtain a wider angle on the projects.
- The battery backup on the Sony Handycam and the Vaio laptop is only 90 minutes

In order to reduce the problems associated with the temperature of the Streamer™, a custom manufactured backpack has to be used that has a number of pores on its surface to allow the free circulation of air to cool the devices. In warmer climates, the backpack needs to be equipped with cooling fans that are battery operated.

The Sony Handycam is outdated and none of the new Handy cameras manufactured by Sony enable live video streaming. The battery for the available camera is not being produced anymore and it is necessary to look for alternative equipment. Although, the camera has exceptional zoom capabilities in a regular construction environment it is necessary to have a camera that does not have a tunnel vision and provides a wider-angle of the surroundings. There are two solutions for this: one is to add a wide-angle lens to the existing camera or purchase alternative equipment that can provide a better vision to the virtual participants.

Ladybug®2 is a highly affordable camera that is manufactured by Point Grey. The excellent feature about this spherical digital video camera system is that it has six cameras on different sides of the device that enable the system to collect video from more than 75% of the full sphere. The camera is very compact as shown in Figure 33 and can be mounted to the hard hat of the person operating the technology at the site.

Figure 33: Ladybug Spherical Camera

These cameras provide a vision that is wider than those found on normal handy cameras, which makes them unique. A snap shot of the output video from the camera has been shown in Figure 34.

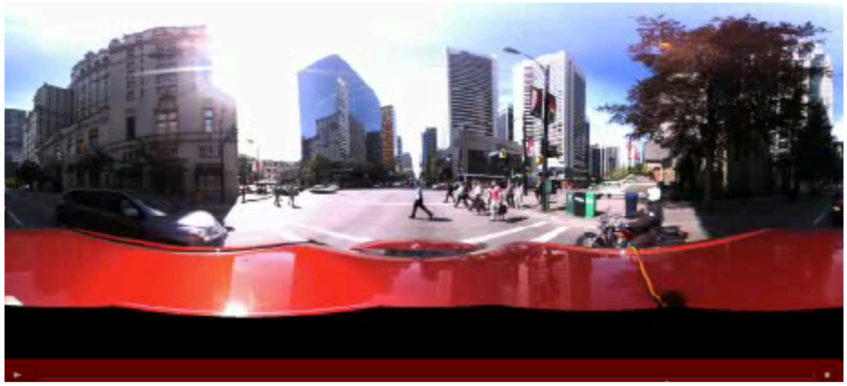


Figure 34: Snapshot of the output video

The additional feature of this technology is that it could be integrated to a GPS and the output viewed on Google Maps in real time. This feature makes it convenient for heavy/highway projects where the experts in the main office know where exactly the video is being transmitted from and can track the movement of the field crew with reference to the project. Figure 35 shows a snapshot of the GPS interface linked with Google Maps.

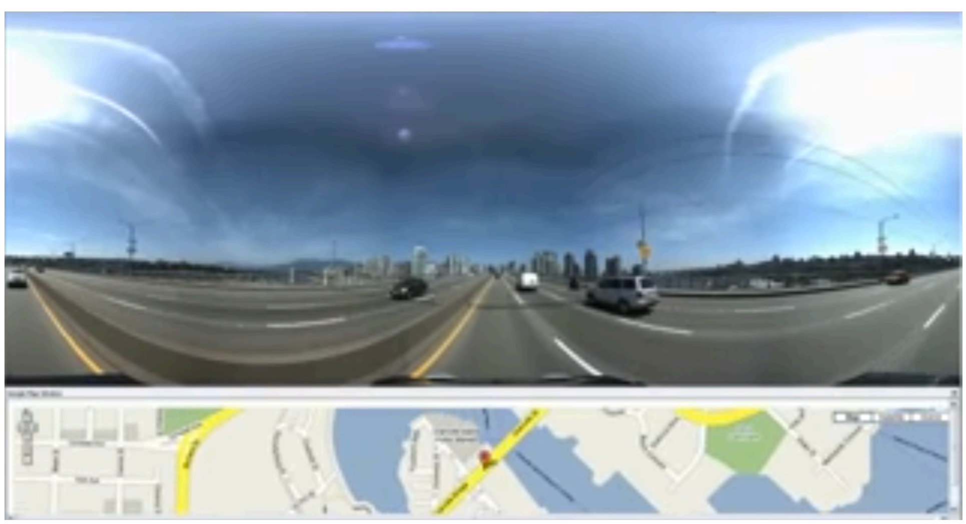


Figure 35: The GPS Interface linked with Google Maps

One other area where this idea could be highly beneficial is for Project Development Firms who wish to determine the extent of a particular site by monitoring it from a remote location. The approach could save time and money for developer firms and help them perform real-time interaction with stakeholders.

The drone at the site is required to interact regularly with the virtual participants while moving around the construction site. Considering the safety factor, it is necessary that the drone is equipped with a hands-free or a wireless device. Uvex AcoustiMaxx Stereo Bluetooth® is an eyewear (shown in Figure 36) with a dual purpose:

1. To be safety eye protection and

2. To work as a hands-free communication device that helps the user complete the tasks safely with a better productivity.

Figure 36: Stereo Bluetooth Eyewear

CHAPTER 9: DISCUSSION OF RESULTS

The series of tests performed with the new approach in various environments has shown that the fact that the entire approach is dependent on mobile network connectivity. The strength of the signal determines the following:

- The delay on the video that needs to be set on the Streamer™
- The bandwidth that need to be selected using the Adobe Flash Media Encoder
- The quality of the output video

The information regarding the signal strength needs to be predetermined before performing any virtual tour or on-site inspection. The signal strength can be determined by learning about the network coverage for the location. For performing this test, the network availability of the location has to be verified through each of the network provider. For instance, the network strength at the Talley Student Center, North Carolina State University was found to be significantly less as compared to the network available at the Hamilton Bridge Project in New York. The projects in New York therefore had a better quality of the video with shorter delay.

An illustration of this process is shown in Figure 37. Ellis Island, located on the Upper New York Bay, is considered as a location where the virtual tour is to be performed using the proposed technology. A Google Map Satellite Image of the location is shown in the first picture of Figure 37. The team needs to determine the signal strength of each of the air cards and hence has to explore the actual network coverage that is available in this particular location. The figure shows three other images of Ellis Island with information on the network coverage of each of the air cards (AT&T, Sprint and T-Mobile, respectively).

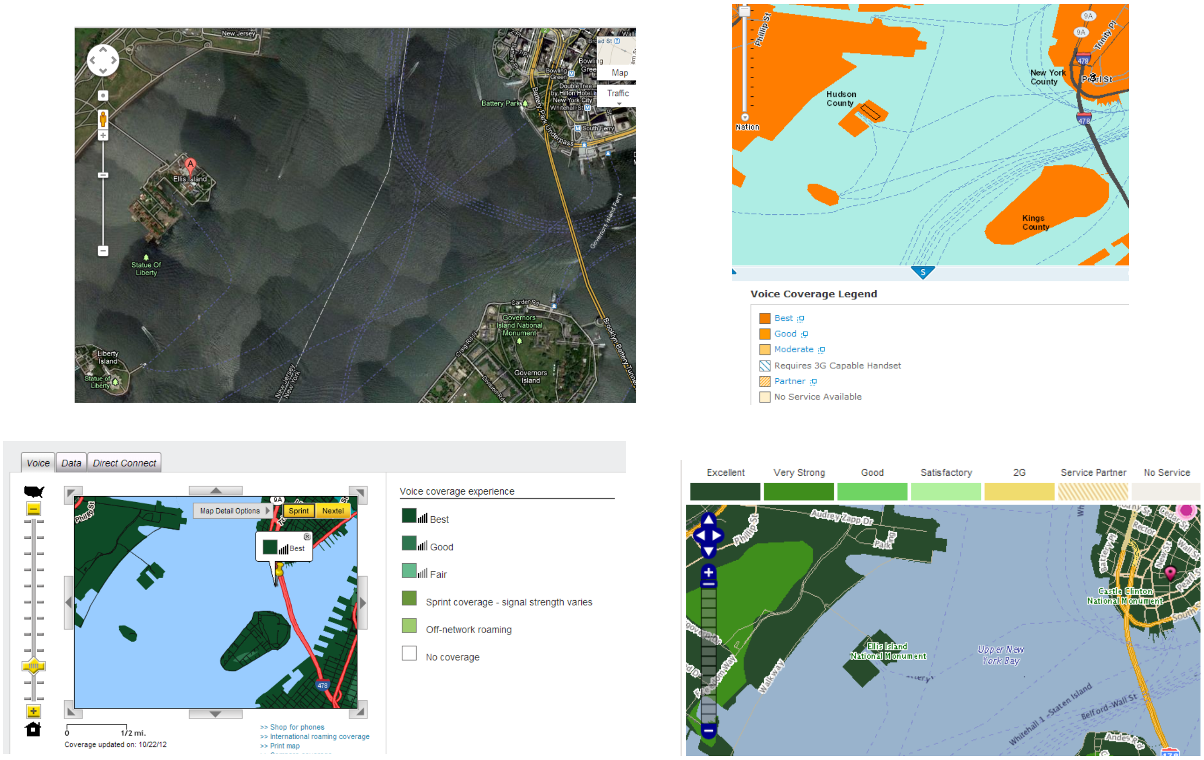


Figure 37: Site Layout Issues in Establishing Virtual Project Management

It can be seen from Figure 37, the signal strength is excellent for all the three network providers; hence it is advisable to use a higher bandwidth, with minimal delay so as to obtain a high quality video.

The proposed technology proved to be successful in all of the virtual tours that were conducted as part of this research. From the residential case study it was found that the virtual training can support newly hired engineers with limited construction experience. It has been very promising in using the tele-presence of professional engineers to employ their knowledge to help solve problems virtually and immediately, avoiding the extra cost of travel or lost productivity. The virtual punch list helped the upper management to get more involved and stay updated on the status of the project without any lost or misleading information. The virtual safety inspection on the building project demonstrated that this approach could be used to replace some of the live jobsite visits. Being on a large site like the Hamilton Bridge or Kew Gardens, it was very nice to have the zoom capability on the video camera – it would have been unsafe with all of the traffic to get to some areas (like the signage on the bridge).

One of the challenges encountered during the testing of this virtual site management concept was the fluctuating internet signals, which made it difficult for the team to control the quality or delay of the video. Internet signal strength was impossible to predict and therefore made it challenging to control the delay of the video. On the Mungo Homes projects, the team performed delay tests at different times of day with different video bandwidths and summarized the findings in Table 10.

Table 10: Summary of Multiple Delay Tests

<table>
<tr><th>Test No.</th><th>Bandwidth</th><th>Delay TimeSet on Streamer</th><th>Actual Delay</th><th>Remarks</th><th>Signal Strength</th><th>Location</th></tr>
<tr><td>1</td><td>300 kbps</td><td>1000 ms</td><td>4 s</td><td rowspan="3">Fair Clarity</td><td rowspan="4">T-Mobile 16%
AT&T 38%</td><td rowspan="4">NCSU</td></tr>
<tr><td>2</td><td>300 kbps</td><td>1500 ms</td><td>6 s</td></tr>
<tr><td>3</td><td>300 kbps</td><td>2000 ms</td><td>6 s</td></tr>
<tr><td>4</td><td>800 kbps</td><td>2000 ms</td><td>6 s</td><td>Video not Continuous</td></tr>
<tr><td>7</td><td>300 kbps</td><td>1500 ms</td><td>5 s</td><td rowspan="3">Continuous,
Better—Quality Video</td><td rowspan="3">T-Mobile 29%
AT&T 54%</td><td rowspan="5">Downtown—Mungo Homes</td></tr>
<tr><td>8</td><td>300 kbps</td><td>1000 ms</td><td>5 s</td></tr>
<tr><td>9</td><td>300 kbps</td><td>8000 ms</td><td>9 s</td></tr>
<tr><td>10</td><td>300 kbps</td><td>1500 ms</td><td>5 s</td><td>Fair Quality</td><td rowspan="2">T-Mobile 38%
AT&T 61%</td></tr>
<tr><td>11</td><td>800 kbps</td><td>1500 ms</td><td>8 s</td><td rowspan="5">Continuous,
Better—Quality Video</td></tr>
<tr><td>12</td><td>800 kbps</td><td>6000 ms</td><td>9 s</td><td rowspan="4">T-Mobile 45%
AT&T 90%</td><td rowspan="4">NCSU</td></tr>
<tr><td>13</td><td>800 kbps</td><td>1500 ms</td><td>6 s</td></tr>
<tr><td>14</td><td>300 kbps</td><td>3000 ms</td><td>6 s</td></tr>
<tr><td>15</td><td>300 kbps</td><td>1500 ms</td><td>4 s</td></tr>
</table>

Column 3 is the delay that was set on the Streamer™ manually by the team, while the Column 4 indicates the actual video delay of the output that was observed by the end users. The bandwidth column represents the bandwidth that was set in the video encoder by the team, while the signal strength column gives an idea of the available bandwidth due to the signal's strength (%) at that particular time and location. The team evaluation of the video quality can be seen in the remarks column.

The inferences from Table 10 are as follows:

- The minimum expected video delay is about 5 seconds.
- The signal strength (%) is an important factor that determines the delay to be set on the Streamer™ and the quality of the video obtained.

- A better-quality continuous video could be produced if a better internet signal were available. However, when signal strength (%) decreases, the video quality also decreases and noncontinuous, or buffered, video may be encountered.
- To reduce the video delay, the selected video bandwidth in the encoder should be decreased.
- The people on-site should first check the available signal strength to decide what video bandwidth and Streamer™ delay should be selected.

The 5 seconds delay on the video is the time required by the Streamer™ to combine the bandwidth of the multiple air cards and send out a continuous output to the video server. There are four parameters that define the final output of the live video stream:

- Signal strength on the various air cards at a particular locality
- Bandwidth set on the Flash media encoder
- Delay defined on the webpage of the Streamer™ and
- Number of end users using the video server

The technology would be very helpful for construction site professionals and on-site engineers to discuss issues, concerns, problems with members at the main office and can help consultants to perform inspection on a regular basis. One other advantage is the fact that architects, design engineers and senior project managers can actively participate and learn the progress at the site on a regular basis and check on the project milestones, without having to travel to the site.

CHAPTER 10: CONCLUSION

The novel approach of video streaming construction site action anywhere on the construction site to remote users has the potential to completely change the way we control and manage construction projects. It can also affect the staffing requirements as well such that the on-site project manager could be in the home office managing several other projects using these remote imaging techniques. The development of modern technology and cellular networks has made it possible to engage stakeholders who would have been previously unable to participate in construction site activities. The results of the case studies have proved the ability of the new approach to serve the construction industry in different areas. It could be of great value to large-sized construction companies that execute projects in different locations and can eventually help save time and cost for professionals by bringing the site to them.

The cost analysis and assessment in this research study has proved that the virtual approach is available at a lesser cost to the industry with the benefit of having multiple remote participants present at different locations to contribute and succeed in achieving an improved performance of projects. The participants of the research study believed that the technology would be very helpful for construction site professionals and on-site engineers to discuss issues, concerns, and problems with members at the main office and provide instantaneous solutions.

The reliability of the technology needs to be continuously tested in different environments for various purposes. The virtual approach needs to be tested as a tool to enable mediation and arbitration processes to help the facilitator understand the problems at the construction site. The camera has to be replaced with a wide angled lens to make the vision easier for the virtual participants. The technology requires the necessity to be integrated with GPS devices to track the position of on site members that would be helpful for heavy highway projects.

CHAPTER 11: RECOMMENDATIONS AND FUTURE WORK

One concern regarding the virtual approach is the tunnel vision that is obtained through the video camera. In order to overcome this issue, the alternatives of using a wide angled lens on or the purchase of a different type of video camera with a greater field of view has been discussed. With advancements in cellular technology, the strength of the signal is continuously being improved which can aid transmission of higher resolution videos.

Telepresence applications are not limited to what has been tested and there are other approaches that would help to achieve the desired advancement in the construction industry. The concept has an excellent academic potential where it can be used to bring different types of construction projects to classrooms involving the participation of a large group of students. The students could interact with on-site professionals and also have other project stakeholders watch the video to provide their perspectives on activities at the site. A majority of the participants (e.g., lenders, investors, company executives, etc.) would participate regularly in monthly contractor progress reviews if remote participation was available using this tele-presence approach.

Some of the other applications that the team should consider investigating are as follows:

1. The proposed technology can be used to assist and create job opportunities for a large number of unemployed disabled, retired, or senior citizens in the United States. This approach will enable the physically challenged to participate in virtual construction site visits and contribute from remote locations. The department could

also provide online training courses and certificates for those who do not have any background in construction to prepare them for the industry.

2. Use of the Tele-Engineering and Management (TEAM) Laboratory for virtual status monitoring of construction projects. The person in the laboratory would be able to manage any unforeseen risks and perform a cost/benefit analysis by monitoring the project's cost and schedule. Furthermore, this person could virtually visit the site at any time from any location to confirm the submitted documents and reports from the on-site management and verify the actual status of each activity.
3. The proposed methodology has the potential to promote virtual safety inspections. The safety inspection conducted in this study had a number of positive outcomes. The technology can promote active participation of all the project stakeholders and increase their involvement from remote locations.
4. Tele-presence can also be used as a tool to guide mediation and arbitration processes, to help the facilitator understand the situation and involve active participation of all the parties from different locations. An additional advantage is that everyone can view the exact problem at the site and its current real time status.
5. The possibility of labor unions raising concerns about using this technology needs to be considered and appropriate research has to be performed to understand their perspective of using this technology at construction sites. There is a necessity to reach out to project managers of projects such as the Hamilton Bridge Rehabilitation to understand if they can see any issues.

6. Future research should consider looking into the legal implications of virtual approach against live site monitoring and management. The advantage of having the virtual tours documented may raise concerns to a few project stakeholders.
7. The virtual technology can be connected to appropriate instruments while performing virtual inspections. For instance, while the inspection involves checking rebar cover through concrete, x-ray inspection of field welds, and say torque readings for bolts, the data from each sensor could be transmitted real-time to the lab making the quality assurance and control task easier for virtual inspectors.
8. A joint research project with organizations like NSF can be conducted along with experts in psychology to study human interaction aspects of this idea. The idea behind the research would be to study interactions with laborers and foremen to look into leadership and management differences associated with this approach.
9. The virtual approach needs to be used during project planning stage to help subcontractors with staging materials and trailers at the site. The suppliers will have the ability to see how their product will fit the purpose and aid in coordination of crews. The approach can also be used to perform productivity studies at construction sites.
10. The National Institute for Occupation Safety and Health (NIOSH) can be approached to understand their interests and contribution towards funding a project related to the use of virtual safety inspections.

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APPENDICES

Appendix A
Survey on the use of Virtual Project Management Techniques
North Carolina State University

1. Please indicate your affiliation (circle one): Owner, Contractor, Designer, or Other—please specify.
2. What is your title? ____
3. What type of construction projects do you typically work on (select all that apply)? Commercial, Heavy/highway, industrial, or residential.
4. How many years of experience do you have in the construction industry? ____________ (years)
5. How many projects are you involved with at one time? _________ (#)
6. What is the frequency of your construction site visits? ________ (#/month)
7. What is the **range** in your travel cost and time associated with each visit?________________ (travel cost, $) _______________ (time, hrs)
8. On **average** what is the travel cost and time associated with each visit?________________ (travel cost, $) _______________ (time, hrs)
9. What do you feel are the benefits of using this virtual approach to visiting construction sites (provide comments below)?
10. What do you see as the challenges to using this tele-presence approach (provide comments below)?

Additional Questions:

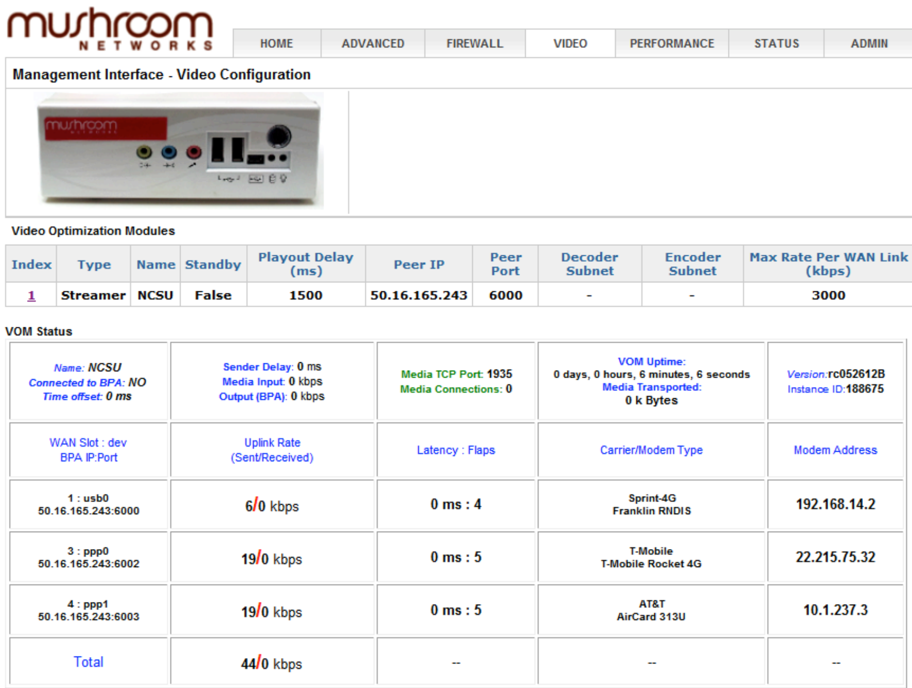
1. What percentage of your projects have used fixed web cams to broadcast digital images from the project site to a website? ___________ (%)
2. Do you believe more project stakeholders (e.g., lenders, investors, company executives, etc.) would participate in monthly contractor progress reviews if remote participation was available using this tele-presence approach (select one)? Yes, No, Maybe, Don't have a sense.
3. Other comments concerning this idea?

Appendix B

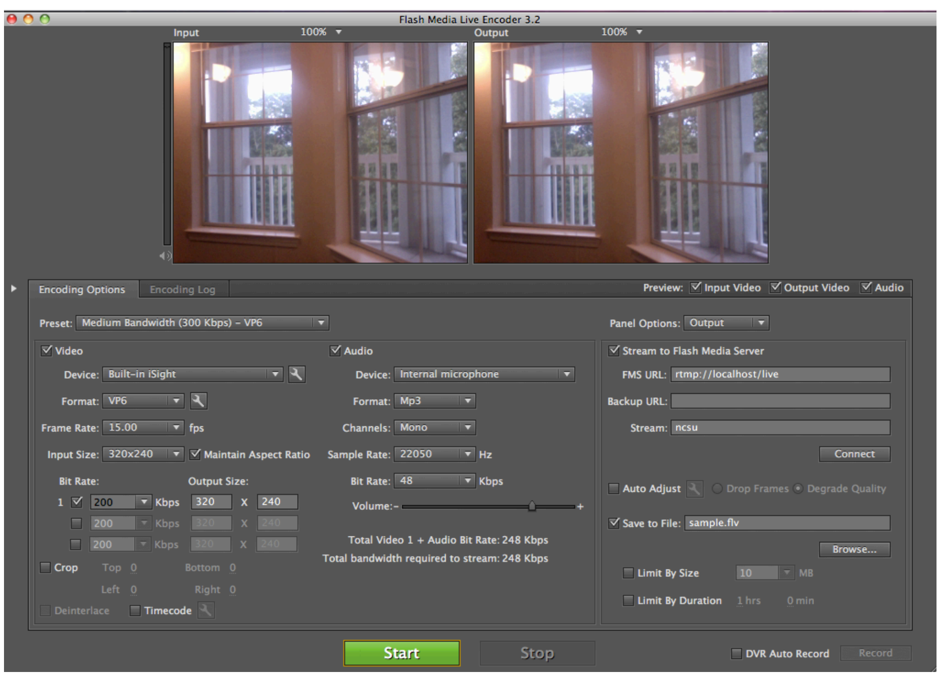
Steps to Broadcast a Video Through the Cloud Using a Video Server and Streamer™

Step 1	Use the AC power adapter to power the streamer™. There is a power button on the unit to turn it on and off.
Step 2	Plug the air-cards (AT&T™, T-Mobile®, and Sprint™) directly into any of the four USB ports on the unit. There are two in the front and two in the back.
Step 3	Use an Ethernet cable to connect the streamer™ to a laptop (Sony VAVIO®); use a USB cable to connect the Handycam.
Step 4	Wait about 3 minutes for the unit to boot up, and open the browser to http://192.168.249.99 to see the streamer™ GUI.
Step 5	Check the air-card's connectivity, and then click on the Home tab on the GUI to see if the modems have reached a "connected" state.
Step 6	Log in to the AWS™ system at http://aws.amazon.com/, set up the AWS™ cloud, and obtain an IP address (XX.XX.XXX.XXX). See the appendix for more details.
Step 7	To connect the streamer™ to the AWS™ cloud and manually set the video delay, click the Video tab on the streamer™ GUI, and then click the "1" in the leftmost column in the table at the top. In the pop-up window, enter the IP address obtained in Step 6 in the field "Peer IP," and enter the desired playout delay in milliseconds (see Figure 8).
Step 8	Look for the "Connected to BPA" status indicator. If it shows "YES," you are ready to start streaming from the same computer on which you are viewing the GUI.
Step 9	Open the video encoder, and then enter the IP address obtained in Step 6 in the "FMS URL" of the right table. Once this step is completed, video streaming and encoding can begin. Figure 9 is a picture of the video encoder.
Step 10	Use the video server at http://XX.XX.XXX.XXX/cgi-bin/streamer.cgi to deliver the video to the users (see Figure 10).

Appendix C
Snapshot of Streamer™ GUI and Video Encoder



http://192.168.249.99



Adobe Flash Media Live Encoder