LOW-COST SURVEILLANCE FOR RURAL EVACUATION ROUTES

SYSTEM RECOMMENDATIONS REPORT

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1 INTRODUCTION

This document applies to the Low-Cost Surveillance for Rural Evacuation Routes System (LCSRERS). The document control number for this document is contained in the document footer and the file name for the electronic rendition of the document is recorded in this document's table of contents.

1.1 Purpose

This document summarizes the LCSRERS pilot project, the project's findings, and the system recommendations resulting from pilot system testing and analysis. These recommendations are intended to be used by the Federal Highway Administration (FHWA) as well as Departments of Transportation (DOT's) across the nation when implementing their own LCSRERS systems. This document can also be used as a cost and configuration guide when determining what type of system configuration will provide the best cost to benefit ratio for a given system deployment.

1.2 Scope

The project's goal is to provide a Low-Cost Surveillance system model that can be used to monitor rural evacuation routes, routes that would typically not utilize surveillance due to normally low traffic volumes. With the LCSRERS in place, transportation system managers can better manage the road network and provide the public with better routing information during an evacuation. This could save lives and make evacuations safer and more efficient. It could also save time and money as not only can evacuees expedite their travel, but first and second responders can more quickly enter and secure the evacuated area.

As the devastation caused by recent hurricanes demonstrates, efficient evacuations have become increasingly important. In some cases, evacuations not only took place before the destruction, but after as well. A traffic monitoring system could have provided information during the pre-event evacuation phase. Further, if the camera and communication networks were not completely destroyed, they might have provided useful information regarding transportation system status to local officials. Also, emergency evacuations typically will involve areas that are not fully instrumented with traffic surveillance systems. In such instances, the LCSRERS can supplement traditionally higher cost traffic surveillance systems.

The basic design of the LCSRERS places multiple instruments with communication along rural evacuation routes. Each installation consists of two or more cameras and/or sensors that provide traffic flow data every few minutes. If additional speed, volume, and occupancy verification is required, additional sensors may be placed between camera installations. It is also possible for enhanced software to use the camera images to calculate speed, volume and occupancy.

Each surveillance installation has the ability to be activated remotely with the option to be independently powered or wired to the nearest commercial power source. Each camera provides color images and operates within a weatherproof enclosure. As with power options, the system can utilize both wired and wireless communication methods.

This document's scope includes system requirements, including documentation of assumptions and dependencies, as well as the available communications, power, camera, and sensor technologies. The document then identifies recommended technologies that meet the system requirements, and provides a brief discussion of why some technologies may be inappropriate for the LCSRERS. Many technologies were tested, each with unique advantages and disadvantages. Because each technology has distinct advantages and disadvantages, more than one technology may be suitable for a given system deployment depending on factors such as climate, location, budget and existing infrastructure. This can result in a wide variety of different configurations capable of satisfying the system owner's needs. Therefore, it is the system designer's responsibility to identify those requirements most appropriate for a given deployment, and design and assemble the system around those requirements.

Next, this document discusses the system installation and evaluation process. This includes detailing the testing methods as well as optimal factors for each recommended technology. From this discussion, the user can better understand the trade-offs between system capital costs, installation requirements, system performance, and recurring operational costs. Finally, recommendations for a complete system configuration will be made based upon the field test, final system life-cycle costs, and operational considerations.

1.3 Definitions, Acronyms, and Abbreviations

This memorandum may contain terms, acronyms and abbreviations that are unfamiliar to the reader. A dictionary of these terms, acronyms and abbreviations can be found in APPENDIX H – DEFINITIONS, ACRONYMS, AND ABBREVIATIONS.

1.4 References

The following documents contain additional information pertaining to this project and the requirements for the system:

1. IEEE Std 829-1998, IEEE Standard for Software Test Documentation, ISBN 0-7381-1443-X SH94687
2. IEEE Std 610.12-1990, IEEE Standard Glossary of Software Engineering Terminology.
3. *Low-Cost Surveillance for Rural Evacuation Routes System*, *Requirements Identification Technical Memorandum*, 05001-rq201srs0111. Mixon/Hill, Inc., April 2005.
4. *Low-Cost Surveillance for Rural Evacuation Routes System*, *Recommended Technologies*, 05001-sa301srs0100. Mixon/Hill, Inc., July 2005.
5. *Low-Cost Surveillance for Rural Evacuation Routes System*, *System Test Plan*, 05001-dz401stp0100. Mixon/Hill, Inc., August 2005.

1.5 Overview

The remaining sections of the document contain requirements for the traffic monitoring and surveillance needs, working conditions and technology alternatives, system assessment and evaluation, and, finally, the system recommendations. This document also contains appendices with extensive details on system requirements, costs, test logs, and sample camera images. A brief description of the sections follows.

Section 2 –REQUIREMENTS IDENTIFICATION. Based on the Requirements Identification Technical Memorandum, this section describes the traffic monitoring and surveillance requirements necessary for the system to be effective during evacuations in rural areas.

Section 3 – TECHNOLOGY RECOMMENDATIONS. This section describes the conditions under which devices must perform, the levels of performance required or desired by users, and the available technologies that will meet these constraints.

Section 4 – ASSESSMENT AND EVALUATION. Based on the System Test Plan, this section describes the testing, results, and assessment of selected devices. The section also discusses the strategy for integrating these devices into existing transportation management systems.

Section 5 – SYSTEM RECOMMENDATIONS. This section identifies future efforts that could be undertaken by FHWA, state and local transportation agencies, and the private sector to meet the real-time traffic monitoring requirements for rural evacuations. These recommendations will address the limitations of existing devices, the challenges of providing the supporting infrastructure (e.g., communications or power), and the needs required to fully integrate these new devices and systems into existing operational transportation management environments. The recommendations will also consider where gaps in existing knowledge may require additional research and development activities.

2 REQUIREMENTS IDENTIFICATION

2.1 General Description

As a prelude to the specific requirements, the General Description section seeks to provide a general overview of the entire system and illustrate the factors that affect the system and its requirements. This section does not state specific requirements, but instead is intended to make the requirements easier to understand by giving them context.

2.1.1 Product Perspective

The LCSRERS is a self-contained system used when the evacuation from or into a non-urbanized area is needed. Congestion and delays due to the volume of traffic moving or an incident can place the lives of evacuees in danger. These conditions can also hamper the movement of emergency responders, relief organizations, or the military as they deploy resources to the site of a disaster or emergency. The system's traffic surveillance will help obtain a clear picture of how traffic is moving over a region's highway network. This system's functions also support transportation, public safety, and emergency management agency responses to such an incident.

Even carefully laid out evacuation plans can have a diminished capacity or even become ineffective because of a crash or disaster blocking a vital evacuation route. During an evacuation it is important to have timely, visual confirmation of evacuation route conditions. By providing this capability, the LCSRERS will give local officials, emergency vehicles and the public the best chance of getting to where they need to be. By having a network of cameras and sensors on these evacuation routes, people will quickly become aware of any evacuation route blockages. For example, if a flood occurs and the main evacuation route becomes blocked by water, the system managers will be able to identify the problem and immediately start directing people to alternative routes. This will decrease both the time it takes to complete the evacuation and the number of casualties during the evacuation.

The LCSRERS is designed to fulfill the system requirements while minimizing the outlay and maximizing the results. This assumes that power and communications will be nearby, allowing for cost effective hard wiring of the system. Such assumptions, however, increase the reliance on external communication and power systems for system function. Because this system could be implemented in many different parts of the country, it is important that the system configuration has flexibility. Therefore, the system has the option to utilize wireless power and communications albeit at an additional capital cost. For systems installed in remote locations, self-contained power and communications will not be an option but rather a requirement. Some locations may need housings or enclosures that are specially designed to keep equipment operational in sub-zero or extreme temperatures.

2.1.2 Product Functions

The purpose of the LCSRERS is to provide information to system managers regarding evacuation route traffic conditions. A network of cameras and/or sensors will be used to monitor the status of each evacuation route. The coverage of this system will begin with the primary evacuation routes on the identified region plan and grow from there as system expandability and/or funding allow. The main data parameters for each installation will be still images from cameras and speed measurements from sensors.

Incident detection is a major function of this system. There will be two cameras at each installation, one to view each direction of travel, with camera installations placed roughly every five miles. Motion images are not required because the still images captured during each sampling period will satisfy the system's requirements while using much less bandwidth. Sensors placed next to camera installations will also be used to monitor the flow of traffic in this application. Speed will be the most important factor that each sensor will monitor, while volume and occupancy data will only be utilized if such data does not detrimentally affect the sensor cost or communication and power requirements. High precision accuracy is not required from the sensors; the sensors need to report speed within a broad range. For example, the sensors must report no movement, stop and go movement, moderate movement and free flow movement. Further, only non-intrusive sensor technologies will be considered as they are easier and typically less expensive to install and maintain, and more conducive to low-volume, rural roads. The precision of images received will be 480 x 512 pixels for all cameras. The typical sample period for the system will be every few minutes for both camera images and traffic sensors.

Once in the monitoring network, the collected data will then be disseminated to system managers, operators, and other emergency responders. The operators can use that information to manage the evacuation by providing the status of evacuation routes to different public warning systems such as television, radio, Internet, and telephone outlets. The evacuees and emergency responders may then modify their planned course to take more effective routes during their evacuation or incident responses. The system requirements will be flexible enough that each system will require minimal additional design work before installation. Figure 1 – Rural Evacuation System Overview, graphically depicts the system's functionality.

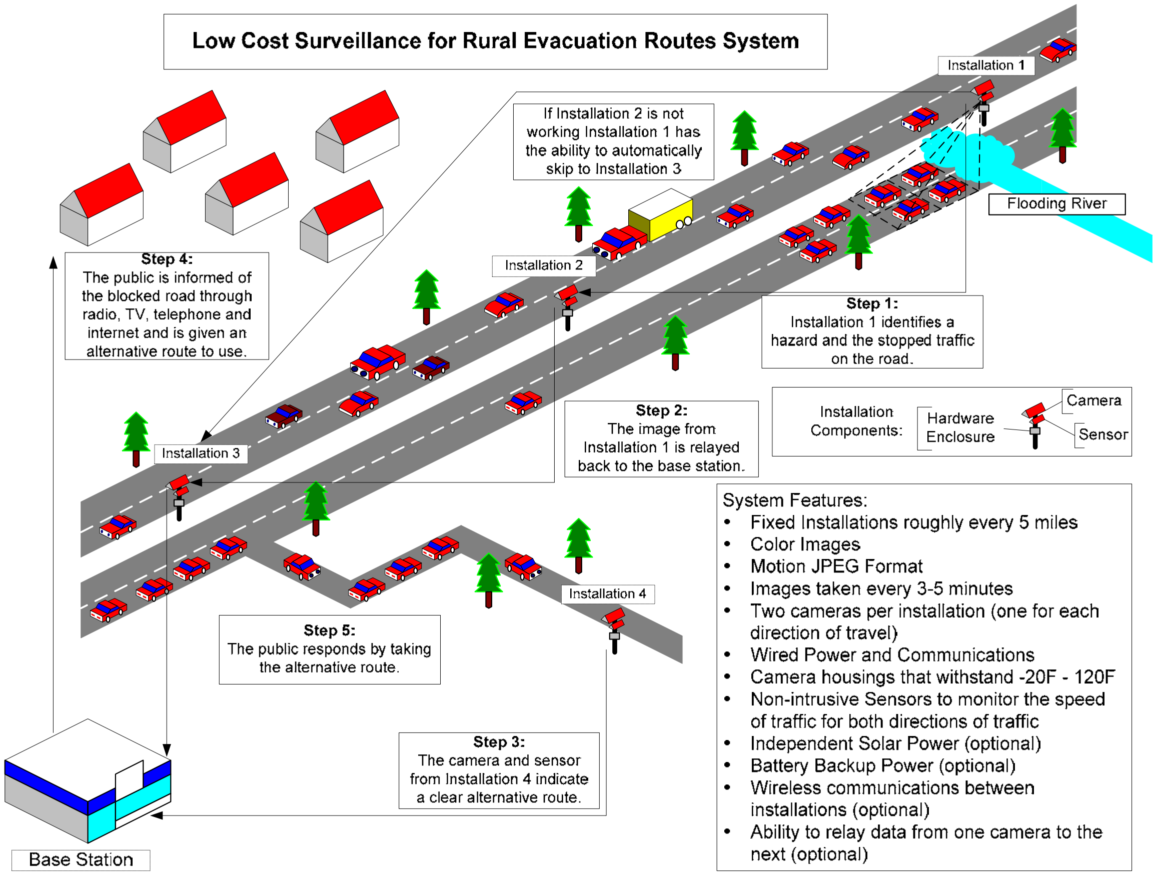


Figure 1 – Rural Evacuation System Overview

2.1.3 User Characteristics

The primary system users will be traffic managers/operators, emergency management personnel and system administrators. Each of these users will require system training. Traffic managers/operators will require training to utilize the system to make routing decisions and/or recommendations. Emergency management personnel will require training to use the system for effective incident response. System administrators will require training for system management, maintenance and modification as they will be the software and hardware maintenance personnel. Any public users will need to be able to find data about the evacuation routes they will travel or plan to use; this will largely be a function of the region's Advanced Traffic Information System (ATIS).

2.1.4 General Constraints

This system has constraints due to the rural, sometimes remote locations and the need to withstand weather extremes, while at the same time remaining relatively low in cost. The specific constraints follow:

- Visual data must be clear enough to interpret;
- Bandwidth for information transmission may be limited;
- System shall be capable of wired and/or wireless communication;

- System shall be capable of self-sustaining power (combination of batteries/solar/wind);
- System must power on/off and have the ability to reset remotely;
- Monitoring units, power, and communication must be able to operate in conditions of extreme heat, rain, ice, snow, and high winds;
- Installation must be relatively easy and system maintenance should be minimal;
- The system lifetime must be at least 10 years;
- Cost (capital and recurring) per unit must be relatively low;
- The system must be capable of using any combination of power, communication, and hardware to fit specific installation requirements; and
- Depending on the type of sensor used, accuracy may decrease during severe weather conditions.

2.1.5 Assumptions and Dependencies

The LCSRERS implementation requires appropriate communications hardware, cameras, power, and application software to operate properly. Either the system location will have nearby electrical power or independent power will be required to support the system. Depending on the system demand and available camera locations, a combination of the following solutions can be used: solar/wind power, commercial power, backup batteries, wireless communications, wired communication, and heated cases. Many factors need to be considered when choosing how much or how little of the system infrastructure must be implemented to make the system work properly.

The first system assumption is that a power supply will be available within a reasonable distance, and, if not, independent power will be installed, as power is essential for the system to function. When the installation is close to a populated area, power may be close as well. In this case a wired system could be used, but the further from this area, the more likely an independent power source will be required. To ensure power independence, backup batteries and a charging system may be used. The secondary power supply will be capable of powering the system for twenty (20) hours without an outside power source, allowing adequate evacuation time. When determining the power source used, system independence and system cost should be considered.

It is also presumed that the network will be able to communicate wirelessly if it is determined that this method is cost-effective or necessary for system independence. Wired as well as wireless networks may be implemented with this system, each having strengths and weaknesses. Wired networks require nearby infrastructure and may be unavailable during emergencies; wireless networks may have range limitations and line of sight issues along with higher installation costs.

Each installation will contain one or more cameras such that traffic in both travel directions can be monitored. A single fixed camera with an adequately wide field-of-view, a single pan-tilt-zoom (PTZ) camera, or two fixed cameras with one facing each travel direction will allow both directions to be monitored.

A single fixed camera represents the minimum hardware needed to provide a functional system. However, to appropriately locate a single fixed camera, it must be placed far enough away from the roadside to provide visual confirmation of both travel directions. Not only could this result in poor road image quality/content that does not meet the system's functional requirements, it could also cause the camera to be placed outside the right-of-way. While this is an acceptable option for system location, installation expenses increase from the extra steps taken to obtain additional right away.

A single PTZ camera is more easily placed in the right-of-way, but is generally more expensive to purchase, requires higher level communications to control, and is prone to mechanical failure. The dual fixed camera configuration requires more hardware to control each camera's data as well as additional power to keep the system running. This option's main advantage is it represents a balance between image quality/content, roadway coverage, cost, and communication system requirements.

This system will need to operate at night and in low light conditions quite often. It is presumed that this installation will be able to detect traffic flow in low light conditions due to vehicle lighting. No additional external lighting will be required because the number of head/tail lights will be the main indicator of traffic volume and flow.

While most sensors have the capability to measure multiple data types, the system expectations will not require the level of data and data accuracy typically found in urban sensor applications. Sensors will be placed adjacent to camera installations to minimize power and communication requirements. Using such a configuration, the sensors can share the camera installation's power and/or communication subsystems.

2.2 Summary of Data Sources Reviewed

2.2.1 Equipment Vendors and Retailers

Research was conducted in a variety of ways. Vendor literature from trade shows and the Internet coupled with communication with professionals from well established companies provided information about uncommon camera accessories that were rarely mentioned in literature. In addition, face-to-face meetings with vendors were part of the information gathering process. Though accessories such as solar and wind power units are rare, vendors provided information regarding cost, capabilities and limitations.

As an evacuation may occur during inclement weather, the system must also function during harsh conditions. Discussions with vendors narrowed the products and technologies that would satisfy the project requirements. Appendix G provides a list of vendors researched or used during this project.

2.2.2 Gathered Reports and Workshops

Research included installations of similar isolated cameras as well as various documents provided by the FHWA. The documents reviewed provided examples of how previous surveillance systems have been implemented to monitor different traffic situations. The documents and sources reviewed are:

- Results of the regional FHWA sponsored emergency response/recovery workshops;
- Results of the Reducing Vulnerability of Agency-Owned Telecommunications project – this project may provide information that impacts communications requirements associated with evacuation route surveillance technologies;
- Emergency management case studies including Transportation Operations Under Catastrophic Conditions;
- Alternate Route Development Methodologies – surveillance will often support identification of comparative performance of different routes; and
- Automated Detection of Potential Vehicle Threats to Bridge Structures.

2.2.3 Government Personnel

Government personnel provided valuable research information. FHWA meetings as well as one-on-one interviews conducted with FHWA personnel provided feedback and information about the requirements for the system.

Other state and regional government officials with extensive rural camera system experience were also consulted, providing insight as to which requirements would be useful and under what conditions they would be most effective. Interviews with these potential system users provided information regarding system price sensitivity as well.

2.3 Technologies Reviewed

This section discusses the different technologies analyzed while determining the LCSRERS requirements. Although the cameras needed for this system have very specific requirements, there are multiple ways to satisfy the requirements. Therefore, many data sources were consulted to find a viable combination of technologies.

2.3.1 System Communication

The system communication will define how the system gets data from each installation to the system control center. The communications infrastructure is a vital part of this system. Multiple methods of providing the communication infrastructure can be utilized, with each method having certain advantages and disadvantages depending on system location and user needs.

2.3.2 Wired Communication

Wired communication is often the easiest and the most common way to connect a system or network. Wired communication is reliable and inexpensive when there is a telephony or internet communications infrastructure nearby. As this system is designed for installation in rural areas, there may be no previously established communications infrastructure. Therefore, providing wired communication infrastructure, either POTS or fiber optic systems, can be very expensive if new cable needs to be laid. DOT's have provided a general estimate for communication line installed costs. These estimates vary due to differences in terrain, labor, and equipment. The installed cost of trenched communication ranges from $20 to $50 per foot while the installed cost of aerial communications ranges from $10 to $40 per foot.

On the other hand, if wired power must be installed the extra cost of running wired communications with it is only a few extra dollars per foot. A wired communication infrastructure will also allow less flexibility for system expansion because in the event a unit is moved, new communication cable must be installed.

2.3.3 Wireless Communication

As previously mentioned, this system is designed for installation in rural areas where installed communication infrastructure may not exist. Installing sufficient wired communication infrastructure to connect multiple cameras along several rural routes would dramatically increase the system cost.

As a result, wireless communication methods were evaluated for system usage. Wireless communication methods will virtually eliminate the need for wired communication infrastructure, thereby reducing system installation costs. Wireless technology also allows for system expansion without additional infrastructure installation.

System installation locations may also be changed, accounting for changes in evacuation routes, with little or no cost. Disadvantages include increased initial purchase costs due to additional hardware requirements, and communication range and line of sight limitations. Certain weather conditions such as lightning and heavy precipitation can weaken some wireless signals. To combat this disadvantage, receivers for the wireless network must be placed well within their maximum range. This allows for weakened signals to still be received in harsh weather conditions.

Depending upon the wireless option selected, monthly access charges may be incurred. Naturally, this can significantly affect system life cycle cost.

2.3.3.1 Store and Forward Radios

Store and Forward is an option for communicating wirelessly without having to install towers. Store-and-Forward communication uses wireless radio modems to relay information through a chain of modems until it arrives at the terminality station. There are 2.4 GHz models that have up to a 35-mile range and 900 MHz models that have up to a 20-mile range.

Although it is anticipated the ultimate system would install camera units every 5 miles, providing a longer communication range helps provide redundancy. If one of the units along the chain stops working, the extended range allows the radio to pick up the next unit. This makes the system more robust and reliable.

While the 2.4 GHz models have a longer range and are less likely to pickup interference, they are more expensive, and more susceptible to line-of-sight and weather interference issues. The 900 MHz models do not have as many line-of-sight issues, are not as susceptible to weather interference, have higher bandwidth capabilities and are not as expensive.

2.3.3.2 Motorola™ Canopy Systems

A Canopy system uses a tower that covers a 3 to 5 mile radius. As long as there is a subscriber unit, the application can go anywhere inside the range of the tower. This type of system can be extended by back haul units that can range up to 15 miles. There is no monthly fee with this type of system but the short range of main tower and the high cost of installing the system keeps it from being a viable option in most deployments. The use of back haul units to connect cameras was considered but each unit was more expensive than other options and requires the construction of a main tower. The functionality of these systems can be met through other methods at a lower cost.

2.3.3.3 Cellular Phone Services

Some cameras can use cellular phone services to transmit data. This type of system eliminates the need to install towers or radio systems which may provide installation cost advantages.

One disadvantage of a cellular solution is the sometimes sparse coverage in rural locations. In addition, the system is dependent on cellular service which often experiences peak usage during emergency events. This could prevent system functionality during such an event.

Usage of cellular phone services also introduces monthly fees for each camera. Sprint, Verizon, and AT&T all have departments that help provide solutions for government agencies doing similar projects. Based on talks with Iwapi Inc., data transfer typically costs $9/month for 1 megabyte, $30/month for 60 megabytes and $60/month for an unlimited amount. This is in addition to access charges. Because this system would not be used very often, the months with no use would cost $9 and the months in which the system is turned on for a few days would cost $30. Because of recurring costs, the use of cellular phone carriers for data transfer increases the system life cycle costs dramatically.

2.3.3.4 Meteor Scatter

Meteor scatter is a seldom used, but effective way of sending low bandwidth data over very long distances. Meteor scatter works by bouncing signals off ion trails left by micro-meteors incinerated in the upper atmosphere. This system does not require the user to install any towers and can send data 250-1500 miles.

The main disadvantage of this system is a ‘dark spot’ within a 250 mile radius of the transmitter due to the reflection angle off the ion trails. One method to resolve this problem is installing two meteor scatter receivers so each covers the other’s ‘dark spot’.

Meteor scatter is a possible solution for networks that are trying to cover a very big area but is not feasible for smaller networks that would need to place the receivers far away, possibly in other jurisdictions, from the desired coverage area.

Another issue with meteor scatter communication is that the signal strength varies based on the amount of meteors hitting the earth's atmosphere making usable ion trails; this could create dependability issues for an emergency system.

2.3.3.5 Existing 800 MHz Radio System

Using pre-existing 800 MHz communications for the wireless infrastructure of this system was investigated as a possible option. Although the 800 MHz frequency does have a range of 15 to 20 miles, it also has a relatively low bandwidth of 19.2 Kb/s.

Assuming each camera is sending 60 KB images, the system should be able to support 10 cameras sending back images every five minutes. Each camera placed on the system, after the first ten, will increase the latency by a few seconds.

Ethernet-based cameras introduce additional message overhead, further exacerbating the bandwidth shortage. This results in longer transmit times due to high amounts of meta-data used to send the actual image data.

A private channel for the cameras would also be required due to the high probability of corrupted data resulting from interference with other communications.

Regardless, the latency issues remain for a system with more than 10 cameras.

2.4 System Power

Powering the system is another vital area requiring reliability. Even the best communication equipment will be useless with out a reliable power source. This overall system is designed to use as little power as possible, allowing for alternative independent power sources such as a solar, battery and/or wind.

The system also has the option of using wired power if it is determined to be the most cost effective solution. However, a hard wired power system is susceptible to the system not providing power when it's needed most. The following sections list the options for powering each installation.

2.4.1 Independent (self-sufficient) Power

Although wired power is usually easier to obtain than wired communication there are still many potential installation locations that will not have nearby wired power access. Independent power has many of the same benefits as wireless communications such as flexibility and no monthly charges. Unfortunately, independent power may have higher initial costs and could introduce some performance issues. For example, inclement weather might preclude the power subsystem from providing sufficient power to the camera and communication subsystems. Also, independent power introduces additional points of failure into the system. The following independent power options were examined.

2.4.1.1 Solar Power

Solar technology represents a likely option to power the system as well as keep a backup battery charged. A limited selection of solar technology vendors results in limited choices and relatively high costs for such a power system.

The solar panel is designed to run the system during the day and charge a battery that will power the camera when there is no sunlight. With solar power and wireless communication an installation can be independent without incurring monthly power costs. Solar power may also reduce maintenance costs when compared against other power options.

Although more expensive initially, solar power provides flexibility that hard-wired power systems cannot offer, and extends the life of backup batteries.

2.4.1.2 Wind Power

Wind-powered installations are even rarer than solar powered installations because they are not efficient in every part of the country. Obviously, if there is no wind, no power will be generated and the installation will not work when needed. Wind power technology is also expensive, but it can be a very good power option if the system must use independent power and is deployed in a consistently windy area.

2.4.1.3 Backup Battery Power

Most power sources will fail to produce power for some time period. Certain independent power sources, such as solar, are not designed to work constantly.

A backup battery can power the system when the primary power source is not functioning. The LCSRERS must operate during most environmental conditions. It is possible that hard-wired power may be unavailable due to severe weather conditions. A backup battery ensures the system can operate when no other power source is available.

Batteries that are not being used still lose power over long periods and must be recharged through a primary power source, either solar, wind or hard-wired. Backup batteries represent an additional cost, but will likely help the system remain effective and available when it is most needed.

2.4.2 Hard-wired Power

Hard-wired power is similar to wired communication in that post-installation costs may be reduced. However, if infrastructure is required for remote locations, installation costs may actually be greater than independent power systems.

Conversations with various power companies and state DOT's have provided a general estimate for power line installed costs. These estimates vary due to differences in terrain, labor, and equipment. The installed cost of trenched power ranges from $30 to $60 per foot while the installed cost of aerial power ranges from $20 to $50 per foot. This cost includes the step-down transformers that are needed at each installation to give it the correct voltage.

Because installation costs are so high, it is unlikely that a new, wired power subsystem will be used with this monitoring system. A hard-wired power subsystem also introduces the risk of having the system unavailable at times of need. However, if hard-wired power is already nearby, with step-down transformers already in place, this option may be a cost effective solution.

2.5 Camera Options

Cameras are the eyes of this system and support the primary functional role, observing traffic conditions on evacuation routes. Although there are many cameras on the market and only a small subset satisfy the system requirements. Many contain features that are not needed for the LCSRERS, and the additional features increase the camera's price. Listed below are the options for cameras that offer useable features.

2.5.1 CCTV Cameras

Closed-circuit television cameras (CCTV) are used to directly send images to a video monitor or monitors using a switch. They are usually cheaper than web-based cameras because they do not require an embedded processor and web server to send information. These types of cameras typically do not come with the option to be wireless and are more geared toward video than individual images. CCTV cameras must also be wired directly into a monitoring system, whereas IP Addressable cameras can be viewed from any computer with an Internet connection.

Each CCTV camera uses analog National Television Standards Committee (NTSC) signaling on a coaxial transmission cable. In order to avoid the need for a monitor for every camera, there needs to be either an electronic or manual switch that connects a few monitors to every camera on the system. This configuration allows the operator to view the cameras of interest as needed. The system is inherently more secure as the video feed goes to one central location, but this may also create issues should that facility be unavailable. To be cost effective, a CCTV-based system would use a relatively small amount of cameras in a close proximity to the monitoring facility.

NTSC analog signals can only be sent approximately 10 miles on coaxial cable. For distances farther than 10 miles, expensive signal repeaters must be used. Therefore the option of sending data via Ethernet was researched.

CCTV cameras are capable of using Ethernet encoders and decoders to work over Ethernet. This, coupled with a wireless Ethernet adapter, gives CCTV cameras roughly the same capabilities of wireless IP addressable cameras. Although CCTV cameras are generally cheaper than IP Addressable cameras, the additional hardware needed to convert standard CCTV cameras to Ethernet CCTV cameras makes them more expensive overall.

Also, the added number of parts increases the risk of incompatibility issues as well as the possible points of failure. The additional hardware will also need power, which may cause additional strain on independent power supplies. Therefore, IP Addressable cameras provide a less expensive and more reliable option than CCTV cameras deployed to work over Ethernet. Because of this it is still undetermined whether or not CCTV cameras will be used in this application.

2.5.2 IP Addressable Cameras

Also known as "web cams," IP addressable cameras were researched because they are built to post the images they collect to a website. Many web cams come with a built-in web server, which minimizes the need for additional hardware and software. Web cams may be programmed to take JPEG images every few minutes, which is exactly what the LCSRERS scope requires. Some web cams are inexpensive but are not designed for outdoor use; these require a protective case with perhaps a heater and blower. This will consume additional power and put a strain on independent power supplies such as solar, wind or battery backup. Web cams work well on systems with multiple cameras and can be easily adjusted to fit the system's needs.

2.5.3 Fixed Cameras

Fixed cameras are put into place and do not move. They are usually cheaper than pan, tilt, zoom (PTZ) cameras and have a fairly wide view. They don't have any moving parts and use much less power. A disadvantage of fixed cameras is that each installation will require two cameras to view both directions of traffic. This results in more cameras as well as associated mounting equipment, enclosures and power and communications equipment. Using two cameras for each installation almost doubles the camera cost and the power requirements.

2.5.4 Pan, Tilt, Zoom

Pan, tilt and zoom cameras are capable of being controlled remotely to look where ever needed within a 360 horizontal degree by 180 vertical degree coverage area; one PTZ camera can do the job of two fixed cameras. This reduces the number of cameras required for a given system. Disadvantages of the PTZ camera include a higher cost for functionality not required by this system. Also, as the system will only be utilized during emergencies, PTZ cameras may require more maintenance of the moving parts or be more susceptible to mechanical failure.

2.5.5 Night Vision (Infrared)

Night vision is very helpful when trying to get a detail view of what is happening in low light conditions. Night vision typically works by collecting tiny amounts of light, including the lower portion of the infrared light spectrum, that are present but may be imperceptible to our eyes, and amplifies it to the point that we can easily observe the image. For systems requiring detailed low-light images, night vision is certainly a requirement. The LCSRERS only requires determining the number of cars on the road. If the evacuation occurs in low light, the vehicle headlights and tail lights should allow this level of observation without night vision. Night vision can be useful, however, when the camera is trying to determine whether or not the road is blocked by water or debris. Night vision adds additional cost and power requirements as opposed to a standard camera.

2.5.6 Motion Sensors

Motion sensing cameras take picture and shoot video when something is moving in front of them. For the LCSRERS, cameras will be turned on during emergency evacuations and turned off after the evacuation is over. Motion sensing can be done with simple motion sensors or with Digital Signal Processing. Motion sensors are a desirable feature because they would help determine whether there is stopped traffic or none at all.

2.5.7 Digital Signal Processing (DSP)

There are several types of DSP, ranging from simple motion sensing to complex algorithms allowing computation of speed, volume, occupancy, and vehicle classification. Most cameras and sensors that do calculations on the data they collect use DSP. DSP can be in the camera or using external equipment and a video feed. Most currently available DSP systems require a continuous video image and will not work with still images.

2.5.8 Full Color

Full color video is very useful when trying to determine image detail. Unfortunately using this option requires higher bandwidth than black and white images. Regardless, color images is the industry standard of today's cameras, meaning black and white cameras are usually just as expensive as color cameras and harder to obtain. The LCSRERS will likely utilize color images because such cameras are equal or less expensive than comparable black and white cameras.

2.5.9 Black and White

Black and white images can be used to give a basic view of the traffic situation while utilizing less bandwidth than a color image. Therefore, black and white images can be viewed at higher resolutions while using the same bandwidth as a lower resolution color image. Most black and white cameras are more expensive than the color versions and more difficult to obtain. The LCSRERS requirements are not inherently high bandwidth; therefore it is not critical to have the more expensive black and white cameras.

2.5.10 Streaming Video

Many web cams that monitor traffic today use a streaming video format that is live and gives users a very good idea of the traffic situation. If the LCSRERS was designed to have only one or two cameras this would be a viable option. Because the system is designed to have dozens of cameras in place using relatively low bandwidth communication, and streaming video exceeds the system's functional requirements, streaming video will not be utilized for this system.

2.5.11 JPEG Image Capturing

In a system with multiple cameras, live streaming video from every camera uses large amounts of bandwidth. Therefore many systems set their web cams to capture one image every few minutes. This allows the users to still get a very good idea of what is going on in a way that doesn't sacrifice the system's performance. Because this system will be bandwidth constrained, and streaming video is not a functional requirement, JPEG cameras will be considered. A disadvantage of JPEG cameras is they are more expensive than CCTV cameras and require built-in web servers to post their images to the network.

2.5.12 Protective Enclosures

The system will be deployed outdoors, and must withstand sometimes harsh elements. Therefore, protective enclosures, while expensive, are critical to housing and protecting the equipment. One enclosure will be required for the camera and another for the batteries and communication equipment. The camera enclosure must be waterproof, be wind resistant, have a sun visor to shield against glare, and be tamper proof. The battery and communication enclosures must also be waterproof, be wind resistant, and be tamperproof. While these cases may be fairly expensive, they are absolutely essential for the system to work properly.

2.5.13 Camera enclosures with heaters and blowers

Many camera enclosures today have built in heaters and blowers. These enclosures keep the camera from getting too cold or hot and eliminate condensation on the camera lens. Such an enclosure allows the camera to operate in very warm and cold environments. These cases are more expensive than non-heated cases and use more power. Heated enclosures are not an option if the system is using an independent power source such as solar power. During overcast and snowstorm conditions, the solar panels will not be generating any power and the heater will drain the backup battery relatively quickly. Therefore, heated cases are only an option for extreme temperature situations where wired power is readily accessible. Fortunately, most outdoor cameras do not require heaters or blowers unless they are in environments with temperatures below -40°F or above 120°F.

2.5.14 Camera Software Packages

Many available software programs can monitor cameras on a network. These software programs not only manage cameras but can display them simultaneously. The disadvantage of these software packages is the additional cost. Further, they may not be necessary with IP addressable cameras.

2.6 Non-Intrusive Sensors

As mentioned in Section 2.1.2, only non-intrusive sensor technologies will be considered. Non-intrusive sensors are those that do not require the direct installation into or onto a road surface.

Sensors are used to monitor different aspects of roadway traffic flow. Although traffic sensors are capable of giving information about the speed, volume, and occupancy, the LCSRERS only requires general information about traffic speeds. Some cameras have these capabilities built in and act as both a sensor and a camera. This additional information uses more bandwidth, and increases the camera cost. Sensors used in this system will be installed next to camera installations to give the system managers a general idea of how fast traffic is moving, while keeping power and communication costs to a minimum.

2.6.1 Video Image Processor

This sensor type is built into a camera and uses a microprocessor to compute images into traffic flow data. These video image processors are capable of monitoring speed, volume, and occupancy. By analyzing imagery changes from each successive frame, the system detects vehicles and their speeds. Algorithms are used to remove gray areas in images caused by weather, shadows, and glare. Image formatting and data extraction are performed with firmware that allows the algorithms to run in real time. This sensor type could reduce installation costs because it combines a camera and a sensor, therefore eliminating the need to purchase two separate products. Disadvantages of this sensor type are a vulnerability to viewing obstructions and image distortion due to headlights, both of which result in reduced performance.

2.6.2 Microwave Radar

Microwave radars use a wavelength of transmitted energy, usually between 1 GHz and 30 GHz. Most commercially available microwave radar sensors used in traffic management application transmit at a frequency of 10.525 GHz. The distribution of energy across the aperture of the antenna determines the beam width. When a vehicle passes through the antenna beam some of the energy is bounced back to the antenna. A receiver picks up that returned energy, which is used to determine the volume, speed and occupancy of traffic. Advantages of this sensor type are its insensitivity to inclement weather, its direct measurement of speed and the capability of multiple lane operation. Unfortunately, these sensors have performed poorly as volume counters at intersections.

2.6.3 Infrared Sensors

Active and passive infrared sensors are also used in traffic applications. They are usually mounted overhead to view approaching or departing traffic. Active infrared sensors illuminate a region with infrared energy, which is reflected back to the sensor by passing vehicles. Passive infrared sensors work by detecting energy that is emitted from vehicles, road surfaces, other objects, and the atmosphere. Both types of infrared sensors use a light-sensitive receiver that converts the reflected or emitted energy into electric signals. These signals are then analyzed in real-time to determine the volume, speed and occupancy of traffic. Advantages of these sensors include their ability to measure multiple lanes with a single installation and the use of multiple beams for accurate measurements. A disadvantage is that glint from sunlight, atmospheric particulates and inclement weather can scatter or absorb energy that would have been reflected back to the sensor thereby resulting in decreased performance.

2.6.4 Ultrasonic Sensors

This sensor type transmits pressure waves of sound energy at a frequency between 25 and 50 KHz, above the human audible range. Most sensors of this type use pulse waveforms to monitor traffic. Pulse waveforms measure distances to the road surface by detecting energy reflected back to the sensor. When that distance changes, the sensor interprets it as a passing vehicle. The ultrasonic energy received is converted into electrical energy, which is then analyzed by signal processing electronics to determine the volume, speed and occupancy of traffic. Unfortunately this sensor's performance can be negatively affected by temperature changes and heavy winds.

2.6.5 Passive Acoustic Array Sensors

Passive acoustic array sensors detect vehicle passage, presence and speed by detecting acoustic energy and audible sounds the vehicle produces. When a vehicle passes through the detection zone, a signal-processing algorithm uses the increased sound energy to recognize the presence of a vehicle by activating a vehicle present signal. When the vehicle leaves the zone the noise energy returns to normal and the vehicle present signal is terminated; this time is converted into a vehicle speed. Acoustic sensors are not sensitive to rain and multiple lane operation is possible. Data accuracy can be negatively impacted by cold temperatures and slow moving vehicles in stop and go traffic.

3 TECHNOLOGY RECOMMENDATIONS

The basic design of the LCSRERS will place multiple instrument and communication installations along rural evacuation routes. Each installation will consist of a camera and/or sensor that provide traffic flow data every few minutes. If additional verification is required for sensors to provide additional speed, volume, and occupancy information, additional sensors may be co-located with cameras (i.e. multiple sensors per location), or they may be placed between cameras.

Each surveillance installation will have the ability to be activated remotely with the option to be independently powered or wired to the nearest utility grid. All cameras will provide color images and have a weather proof enclosure. As with power options, the communication package can support both wired and wireless communication.

The following paragraphs describe the most promising of the technologies investigated which match the system requirements detailed in the Requirements Identification Technical Memorandum. Some features may be more or less cost effective depending on the region in which they are being implemented. Regionally, variable cost features (power and communications) should be evaluated for each specific installation.

3.1 Cameras

3.1.1 Fixed Cameras

Fixed cameras are recommended over PTZ cameras as they meet the system requirements while keeping cost low and use less power. Fixed cameras avoid the expense of movement motors and control software. Removing the motors saves power and no communication bandwidth is used for position control messages. This helps fulfill power requirement PHW-030106.

The primary advantage of fixed cameras is that they have reduced maintenance costs due to the absence of moving mechanical parts. However, fixed camera installations have the disadvantage of doubling the camera count at each location. There must be two cameras along each road to view both directions of travel.

Calculations show an additional camera at each location still costs less than a single PTZ camera. Volume purchase discounts of the same camera unit will also apply. Reduced cost and higher reliability support fixed camera usage when implementing a low cost, low bandwidth system.

3.1.2 Full Color

Color cameras are the industry standard today. Supply and demand market forces in commodity electronics, such as cameras, have resulted in color cameras costing the same or less than black and white cameras. Color cameras are now available in a greater selection of models with more features. Farther, color cameras satisfy requirement PHW-030105, because the color images provide better clarity at the 640 x 480 resolution than black and white cameras. Color pictures require more data for transmission than black and white pictures of the same resolution, but the differential bandwidth required is inconsequential for this application. Color is the best option for this application because, for a comparable cost and bandwidth usage, it provides more detail when viewing each picture, thereby providing better confirmation of the road conditions.

3.1.3 JPEG Image Capturing

The camera data will be transmitted to the system managers as a series of still shots in JPEG format. Many IP Addressable cameras come with JPEG compression hardware built in. The main advantages of JPEG images are their low bandwidth requirements and ease of integration into existing TMC systems.

Alternatively, motion video could be used. However, this approach requires a substantially larger amount of bandwidth than available via most wireless networks, and motion video is not required to satisfy the system requirements.

Cameras using JPEG compression are the most appropriate option. The use of a JPEG image capture helps to satisfy requirements IAD-020401 and FDA-010401.

3.1.4 IP Addressable Cameras

IP addressable cameras are appropriate for this application because they are capable of using LAN, Cable, DSL, POTS, or wireless communication subsystems. The data from these cameras is divided into discrete information packets. These packets are easily transmitted over IP and Ethernet networks.

IP addressable cameras satisfy requirements FGF-010002, FDA-010402, FGF-010007 and IAP-020504. IP Addressable cameras available on the market today use very little energy which makes them ideal for independent power sources such as solar power. These cameras produce color JPEG images and can be configured to meet local requirements. IP Addressable cameras are also capable of withstanding temperatures specified in requirement PHW-030108 when placed in a non-heated enclosure.

The cost of IP addressable cameras varies from $200-$700, not including required protective enclosures. Certain models require attachments to use a wireless communication subsystem. These attachments can add between $150 and $300 to the cost of the camera but also eliminates the need for additional, sometimes more expensive, hardware.

3.2 Communication

3.2.1 Store and Forward Radio Subsystem

Radio modems represent the optimal wireless solution for this application. The radios are reliable and provide flexibility for future system expansion and/or reconfiguration. They also avoid dependence on a public wired/wireless communications network that may be unusable during an evacuation. There are two frequency bands available for this kind of service: 900 MHz and 2.4 GHz. The 2.4GHz has a greater bandwidth, while the 900 MHz frequency is less likely to experience interference and is less susceptible to line of sight issues. Because of this more consistent performance, 900 MHz is the preferred solution.

Radio modems have a range that satisfies requirement DIR-040502 and are capable of withstanding temperatures specified in requirement PHW-030108, when placed in a NEMA 4 enclosure. These modems use low DC power, making them ideal for an independent power source.

A store and forward radio communication subsystem design will allow the installations to be chained together, while their range will allow overlapping coverage. The additional coverage would allow a design where an individual unit could fail and still maintain the overall communication subsystem function. When using a 900 MHz store and forward radio subsystem in this application, the individual radios will be placed at approximately five mile intervals although the radios have a range of 20 miles.

The store and forward radio subsystem fulfills the system performance requirements without generating a recurring monthly cost, but each unit costs approximately $1,800. The purchase of an antenna and additional coax cable is also required, which costs around $300. A life cycle analysis would be required to compare true system costs against other alternatives such as standard telephone lines or cellular data services.

3.2.2 Wired Communication Subsystem

Physical cabling is often the easiest and the most secure way to connect a system or network. Available wired communication would satisfy requirement DHW-040211. Wired communication is reliable and inexpensive when communications infrastructure is nearby. However, as this system is designed for installation in rural areas, there may be no previously established communications infrastructure.

A wired communication structure may provide less system expansion flexibility, violating requirement QAV-050106. In the event a unit is moved or more nodes are added, new communication cable must be installed or a hybrid wired-wireless communication subsystem must be adopted.

Providing wired communication infrastructure, either POTS (Plane Old Telephone Service) or fiber optic systems, can be expensive if new cable is required. Research found the installed cost of trenched communication ranges from $20 to $50 per foot while the installed cost of aerial communications ranges from $10 to $40 per foot. The cost range results from differences in terrain, labor, and equipment. If wired power must be installed, the additional cost of running wired communications simultaneously is only a few dollars per foot.

3.2.3 Cellular Service Subsystem

Some cameras can use cellular service to transmit data. Using a cellular service subsystem eliminates the need to install communication towers or radio backbone systems. This can provide installation cost advantages. Cellular technology satisfies requirements DIR-040502 and PHW-030108.

One disadvantage of a cellular solution is the sometimes sparse coverage in rural locations. In addition, cellular service often experiences peak usage during emergency events. This could prevent system operation during such an event, violating requirement FGF-010002.

The costs associated with fitting a camera with a cellular service antenna and modem is roughly $500. Usage of cellular service also introduces monthly fees for each camera. Because of recurring and upfront costs, the use of cellular phone carriers for data transfer increases the system life cycle costs above the low initial cost. This is shown in Appendix C.

3.3 Hardware and Parts

3.3.1 Ethernet Switches

Any design that uses Ethernet to connect cameras to the radios will require an Ethernet switch. A standard four port Ethernet switch connects the two cameras to an Ethernet radio modem, which controls the data being sent and received. These switches need to have a temperature operating range meeting requirement PHW-030108, and support voltages between 10V and 30V. At a cost of about $100, this switch satisfies requirement DHW-040219 when using Ethernet radios as a wireless solution.

3.3.2 Protective Cabinets

The system will be deployed outdoors, and must withstand sometimes harsh elements. Cabinets or other weather protection measures will be required for protection of the batteries and electronic equipment at each installation. Protective cabinets are critical to housing and protecting the equipment and are absolutely essential for the system to work properly. These cabinets must also be waterproof, wind resistant, and tamperproof (i.e. equipped with locks). NEMA 4 cabinets are standardized and priced around $100, depending on their size. These cabinets meet requirements PHW-030112, PHW-03110, PHW-030115, QSE-050205 and DHW-040211. Additional mounting hardware may be required to anchor these cabinets to poles or other structures. If the size or weight of the enclosures becomes too great, separate foundations may be required for the cabinets. Due to the cost of installing cabinets with separate foundations, this should be avoided whenever possible.

3.3.3 Protective Camera Enclosures

In addition to protective cabinets, protective camera enclosures are essential for cameras to function in the required environments. These enclosures may be separate or may utilize the protective cabinet, and are particularly important for a system that needs to function during evacuations resulting from severe weather. Much like protective cabinets, separate camera enclosures researched satisfy requirements PHW-030112, PHW-03110, PHW-030115, QSE-050205 and DHW-040211.

In extremely cold or hot environments, a heater/blower may be necessary additions to the camera enclosures. A heater/blower can expand the operating temperature range by 20 degrees at both ends of the spectrum, but are more expensive and add to the power requirements for each installation. This increases the system cost and power subsystem requirements. Most environments can be adequately served without requiring a heater/blower. The cost of each separate enclosure, without a heater/blower, ranges from $150 - $250.

3.4 Sensors

3.4.1 Radar

Radar sensors may be used in conjunction with cameras to give a better idea of road conditions. Radar sensors can be placed in areas that are out of the camera's vision. Advantages of radar sensors are their insensitivity to inclement weather, their direct measurement of speed, and their ability for multiple lane operation. Radar sensors are also able to differentiate between stopped traffic and no traffic at all.

Radar sensors are recommended (if required) because they are the most cost effective sensor on the market today, with an average cost of $1800 for a typical 2-lane road. While their performance satisfies requirement FDA-010403, their cost does not satisfy requirement QAV-050102. Radar sensors add minimal functional value to a camera-based system.

3.5 Power

3.5.1 Solar Power

Solar power is the most affordable and practical way to provide immediate power in rural locations. The size of the solar panel is dependent upon how much power is needed. Although solar panels are capable of withstanding all types of weather, extended low light conditions render them ineffective. Therefore, solar powered installations will require backup batteries to provide power during low light conditions.

Solar panels produce a limited amount of power. Therefore, installations using solar energy are limited to equipment using low amounts of electricity. Equipment such as heaters/blowers and PTZ cameras use large amounts of energy and may not work with a solar power solution. The use of solar panels satisfies requirements FGF-010001 and DHW-040212.

A complete solar package system will cost $600 - $900 depending on power and backup battery life requirements Solar panels have no recurring operating costs and provide system flexibility. Costs will vary because of the rapid fluctuations of supply and demand in the Solar panel market.

3.5.2 Commercial Power

Although commercial power may not be a cost effective solution for rural installations, it may be cost effective for areas that are close to the appropriate infrastructure. If commercial power with existing step-down transformers is nearby, this option may be preferable over independent power and would fulfill requirement FGF-01006.

Commercial power is resistant to most weather and meets the temperature requirements. A disadvantage of a commercial power subsystem is that it also introduces the risk of having the system unavailable at times of need. During severe weather, power outages can be common. Without battery backup, the individual installation may be exposed to the risk of inoperability. Therefore, it is recommended that back up batteries be used with hard-wired power to ensure continued operation during power disruption.

Using commercial utility power will be extremely expensive in rural areas. The installed cost of trenched power ranges from $30 to $60 per foot while the installed cost of aerial power ranges from $20 to $50 per foot. This cost includes the step-down transformers that are needed at each installation to provide the correct voltage. Because installation costs are so high, it is unlikely that commercial power will be used at most locations with this monitoring system. An additional cost of using commercial power is the monthly power bill. Costs vary depending on the amount of power used. While likely minimal, the monthly cost of powering hard-wired installations should be reviewed when determining power solutions.

3.5.3 Backup Battery Power

Both solar and commercial power sources will require the use of backup batteries. Solar power needs batteries to operate overnight and during low light conditions. This is in accordance with requirements PHW-030103 and DHW-040212. Backup batteries can also be used with commercial power sources to provide power during service interruptions.

Backup batteries require a method to maintain a full charge; either by solar, wind or commercial power. Regardless of the primary power source, the power source will need to be able to recharge batteries while the system is in use.

Batteries are capable of withstanding temperatures set by requirement PHW-030101 and powering a system for days, fulfilling requirement PHW-030108.

A backup NiMH battery, which will last approximately three to ten years, costs between $119 and $1000 dollars depending on the model purchased. At the lower end of the price scale are batteries with a three-year shelf life and no charge controller. At the upper end of the price scale are batteries with more amp-hours of power, a 10-year shelf life, and a built-in charge controller.

3.6 Software

3.6.1 Camera Software Packages

Software packages are available to organize how cameras are viewed. These software packages organize the cameras on the system and allow easy selection and viewing. Although a software package may not be a necessity for system operation, it can improve system efficiency. The type of software purchased will depend on the type and quantity of cameras being deployed on the system.

This will be a project-specific design decision, evaluating these factors along with existing/proposed computer hardware, computer software, and functional software requirements. Utilizing a camera software package satisfies requirement IAD-020301.

The cost of most camera software packages is between $50 and $100 for each individual license.

3.7 System Configuration Summary

The recommended LCSRERS will use fixed IP Addressable cameras installed roughly every five miles to view traffic conditions along rural evacuation routes. Installations will be powered by solar panels unless commercial power is more cost effective. In both cases, battery backup power is recommended.

Communications may be provided by wireless options such as cellular service and/or Ethernet radio, through direct wired communication, or a combination of these options depending on local circumstances. While the power subsystem may use a variety of options, use of a homogeneous communication subsystem offers operational and maintenance advantages. Store and forward radios, for example, use a relay communication method. Mixing installations with such a system could impact the communications chain for these radios. These advantages, however, may be outweighed by the cost savings of a hybrid wired-wireless communications subsystem.

3.8 Technologies Considered and Not Recommended

Of the many technologies researched, only a few were chosen to be tested with this system. Using the requirements developed in Task 2, various technologies were compared against the system requirements to determine which available technologies satisfied the system requirements.

The low-cost requirement (QAV-050101) was a major factor in determining which technologies could be used with this system. Many technologies satisfy the system's technical requirements but were unable to satisfy requirement QAV-050101. The following technologies were researched, but ultimately could not be recommended.

3.8.1 Communications

For the communications infrastructure, flexibility, compatibility, reliability, and cost, were the priorities.

A Motorola Canopy™ system was evaluated. This system uses a tower to cover a three to five mile radius. Devices can be placed anywhere within this range. This system can be extended by back haul, with ranges of up to 15 miles. This technology was not recommended as it is very costly and its design does not optimally support this system's linear layout.

Another communication technology considered was meteor scatter. This technology works by bouncing signals off ion trails left by micro-meteors incinerated in the earth's upper atmosphere. Meteor scatter was not recommended as it is designed to make much larger data hops than the system requires and it does not have a documented history with this type of application.

3.8.2 Power

The only power technology evaluated and not recommended is wind generation. Wind generation did not satisfy the requirements because it is expensive, inconsistent and has limited effectiveness on a nationwide scale.

3.8.3 Cameras

Cameras with pan/tilt/zoom capability and black and white cameras were not recommended for this system. While some of these camera technologies can satisfy the project's technical requirements, those that can typically lack the additional image clarity or the low cost of fixed view, color cameras. IP-video was recommended over standard NTSC video (used by most CCTV cameras) because images can be posted to the internet without incurring additional encoding costs. Additional details regarding this recommendation can be found in Section 2.5 of this document.

3.8.4 Sensors

Many non-visual sensors were researched, including video image processing, microwave radar, infrared, ultrasonic and passive acoustic array. Each of these sensors can meet the system's technical requirements, but only the microwave radar comes close to meeting cost requirement QAV-050101. Therefore, only microwave sensors were recommended in this document.

Subsequent research into cell phone probes has yielded some positive results. Though not as accurate as the more traditional sensor systems, this approach can yield sensor data over large areas at costs approaching $2,000 per mile for both directions of travel. Lane by lane data is not available from this type of system. These systems have substantial start-up costs and are only practical (in terms of cost per mile) over thousands of miles of monitored roadway. Because of budget constraints, this technology could not be deployed for evaluation on this project.

4 ASSESSMENT AND EVALUATION

4.1 Final System Requirements

The system requirements were originally developed earlier in the project and submitted in the Requirements Identification Technical Memorandum. Because of factors such as equipment costs and technology constraints, some requirements evolved during the course of the project. This section summarizes the final requirements and organizes them by installed subsystem. Some requirements have undergone changes to better accommodate successful configurations. The high level requirements that have been removed or replaced will also be referenced here.

4.1.1 Communication Requirements

The following are the critical communications requirements for the LCSRERS.

- The system shall be available at any time.
- Communications shall be capable of using wired or wireless communications.
- Cameras shall send information as an image that is captured every few minutes.
- The system shall be able to access the cameras' images remotely.
- The system shall be able to be reset remotely.
- Multiple cameras shall be able to be viewed simultaneously.
- The managing entity shall be able to republish information through various public mediums.
- The information being sent by each camera shall be viewable only by the managing entity via system network.
- The images that IP addressable cameras post shall be on password protected HTTP or HTTPS addresses.
- Image information shall be in a standard format, such as JPEG and MJPEG, to be easily displayed and viewed.
- Cameras shall record images at a resolution 640 x 480 pixels or greater.
- Transmission delays shall not exceed 20 seconds if cameras are fixed.
- Wireless installations shall be able to send/receive information a minimum of 5 miles.

4.1.2 Power Requirements

The following are the critical requirements that deal with powering each installation.

- Installation power shall be able to be provided by a source independent of a utility power grid.

- Installation power shall be able to be provided by a utility power grid.
- Installations shall have a 2-day backup battery power supply.
- Batteries powering the cameras shall be able to be charged by auxiliary power sources.
- Cameras shall consume no more than 5 watts.
- Solar panels shall be used to recharge batteries and power the system.

4.1.3 Structural/Hardware Requirements

The following are the critical Structural/Hardware Requirements for the LCSRERS.

- Over 90% of the installations shall be operational when the system is activated.
- Cameras and Hardware shall be non-intrusive.
- Parts for each installation shall be the same model when ever possible.
- Cameras shall have highly protective and weather resistant cases when needed.
- Cameras shall face both directions of travel.
- Mounting poles shall be tall enough to get a good view of the road and be able to transmit data.
- Installations on the system shall be in a fixed location when possible.
- Installations shall be placed every 2 – 10 miles on evacuation routes.
- Installations shall be placed on pre-existing stands when possible, i.e. telephone poles.
- Cameras and installation hardware shall be low cost.
- There shall be little maintenance required after installation.
- The system shall have a 10-year life cycle.

4.1.4 Discarded Requirements and Features

The following are requirements that were added and have been disregarded due to factors such as price, usability, and design constraints.

- The system shall incorporate a software package to help monitor and control the cameras on the system.
- Cameras shall consume no more than 3 watts.
- Cameras shall able to zoom 10X or greater.
- Camera enclosures shall be locked to withstand theft attempts.
- Transmission and camera control delays shall not exceed 1 second if PTZ cameras are used.

- All units shall use an Ethernet switch into which both cameras will be plugged.
- All wired units shall have a modem to convert data.
- The system shall have the option of placing up to 4 cameras at designated intersections.

4.1.5 Sensors

In the original set of requirements the system was being designed to use sensors as an additional method of detecting traffic. Sensors were not used in this system as they were expensive and provided low value traffic data. They would also increase the power and bandwidth demands at each installation. Therefore no sensor requirements were tested as part of the pilot deployment.

4.2 Final Working Conditions and Technology Alternatives

4.2.1 Working/Environmental Conditions

These requirements include the conditions in which the system must be fully functional to make it effective. These requirements are based on the Requirements Identification Technical Memorandum from Task 2 – Requirements Identification.

- Theft protection shall be provided by lock or by the height at which the equipment is installed.
- Camera enclosures, hardware enclosures and mounting hardware shall be able withstand temperatures of -20F to 125F.
- Camera enclosures and mounting hardware shall be able to withstand sustained winds of 60 mph and gusts of 140 mph. (This is constrained by the solar panel.)
- Camera enclosures, hardware enclosures, and mounting hardware shall be weatherproof.
- Mounting poles shall be able to withstand sustained winds of 80 mph and gusts of 120 mph. With less then a half in degree shift in position during 30 mph sustained winds.
- Cameras shall provide useful information independent of the lighting conditions.

4.2.2 Technology Alternatives

This section describes several available technologies which may be useful in certain situations, but were not tested in the demonstration. These technologies were not implemented as part of the test because they did not comply with the conditions of the test site or the design of the system. There was also a limited test budget during this project that prevented the purchase of more equipment. Each of these alternatives has been previously discussed in the Task 3 document, Recommended Technologies.

4.2.2.1 Meteor Scatter

This technology works by reflecting signals off ion trails left by micro-meteors incinerated in the earth's upper atmosphere. Meteor scatter was not recommended as it is designed to make much larger data hops than the system requires and it does not have a documented history with this type of application. However, this technology is developing rapidly and may be ideal for a LCSRERS that needs to cover a very broad area.

4.2.2.2 Wind Power

Wind generation did not satisfy the requirements because it can be more costly than other options and has limited effectiveness on a nationwide scale. This technology should be investigated as a possibility for locations with consistent winds. Wind power can be a viable alternative where winds are consistent and can help level the costs associated with the currently volatile solar panel supply availability.

4.2.2.3 Wired Power and Communication

Wired power and communication were not used in the test installations because they were not close to a wired infrastructure and other wireless methods were being tested. Wired power and communication should always be looked at as a possible solution when it is available nearby. Wired power can quickly become very expensive when the cable is run over long distances and step-down transformers need to be installed. An advantage is that wired communication can be run with power for little additional cost. Because wires tend to rely on the local infrastructure and have a monthly service provider fee they should only be used when it is extremely convenient and inexpensive to do so. In all cases, a battery backup should be utilized to operate the system during power outages.

4.3 Test System Description

The test period was divided into two segments, each test time segment was used to evaluate a different hardware and camera configuration. Each installation was mounted on standard luminaire poles near the same intersection. These cameras were deployed to monitor the same intersection; this provided a more accurate comparison of each camera's quality. Each configuration test was scheduled for approximately one month.

4.3.1 Test Configuration #1

The first configuration was installed on August 9-10, 2005 with the help of Nebraska Department of Roads (NDOR) District 6 in North Platte, Nebraska. This installation is wireless and self-contained, using Ethernet radio modems for communication and a combination of a solar panel and a NiMH battery for system power. The two cameras featured on this installation are the Stardot Netcam standard model and the Vivotek IP 2111.

A NEMA 4 enclosure houses and protects communication and power hardware. This hardware includes a remote power switch, Ethernet radio modem, Ethernet switch, and a NiMH battery with a built-in charge controller. Images may be viewed by typing in the appropriate URL into an Internet browser. The system was able to be activated and deactivated remotely with ease, allowing power to be saved when no surveillance is required.

Camera images were transmitted over a secured wireless and wired medium. The wireless transmission was encrypted by the radio modems. Wired transmission was protected by a private network and accessed using a password with a Virtual Private Network (VPN) connection. Therefore, only users with the appropriate password could view the camera images or turn the system on or off.

Figure 2 – Test Configuration #1 2 shows the completed installation on a luminaire pole. Pictured below in Figures 3 and Figure 4 are inside views of the NEMA 4 enclosure (with and without the battery). Figure 5 shows the completed installation location. Testing for this installation started on August 15, 2005 and concluded October 14, 2005.

Figure 2 – Test Configuration #1

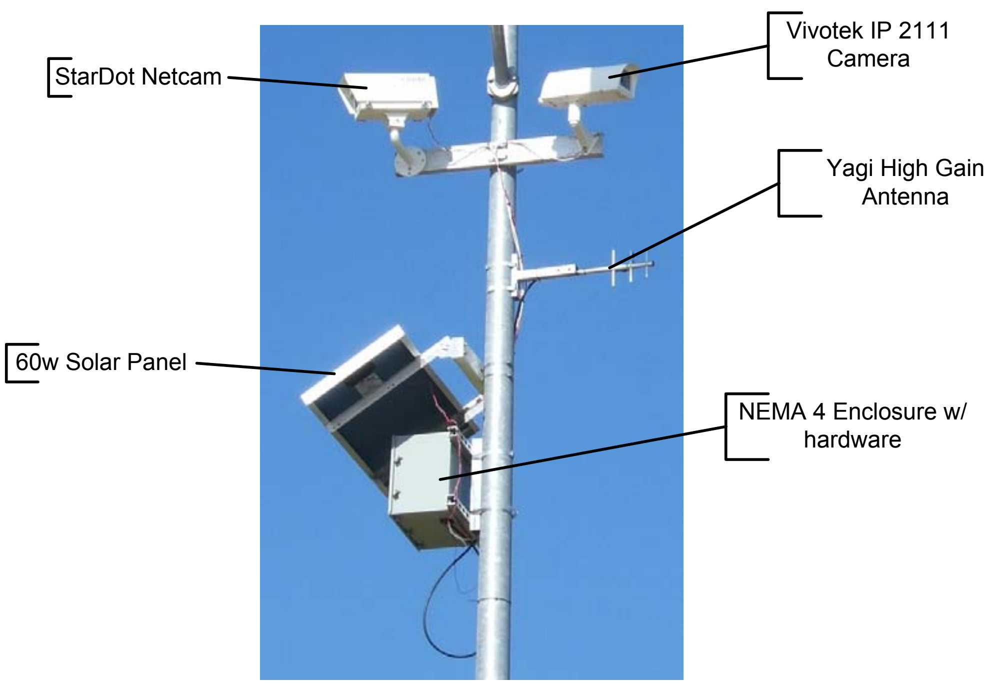


Figure 3 – Test Configuration #1 Hardware

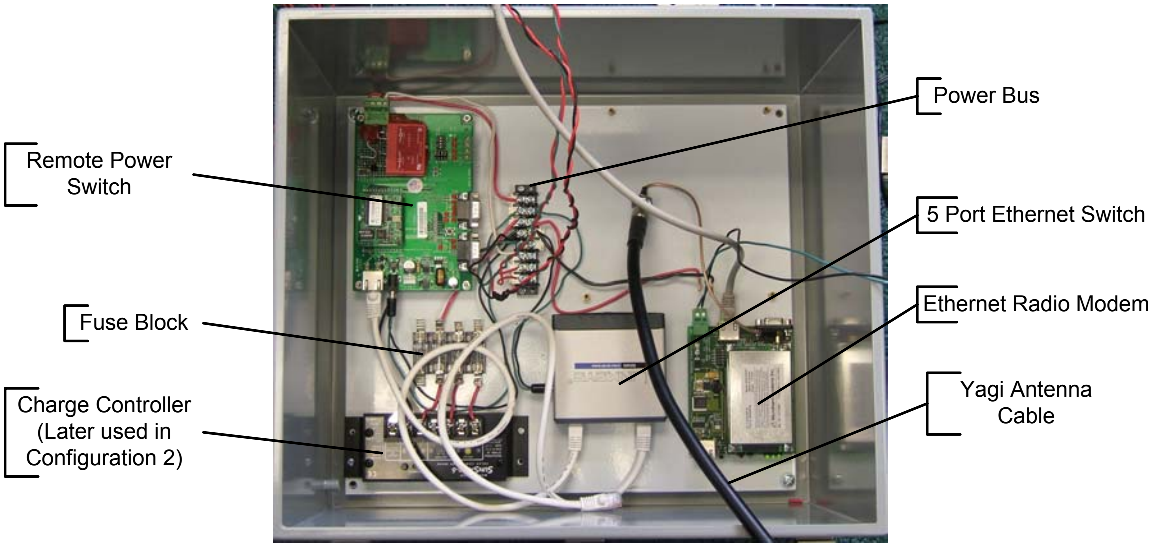
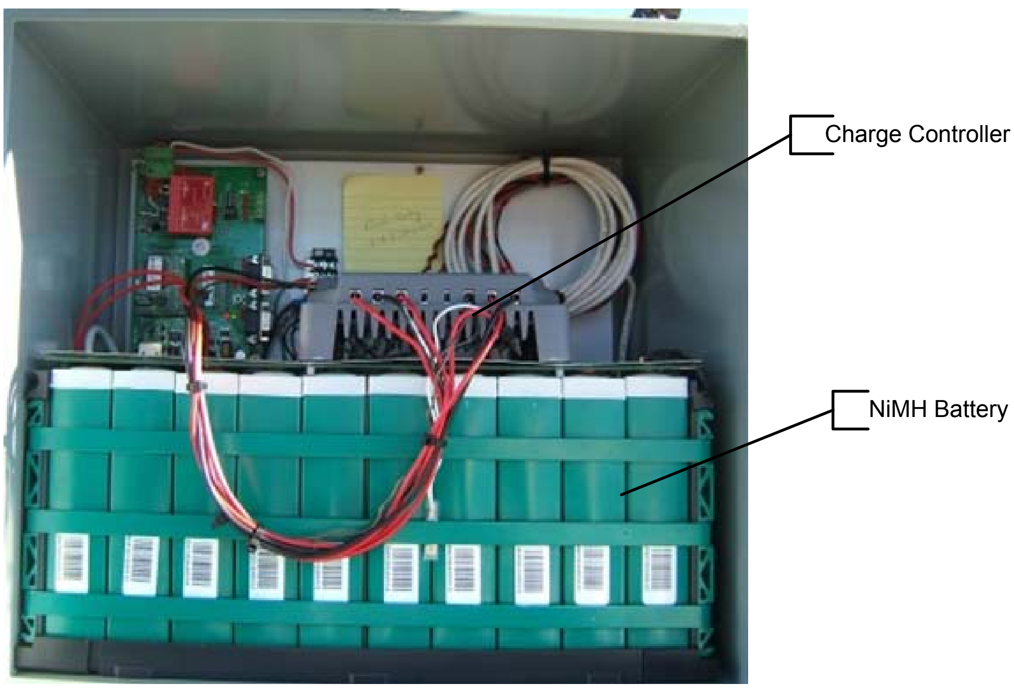


Figure 4 – Test Configuration #1 NEMA 4 Cabinet with NiMH Battery and Built-In Charge Controller



4.3.2 Test Configuration #2

The second configuration was installed on September 26, 2005. This configuration consists of two Logitech Quickcam 4000 Pro web cams controlled by a computer motherboard using a Linux operating system.

The power and communication subsystems were wireless but differ slightly from Test Configuration #1. Power was similar to Test Configuration #1, using a lead-gel battery that is recharged by a solar panel. The lead-gel battery used in this configuration did use and external charge controller. The lead-gel battery is less costly than the NiMH battery. However, it needs to be replaced every three (3) years, while the Test Configuration #1 NiMH battery will last ten (10) years.

Communications used an Alltel cellular phone with dial-up Internet access. The cellular phone used an external antenna to communicate with the cellular network.

The motherboard, fuse block, charge controller, cellular phone, and battery are all contained within the NEMA 4 cabinet.

Due to time limitations, the system could not be configured to be remotely restarted. Consequently, the system was set up to call out every five minutes and transmit the DHCP acquired address for one minute even if no data was being polled. The acquired IP address was transmitted to a pre-configured server address, so the receiving server could be used to easily view captured images. As long as new images are requested in less than 60 seconds, the connection remains active. If 60 seconds passes with no image request, the system disconnects from the cellular network and retries again once every five minutes. Figure 6 shows an outside view of Test Configuration #2.

Figure 6 gives a close-up view of the north web cam. The final installation looked similar to Test Configuration #1 (Figure 5).

Figure 5 – Test Configuration #2

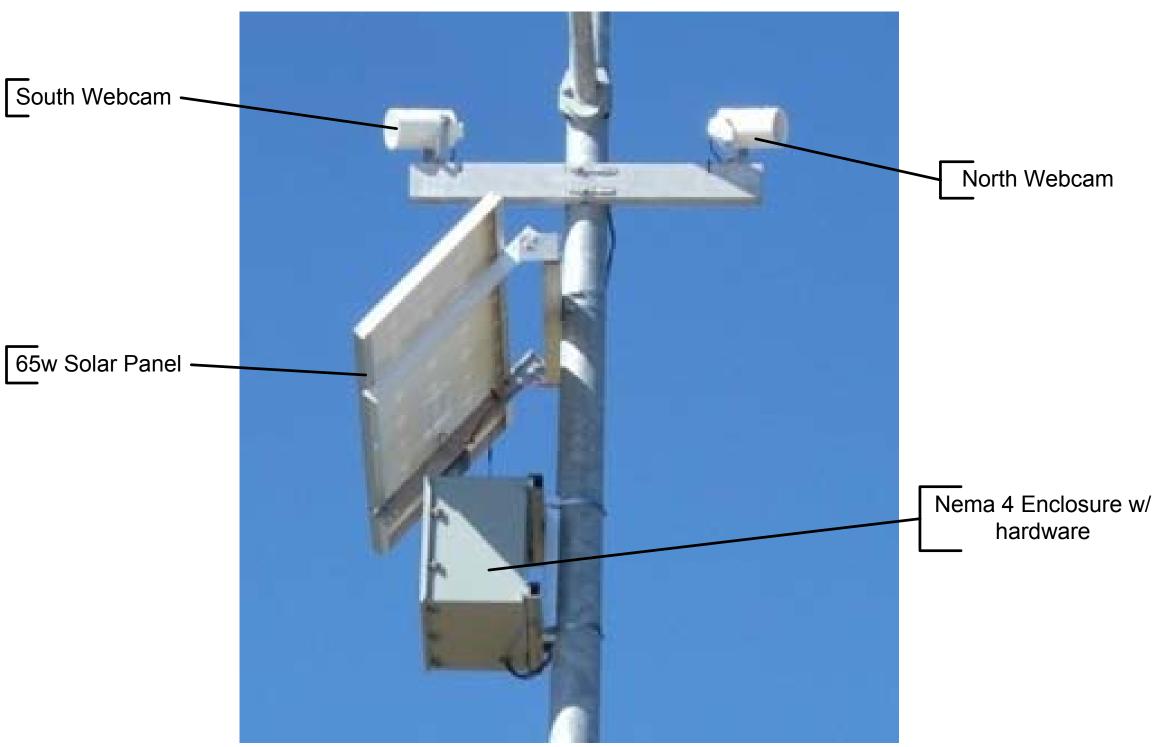


Figure 6 – Test Configuration #2 North Web Cam Close-up

4.4 Installation, Integration and Implementation Issues

This section discusses the installation, integration and implementation issues encountered with each system. By understanding these issues, future system implementers should be able to mitigate the impacts of these issues.

4.4.1 Programming

The cameras in Test Configuration #1 each contain a single purpose computer specific to their function. In that regard they are video appliances, making them plug and play.

In contrast to Test Configuration #1, Test Configuration #2 was built in house from off-the-shelf components. Test Configuration #2 also contains an embedded computer, but in this case it is a multi-purpose computer used to manage both cameras. The computer was installed with a Linux operating system, Logitech camera drivers and software to control the cameras. In addition, Test Configuration #2 was also dependent on the communication abilities of the cellular phone modem. This became a significant issue as time constraints did not allow the team to resolve communications issues between the remote switch and the USB adapter for the cellular phone.

Perhaps more importantly, Test Configuration #2 requires custom programming for each installation. This is due to differences for each vendor's cellular data network, and even differences in a single vendor's data network throughout the country. While this adds little to the hard costs unless performed by a consultant/contractor, it does add significantly to the required system setup time.

Manufacturers of this system need to be aware of these development issues when trying to produce this configuration. However, clients should not notice a difference in functionality.

4.4.2 Networking and Security Configuration

Only Test Configuration #1 was set up to operate over NDOR's network. This included determining and assigning each camera's static IP address, allowing each device to consistently be found. Network parameters were set to ensure the new hardware would be recognized and accessible. Also, a VPN was created to allow viewers outside the NDOR network firewall to access the cameras and their images. This connection provided security through password protection.

Test Configuration #2 used Alltel's cellular network and was directly accessible through the internet. The only step required was to type the appropriate address into a web browser. While this eased access, it provided no security of the captured images and left the system vulnerable to potentially malicious activity.

Both installations were configured with the network to either statically or dynamically set their IP addresses. As each network has different security settings, an on site time and resource commitment is required to integrate these capabilities within an existing network.

4.4.3 Infrastructure

NDOR's existing infrastructure eased installation of Test Configuration #1. When using Ethernet radio modems for communication, one end point Ethernet radio needs to be installed at the managing entity. The modem installed at NDOR was connected to the Internet via Ethernet cable and its Yagi antenna was connected with an antenna cable on their existing tower. Therefore, it is valuable to have a tower or pole close enough to facilitate antenna mounting; this antenna will communicate with the nearest Ethernet radio modem.

Also important for mounting the cameras and the field antenna is a pole, tower or other permanent structure at each installation. These should be roughly 5 miles apart and within line of sight. Any site that needs an installation where there is no suitable man-made structure in place will need to install one. Installing a pole for only this purpose can be very expensive.

Figure 7 – Completed Test Configuration #1

4.4.4 Hardware

Many system components come with mounting hardware, but this hardware may not always work with every type of pole or tower. Therefore, additional mounting hardware may be required. NDOR employees helped with the construction of custom mounting brackets for the NEMA 4 cases, cameras and antennas. Solar panels were the only piece of equipment that did not need additional hardware for proper installation. However, solar panels required mounting hardware to be purchased separately.

Inside the NEMA 4 case, smaller parts required mounting as well. Each piece of hardware needed to have holes drilled in order for it to be bolted to a mounting plate. The mounting plate then was attached to the back of the NEMA 4 cabinet giving the battery room to sit in front.

4.4.5 Tools

The installation, construction, and setup of these test installations require many different types of tools. Besides standard tools such as screwdrivers and drills, field installation required a bucket truck capable of hoisting two people over 30 feet. Without a bucket truck, system installation at a reasonable height would be difficult at best. Computers were also needed throughout the installation and setup process for a variety of tasks, such as programming, networking, and camera configuration.

4.5 System Testing Format

The project testing was divided into two major segments, each lasting approximately one month. During the first month of testing, starting August 15, 2005, Test Configuration #1 was evaluated. Once the system became operational, it was tested to determine operational duration on the backup battery. After the system's battery backup was depleted, tests were conducted to determine battery recharge time. Other tests were conducted concurrently with the power subsystem tests. Each day a weather log was taken and a picture from each camera was saved to evaluate system performance under various weather conditions. To verify equipment limits and failed requirements were recognized, tests were conducted through October 2005.

4.5.1 System Test Results

Each configuration was tested against the current requirements stated in sections 4.1 and 4.2. Much of the testing done was based on observing system availability when placed under certain conditions. These tests were designed to determine the limits and capabilities of the equipment.

4.5.1.1 Test Configuration #1 Test Results

This installation passed every test that it was put through while meeting almost all of the current requirements that were set for it. Each component was a point of failure that could have shut down the entire system. During this test no equipment failed and the configuration ran flawlessly. The radio modems communicated at sufficient speeds and were not greatly affected by the weather. Each camera was able to provide pictures showing roadway conditions. Appendix D shows what tests were conducted and if they passed. Appendix E shows what types of weather conditions the system had to withstand. Because the system was installed in the fall season, this test experienced a range of temperatures and weather conditions.

4.5.1.2 Test Configuration #2 Test Results

Test Configuration #2 was not as successful as Test Configuration #1. During its test, Test Configuration #2 ran for nine days before the system failed. Analysis showed the point of failure was the communication sub-system. Upon further inspection, it was determined the power subsystem was still operational. However, the cell phone had stopped dialing and signs pointed to either a firmware or data storage malfunction, or perhaps a communication subsystem malfunction. The system was manually reset but the communication subsystem would not respond. It should be noted the system stopped working during the season's first cold wave. Because the system stopped working and troubleshooting failed, some tests were unable to be completed.

One main requirement that was not met was the ability to be turned on remotely. The system was always on and had to constantly dial out regardless of information requested. Given more system development time, this issue could have been resolved. While Test Configuration #2 was communicating, it did so at a sufficient speed and was not greatly affected by the weather. Each camera was able to provide pictures showing roadway conditions. Appendix D shows what tests were conducted and whether or not they passed, while Appendix E shows what types of weather conditions the system had to withstand before it's failure. This system withstood temperatures ranging from freezing to hot and also experienced a multitude of weather conditions before shutting down.

In the course of this project, an additional consideration for Test Configuration #2 was uncovered. The project team was repeatedly advised that cellular networks were often unavailable when most needed. ITS devices controlled by a cellular communication subsystem are often unreachable during winter storms; this results from user demand exceeding the available network capacity. Because these systems are located in rural areas with normally low call volumes, it is unlikely the available cellular capacity will meet emergency-level needs. Therefore, consideration should be given to deploying an LCSRERS with a cellular communication subsystem.

4.5.2 Configuration Costs Estimates

Appendix C details the costs for each installation including recurring costs. Note that many vendors stated unit prices will drop as purchase volumes increase.

5 SYSTEM RECOMMENDATIONS

These recommendations are based not only on overall price versus performance, but which system and/or components will work best during an actual evacuation. For example, Test Configuration #2 used cellular phones and cellular phone towers to communicate. This placed a reliance on a cellular network, which is often overloaded and unavailable during emergencies; this can render a system dependent upon a cellular communication subsystem nonfunctional when most needed.

There is no single configuration that will work for every installation or situation. Factors such as time, installation and maintenance availability, capital versus recurring costs, and deployment location play a crucial role in deciding what configuration satisfies users' needs. This section will recommend configurations based on cost, setup time and existing communications.

5.1 Low Cost Recommendation (Parts of Test Configuration #1 and #2)

The lowest life-cycle cost system is a combination of both configurations. This type of configuration is also much less complicated when it comes to wiring the system because there are fewer pieces. The cameras, camera enclosures and motherboard from Test Configuration #2 are less expensive and will be used. They performed adequately and provided images with enough resolution to show roadway conditions. The radio modems from Test Configuration #1 are the least expensive solution from a life cycle perspective, as they do not have a monthly cellular service bill.

Although this configuration is the least expensive to buy, it does require more assembly time. As mentioned above, the motherboard must be loaded with an operating system and camera drivers, then programmed to broadcast to an IP address. Also, as shown by the test log, freezing temperatures may adversely impact the system. Therefore, a more robust, solid state approach should be used. This could include using a flash drive to store necessary software, as it has a wider temperature range and no moving parts.

Because this type of system requires more set up time, total costs may be less for another configuration. However, this configuration is more easily customized and can be less expensive if it can be quickly setup by an experience person. Table 16 shows the cost breakdown for this type of configuration.

5.2 Plug-and-Play Recommendation (Test Configuration #1)

Labor costs are significant and buying a low cost system may not provide the lowest actual cost. As mentioned above, the low cost recommendation requires significant setup and development time. An alternative would be to purchase Test Configuration #1 as it requires minimal setup. Further, this system has already been proven by withstanding two months of widely varying weather and passing the entire test suite, all with no additional maintenance. The cameras used for this configuration are made to plug in and immediately make images available. Configuring the cameras with the network and security features is the only setup that needs to be completed, and there are configuration options to minimize this as well. With minimal setup times and rugged, high quality, professional equipment, this configuration may be an optimal solution.

5.3 Recommendations based on existing infrastructure/conditions

In some cases the existing infrastructure (or lack thereof) can limit the system configuration options. In most cases, radio modems will be the preferred choice of communication. This is due to lower life cycle costs versus other options, coupled higher availability than cellular during actual emergencies. However, in rocky, hilly, or heavily forested areas, using a cellular network may be the only reliable wireless solution. This is one situation where cell phone communication would be preferable over radio modems. In some areas, cellular service may not be available or environmental factors may prevent consistent performance. In such cases, the other communication explored in section 2.3 may provide the only solution.

In rare instances, there may be adequate wired power and communication infrastructure to operate the system. In this case, the use of a completely wired system could be recommended provided life cycle cost analysis shows it to be a true cost savings. For such a configuration, consideration must also be given to system availability should the power and communication infrastructure fail.

APPENDIX A - SPECIFIC REQUIREMENTS

This section presents the detailed requirements for the LCSRERS and the associated institutional program necessary to achieve the needs and goals described by the LCSRERS Project Management Plan. In this section, the requirements are divided into the following:

- Functional Requirements – Lists the characteristics that the software must support for each human interface. Identifies what is to be done by the product, what inputs should be transformed to what outputs, and what specific operations are performed.
- External Interface Requirements – Details logical characteristics between the system and external data sources. Specifies any communications interfaces and protocols that should be supported.
- Performance Requirements – Specifies the capacity for information gathering, equipment capabilities, and other performance related factors.
- Design Constraints – Identifies constraints imposed by standards, regulations, or hardware limitations.
- Quality Characteristics – Provides requirements addressing the general quality, usability, extensibility, flexibility, and maintainability of the system.
- Other Requirements – Includes requirements for policies and procedures to support the implementation, operations, training, and institutional requirements to support the system.

Table 1 shows the general layout of the requirements tables and explains the purpose or content of each column of the requirements tables. The requirements in this memorandum are a subset of the requirements information that is tracked in the system "Requirements Matrix." While this document is intended to record the requirements that apply to a particular implementation of the system, the Requirements Matrix tracks all proposed requirements. The Matrix includes requirements that may apply to future system versions and those that have been deferred due to cost or complexity.

Table 2 shows an explanation of the requirement identification numbering system.

Table 1 – Explanation of the Requirements Tables

ID	Requirement	Source	Comment	Priority	Risk	Version
The requirement identifier (ID) is a unique identifier used to trace requirements from beginning to end in a system development process.	This column in the table contains the text of the actual requirement.	In this column we list the source(s) of each requirement, either by listing a reference document or identifying a "parent" requirement.	In this column we add any explanations that help elaborate on the requirement, its priority, or the risks associated with implementing the requirement.	In this column we assign a priority for each requirement: **H** – indicates that it is essential to the product, **M** – indicates that it should be implemented (budget and schedule permitting), and **L** – indicates "nice to have", but only if there is little or no cost impact.	In this column we assign a level of risk associated with implementing the requirement: **H** – indicates there could be significant cost or schedule impacts. **M** – indicates there could be some cost or schedule impacts. **L** – indicates there are no anticipated cost or schedule impacts	In this column we list the version of the software or system which will FIRST implement the required function or feature. If there are no current plans to implement the required functionality, this column may be left blank.

Table 2 – Requirement ID Format

Requirement ID Format	Explanation of Format
ABB-NNNnnn	**A – represents the classification of the requirements within the requirements document. The following classifications have been used in this requirements specification:** F - Functional Requirements (see section 3.1 of this specification) I - External Interface Requirements (see section 3.2) P - Performance Requirements (see section 3.3) D - Design Constraints (see section 3.4) Q - Quality Characteristics (see section 3.5) O - Other Requirements (see section 3.6) **BB – represents a sub-classification of the requirements within the above classifications. The following sub-classifications have been used in this requirements specification:**

(F)GF – General Functional Requirement (section 3.1)	(D)ST – Standards (section 3.4)
(F)FP – Functions and Processes (section 3.1)	(D)HW – Hardware (section 3.4)
(F)CO – Content (section 3.1)	(D)SW – Commercial off the Shelf Software (section 3.4)
(F)DA – Data Acquisition (section 3.1)	(D)PP – Processes & Procedures (section 3.4)
(F)AD – Archiving Data (section 3.1)	(D)IR – Installation Requirements (section 3.4)
(F)RE – Reporting (section 3.1)	(Q)AV- Availability (section 3.5)
(I)US – User Screen Interface (section 3.2)	(Q)SE – Security (section 3.5)
(I)PU – Public User Interface (section 3.2)	(O)AC – Accessing capabilities (section 3.6)
(I)AU – Administrative interface, Users/security (section 3.2)	(O)DE – Data Elements, records, files, relationships (section 3.6)
(I)AD – Administrative interface, Data (section 3.2)	(O)FU – Frequency of Use (section 3.6)
(I)AP – Administrative interface, Processes (section 3.2)	(O)IR – Initialization Requirements (section 3.6)
(P)HW – Hardware performance requirements (section 3.3)	(O)AY – Accuracy Required (section 3.6)
(P)DR – Data performance requirements (section 3.3)	(O)RG – Organization (static and dynamic) (section 3.6)
(P)TR – Transaction performance requirements (section 3.3)	(O)RR – Data retention Requirements (section 3.6)
(O)TI –Types of Information (section 3.6)	(O)CO – Cost Requirements (section 3.6)

NNNnnn – represents the sequence number. We usually start numbering the requirements in the 1000s, leaving room between sequence numbers to add additional related requirements when they are discovered.

Functional Requirements

This section lists the characteristics that the software must support for each human interface. It also identifies what is to be done by the product, what inputs should be transformed to what outputs, and what specific operations are required.

ID	Requirement	Source	Comment	Priority	Risk	Version
FDA-010401	Cameras shall send information as an image that is captured every few minutes.	FHWA	The video should refresh every few minutes to provide reasonably useful and updated images to maximize the number of cameras that can be deployed using the available bandwidth.	H	L	1
FDA-010402	The system shall be able to access the camera's images remotely.	FHWA	The ability to view rural roadway from very far away is the primary objective of this system.	H	L	1
FDA-010403	Sensors shall provide information about traffic speed.	FHWA	Speed is the system's main requirement for sensors, while volume and occupancy are not.	H	M	1
FDA-010404	Sensor data shall be checked by cameras monitoring the same area.	FHWA	For example, if the sensor is showing a traffic speed of zero, cameras will be able to tell whether or not there are a bunch of cars at a stand still or no cars at all.	H	M	1
FFP-010101	Data in the region shall be collected by one managing entity.	FHWA	Data should be sent to only one source to avoid confusion and redundancy, while increasing security.	H	L	1
FFP-010102	The system shall be able to be started or placed on standby remotely.	FHWA	This will preserve battery lifetime and usability during its life time.	H	M	1
FFP-010103	The system shall be able to be reset remotely.	FHWA		H	M	1
FGF-010001	Installation power shall be able to be provided by a source independent of a utility power grid.	FHWA		M	M	1
FGF-010002	Camera images shall be available at any time.	FHWA	A disaster can occur at any time. Therefore, the system must be ready to respond immediately.	H	M	1
FGF-010003	Sensor data shall be available at any time.	FHWA	A disaster can occur at any time. Therefore, the system must be ready to respond immediately.	H	M	1
FGF-010004	Over 90% of the installations shall be operational when the system is activated.	FHWA	With at least 90% of the installations working, the system will be able to give the user a good idea of what the road conditions are.	H	M	1
FGF-010005	Cameras shall be able to zoom.	FHWA	This would be a nice function to incorporate but it is not necessary.	L	M	1
FGF-010006	Installation power shall be able to be provided by a utility power grid.	FHWA		M	M	1
FGF-010007	Multiple cameras shall be able to be viewed simultaneously.	FHWA		M	M	1
FGF-010008	Multiple sensors shall be able to be read simultaneously.	FHWA		M	M	1
FGF-010009	The system shall have a 5-10 year life cycle.	FHWA	This system is made to last at least 5-10 years before needing replacement.	H	M	1

External Interface Requirements

This section covers the requirements that define logical and functional characteristics of the interfaces between the software and everything else. This includes users, the hardware the system runs on, supporting software, communications interfaces and protocols for external system interfaces.

ID	Requirement	Source	Comment	Priority	Risk	Version
IAP-020501	The managing entity shall be able to republish information through various public mediums.	FHWA	A vital part of this system is the ability to take in all the information the system displays and turn it into public information.	H	L	1
IAP-020502	The system shall incorporate a software package to help monitor and control the cameras on the system.	FHWA	There are many software packages designed to help monitor the cameras and their pictures, these can be very helpful when trying to monitor many cameras.	M	M	1
IAP-020503	The information being sent by each camera shall be viewable only by the managing entity via system network.	FHWA		H	M	1
IAP-020504	The images that IP addressable cameras post shall be on password protected HTTP or HTTPS address.	FHWA		H	M	1
IAP-020505	A central server shall be able to scan all sensors for the latest data every few minutes using the sensor's protocol.	FHWA		H	M	1
IAD-020401	Image information shall be in a standard format, such as JPEG and MJPEG, to be easily displayed and viewed.	FHWA		H	M	1
IAD-020402	Sensor vendors shall provide a NTCIP 1209 compatible protocol or publish their proprietary protocol for other vendors to use.	FHWA	This allows the system to install drivers to retrieve sensor data	H	M	1
IAU-020301	All information sent over the system network shall be password protected.	FHWA	The network will be private and therefore users will need to have the appropriate passwords to access the information being sent.	H	M	1
IPU-020201	The public shall be able to view evacuation information through public sources only.	FHWA	Information disseminated by this system will be posted to TV, web, 511 (telephone), and radio.	H	M	1

Performance Requirements

The requirements in this section specify static and dynamic capacity for the number of users, connections, and other related factors.

ID	Requirement	Source	Comment	Priority	Risk	Version
PHW-030101	Installations shall have a 2-day backup battery power supply.	FHWA	In a disaster the power may not work but the system still needs to work.	H	M	1
PHW-030102	The transmission interval for data from cameras shall be configurable to a range between 3-5 minutes or better.	FHWA	Information should be sent with little delay every 3-5 minutes for the quickest reaction from users.	M	M	1
PHW-030103	Batteries powering the cameras shall be able to be charged by auxiliary power sources.	FHWA		M	H	1
PHW-030104	Traffic sensor data shall be polled every 3-5 minutes.	FHWA	Sensors will assist with monitoring the evacuation status in-between cameras	H	M	1
PHW-030105	Cameras shall record images at a resolution 640 x 480 pixels or greater.	FHWA	It is important for the images to be very clear.	H	M	1
PHW-030106	Cameras shall consume no more than 3 watts.	FHWA	Lower power consumption increases battery run time.	H	M	1
PHW-030107	Cameras shall able to zoom 10X or greater.	FHWA	Zoom may not be necessary but will help the camera get a better view of the road it is monitoring.	L	M	1
PHW-030108	Cameras shall able withstand temperatures of -20F to 125F.	FHWA	The cameras need to be able to function in a broad range of temperatures.	H	M	1
PHW-030109	Sensors shall able withstand temperatures of -20F to 125F.	FHWA	The sensors need to be able to function in a broad range of temperatures.	H	M	1
PHW-030110	Camera enclosures and mounting hardware shall be able to withstand sustained winds of 40 mph and gusts of 80 mph.	FHWA	The cameras must be able to withstand high winds because they are most likely to be used during hurricanes and other severe storms.	H	M	1
PHW-030111	Sensors and mounting hardware shall be able to withstand sustained winds of 40 mph and gusts of 80 mph.	FHWA	The sensors must be able to withstand high winds because they are most likely to be used during hurricanes and other severe storms.	H	M	1
PHW-030112	Camera enclosures and mounting hardware shall be weather proof.	FHWA	Enclosures should conform to a NEMA-4 or other similar weather proofing standards.	H	M	1
PHW-030113	Sensors and mounting hardware shall be weather proof.	FHWA	Enclosures should conform to a NEMA-4 or other similar weather proofing standard.	H	M	1
PHW-030114	Service poles shall be able to withstand sustained winds of 40 mph and gusts of 80 mph with less then a 5 degree shift in position.	FHWA	Camera enclosures cannot be allowed to move a great deal or the pictures taken will be out of focus.	H	M	1
PHW-030115	Camera enclosures shall be locked to withstand theft attempts.	FHWA		H	M	1
PHW-030116	Sensor enclosures shall be locked to withstand theft attempts.	FHWA		H	M	1
PDR-030101	Transmission delays shall not exceed 20 seconds if cameras are fixed.	FHWA	The system is designed to use a low amount of bandwidth and therefore the delay of information being sent should be low.	M	M	1
PDR-030102	Transmission and camera control delays shall not exceed 1 second if PTZ cameras are used.	FHWA	There should be no delay when moving PTZ cameras otherwise they become very difficult to control.	H	H	1

Design Constraints

The requirements in this section specify constraints imposed by standards, regulations, or hardware limitations.

ID	Requirement	Source	Comment	Priority	Risk	Version
DHW-040201	Cameras shall be non intrusive.	PMP – Section 5.1	The cameras should occupy a space not larger than 3 cubic feet.	M	L	1
DHW-040202	Sensors shall be non intrusive.	PMP – Section 5.1	Sensor should occupy a space not larger than 3 cubic feet.	M	L	1
DHW-040203	Hardware shall be non intrusive.	PMP – Section 5.1	The Hardware should occupy a space not larger than 5 cubic feet.	M	L	1
DHW-040204	The mounting system for all cameras shall be the same model when possible.	FHWA	Similar hardware increases the interoperability and interchangeability of the system.	H	M	1
DHW-040205	The mounting system for all sensors shall be the same model when possible	FHWA	Similar hardware increases the interoperability and interchangeability of the system.	H	M	1
DHW-040206	The protective enclosures shall be to same for every camera when possible.	FHWA	Similar hardware increases the interoperability and interchangeability of the system.	H	M	1
DHW-040207	Cameras shall be the same model whenever possible.	FHWA	Similar hardware increases the interoperability and interchangeability of the system.	H	M	1
DHW-040208	Sensors shall be the same model whenever possible.	FHWA	Similar hardware increases the interoperability and interchangeability of the system.	H	M	1
DHW-040209	Batteries for each installation will be the same model whenever possible.	FHWA	Similar hardware increases the interoperability and interchangeability of the system.	H	M	1
DHW-040210	Poles for the installations shall be the same whenever possible.	FHWA	Similar hardware increases the interoperability and interchangeability of the system.	H	M	1
DHW-040211	The system may use any combination of wired and wireless connections.	FHWA		H	M	1
DHW-040212	Solar panels shall be used to recharge batteries and power the system.	FHWA		M	M	1
DHW-040213	Cameras shall have highly protective and weather resistant cases when needed.	PMP – Section 5.1	Since this system will be outside and will need to be protected from the elements.	H	M	1
DHW-040214	Sensors shall have highly protective and weather resistant cases when needed.	PMP – Section 5.1	Since this system will be outside and will need to be protected from the elements.	H	M	1
DHW-040215	Camera enclosures shall have the option of having heaters.	FHWA	Without a heater the camera may not function in cold weather situations.	M	M	1
DHW-040216	Cameras shall face both directions of travel.	FHWA	This will allow both directions of traffic to be monitored.	H	L	1
DHW-040217	Mounting poles shall be tall enough to get a good view of the road and be able to transmit data.	FHWA	The places cameras are mounted must be high enough to not be blocked by any obstacles when viewing the road.	H	M	1

ID	Requirement	Source	Comment	Priority	Risk	Version
DHW-040218	If the installation is wireless, information shall be relayed through the system by Ethernet Radio Modems going into a fiber cable or being directly sent to the receiving entity wirelessly.	FHWA	To make the system easy to update, cameras need to be a short distance from each other but can be placed anywhere within range.	M	L	1
DHW-040219	All units shall use an Ethernet switch into which both cameras will be plugged.	FHWA	When there is more than one camera on the system they need a network switch to control sending and receiving information.	H	M	1
DHW-040220	All wired units shall have a modem to convert data.	FHWA	Wired units will need a modem to convert the Ethernet cameras to the data phone lines can transmit.	H	M	1
DHW-040221	Sensors shall be the same model when possible.	FHWA	Similar hardware increases the interoperability and interchangeability of the system.	H	M	1
DHW-040222	Sensors shall cover both directions of travel.	FHWA	There will be a sensor for both directions of travel.	H	M	1
DIR-040501	Installations on the system shall be in a fixed location when possible.	FHWA	There will not be time to move cameras to a different route in an emergency.	M	M	1
DIR-040502	Installations shall be placed every 2 – 10 miles on evacuation routes.	PMP – 8	The goal is to have dense coverage over a large area.	H	M	1
DIR-040503	Sensors shall be placed close to cameras at each installation.	FHWA	This way the cameras and sensors can share power and communications.	H	M	1
DIR-040504	The system shall have the option of placing up to 4 cameras at designated intersections.	FHWA	This way the system will be able to monitor important intersecting roads.	M	M	1
DIR-040505	The system shall have the option of placing up to 4 sensors at designated intersections.	FHWA	This way the system will be able to monitor important intersecting roads.	M	M	1
DIR-040506	Installations shall be placed on pre-existing stands when possible. (i.e. telephone poles).	FHWA	This helps reduce cost to the system by using existing structures.	H	L	1
DIR-040507	Physical installation of the system shall not take any longer than one week.	FHWA		M	L	1

Quality Characteristics

The requirements in this section address the general quality, usability, extensibility, flexibility, and maintainability of the system.

ID	Requirement	Source	Comment	Priority	Risk	Version
QAV-050101	Cameras shall be low cost.	FHWA	Many cameras will need to be installed and therefore they must not be too expensive.	H	L	1
QAV-050102	Sensors shall be low cost.	FHWA	Many sensors will need to be installed and therefore they must not be too expensive.	H	L	1
QAV-050103	Cameras shall provide useful information independent of the lighting conditions.	FHWA	The system will still work when it is dark outside because they can see headlights and taillights of cars.	H	L	1
QAV-050104	Sensor shall provide useful information independent of the lighting conditions.	FHWA		H	L	1
QAV-050105	The system shall be secure.	FHWA	All information transmitted will be passed through a secure channel that only appropriate personnel can access.	H	M	1
QAV-050106	The system design shall be flexible.	FHWA	This system is designed to be used in many different placed across the country.	H	M	1
QAV-050107	The system shall be reliable.	FHWA	When the system is turned on it is expected that greater than 90% of the installations will be fully functional.	H	M	1
QAV-050109	The system shall be testable.	FHWA	To test the system, turn it on and images and sensor data should be sent back in a 3-5 minutes.	H	M	1
QAV-050110	The system shall be easy to maintain.	FHWA	The batteries are solar powered, the cases are weather proof, the cameras use low amounts of power and the system is seldom used. This means after installation and setup the system should be able run for a very long time with very little maintenance.	H	M	1
QAV-050111	The data shall be accurate and the picture will be clear.	FHWA	If the data is not reliable then the system is useless. Images will use a good resolution that is clean but does not make the data too big.	H	L	1
QSE-050201	The network shall be private.	FHWA	The network will be private because there may be images that the public should not see.	H	L	1
QSE-050202	There shall be little maintenance required after installation.	FHWA	The cameras should be ready to work as soon as they are installed with little upkeep for many years.	H	M	1
QSE-050203	Cameras, with appropriate enclosures, shall be able to resist most types of severe weather.	FHWA	This system will be turned on in severe weather conditions; therefore it is imperative that it can function in almost all weather.	H	L	1
QSE-050204	Sensors, with appropriate enclosures, shall be able to resist most types of severe weather.	FHWA	This system is will be turned on in severe weather conditions; therefore it is imperative that it can function in almost all weather.	H	L	1
QSE-050205	Equipment shall be secured against theft.	FHWA	This system is going to be out in the open and subject to theft therefore it must be physically protected by locking mechanisms.	H	L	1

Other Requirements

This section includes requirements for policies and procedures to support the implementation, operations, training, and institutional requirements to support the system.

ID	Requirement	Source	Comment	Priority	Risk	Version
OCO-060801	Each wireless Camera unit shall cost less than $1000.	FHWA	Each camera unit must be as inexpensive as possible to maximize the number of them that can be deployed.	H	H	1
OCO-060802	Each wired unit shall cost less than $1000.	FHWA	Each camera unit must be as inexpensive as possible to maximize the number of them that can be deployed.	H	H	1
OTI-060901	Training of system administrators shall take no more than 20 hours.	FHWA	This system is fairly simple and should not have an extensive training period.	H	L	1
OTI-060902	Training of system operators shall take no more than 15 hours.	FHWA	This system is fairly simple and should not have an extensive training period.	H	L	1
OTI-060903	There shall be no training for the general public to be able to receive the information.	FHWA	The job of the system operators is to push information to the public; therefore they should be able to easily access it.	H	L	1
OTI-060904	Every year there shall be a refresher course on how to operate the system.	FHWA	Evacuations do not happen frequently, therefore is it important that people do not forget how to use the system.	H	L	1
OTI-060905	The public shall be notified regularly on how/where the information will be displayed.	FHWA	The public will need to know how to access information during an evacuation ahead of time.	H	L	1

APPENDIX B - INDIVIDUAL METHOD COST ANALYSIS

The Low-Cost Rural Evacuation system can be separated into four modules for equipment cost analysis. The four modules are: power, camera control, communication, and infrastructure. Each module can be configured with different options that affect both their cost and function.

A modular approach helps to simplify and group important factors together. The module configurations can then be compared against overall system requirements and assembled to meet the project goals. This also simplifies the calculation of per-unit cost, followed by overall project cost when the number of units is known.

The system equipment, maintenance, and monthly power and communication fees—if applicable—are fixed recurring costs. The initial deployment labor expense is the variable cost for the project. The goal of this appendix is to give the readers easily interpreted configuration and cost information so they may determine project expectations for themselves.

There are two configuration options for the power module, two for the camera control module, three options for the communication module, and two options for the infrastructure module. This represents twelve possible configuration combinations—excluding the infrastructure module. The infrastructure module is excluded to reduce the number of configurations and it also has a small impact to the per-unit cost of approximately $100. In this appendix, eleven of twelve configurations are presented. Although it is possible to have a situation where wired communication is available and wired power is not, this 12^{th} case is rare and therefore not presented.

The power and infrastructure modules each contain a component that is present regardless of the configuration chosen. To meet continuous operation requirements, the power module should always contain a rechargeable battery for this analysis regardless of the implementation; it is included in the cost analysis to emphasize capital costs. Likewise, the infrastructure module always contains an elevated equipment mounting point such as a utility pole, bridge, or other accessible structure. Such infrastructure is extremely variable and may be already installed so it is not included in the analysis.

Commercial or independent solar power were the options considered for the power module. The camera control module can have a single video processor for multiple cameras at one location, or one video processor for each camera. The communication module can use directly wired, spread-spectrum packet radio, or cell tower data transmission. Infrastructure module options are the construction materials for the cabinet that houses the other components, and are excluded from this analysis due to minimal impact to the per-unit cost and for simplification.

Each configuration is labeled with the selected options for each module and the estimated cost of that configuration. That information is followed by a table that lists the equipment, the equipment purpose, and estimated cost for that particular configuration in USD.

Table 3 – Commercial power, separate camera control, wired communication

Module	Equipment	Quantity	$ Each	Total $
Power	12 gauge electric cable	500 ft	3 / ft	1500
Power	AC-DC power supply	1	100	100
Power	DC power bus	1	100	100
Power	Battery charger	1	200	200
Power	Rechargeable battery	1	500	500
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	500	1000
Control	Camera enclosure	2	220	440
Communication	Ethernet cable	500 ft	3 / ft	1500
Communication	Ethernet switch	1	100	100
			Total Cost:	$5490

Table 4 – Commercial power, separate camera control, packet radio communication

Module	**Equipment**	**Quantity**	**$ Each**	**Total $**
Power	12 gauge electric cable	500 ft	3 / ft	1500
Power	AC-DC power supply	1	100	100
Power	DC power bus	1	100	100
Power	Battery charger	1	200	200
Power	Rechargeable battery	1	500	500
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	500	1000
Communication	Ethernet switch	1	100	100
Communication	Ethernet cable	500 ft	3 / ft	1500
Communication	Packet radio modem	1	1000	1000
Communication	Packet radio antenna	1	250	250
			Total Cost:	$6300

Table 5 – Commercial power, separate camera control, cell tower communication

Module	Equipment	Quantity	$ Each	Total $
Power	12 gauge electric cable	500 ft	3 / ft	1500
Power	AC-DC power supply	1	100	100
Power	DC power bus	1	100	100
Power	Battery charger	1	200	200
Power	Rechargeable battery	1	500	500
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	500	1000
Control	Camera enclosure	2	220	440
Communication	Cell Phone Modem	2	400	800
			Total Cost:	$4690

Table 6 – Commercial power, shared camera control, wired communication

Module	Equipment	Quantity	$ Each	Total $
Power	12 gauge electric cable	500 ft	3 / ft	1500
Power	AC-DC power supply	1	100	100
Power	DC power bus	1	100	100
Power	Battery charger	1	200	200
Power	Rechargeable battery	1	500	500
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	60	120
Control	Single-board computer	1	350	350
Communication	Ethernet cable	500 ft	3 / ft	1500
			Total Cost:	$4420

Table 7 – Commercial power, shared camera control, packet radio communication

Module	Equipment	Quantity	$ Each	Total $
Power	12 gauge electric cable	500 ft	3 / ft	1500
Power	AC-DC power supply	1	100	100
Power	DC power bus	1	100	100
Power	Battery charger	1	200	200
Power	Rechargeable battery	1	500	500
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	60	120
Control	Single-board computer	1	350	350
Communication	Packet radio modem	1	1000	1000
Communication	Packet radio antenna	1	250	250
			Total Cost:	$4170

Table 8 – Commercial power, shared camera control, cell tower communication

Module	Equipment	Quantity	$ Each	Total $
Power	12 gauge electric cable	500 ft	3 / ft	1500
Power	AC-DC power supply	1	100	100
Power	DC power bus	1	100	100
Power	Battery charger	1	200	200
Power	Rechargeable battery	1	500	500
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	60	120
Control	Single-board computer	1	350	350
Communication	Cell Phone Modem	1	400	400
			Total Cost:	$3320

Table 9 – Independent power, separate camera control, wired communication

Module	Equipment	Quantity	$ Each	Total $
Power	60W solar panel w/mount	1	400	400
Power	Battery regulator	1	100	100
Power	Rechargeable battery	1	500	500
Power	DC power bus	1	100	100
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	500	1000
Control	Camera enclosure	2	220	440
Communication	Ethernet cable	500 ft	3 / ft	1500
Communication	Ethernet switch	1	100	100
			Total Cost:	$4190

Table 10 – Independent power, separate camera control, packet radio communication

Module	Equipment	Quantity	$ Each	Total $
Power	60W solar panel w/mount	1	400	400
Power	Battery regulator	1	100	100
Power	Rechargeable battery	1	500	500
Power	DC power bus	1	100	100
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	500	1000
Control	Camera enclosure	2	220	440
Communication	Ethernet switch	1	100	100
Communication	Packet radio modem	1	1000	1000
Communication	Packet radio antenna	1	250	250
			Total Cost:	$3940

Table 11 – Independent power, separate camera control, cell tower communication

Module	Equipment	Quantity	$ Each	Total $
Power	60W solar panel w/mount	1	400	400
Power	Battery regulator	1	100	100
Power	Rechargeable battery	1	500	500
Power	DC power bus	1	100	100
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	500	1000
Control	Camera enclosure	2	220	440
Communication	Cell phone modem	2	400	800
			Total Cost:	$3390

Table 12 – Independent power, shared camera control, packet radio communication

Module	Equipment	Quantity	$ Each	Total $
Power	60W solar panel w/mount	1	400	400
Power	Battery regulator	1	100	100
Power	Rechargeable battery	1	500	500
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	60	120
Control	Single-board computer	1	350	350
Communication	Packet radio modem	1	1000	1000
Communication	Packet radio antenna	1	250	250
			Total Cost:	$2770

Table 13 – Independent power, shared camera control, cell tower communication

Module	Equipment	Quantity	$ Each	Total $
Power	60W solar panel w/mount	1	400	400
Power	Battery regulator	1	100	100
Power	Rechargeable battery	1	500	500
Power	Fuse block, fuses, connectors, wiring	1	50	50
Control	Camera	2	500	1000
Control	Camera enclosure	2	220	420
Communication	Cell phone modem	1	500	1000
Communication	Ethernet switch	1	100	100
			Total Cost:	$3570

APPENDIX C - TOTAL SYSTEM COSTS

Below are the life cycle costs of each configuration, including the equipment comprising each configuration. This life cycle cost analysis is for a 10-year system life and does not include labor costs for system assembly, system installation, or system maintenance nor does it include shipping and handling for hardware purchases. The system is assumed to have 25 installations of each configuration; an installation is defined as a unit with two cameras, communication, and power. For the configuration #2 communication cost, the total recurring monthly service charge throughout the system life was estimated at $20/month. There are additional variables that may affect the pricing of each installation; therefore these numbers should be used only as an estimate.

Table 14 – Total System Costs

System Equipment	Config. #1	Config. #2	Low Cost Config.
Netcam Camera w/case	$550		
Vivotek Camera w/case	$435		
Rechargeable NiMH Battery	$1,000		$1,000
Solar Panel Mount	$87	$87	$87
60W/12V Solar System	$299	$299	$299
5 port Ethernet switch	$33		
NEMA 4 Enclosure	$129	$129	$129
900 MHz Radio	$1,158		$1,158
Yagi Antenna	$150		$150
Antenna Cables	$50		$50
Fuse Block/Fuses/Switches/Connectors/Bus	$30	$30	$30
Remote Power Switch	$200		
Misc. Cables	$29	$29	$29
Mounting Hardware	$150	$150	$150
Logitec Quickcam 4000 Pro (2)		$140	$140
Computer Motherboard		$198	$198
Cell Phone		$150	
Cell Antenna w/cable		$45	
Adapter		$10	
Compact Flash/RAM		$90	$90
Camera Case (2)		$50	$50
Rechargeable Lead-Gel Battery		$250	
Initial Cost per Installation	$4,300.00	$1,657.00	$3,560.00
Total Installation Cost	$107,500.00	$41,425.00	$89,000.00
Operating Requirements			
Battery Replacement (3 Year Life, 3 batteries needed per installation)	$0.00	$3,000.00	$0.00
Total months of cellular service needed	0	120	0
Average Cost of cell service per month per installation	N/A	$20.00	N/A
Total Communication Cost/Year	$0.00	$6,000.00	$0.00
Total Recurring Cost	$0.00	$69,000.00	$0.00
Total System Cost	$107,500.00	$110,425.00	$89,000.00

Table 15 – System Life Cycle Graph

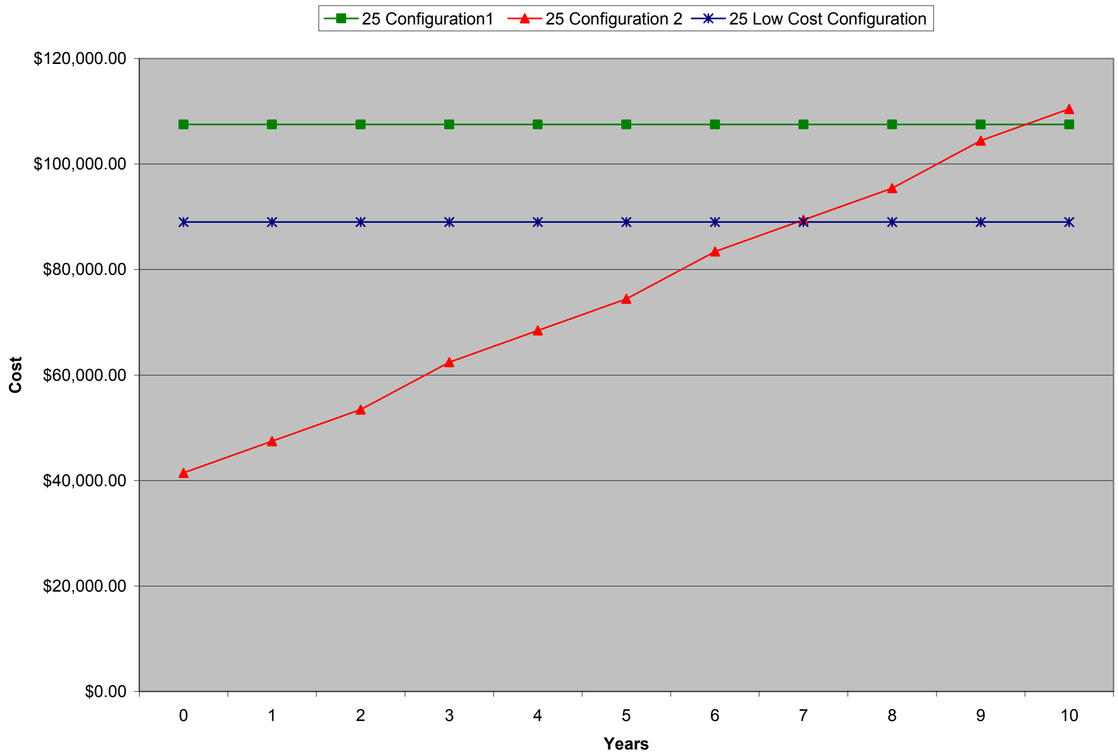


Table 16 – System Configuration Costs/Year

Cost per Year			
# Units:	25	25	25
Years	***Configuration1***	***Configuration 2***	***Low Cost Configuration***
0	$107,500.00	$41,425.00	$89,000.00
1	$0.00	$6,000.00	$0.00
2	$0.00	$6,000.00	$0.00
3	$0.00	$9,000.00	$0.00
4	$0.00	$6,000.00	$0.00
5	$0.00	$6,000.00	$0.00
6	$0.00	$9,000.00	$0.00
7	$0.00	$6,000.00	$0.00
8	$0.00	$6,000.00	$0.00
9	$0.00	$9,000.00	$0.00
10	$0.00	$6,000.00	$0.00

APPENDIX D - SYSTEM TEST LOGS

Table 17 – Test Configuration #1 System Test Log

Scenario Step Description	Test Method	Pass/ Fail	Comments
Entire Configuration			
Days the system can operate consecutively	Analysis	Pass	6 Days (8/15/05 - 8/21/05)
Run on Battery only	Analysis	Pass	36 Hours
Temperature	Analysis	Pass	High 98F Low 17F
Humidity	Analysis	Pass	0% - 100%
Wind	Analysis	Pass	45 mph Maximum
Precipitation	Analysis	Pass	Withstood 100% precipitation many times
Speed of connection	Analysis	Pass	Very good (100 kb/s) but can experience network delays
Remote Power on/off from MHI	Analysis	Pass	
Remote Power on/off from a direct connection	Analysis	Pass	
Remote Power on/off from NDOR	Analysis	Pass	
Physical Security Features	Analysis	Pass	Placed up 35ft on a light pole
Network Security Features	Analysis	Pass	Password Protected
Battery Recharge Time	Analysis	Pass	4 Days (8/22/05 - 8/26/05)
Solar Powering the system alone	Analysis	Pass	System was able to start up immediately
Vivotek Camera Tests			
Image size	Test	Pass	Non-standard aspect ratio (700 X 400)
Image quality	Test	Pass	Acceptable, lower quality then Netcam
Resistant to the elements	Test	Pass	
Daytime/Night Time Vision	Test	Pass	
Netcam Tests			
Image quality	Test	Pass	
Image size	Test	Pass	

Scenario Step Description	Test Method	Pass/ Fail	Comments
Netcam Tests (continued)			
Resistant to the elements	Test	Pass	
Daytime/Night Time Vision	Test	Pass	
Hardware Points of Failure			
5 Port Switch	Inspection	Pass	
Radio Modem	Inspection	Pass	
Battery	Inspection	Pass	
Remote Power Switch	Inspection	Pass	

Table 18 – Test Configuration #2 System Test Log

Scenario Step Description	Test Method	Pass/ Fail	Comments
Entire Configuration			
Days the system can run consecutively	Analysis	Pass	6 Days (9/29/05 - 10/4/05)
Run on Battery only	Analysis	Fail	Could not run the test due to system failure
Temperature	Analysis	Fail	High 93F Low 28F (Freezing temps cause system failure)
Humidity	Analysis	Pass	0% - 100%
Wind	Analysis	Pass	45 mph Maximum
Precipitation	Analysis	Pass	Withstood 100% precipitation
Speed of connection	Analysis	Pass	Acceptable (28 kb/s) can experience network delays
Remote Power on from MHI	Analysis	Pass	
Remote Power off from MHI	Analysis	Fail	Can't turn off remotely (was not implemented into the system)
Physical Security Features	Analysis	Pass	
Network Security Features	Analysis	Pass	
Battery Recharge Time	Analysis	Fail	Could not run the test due to system failure
Solar Powering the system alone	Analysis	Fail	Could not run the test due to system failure
Web Cameras			
Image size	Test	Pass	
Image quality	Test	Pass	
Resistant to the elements	Test	Pass	
Daytime/Nighttime Vision	Test	Pass	
Hardware Points of Failure			
Motherboard	Inspection	Pass	Possible Point of Failure
Charge Controller	Inspection	Pass	
Battery	Inspection	Pass	
Cell Phone	Inspection	Pass	Possible Point of Failure
Hard Drive	Inspection	Pass	Possible Point of Failure

APPENDIX E - DAILY WEATHER LOG SUMMARY

Table 19 – Test Configuration #1 Daily Weather Log Summary

Day #	Prevailing Weather Condition	Max Wind	Temp (min – max)	Date dd/mm/yyyy	Pass/Fail P/F	Comments
1	Clear	20 mph	52F – 81F	8/15/2005	P	System is fully operational (running constantly)
2	Clear	22 mph	54F – 84F	8/16/2005	P	System is fully operational (running constantly)
3	Light Rain/Cloudy	33 mph	61F – 85F	8/17/2005	P	System is fully operational (running constantly)
4	Clear	24 mph	53F – 89F	8/18/2005	P	System is fully operational (running constantly)
5	Light Rain/Cloudy	24 mph	64F – 86F	8/19/2005	P	System is fully operational (running constantly)
6	Clear	14 mph	57F – 88F	8/20/2005	P	System is fully operational (running constantly)
7	Fog/Mist/Partly Cloudy	22 mph	63F – 90F	8/21/2005	P	System battery discharged (system shut down)
8	Overcast	24 mph	58F – 77F	8/22/2005	P	System is Recharging (can be checked)
9	Overcast	24 mph	59F – 78F	8/23/2005	P	System is Recharging (can be checked)
10	Mostly Cloudy	24 mph	59F – 86F	8/24/2005	P	System is Recharging (can be checked)
11	Overcast	30 mph	68F – 82F	8/25/2005	P	System is Recharging (can be checked)
12	Clear	17 mph	57F – 82F	8/26/2005	P	System is Recharging (can be checked)
13	Clear	13 mph	57F – 92F	8/27/2005	P	System running, network is running slowly
14	Clear	39 mph	56F – 92F	8/28/2005	P	System is fully operational
15	Clear	17 mph	49F – 89F	8/29/2005	P	System is fully operational
16	Clear	24 mph	54F – 93F	8/30/2005	P	System is fully operational (No Solar power @ 9am)
17	Clear	39 mph	47F – 89F	8/31/2005	P	System is fully operational (No Solar power)
18	Clear	20 mph	41F – 83F	9/1/2005	F	System is down (Battery discharged @ 6am)
19	Scattered Clouds	26 mph	53F – 87F	9/2/2005	P	System is working/charging (Solar panel reconnected)

Day #	***Prevailing Weather Condition***	***Max Wind***	***Temp (min – max)***	***Date dd/mm/yyyy***	***Pass/Fail P/F***	***Comments***
20	Clear	28 mph	60F – 92F	9/3/2005	P	System is fully operational
21	Clear	30 mph	65F – 94F	9/4/2005	P	System is fully operational
22	Clear	25 mph	63 – 92F	9/5/2005	P	System is fully operational
23	Clear/Light Rain	23 mph	56F – 82F	9/6/2005	P	System is fully operational
24	Overcast	21 mph	65F – 85F	9/7/2005	P	System is fully operational
25	Mostly Cloudy	20 mph	56F – 92F	9/8/2005	P	System is fully operational
26	Clear	37 mph	60F – 93F	9/9/2005	P	System is fully operational
27	Clear	30 mph	67F – 92F	9/10/2005	P	System is fully operational
28	Partly Cloudy	40 mph	67F – 95F	9/11/2005	P	System is fully operational
29	Clear	30 mph	56F – 86F	9/12/2005	P	System is fully operational
30	Mostly Cloudy	25 mph	52F – 74F	9/13/2005	P	System is fully operational
31	Clear	18 mph	45F – 77F	9/14/2005	P	System is fully operational
32	Clear	18 mph	44F – 80F	9/15/2005	P	System is fully operational
33	Clear	37 mph	54F – 85F	9/16/2005	P	System is fully operational
34	Clear	24 mph	56F – 909F	9/17/2005	P	System is fully operational
35	Overcast	24 mph	54F – 72F	9/18/2005	P	System is fully operational
36	Partly Cloudy	21 mph	55F – 82F	9/19/2005	P	System is fully operational
37	Clear	28 mph	48F – 95F	9/20/2005	P	System is fully operational
38	Clear	35 mph	56F – 98F	9/21/2005	P	System is fully operational
39	Light Rain/Cloudy	24 mph	48F – 72F	9/22/2005	P	System is fully operational
40	Mostly Cloudy	26 mph	46F – 79F	9/23/2005	P	System is fully operational
41	Overcast	29 mph	57F – 85F	9/24/2005	P	System is fully operational

Day #	Prevailing Weather Condition	Max Wind	Temp (min – max)	Date dd/mm/yyyy	Pass/Fail P/F	Comments
42	Overcast/Light Rain	30 mph	48F – 58F	9/25/2005	P	System is fully operational
43	Clear	15 mph	38F – 76F	9/26/2005	P	System is fully operational
44	Clear	45 mph	48F – 93F	9/27/2005	P	System is fully operational
45	Overcast	44 mph	32F – 72F	9/28/2005	P	System is fully operational
46	Clear	29 mph	28F – 73F	9/29/2005	P	System is fully operational
47	Fog/Clear	14 mph	34F – 87F	9/30/2005	P	System is fully operational
48	Clear	22 mph	39F – 87F	10/1/2005	P	System is fully operational
49	Fog/Overcast	17 mph	53F – 91F	10/2/2005	P	System is fully operational
50	Clear	30 mph	51F – 83F	10/3/2005	P	System is fully operational
51	Mostly Cloudy	30 mph	43F – 62F	10/4/2005	P	System is fully operational
52	Light Rain/Cloudy	39 mph	31F – 55F	10/5/2005	P	System is fully operational
53	Overcast	21 mph	27F – 53F	10/6/2005	P	System is fully operational
54	Clear	29 mph	17F – 64F	10/7/2005	P	System is fully operational
55	Clear	32 mph	36F – 72F	10/8/2005	P	System is fully operational
56	Overcast	24 mph	46F – 61F	10/9/2005	P	System is fully operational
57	Light Rain/Cloudy	25 mph	46F – 57F	10/10/2005	P	System is fully operational
58	Clear	7 mph	40F – 55F	10/11/2005	P	System is fully operational
59	Cloudy	16 mph	52F – 69F	10/12/2005	P	System is fully operational
60	Cloudy	13 mph	50F – 72F	10/13/2005	P	System is fully operational
61	Cloudy	10 mph	45F – 68F	10/14/2005	P	System is fully operational

Table 20 – Test Configuration #2 Daily Weather Log Summary

Day #	*Prevailing Weather Condition*	*Max Wind*	*Temp (min – max)*	*Date dd/mm/yyyy*	*Pass/Fail P/F*	*Comments*
1	Clear	45 mph	48F – 93F	9/27/2005	P	System is fully operational (running constantly)
2	Overcast	44 mph	32F – 72F	9/28/2005	P	System is fully operational (running constantly)
3	Clear	29 mph	28F – 73F	9/29/2005	P	System is fully operational (running constantly)
4	Fog/Clear	14 mph	34F – 87F	9/30/2005	P	System is fully operational (running constantly)
5	Clear	22 mph	39F – 87F	10/1/2005	P	System is fully operational (running constantly)
6	Fog/Overcast	17 mph	53F – 91F	10/2/2005	P	System is fully operational (running constantly)
7	Clear	30 mph	51F – 83F	10/3/2005	P	System is fully operational (running constantly)
8	Mostly Cloudy	30 mph	43F – 62F	10/4/2005	P	System is fully operational (running constantly)
9	Light Rain/Cloudy	39 mph	31F – 55F	10/5/2005	F	System is NOT functional
10	Overcast	21 mph	27F – 53F	10/6/2005	F	System is NOT functional
11	Clear	29 mph	17F – 64F	10/7/2005	F	System is NOT functional
12	Clear	32 mph	36F – 72F	10/8/2005	F	System is NOT functional
13	Overcast	24 mph	46F – 61F	10/9/2005	F	System is NOT functional
14	Light Rain/Cloudy	25 mph	46F – 57F	10/10/2005	F	System is NOT functional
15	Clear	15 mph	40F – 50F	10/11/2005	F	System is NOT functional
16	Cloudy	16 mph	52F – 69F	10/12/2005	F	System is NOT functional
17	Cloudy	13 mph	50F – 72F	10/13/2005	F	System is NOT functional
18	Cloudy	10 mph	45F – 68F	10/14/2005	F	System is NOT functional

APPENDIX F - SAMPLE CAMERA IMAGES

Figure 8 – Test Configuration #1 Daytime Stardot Netcam Image

Figure 9 – Test Configuration #1 Nighttime Stardot Netcam Image

Figure 10 – Test Configuration #1 Daytime Vivotek IP 2111 Image

Figure 11 – Test Configuration #1 Nighttime Vivotek IP 2111 Image

Figure 12 – Test Configuration #2 Daytime North Camera Image

(Note: The timestamp displayed is offset 12 hours)

Figure 13 – Test Configuration #2 Nighttime North Camera Image

(Note: The timestamp displayed is offset 12 hours)

Figure 14 – Test Configuration #2 Daytime South Camera Image

(Note: The timestamp displayed is offset 12 hours)

Figure 15 – Test Configuration #2 Nighttime South Camera Image

(Note: The timestamp displayed is offset 12 hours)

APPENDIX G - LIST OF VENDORS CONSULTED

The following table provides a list of all the vendors and their descriptions.

Vendor	Description
123 Security Products	This vendor sells an Everfocus Ez180 outdoor CCD camera, as well as many other products. (Website: www.123securityproducts.com)
Affordable Solar	This company provided the solar panels, charge controllers and solar mounts used in these test installations. (Website: www.affordable-solar.com)
Allternativewireless.com	Provides a headset and external antenna for the cell phone. (Website: www.allternativewireless.com)
AT&T	Provides wired and wireless cellular service for the system to send data on. (Website: www.att.com)
Autoscope	The Autoscope system provides wide area video vehicle detection by using a high performing microprocessor-based CPU with specialized image processing boards contained in either a camera, box or card format and software to analyze video images. (Website: www.autoscope.com)
Axis Communications	This company sells the AXIS 2120 Network camera. This is an IP Addressable camera with a built in web server. They also sell the 290B Outdoor housing for this camera. (Website: www.axis.com)
Beau Software	This company sells the Netcam Watcher Professional, which is designed to help with the organization of cameras on your system. (Website: www.beausoft.com)
CCTV Wholesalers	This vendor sells a 1/3" Color Sony Super HAD CCD camera. This is another CCTV camera that can be used for the system. This vendor also sells enclosures for this camera. (Website: www.cctvwholesalers.com)
CISCO	This company sells 3200 wireless and mobile routers. (Website: www.cisco.com)
Cobasys	This company custom made and produced a Nigh battery with a built-in charge controller. (Website: www.cobasys.com)
Crazy Pixels	This company sells the CamSurveillance Security Application. This program can help organize and control 50 network cameras. (Website: www.crazypixels.com)

Vendor	Description
Data-Linc Group	Data-Linc sells the SRM6210E Ethernet Radio Modem. This is a 900MHz modem that has a rated range of 20 miles. (Website: www.data-linc.com)
DSC	This company sells a DVR Surveillance Cameras, outdoor enclosures, and mounting hardware. These CCTV cameras are much less expensive than the IP Addressable cameras that are available. (Website: www.dvr-sureillance-cameras.com)
e-Automation Pro	This vendor sells an ADAM-6510 Ethernet hub. This 4 port hub is used to plug multiple cameras into a single piece of hardware, such as a radio modem. (Website: www.eautomationpro.com)
Electronic Integrated Systems Inc.	This company provides a RTMS (Remote Traffic Microwave Sensor) radar that is a low-cost, general-purpose, all-weather traffic sensor which detects presence and measures traffic parameters in multiple independent lanes. (Website: www.rtms-by-eis.com)
EZ watch store	This vendor sells outdoor, day/night, color, CCTV camera that is equipped with night vision. (Website: www.ezwatchstore.com)
Fulcrum	This company provides wireless solutions for cameras by using cellular phone services. (Website: www.fulcrummicro.com)
GMH Engineering	This company provides a DRS1000 Delta Speed Sensor which is a radar speed sensor. (Website: www.gmheng.com)
Hammond Manufacturing	This company sells a variety of NEMA type 3 and 4 enclosures that will protect the hardware for each installation. (Website: www.hammondmfg.com)
Iteris	This company sells a VH-200 Network Hub, which will take normal video feeds and converts them into Ethernet format. This hardware is essential if the system uses CCTV cameras. (Website: www.iteris.com)
iwapi Inc.	This company specializes in wireless technology and connectivity, application development, hardware development and programming. (Website: www.iwapi.com)
Kansas City Power and Light	This company provides power and gas services to the Kansas City area. (Website: www.kcpl.com)

Vendor	Description
Kantronics	This company sells a KPC-#+ which is a packet radio communicator. It is designed for dependable and versatile digital communications. (Website: www.kantronics.com)
Kintronics	This company offers SoftSite32 and NetDVR-64, each allows the user to create a complete IP Addressable surveillance system. (Website: www.kintronics.com)
LaptopsforLess.com	This company sold the 5 volt adapter used to power the cell phone. (Website: www.laptopsforless.com)
Logic Supply	This company provided the motherboard and power supply used in configuration 2. (Website: www.logicsupply.com)
Motorola	Motorola offers a wireless solution called the Canopy system. This is an ideal wireless solution for networks that are in a two mile radius and require high speed connections. (Website: www.motorola.com)
OkSolar	OkSolar offer a complete package that includes the camera, stand, enclosures, power and communications. These units are completely wireless and self sustained. (Website: www.oksolar.com)
PalmVid Video Cameras	This company offers a Wired Weatherproof Security Camera. This is a CCTV camera and has an enclosure that that is already weather proof. (Website: www.palmvid.com)
Schwartz Electro Optics	This company provides AUTOSENSE and TRAFFICSENSE units that utilize an eye safe laser to scan the roadway and objects (vehicles) passing through the sensor's beam field. (Website: www.seo.com/SEOMain.asp)
Securityideas.com	This vendor sells a Vivotek IP2111 Outdoor Package w/heater, blower and wall mount. This package includes a Vivotek IP2111 camera, TPH5000 Housing and mount, 24VAC 50VA Power supply. (Website: www.securityideas.com)
SmartSight	This company sells Ethernet Video Servers that allow for CCTV cameras to use Ethernet. (Website: www.smartsightnetworks.com)
Southwest PV Systems, Inc	This company sells independent solar power systems. They provide an all inclusive turn-key system that meets the power requirements of this system using BP solar panels. (Website: http://www.southwestpv.com)

Vendor	Description
Sprint	Provides wired and wireless cellular service for the system to send data on. (Website: www.sprint.com)
Spytown	This vendor sells camera housings and mounts at low costs. (Website: www.spytown.com)
StarDot Technologies	This company sells an IP Addressable camera called a Netcam that is very well suited for this application. They also sell an outdoor camera enclosure that comes with mounting hardware. (Website: www.stardot-tech.com)
Sumitomo Electric	This company provides an Utrasonic Vehicle Detector which is capable of detecting presence, occupancy and classification. (Website: www.sei.co.jp)
Synetcom	This company sells a 900 Mhz Ethernet Radio Modem that is can be used in wireless applications for this system. (Website: www.synetcom.com)
Thomas Computer Corporation	This company offers many different options and solutions for camera networks. They have IP Addressable cameras, wireless cellular connections, solar power, wind power and camera enclosures. (Website: www.thomascomputer.com)
Verizon	Provides wireless cellular service for the system to send data on. (Website: www.verizon.com)
Wavetronix	This company sells the NEMA rated CLICK! 600 Ethernet switch. (Website: www.wavetronix.com)
Xcel Energy	This company provides electricity and natural gas services in the Midwest area. (Website: www.xcelenergy.com)
ZipZoomFly.com	This company sells the Logitech webcams and motherboard parts used in Configuration 2. (Website: www.zipzoomfly.com)

APPENDIX H - DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

The following table provides the definitions of all terms, acronyms, and abbreviations required to properly define terms used in this design description.

TERM	DEFINITION
ATIS	Advanced Traffic Information System
BIOS	Basic Input Output System. This is used to configure the basic settings on a computer motherboard.
CCTV	Closed-Circuit Television camera with a direct connection to output on video switches.
DSL	Digital Subscriber Line – a method for moving data over regular phone lines. A DSL circuit is much faster than a regular phone connection, and the wires coming into the subscriber's premises are the same (copper) wires used for regular phone service.
Ethernet	A communications protocol that interconnects logically switched computers using the ieee-802 communications standards. Ethernet is widely used for LANS because it can network a wide variety of computers, it is not proprietary, and components are widely available from many commercial sources.
FHWA	Federal Highway Administration – the federal agency that administers federal highway programs. The agency reviews all transportation plans and transportation improvement programs to ensure compliance with federal planning and funding requirements.
GHz	Gigahertz – one billion cycles per second.
Hertz	The unit of frequency used to measure the clock rate of modern digital logic, including microprocessors in cycles per second.
Incident	Any event that is not part of the standard operation of a service and that causes, or may cause, an interruption to, or a reduction in, the quality of that service.
Installation	An installation is a completely working unit of the system and consists of cameras, power, wiring, communications, enclosures, and physical mounting.
IP	Internet Protocol – a communication method or protocol by which data is sent from one computer to another on the internet. Each computer (known as a host) on the internet has at least one IP address that uniquely identifies it from all other computers on the internet.

TERM	DEFINITION
JPEG/JPG	Compression technique for color images and photographs that balances compression against loss of detail in the image. The greater the compression, the more information is lost (this is called lossy compression).
Kb	Kilobytes – 1024 bytes.
Kb/s	Kilobits per second – one thousand bits per second.
LAN	Local area network – a communications network that serves users within a confined geographical area; it is made up of servers, workstations, a network operating system and a communications link.
LCSRERS	Low-Cost Surveillance for Rural Evacuation Route System
Meta-Data	Provides information about the content, quality, condition, and other characteristics of data (data about data).
MHI	Mixon/Hill, Inc.
MHz	Megahertz – millions of cycles per second.
NDOR	Nebraska Department of Roads
NEMA	National Electrical Manufacturers Association - an organization of electrical equipment manufacturers set up to establish uniform standards and nomenclature throughout the industry.
NiMH	Nickel medal hydride – a high energy density rechargeable battery with excellent humidity, temperature, and recharging operating properties.
NTSC	National Television Standards Committee – a group that is responsible for setting the standard for broadcast and reception of analog television signals in the United States and Japan.
POTS	Plain Old Telephone System – this is the standard telephone service that most homes use. It is also referred to as the PSTN, or the public switched telephone network.
PTZ	Pan, Tilt, Zoom – this is a motorized camera that can be dynamically repositioned to focus on points of interest.
TMC	A traffic management center is a physical location from which traffic is monitored within a designated area.
VPN	Virtual private network – describes a procedure which enables private networks to be "tunneled" via unsecured networks (which is in most cases the internet)