A CASE FOR INTELLIGENT TRANSPORTATION SYSTEM (ITS) TELECOMMUNICATION ANALYSIS

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Maryland State Highway Administration's ITS Telecommunications Study

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1. Introduction

In the fall of 1995 the Maryland State Highway Administration (MSHA) decided to take a closer look at how to build an affordable ITS network to support its growing Chesapeake Highway Advisories for Routing Traffic (CHART) program. In doing so, the MSHA departed from the prevalent ITS practice of building a private fiber optic telecommunications infrastructure in favor of first performing a telecommunications analysis to determine if a build option was the most cost-effective approach for meeting its telecommunications needs. Telecommunications analysis is not uncommon in the private or federal government sectors and is usually undertaken prior to implementing a large communications infrastructure not only because of the cost, but also to avoid building a network that will not meet operational needs. This communications analysis was the second of two studies that MSHA undertook using a systems engineering approach to define a communications infrastructure that met its business needs. In each case, the agency made or changed previous decisions based on the information and recommendations presented in the analyses.

The decision to perform the analysis was based, in part, on the success of a previous study which examined MSHA's network environment and then developed a technical recommendation to build a network that would link the agency's 45 facilities together. The analysis recommended a fairly sophisticated solution that minimized lease charges and employed advanced hardware and software. The study's recommendations were subsequently implemented, the result of which created a well-architected, robust, state-of-the-art enterprisewide network. The success of this existing network is largely attributable to the analysis that preceded it and attests to the importance of performing such an analysis before building a large communications infrastructure.

Similarly, the case was made that such an analysis should also be performed prior to building MSHA's ITS communications network. The agency recognized that it did not have the resident expertise in building and maintaining a large telecommunications infrastructure and turned to a systems integration firm to perform the study. Computer Sciences Corporation (CSC), Systems Engineering Division under subcontract to Parsons Brinckerhoff Farradyne Inc. (PBFI) performed the analysis. CSC is a large systems integration firm with expertise and experience in analyzing and building large complex networks. The analysis developed technical options based on functional and performance requirements and compared the costs of those options (including owning versus leasing) over a ten year life cycle. The analysis lasted nine months and consisted of three phases: 1) functional and performance requirements analysis and validation, 2) development of various network options, and 3) the costing of those options.

As a result of the analysis MSHA decided not to build a fully owned private fiber optic network. Instead, MSHA decided to build hybrid network infrastructure relying predominantly on leased services while. also pursuing resource sharing initiatives. By opting not to build its own fiber optic network, MSHA will save 72 million dollars. This decision was based primarily on cost in the ten-year lifetime but also on identified technical solutions that could fulfill defined business objectives and mitigate the agency's risk from rapid technology and telecommunications industry change. While the lease versus build issue was an important theme of the analysis, other critical system factors came to light that affected decisions for ITS communications and diminished the lease versus build issue. The lease versus build question simply became two options of many that could fulfill MSHA's ITS requirements.

The US Department of Transportation Intelligent Transportation Systems Joint Program Office, (ITS/JPO) requested that the methodology used for the analysis be documented after it learned of Maryland's approach shortly after the study began. This report describes Maryland's experience in performing an ITS telecommunications analysis including: the reasons for performing the analysis, the approach used, the findings of the analysis, lessons learned, the merits and drawbacks of performing such an analysis and some considerations other DOTS may want to use in making a similar decision. This experience underscores the importance of performing a communications analysis prior to building an ITS or any large communications network.

2. CHART Program Overview

The MSHA's CHART program is one of the first statewide ITS programs in the nation. MSHA operates a Statewide Operations Center (SOC) that serves the entire state, and any network analysis would have to examine the long term needs necessary for a network covering a broad geographic area. The CHART program plans called for 1019 device locations to be located along 546 miles of highways across 58 road segments. Devices to be used included: closed circuit television (CCTV), changeable message signs (CMS), traveler's advisory radio (TAR), radar detectors, loop detectors, and pavement and weather sensors. The MSHA also wanted to be able to integrate the traffic signal system and distribute information to public kiosks and the Internet. Information flowing from these devices feeds into an information system that processes the data into information that allows operators to monitor and manage the transportation systems and advise travelers accordingly.

The CHART program is jointly operated by three State agencies; the MSHA, the Maryland State Police (MSP) and Maryland Transportation Authority (MdTA), but also includes coordination with other agencies such as the Mass Transit Administration (MTA). The program has four principle functional components: traffic monitoring (surveillance and detection), incident response and management, traffic management, and traveler's information. Operationally, the CHART program involves the coordination of a number of business units from several state and local agencies to perform these functions. Information is gathered from field devices, motorist call-ins and field patrols and relayed to the SOC. The SOC manages the transportation system by using this information to advise field units, other agencies, and travelers of incidents and roadway conditions. Resources are deployed from satellite traffic operation centers, maintenance shops, district offices, toll facilities, and MSP barracks or roving patrols in response to incidents and emergencies. Information is fed to the local media, changeable message signs and traveler's advisory radio to alert the public of traffic conditions. The CHART program has a long history of coordination and cooperation in this multi-jurisdictional environment that is the cornerstone of its success,

Communications, while not a functional area, plays a critical role in CHART operations. The mixture of devices, systems and people needs to be linked electronically to provide the flow of information necessary for monitoring and managing traffic conditions. The CHART program represents a multi-million dollar investment and the communications infrastructure required for such a system was originally estimated at over 100 million dollars. MSHA recognized that building a private fiber optic network was costly and to avoid such costs, MSHA had pursued two resource sharing initiatives in which right-of-way access was offered in exchange for telecommunications capacity. In the first initiative the State of Maryland received approximately 75 miles of dark fiber optic cable (48 strands) on I-83, the west side of I-695, and I-95 from Baltimore to Washington, DC. The second initiative did not yield any bidders. With the less than successful outcome of the second initiative, the MSHA was faced with building the network infrastructure at its own cost.

3. Background - What led to the Analysis

Like many ITS programs, MSHA was seriously considering building a private fiber optic network to support ITS applications. A fiber optic network was considered because it could deliver the high bandwidth necessary for the network architecture being considered at the time. MSHA wanted to upgrade its compressed video to full motion video and add approximately 200 new cameras and several hundred non-CCTV field devices. In addition, by owning the network, MSHA could have maximum control over network availability and reliability -- a key consideration for an agency sensitive to public safety issues.

The existing ITS network transmits video in compressed format from 22 field-based CCTV cameras via Tl carrier circuits and data from dedicated and dial-up connections to a Statewide Operations Center (SOC). It is important to note that this existing architecture is a “star” configuration composed entirely of point-to-point leased lines from field devices to the SOC. These links did not consider Local Access Transport Areas (LATAs) and therefore leased charges were quite high, particularly for the long-distance dial-up lines.

Additionally, the long term costs of leasing versus building were considered to outweigh the high initial capital costs to build a fiber optic network. Based on the network design being used at the time lease charges were considered excessive since there were instances of thousand dollar monthly phones bills per device. There was also a distrust of service providers being able to adequately provide “good” availability and reliability. Sensitive to public safety concerns, MSHA staff were emphatic that the network “had to be up.”

These reasons for owning a private network are common to DOTs and ITS programs and, likewise, MSHA considered the build option. Internal MSHA staff, however, had not performed any in-depth analysis that considered life-cycle network operations and maintenance costs nor did they consider different network architectures that would minimize lease charges. There was little internal expertise or experience with service provider pricing or with optimizing network architecture for communications loads and cost. Moreover, statistics were not kept that could substantiate claims of poor service from service providers. MSHA staff could not quantify what “had to be up” meant because they were unfamiliar with reliability and availability performance measures. They could not identify what they were currently achieving in terms of reliability and availability or what they wanted to have. Without complete costs, consideration of alternative network architectures or adequate data to measure availability or reliability, the premise that owning was superior to leasing could not be validated.

MSHA decided to perform the study because the agency made a business decision to analyze cost and technical options based on defined business requirements before spending millions of dollars. This approach is generally followed for capital-intensive road projects and is a widespread practice for most organizations when building similarly sized networks. As a public-sector agency subject to legislative and executive oversight and accountability, performing a cost analysis was the prudent choice given the high cost and surrounding circumstances. Moreover, there were several specific reasons why the MSHA decided to perform the analysis, all of which underscored the fact that ITS communications infrastructure represented a large capital investment and there was significant risk in making unwise and long lasting decisions. Specifically:

- Full funding needed to build a private network was not available and resource sharing efforts had been only partially successful.
- A previous enterprisewide network study for administrative and engineering applications indicated that there was potentially a long break-even point if a build option was pursued. The break-even point is defined as the number years for leased line charges to equal the cost for building a private fiber network assuming use of compressed video.

The MSHA was in the process of networking its facilities in order to support its business information systems and e-mail. This effort necessarily involved first performing a network analysis to determine bandwidth requirements and an appropriate network infrastructure for the MSHA. During the course of this study it was noted that MSHA was building two wide area networks: an administrative one for carrying business applications and e-mail, and an ITS network. Recognizing that there may be efficiencies to be gained, the study was expanded to include the ITS network, but only a cursory, high level, break-even analysis was performed. This analysis indicated that a proposed fiber optic network would cost 119 million dollars and the break-even point could be as high as 88 years. This analysis, however, was based on rough estimates of equipment, did not consider alternative architectures, and did not fully consider operations and maintenance costs. Recognizing this, the study team recommended a more in-depth cost analysis be performed before making a build decision.

- Internal consensus could not be reached on how best to build an expanded ITS network. This was a result of unfamiliarity with telecommunications technology, uncertainty about technological change, uncertainty about changes in the telecommunications industry and loosely defined business requirements. Requirements and technology choices kept shifting, this resulted in a moving target syndrome, and decisions could not be easily made.
- Given the size and scope of the network to be built, it was important to consider the feasibility of allowing other State agencies to use the network. As an Executive branch agency, a “good citizen” policy was adopted by the MSHA requiring that the network be built in concert with the statewide telecommunications direction. As a result, the study was conducted with the Maryland Department of General Services’ participation. The MDGS is the State agency responsible for planning and providing telecommunications services for the State.

Given the high cost of the telecommunications portion of the CHART program, it was clearly the intent of the agency to make a cost-effective, prudent and defensible decision regarding its telecommunications infrastructure.

4. Methodology

Like many other state DOTs, MSHA increasingly relies on information technology to improve and perform its core functions. ITS applications represent, perhaps, the largest technology investment DOTs will make in the next several years; an investment that rivals, in cost, significant civil engineering projects. While the MSHA has significant expertise in building and maintaining highways and bridges, the agency recognized that it did not have a similar level of expertise in building and maintaining a large telecommunications infrastructure required for ITS deployment. Accordingly, the agency turned to a systems integration firm, CSC, with telecommunications expertise and experience in building large complex networks. This was not a departure from the traditional transportation consulting firms which specialized in ITS, but rather a necessary addition and complement to the range of disciplines needed to build large-scale ITS systems. In fact, the systems integration firm worked closely with the traffic engineering consulting firms as well as internal engineering staff to conduct the analysis. A team was assembled that included MSHA senior management, internal ITS stakeholders, the traffic engineering and ITS consultants, IS/IT staff, CHART users and operators, and MSHA project engineers. Each contributed to various stages of the study as it progressed. What the systems integration firm brought to the table was a well-defined system engineering methodology and extensive telecommunications expertise needed to clearly define business requirements, perform alternatives analysis and make sound technical recommendations in the context of a changing technology environment

A summary of the systems engineering and cost analysis is provided below. A detailed report describing the methodology employed for this analysis is available from the U.S. DOT ITS/JPO or the Maryland State Highway Administration.

4.1. Systems Engineering Method

The Systems Engineering method used by MSHA is derived from a CSC corporate methodology for complex technology projects and includes five major steps: 1) defining program goals, objectives, and high-level requirements; 2) deriving lower-level technical requirements that had not been identified by MSHA, 3) assessing available standards and technology capable of meeting the requirements, 4) analyzing various telecommunications topologies (i.e., ways to connect devices), and 5) developing alternatives in terms of lease, buy, and lease/buy hybrid options.

Requirements Analysis

It was important to first achieve stakeholder consensus on CHART goals, functional requirements and deployment schedules before developing technical solutions. This is similar to the situation where design, engineering and construction of new roadways and bridges cannot begin until careful planning identifies why they are needed, who they will serve and where they will be. Only then can the road be adequately designed based on the nature of the traffic and expected volume of vehicles expected to travel over it. Likewise an efficient telecommunications network for CHART could not be implemented without similar knowledge of why it was needed, who would be served and how it would be used by the CHART program. Only then could the technical characteristics of the data, video, and voice traffic be identified with any certainty.

Without identifying detailed telecommunications requirements produced by a consensus on functional objectives, there is no basis for a technical solution other than its technological appeal.

Therefore the risk is high that the solution employed would not meet the functional program requirements and may have to be re-architected at significant cost. This is similar to a case where a road or bridge is under-designed and must be rebuilt because volumes or vehicle types were poorly understood prior to design. MSHA wanted to avoid this,

The next step was to derive detailed requirements based on the defined functional requirements. MSHA did not want to bias for or against any solution, equipment, or acquisition method, so requirements were described by the nature of the traffic that the network would have to support. This included serial data from the ITS devices and field controllers, LAN data, voice, and video traffic. Important requirements were derived for each type. Examples of the detailed requirements are device message sizes and formats, frequency of transmission, and polling interval for low-speed devices; image and motion quality, transmission delay, number of simultaneously viewable images, and camera selection and control constraints for CCTV. Overall reliability, maintainability, and availability requirements for the network backbone were also derived during this step from information obtained about ITS device failure rates and the ability to respond to outages on the road systems during peak travel times.

Technical Architecture Alternatives

Key to the lease versus own issue for CHART was first describing what kind of network was needed regardless of how it would be obtained. Lease or own became secondary to finding the technical approach that best met CHART's needs. The fact that several telecommunications providers have expanding and robust fiber optic infrastructure in Maryland upon which they base commercial services validated this approach.

Another reason that the technical approach to the network was considered important was the status of resource sharing in Maryland at the time. Maryland had a resource sharing initiative primarily for fiber along the right-of-way pending in the form of a Request-For-Proposal (RFP). Therefore one of the constraints imposed on any recommended architecture was that the implemented network be able to accommodate either fiber optic media or leased commercial services depending on the timing and success of this future initiative. MSHA needed to be in a position to support, fund, and provide for a CHART network that would be indifferent to whether or not this initiative proved successful. Finding a technical solution that could be used regardless of whether CHART used fiber optic media or leased commercial services was critical.

These and other issues were taken into account during the development of alternatives. Technical architectures were developed by assessing available communications technologies, commercial services, and centralized and decentralized topological alternatives (i.e., how devices are connected to operations centers). These were then expressed in terms of lease, buy, and hybrids for costing. Since MSHA has approximately 40 maintenance facilities across the state, they were considered for incorporation into the telecommunications network by the architecture as hubbing points for leased circuits coming from the ITS field traffic management device locations. This allowed a decentralized communications strategy to be compared with the more traditional centralized method of terminating field device communications.

The technologies considered included traditional ITS fiber-based approaches that rely on analog video and SONET-based data and voice, as well as consolidated multimedia digital networks that combined all traffic over Asynchronous Transfer Mode (ATM), Time Division Multiplexing

(TDM), and Synchronous Optical Network (SONET) backbones. For low-speed devices, direct connection to fiber as well as leased solutions including dedicated leased, switched analog, and switched digital Integrated Services Digital Network (ISDN) were evaluated. Once this was done, achieving the desired solution at the lowest possible cost with respect to lease versus own was targeted.

4.2. *Cost Analysis Method*

Communications costs were grouped into five cost elements: construction, leased circuits, network equipment, the operations, administration, maintenance, and provisioning (OAM&P) labor necessary, and communications software.

Construction - Construction costs included roadside enclosures and cable plant installation costs for backbone cable paralleling the right-of-way, and connections to the backbone from individual devices. Likely construction methods for each type of installation and associated unit costs were supplied by MSHA engineers and were based on recent bids. When cable installations for power and communications were anticipated to be co-located in the same trench, the cost was considered a “sunk” investment and not included for any alternative. These costs were then included in a separate assessment of device costs.

Leased circuits - Leased circuit costs included the installation of commercial telecommunications lines and associated recurring costs obtained from vendor quotations Cost data from multiple providers was requested, obtained, and used in the study. MSHA was provided with summarized cost data for circuits by CSC but not individual circuit prices to protect the providers’ confidentiality. The providers were shown network architecture drawings and given detailed cost worksheets to fill out for individual circuits between CHART sites. Leased circuit activation schedules were derived from the CHART device deployment timeline. The total leased circuit cost for each life cycle year was calculated by summing the one-time, fixed recurring, and variable recurring for all circuits activated and active during that year.

Equipment - Equipment costs included the purchase cost and maintenance for representative electronics, hardware, and management systems. A modest market survey of manufacturers and resellers was conducted to identify representative products which could satisfy each technical architecture. A representative network layout based on the relevant equipment types was developed to determine the appropriate equipment models and quantities needed to match deployment to the designated locations. Next, a sample equipment configuration was created for each distinct acquisition option. These configurations were verified with vendor representatives, and purchase and warranty costs were obtained. Since most vendors’ outside maintenance plans are at least 1O-l 5 percent of purchase each year, in-house sparing and replacement was assumed as a more realistic maintenance alternative. Sparing and upgrades were assumed to be at an annual level of 5 percent of the equipment purchase cost starting in the year of purchase. Maintenance-related labor was covered under OAM&P staffing costs.

Labor - OAM&P labor costs included full-time staff to operate, control, configure, administer, and troubleshoot the network, and on-call labor to replace communications electronics and hardware based on typical mean time between failures (MTBF) and mean time to repair (MTTR) data. A professional communications engineering staff and 7x12 central help desk was assumed and staffing and labor costs for it were obtained from industry surveys

Software - Communications software costs included the purchase of commercial off-the-shelf (COTS) software to manage the network equipment as well as estimates for providing application software and systems needed to manage the collection, delivery, and distribution of CHART data and video to the user workstations. This was done to provide a realistic estimate of costs to SHA, especially in the case of integrating a distributed network with existing centralized software systems.

5. Requirements Definition

At the outset, the analysis team decided to conduct a requirements analysis that included a technique called "Use Case Analysis" to determine key business requirements for the CHART telecommunications network. This was done to develop stakeholder consensus on issues such as optimum incident detection times, video quality, who needed to have access to CHART information, how many cameras needed to be displayed at one time, how often did devices need to communicate with the Statewide Operations Center and what kind and how many devices needed to be connected to the network. Based on this information, viable network alternatives were defined and subsequently costed.

This phase consisted of interviewing key stakeholders in the MSHA ITS program, iteratively validating business and technical requirements and documenting the requirements. As a result, several important requirements were identified that directly impacted the development of technical alternatives. The following only highlights the key findings of this phase; a detailed description can be found in the ITS Telecommunications Analysis which is available from the U.S. DOT ITS/JPO or the MSHA.

5.1. Decentralized Network

During the course of the requirements phase, it became apparent that several stakeholders wanted access to CHART video and information. The most surprising finding was that those responsible for responding to incidents or during emergencies (e.g., snow storms, hurricanes, etc.) were emphatic about having direct access to CHART video and information. They reasoned that as first responders they needed to see an incident to determine what resources were needed to adequately respond to it. These stakeholders included the Maryland State Police, Maintenance Shops, MSHA District Offices and the Maryland Transportation Authority, all of which have responsibilities to respond to incidents or conduct emergency operations. This finding meant that while there was a central Statewide Operations Center with a command and control mode of operations, information was required by several facilities located throughout the State.

While this seemed an obvious requirement, it directly affected development of viable technical alternatives and expanded the scope of the analysis. The initial scope of work for CSC was to consider the lease versus buy issue with respect to the existing CHART network architecture. CHART's existing network architecture has all CCTV, devices and satellite Traffic Operations Centers connected to the Statewide Operations Center via point-to-point lines in a star topology. CSC recommended that a decentralized network architecture be explored since it may yield a more cost-effective approach than the star configuration by minimizing lease charges, particularly since the number of devices was high.

5.2. Video requirement

Another important and somewhat contentious issue among technical personnel planning the CHART system was the quality of video that was needed to support real time traffic monitoring and display to the public via local media outlets. Two forms of video are readily available in the marketplace: high-quality full motion video, which needs dedicated fiber or copper media or a very high bandwidth digital medium, or lower-quality compressed video, which can be digitized and carried over dedicated media as well as through public telecommunications circuits at much less capacity. The important discriminator between the two is the bandwidth needed to carry the resulting video signals. Full motion video requires at least 45 Mbps compared to a minimum of 384 Kbps for compressed, a difference between thousands per month and hundreds per month in lease costs per individual leased line.

The issue of video was determined by recording on videotape the two qualities of video and showing it to the CHART users and operators while posing the question, “Will this allow you to do your job?“. The question of “Which do you like better?’ was intentionally not asked. The results showed that the lower-quality signal was indeed adequate for all interested parties, so a decision was made to validate it as the minimum requirement for video.

6. Technical Requirements

Based on information developed during the study, critical CHART functional, operational, and performance requirements are now documented. Specific locations, types, and timeline for installation for devices have been identified on each CHART route. The role each MSHA facility is intended to play in terms of CHART data, video, and supporting system operation has been defined through the Use Case technique. Operational aspects that impacted the nature and sizing of the network have been identified. These include how frequently loops and detectors would communicate with CHART systems, at what data rate, and whether they would be polled or report based on preset conditions Rules for how the system would allow multiple operators to select, view, and control cameras simultaneously from different locations was defined. How CCTV images would be distributed within MSHA and externally to the media was identified, and how many images were required to be transmitted simultaneously and where they would be viewed was determined.

This information, along with the minimum quality of video needed was critical to obtain at the outset as it allowed bandwidth and delay requirements to be identified not just in general CHART terms, but for each specific telecommunications link in the network. Overall network requirements were identified by MSHA for reliability, availability, and maintainability. A goal of 99 percent for major backbone links was set, as well as a 4 hour response to failures. These requirements were deemed sufficient and consistent with the reliability of the field traffic management devices and MSHA’s ability to respond to device failures in the right-of-way during rush hour.

7. Development of Technical Alternatives

The network of roadways in Maryland designated as part of the CHART coverage area spreads across the entire state. It encompasses 546 miles, two major metropolitan areas north and south, a smaller population center to the west, and a heavily traveled tourist path eastward, to the ocean. Traffic volume, expectations for increases in volume, recurring congestion, and incidents that cause non-recurring congestion vary by major geographic area and even from roadway to roadway.

Based on the geography and Maryland's road network, 1019 ITS device sites with various inter-device densities were carefully planned by MSHA for each major geographic area, roadway, and intersection on an individual basis. For this reason, the decision was made that the question of build or lease had to be determined on the basis of individual roadways or groups of roads given placement and number of device sites as opposed to a binary decision of either building or leasing communications for the entire statewide coverage area.

The telecommunications alternatives were assembled to discover the most cost-effective strategy for major CHART routes. This was done by allocating to build or lease portions of the state defined by certain roadways or road segments into an option. The various items of cost needed to form a viable network were then accumulated. Factors considered in the allocation included each route's respective device density, the priority for installation of devices, the proximity of the route to major metropolitan centers, and the option to place communications equipment at various MSHA sites within the state. Multiple combinations of roadways were used with an increasing number of road miles with fiber optics for this series of options called hybrids. A total of 18 different hybrids were developed ranging from 68 miles of MSHA's existing fiber to 120 miles of new fiber construction. Where no construction was assumed for fiber to link device sites to MSHA facilities, leased circuits where included to the nearest MSHA site, then onto a fiber backbone at that point.

In addition to the hybrid options, four options were developed that used all leased circuits and no new construction of fiber on any CHART route. Leased options used two major topologies, centralized and decentralized. In one case, MSHA's shops and engineering offices suitable for equipment were included as network nodes for aggregating leased circuits from multiple field device sites. In this case, most of the resulting leased communications lines were analogous to local calls. In the other case, only the Statewide Operations Center was included in the network option, and most of the communications links were long distance lines.

8. Costs

The lowest cost telecommunications option evaluated was a hybrid which capitalized on 68 miles of pre-existing and available fiber optic capacity to link the SOC with major SHA engineering offices in Brooklandville and Greenbelt, and leases for all other telecommunication links. The total cost for a ten-year life cycle is estimated to be approximately $68600,000 in constant dollars and approximately $61,900,000 when discounting costs in out years to account for the effects of inflation. The cost of the most aggressive build option evaluated was approximately $92,300,000 in constant dollars and approximately $86,600,000 when discounting costs for the effects of inflation. Up-front expenditures would be approximately $29,000,000 higher than the lowest cost option.

9. Findings

Several useful findings result from the study that will guide MSHA's deployment of telecommunications and the CHART ITS program in general. From a dollars perspective, both the magnitude and the composition of the cost numbers tell a story. Since a hybrid lease/build option with a large percentage of lease is expected to generate the lowest life-cycle costs, it was the recommended option. By comparison, if MSHA would have undertaken a completely private telecommunications network, costs were estimated to be two times that of the recommended option, a difference of some $70M. For this reason consideration of an exclusively private network was dropped early in the study. Costs for each of the hybrid options evaluated were progressively higher -- proportionate with the amount of new construction needed to build the network. Life-cycle costs for all options considered are shown in Table 1.

Table 1- Costs for All Options Evaluated

	Ten Years		Five Years	
Option	current $	discounted $	current $	discounted $
L1	$92,251,741	$80,109,374	$43,170,796	$40,229,920
L2	$98,641,212	$85,700,681	$46,398,357	$43,248,855
L3	$71,378,211	$64,374,449	$45,929,005	$43,665,761
L4	$69,245,663	$62,426,815	$44,405,653	$42,212,837
H1	$68,619,035	$61,955,612	$44,513,519	$42,340,017
H1b	$69,770,552	$62,943,052	$45,127,084	$42,909,093
H1c	$71,278,408	$64,481,732	$46,911,703	$44,671,165
H1d	$69,704,264	$62,878,595	$45,063,677	$42,846,853
H1e	$71,155,086	$64,361,818	$46,793,743	$44,555,376
H2b	$74,140,350	$67,927,332	$52,153,555	$50,052,991
H2c	$78,014,008	$71,920,982	$56,873,408	$54,733,573
H2d	$74,952,971	$68,717,944	$52,929,352	$50,815,276
H2e	$78,461,634	$72,356,239	$57,301,572	$55,153,859
H3b	$75,410,631	$69,297,599	$53,951,764	$51,856,556
H3c	$79,555,690	$73,557,665	$58,953,905	$56,812,223
H3d	$75,903,314	$69,776,669	$54,423,026	$52,319,147
H3e	$79,606,552	$73,607,122	$59,002,556	$56,859,979
H4a	**$84,054,461**	**$78,208,153**	**$64,508,037**	**$62,320,299**
H4b	**$85,849,053**	**$80,094,434**	**$67,059,776**	**$64,821,887**
H4c	**$92,280,932**	**$86,596,380**	**$74,213,512**	**$71,897,179**
H4d	**$86,345,131**	**$80,576,804**	**$67,534,285**	**$65,287,666**
H4e	**$91,640,226**	**$85,973,377**	**$73,600,663**	**$71,295,605**

The composition of the individual life-cycle costs showed that for any option, the percentage of total cost for O&M was so significant (around one fourth) that special attention was given to how MSHA would provide for O&M Without proper O&M, any investment would be poorly spent. The detailed component costs for the lowest cost alternative are shown in Figure 1.

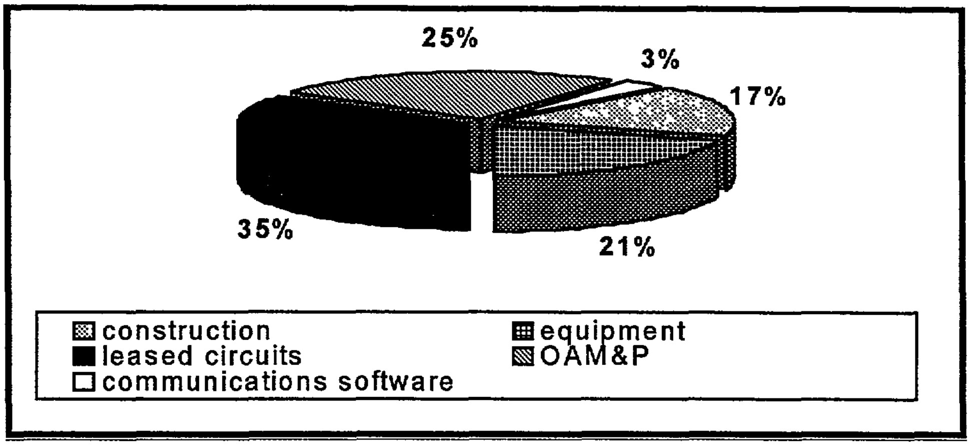

Figure 1 - Percentage of Life-Cycle Cost for Network Components

The large difference in dollars between more lease and more build is attributed to the cost of construction of the fiber optics, and the significant cost to connect to it from the ITS devices along the right-of-way, once fiber is placed. In Maryland, where power for roadside devices is obtained from the same aerial poles that telecommunications providers provide telco services from, it was cheaper to connect device sites to the telephone poles than to connect to fiber optic cabling in the right-of-way or median. This didn't imply that fiber isn't valuable to CHART, but that using it in a different way was more economical. Since the ITS devices CHART needs individually don't require much communications bandwidth, it made sense to aggregate them at a common point, then provide high-capacity links over fewer strands of the available fiber. This did two things to the MSHA network: first it eliminated expensive connection costs to the fiber and at the same time it preserved fiber strands for other use.

When looking at various comparisons between the cost numbers, several analyses were telling. When cumulative life-cycle costs were graphed for each year of the network's lifetime, it was estimated to take 25 years for convergence of the lease and hybrid options, even when hybrid meant that only half the network was built using private fiber optics. (See Figure 2). For a full build-out, the period of time to reach cost convergence was estimated to be much longer, about 45 years. With this in mind, potential shared resource agreements should be thoroughly explored before a decision is made to build all or part of the network as this will likely lower cumulative costs.

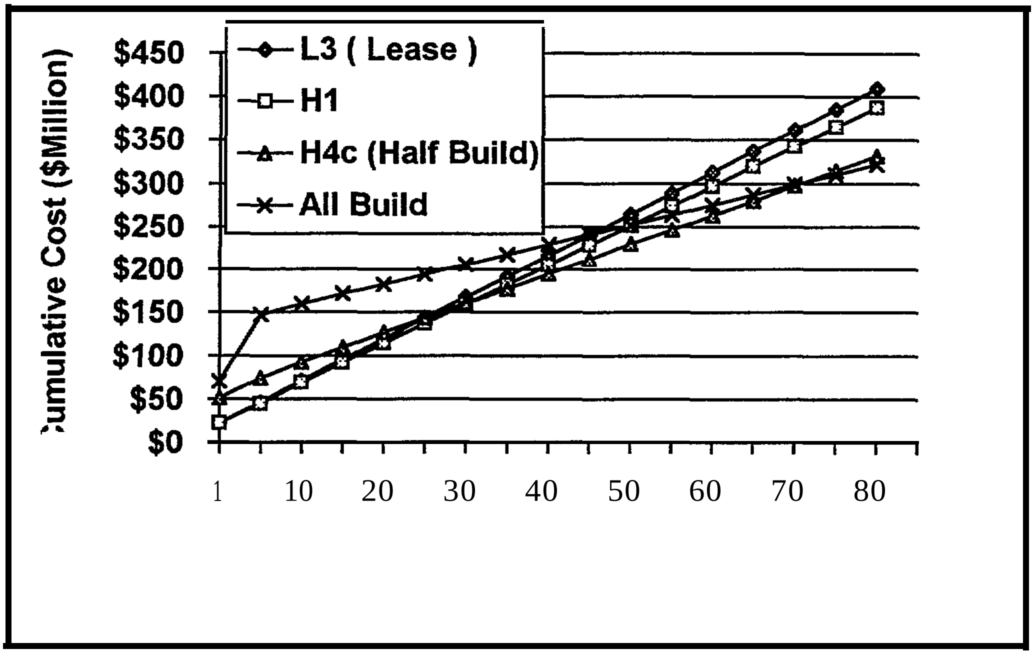

Figure 2 - Lease versus Hybrid and Build Break-Even Analysis

10. Lessons learned

Overall, this comprehensive study raised several important issues for MSHA to consider. It provided a structured basis to gather and analyze information regarding requirements, costs and comparison of various technical alternatives; its careful methodology and analysis resulted in some unexpected findings for MSHA. The following is a summary of lessons learned:

10.1. Architecting networks is a complicated undertaking and requires a skill set not readily available in MSHA

Perhaps the most important lesson learned in performing the analysis and what led MSHA to use a systems integration firm to do the analysis was the fact that the agency did not have the appropriate expertise and experience in designing and building large-scale networks. Equally important, the agency recognized that this expertise was not readily available through the traditional ITS or transportation engineering consultants. A DOT would not normally allow a telecommunications firm to plan, engineer and build a highway or bridge. Following the same logic, a DOT may want to examine the wisdom of allowing a civil or traffic engineering firm to plan, engineer, and build a large-scale telecommunications network. The optimum solution is to have the two disciplines work in concert with each other since ITS telecommunications development requires both.

10.2. How you designed a network is as important, if not more so, as the lease vs. build issue in regards to cost and viability

While the study analyzed the age-old question of whether to lease or build, this issue was not the basis of the analysis, but two options among several that were considered for technical merit and cost. The goal of analysis was to define the most cost-effective and viable option based on defined functional and performance requirements. There may be several ways of architecting a network such that it meets requirements, but each alternative can have widely varying costs particularly when using leased services. Consider the following table of five technical alternatives:

Alternative	Cost (present dollars, in millions)
L2 - All lease, star configuration	$98.6
L3 - All lease, decentralized backbone	$71.4
Hl - Mostly leased, uses 75 miles of existing fiber	$68.6
H4 - Most aggressive build with 188.7 miles of owned fiber	$92.3
All build	$140 (est.)

The L2 alternative was a fully leased network based on the existing star configuration employed by CHART. It represented the most expensive option of all. The L3 alternative using a decentralized backbone that minimized carrier charges was approximately 26 million dollars less than alternative L2 and was the second least expensive option. This wide difference indicates that how you design the network, whether it is owned or not, was a critical factor in the cost of the network. If MSHA had continued in a leased star configuration, the lease costs would have been higher than the most aggressive hybrid option.

10.3. Leased less expensive than build

It was assumed that the accumulation of long term lease charges would be higher than the capital costs of building a fiber optic network over time. It, therefore, was unexpected that the least expensive leased option (L3) was half the cost ($71.4 million) of the full build option ($140 million) for the ten-year period. Ten years was deemed an appropriate network life cycle for which to base a decision on since it was long enough to consider factors such as technical obsolescence but short enough to assume the value of leased bandwidth remained unchanged for each year. The leased architecture that yielded the lowest cost was architected to minimize lease charges. Using this architecture, the payback period would be 45 years when compared to building the full network. Clearly, technical knowledge of network engineering coupled with knowledge of the telecommunications industry (e.g., cost factors imposed by the effect of LATA boundaries) was critical to minimizing lease charges.

I0. 4. *Risk is mitigated*

By undertaking the analysis, MSHA mitigated two important risks: 1) that the agency would build a network that would not meet its needs, and 2) that the agency could not capitalize on technology and competitive changes that may yield lower communications costs during the life of the network. By understanding its requirements, particularly, who needed access to the information and how much bandwidth was required, MSHA could build a network that adequately addressed these requirements. Without understanding its requirements, MSHA ran the risk of building the "wrong" network that would be costly to change or redesign once built.

Technology improvements could be expected given a rapidly changing technology industry. Technology trends have generally resulted in overall lower costs of equipment and services. Additionally, with the passage of the Telecommunications Act of 1996 and the unfolding of a deregulated environment, prices for communications services could be expected to decline. CSC recommended that MSHA explore or keep a watchful eye on certain technologies that could reduce lease charges (e.g., Digital Subscriber Line technologies). CSC also recommended that MSHA not pursue long-term leases but rather only 3-year leases so that MSHA could capitalize on telecommunications reform. If lower costs do not materialize, the agency could still pursue a build option or renegotiate with providers for better prices. Were MSHA to build its own network with a large up-front capital investment, the agency's options would be significantly curtailed in a changing telecommunications environment.

11. Considerations for Other ITS Programs

Undertaking an analysis of the size and complexity of Maryland's effort may seem a daunting option for many ITS programs. DOTs may want to consider several issues when contemplating a similar approach to the one Maryland used.

Telecommunications analysis is a common and mandatory practice in the private and federal sectors when building large telecommunications infrastructures. Such analysis is also common practice in the civil engineering field when building highway or mass transit infrastructure. It is standard operating procedure in state DOTs for civil engineering projects. Often, a civil engineering project is years in planning before it ever reaches design. The method used in such projects is quite similar to the one used for the Maryland study: requirements and costs are carefully analyzed for several alternatives before a final decision is made on a particular option. ITS telecommunications is one of the most expensive components of ITS programs and ITS projects rival in cost medium to large civil engineering projects. It, therefore, makes sense to perform the same kind of up-front planning and analysis that is performed for civil engineering projects.

Like transportation, the telecommunications industry is huge and complex with an entirely different set of technical disciplines that DOTs may not be familiar with. This should be recognized up front and planned for either by retaining appropriate in-house staff or contracting with a firm experienced in this industry with a range of technical disciplines. It is extremely important that DOTs arm themselves with appropriate telecommunications expertise and experience to adequately play in this arena. Not to do so heightens the risk of making unwise cost and design decisions.

The study results are not transferable to other ITS programs since the results were based on the costing of technical alternatives that met defined MSHA requirements. If the requirements were to change so too would the technical alternatives and, therefore, costs. For example, if MSHA had decided that full motion video was required, then a build option may have been the most cost-effective option. While this is true, other programs should consider performing a structured analysis prior to making decisions on what type of network to build. Just having information on "costs and technical alternatives may cause states to reexamine their requirements. This can be compared to shopping for a new car; while a Mercedes is a very nice car to have, the price may cause one to reconsider a lesser model, but with same basic functionality.

While the results are not transferable, the systems engineering and cost analysis method is. Performing an analysis allows an agency to define its requirements and then to objectively weigh the pros and cons of technical alternatives with associated costs. It also provides agencies the ability to consider the opportunity costs associated with building the telecommunications portion of an ITS system. A less expensive network may allow an ITS program to devote more of its budget to ITS functions (e.g., more coverage area being served, more devices deployed, etc.) thereby making the program more effective. A cost savings identified of 70 million (if full build were performed) or even 23.6 million (the most aggressive hybrid option) can go a long way for Maryland's ITS program or even other transportation areas in the next ten years.

One of the most important requirements to identify for an ITS telecommunication infrastructure is how much area must be covered. Since CHART is a statewide program, the analysis considered the need for a network covering a wide geographical area, therefore costs and technical architectures could be identified for the full network. Many ITS programs are urban in nature and initially confined to a small geographic area, but planned to be expanded later when funds become available. It may be important to consider beforehand what the ultimate geographic area will be, since the type and nature of a network design may change significantly based on the size and scope of the network. MSHA's star configuration may have been an adequate network design for a relatively small initial implementation, but would have become the second most costly option to implement when the program expanded Likewise, an owned fiber optic network may not seem so costly when confined to a small geographic area, but when building out to a fuller geographic area, costs quickly escalate. Should the ITS program expand to wider geographic area, an analysis should be performed based on the changed requirements set.

12. Advantages and Disadvantages

Clearly, the analysis was very beneficial to MSHA. Many of the benefits of performing the study have already been identified in this report. Generally, it provided the information the agency needed to make an informed decision regarding its ITS telecommunications infrastructure. Overall, the agency's risk was lowered both with respect to identifying a network architecture that would meet its long term needs and in terms of cost and technical strategies to well-position the agency in a changing telecommunications environment.

Despite an obvious and logical need to perform such an analysis, there are some disadvantages, particularly for programs that are already well underway or have already contemplated certain network architectures. The most obvious disadvantage is time. The study took nine months to complete and for agencies eager to deploy ITS systems this may seem an inordinate and unacceptable amount of time. This is a relatively short time frame, however, when compared to civil engineering planning and analysis. Stakeholders may become very frustrated with the delay, particularly when work is stopped or delayed pending the results of the study. This was the case for MSHA, when work and Request-for-Bids were delayed raising the frustration level of internal and external stakeholders.

Another disadvantage is that organizational stress may occur because existing stakeholders may not welcome an analysis. Technical positions may be questioned based on defined requirements and cost, and different decisions may be made as a result of the analysis. This creates a great deal of organizational stress for an agency since some stakeholders may have their positions overturned This situation applies to both internal and external stakeholders. For example, the study recommended that MSHA pursue digital video transmission rather than analog since the agency did not have a legacy stake in analog technology and there were clear advantages to using digital. This recommendation, if employed, would obviate the need to use any analog equipment. The analog equipment vendor, therefore, could become disconsolate with the potential loss of business. Likewise, internal stakeholders may also feel threatened if their positions on technical matters are challenged. Change, no matter how large or small, is always difficult to manage for organizations. Internal stakeholders may fear a loss of status, control or even begin to question their role in the organization. To mitigate this stress, it is critical to conduct the analysis in the most objective manner as possible and to involve stakeholders as much as possible.

13. Cost of Analysis

The cost of the analysis was $270,000, of which $50,000 was directed towards the documentation of the method used. This represents less than one percent the cost of building the network The network design is estimated to be approximately $350,000 to $500,000 making the combined cost about 1 to 2 percent of the total cost to build ($68.6 million over a IO-year life cycle). This cost can be favorably compared to similar size civil engineering planning, specifications and estimates, and design costs which generally run greater than 10 percent of the total cost of the project.

14. Summary

Findings of the cost analysis were significant. A decentralized hybrid option with a substantial portion of leased communications circuits was the lowest cost over the life cycle -- approximately $70M. By comparison, a complete private fiber optic build-out was estimated to be $140M. Hybrid alternatives increased from $70M to $90M according to the amount of fiber optic construction. The more fiber optics, the higher the cost.