NEXT GENERATION TRAFFIC MANAGEMENT CENTERS

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FINAL REPORT

NEXT GENERATION TRAFFIC MANAGEMENT CENTERS

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16. Abstract

Traffic management centers (TMCs) are critical to providing mobility to millions of people travelling on high-volume roadways. In Virginia, as with most regions of the United States, TMCs were aggressively deployed in the late 1990s and early 2000s. Thus, most TMCs use technology of this time period. Recent advances in technology may provide improvements for TMCs in terms of function and cost. The purpose of this project was to assess the current state of the traffic management center as well as to look at what TMCs may be able to implement to further improve operations and accomplish their goals. The primary focus is on new technology as well as an evaluation of business philosophy and the decision-making process used by TMCs. The report concludes with recommendations for potential areas of improvement and the feasibility of implementation of those recommendations.

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Abstract

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Introduction

Since the late 1980s, over 288 traffic management centers have been built in various regions of the United States to monitor freeways and major arterials (as shown in Figure 1). TMCs have had to quickly adapt to rapidly changing technology throughout the past two decades. This has allowed TMCs to perform services that were not possible to perform in the past. It has also allowed TMCs to perform the services they already were able to perform in more efficient and cost-effective ways. With rapid advancements in technology, though, there is always room to improve upon current traffic management methods.

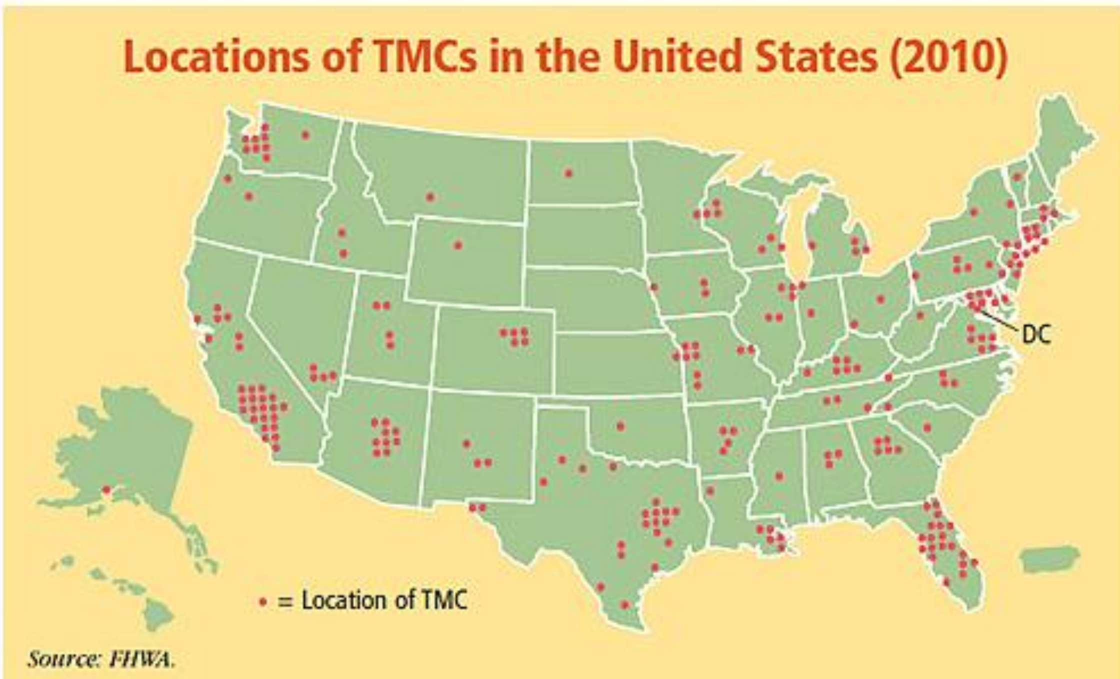

Figure 1 - Locations of TMCs in the United States (2010), Chu and Radow 2012

Meanwhile many metropolitan areas are growing at alarming rates while others have had serious traffic congestion issues for years. As the number of vehicles on the road increases, combined with climate change and strict air quality policies, every aspect of what a TMC does becomes significantly more important. As a result there should be ongoing investigation into technology advancements that a TMC can use to keep the roadways both safe and as free flowing as possible.

TMCs frequently are built to operate from the same location as local DOT offices. They communicate frequently with local emergency operations centers. Many of the systems deployed by the TMC, such as emergency vehicle preemption (EVP), can benefit both the TMC and other organizations. The amount of collaboration and communication varies throughout regions and is one of the primary reasons different TMCs use different procedures across the country.

TMCs need to make decisions on what technology to implement. Adoption of new technology should be carefully thought out and must have a clear benefit. These benefits should include one or more of the following:

- Save money
- Increase mobility
- Increase safety
- Reduce environmental impacts

If one or more of these are not achieved, either directly or indirectly, then the technology should not be considered for use by a TMC.

Purpose

The primary goal of this research effort is to identify specific ways that TMCs can take advantage of developments in technology to improve their effectiveness. To do so, the project first evaluates current state of practice, which may or may not involve using outdated or inefficient methods. The second goal is to determine what new technologies, developed both within the transportation engineering field and outside of it, TMCs can apply to operations. Each function TMCs carry out will be evaluated and suggestions be made based on that evaluation. All suggestions will include the benefits and drawbacks needed to make a decision on implementation. Lastly it is important that TMC decision makers know what research is in progress so they have as much information as possible available to them.

Current State of the Traffic Management Center

TMCs were created for two primary purposes and also carry out some additional secondary functions. The two primary purposes are improved safety and reduced delay on the roads. These can range from alerting proper authorities of an accident in a timely fashion, to alerting travelers of congestion along routes. Secondary functions include data collection and management.

TMCs rely on numerous Intelligent Transportation Systems (ITS) to perform the tasks for which they were created. Devices managed include variable message signs, ramp meters, closed-circuit television (CCTV) cameras, Bluetooth detectors, and video detection cameras, among numerous others. These all help the TMC carry out its tasks efficiently and to the best of its ability.

Variable message signs are used to display messages to drivers driving past a certain location along the route. There are numerous types of these signs, some permanent and some temporary. Of the permanent ones, the overhead message signs are the most common along freeways, and their display warnings are tailored to drivers based on direction. They frequently display travel times to certain exits, warnings regarding weather conditions, or notification of an accident including length of backup or time of delay. Other permanent variable message signs may include variable speed limit signs or be included in a regular highway sign to display travel time to a specific location. Temporary variable message signs are most commonly used for sites with construction or expected road closures and include information that alerts drivers of the changed conditions.

Ramp meters are used to regulate entry to the freeway to maintain traffic flow and prevent major delays. Generally they are only operational during peak hours through a freeway segment prone to major traffic jams. TMCs are responsible for monitoring the conditions along the freeway and major arterials and use the observations to determine when to activate the ramp meters. Since most areas' traffic conditions are predictable, these are frequently set to turn on at a certain time depending on the day of the week. These can be manually adjusted if needed.

CCTV cameras relay footage of the monitored segments of freeway to the TMC so operators can manually observe traffic. Inside the TMC, there are televisions that display these feeds. Cameras can be manually rotated or zoomed in or out in order for the operators to view large segments without having many cameras. They are used to help report accidents and monitor delay due to accidents. Reports of accidents are verified using the CCTV cameras and then information is passed along to drivers through variable message signs and traveler information systems.

Automatic detection technology is pivotal to a TMC's operations. The two main types of detectors are probes and sensors. Sensors are the more common type but are generally less accurate than probes. Meanwhile, probes can receive more detailed information; however, they require something to probe, such as a phone or mobile. Loop detectors, cameras, and Bluetooth devices are the main types of detection systems currently in use. Detectors are used for both data collection and at actuated traffic signals. Another use for detectors that is becoming increasingly popular is queue monitoring and interchange traffic signals, which automatically trigger the signal's green phase, if traffic backs up onto the freeway.

Loop detectors are sensors that can be used to collect speed and occupancy data. They are closed circuits that create magnetic fields over the site of detection. When metal objects travel over the loop, they are detected by changes in the magnetic field. These are accurate; however, they are in the pavement, which means that for installation and maintenance, pavement will need to be torn up and replaced.

Bluetooth detectors are roadside receivers that detect the presence of phones and other portable devices with the Bluetooth feature activated. They can be used to determine speed and location. The devices assign a completely anonymous MAC address to the Bluetooth device it reads. The MAC address is tracked as it passes various devices and travel times can be used to calculate speeds. On average, it reads about 1 in every 20 vehicles that pass the device. Operators in the TMC then monitor speeds to look for irregularities in traffic patterns.

Video Imaging Detector Systems (VIDS), or video detection cameras, are sensor detection technology, placed along monitored routes that automatically collect data from vehicles passing. Footage is generally not recorded, but volume and speed data are transmitted back to the TMC for use. The data collected are then used as an input into variable message signs, the 511 system, or other traveler information data sources. VIDS can also alert TMCs automatically of a stopped vehicle for them to verify using the CCTV cameras.

Data collection, management, and sales are also a major part of a TMC's operation. Some data collection methods have already been discusses, but TMCs and DOTs in general sometimes use other methods designed solely for data collection. These can include installation of count stations, pneumatic road tubes, or even sending people out to count vehicles occasionally. The data collected is then used as an input into variable message signs, the 511 system, or other traveler information systems.

Many TMCs run programs designed to help with incident management. These programs involve "safety patrols" consisting of vehicles driving around helping motorists with any problem they may have, such as a flat tire, empty gas tank, or a collision. In the event of a collision, these vehicles help authorities such as emergency medical staff, set up cones to direct traffic around the incident and clean up debris.

Other TMC operations may include traffic signal management, reversible lane management, inclement weather response, prioritizing signals for emergency vehicles and transit, reporting incidents to the proper authorities, HOV lane management, natural disaster evacuations, and maintaining equipment. See Figure 2 for a summary of functions performed by TMCs.

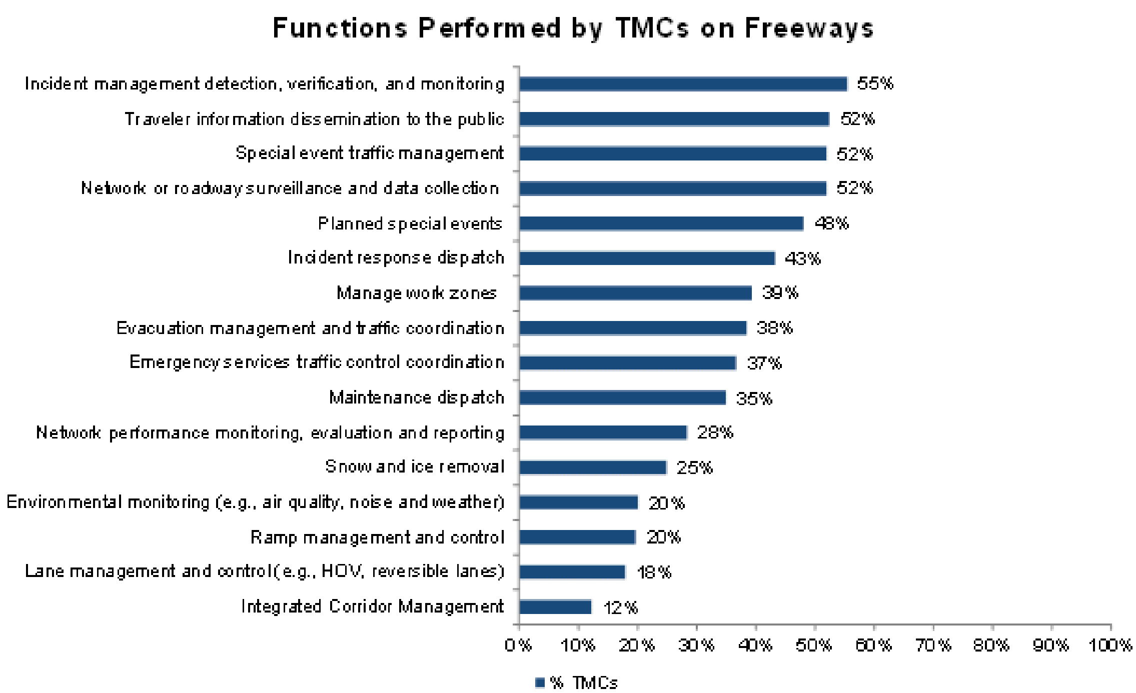

Figure 2 – Functions performed by TMCs for freeways, *RITA ITS 2010*

The Intelligent Transportation Systems branch of the Research and Innovation Technology Administration (RITA) conducts an annual survey of traffic management agencies around the country, inquiring mostly about perceived value of different technologies used, as well as inquiring about plans for future expansion. Planning to improve is very important, yet expansion or technological upgrades are not always the answer. In 2011, of the TMCs surveyed, 78% said they were planning to expand current ITS coverage, while 56% said they plan on investing in new ITS (Gordon and Trombly 2011). Figure 3 shows the responses to the survey made by freeway management agencies asked to rate, on a scale from 1-5 (1 = no benefit, 5 = significant benefit), ITS technologies based on perceived benefits. The average score is shown below each label.

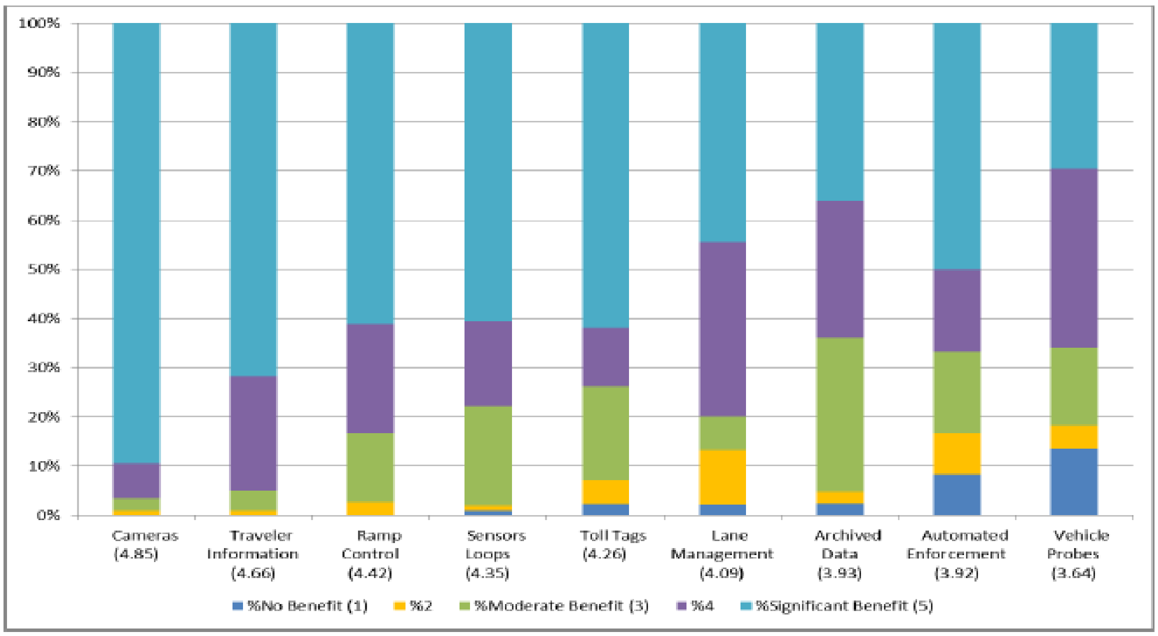

Figure 3 - RITA Survey Response from Freeway Management Agencies, *Gordon and Trombly 2011*

Background – High-Potential Technologies

The research team identified the following technologies as providing high potential to support the services provided by TMCs. Background on their capabilities is provided in this section to provide a foundation for the remainder of the report.

- Smart Phones

  Smart phones have quickly become ubiquitous in American society. Nearly half of all Americans owned a smart phone as of mid 2012, with this rate growing steadily. These devices are quite capable, generally integrating accelerometers, GPS, 4G wireless connections, and other features that make them intriguing for use in data collection and traffic monitoring. They also support applications (i.e., “apps”) that can be used as either background programs or for their user interfaces that can provide assistance to motorists. These have penetrated the market well over the past decade and are constantly improving to provide services over wider coverage and faster. However, TMCs need to be especially careful with the use of smart phones, since distracted driving is one of the leading causes of avoidable accidents.

- Cloud Computing

  Cloud computing essentially moves computing from devices that must be owned and maintained by a TMC to a service accessed via high-speed communications. Using cloud computing, the TMC can eliminate the need for local servers and remotely access elements of the TMC's software from any computer. There are other situational uses of this technology and it eliminates the need to maintain large, on-site servers.

- 4G Wireless

  4G wireless provides mobile devices with a high-speed connection to the Internet. Everything is routed through cell sites, usually operated by cell phone companies. This technology has the potential to replace fiber optic cables used to connect TMC field devices. It is also necessary to connect smart phones to the Internet for certain interactions between motorists and a TMC, such as social media and alerting TMCs of a problem with vehicles being stalled.

- Connected Vehicles

  Connected vehicles is a collection of technology that is still being researched and refined. The basic idea is that vehicles will be equipped with on-board equipment that can relay messages (warnings, traveler information, data, etc.) via short range radio to other vehicles and roadside equipment. This changes the way drivers can receive information and the availability of data to a TMC. The primary caveat with this technology is that it is not currently standard practice, and it is difficult to tell if and when it will become standard practice. The benefits of this technology to a TMC are very apparent and the progress of this technology's approval should be monitored closely.

Potential Areas to Incorporate High-Potential Technologies

This section presents and discusses a number of areas identified by the research team where new technology may be incorporated to improve TMCs.

<u>Field Communications</u>

In the early 2000s fiber optic cables became preferred over copper wires for communications uses. Laying down cables is very expensive. The cost scales sharply as network size increases. It can be especially expensive when a trench is required to be dug into an existing road. This is a very intrusive process that disrupts traffic flow and the nearby business districts. Also, it requires that the entire road be resurfaced, lest local users complain about a strip in the road that is not aesthetically pleasing. In addition, if maintenance is required, the trench must be reopened.

Fiber optic cables are still the primary method for connecting ITS to TMCs, as well as for transferring data back. Such devices include variable message signs, ramp meters, and traffic signal controllers. The fiber optic cables provide a huge amount of bandwidth, most of which goes to waste, since the commands sent to the devices are generally very simple, such as turning a ramp meter on or off. In addition to the unnecessary capacity, fiber optic cables are extremely expensive to deploy, especially when a segment of road needs to be torn up and replaced.

Over the past decade, wireless technology has provided an alternative to fiber optic cables. Connecting devices to cell towers through 4G networks would allow the TMC to operate a device such as a variable message sign without incurring the massive capital cost of laying down fiber optic cables. Using 4G technology would require either setting up government-owned cell sites across the country, or incurring a monthly fee from a cell company that would be willing to provide that service.

Setting up government-owned cell sites would defeat the purpose of switching due to the massive cost of setting up an entire network of cell sites and the fact the much of the fiber optic network is already complete. Still, the cost of setting up a single cell site in 2010, according to md7 (2012), was $40,000 and has been trending downward since being invented. This cost is not nearly as much as the cost of trenching and installing cables to every location that the cell site can provide service. This means it may be worthwhile to set up a cell site if there is a gap in the fiber network that would cost more than $40,000 to install.

Purchasing a service from a private company may be a better course of action. This depends on how much the company is willing to accommodate the needs of the government. The main requirement for this would be widespread cellular coverage. Since ITS devices are fixed to their position, placement in a location with coverage is key, but it does not matter if there is no coverage a short distance away. Obviously cost benefit analysis would need to be done to help determine a fair monthly fee. In 2010, md7 (2012) leased new sites for $7,200 annually. The idea of paying a monthly fee is rarely taken advantage of by the government, although it is absolutely worth exploring due to the nature of technological advancements in recent years. This can allow the government to stay up to date on technology without needing to sink money into new equipment every year.

Clearly the technology to pursue using wireless controls on ITS devices is available; however, there are some questions that must be considered as well. First, what is the current condition of the fiber optic cable network? If everything is operating well and coverage is widespread, there is no reason to switch.

Second, how secure is the wireless network compared to the fiber optic cable network? Since the government owns the fiber optic network it uses, that network should be fairly secure and is unlikely to be hacked into. Implementation of a secure network is extremely important, and an argument can be made that the government needs to own its own cell site for security purposes.

The third question is in regard to bandwidth availability. It was stated before that fiber optic cables have bandwidth capabilities that are excessive. Not having enough bandwidth is a much bigger problem than having excessive bandwidth. The ability to manage ITS devices is pivotal in emergency situations, which are frequently when cell networks are busiest. This is where another argument can be made in favor of setting up government-owned cell sites. It should be noted that certain key equipment can always stay connected to the fiber network so there is no doubt it will function in such situations. By purchasing services from a partner company, a large amount of money could be saved; however, these two critical issues must be addressed.

Variable Message Signs and Traveler Information Systems

Variable message signs are currently connected to and controlled by TMCs via fiber optic cables. As discussed previously, technology exists to connect wireless controls to variable message signs. These adaptations may not be necessary, since the benefits of variable message signs are unclear and there are alternative methods to convey such messages.

It is very difficult to estimate the benefits of traveler information systems, such as 511 or a variable message sign, for a few reasons. First, it is difficult to know when drivers use an alternative route. Second, if drivers do use an alternative route based on an old message, they may actually be increasing their travel time by taking an alternate route when their original planned route was already clear. Lastly, the network is a dynamic and rapidly changing system, so an incident may occur even after the driver used the information system.

Variable message signs can either be very beneficial to drivers or they can be completely useless. Frequently, when there are not any incidents along the route, the sign either displays travel times to certain locations along the route or nothing. However, the alerts can be very beneficial. Alerts include incident notifications as well as weather warnings, such as ice on the road, and emergency evacuation information.

For a driver to truly benefit from the message on a variable message sign, two things must be true. The message needs to be relevant to the driver and he or she must be familiar enough with the area to alter his or her route quickly. Also, the incident needs to be far enough away from the sign for traffic not to be backed up past the sign, but close enough to the sign that it is likely to be relevant to drivers. This leaves a small window for an incident to occur with a sign being useful. One solution to all of these issues could be to simply install more signs. Frequent signage could allow for detailed detour directions, show all route information, as well as be more likely to alert drivers with ample time to alter their routes. However, this would be an expensive and most likely unnecessary alternative due to progressions in technology.

With the rise in use of smart phone technology and the current outlook of connected vehicle technology, fixed-variable message signs will likely be unnecessary in the near future. Smart phones can allow for messages that would normally be on a sign to be sent directly to the smart phone. This can allow for personalized messages based on the route the driver is taking. It will also allow for drivers to receive the message well before they enter the freeway. The design of the app would need to be such that the driver does not need to look at the phone while driving. Sending messages to connected vehicles would work the same way, except it would send the message to an interface on the car instead of to a user’s phone.

There may still be a niche for temporary variable message signs. These are used primarily in construction zones where there may be violations of driver expectation. A phone or connected vehicle's ability to convey messages regarding driver expectation violations are unknown. This is a topic that some research studies may help to clarify.

It is ultimately up to each DOT to decide if variable message signs are in their plans for the future. Based on the 2011 survey conducted by RITA, VMS deployments are still in many TMCs' short-term plans. More studies and some cost-benefit analyses should be done before a decision is made. Upon full integration of connected vehicle technology to the vehicle fleet, however, variable message signs will most likely not be necessary and this should be considered in the decision.

Much of the decision should be based on the implementation of connected vehicles. Upon acceptance of the technology (which may take a while), it still will take roughly 15 years for the majority of the public vehicle fleet to be equipped with the technology. However, the premise can be tested today with smart phones. By developing a smart phone app, TMCs can run a pilot test of the concept. The results will help make the decision on benefits of fixed overhead variable message signs versus directly messaging users. Decision makers should be aware of the emergence of connected vehicle technology, since it can replace numerous aspects of a TMC's ITS. Monitoring the progress of connected vehicle technology will help TMCs to make decisions on multiple systems, not just variable message signs.

Traveler information systems, such as 511, are better for distributing messages than variable message signs. These systems allow for travelers to obtain route-specific information so they can plan according to traffic, instead of receiving the message while they are in traffic. The primary drawback to this is that drivers must make an effort to check this system, either on the phone or on the Internet before they leave. Figure 5 shows that 511 calls have increased in recent years, most likely due to advertisement and some improvements to make the system more user friendly.

The 511 system has become increasingly popular in recent years, and could become even more popular given additional marketing effort. All drivers should be aware that the 511 system is a reliable option. Unfortunately, large groups of people still don't know about the 511 system. Advertisement through the Internet, television, and radio could go a long way to increasing the system's use. The marginal cost of more users is very low, since the system gets updated with little regard to the number of calls. It is possible that money could even be saved, since this system is a substitute for variable message signs. Figure 4 shows that in 2007 the number of variable message signs decreased, and Figure 5 shows that the number of calls to 511 increased, suggesting that 511 could be a viable substitute for signs (Hagemann et al. 2010).

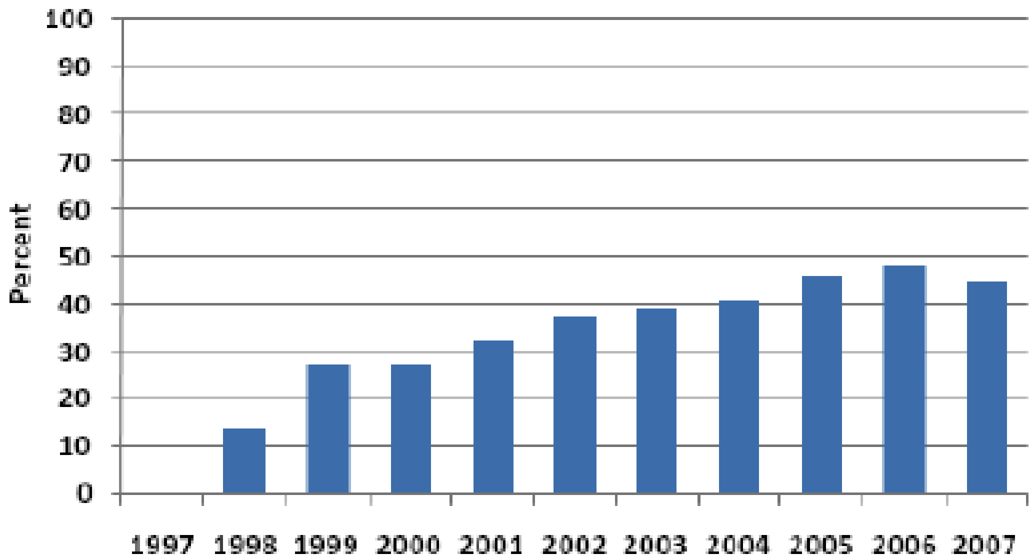

Figure 4 - Metropolitan Area Miles Covered by VMS, *Hagemann et al. 2010*

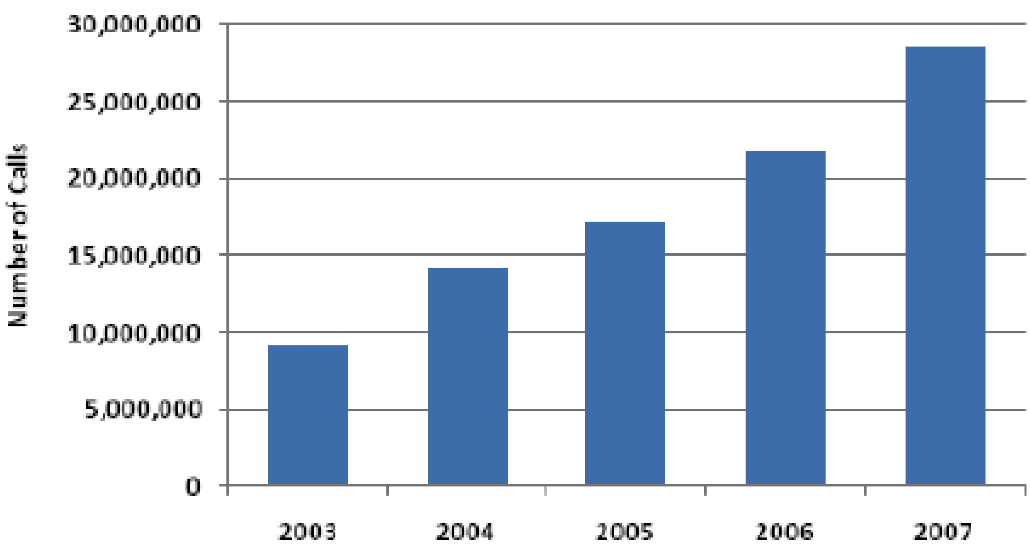

Figure 6 - Number of Calls to the 511 System, *Hagemann et al. 2010*

Social media, such as Facebook and Twitter, can also help a TMC to distribute information at a low cost. This way, when people log on to their account they will see messages if they choose to follow the TMC. This is something that many people do already, so they do not even need to go out of their way to make a phone call or check a specific website. The hardest part of running a successful social media operation would be to acquire followers, which will cost money to advertise. An additional benefit is that sometimes followers can provide information to the TMC on an accident or problem. Again, a detailed research project quantifying the benefits and costs would help to make decisions on how much effort to commit to advertisement.

Other frequently used methods of releasing information include using radio announcements, web pages, and subscription e-mail lists. Many DOTs run a radio station that constantly reports traffic information. Most normal radio stations report the traffic regularly over peak periods as well, although sometimes this information comes from listeners to the station and not the TMC. Posting the information on the Internet through a DOT website and Twitter incurs a very low cost compared to ITS installation, and is an easy task. Not enough agencies are taking full advantage of these options.

Data Collection, Management, Storage, and Sales

Good data collection methods are extremely important to a TMC, since nearly everything else they do requires data. Data collected is the primary input to a VMS, 511 system, and other forms of traveler information. It is also used to justify nearly every decision made by the TMC and helps to generate a list of improvements for the road network.

Data are collected via automatic detection technology. Vehicle presence detectors are primarily used to obtain vehicle counts and speed data along freeways and major arterials. Additionally, Bluetooth probes are used to try and determine speed data. These probes may not be perceived as useful by a DOT, simply because about 1 in 20 cars has an activated Bluetooth device in the vehicle, meaning there is a limited amount of data collected from the probes. However, knowing the ratio can allow for the TMC to estimate counts. Another caveat with Bluetooth is that using the travel time between detection points and the distance between detection points can only calculate the average speed. Since smart phones are equipped with accelerometers, instantaneous speed, 3-direction acceleration, and yaw data can all be registered, creating a pseudo-connected vehicle environment via Bluetooth.

Numerous improvements can be made to the process of data collection and data storage. Accuracy and type of data available are the two primary areas that require improvement. Currently the government invests a lot of money in purchasing equipment to collect data along the freeway. This primarily consists of Bluetooth detection devices, video detection cameras, and inductive loops. The data are then generally stored on on-site servers and can be used internally or sold to anyone else who needs it.

Especially with connected vehicle technology approaching, primary data collection methods may soon be obsolete. However, as previously stated, connected vehicle technology is still being tested and is not guaranteed to meet its full potential. Unlike variable message signs, though, curtaining the collection of data while waiting for this technology's fate to be decided is not an option. This means that the traditional methods cannot be put aside until connected vehicles are fully implemented. It also means that DOTs may want to consider alternate methods of data collection rather than investing in equipment that will be obsolete in the foreseeable future.

DOTs have the option to stop installing these types of detection devices and simply rely on a combination of the existing devices as well as possibly purchasing the data from a private data collection company, like Inrix® or even a company like Google®, which has potential to easily enter the market with the extensive android system. OnStar® and other in-vehicle support services are also equipped to provide some data if they decide they are interested in entering that market. Using such companies for data collection would be beneficial, knowing connected vehicles could be approved at any time.

Although these sources are available, they are not completely necessary just yet. It is uncertain when or even if this technology will get approved and become standard, and government agencies cannot afford to operate based on speculation. If connected vehicles do get approved though, the DOT should immediately stop installing other data collection devices and begin preparing for the installation of roadside equipment (RSE) instead.

In terms of data storage, large servers take up a lot of physical space and are no longer ideal. Cloud computing is a resource that all TMCs should move toward. Use of The Cloud can provide easy access to data from any location as well as a more centralized storage area. Other disciplines in transportation and planning are already experimenting with use of The Cloud to sell a product as well. A few metropolitan planning organizations have transferred their model to the cloud to allow users to interface with it directly, for a fee. A TMC could very easily create a cloud-based interface to allow private companies to purchase collected data. This allows for easy access to customizable data sets in a timely manner.

Emergency Events

In the event of a disaster that requires immediate evacuation, special circumstances are present and proper traffic management techniques can significantly enhance the speed of evacuation. This requires that a TMC be prepared with a plan, since most such disasters occur without warning. Some may be expected in regions that are prone to certain disasters, such as hurricanes along the gulf and east coasts or earthquakes in California. Others, such as terrorist attacks, could occur anywhere. Although these events are infrequent, they are also just the events where everything needs to be functioning in order to have a successful evacuation.

Cloud computing offers the ability to manage such events from remote locations. This means that TMC operators do not need to be in the TMC to manage traffic. In emergency events operators can manage traffic safely from a remote location by simply logging into their server via the Cloud. Additionally, if something occurred that directly affected the TMC, operators could move to a location that was unaffected. This could also allow for support from neighboring agencies during such events.

Secondly, during an emergency event, bandwidth availability can be an issue, as discussed previously. This means that if wireless cell technology is used, a viable backup system must be available for certain key systems. Fiber is generally available in metro areas and should still be connected to the devices that are deemed to be most important in emergency situations.

Manual Traffic Monitoring

One of the primary reasons TMCs exist is to monitor traffic and respond to incidents on the freeway. CCTV cameras are the primary method for accomplishing this task. The control room of a TMC usually consists of a wall full of TV screens where the feed from the CCTV cameras is outputted. The cameras can be manually controlled from the TMC to zoom in or out, as well as rotate. That way, if the TMC operator notices an anomaly in the travel speeds from data collected, the operator can further investigate the problem via CCTV cameras and respond appropriately. This is one of the few ITS devices for which it may be more beneficial to stick to normal fiber optic cables, since they require large amounts of bandwidth to return high-resolution camera feeds.

One improvement TMCs are beginning to make is putting CCTVs on a predefined route. This can be beneficial but will not drastically improve the ability of a TMC to respond to an incident, nor will it save money.

Another option that offers potential could be the use of military drones. Drones can do the same thing as CCTV; however, since they produce an aerial view from about 20,000 ft, they offer the potential to cover areas that would normally be covered by multiple CCTV cameras. They also have the ability to zoom in on multiple locations at once, so in the event of multiple incidents, they would not be limited by a small number of cameras. Possible drawbacks would be the monitoring of an urban area, such as Manhattan, with many tall buildings to block the line of sight. This may make drones better suited in more rural, open areas. These would be the least effective areas to install CCTV anyway, due to the high cost of laying fiber. Further study is required to determine locations where the use of drones would be both feasible and more cost effective than CCTV.

Conclusion

The results presented in this report make it very clear that recent and emerging advances in technology will have a significant influence on TMCs. It is critical that transportation agencies carefully consider this technology as TMCs are maintained, upgraded, and expanded. Continued investment in traditional technologies will prove to be quite limiting. In particular, agencies should carefully consider smart phones and wireless networks, cloud computing, and the development of the connected vehicle program.

References

Clark, K. (2012). Cobb County Department of Transportation (Personal Communication, June 28, 2012).

Chu, J., and Radow, L. (2012). Behind the scenes at TMCs. *Public Roads*, 76(1).

Fancher, L. (2012). "Connected Cars Take to Michigan to Reshape Driving World." Retrieved August 27, 2012, from http://www.wired.com/autopia/2012/08/umtri-michigan-connected-car/

Georgia Department of Transportation (2010). *NaviGAtor.* Retrieved August 30, 2012, from http://www.511ga.org/index.html

Gordon, S., and Trombly, J. (2011). *Deployment of ITS: A Summary of the 2010 National Survey Results.* Final Report No. FHWA-JPO-11-132, Research and Innovative Technology Administration.

Hagemann, G., Michaels, J., Minnice, P., Pace, D., Radin, S., Spiro, A., and West, R. (2010). *ITS Technology Adoption and Observed Market Trends from ITS Deployment Tracking.* Final Report No. FHWA-JPO-10-066. Cambridge, MA: Research and Innovative Technology Administration.

Iliaifar, A. (2012). "Latest U.S. Military Drone Features 1.8 gigapixel Camera." Retrieved August 27, 2012, from http://www.digitaltrends.com/cool-tech/latest-us-military-drone-features-1-8-gigapixel-camera/

Jang, J. A., Kim, H. S., and Cho, H. B. (2011). "Smart Roadside System for Driver Assistance and Safety Warnings: Framework and Applications." *MDPI Sensors, 11*(8) doi: 10.3390/s110807420

md7. (2012). "For Cell Site Rents, It's About Time." Retrieved Sept 12, 2012, from http://www.md7.com/assets/001/5073.pdf

Nazemeh, S. (1995). "Human Factors in Advanced Transportation Management Systems." *Public Roads, 58*(3):35.

"Real-time System Management Information Program." (2012). Retrieved August 28, 2012, from http://www.ops.fhwa.dot.gov/1201/

Research and Innovative Technology Administration. (2011). *ITS Deployment Tracking.* Retrieved September 1, 2012, from http://www.itsdeployment.its.dot.gov/

Row, S. J. (2011). "IntelliDrive: Safer. smarter. greener." Retrieved August 28, 2012, from http://www.fhwa.dot.gov/publications/publicroads/10julaug/04.cfm

Sawyer, T., Armistead, T., and Starrett, W. (2005). "Data Demand Sparks Race to Bring Fiber Optics Home." *Engineering News-Record,* 26-27-29.

Siemens. "Central and Adaptive Traffic Management Applications." Retrieved August 28, 2012, from http://www.itssiemens.com/en/s_nav12.html

Shi, X., Strong, C., Larson, R., Kack, D., Cuelho, E., El Ferradi, N., Seshadri, A., O'Keefe, K., and Fay, L. (2006). *Vehicle-based Technologies for Winter Maintenance: The State of the Practice*. Retrieved from Western Transportation Institute website: http://www.transportation.org/sites/sicop/docs/Vehicle-Based_WinterMaintenance_Final Report.pdf

Smith, B. L. (2000). "Transportation Management." *Intelligent Transportation Primer* (pp. 4-1-4-2 - 2-11). Washington, D.C.: Institute of Transportation Engineers.

Spurgin, J. T. (2007). Fiber to the Premises (FTTP): Force Them to Pave? *American Public Works Association*, 74(9), 62-63-65.

Stevanovic, A. (2010). *Adaptive Traffic Control Systems: Domestic and Foreign State of Practice.* (Synthesis No. 403). Washington D.C.: Transportation Research Board, NCHRP.

TrafficCast. (2012). "BlueToad." Retrieved August/8, 2012, from http://trafficcast.com/products/view/blue-toad/

United States Department of Transportation. (1999). *Transportation Management Center Concepts of Operation: Implementation Guide*. Retrieved from http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/TMCConOpsImplmGuide.pdf

Virginia Department of Transportation. (2010). *Northern Virginia Traffic Management Program.* Retrieved September 12, 2012, from http://www.virginiadot.org/travel/smart-travel-nova.asp

Wisconsin Department of Transportation. (2012). *Programs - MONITOR.* Retrieved September 18, 2012, from http://www.dot.wisconsin.gov/travel/stoc/monitor.htm

Young, S. (2008). *Bluetooth Traffic Monitoring Technology*. College Park, Maryland: University of Maryland Center for Advanced Transportation Technology.