Final report of ITS Center project: Route 460 Wireless Network

A Research Project Report

For the Center for ITS Implementation Research

A U.S. DOT University Transportation Center

ROUTE 460 WIRELESS NETWORK

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Introduction

The Virginia Tech Transportation Institute in cooperation with VDOT's Christiansburg Residency deployed one of the first serial wireless networks in the country along Route 460 in Christiansburg and Blacksburg.

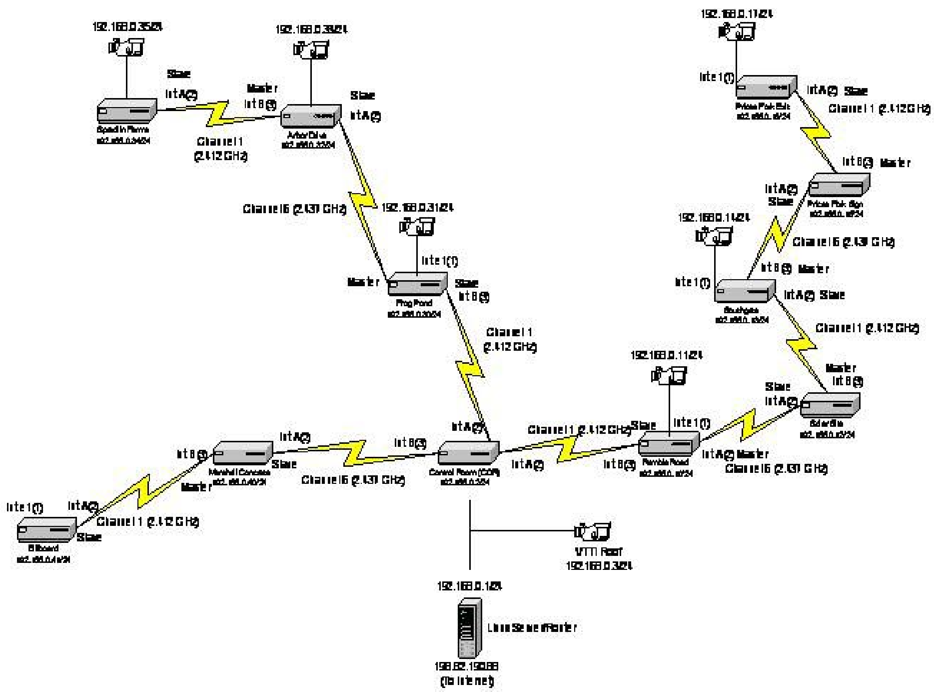


Figure 1. Schematic of Route 460 Wireless Video Network

This deployment provided the foundation for continuing research through the ITS Implementation Center. The Implementation Center project sought to investigate further the performance capabilities of wireless networks and the deployment issues that DOTs might face.

The Smart Road Reconfigurable Wireless Testbed

VTTI developed a reconfigurable wireless testbed on Virginia's Smart Road due to the difficulty of researching on a live highway such as Route 460. The Smart Road testbed allows for easy setup of a variety of wireless components such as radios and antennas. In addition, the network topography can be manipulated to evaluate different configurations.

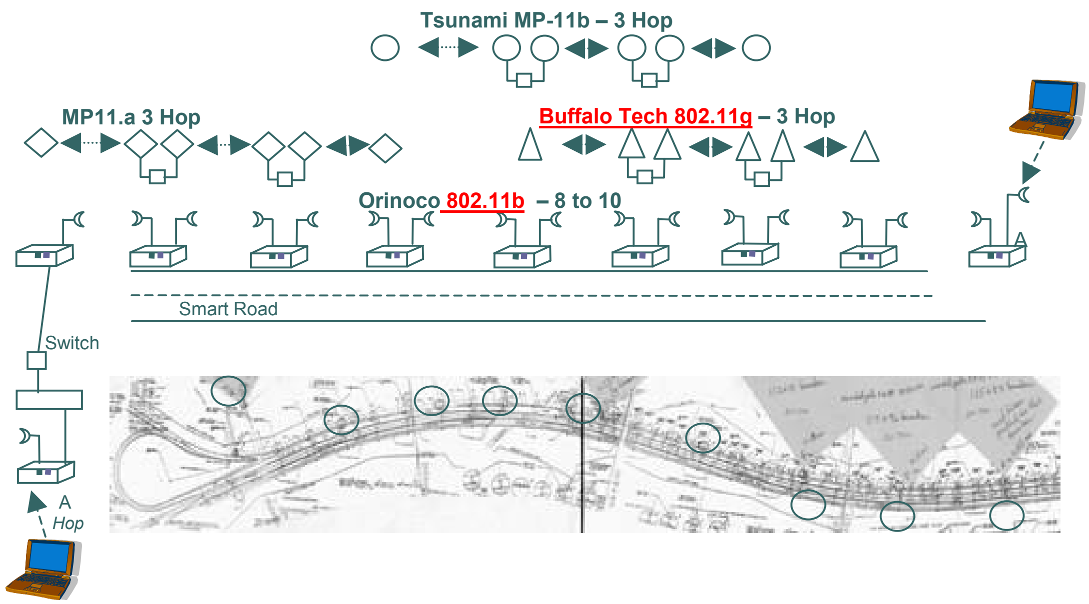


Figure 2. Schematic of Smart Road Reconfigurable Testbed

With this testbed, VTTI has been able to evaluate several different wireless technologies including, 802.11a, b, g and some proprietary products such as the Proxim Quickbridge.

This report is in two parts. The first analyses the various functional aspects involved in deploying the system. The second is a cost/benefit analysis of the 460 wireless network comparing it to more traditional communications such as fiber optics and wire line subscription services.

Part 1: Facilities Build-out

The purpose of this job analysis is to give VDOT some indication of the types of functions that are necessary to design, develop, and operate a Wireless LAN project. This analysis provides general guidance for VDOT as to what functions may be necessary to carry out such a program; through this analysis each VDOT district must determine:

1) If staff and resources are available in-house to carry out Wireless LAN design, development, and operations,
2) If training will be conducted with current staff to accomplish the new functions,
3) If new staff will be hired that can carry out the new functions, or
4) If the new functions will be contracted out.

This analysis is meant to point out the functions required to carry out a Wireless LAN project and the types of staff who may be able to accomplish the various functions. The analysis is not meant to advise VDOT on how to fulfill these functions as each district will have to consider its own unique circumstances in terms of staff and resources.

With this in mind, there were three major steps to this analysis process. The first step involved interviews with VTTI staff who are currently working on the 460 Wireless LAN project in order to determine what functions they carried out at each stage of the project (i.e., design, development, and operations). The second was to consider, based on a review of VDOT job descriptions, what types of staffing may be needed by VDOT to carry out these same functions. The final step involved the comparison of pay ranges for each position across VTTI, VDOT, and the private sector.

The result of this analysis is a series of organizational charts, one for each stage of the Wireless LAN project. For each box in an organization chart, a brief bulleted point description is provided below detailing major functions that should be carried out by each position.

The first set of organizational charts details the positions and accompanying functions that VTTI had during the design, development, and operation phases of the 460 Wireless LAN project. The actual staff that carried out each job position is also listed. The second set of organizational charts points out the job positions and functions that may be needed if VDOT were to design, develop, and operate a similar wireless program.

The final section of this analysis is the comparison of pay ranges for each job position. This information was found via coordination with human resource staff at VTTI and VDOT. Research was also conducted on the Internet to locate equivalent private-sector salary ranges. A matrix is provided at the end of this document that includes the comparison of the pay ranges for each position.

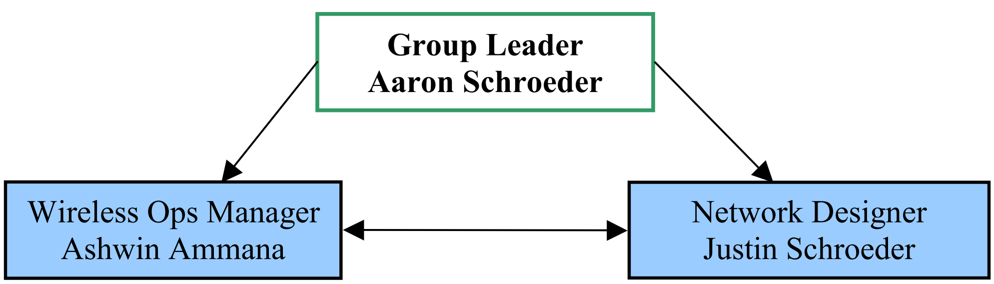
Organizational Charts

VTTI Organizational Charts

The first set of organizational charts provide an overview of the people who carried out the 460 Wireless LAN project at VTTI and their functions during the design, development, and operations phases of the project. When looking at the VTTI organizational charts, it is important to note that VTTI is a research institute and that the 460 Wireless LAN project was proposed and executed because VTTI had the staffing capabilities to do so. This is important because some of the staff performed multiple functions that would have been broken out and distributed across several people in most organizations.

Below is an organizational chart for each phase of the VTTI 460 Wireless LAN project (i.e., design, development, and operations). After each organizational chart is a list of the functions performed by each position.

Chart 1: VTTI Design Phase



Design Position Functions

Group Leader

- Defines what the wireless system needs to accomplish
- Aids in design of the wireless system
- Supervises overall wireless project design

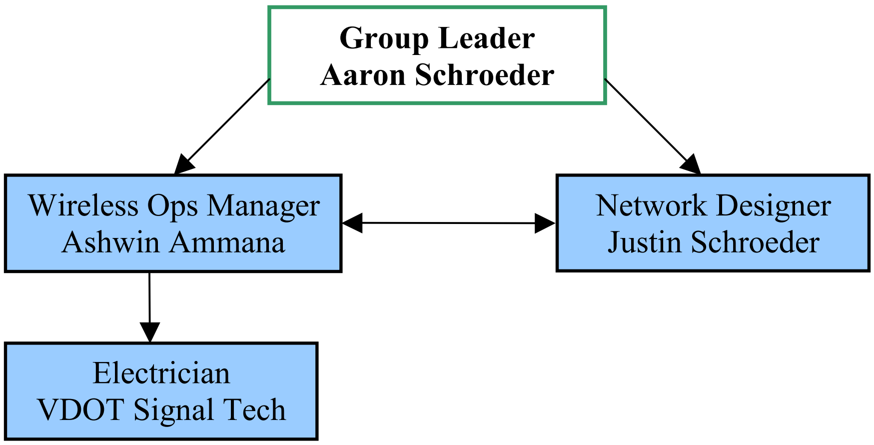
Wireless Operations Manger

- Defines what devices are needed in the system and where in the system they are to be placed (cameras, sensor, VMS, etc.)
- Details location of poles, line of sight, and identifies power sources
- Studies wireless products available and new updates
- Plans interface with user system and applies it to the design

Network Designer

- Aids the wireless operations manager in designing the system
- Determines how the wireless system will network with VTTI's system
- Designs security measures for the system
- Performs frequency allocation, network routing, and IP networking

Chart 2: VTTI Development Phase (Installation and Testing)



Development (Installation and Testing) Position Functions

Group Leader

- Supervises overall wireless project development
- Manages the use of the wireless system to meet VTTI's and VDOT's needs

Wireless Operations Manager

- Installs and tests devices to insure proper operation
- Studies wireless products available and installs new updates
- Troubleshoots devices and location problems
- Makes sure the wireless system and the network are working properly

Network Designer

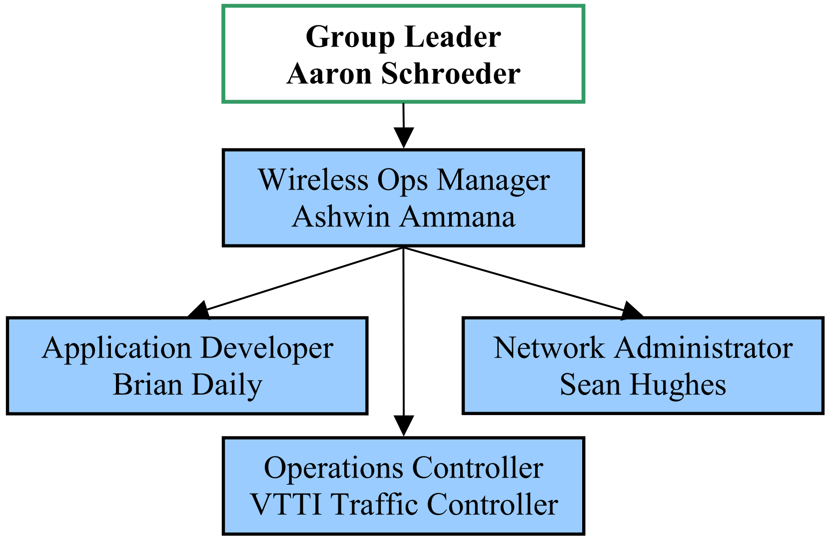
- Aids wireless operations manager in installation and testing of devices
- Interfaces system with the VTTI Internet connection
- Tests wireless system security and robustness
- Troubleshoots network problems
- Installs new software updates

Electrician

- Runs power to all locations

- Aids in installation and connection of equipment
- Operates the bucket trucks when needed
- Infrastructure installation (electronic cabinets, etc.)

Chart 3: VTTI Operations Phase



Operations Position Functions

Group Leader

- Supervises overall wireless project operations
- Manages the use of the wireless system to meet VTTI's and VDOT's needs

Wireless Operations Manager

- Studies wireless products available and installs new updates
- Maintains and troubleshoots wireless devices

Network Administrator

- Maintains and troubleshoots wireless network
- Tests wireless system for operation effectiveness, security, and robustness
- Installs software updates

Application Developer

- Rededication of content to delivery modes

Operations Controller

- Uses traffic devices (cameras, sensors, VMS, etc.) to supply information to VDOT and the public
- Alerts wireless manager to system problems beyond basic troubleshooting

Electrician/Signal Technician

- Troubleshoots devices and field problems
- Updates and installs any new equipment
- Alerts Wireless Operation Manager to problems

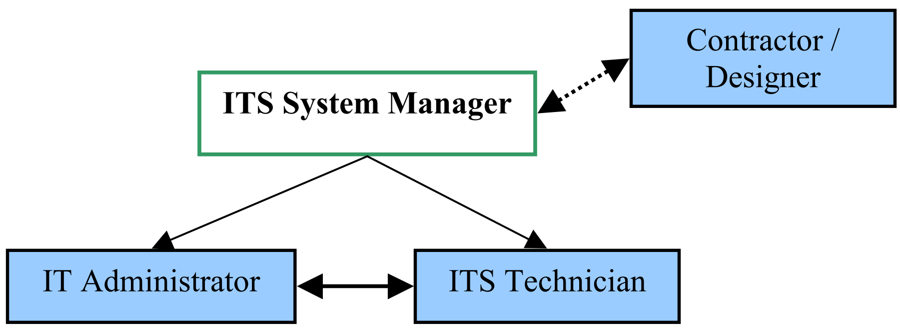
- Performs work under supervision of Wireless Operations Manager

VDOT Organizational Charts

Though the VDOT organizational charts are based on those created for VTTI, they are a bit different for several reasons. The first is that VTTI was conducting this project for research purposes: something VDOT will not be doing. The second is that VTTI had staff dedicated to this project who accomplished a variety of functions, whereas VDOT will likely have several people who will carry out these functions. VDOT may also choose to contract out some of the functions that VTTI carried out in-house.

As with the VTTI analysis, there are three sets of organizational chart, one per phases: design, development, and operations.

Chart 4: VDOT Design Phase



Design Position Functions

ITS System Manager (VDOT Role Title- Engineering Mgr I):

- Defines what the wireless systems needs to accomplish
- Supervises overall wireless project design
- Works with designer to determine what devices need to be located on the system and where (i.e., sensors, VMS, cameras, etc.)

Contractor / Designer

- Works with the ITS Manager to create a wireless design to meet VDOT's needs
- Works with the ITS Manager and ITS Technician to determine location of poles, power sources, line of sight, and devices
- Works with IT Administrator to design a system to work with VDOT's network
- Designs security measures for the system

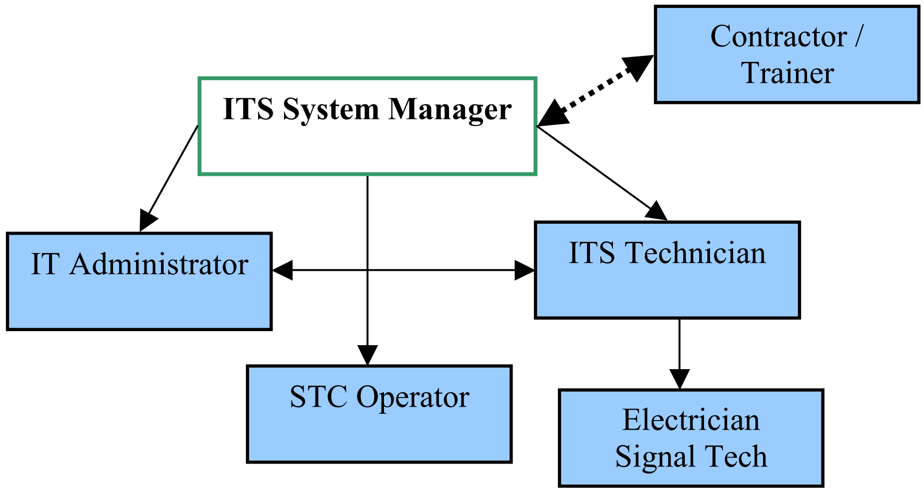
IT Administrator (VDOT Role Title- IT Specialist III):

- Works with designer to determine how the wireless network will integrate with the VDOT network

ITS Technician Supervisor (VDOT Role Title- Electronic Technician III):

• Works with designer to determine location of poles, power, and line of sight

Chart 6: VDOT Development Phase (Installation, Testing, and Training)



Development (Installation, Testing, and Training) Position Functions

ITS System Manager (VDOT Role Title- Engineering Mgr I):

- Supervises overall wireless development phase
- Manages use of devices to meet the public's and VDOT's needs
- Inspects infrastructure

Contractor / Trainer (Optional, could be performed by VDOT after training)

- Trains VDOT personnel involved with the wireless system
- May install devices and test for proper operation
- May be involved with troubleshooting
- May be involved with expansions and/or redesigns
- May test wireless system's security and robustness

IT Administrator (VDOT Role Title- IT Specialist III):

- Makes sure the network, including the wireless system, is working properly
- Troubleshoots network problems and makes sure network is secure
- Installs any new software updates
- Interfaces wireless system with VDOT's network

ITS Technician Supervisor (VDOT Role Title- Electronic Technician III):

- Works to keep all devices functioning properly
- Troubleshoots devices and location problems
- Aids in installation and testing to insure proper operation
- Inspects infrastructure

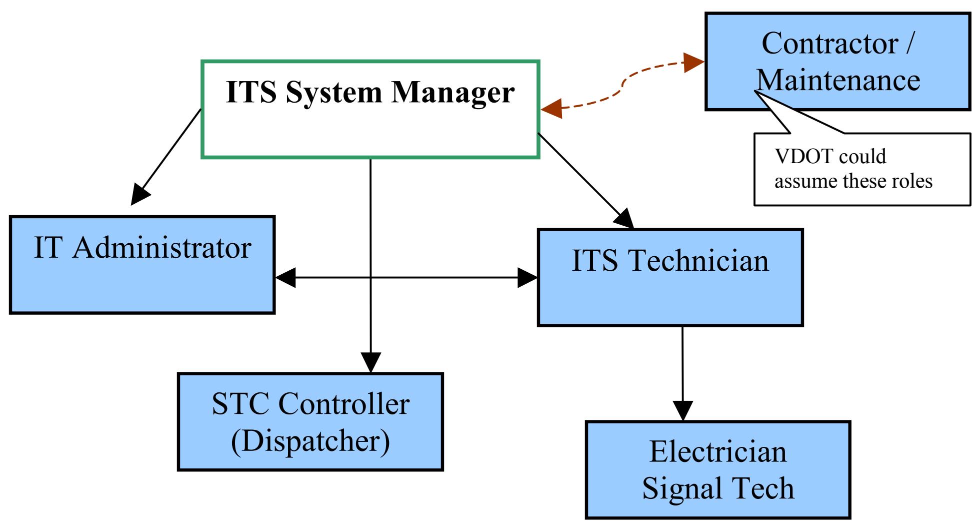
STC Controller (Dispatcher / Security Officer III):

- Uses VDOT devices to provide travel information
- Performs basic troubleshooting of network devices

Electrician / Signal Technician (VDOT Role Title- Electronic Technician I):

- Runs power to all locations
- Aids in installation, connection, and updates of equipment
- Troubleshoots devices and field problems
- Operates bucket truck if needed

Chart 6: VDOT Operations Phase



Operations Position Functions

ITS System Manager (VDOT Role Title- Engineering Mgr I):

- Supervises overall wireless system operations
- Uses devices to meet the public's and VDOT's needs

Contractor / Maintenance (Optional, could be performed by VDOT)

- Maintain wireless system including upgrades, troubleshooting, maintenance

IT Administrator (VDOT Role Title- IT Specialist III):

- Makes sure the network, including the wireless system, is working properly
- Troubleshoots network problems
- Tests wireless system for operational effectiveness, security, and robustness
- Installs any new software updates

ITS Technician Supervisor (VDOT Role Title- Electronic Technician III):

- Works to keep all devices working properly

- Troubleshoots devices and location problems

STC Controller (Dispatcher / Security Officer III):

- Uses VDOT devices (cameras, sensors, VMS, etc.) to supply information to VDOT and to provide travel information to the public
- Performs basic troubleshooting of devices
- Alerts wireless system manager to system problems beyond basic troubleshooting

Electrician / Signal Technician (VDOT Role Title- Electronic Technician I):

- Troubleshoots devices and field problems
- Updates and installs any new equipment
- Alerts ITS Manager to problems

Pay Range Comparison

The second part of this job function analysis was to consider the pay ranges of those who currently carry out the 460 Wireless LAN project and those in VDOT who may be able to carry out such a project in the future. Below is a chart matrix comparing positions capable of handling wireless LAN duties in VTTI, VDOT, and the private sector.

This chart shows the addition expenses of a Wireless LAN system if the positions are contracted out compared to an in-house operation. In general the salaries for the individuals in the private sector are significantly higher than in VDOT; therefore, money could be saved if the wireless system was developed and operated within VDOT. This does not take into account the training that might have to take place to prepare current VDOT staff to conduct these new functions.

VTTI Job Position/Pay Range	VDOT Job Position/Pay Range	Private Sector Job Position/Pay Range
Group Leader* ($59,581-$122,281)	ITS System Manager RT: Engineering Mgr I ($34,910 - $71,646)	Business Development Mgr, Sr ($86,183 - $111,520)
Wireless Operations Manager* ($45,607-$93,599)	ITS Technician Supervisor RT: Electronics Technician II ($26,722 - $54,842)	LAN Support III ($47, 837 - $63, 478)
Wireless Network Design ($34,910-$71,646)	*Contracted Out*	Information Services Consultant ($68,875 - $86,546)
Network Administrator ($34,910-$71,646)	IT Administrator RT: IT Specialist III ($45,607-$93,599)	Network Administrator Sr. ($57,474 - $72,545)
Application Developer* ($34,910-$71,646)	*Application Developer* *($20,455-41,980)*	Operating System Programmer I ($36,393 - $46,586)
Operations Controller ($20,455-41,980)	STC Operator RT: Security Officer III	*Not Applicable*

	($20,455-41,980)	
Not Applicable	Electrician (Signal Tech) RT: Electronics Technician I ($20,455 - $41,980)	Electrician ($25,556 - $34,143)

Chart Legend
RT: Role Title
*Please note that faculty at Virginia Tech do not have assigned pay bands. The ranges here are estimated on the classified pay bands, but faculty jobs may vary from this depending upon the experience, education, and skills of the faculty member.

Conclusions

This job position analysis outlined the functions VTTI carried out in the 460 Wireless LAN project (i.e., design, development, and operations) and what VDOT functions would be necessary to conduct a similar project. VTTI then reviewed job descriptions within VDOT to find positions that were capable of carrying out the same functions that had been undertaken by VTTI. From reviewing VDOT job descriptions, all positions studied have general computer knowledge requirements. However, most VDOT personnel have limited wireless knowledge. Therefore, training may be needed for VDOT personnel, depending on the position and VDOT's decision on contracting out wireless services. Where there was not position available (i.e. network designer) to handle the necessary functions VTTI listed the job position as a contractor. VTTI also considered the salary ranges of those in VTTI, VDOT, and private sector that could carry out these functions.

While this analysis is a general guide and provides some idea of who could implement a Wireless LAN project, each district will need to determine for itself whether the project is done in-house, if training is required with current staff, or if functions will be contracted out. For instance, for each phase of a Wireless LAN system, VDOT could choose to contract out the maintenance or keep the function within VDOT. The costs for contracting out would increase the costs of the system and would make VDOT rely on the contractor. Most contracts for maintenance allow a maximum of a 24-hour down period before being fixed; therefore, the cameras and other traffic devices on the wireless network could be down for hours when only a few minutes might be required for troubleshooting. Therefore, from a cost and operations standpoint, VDOT may want to consider keeping the wireless function within the organization rather then contracting the duties to the private sector. All of these decisions about contracting out or keeping work in-house will depend on VDOT's priorities, current staff, and resources.

Part 2: Evaluation

I. Introduction

The Virginia Tech Transportation Institute (VTTI) and the Virginia Department of Transportation (VDOT) have installed a wireless network data backbone communication system for assets management along a six-and-a- half-mile stretch of Highway 460 between Christiansburg and Blacksburg. Located between the Prices Fork Exit and Arbor Road on 460, the system includes six controlled cameras. This area was chosen based on the need for the cameras to observe congestion, traffic patterns, and the location of the Virginia Tech Transportation Institute. The purpose of the following cost-effectiveness analysis is to make a quantitative and qualitative comparison between the current 460 wireless technology data backbone and traditional data backbone systems that could have been chosen. The traditional configuration options that could have been chosen to be analyzed in this study include fiber-optics, DSL, T1, dialup, and ISDN. The following analysis compares the initial costs, reoccurring costs, net present costs after five years of operation, and the usability of each of the data backbone system configuration options.

II. Geographic Analysis and System Location

The current wireless data backbone system was installed by VTTI and VDOT along a six and a half mile stretch of Highway 460. The system is located between the Prices Fork exit sign, on 460 near Blacksburg, and Arbor Drive, located on 460 Business in Christiansburg. Figure 1.1 is a topographical map illustration of the current wireless backbone in Blacksburg Virginia. The area between Ramble Road and Prices Fork is mainly rural, with fields bordering Highway 460. In contrast, the area between VTTI, the County Road site, and the Arbor Road site is urban, with businesses located on both sides of the road. These geographic factors influence the feasibility of the various data backbone systems and configuration options.

Current 460 Wireless Data Backbone

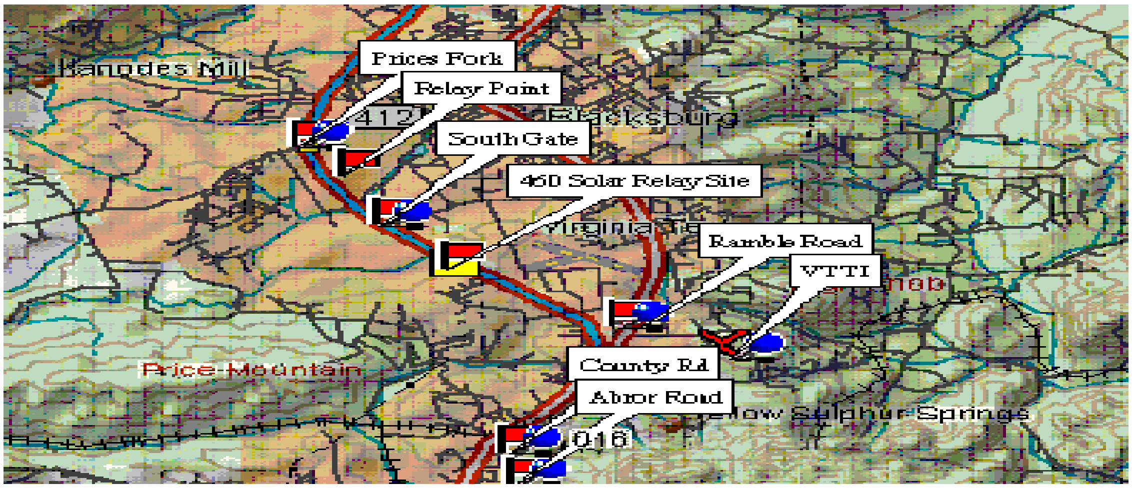


Figure 1.1

The illustration in Figure 1.1 represents the current 460 wireless data backbone with a total of eight sites. Of the eight sites, six contain cameras; these cameras are located at the Prices Fork Exit, South Gate Drive, Ramble Road, VTTI, County Road, and Arbor Drive sites. The remaining sites, 460 Solar Relay Site and the 460 Relay site, are relay points that are needed to connect the Prices Fork camera site to the wireless backbone.

III. Wireless Data Backbone (Currently Operating)

In building the system, a central outdoor router (COR) was placed on the roof of VTTI. From there, a point-to-point wireless LAN connection was established to the east and west along Highway 460. In the system, there are two relay-only sites, where remote outdoor routers (ROR) are stationed. These relay-only sites include the 460 Solar Relay Site and the Relay Point. These relay points are needed to continue the wireless system along its path to the Prices Fork camera location. At the other six sites, there are remote outdoor routers and cameras.

This point-to-point wireless backbone system provides VTTI with streaming video at a data-transfer rate of up to 11.6 Mbps. This data-transfer rate enables VTTI to control the six cameras and gives VTTI has the capabilities to add additional equipment, if needed. With this information in mind, the following chart, Figure 1.2, presents the total cost for the wireless option, as installed by VTTI and VDOT. The full cost analysis can be viewed in Appendix 1.

Wireless Backbone Summary Cost

Year 1 Cost	Recurring Cost	Net Present Costs 5 Years of Operation
$74,036.79	$4,571.64	$92,323.35

Figure 1.2

IV. Alternative Options

Option 1: Fiber-optics

Fiber-optic systems are currently being used in the Hampton Roads area to monitor traffic. The main benefit of fiber-optics is a speedy data-transfer rate, which can reach 155 megabits per second (Mbps) (155,000 k) to 2.5 gigabits per second (Gbps) (2,500,000 k) using SONET technology. In this analysis, VTTI assumed a data-transfer rate of 1,237,500 Kbps. This assumption was calculated by taking the average of the SONET technology data-transfer rates. This fast data-transfer rate would allow for excellent video feedback; however, fiber-optic data backbone systems are very expensive. For example, the Hampton Roads system's projected cost, scheduled for completion in October 2003, is approximately $139 million. While the Hampton Roads system is much more complex than what would be needed for Highway 460, even simple fiber-optic systems are very expensive.

When outlining a fiber-optics system, the optic line is generally installed below ground with the line running from the origin, VTTI, to all of the corresponding equipment in the system. Underground installation involves a large capital outlay for the installation crew and equipment. In addition, the fiber-optic cable must be capable of stretching long distances and providing capabilities for the current system and for additional future equipment that might be added. After taking these qualities into consideration, a 24-strand single-mode fiber cable with armor was chosen. This line gives the strength needed for a long stretch distance and the armor for protection. Of the 24 fibers in the cable, only 12 will be needed for the current project, leaving 12 fibers for future expansion and upgrading.

When considering fiber-optic installation, there are three main installation procedures available, including boring, plowing, and trenching. Of the three installation options, trenching requires the largest work area because it involves digging a trench and then installing the cable. For Blacksburg and much of Virginia, trenching is not feasible because of the large work area necessary for this type of installation. Therefore, in this cost effectiveness analysis VTTI assumed that for Blacksburg, like much of Virginia, the fiber-optic cable would be installed using plowing or boring. It was assumed that half of the installation would be performed using plowing and the other half would be performed using boring. Total estimated costs for installation and the equipment necessary for the implementation of a fiber-optic system for the 460 data backbone system can be viewed in Figure 1.3 below. The full cost analysis of this option can be viewed in Appendix 2.

Fiber-Optic Summary Cost

Option	Total Costs	Net Present Costs 5 Years of Operation
Bore / Plow without conduit	$348,559.12	$358,079.12
Bore / Plow with conduit (See notes below)	$365,719.12	$375,239.12
Bore / Plow without conduit but rock busting	$362,287.12	$371,807.12
Bore / Plow with conduit but rock busting	$379,447.12	$388,967.12
Recurring Cost Per Year	$2,380.00	

Figure 1.3

Option 2: Fiber-optics Existing Line

In addition to laying a new fiber-optic line it is possible that an existing fiber-optic line might be in the area. For this scenario to work, the fiber-optic line would need to be present at the locations at which devices were to be installed. Moreover, in order to have access to the line, VDOT or VTTI would either have to own the line or purchase the rights to the needed fibers for the system. Therefore, under this scenario, it was assumed that the line would be owned by VDOT, that the fiber was in the exact locations needed for the system, and that enough excess fibers were present to support the traffic devices in the system. However, the likelihood of these assumptions occurring in the needed area is unlikely. Aside from these assumptions, the setup for this scenario is very similar to that for the new fiber-optic line.   With these assumptions in mind, the total cost for using an existing fiber-optic line can be viewed in Figure 1.4 below. The full costs analysis can be viewed in Appendix 3.

Fiber Optics Existing Line Summary Cost

Total Cost (Year 1)	Recurring Costs	Net Present Costs
Service & Installation Fee	Service Fee	5 Years of Operation
$101,383.12	$2,380.00	$101,383.12

Figure 1.4

From Figure 1.4, it is clear that using an existing fiber-optic line is much more affordable than employing a new fiber-optic line scenario. Most of this cost difference can be explained by the lack of fiber-line installation costs. For example, with the new fiber-optic line the scenario included costly items, such as the fiber-optic line and the installation labor.

Option 3: DSL

Another option that could have been pursued for Highway 460 was Digital Subscriber Lines (DSL). DSL is a service that uses existing cooper telephone lines to transfer data via the Internet. For this technology to operate, a telephone line is needed at each site. In this scenario, DSL service over telephone lines would need to be run to each of the camera locations to provide a data backbone for transferring the video back to VTTI. In analyzing DSL, VTTI studied two forms: symmetrical and asymmetrical. Symmetrical DSL has the same up-streaming and down- streaming data-transfer rates, while asymmetrical DSL has higher down-streaming capability compared to up-streaming capability. For example, the data-transfer rate for a Symmetrical DSL line might be 384 Kbps down streaming and 384 Kbps up streaming (384 / 384 k), while the Asymmetrical DSL line might be 7.1 Mbps down streaming and 768 Kbps up streaming (7.1 M / 786 k). Since this option uses existing telephone-line infrastructure, the cost is much less than fiber-optics. However, the drawback to all DSL is that it is only available in limited areas. In general, to receive premium DSL service, the location needs to be within three miles, or 15,000 feet, of the central office (Moss, 4). With distance as a limiting factor, the following chart details various DSL speeds with the maximum allowable distance between the location and the provider's central office.

DSL Maximum Distance from Provider's Central Office

DSL Type	Down Streaming	Up Streaming	Max Distance from Central Office
Symmetrical DSL	160 Kbps	160 Kbps	22700 ft.
	208 Kbps	208 Kbps	20000 ft.
	784 Kbps	784 Kbps	15000 ft.
	1.5 Mbps	1.5 Mbps	9000 ft.
Asymmetrical DSL	8 Mbps	1 Mbps	18000 ft.

Source: Computer Desktop Encyclopedia © 2000 The Computer Language Co. Inc.

Figure 1.5

Figure 1.5 illustrates the importance of proximity to a DSL central office raising the point that it is unlikely that DSL will be available in all locations throughout Virginia. Therefore, a scenario using all DSL would need to be located near a provider's central office, which most likely would include large towns and cities. If large traffic-device systems are planned using DSL, the availability of the DSL service would have to determined first.

Since DSL systems transfer data using phone lines, an active phone line must be present at each location. If a phone line is not present at the location, as is the case with the locations in the Highway 460 scenario, a phone line must be installed at each location. This requirement adds to the cost of the option since it includes phone-line installation, monthly charges for phone service, and monthly charges for DSL service. With these costs in mind, the total cost for various DSL options can be viewed in Figure 1.6 below. The full costs analysis can be viewed in Appendix 4.

DSL Summary Cost

DSL Speed Option	Total Cost (Year 1) Service & Installation Fee	Recurring Costs Service Fee	Net Present Costs 5 Years of Operation
DSL 384K / 384 K Static IP	$38,357.52	$9,356.40	$75,783.12
DSL 768K / 768 K Static IP	$41,957.52	$12,956.40	$93,783.12
DSL 7.1 M / 768 K Static IP	$47,357.52	$18,356.40	$120,783.12

Figure 1.6

<u>Option 4: Dedicated Service Connection (T1)</u>

In addition to DSL, most telephone providers and other Internet businesses can supply high-speed-data-transfer using T1 lines. In a T1 scenario, a T1 line would run from the service provider to the specific location. However, the provider charges for the installation as well as the T1 data-transfer service. The main downfall to T1 service is the large reoccurring service charges per month. However, the maintenance of the T1 line is included in the service fee. For the analysis of the T1 option, VTTI priced and analyzed three partial T1 symmetrical options, including service at 384 Kbps, 512 Kbps, and 786 Kbps. The total cost for these partial T1 options can be viewed in Figure 1.7 below. The full costs analysis can be viewed in Appendix 5.

Partial T1 Summary Cost

Partial T1 Speed Option	Total Cost (Year 1) Service & Installation Fee	Recurring Costs Service Fee	Net Present Costs 5 Years of Operation
T1 (384K)	$61,203.12	$25,200.00	$162,003.12
T1 (512K)	$68,403.12	$32,400.00	$198,003.12
T1 (786K)	$75,603.12	$39,600.00	$234,003.12

Figure 1.7

Option 5: ISDN

Integrated Services Digital Network (ISDN) is a service that is provided by telephone companies and is available in most areas of Virginia. Using this service, it is possible to achieve a data-transfer rate of 128 Kbps by combining two 64-Kbps phone lines. However, to achieve the 128-Kbps transfer rate, the two lines must be fused together at just the right moment; otherwise, the connection speed will be less than 128 Kbps. For this option, each site location needs two active phone lines for the ISDN service to work. Therefore, similar to the DSL option, phone lines would need to be installed at each site, leading to a phone-line installation fee. In addition to the monthly charges for phone lines, the provider will charge a monthly ISDN service fee for the system. The total cost for ISDN system can be viewed in Figure 1.8 below. The full cost analysis can be viewed in Appendix 6.

ISDN Summary Cost

Total Cost (Year 1)	Recurring Costs	Net Present Costs
Service & Installation Fee	Service Fee	5 Years of Operation
$54,771	$24,480	$152,691.12

Figure 1.8

Option 6: Dialup Internet

The final option, dialup Internet access, provides a maximum of 56-Kbps data-transfer. Under this scenario, a phone line would be needed at each location, similar to DSL. In addition, each location's phone line would need Internet access, which could be provided by various Internet providers. Once phone and Internet service is established, video images could be sent and received using the Internet access through each location's phone line. Of the options studied in this analysis, dialup Internet data-transfer provides the least capabilities due to the limited 56-Kbps transfer rate, but this option is the most affordable and does not have the area limitations of DSL. The total cost for a dialup internet access system can be viewed in Figure 1.9 below. The full costs analysis can be viewed in Appendix 7.

Dialup Internet Summary Cost

Total Cost (Year 1)	Recurring Costs	Net Present Costs
Service & Installation Fee	Service Fee	5 Years of Operation
$31,167	$2,880	$42,687.12

Figure 1.9

V. Cost Comparison

After analyzing the various data backbone system configuration options, it is clear that the initial costs, reoccurring costs, and net present costs for five years of operation varies significantly among the options. Figure 2.0 presents these variations in the costs of each option.

Data Backbone System Configuration Options Cost Comparison

Option	Option Theoretical Internet Transfer Speed (k)	Year 1 Cost	Recurring Cost	Net Present Costs after 5 Years of Operation
Wireless	11,000	$ 74,036.79	$4,571.64	$92,323.35
Fiber (Existing Line)	1,237,500	$101,383.12	$2,380.00	$110,903.12
Fiber (New)	1,237,500	$379,447.12	$2,380.00	$388,967.12
Dialup Internet	56	$31,167.12	$2,880.00	$42,687.12
ISDN Internet	128	$54,771.12	$24,480.00	$152,691.12
DSL 384K / 384 k	384	$38,357.52	$9,356.40	$75,783.12
DSL 768K / 768 k	786	$41,957.52	$12,956.40	$93,783.12
DSL 7.1 M / 768 k	768	$47,357.52	$18,356.40	$120,783.12
T1 (384k)	384	$61,203.12	$25,200.00	$162,003.12
T1 (512k)	512	$68,403.12	$32,400.00	$198,003.12
T1 (786k)	786	$75,603.12	$39,600.00	$234,003.12

Figure 2.0

From Figure 2.0, it is clear that the fiber-optic scenarios are the most expensive. A cost comparison of Year 1 costs, which includes installation and equipment, can be viewed graphically in Figures 2.1 and 2.2. The second graph, Figure 2.2, compares Year 1 costs for the various options, but the fiber-optics (new line) scenario has been removed in order to better view the costs of the other options. By viewing the graph, it is easy to tell which of the options have the least costs for Year 1.

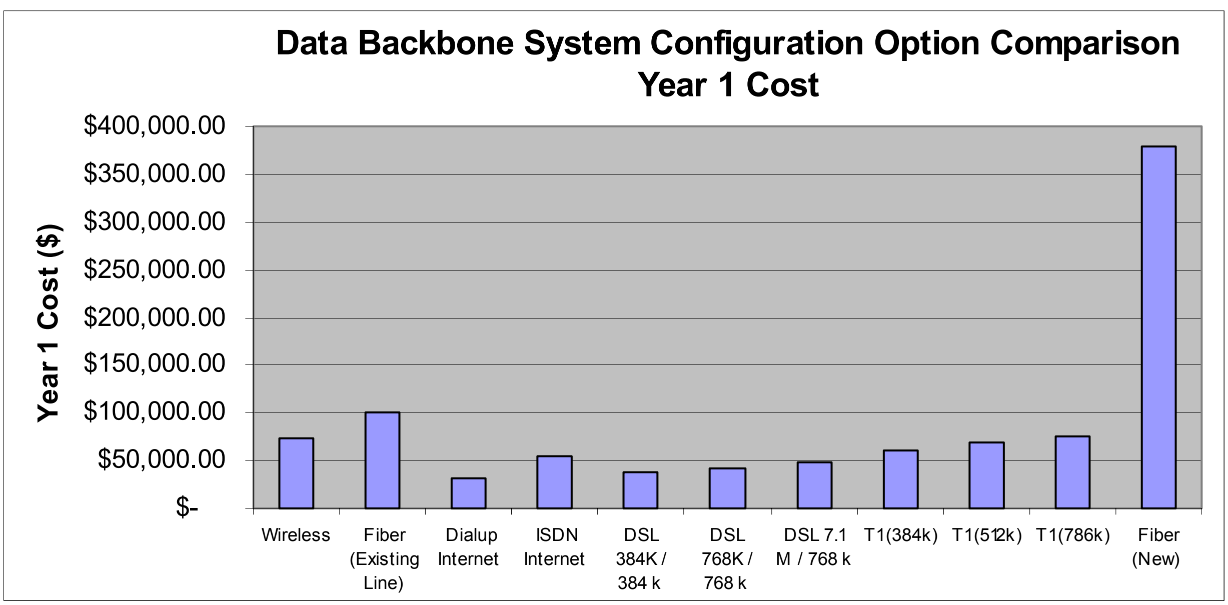


Figure 2.1

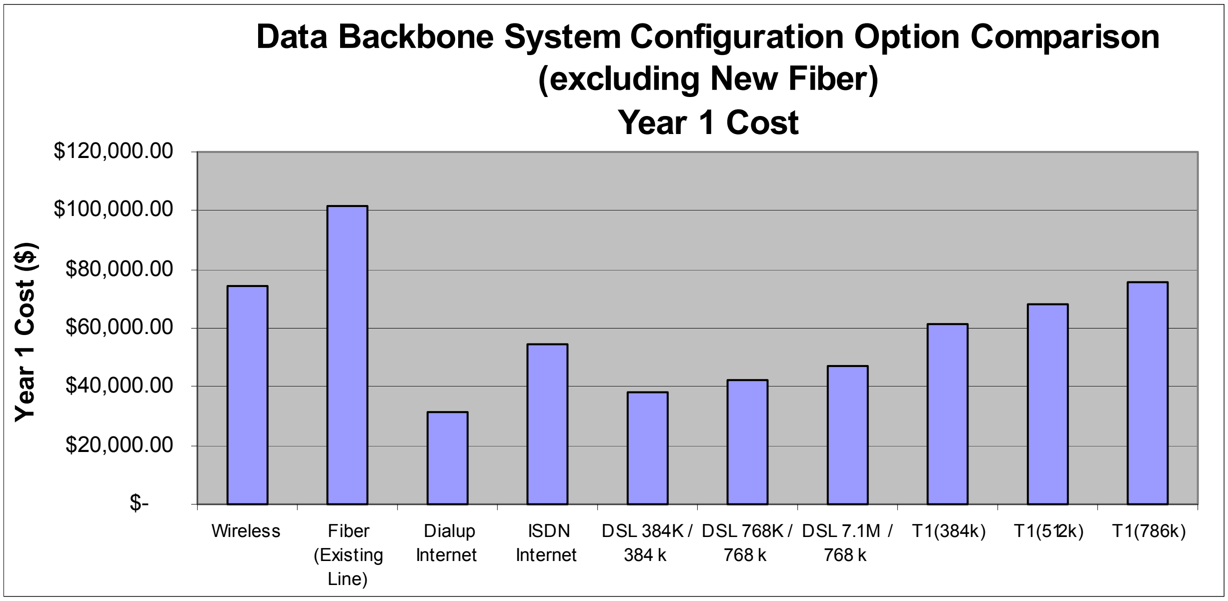


Figure 2.2

After analyzing the Year 1 costs, it was necessary to calculate the net present cost after five years of operation for each of the data backbone system configuration options. The calculation for net present costs after five years of operation includes the following costs:

1) Initial Year 1 Costs: (Design, Installation, Start Up Equipment, Service Fees, Maintenance, Operation Costs)

2) Recurring Costs: Years 2-5 (Service Fees, Maintenance, Operation Costs)

Since all itemized costs for each option were presented in today's dollars (2003), the net present cost for the five years of operations could be determined by summing the cost for each of the five years without deflating the future costs. Therefore, the net present cost formula would be as follows.

Net Present Cost = Year 1 Cost + Year 2 + Year 3 + Year 4 + Year 5

The option comparison chart located on page 11, Figure 2.0, depicts the reoccurring costs and net present costs after five years of operation. The following graphs, Figure 2.3 and Figure 2.4, show the difference in net present costs after five years of operation. The second graph, Figure 2.4, is the same as Figure 2.3, but the fiber-optics (new line) scenario has been removed in order to better view the costs of the other options.

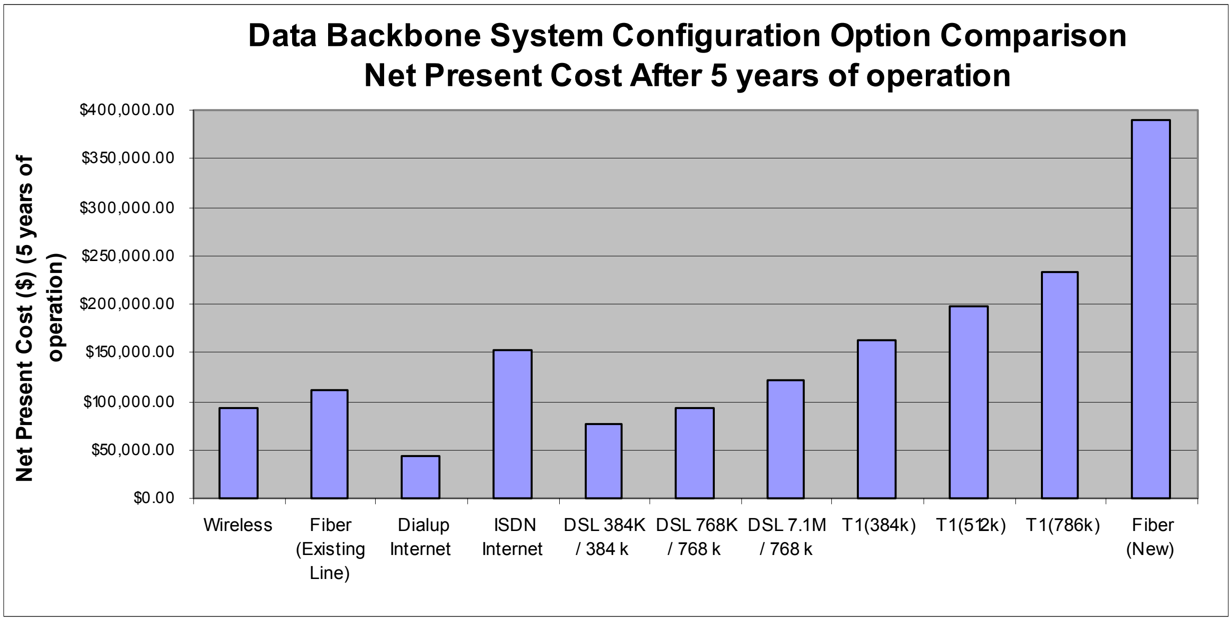


Figure 2.3

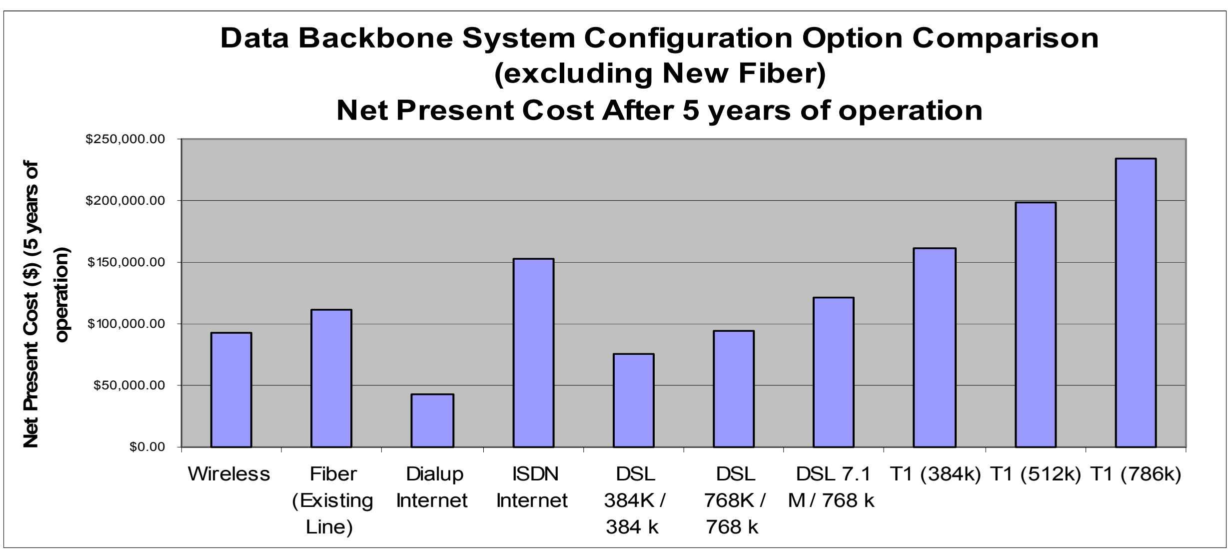


Figure 2.4

From this graphical comparison, the eleven options can be evaluated easily to determine the least costly option. From viewing the cost analysis for five years of operations, the wireless data backbone scenario seems to be a good decision as only two options, dialup Internet and DSL 384, are cheaper. However, there are factors other than costs that need to be analyzed in order to determine the best overall data backbone system configuration option. Therefore, the following sections of this analysis will compare options' qualitative considerations, future expandability, and mobility factors to give a more complete and firm understanding of the overall best data backbone system configuration option.

VI. Adaptability and Expandability

When comparing the prices of various options, fiber-optics can be ruled out easily due to its extreme cost in comparison to the other options. However, the net present costs for five years of operations for many of the other options are very close in price. Since the other options, except fiber-optics, are comparable in price, the future adaptability and expandability should be considered.

Those options using telephone lines, including DSL, ISDN, and dialup Internet are fixed to the location where the phone line is present. Therefore, in order to expand to a new location, a phone line would need to be installed. For each new location, the provider will charge a service fee for the phone-line installation, phone-line service, and data-transfer. Concerning adaptability of the telephone-line options, it appears that DSL would be the only option that could provide enough excess bandwidth to support additional traffic devices, such as a VMS board, sensors, or additional cameras. The other options only have enough data-transfer ability to support the current configuration.

The T1 line is also a permanent option, but it has a copper in-ground line instead of a telephone line. T1 systems are currently being used in many areas of the department of transportation as a method of transferring data. However, in order to receive a high-speed connection, the location must be within a certain radius of the supplier, Ntelos. As the distance from the supplier to the location increases, a lower data-transfer speed results. If the system was to be expanded, a new T1 line would need to be installed at each location. The provider, such as Ntelos, would charge an installation fee and service fee for each new location. However, the T1 line does provide a large enough data-transfer rate that additional technologies, such as a VMS boards, sensors, and additional cameras could be added to the system and controlled using the current T1 line data-transfer speed.

The final option, wireless Internet using point-to-point communication, is very mobile. If the current device is located with the wireless LAN, the only concern for moving the device is a power source. The power-supply problem can be solved in two ways: traditional electrical lines or solar panels. If the devices are powered using moveable solar panels, the mobility is limitless. In order to move the devices within the wireless LAN, the device simply needs to be moved to the desired location and powered using solar cells. Using the wireless LAN, the components have access to the wireless Internet signal in an area up to two miles from the access point. A device's connection can be reached and traffic devices can be controlled anywhere in the two-mile LAN radius. If the new location is not currently in the wireless LAN area, a new access point would need to be established. Adding or moving a current remote outdoor router to the location easily establishes the location with wireless Internet. In addition to this option being very mobile, it does not have the reoccurring monthly costs of the traditional wire-line telecommunication system. These qualities enable wireless Internet to excel past the traditional data-transfer options.

VII. Qualitative Analysis

When comparing the different communications options, it must be noted that there is a fundamental difference between the wireless option and the other options. For fiber optics and the traditional subscription services, each camera is placed on its own dedicated communications line. There is no sharing of bandwidth between cameras. For example, the fiber optic option calls for an individual fiber to be terminated at each camera, while the other solutions call for individual T1 or DSL accounts to be connected at each camera. The advantage to individual accounts is that there is no sharing of bandwidth, while the drawback is that each connection incurs a monthly charge. The wireless option is distinctively different than the other options in that each device on the network must share the available bandwidth.

The wireless network is created by relaying a signal in a serial fashion from one location, or node, to the next. Any device placed at a node must share the available bandwidth with other devices co-located at that node or placed at other nodes. In addition, the available bandwidth begins to decrease the farther away one is from the starting node. This bandwidth degradation occurs due to network processing that occurs at each node which cumulatively adds up over successive hops. Figure 2.5 shows how the available bandwidth begins to decrease over successive hops away from the base node.

For this analysis, a standard camera configuration was defined in order to qualitatively compare the systems against each other. A total of six cameras using MPEG1 compression at the 320x240 picture size is compared across the different options. MPEG1 compression allows the user to select a camera bit rates between 260 Kbps and 3500 Kbps. The picture clarity increases at higher bit rates. Systems with multiple cameras are more efficiently monitored by looking at still pictures updated on timed intervals. As needed, operators can open streaming video from an individual camera.

Figure 2.8 compares streaming capabilities across the different options. This chart indicates that most of the telephony solutions can accommodate streaming from all six cameras, except dialup Internet. This is due to the fact that each camera has a dedicated line providing enough bandwidth to support streaming video.

The fiber-optic options have the capability of streaming all six cameras using a set bit rate ranging from 260 to 3500 kb/s. The extremely high bandwidth capable with fiber-optics allows video to stream at the maximum bit rate from all the cameras simultaneously due to the home run fiber configuration. However, there is significant amount of excess bandwidth that is not be utilized. Therefore, the extreme cost of placing the fiber optics is not fully recovered due to insufficient utilization of the fiber-optic's capabilities.

The dialup Internet and the ISDN internet have the capability to show still JPEG images updated on timed intervals. However, these two options do not have the ability to stream MPEG1 video because the available bandwidth is less than the minimum bandwidth needed for this particular MPEG1 camera. A more efficient video compression such as MPEG4 would most likely work on ISDN and dial up internet. The need for streaming video depends on the user's concept of operations. In locations where streaming video is not needed and only a still picture will suffice, then, ISDN and dialup are viable options.

Dedicated DSL connections placed at each camera have the capability to provide still pictures updated on a desired time interval and stream video from the cameras. The bit rate of streaming video depends on which DSL connection has been purchased. The higher bandwidth DSL connections allow the user to assign a higher bit rate to the camera and achieve a higher resolution picture. The main drawback to DSL is the limited availability area. Generally, DSL is available in a defined radius from a provider's central switch; therefore, for many rural Virginia and I-81 applications DSL is not feasible. Concerning asymmetrical DSL options it is important to note the bandwidth is different for up-streaming and down-streaming. For individuals connecting to the Internet from home or work, a high down-streaming speed is more beneficial than having a high up-streaming speed. However, for a camera in the field, a high up-streaming rate is much more desired than a high down-streaming rate.

Similarly to DSL, the T1 options have the capability to provide still pictures updated on a desired time interval and stream video from the cameras. The T1 connections are hard wired installations that do not have the same limitations as DSL in terms of placement. However, it is up to the telephone provider to approve locations where they are willing to install a T1 line. An additional drawback to T1 lines is the higher monthly and recurring costs.

In the wireless scenario, the cameras share the total available bandwidth. In addition, the total available bandwidth decreases the farther away from the base node the camera is located. From the accompanying chart at the first 'hop' away from the base node, approximately 4.2 Mbps of bandwidth are available. This amount of bandwidth can support up to six cameras streaming. As the number of hops away from the base node increases, the available bandwidth decreases. In this option up to six cameras can be accommodated as long as the selected bit rate of the cameras is decreased so that the total of the bit rates does not exceed the available bandwidth. For example, at the fifth hop the total available bandwidth is 2.3 Mbps. A six camera system set at a bit rate of 260 kbps requires a total of 1.56 Mbps which does not exceed the available bandwidth of 2.3Mbps. However, at six hops away, the available bandwidth is 1.5 Mbps. Therefore, from this location a total of five cameras could be streamed.

Cameras Streaming on Orinoco Wireless Network

# of Hops away	Available bandwidth	# of Still Pictures	# of Streaming cameras
1	4.2 Mbps	6	1 to 6
2	3.86 Mbps	6	1 to 6
3	3.5 Mbps	6	1 to 6
4	3.2 Mbps	6	1 to 6
5	2.3 Mbps	6	1 to 6
6	1.5 Mbps	6	1 to 5
7	1.2 Mbps	6	1 to 4
8	800 Kbps	6	1 to 3

Figure 2.5

Highway 460 Wireless Architecture Configuration

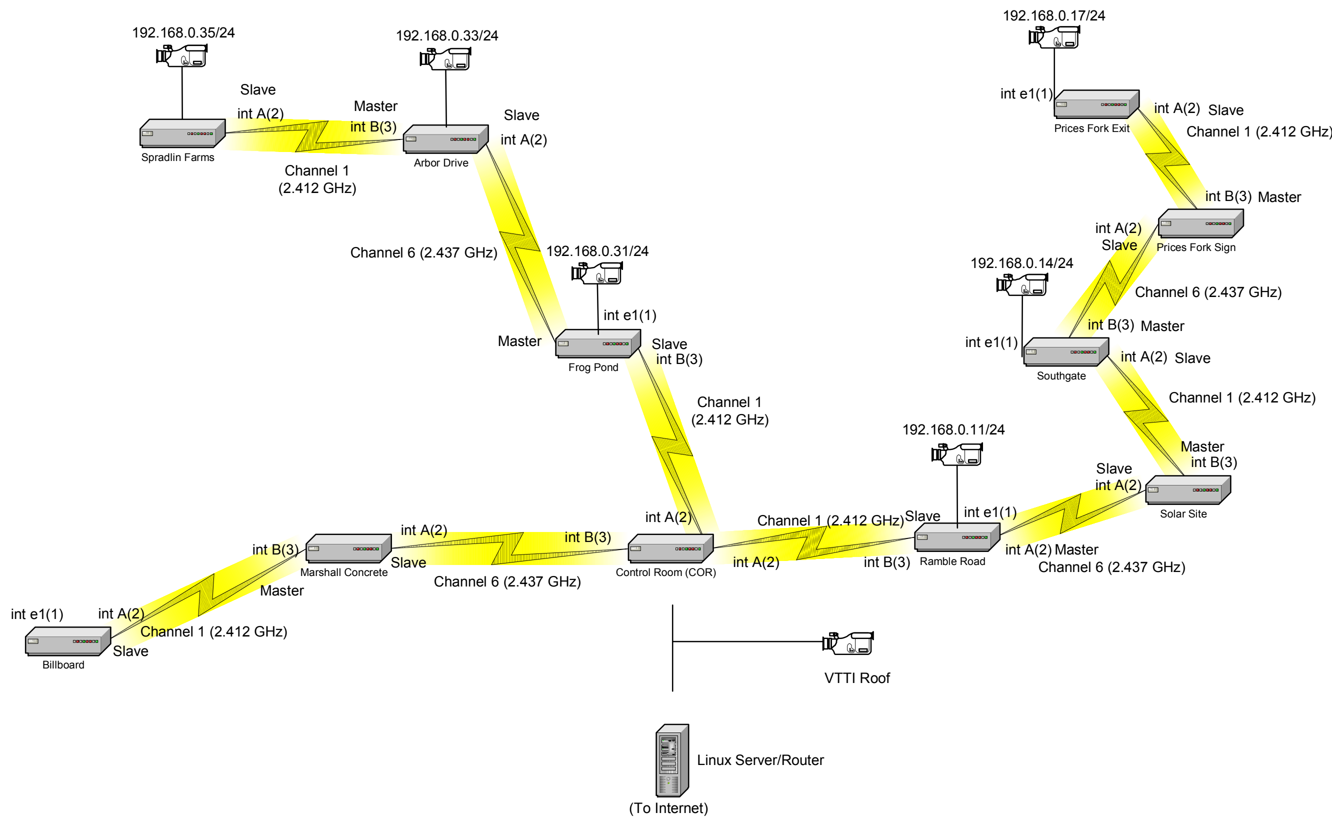


Figure 2.6

Figure 2.6 diagrams the wireless architecture of the 460 camera system. The control room is the base node, or location. The cameras are located along two separate spurs away from the central node. There are three hops on one spur, and five hops on another spur. With this architecture there are 3.2 Mbps available along one spur and 2.3 Mbps available on the other spur, and three cameras are located on each spur. In this particular architecture, all six cameras can stream at the same time provided that the bit rates chosen from the camera do not exceed the available bandwidth on each spur.

VII. General Qualitative Conclusions:

Fiber optic options provide the greatest amount of bandwidth however they also come with the greatest cost. Unless the excess bandwidth is resold by the owner, the high recurring and installation cost may not be worth it to the owner.

Dialup and ISDN are options that are viable for many locations. However the limited bandwidth makes them less desirable. They should be considered as options where streaming video is not needed and for locations that are extremely isolated. Isolated locations may be difficult to create a wireless backbone, so a dedicated ISDN or dialup may make more sense for these situations.

DSL options provide an acceptable amount of bandwidth for streaming video. One drawback that is applicable to all the traditional options is that each device location requires its own dedicated subscription connection, each with its own monthly bill. In addition, DSL is very limited on where it can be placed. These limitations may make it impossible to get DSL where the DOT needs it. Finally, the asymmetrical options with low up-streaming data transfer rates provide little value to a transportation application where devices are placed remotely in the field.

The T1 options have similar advantages and disadvantages to DSL. They are acceptable for streaming video; however, they suffer from the same need for dedicated lines run to each device. T1 options do not suffer from the same level of limitations as DSL, however, there will be some limitations as to where they can be placed. In this situation the DOT is at the mercy of the T1 provider as to where the T1 line can be installed. The monthly costs for T1 lines are significantly higher than DSL which makes them less desirable for long term situations.

Wireless provides and option that is much easier and cheaper to install than the other options. The infrastructure is owned by the DOT and is not as permanent as other options. With this there are no monthly costs of individual nodes. The only additional cost might be for Internet backdrops, if they are required. The drawbacks to wireless includes that each device must share the available bandwidth and the bandwidth degrades over successive hops. However, with today's digital camera compression technologies, streaming video is still very viable over multiple hop wireless networks.

Option Constants

# of Cameras	Coverage Distance (miles)	Camera Compression	Picture Size (Pixels)
6	6.5	MPEG 1	320 x 240

Notes: MPEG 4 is better than MPEG 1 compression. However, VTTI has not performed extensive testing on MPEG 4.

Figure 2.7

Option Variables

Option	Option Theoretical Internet Transfer Speed	Camera Bandwidth (K)	# of Still Pictures	Stills Update Every	# of Cameras Streaming	Notes:
Wireless	11,000 k	260 - 750	6	30 seconds	See Figure 2.5	
Fiber (Bore / Plow without conduit)	1,237,500 k	260 - 3500	6	30 seconds	6	
Fiber (Bore / Plow with conduit)	1,237,500 k	260 - 3500	6	30 seconds	6	
Fiber (Bore / Plow without conduit but rock busting)	1,237,500 k	260 - 3500	6	30 seconds	6	
Fiber (Bore / Plow with conduit but rock busting)	1,237,500 k	260 - 3500	6	30 seconds	6	
Fiber (Existing Line)	1,237,500 k	260 - 3500	6	30 seconds	6	
Dialup Internet	56 k	N/A	6	30 seconds	N/A	Will not stream at any picture size
ISDN Internet	128 k	N/A	6	30 seconds	N/A	Will stream at (160 / 120) picture size at 66 - 128k bit rate
			6			
DSL 384K / 384 k Static IP	384 / 384 k	260 - 384	6	30 seconds	6	
DSL 768K / 768 k Static IP	786k / 768 k	260 - 786	6	30 seconds	6	
DSL 7.1 M / 768 k Static IP	7.1 M / 768 k	260 - 786	6	30 seconds	6	
T1 (384k)	384 k	260 - 384	6	30 seconds	6	
T1 (512k)	512 k	260 - 512	6	30 seconds	6	
T1 (786k)	786 k	260 - 786	6	30 seconds	6	

Figure 2.8

Option Qualitative Comparison

Option	Major Benefits	Major Drawbacks
Fiber-Optics	• 155 Mbps to 2.5 Gbps transfer rate • More than enough bandwidth for the cameras in the system. • Additional bandwidth could be sold	• Expensive • Underground Installation fees • Permanent • VTTI or VDOT will have to contract out maintenance • Difficult and expensive to reconfigure • Aesthetics
T1 Line	• Various Speed Options (384 K, 512 K, 786 K) • Repairs covered by provider (ie. Ntelos) • Adaptable*	• Permanent (Line to location) • Reoccurring service fees • Contract for 1 year • Difficult and expensive to reconfigure • Aesthetics
DSL	• Various Speed Options (384 K, 786k, 7.1 Mbps) • Repairs covered by	• Reoccurring service fees • Contract for 1 year • Phone line needed at each location

	provider (ie. Verizon) • Adaptable*	• Limited Service Area
Dialup Internet	• Available almost everywhere	• Phone needed at each location • Slow data-transfer rate (56 Kbps) • Limited streaming video capability, but not available at MPEG 1 or 2 • Reoccurring service fees
ISDN	• Speed 128 Kbps possibly • Available in most of VA	• Two phone lines needed at each location • Reoccurring service fees • Will provide streaming video only at small picture size (160/120)
Wireless Internet	• 11.6 Mbps Data-transfer • Mobile in all aspects • No in ground lines • Access and control assets from Internet anywhere • Expandable* • Adaptable**	• Requires line of site • Non licensed communication frequency

*Expandable – Ability to expand the system to new locations without additional service fees.

** Adaptable – Option provides enough excess bandwidth to support additional traffic devices such as a VMS board, sensor, or additional camera at the current location.

Figure 2.9

IIX. Conclusion and Recommendations

After completing this analysis, it appears that wireless Internet is similar in price to dialup internet, DSL 384 K, and DSL 768 K options. Of the competitors, dialup would not provide enough excess bandwidth to allow for adaptability or streaming video and can, therefore, be eliminated. After qualitatively comparing the options, the wireless data backbone configuration system is the only option that provides a combination of benefits, including streaming video, adaptability, mobility, and expandability, at a competitive price to the other options. Therefore, it appears that installing a wireless backbone configuration system along Highway 460 was the appropriate choice. In addition, wireless Internet should be further researched to determine how the transportation industry, specifically the Virginia Department of Transportation can enjoy its benefits.

IX. Sources:

Fiber-optic Speeds: SONET
http://compnetworking.about.com/library/weekly/aa092800a.htm

Moss, George B. DSL or Cable Modems, Which is Better?
http://faculty.ed.umuc.edu/~meinkej/inss690/dsl.pdf

Applied Fiber Optics, Brian McCollum, 540-520-6888, macafo@cs.com

Force Inc., Beverly Sorten, 540-382-0462 Ext. 4147

Verizon Online, www.verizon.com

Ntelos, www.ntelos.com, Robin Boston, 540-953-3580, Ext. 5452

DSL availability, www.dslreports.com

Appendix I: Wireless

Wireless Costs (VTTI)

Item	Item Totals	Item Costs	Total Costs
ROR 1000	7	$804.00	$ 5,628.00
COR 1000	1	$1,100.00	$ 1,100.00
Orinoco PC Cards (Silver)	15	$43.81	$ 657.15
19" Pigtail Connector	14	$20.00	$ 280.00
40' Length LMR 400 Cable	13	$56.00	$ 728.00
16 dBi Panel Array Antenna	9	$50.00	$ 450.00
RGA Signal Cabinet (large)	6	$400.00	$ 2,400.00
Lightening Arrestor	15	$82.00	$ 1,230.00
Power Strip	8	$7.00	$ 56.00
JVC VNC 3WU Camera (With integrated housing and flex conduit)	6	$2,640.00	$ 15,840.00
Zip Ties, Double sided tape, etc…	8	$3.00	$ 24.00
Solar Panel array w/ bracket	1	$2,264.00	$ 2,264.00
Marine Batteries	2	$65.00	$ 130.00
Solar Controller	1	$70.00	$ 70.00
Power Adapter Circuit for 12 Volt Power	1	$100.00	$ 100.00
Associated wiring for solar system	1	$25.00	$ 25.00
14 dBi Yagi antenna	1	$80.00	$ 80.00
24 dBi Parabolic Antenna	4	$65.00	$ 260.00
15 dBi Parabolic Antenna	1	$50.00	$ 50.00
Conduit antenna mounts	2	$5.00	$ 10.00
70' LMR 400 Cable ($.43/ft)	2	$60.00	$ 120.00
Short Ethernet Cable	1	$9.00	$ 9.00
Long Ethernet Cable	1	$25.00	$ 25.00
Splitter	1	$60.00	$ 60.00
Powered Amplifier	1	$200.00	$ 200.00
RGA Signal Cabinet (small)	1	200	$ 200.00
Ethernet Hub	1	15	$ 15.00
Extension Cord	1	7	$ 7.00
U Bolts	26	4	$ 104.00
Equip. Replacement Costs			$ 1,500.00
VTTI Design Labor	hrs	$/hr	
Ashwin	80	$33.46	$2,676.80
Justin	40	$25.61	$1,024.40
VTTI Installation Labor	hrs	$/hr	
Ashwin	96	$33.46	$3,212.16
Justin	32	$25.61	$819.52
VTTI Operations Labor	hrs	$/hr	
Ashwin	52	$33.46	$1,739.92
Sean	52	$25.61	$1,331.72

Employee	Middle of Salary Band	$/hr
Ashwin	$69,603.00	$33.46
Justin	$53,278.00	$25.61
Sean	$53,278.00	$25.61

Other Costs	Price per item	# of sites	Total
Cameras	$2,642.00	6	$15,852.00
VDOT Installation Fees	See VDOT Wireless worksheet		$13,758.12

Total Costs Year 1			$ 74,036.79
Total Reoccurring Costs			$4,571.64
	Operations Costs		$3,071.64
	VTTI Equip Replace Costs		$1,500.00

Wireless Backbone		
Year 1 Cost	Reoccurring Cost	Net Present Costs 5 Years of Operation
$ 74,036.79	$4,571.64	$92,323.35

Assumptions

1. VTTI will be responsible for maintenance, could be contracted out if desired
2. Development Labor is estimate at 16 hours per site with 8 hrs for Ashwin and 4 for Justin per site, 8 sites total
3. Operations Costs is estimate at 104 hours/year (2hrs per week maintenance X 52 weeks per year)
4. Operations Costs = 1hr for Ashwin, 1 hr for Sean each week, some weeks will be more or less depending on the tasks
5. Equipment Replacement Costs - $1,500 estimate each year to cover radio replacements and other devices as needed

Notes

1. Theoretical Maximum speed transfer is 11 Mbps (11,000 k)
2. Source: Wireless device prices from either CDW.com or Hyperlink Technologies (http://www.hyperlinktech.com/) from April, 2003
3. VDOT wireless install fees calculated in March 2003
4. $/hr is calculated by taking middle of salary pay range / (2080) total hrs worked in year
5. Design Labor is an estimate from Ashwin the designer of the system

Appendix II: Fiber-optics (New Line)

Fiber Optics Blacksburg New Line Scenario (1/2 Bore, 1/2 Plow Installation)				
Material Items	**Description**	**Units**	**Price / unit**	**Total**
Fiber Optic Line	24F Single Mode with Armor (.75$/ft)	34320	$0.75	$25,740.00
Hand holes	30" X 48" needed at each site location	6	$250.00	$1,500.00
Metallic Marker Tape	Needed to mark path for future construction (.05/ft)	34320	$0.05	$1,716.00
Cabinet & Concrete Pad	Cabinet and Concrete pad at each location	6	$4,000.00	$24,000.00
Cameras	JVC VNC 3WU Camera	6	$2,642.00	$15,852.00
Transceiver	Need to transmit video, Model 2768 T-SCST	6	$615.00	$3,690.00
Receiver	Need to receive video, Model 2768 R-BFST	6	$565.00	$3,390.00
Wall Mount Power Supply	Supplies power to transceivers and receivers	12	$20.00	$240.00

Labor Items	Description	Units	Price / unit	Total
Bore	Bore to install conduit or cable (36" deep)	17160	$9.50	$163,020.00
Plowing	Plowing to install conduit or cable (36" deep)	17160	$2.00	$34,320.00
Connect Fiber	Splice fiber trunk to device fiber optic drop	6	$1,250.00	$7,500.00
Pull cable	Pull cable	17160	$0.50	$8,580.00
Conduit construction	Conduit will be needed leading into pad in all options	6	$1,000.00	$6,000.00
Splice Fiber Optics	Splice Fiber optics at truck to lateral	6	$1,250.00	$7,500.00
Install Control Electronics	Wire Cabinet to outside signal inputs	6	$1,800.00	$10,800.00
Engineering Documentation	Design the fiber optic system & test system, usually rolled into project overhead	1	$8,000.00	$8,000.00
VDOT Installation Fees	See non-wireless VDOT costs worksheet	6	see worksheet	$11,031.12
Lane Closure Fee	VDOT cost for closing lane for construction	10	$850.00	$8,500.00
Grass Reseeding	VDOT cost for reseeding grass at each site location	6	$800.00	$4,800.00
Maintenance	VDOT Service Tech # of days (See notes below)	20	$119.00	$2,380.00

Grand Total Plowing No Conduit	$348,559.12

Additional Costs (If Conduit Is Used)				
Material Items	**Description**	**Units**	**Price / unit**	**Total**
Conduit	1.5"-2.0" conduit housing for fiber	17160	$1.00	$17,160.00

Additional Costs For Using Conduit	$17,160.00

Additional Costs (Rock Busting Needed)				
Labor Items	**Description**	**Units**	**Price / unit**	**Total**
Rock busting *	1-12" depth per ft of distance in ft	1716	$8.00	$13,728.00

Additional Costs For Rock Busting	$13,728.00

Option	Total Costs	Reoccurring Cost	Net Present Costs 5 Years of Operation
Bore / Plow without conduit	$348,559.12	$2,380.00	$358,079.12
Bore / Plow with conduit (See notes below)	$365,719.12	$2,380.00	$375,239.12
Bore / Plow without conduit but rock busting	$362,287.12	$2,380.00	$371,807.12
Bore / Plow with conduit but rock busting	$379,447.12	$2,380.00	$388,967.12

* Assumes 10% of the total length to contain rocks that will have to be busted

Assumptions

1. Handholes will be needed at every device location
2. For the Fiber Optic theoretical speed the mean of the of the SONET range was taken (1,237,500 k)
3. 10 days of Lane closures will be needed, just an estimate
4. Grass reseeding will be needed at the 6 site locations
5. For Virginia and 460 a scenario with 1/2 bore and 1/2 trenching will be most realistic
6. Maintenance will be performed by a VDOT Service Technician RT: Electronics Technician I Salary ($31,000 year) ($119 day)
7. One VDOT Service Tech for maintenance will be needed for around 20 days per year (Source: Brain McCollum)

Appendix II: Continued - Fiber-optics (New Line)

Notes

1. Additional Handholes may be needed for connections or to change direction of the line while being constructed.
2. "Directional boring without conduit is not done often as the trade-off of cost vs. no protective conduit isn't considered sensible" (BM)
3. If directional boring without conduit is done the cable must be pulled in immediately for fear of the bore hole collapsing leaving a blocked path, which will change the work flow.
4. Soil type is also critical, if sandy soil is present conduit will be necessary. Soil Preference : Bentoinite Clay
5. Metallic marker tape should be used along entire route. This locates the route for future construction and maintenance.
6. To get an idea of amount of rock that may be encountered site survey, historical records, or previous VDOT projects should be consulted.
7. Prices as of March 2003 from Applied Fiber Optics, Brian McCollum, macafo@cs.com, 540-520-6888
8. Transceiver, Receiver, and Wall mount power supply prices from Force Inc. 540-382-0462 (Beverly Sorten, Ext 4147)
9. 1/2 of the stretch will be bore and 1/2 trench, this will represent 460 and other areas in Virginia
10. 6.5 mile stretch, 5280 feet in mile, 34320 total, 17160 ft will be bore, 17160 will be trench
11. Pulling of cable is not necessary when plowing is used.
12. Plowing - Cable will flow into the ground through a "chute" or "tooth" directly into the ground without conduit
13. Maintenance for system will mainly include camera cleaning and replacing damage electronic equipment (lightning damage)
14. Fiber Optic SONET commonly transmits data at speeds between 155 megabits (155,000 k) per second (Mbps) and 2.5 gigabits per second (Gbps) (2,500,000 k).

Appendix III: Fiber-optics (Existing Line)

Fiber Optics Existing Line Scenario				
Material	**Description**	**Locations**	**Price / unit**	**Total**
Tap Existing Line	Labor and Maintenance for splicing, conduit construction, concrete pad & cabinet at each location	6	$10,000.00	$60,000.00
VDOT Installation Fees	See non-wireless VDOT costs worksheet	6	see worksheet	$11,031.12
Cameras	JVC VNC 3WU Camera	6	$2,642.00	$15,852.00
Grass Reseeding	VDOT cost for reseeding grass at each site location	6	$800.00	$4,800.00
Transceiver	Need to transmit video, Model 2768 T-SCST	6	$615.00	$3,690.00
Receiver	Need to receive video, Model 2768 R-BFST	6	$565.00	$3,390.00
Wall Mount Power Supply	Supplies power to transceivers and receivers	12	$20.00	$240.00
Maintenance	VDOT Service Tech # of days (See notes below)	20	$119.00	$2,380.00
Grand Total Costs Existing Line Scenario				$101,383.12

Fiber Optics (Exsisting Line) Total Cost		
Total Cost (Year 1)	Reoccurring Costs	Net Present Costs
Service & Installation Fee	Service Fee	5 Years of Operation
$101,383.12	$2,380.00	$101,383.12

Assumptions

1. Fiber Optic Line present were needed at each location
2. Fiber Optic Line owned by VDOT or VTTI
3. Enough unused fibers to support the planned traffic devices
4. Grass reseeding will be needed at the 6 site locations
5. Maintenance for system will mainly include camera cleaning and replacing damage electronic equipment (lightning damage)
6. Maintenance will be performed by a VDOT Service Technician RT: Electronics Technician I Salary ($31,000 year) ($119 day)
7. One VDOT Service Tech for maintenance will be needed for around 20 days per year (Source: Brain McCollum)

Notes

1. Fiber Optic SONET commonly transmits data at speeds between 155 megabits (155,000 k) per second (Mbps) and 2.5 gigabits per second (Gbps) (2,500,000 k).
2. For the Fiber Optic theoretical speed the mean of the of the SONET range was taken (1,237,500 k)
3. Prices as of March 2003 from Applied Fiber Optics, Brian McCollum, macafo@cs.com, 540-520-6888
4. Transceiver, Receiver, and Wall mount power supply prices from Force Inc. 540-382-0462 (Beverly Sorten, Ext 4147)

Appendix IV: DSL

DSL Costs				
DSL Speed Options	Price / Month	# of months	# of sites	Yearly Service Charge Per option
DSL 384K / 384 K Static IP	$109.95	12	6	$7,916.40
DSL 768K / 768 K Static IP	$159.95	12	6	$11,516.40
DSL 7.1 M / 768 K Static IP	$234.95	12	6	$16,916.40

Additional DSL Costs	Price / unit	# of months	# of units	Total Charge
Phone line (monthly)	$20.00	12	6	$1,440.00
DSL Setup Fee	$60.00		6	$360.00
DSL Modem	$99.00		6	$594.00

Verizon Phone Line Installation Costs	Price / unit	# of unit	Total Charge
Order Processing	$64	6	$384
Phone jack and wire	$10	6	$60
Installation labor (1st hour)	$120	6	$720

Other Costs	Price per item	# of sites	Total
Cameras	$2,642.00	6	$15,852.00
VDOT Installation Fees	See worksheet	6	$11,031.12

DSL Options Total Cost			
DSL Speed Option	Total Cost (Year 1) Service & Installation Fee	Reoccurring Costs Service Fee	Net Present Costs 5 Years of Operation
DSL 384K / 384 K Static IP	$38,357.52	$9,356.40	$75,783.12
DSL 768K / 768 K Static IP	$41,957.52	$12,956.40	$93,783.12
DSL 7.1 M / 768 K Static IP	$47,357.52	$18,356.40	$120,783.12

Assumptions
1. No existing phone lines present at sites, installation will be needed
2. First hours of labor will cover installation
3. No connection charge for DSL (Verizon as of 2/20/03)
4. DSL must be available in the area

Notes
1. Prices as of 2/20/03
2. Phone line is required for DSL service to a site
3. Extra charges may be applied if existing phone line is not within reasonable distance of site
4. Additional labor for phone line installation if needed is $40 per 1/2 hour after the 1st hour
5. DSL is only available within limited distances of a provider central office
6. Source: Verizon Online
7. Website to determine DSL availability http://www.dslreports.com/

Appendix V: T1

Partial T-1 Costs				
Partial T-1 Speed Options	Price / Month	# of months	# of sites	Yearly Service Charge Per option
T1 Port Fee (384K)	$350.00	12	6	$25,200.00
T1 Port Fee (512K)	$450.00	12	6	$32,400.00
T1 Port Fee (768K)	$550.00	12	6	$39,600.00

Additional T1 Fees	Fee	# of sites	Total start up costs
T1 Installation Fee	$545.00	6	$3,270.00
T1 Circuit and Transport Fees	$975.00	6	$5,850.00

Other Costs	Price per item	# of sites	Total
Cameras	$2,642.00	6	$15,852.00
VDOT Installation Fees	See worksheet	6	$11,031.12

Partial T1 Options Total Cost			
Partial T1 Speed Option	Total Cost (Year 1) Service & Installation Fee	Reoccurring Costs Service Fee	Net Present Costs 5 Years of Operation
T1 (384K)	$61,203.12	$25,200.00	$162,003.12
T1 (512K)	$68,403.12	$32,400.00	$198,003.12
T1 (786K)	$75,603.12	$39,600.00	$234,003.12

Assumptions

1. Prices as of March 10, 2003
2. Prices assume 1 year contract
3. A partial T-1 line is needed at every site location since locations are separate

Note:

1. Source: Ntelos Contact, Robin Boston 540-953-3580 Ext. 5452

Appendix VI: ISDN

ISDN Costs				
Item	Price / unit	# of unites	# of months	Total Charge
Phone line (monthly)	$20.00	12	12	$2,880
ISDN 128 kbps service (monthly)	$300	6	12	$21,600
Router	$300	6		$1,800

Verizon Phone Line Installation Item	Price / unit	# of sites	total units	Total Charge
Order Processing	$64	6	12	$768
Phone jack and wire	$10	6	12	$120
Installation labor (1st hour)	$120	6	6	$720

Other Costs	Price per item	# of sites	Total
Cameras	$2,642.00	6	$15,852.00
VDOT Installation Fees	See worksheet	6	$11,031.12

ISDN Options Total Cost		
Total Cost (Year 1)	Reoccurring Costs	Net Present Costs
Service & Installation Fee	Service Fee	5 Years of Operation
$54,771	$24,480	$152,691.12

Assumptions

1. 2 phone lines are needed at each location for ISDN
1. No existing line present at site, installation will be needed
3. First hours of labor will cover installation of both lines needed at each site
3. ISDN Service selected is the ISDN LAN unlimited service
4. Router will be needed at each sites to direct the service to the devices
5. ISDN Service must be available in the area

Notes

1. Prices as of 2/20/03
2. Phone line is required for ISDN service to a site, 64 kbps per line, 2 lines needed to achieve 128 kbps
3. Extra charges may be applied if existing phone line is not within reasonable distance of site
4. Additional labor for phone line installation if needed is $40 per 1/2 hour after the 1st hour
5. Source: Verizon Online

Appendix VII: Dialup

Dial-up Phone Access Costs				
Item	Price / unit	# of units	# of months	Total Charge
Phone line (monthly)	$20.00	6	12	$1,440
Internet service (monthly)	$20	6	12	$1,440

Verizon Phone Line Installation	Price / unit	# of sites	total units	Total Charge
Order Processing	$64	6	6	$384
Phone jack and wire	$10	6	6	$60
Installation labor (1st hour)	$120	6	8	$960

Other Costs	Price per item	# of sites	Total
Cameras	$2,642.00	6	$15,852.00
VDOT Installation Fees	See worksheet	6	$11,031.12

Dialup Internet Options Total Cost		
Total Cost (Year 1)	Reoccurring Costs	Net Present Costs
Service & Installation Fee	Service Fee	5 Years of Operation
$31,167	$2,880	$42,687.12

Assumptions

1. Phone line needed at each location
2. No existing line present at site, installation will be needed
3. One hour of Verizon labor needed for 2/3 of the sites and two hours needed for 1/3 of the sites because some of the sites will be more difficult to get a phone line installed.
4. Dialup internet service will be unlimited (speed 56 kbps)

Notes

1. Prices as of 2/20/03
2. Extra charges may be applied if existing phone line is not within reasonable distance of site
3. Additional labor for phone line installation if needed is $40 per 1/2 hour after the 1st hour
4. Source: Verizon Online