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16. ABSTRACT

An evaluation of communication technologies for application to TMC-TMS (Transportation Management Center to Transportation Management Site) communications in Caltrans District 1. Wireless and wired technologies have been evaluated for prospective use, with pros and cons presented in general as well as site-specific analysis. The results of this study are applicable to other Districts and DOTS, for both rural and urban use. Three major deliverables were received as a result of this research:

- Literature Review of Communications Methods Used to Connect Rural Field Elements to a TMC and Related Remote-Sensing Communications Techniques
- Research Analysis of Preferred Technologies and Site Evaluations for the project entitled: Improve communications between TMC and TMS elements in a rural environment through a system that is deployable statewide (2004MOB.10) – #TS-507
- Handbook for Evaluating TMS to TMC Communication Options for the project entitled: Improve communications between TMC and TMS elements in a rural environment through a system that is deployable statewide (2004MOB.10) - #TS-507

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Improve Communications Between TMC And TMS Elements In A Rural Environment Through A System That Is Deployable Statewide

Division of Research
& Innovation

Final Report

Report CA08-0971
October 2008

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Final Report

Report No. CA08-0971

October 2008

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DISCLAIMER STATEMENT

Final Report for the project entitled:

Improve communications between TMC and TMS elements in a rural environment through a system that is deployable statewide (2004MOB.10) – #TS-507

by

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EXECUTIVE SUMMARY

In cooperation with the California Department of Transportation, Montana State University's Western Transportation Institute has conducted an evaluation of communication technologies for application to TMC-TMS (Transportation Management Center to Transportation Management Site) communications in Caltrans District 1. Wireless and wired technologies have been evaluated for prospective use, with pros and cons presented in general as well as site-specific analysis. The results of this study are applicable to other Districts and DOTS, for both rural and urban use.

In addition to and preceding this final report, three in-depth reports were produced as project deliverables:

- Literature Review of Communications Methods Used to Connect Rural Field Elements to a TMC and Related Remote-Sensing Communications Techniques
- Research Analysis of Preferred Technologies and Site Evaluations for the project entitled: Improve communications between TMC and TMS elements in a rural environment through a system that is deployable statewide (2004MOB.10) – #TS-507
- Handbook for Evaluating TMS to TMC Communication Options for the project entitled: Improve communications between TMC and TMS elements in a rural environment through a system that is deployable statewide (2004MOB.10) - #TS-507

This document is presented as a high-level summary, and the documents above should be referenced for further detail regarding project work and associated analysis and recommendations.

1. INTRODUCTION

In rural areas there are three primary factors that define potential communication capabilities: environment, power and communications infrastructure. The object of this study was to determine ways to provide communication links to remote field element locations so that they are as reliable as possible given the constraints imposed by the environment, power and communications infrastructure.

The California Department of Transportation (Caltrans) District 1 Transportation Management Center (TMC) coordinates transportation operations for northwest California, serving Del Norte, Humboldt, Lake and Mendocino counties. The TMC performs a wide range of functions, including traffic surveillance, incident detection and management support, environmental monitoring, information dissemination, data collection and evacuation support. Given these functions, the TMC may be thought of as the hub to which numerous spokes (ex. field elements – CCTVs, sensors, etc.) are connected.

District 1 has deployed field elements at key Transportation Management Sites (TMS) including Changeable Message Signs (CMS), Highway Advisory Radio (HAR), Road Weather Information Systems (RWIS), Closed Circuit Television Cameras (CCTV), Radar CMS, signal controllers and Weigh-in-Motion (WIM) detection systems. Most of the CCTV cameras within District 1 are pointed at CMS for message and sign operation verification purposes. A cursory estimated inventory lists 28 CCTV, 19 CMS, and 6 RWIS field elements in District 1.

The primary technologies used for TMC-TMS communications in District 1 are dial-up Plain Old Telephone Service (POTS) and General Packet Radio Service (GPRS) cellular. Digital Subscriber Line (DSL) services are available in some areas, but have not been implemented for this application. District 1 uses an Internet Protocol (IP) based communications network.

District 1 faces communications challenges associated with terrain, vegetation (including redwood forests – see Figure 1), distance and remoteness. In sparsely populated rural locations, cellular and even landline telephone services and infrastructure may be unavailable or, at best, they are unreliable and/or their use may be expensive. Alternatives, such as satellite, are available, but suffer from their own limitations and may be cost-prohibitive. Establishing communications with field devices in rural areas poses significant challenges resulting in low data transfer rates; poor reliability; decreased effectiveness and higher deployment, operational, monitoring, and maintenance costs.

To address these problems, the evaluation of new technologies, investigation of the reallocation of the RF spectrum for public safety use and investigation and evaluation of the current infrastructure merit further consideration. Telecommunications systems of this type use a combination of technologies. Ideally these systems can integrate existing field elements and allow for future expansion and technologies as needs evolve. New technologies may enhance current communications techniques and technologies used by Caltrans. Improving the communications technologies utilized to communicate with TMS in remote areas would also have a significant impact on traveler safety and enhance department and emergency operations.

Figure 1: Redwood Forest near CMS along US 101 in Caltrans District 1 – WTI Photo

2. BACKGROUND AND METHODOLOGY

A single site and the challenge of deploying a field element at that site provided the origin of this project, with the scope subsequently defined to cover the entire District, with potential statewide application. Caltrans wanted to deploy a camera at Collier's Tunnel (Figure 2) on US 199 near the Oregon border. In the absence of other options, GPRS Ethernet modems were tried and didn't work, even with high-gain Yagi antennas. Other options such as landline telephone service were not available. Environmental issues, particularly a tree fungus, prohibited microwave towers from being installed in this area for fear of spreading the fungus. Thus, there were few options to provide communications capability at this site.

Figure 2: Collier's Tunnel - WTI Photo

Caltrans posed this problem in more general form as Research Problem Statement #TS-507, entitled, "Improve communications between TMC and TMS elements in a rural environment through a system that is deployable statewide." This problem statement was posted in the Caltrans Division of Research and Innovation's 2005-2006 Research Problem Statements, and called for the following tasks and considerations:

- Conducting a literature search for communications methods tried elsewhere to connect field elements to the TMC.
- Choose the most promising technologies for connection in rural environment and develop test installations to prove which is most reliable and cost effective.
- Consider the use of current State systems including 800 MHz and microwave backbone.
- Document results in handbook form for utilization by other Districts in future installations.

A natural question arises from this solicitation: Why was the problem considered research? The answer is that the problem is difficult and no-one has a one-size-fits-all solution. There is no "silver bullet." The project team recognized the challenges of the problem and its research nature when writing their proposal, and included the following major tasks:

- Task 1: Literature Review
- Task 2: Technology Research and Evaluation
- Task 3: (Vendor) Demonstration
- Task 4: Document results in handbook form for utilization by other Districts in future installations

The proposal adhered closely to the research problem statement. The most significant deviation was the replacement of "test installation development" with "vendor demonstration." The project team recognized that the "solution" would be a "system" greater than individual installations and technologies. It would depend heavily on backbone or other backhaul capability, coupled with technologies that would link sites to such infrastructure. The third bullet point of the research problem statement asks for consideration of current State systems including 800 MHz and microwave. These systems, in conjunction with the allocation and auction of 700 MHz spectrum for public safety and other use, would be key considerations for prospective TMC-TMS communication systems.

The project team proposed to further investigate the following general classes of communication systems:

- Wireless wideband IP networks including WiMax and mesh networks,
- Point-to-point and point-to-multipoint RF systems,
- Satellite based networks, and
- Commercial telecommunications infrastructure.

In conjunction, the project team would conduct radio frequency (RF) path and propagation analyses to account for the impact of terrain, use tools such as Net Present Worth (NPW) to compare costs over time and investigate network topologies such as star, mesh and multi-hop to overcome the challenges of rural deployment.

Note that the problem statement called for statewide applicability. While the focus of this research would be District 1, it was recognized that solutions could and should have broader applicability. With that said, it was recognized that District 1 has challenges rivaled by few other areas in the continental United States.

3. LITERATURE REVIEW

The first project deliverable was a literature review. In conjunction with the literature review, the project team collected further background information about District 1 through a site visit and kick-off meeting, developed an overview of the District 1 ITS Architecture, and conducted a case study analysis of the Caltrans District 2 Field Element Network. The project team investigated and documented numerous applications of communication technologies to transportation and public safety. These technologies formed a base set of specific technologies and technology classes for further consideration and analysis, as they might be applied in District 1. Included were wireless technologies and spectrum classes:

- Wireless Fidelity (WiFi) – 802.11 a/b/g,
- WiMax (802.16),
- Mesh Networks,
- Dedicated Short Range Communications (DSRC),
- Cellular Technologies,
- Very High Frequency High Band (VHF High Band),
- Ultra High Frequency (UHF),
- 700, 800, 900 MHz,
- 2.4, 4.9, 5.8 GHz,
- Satellite,
- Other Technologies – e.g., Motorola Canopy System,
- Meteor Scatter,
- Point-to-Point Microwave,

and wired technologies:

- Plain Old Telephone System (POTS),
- Integrated Services Digital Network (ISDN),
- Digital Subscriber Lines (DSL),
- Fiber Optics, and
- Television (Cable).

In looking for similar, successful rural transportation deployment models, the project team found a useful example in District 1's neighbor to the east, District 2. Headquartered in Redding, Caltrans District 2 covers Northeastern California, including rural areas in the Northern Sierra and Trinity mountain ranges. Admittedly, District 2 has a greater population and more available infrastructure than District 1, and it does not have the redwood rain forests that characterize District 1. Still, District 2 faces the same challenges that typify rural Intelligent Transportation Systems (ITS) deployment, and District 2 ITS engineers have created what the project team viewed as the best known example of a rural ITS communications network deployment.

The District 2 ITS network has key elements that should be considered in District 1 including: a defined communication system migration path, a well-defined network topology consisting of a backbone and TMS, and the use of IP-based communications. District 2 used a hybrid network, and initiated many of their sites using POTS or ISDN, depending on availability, with dial-on-demand routing. District 2 implemented a private microwave network and continues to build out that network. Legacy sites are subsequently migrated to microwave. Initially, the network used engineered, point-to-point, unlicensed links. The next step in migration is to replace unlicensed links with licensed links.

As important as the hybrid nature of the network and the migration plan was the network topology. District 2 developed the concept of "ITS Nodes" (See Figure 3) in 2002 as aggregation points that connect field elements in proximity to provide a "gateway" to the microwave backbone (See Figure 4 and Figure 5) or to telco-provided backhaul infrastructure. The concept of "Roadside LANs" was used to describe the local area field element network. These concepts are fundamentally consistent with IP-based networks in general. Since District 1 was already using an IP-based network, it was apparent that similar techniques were applicable in District 1.

Figure 3: District 2 ITS Node South of Redding

Figure 4: A District 2 Backbone Site North of Reading

Figure 5: View to North from District 2 Backbone Site - WTI Photo

4. ANALYSIS OF PREFERRED TECHNOLOGIES AND SITE EVALUATIONS

The second project deliverable was the "Research Analysis of Preferred Technologies and Site Evaluations," which combined the general analysis of technologies with the specific analysis for prospective application to representative sites chosen in District 1. As exemplified by Collier's Tunnel, each site provides its own challenges and no single technology best meets the needs of all sites. The project team chose to present technologies for general applicability, with pros and cons enumerated, while recognizing that the selection of specific technologies would be site-dependent. Again, environment, power and communications infrastructure determine communications capability. Varying site and field element requirements necessitate analysis, including in-depth on-site analysis that is beyond the scope of this project, on a case-by-case basis.

4.1. Analysis of Preferred Technologies

The technologies identified in the literature review were further analyzed, with several additions (user-implemented fiber, DSL and copper) and deletions (DSRC) to create a final list of preferred technologies. Borrowing from the networking model used by District 2, the project team defined four primary network components or subsystems for analysis: backbone, gateway to backbone, roadside LAN and direct TMC to TMS. The direct TMC to TMS classification was used to include communication links that do not require the use of a District or State- dedicated backbone network. Telco-provided services naturally fall into this classification, as does the potential for direct links to the TMC.

Implicit in this analysis, and fundamental to subsequent site evaluation, was the assumption of a "best case backbone" consisting of existing sites in the State of California Public Safety Microwave Network and the State of California Public Safety 800 MHz Network. It must be noted that many of these sites are not enabled for the desired application at this time. For instance, many of the microwave sites are analog only. For this reason and because of the unlikelihood of developing further mountain-top and other off-road sites in District 1, the assumed backbone is referred to as "best case." Furthermore, the State of California Department of Government Services (DGS) has not been consulted regarding the feasibility of using its towers or facilities. The project team assumed the presence and capability of this network with a clear understanding that significant further development would be needed to enable it as such. Furthermore, it was determined that the development of an alternate backbone would be outside the scope of this research project. It should be noted, however, that alternate network topologies, particularly multi-hop "store and forward", were identified as promising means to extend roadside LANs. Creating such LANs and extending them is a formidable challenge in the presence of rugged terrain and dense vegetation. Given that the Department of Transportation owns the right of way and that there is generally a prohibition on creating new mountain top sites, this approach may provide the greatest flexibility in extending networks to challenging sites.

The preferred technologies were subsequently evaluated for applicability to the four network components defined above, along with the potential to satisfy the requirements for prospective field elements. There isn't sufficient space to enumerate all the pros and cons of the preferred technologies in this paper.

Generally there were few surprises, with most of the information associated with each technology being well-published, and the real insight coming from application to this problem. For example, RF technologies that operate on unlicensed frequencies are susceptible to interference. However, the likelihood of interference in rural areas may be small enough, particularly when using well-engineered paths and directional antennas, that the use of such technologies deserves serious consideration when compared to more expensive licensed options. Satellite systems require a "clear view of the sky," but terrain and vegetation obviously may obstruct the sky. Low Earth Orbit (LEO) satellite systems might be considered for low data rate applications in remote areas, but expense and the likelihood of service disruptions must be evaluated before deployment. Pushing the limit further in terms of remote deployment, one might consider "meteor scatter" technology for deployment of weather stations. Numerous agencies have used this technology for remote deployments, but it is unlikely that this technology is compatible with the Road Weather Information Systems (RWIS) currently deployed in California. Obviously Meteor Scatter and LEO satellite systems would be of no use in deploying CCTV. At the other extreme, optical fiber could satisfy the communication requirements of virtually any field element deployment. The installation of new fiber may be considered favorable when done in conjunction with road construction to utilize the right-of-way.

Two RF technology classes that are representative of those that might be considered for gateway links between roadside LANs and the backbone are 700 MHz and 900 MHz. These near-line-of-sight technologies offer appealing propagation characteristics for District 1. There are both licensed and unlicensed options in 900 MHz, which Internet Service Providers (ISPs) and others have been using to provide client services for years. 700 MHz may offer greater future potential when considering recent action by the Federal Communications Commission (FCC) to enable use for public safety including transportation. This spectrum has become available through the digital television transition, to be fully completed in 2009. The project team estimates, however, that it will take up to 10 years for the public safety "D-block" to be applicable in rural areas such as District 1. This block was not purchased in the recent FCC auction, and further developments must occur before complete assessment can be made of the potential for application. In the mean time, however, it is understood that the FCC will license 700 MHz for use in areas that are otherwise uncovered by the "D-block", so application of 700 MHz may apply. On a related note, Verizon Wireless was successful in acquiring the 700 MHz C-block and plans to deploy a "4G" network using this and other spectrum that it controls. Considering the strong and expanding presence that Verizon has had in District 1 in the past several years, Verizon should be considered for cellular data service along with all other major providers in the District.

4.2. Site Evaluations

Seven "Representative Sites" in District 1 were chosen specifically or in general at the project kick-off meeting by Caltrans representatives and the project team. These sites were intended to be representative of the diverse challenges faced in District 1 and are listed below:

- US 199: Collier's Tunnel North – hypothetical site – selected at the Kickoff meeting. This site is the "reason" this study was conducted.
- US 199: Idlewild Maintenance Yard – hypothetical site – selected at the Kickoff meeting.
- US 101: South of Cushing Creek- selected at the Kickoff meeting

- Eureka – Wabash Maintenance Yard – selected at Kickoff meeting. (Subsequently removed because communication is well established at this location.)
- US 101: Confusion Hill- selected at the Kickoff meeting.
- SR 299: West of M&W Ranch Road – hypothetical site – a location between District 1 and District 2 on route 299 was agreed upon at the Kickoff meeting. The WTI project manager selected the final location based on this discussion.
- SR 20: East of SR 53 - general location agreed upon by the stakeholders. The terrain features at this location differ from other areas and there is relatively little vegetation.

Figure 6: Seven "Representative Sites" in District 1, Map Created Using Microsoft MapPoint™

"Hypothetical" sites are sites that currently don't exist as TMS. In the case of Collier's Tunnel, there was a desire to create at TMS at the location. Other sites were chosen from existing sites having known, but perhaps limited, communication capabilities, along with sites at apparently challenging locations such as Idlewild Maintenance Yard and on SR 299 near the District 1 / District 2 boundary. Subsequently, the Eureka Wabash Maintenance Yard site was eliminated from the evaluation list because it is currently well served by a 1.544 MB/s T1 line. In retrospect, it would have been desirable to include an alternate "urban" example and perhaps an example in which the ocean might cause multi-path interference for the sake of completeness.

With that said, the sites were considered representative of the inland challenges faced in District 1.

In conjunction with the site evaluations, the project team drove approximately 1000 miles of state highway in District 1, which is approximately 90 percent of the roadway served by District 1. While driving, the project team collected video footage of the roadway and recorded cellular signal strength readings (see Figure 7) along the roadway. This data not only showed availability (and unavailability) of cellular service in the District, it also provided an indication of signal propagation of a system deployed throughout the district. This data was valuable in validating the predicted results from propagation analysis software.

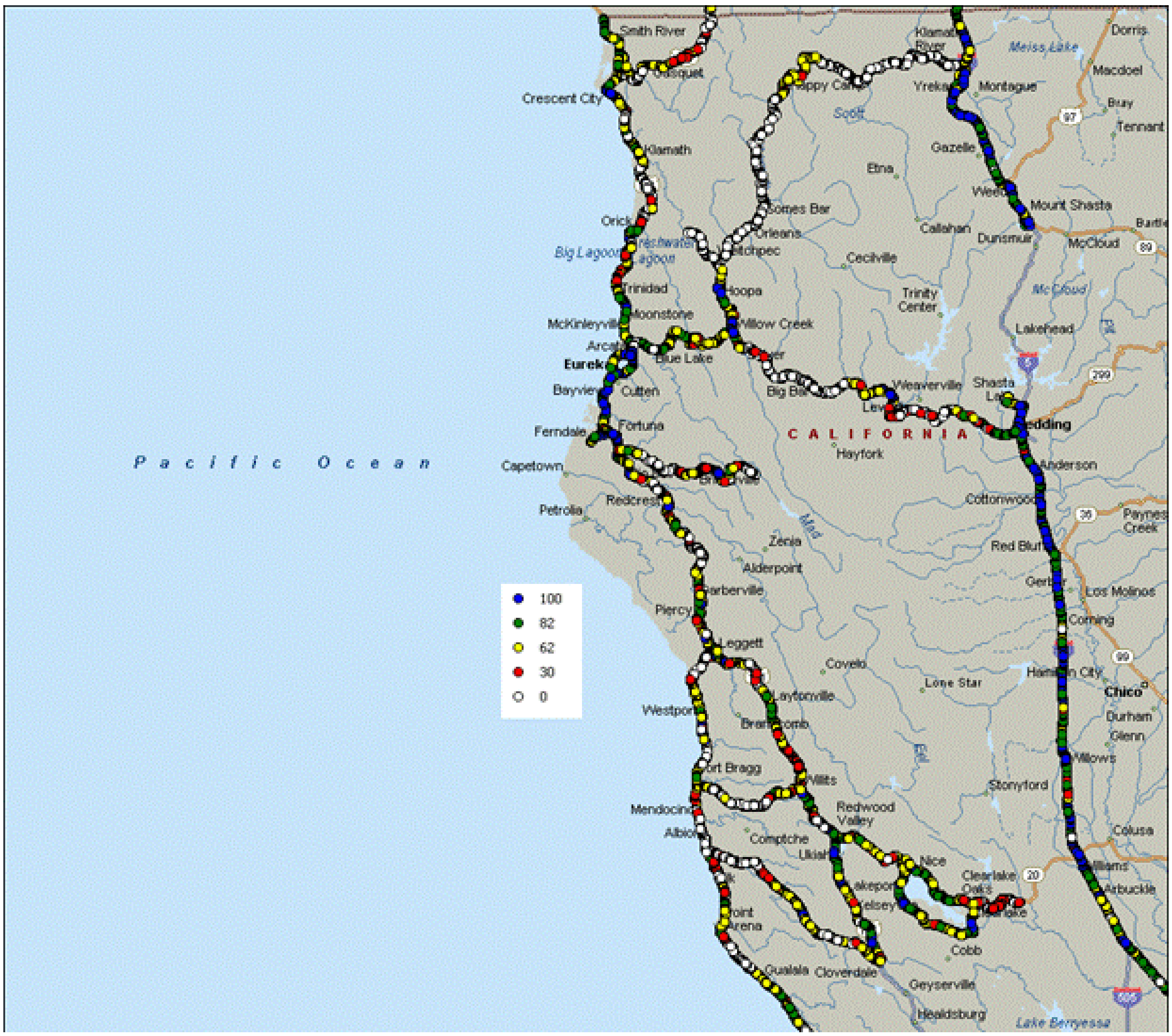

Figure 7: Cellular (CDMA) Signal Strength in District 1 - Summer 2007 – WTI Data, Map Created Using Microsoft MapPoint™

In Figure 7, white circles represent no service, red circles represent poor service, yellow circles represent marginal service, green circles represent good service, and blue circles represent excellent service. Note that there are many areas in District 1 that are not served by cellular.

4.2.1. Site Evaluation – Collier's Tunnel

As previously mentioned, Collier's Tunnel is the chief example of why this project was initiated. Despite attempts by District 1, communication capability was not established at the site sufficient to support transmission of CCTV video at the north entrance of the tunnel. Power is available at this location, but telco service (POTS and ISDN) is not available. Furthermore, cellular service is not available at this site to provide TMC-TMS communications. The project team verified that there is weak service available in proximity to the site, but nothing sufficient for the application. The nearest cell sites are 12.4 miles to the southwest, 19.9 miles to the north and 22.2 miles to the southeast. Obstruction due to terrain is the chief reason for lack of service to this site, in conjunction with distance to towers. Expansion of the cellular network or the landline telco network would be necessary provide service to this site.

There are two 800 MHz sites within two miles of Collier's Tunnel. However, it is understood that these sites are repeaters, with no external connectivity. Even if there was connectivity, they could only support low data rate service to a field element such as an RWIS. Propagation studies show that neither 700 MHz nor 900 MHz could be used for direct connectivity to the site. A relay (wired or wireless), possibly through the tunnel, would be necessary to provide indirect communication connectivity to the site. Future expansion of the state network might make the use of these sites viable.

Remaining options include meteor scatter, which does not provide a sufficient data rate for a CCTV; LEO satellite services, which also don't provide sufficient data rates for CCTV; and fixed geostationary (GEO) satellite service. The project team did confirm reasonable likelihood of clear view of the sky for several satellite service providers including HughesNet and WildBlue, so this last resort option may be viable. Considering that no other options are viable at present, it would be worth further exploration for District 1 to consider satellite service. It should be noted that the project team was concerned about the possibility of rain attenuation at this site, which receives nearly 100 inches of precipitation during the rainy season. However, disruptions may be minimal and acceptable in light of the fact that there are no other options.

4.2.2. Site Evaluation – Other Sites

Analysis was conducted for the other sites and similar results were found. In some cases, certain technologies/services were not viable while in others they were. Three major classes of service corresponding to backbone/backhaul emerged from this analysis: State Network provided, Telco Landline provided, Cellular provided, and other - primarily GEO Satellite.

If the State Network, best case backbone, was enabled for this application, then it could be used at certain sites in which an RF or wired link could be established between a gateway point and the State Network. However, as demonstrated by Collier's Tunnel, connectivity to the network will not be possible at all desired locations. While expansion of the State Network to new sites is unlikely in the near term, it does offer the greatest potential coverage from any state-owned asset.

As demonstrated again by Collier's Tunnel, telco landline service and cellular service may be unavailable at many sites. And where unavailable, it may be challenging at best to link to sites where service is available using relays or multi-hop LANs. Where available, however, these services provide appealing options for initial and even longer-term deployment. This is evidenced by District 1's current use of such service and by District 2's inclusion as their first step in building out sites.

In the absence of all other possibilities, we are left with satellite offerings or nothing at all. Clear view of the sky may not be possible at all locations, particularly those in heavily forested areas, raising doubt about the viability of satellite in some of District 1.

5. HANDBOOK FOR EVALUATING TMC TO TMS COMMUNICATION OPTIONS

As called for in the research problem statement, the project team produced a "handbook" documenting project results as the third project deliverable. The ideal for this handbook would be a guide that leads the general reader step-by-step through a process to select appropriate technologies for a TMC-TMS communication deployment. However, it was clearly not possible to achieve this ideal for several reasons: as stated earlier, there is no single best solution and every site and deployment may exhibit unique challenges; more importantly, there is no substitute for sound engineering judgment and proper design performed by a qualified radio systems engineer.

The project team documented the tools and techniques used for the site analysis within the project in the handbook to guide readers in what should be considered a preliminary analysis of alternatives. These tools and techniques can be used prior to and in conjunction with engineering and design of a system and its components.

Treatment was given to the following software packages:

- ComStudy (see Figure 8), which provides radio system coverage plots over a wide range of frequencies (typically Very High Frequency (VHF) low band through microwave) for one or more base station sites over a geographic area of interest. It utilizes transmitter power, antenna gain, receiver sensitivity, site location (latitude/longitude), site elevation, tower height, system gain and loss, etc., to determine if a transmitter will provide adequate coverage (field strength) for receiver sites (e.g., field elements or mobile units). It is a useful tool in designing and developing RF systems.
- MicroPath, which provides point-to-point analysis of the path between two RF sites. It can be used for frequencies between VHF and microwave. It determines, and displays a plot showing interfering terrain and Fresnel clearance zones. It is a useful tool in evaluating base station coverage at a single site and augments ComStudy.
- MapPoint is a mapping program that allows the user to display such information as date, time, latitude, longitude and other variables. MapPoint was chosen for presentation because of its relative ease of use. Other more advanced Geographical Information System (GIS) options include ESRI's ArcGIS.
- Google Earth is a global three dimensional (3D) mapping program that is available in a basic free version or in a fee-based "professional" version. The program shows information in context relative to surrounding geography, and can be used for general visualization and very rudimentary site analysis. Google Earth allows the user to select a specific location, often by name (cities, landmarks, etc.) or by latitude and longitude. It then allows the user to zoom in or out to reduce or enlarge the viewed area. The view can be tilted to reveal 3D aspects of the area. One can overlay images onto the view, such as an image of a ComStudy coverage map. Such an overlay can provide a view of modeled system coverage near highways or in relation to other field elements.

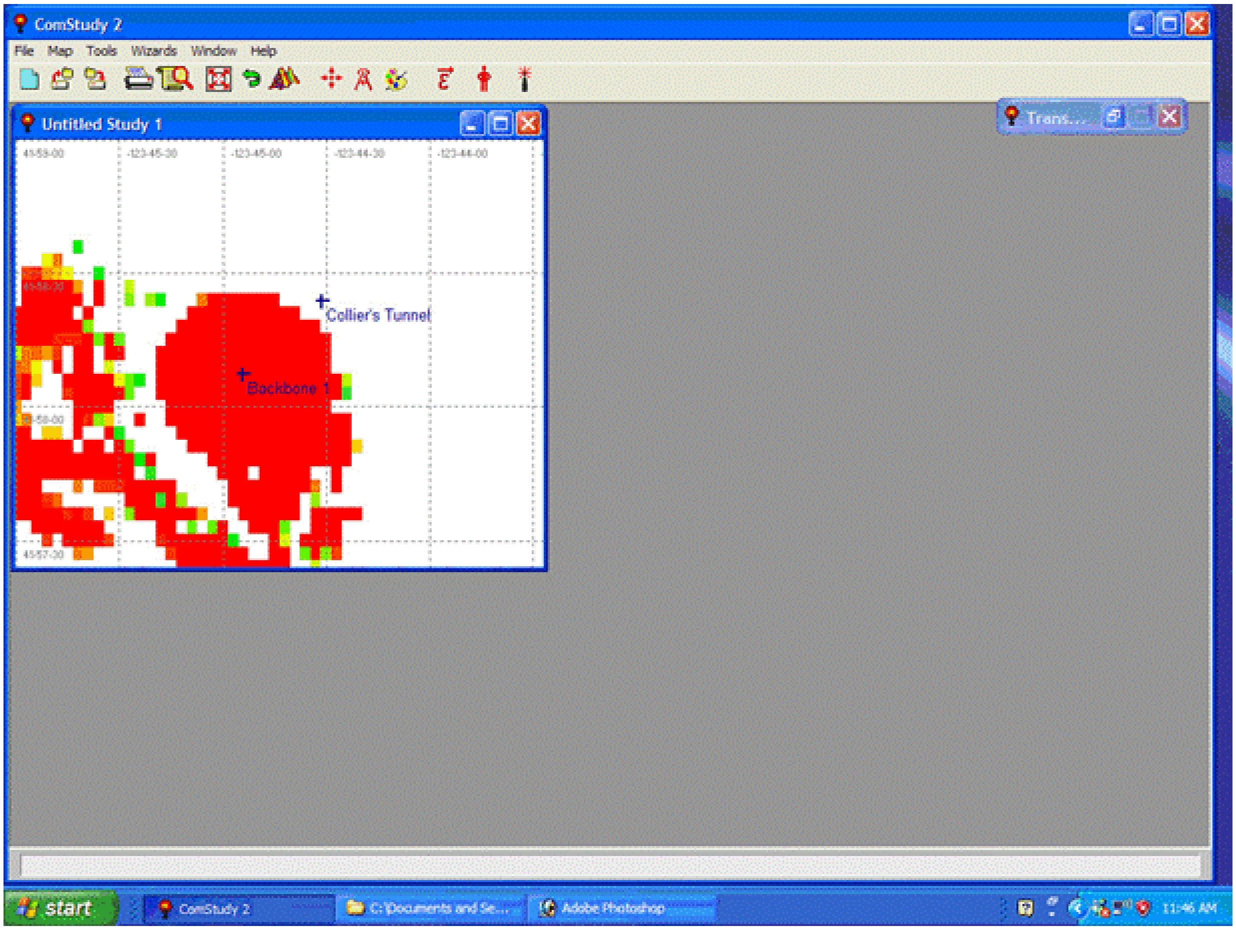

Figure 8: ComStudy Coverage Map for Collier's Tunnel

Additional treatment was given to the following tools for analysis:

- The Friis transmission formula, which is used for theoretical range calculations for communication equipment. This formula uses free space loss and does not account for terrain and vegetation, so it should be used only for theoretical calculations. It is useful in that it demonstrates the relationship between range, power, gain, sensitivity and cable loss. Theoretical range calculations using the Friis formula should be considered best case and compared to vendor specifications and to range as calculated using more advanced models such as the Longley-Rice Irregular Terrain (e.g., mountainous) propagation model, which is available within ComStudy and was used in the examples presented in this Handbook..
- Net Present Worth (NPW), which is used for comparison of prospective system costs, particularly for systems with different cost structures—leased versus direct purchase—as well as to account for maintenance and other costs. NPW calculates the amount in "today's dollars" required to pay for future costs over a given time period, typically 10 years. Using today's dollars as a common basis allows a direct comparison of costs over time. Care should be taken in using NPW and other similar computation methods because it is difficult at best to estimate future costs and other related parameters such as

interest and inflation rates. Other items such as strategic value may be difficult if not impossible to quantify.

While not necessarily complete, this set of analysis tools is effective for preliminary analysis. As demonstrated by the project team, these tools are quite useful in evaluating technologies for prospective use at a site. Once a candidate set of technologies has been identified, a qualified radio systems engineer can further evaluate and design a system for application, taking into account the greater system in which the components will operate.

6. DEMONSTRATION

The project team and sponsor decided to subsequently replace the vendor demonstration task with a demonstration of promising technologies to be conducted by the project team. While there may have been value in soliciting vendor demonstrations, it was decided that without incentive, vendors would be unlikely to participate in such a demonstration. The project team discussed this option with a number of vendors and several showed interest but none made commitments.

In conjunction with the 2008 Western States Rural Transportation Technology Implementer's Forum (WSRTTIF), held at Mt. Shasta, California, the project team demonstrated 5 GHz WiMax and 900 MHz Motorola Canopy equipment, along with cellular as representative of the technology that would most likely be implemented for this application. A traffic detection camera and a surveillance camera were used to represent typical ITS equipment for the demonstration. The project team also demonstrated mesh hardware.

While it was not used as such, the mobile demonstration system would be very suitable to pre-deployment field testing that should be conducted before deploying a system.

Figure 9: Demonstration at WSRTTIF, June 2008 – WTI Photo

7. RELATED RESEARCH

Several separate research projects were conducted in relation to the problem posed in the project. A graduate student researched the use of multi-hop networks to provide TMC-TMS communications. In particular, this student investigated the use of multiple radio frequency bands and/or channels to facilitate a linear, multi-hop network. As anticipated, the performance of the network improves when multiple bands are used. However, the cost of equipment is greater for such systems.

Another graduate student investigated the application of artificial intelligence techniques to the radio network design problem, the problem of locating and allocating network resources to provide a specified level of service. These techniques and algorithms proved to be quite promising in empirical studies, but remain to be proven in practice.

The communications demonstration was enabled through a separately-funded project in which several trailers were outfitted with ITS and communication equipment for mobile demonstration and training. It is anticipated that these trailers will be of great use for future research and demonstration.

In a project funded by the U.S. Department of Homeland Security, Montana State University researchers, including the Western Transportation Institute, investigated mobile ad-hoc networking as applied to public safety. This project focused on low-level routing protocols and provided insight into potential application for transportation.

8. CONCLUSIONS

Ideally, this study would result in a new or previously unknown communications system that solves the challenges faced in District 1. It was known from the start, however, that there was no such "silver bullet" solution. Sound engineering judgment and design are essential to developing a system that meets the needs of District 1. Generally strategies such as those used by District 2 to develop a hybrid, IP-based network with a clear migration plan are applicable and should be used in subsequent deployments. However, there will still be sites such as Collier's Tunnel in which there are few if any viable options. When faced with such challenges, one may have a greater propensity than otherwise to try "anything" that might work. As previously stated and worth stating again, there is no substitute for sound engineering judgment and proper design performed by a qualified radio systems engineer. Furthermore, the problem must be approached from a "systems" perspective, accounting for the entire system rather than isolated deployments.

9. REFERENCES

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