Final Research Report

Best ITS Management Practices and Technologies for Ohio

July 2001

Prepared in cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

KHA
of Ohio, Inc.

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16. Abstract

To address congestion and safety concerns on Ohio's Macro Highway System, the following priorities were identified in this research report as solutions in **urban** areas: (1) incident management, (2) arterial signal coordination (primarily the responsibility of local governments), and (3) traffic control during construction and maintenance activities. On **rural** sections of highway maintained by ODOT, the priorities identified for improvement are: (1) traffic control during construction and maintenance activities, (2) weather/snow and ice monitoring, and (3) advanced traveler information systems. Specific technologies were explored in four areas that were identified to be of primary interest to ODOT: traffic detection, traffic controllers, dynamic message signs, and communications technologies.

The following specific recommendations were made: (1) that ODOT pursue installation and use of non-intrusive detection methods wherever practical; (2) that ODOT continue its direction of procuring and installing 2070 Lite controllers and develop the capability to maintain these devices as well; (3) that limited use be made of the large dynamic message signs that are typically mounted on sign bridges over multiple lanes of freeways, and that smaller, cantilever-mounted or median-mounted signs be used in most situations; and (4) that a common ITS communications architecture /master plan be defined for each region to establish cost-effective deployment and operations of field devices and center components.

It was further recommended that collocation of police and fire agencies be integral to ITS investments in urban areas of Ohio. Flexibility is the key to district staffing levels during the next several years of ITS deployment. To address equity issues, ODOT should centralize ITS operations and maintenance funding until ITS deployment becomes more widespread and integrated into District Offices' planning and operations, and into the Central Office functions including most major units within the Department.

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SUMMARY AND RECOMMENDATIONS

Background

In committing to the creation of an ITS program, the Ohio Department of Transportation (ODOT) executive management wanted to define and document the best practices and policies for ITS, as based on experience from other states and experts in the field. Policy interests included overarching issues such as the appropriate focus of ODOT's program, and highly technical issues such as technology-specific deployment. In response, this research has focused primarily on answering three questions:

- What are the causes of delay on Ohio's macro corridors?
- What is the profile of an ITS program to best address delay?
- What are the best practices and technologies to support Ohio's ITS program?

In keeping with ODOT's owner/operator responsibilities, this study focused on Ohio's macro corridor system. In urban areas, the study's focus is on the freeway systems, as arterial routes within corporate limits are the exclusive province of local public agencies. Thus, discussions about traffic signals in the ODOT context generally refer to systems on state- and US-numbered routes outside incorporated municipalities.

This study also includes a review and analysis of the operational needs and functions provided by ODOT work units involved in traffic data collection and highway maintenance management. To help guide this effort, ODOT convened a Project Advisory Committee (PAC) consisting of approximately 25 individuals from both inside and outside the Department. The PAC reviewed draft documents, including the draft final report, and participated in three workshops involving data gathering and/or feedback exercises. Finally, the research team conducted numerous interviews with both Department staff and external agency representatives to gather data, discuss needs, and review current and desired operational goals.

Causes of Delay

The causes of delay on Ohio's Macro Highway System vary depending on the size of the metropolitan area and urban versus rural freeways. For example, recurrent congestion in the Dayton area is limited to short AM and PM peaks– 15 minutes or less at a time. Congestion in small- to mid-size cities in Ohio is estimated to be almost exclusively incident-related. The three largest cities in the state, on the other hand, have approximately 55 percent of their congestion caused by incidents, according to the recent study of "congestion in America" issued by the Texas Transportation Institute. ODOT estimates that in Columbus, with few geographic constraints and high route redundancy, incident-related congestion probably accounts for 60 percent or more of total congestion. The Cincinnati area, with greater geographic constraints (river bridges being constrictions on throughtravel on a daily and hourly basis), might approach a 50-50 mix of incident-caused congestion and recurrent congestion.

To address congestion and safety concerns on Ohio's Macro Highway System, the following priorities were identified by the research team as solutions in **urban** areas: (1) incident management, (2) arterial signal coordination (primarily the responsibility of local governments), and (3) traffic control during construction and maintenance activities. On **rural** sections of highway maintained by ODOT, the priorities identified for improvement are: (1) traffic control during construction and maintenance activities, (2) weather/snow and ice control, and (3) advanced traveler information systems. These priorities were developed based on a review of previous ITS Strategic Plans developed for various metro areas and the I-71 corridor, interviews with ODOT managers and engineers, discussion with the Project Advisory Committee, and an evaluation of Ohio's needs based on similar experiences of the research team in developing statewide ITS Strategic Plans in other states.

Recommended ITS Program

The recommended ITS program for Ohio was defined in terms of functionality that has a strong connection with the functions defined in the National ITS Architecture:

- Non-technology freeway operations (service patrols, etc.)
- Multi-agency traffic management (collocation of agencies)
- Traffic monitoring (speed, volume, classification)
- Traffic surveillance (video images)
- Traffic control (both passive and active methods)
- Dissemination of traveler information (passive form of traffic control)
- Data collection and analysis (combined functions for planning and operations)

It is recommended that collocation of police and fire agencies be integral to ITS investments in urban areas of Ohio. Optimally, police and fire dispatch offices should be collocated with traffic management. However, even the physical presence of a police and/or fire department representative in a regional traffic management center will provide significant benefits to all agencies involved in emergency response.

Based on the current trends toward market saturation, 9-1-1 cell calls routed to Public Service Answering Points (PSAP) are expected to continue to be the major reporting mechanism for incidents. Call takers determine if the emergency requires a police or fire response; if the call is emergency related, the call takers will record the information on a computer aided dispatch (CAD) system, allowing the emergency dispatcher for each jurisdiction to direct equipment and personnel to the scene.

Specific technologies were explored in four areas that were identified to be of primary interest to ODOT: (1) traffic detection, (2) traffic controllers, (3) dynamic message signs, and (4) communications technologies. Several detailed assessments of various technologies, including names of specific products and vendors, are contained in the body of this research report and in the technical appendices.

Detection

Current trends nationwide in traffic monitoring are moving increasingly toward non-intrusive technologies, which includes such devices as Passive Acoustic Detectors and Microwave. These devices have been demonstrated to outperform inductive loops in three important areas:

- Capability to produce multiple direct and indirect measures of effectiveness with one sensor device, such as speed, volume, density, vehicle classification, queue length, travel time, etc.
- Easier and less expensive to install when considering impacts to existing freeways/ infrastructure, traffic disruption, mounting requirements, and time required for installation
- Good reliability (longer times between failures)

It is recommended that ODOT pursue installation and use of non-intrusive detection methods wherever practical. This should be accompanied by developing the capability to operate and maintain these devices as well. Multiple uses of existing inductive loops, however, such as those used in automated count stations (ATMs), should be encouraged. Basically, detection technologies should match the function being performed.

Traffic Controllers

Of the controller technologies available, the most viable options that are analyzed in this report are:

- Caltrans-specified Model 170E
- Caltrans-specified Model 170E controller with an enhanced PROM module
- Caltrans-specified 2070 "Lite"
- NEMA-specified TS-2
- Vendor-specific controller (for dynamic message signs and closed circuit television)

It is recommended that ODOT continue its direction of procuring and installing 2070 Lite controllers and develop the capability to maintain these devices as well.

Dynamic Message Signs

For Ohio, it is recommended that limited use be made of the large, permanently mounted signs that are typically mounted on sign bridges over multiple lanes of freeways. Instead, somewhat smaller, cantilever-mounted or median-mounted signs will function in most situations, at less cost, provided those signs are large enough to support characters that are visible at specified distances to meet standards. There are multiple types of dynamic message signs that can be deployed in different situations. Signs typically are selected based on the attributes identified in the following table.

Attribute	Best Technology	Second-Best
Reliability	LED	Fiber optic
Legibility	Fiber reflective/flip disk	LED reflective/flip disk
Degradation from heat/sunlight	Fiber reflective/flip disk	Fiber optic
Proven technology in field	Fiber optic	Fiber reflective/flip disk
Washout/backlighting	Fiber reflective/flip disk	Fiber optic
View angle flexibility	Fiber reflective/flip disk	Fiber optic
Capital Cost	LED reflective/flip disk	Fiber reflective/flip disk
Operating Cost	LED reflective/flip disk	LED
Maintenance Cost	LED	LED reflective/flip disk

The fact that LED hybrid (reflective/flip disk) signs are the least expensive in capital and operating cost, coupled with the fact that a desirable feature is that signs be visible in the event of power failure, it is recommended that the LED hybrid be deployed in most cases in Ohio.

Communications

The communications technologies most needed in Ohio should focus on meeting the following recognized needs throughout the state:

- Common communications channels and protocols
- Common database
- Adequate bandwidth
- Clearinghouse for information coordinated with Metro Area Traffic Management Centers

There was no intent to recommend specific subcomponent technologies in this study. However, it is recommended that a common ITS communications architecture/master plan be defined for each region to establish cost-effective deployment and operations of field devices and center components. This study describes leased lines, fiber optics, and wireless as methods of ITS communications.

Leased lines are somewhat attractive from the maintenance standpoint since the majority of the communication network is owned/operated and managed by others. However, the operational costs are high and remain high in perpetuity. There is also a distinct reliance on others for repairing/restoring communications in the event of a public network outage. Other public agencies have encountered slow response times for maintenance/repair requests.

Fiber optic cables coupled with fiber optic transceivers provide digital high-speed capability for the transmission of voice, data, and video. Fiber optic systems are generally the most costly to deploy. However, they also have the most versatility and are the most reliable over any other medium. Fiber is not susceptible to EMI/RFI like twisted-pair/leased-lines or wireless systems. The biggest negative to fiber-optic deployment is that it is a fixed capital infrastructure along the highway that is subject to utility relocation as roadways are widened or structures are modified. The capacity (both bandwidth and distance) and flexibility of application afforded by fiber optic cables far exceeds the higher cost when the decision is made to install wireline infrastructure.

Although the relative costs for an agency-owned wireless system may seem attractive in comparison to the other scenarios, there are other considerations. Negative factors include the potential for FCC frequency re-allocation rendering acquired infrastructure no longer viable, electromagnetic/radio-frequency interference causing communication failures, degraded reliability under severe weather conditions (heavy rain, hail, snow), and public sentiment making it increasingly more difficult to deploy new towers (as seen with cellular tower construction activities). On the positive side, wireless systems do provide a great deal of field element portability in comparison to leased lines and fiber optics. A field element can be relocated a few feet or several hundred yards away and generally a realignment of antennas is all that is needed to restore communications. However, this becomes more complicated when licensed frequencies are used since it may be necessary to re-apply for the new location.

ITS Management and Funding Issues

It is recommended that the PAC continue meeting together to maintain a dialogue on needs identification and ITS technologies. The following ODOT Divisions and Offices were identified to continue their efforts on this "tool kit" for addressing congestion and safety on Ohio's Macro Highway System:

- Office of Traffic Engineering
- Office of Maintenance Administration
- Division of Information Technology
- Office of Urban and Corridor Planning
- Office of Technical Services
- Office of Program Management

Flexibility is the key to district staffing levels during these early years of ITS deployment in Ohio. District Six, as one example, seems to have embraced such flexibility as it implements a freeway management system, freeway service patrols, incident management, and other operational improvements. To address equity issues, ODOT should centralize ITS operations and maintenance funding until ITS deployment becomes more widespread and integrated into District Offices' planning and operations, and into the Central Office functions identified above. While this would decrease the overall amount available to district maintenance allocations, it would reduce equity considerations during these crucial early years of ITS development.

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1.0 INTRODUCTION

The Ohio Department of Transportation stands at an exciting crossroads in its development of intelligent transportation systems (ITS) to support highway operations and management. Many states, especially those that received ITS model deployment initiative (MDI) funding, have developed significant, integrated metropolitan transportation management systems. In these early years of ITS– say from 1991 to present– there were successes and failures, with significant lessons learned through both types of experiences.

For various reasons, Ohio assumed a cautious posture toward ITS during this period. One exception was ARTIMIS (Advanced Regional Traffic Interactive Management and Information System) in Cincinnati, which was a very significant "early start" freeway management system. Like other early deployments, ARTIMIS provided a rich blend of lessons about technology procurement, managing technology vendors, managing traffic, and providing a high level of traveler information.

Although ARTIMIS was typical of other experiences across the country, ODOT executive leadership decided not to embrace a full-fledged ITS program. There were many reasons for this. First, ODOT is similar to most DOTs in its bias toward capacity expansion over aggressive operations management. Second, throughout most of the 1990s, the Department was engaged in the most significant reorganization of any DOT in the country, downsizing staff from almost 8,000 in the mid-1990s to less than 6,000 today. Aside from this organizational restructuring, most strategic focus was placed on asset management activities, creating systems and programs to ensure the viability of a rapidly aging infrastructure. ODOT's experience places pressures on accomplishing further ITS deployment. With eight significant metropolitan areas and other areas in the state expressing interest in ITS technologies, fiscal and equity issues are created.

Because of these challenges, ODOT took a passive stance toward capital investment in ITS, but single champions in the Department should be credited for the substantial ITS planning work that took place over the past ten years. The metro areas of Toledo, Dayton, Columbus, Cleveland, Youngstown, and Akron all received early deployment plan (EDP) funding, as did a rural I-71 Corridor study. However, ODOT's executive direction was to let local public agencies assume the lead on ITS planning and deployment, and deal with project requests through the Transportation Review Advisory Council (TRAC) on an ad hoc basis.

What changed, and why? In 2000, events conspired to raise the level of interest in ITS and the Department's commitment to a formal program. The TRAC was dealing with heightened interest in the form of funding applications for metropolitan ITS systems. There were seemingly wide disparities between the scopes and costs of the requests, not to mention inadequate project implementation plans. In addition, central Ohio interests had developed feasibility plans for an integrated transportation and emergency management center, with ODOT's hilltop location selected as the best site for the multi-agency effort (which meant that ODOT would be responsible for its development). Finally, with other strategic initiatives out of the way and more emphasis being placed on traffic congestion and level-of-service issues, executive attention turned to congestion mitigation and incident management strategies, including ITS.

In summary, the time was right for ITS. Most importantly, the Department could no longer rely on the uncoordinated efforts of various local governments to develop integrated systems; the Department would have to lead ITS development, including the establishment of resources for the effort. Tangible results include the creation of the Office of ITS Program Management and the funding of this study to determine best management practices, policies, and technologies.

1.1 Purpose of the Study

In committing to the creation of an ITS program, ODOT executive management wanted to define and document the best practices and policies for ITS, as based on experience from other states and experts in the field. Policy questions could be macro in nature– such as, what should the focus of ODOT's program be? Or, policy questions could be micro in nature– inductive loops versus non-intrusive traffic detection. Such is the wide scope of this effort.

To carry out this work, the research focused on three primary questions: (1) What are the causes of delay on Ohio's macro corridors? (2) What is the profile of an ITS program to best address the causes of delay on these routes? (3) What are the best practices and most cost-effective technologies to support Ohio's ITS program?

The results of this policy study are significant, as they will impact and guide the planning of ITS deployment for the statewide macro highway system, as well as the various metropolitan regions of the state. Some tangible benefits resulting from this study include: (1) specific functions to be provided by Ohio's ITS program; (2) technology recommendations that will become policy and be incorporated into the design of metropolitan and rural ITS systems; (3) opportunities for data sharing between different work units of the Department; and (4) ODOT organizational structure necessary to support ITS deployment.

1.2 Methodology

In keeping with ODOT's owner/operator responsibilities, this study focused on Ohio's macro corridor system (**Figure 1**). In urban areas, the study's focus is on the freeway systems, as arterial routes in incorporated areas are the exclusive province of local public agencies.
Thus, discussions about traffic signals in the ODOT context generally refer to systems on state and US-numbered routes outside of incorporated municipalities. The study includes an analysis of the operational needs and functions provided by ODOT work units involved in traffic data collection and highway maintenance management.

To help guide this effort, ODOT convened a Project Advisory Committee (PAC) consisting of approximately 25 individuals from both inside and outside the Department (Appendix A). This Committee reviewed draft documents and participated in workshops involving data gathering and feedback exercises. Finally, the research team conducted numerous interviews with both Department staff and external agency representatives to gather data, discuss needs, and review current and desired operational goals. Input was sought from staff in each of the District Offices on ITS activities (if any) in the 12 ODOT Districts (**Figure 2**). The effort provided a sampling of empirical data and opinion on which to shape the program goals, and assisted in the development of recommendations as to the best management practices and ITS technologies for Ohio.

Figure 1

Ohio Macro Highway System

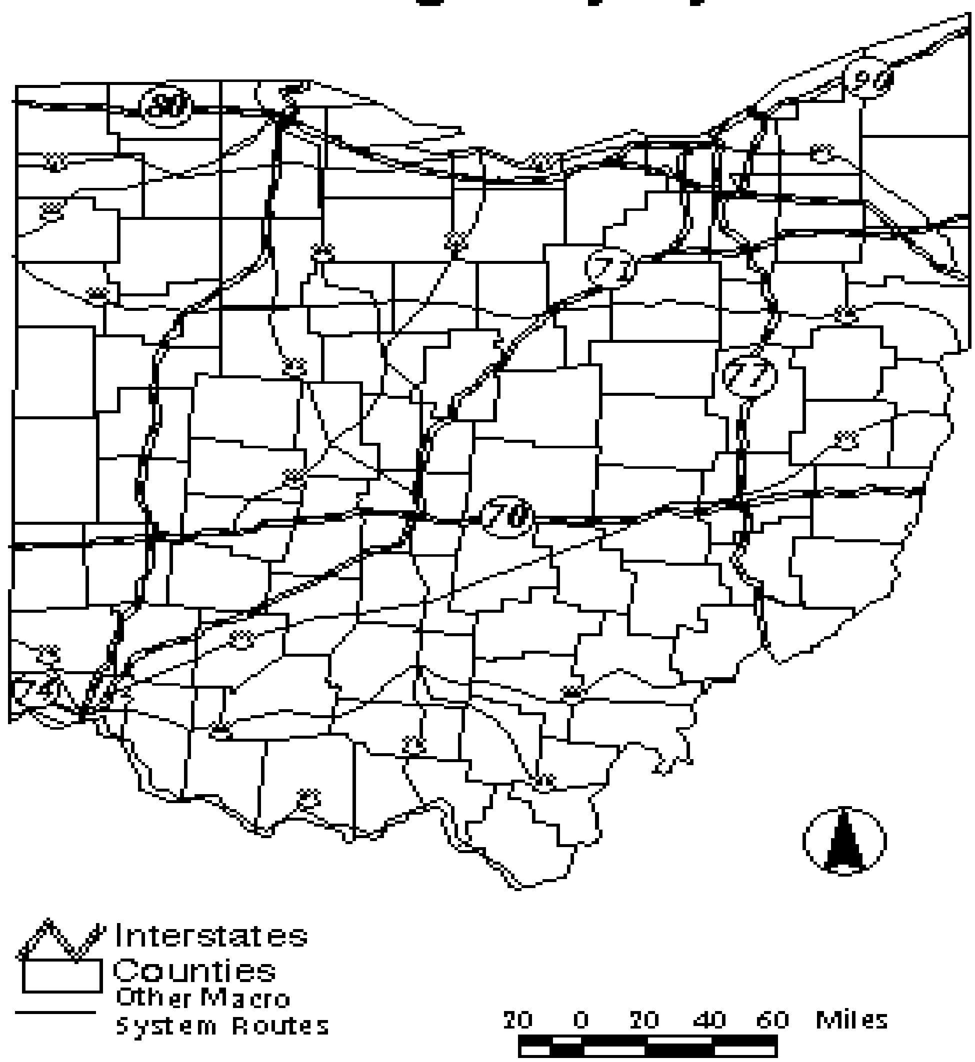


Figure 2


Ohio Department of Transportation
District Map
Michigan
Lake Erie
Pennsylvania
Indiana
West Virginia
Kentucky
Ohio River
1
2
3
4
5
6
7
8
9
10
11
12
Williams
Fulton
Lucas
Ottawa
Defiance
Henry
Bowling Green
Wood
Sandusky
Erie
Lorain
Cuyahoga
Garfield Hts.
Lake
Geauga
Ashtabula
Paulding
Putnam
Hancock
Seneca
Huron
Medina
Summit
Portage
Ravenna
Trumbull
Mahoning
Van Wert
Allen
Lima
Hardin
Wyandot
Crawford
Richland
Ashland
Wayne
Stark
Columbiana
Mercer
Auglaize
Marion
Morrow
Knox
Holmes
Tuscarawas
New Phil.
Carroll
Harrison
Jefferson
Shelby
Sidney
Logan
Union
Delaware
Coshocton
Darke
Miami
Champaign
Franklin
Licking
Jacksontown
Muskingum
Guernsey
Belmont
Clark
Madison
Preble
Mont-gomery
Greene
Fayette
Pickaway
Fairfield
Perry
Noble
Monroe
Morgan
Butler
Warren
Lebanon
Clinton
Hocking
Athens
Washington
Marietta
Chillicothe
Ross
Vinton
Hamilton
Highland
Meigs
Clermont
Pike
Jackson
Gallia
Brown
Adams
Scioto
Lawrence

CONGESTION AND DELAY ON OHIO'S MACRO CORRIDORS

Ohio is unique in its blend of rural geography interspersed with some of the most dense, industrial urban areas of the country. The Appalachian plateau in the south and east, mostly unglaciated, is rolling wooded hill land, while the central and lake plains of western and southwestern Ohio contain some of the richest farmland in the world. Within this physical geography, the state has three of the top 50 urban areas of the nation. Twenty-two of the 25 largest cities in the state are located in these three major metropolitan areas **(Figure 3)**, forming megalopolises of Cincinnati-Dayton, Central Ohio (Columbus), and Cleveland-Akron-Canton. Youngstown and Toledo form the other two distinct urban areas.

In spite of repeated interest in traffic congestion and periodic polls rating traffic congestion as a top policy concern (e.g., Columbus, 2000), there is a frustrating lack of quality data on the subject. This is not due to a lack of traffic data collection; ODOT's traffic data collection efforts serve the project development process, not a real-time operations purpose. Congestion estimates are created by feeding traffic data– in the form of annualized, average daily traffic (AADT) – into macro-scale models that compare volume to capacity. The result is a defensible estimate of the magnitude of congestion, comparable in both a temporal and geographic sense. However, data are not immediately available to directly measure "real" congestion, using measures such as total delay. It is recommended that efforts be made to integrate ODOT's on-going traffic counting program into the various regional Traffic Management Centers in order to make use of this resource and have available additional real-time traffic data.

Using these macro-level tools, the Cincinnati, Cleveland, and Columbus metropolitan areas show congestion increasing over the past decade (**Figure 4**). Vehicle miles of travel (VMT) have increased by 20 percent in the greater Cleveland area, and by approximately 40 percent in the metropolitan areas of Cincinnati and Columbus. **Figure 5** shows congestion indices by District, on both arterials and freeways.

Figure 3

Ohio's 25 Largest Cities

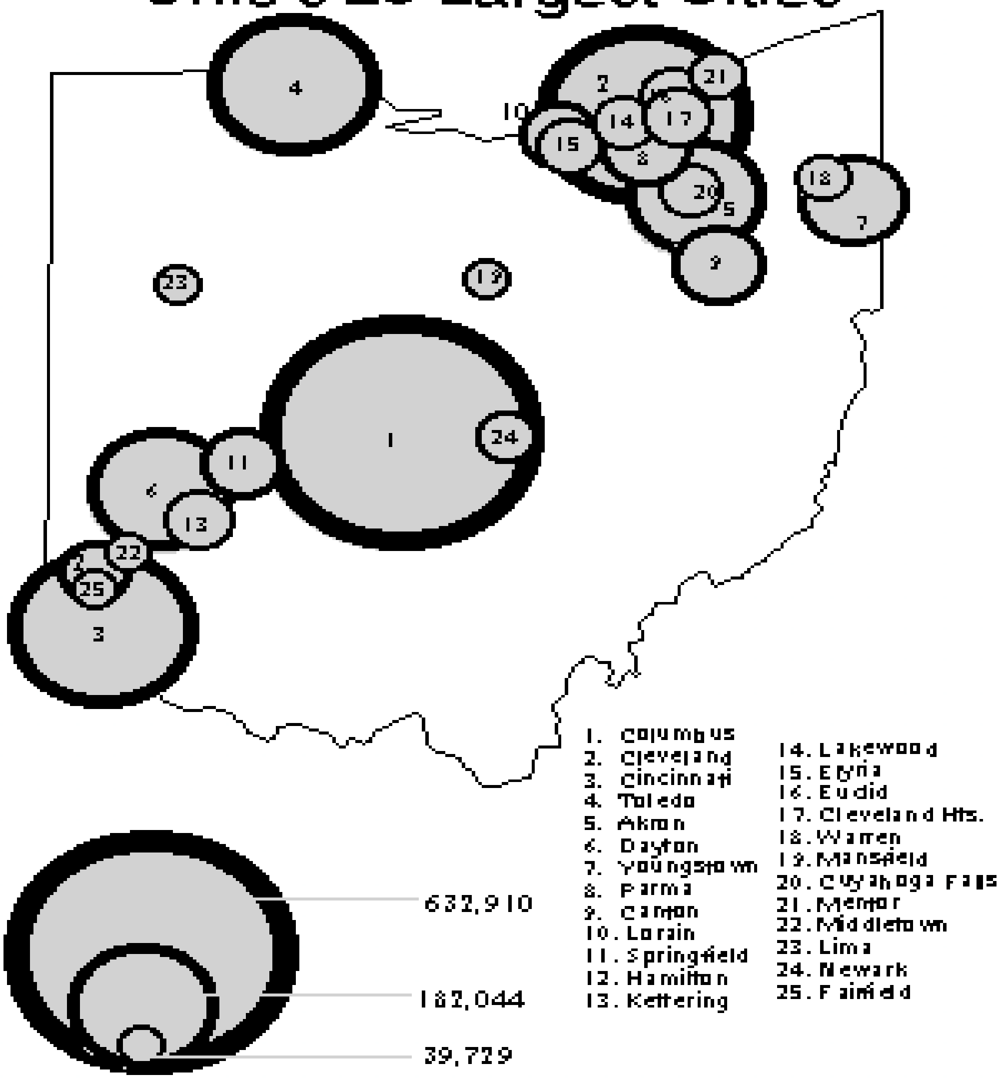


Figure 4

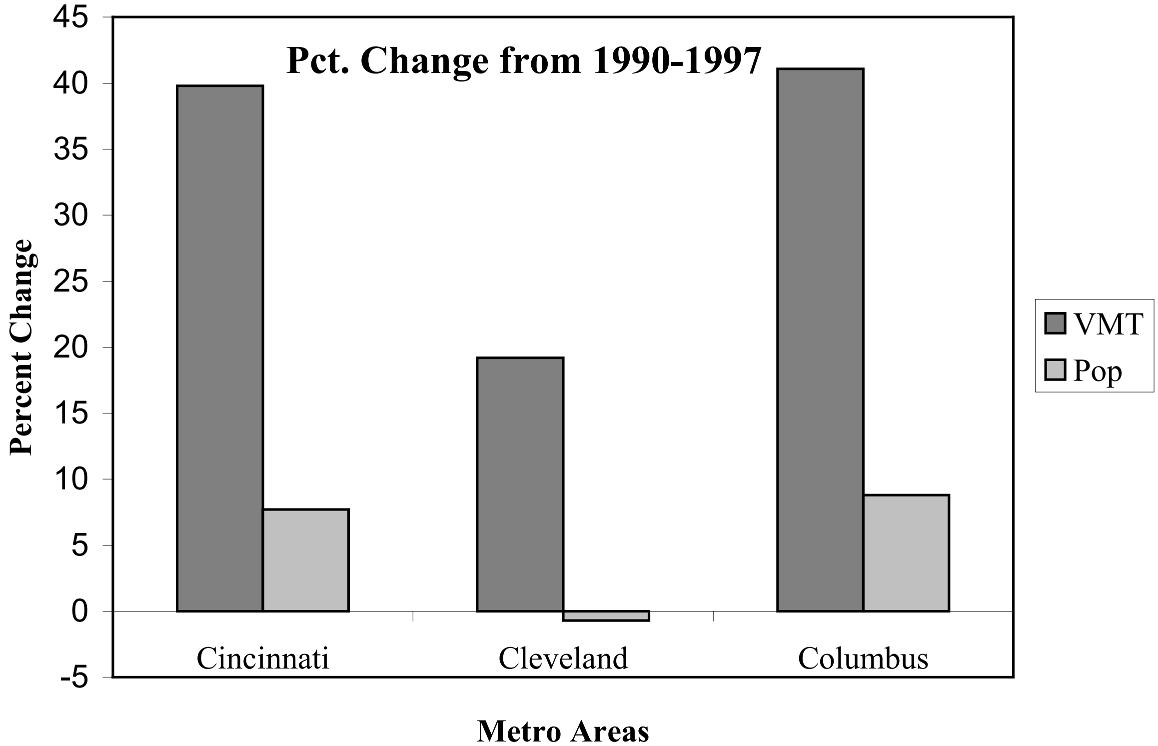
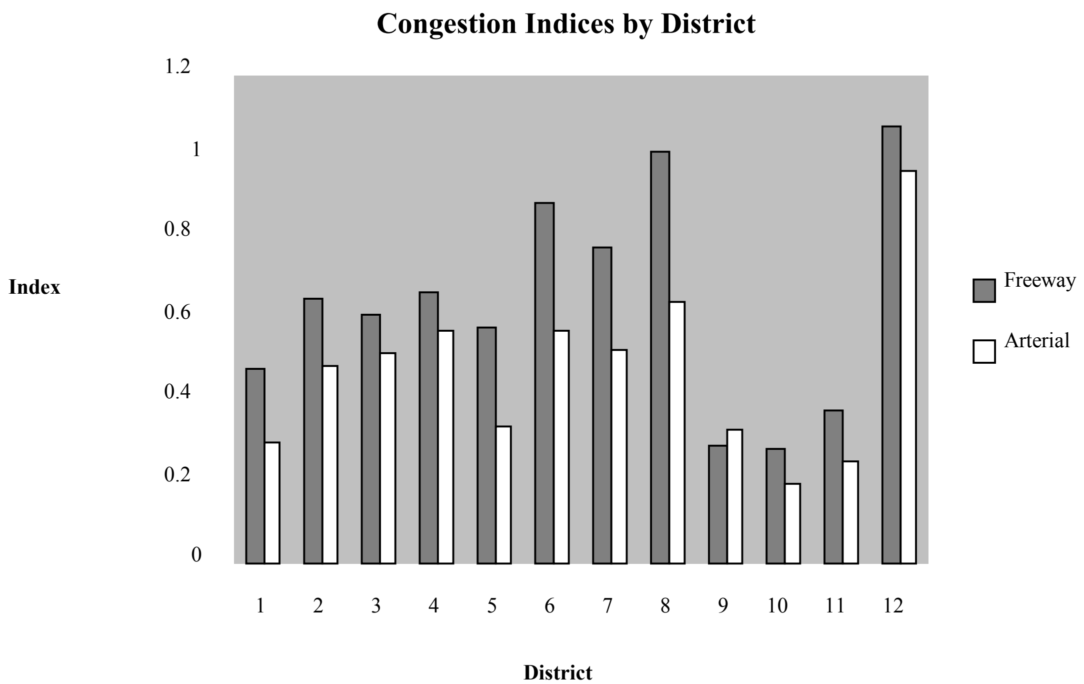

Pct. Change from 1990-1997
Percent Change
45
40
35
30
25
20
15
10
5
0
-5
Cincinnati
Cleveland
Columbus
Metro Areas
VMT
Pop

Figure 5



So, what is causing Ohio's congestion? As indicated above, causal congestion factors are difficult to discern from the detail and frequency of traffic data currently collected. However, one can deduce from the data some important factors in the growth in congestion in Ohio's metro areas. Traffic increases in direct proportion to increases in gross national product. Using this relationship as a way of estimating traffic growth, statewide VMTs have risen in 23 of the past 25 years in Ohio, decreasing only in two years of recession and high oil prices. Statewide VMT has increased from 102 million miles per day in 1976 to 173 million in 2000, a 70 percent increase, based on estimates provided to the Highway Performance and Management System (HPMS).

While traffic growth continues, seemingly unabated, funding for new construction has left highway capacity nearly static. Traffic growth may exceed two percent annually, but annual capacity increases to the system, if any, are a fraction of one percent.

Truck traffic is also a factor, with a disproportionate effect on congestion trends. Ohio's highway network, which is the tenth largest in the country, boasts the fifth-highest volume of truck traffic of any state. In fact, Ohio's truck traffic is growing faster than automobile traffic. Truck VMT have grown 12 million to 22 million between 1976 and 2000 – an 83-percent increase. This growth, based on ATM counts statewide, has illustrated that the percentage of trucks on Ohio's highway system has a significant impact on congestion, with the longer lengths and slower acceleration rates of these vehicles.

The congestion trends referenced above (involving both automobiles and trucks) are severe and of concern to the Department, but implore more data and analysis. Specifically, how bad is recurrent congestion (congestion due to volume versus capacity) compared with incident congestion (congestion due to incidents such as weather, construction, or traffic accidents)? The question is far from academic, as its answer plays directly into the type and effectiveness of ITS programs appropriate for the state.

In lieu of micro-level, on-going data collection efforts that would directly indicate the amount of congestion caused by incidents on a particular facility, a literature search was used to determine the magnitude of incident congestion in Ohio. In addition, the researchers culled empirical data and theory from both Ohio and national experience.

The most comprehensive, national-level review of traffic congestion is conducted annually by the Texas Transportation Institute (TTI), which uses a very crude FHWA model to estimate incident-versus-recurrent congestion. For the three major Ohio cities analyzed, TTI uses a freeway incident-to-recurrent congestion ratio of 1.3, resulting in the following estimates of annual person-hours of delay:

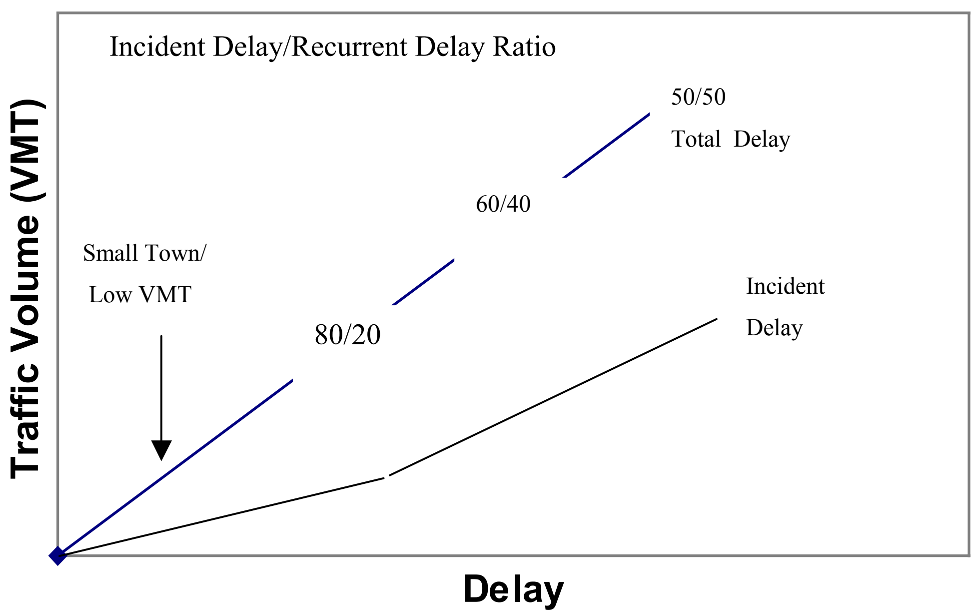
	Recurring	Incident	Total	Pct. Incident
Cincinnati	18,320	22,965	41,285	56%
Columbus	13,230	16,270	29,500	55%
Cleveland	16,490	20,370	36,860	55%

While the ratio is valuable for rough order-of-magnitude estimates of congestion, the TTI figures are somewhat inadequate for structuring a state-level ITS program. One would expect much more elasticity when comparing congestion in cities of varying metropolitan sizes. Two extreme examples help illustrate this point.

At one extreme, a professional familiar with the Seattle freeway system notes that recurrent delay on I-5 often contributes up to 13 hours per day of less-than speed limit travel. In this case, incident delay would likely account for substantially less than 50 percent of total congestion delay. Here, the Seattle context is important: dense urban development, heavily trafficked north-south corridors, with severe constraints from topography and water features.

The other extreme is represented by comments made by a police officer from a small urban area (outside of Ohio). He estimated his area's incident-to-recurrent congestion ratio to be 100 percent. That is, unless there was an incident, traffic was always free flowing. This seems reasonable on its face, with the implication that there is a direct, positive relationship between metropolitan population size/traffic and the percent of recurrent congestion (in the absence of other factors, such as extreme geometric constraints.) This relationship between metropolitan population size/traffic and the percent of recurrent congestion is shown in **Figure 6.**

Figure 6
Relationship Between Traffic Volume and Incident vs. Recurrent Delay



The extreme examples can be used to plot a graph of incident versus recurrent delay, for varying sizes of metropolitan areas/traffic volume. Where would Ohio cities fall on this Figure 6 graph? In all probability, more toward the left. For example, recurrent congestion in the Dayton area is limited to short AM and PM peaks–15 minutes or less; there, congestion is almost exclusively incident-related. Columbus, with few geographic constraints and high route redundancy, probably edges up to the right of the Dayton area, with incident-related congestion accounting for 60 percent or more of total congestion. The Cincinnati area, with greater geographic constraints (river bridges being constrictions on through-travel), might approach a 50-50 congestion mix.

3.0 OPERATIONAL NEEDS

Congestion is certainly not the only problem that ITS can address. ITS infrastructure can also provide services such as weather information, performance monitoring for snow and ice control operations, and multi-modal traveler information, to name just a few. Indeed, it is the coordination of many separate functions that makes ITS planning so important. Based on the congestion analysis summarized in the previous section, the research team's experience, and the input of the Project Advisory Committee, this section creates a hierarchy of needs for ODOT's traffic operations. This hierarchy is categorized by urban and rural contexts.

3.1 Traffic Operations Needs– Urban Context

From a preliminary assessment of ITS best practices based on the research team's experience in other states, and the overview of Ohio traffic congestion, the recommended hierarchy of urban ITS needs becomes clearer: incident management is the number-one functional requirement for urban ITS systems. In a relative sense, this is especially true for smaller urban areas. As metropolitan size grows (as in Cincinnati, Cleveland, and Columbus), with greater congestion issues and an associated growth in the potential for route and modal shifts, then other services become important as well. The urban ITS program recommendations are presented below:

Rank	Need
1	Incident management
2	Arterial signal coordination*
3	Traffic control during construction and maintenance activities
4	Weather/snow and ice monitoring
5	Route diversion
6	Advanced traveler information systems
7	Modal diversion

*Arterial signals are the exclusive province of local governments, but their importance is emphasized here.

3.2 Traffic Operations Needs– Rural Context

The hierarchy of needs for rural corridors is much the same as for urban areas, as shown below:

Rank	**Need**
1	Traffic control during construction and maintenance activities
2	Weather/snow and ice monitoring
3	Advanced traveler information systems

Note the high ranking for traffic control during construction and maintenance activities, for both urban and rural contexts. This finding is consistent with ODOT policy and previous ITS planning studies. Over the past two years, ODOT has instituted an aggressive maintenance of traffic policy, greatly benefiting traffic in major construction zones. Likewise, in the I-71 Corridor ITS Strategic Plan, truckers, automobile travelers, and an ITS advisory committee all identified construction zones as a key area of interest for ITS deployment.

Also, although listed separately above, both snow/ice monitoring and construction zone traffic control are subsets of incident management activities. Focusing on these highest-rated needs will produce the greatest return on Ohio's ITS investments. If funding is limited (and it surely is), then investments should go toward the highest and best uses on this hierarchy. Advanced traveler information is important, but will probably slide to the out-years of ITS efforts.

GENERAL ITS PROGRAM RECOMMENDATIONS

From the hierarchy of needs in Section 3.0 above, the most cost-effective ITS program for urban and rural areas is suggested. An important first step is to evaluate the potential of ITS to solve the problems at hand.

Beyond the relative impact of incident versus recurring congestion, other factors might be uncovered in determining congestion causes. For example, very location-specific operational problems, such as weave or merge lane deficiencies, can contribute to both recurrent congestion and crashes (leading to incident – induced congestion). ITS can improve highway operations, but does not solve every operational problem. Traffic congestion and operations deficiencies must be addressed in a holistic manner; ITS will not solve every operational problem on the freeway system.

It can be estimated that on a large scale, ITS will improve operations of the state's macro corridor system, with some caveats. For example, if there is a regional, inter-agency commitment to incident detection, response, and clearance, then ITS investments can have a large impact on the related congestion. But if such a commitment does not exist, then technology investments might be wasted. A similar situation exists for recurrent congestion: are travelers used to recurrent congestion, factoring delay into their trip schedules? If so, then investments in traveler information systems might be somewhat unnecessary. However, if there are alternate routes or modes of travel, then traveler information may be of great value to travelers, and instrumental in relieving traffic congestion.

4.1 Recommended ITS Program Focus

Ohio's ITS program for its eight largest urban areas should focus on incident management, as broadly defined to include weather and construction- or maintenance-related operations. Of these operations, crash response requires multi-agency and multi-jurisdictional efforts. The level of technological sophistication, and thus investment, should be commensurate with the level of institutional cooperation in a given region.

When using the broad definition of incident management, Ohio's rural ITS program should also focus on incidents: construction/maintenance operations and weather (snow and ice detection). To some extent, this focus already exists through the Department's maintenance of traffic policy, and through its current strategic initiative to improve snow and ice detection.

4.2 Recommended ITS Program Functionality

With incident management as the thrust of the ITS program, the focus first turns to the *functions* (not specific technologies) that should be incorporated into urban, and in some cases rural, programs.

Non-technology Freeway Operations

For heavily traveled urban corridors, freeway service patrols are one of the most effective, and cost-effective, incident management tools. At a minimum, Ohio's three largest urban areas should have specially equipped vehicles outfitted to respond to incidents, and provide quick-clear and traffic control support. Close coordination with local police and fire agencies is critical to efficient operation of these services. This will necessitate working with emergency response agencies to use common radio frequencies.

Multi-agency Traffic Management

DOT, police, and fire agencies usually find themselves with diverging and sometimes conflicting missions:

- The DOT's primary motivation is construction and optimizing traffic flow (though sometimes these activities conflict).
- Police agencies focus on enforcement, and often as defacto first responders to incidents with some attendant traffic control duties. Their responsibilities for accident investigation can close down freeway lanes and substantially impact traffic flow.
- Fire and emergency rescue agencies are primarily concerned with securing an accident scene for the safety of victims and agency personnel. Sometimes an inordinate number of travel lanes are closed for this purpose, with a corresponding impact on traffic.

The key to improving incident response and thus improving traffic flow is to improve the daily communication between the multiple agencies involved in the activity. While workshops and committee meetings are helpful for achieving this purpose, neither surpasses the value of daily interaction between agency personnel. This frequent interaction is best accomplished through the joint location of the agencies. In a collocated setting, there is transfusion of information and mission, improvement in understanding between agencies, and empathy for the others' missions. As discussed below, agencies can collocate in a new dedicated structure, or partner in another agency's facility.

Incident Detection

If agencies are collocated and dedicated to aggressive incident management, rapid detection and response to incidents becomes important to traffic management. Quick response minimizes the delay caused by incidents, which emphasizes the need for a good incident detection function. With collocation, incident notification should obviously be tied into a traffic management facility.

Incident location (regardless of detection) is often cited by fire personnel as a key deficiency of incident response. Put simply, many people are not familiar with directions and geography, which hinders their ability to accurately report the location of an incident. Reference markers placed every fifth of a mile in rural areas and every tenth of a mile in urban areas, help local agencies in accurately dispatching fire crews to incidents.

Traffic Monitoring

For urban (and perhaps rural) ITS systems, it is helpful to monitor traffic speeds and sometimes volume. Speed data, in real time, provides a good indication of a facility's operation. Monitoring is crucial if a system is designed to divert traffic to alternate routes; without information on these routes, traffic cannot be diverted.

Traffic Surveillance (video images)

ITS and freeway management systems create images of video display walls and NASA-style banks of video monitors. What would a traffic management center do without them? Actually, it is an important question to ask, as a great deal of the cost of an ITS system will be tied up in the video quality specified and its attendant telecommunications cost (as shown in best technology recommendations in Section 6.0). Nonetheless, video surveillance is a necessary component of urban traffic and incident management.

Traffic Control

Put simply, the function of traffic control is to reduce demand at a given point of highway, such as during an incident. A range of options exists for traffic control, some passive and some aggressive. On the passive side, providing traveler information through the media can be effective and requires no investment by the public sector (though quality may be suspect). Improved quality may be possible through partnerships between the public sector and broadcast media. On the active side, ramp meters or gates that restrict or limit access are the most aggressive forms of traffic control.

It is recommended that traffic control be a part of urban operations systems. However, the enthusiasm for aggressive traffic control must be tempered by political reality. For example, ramp meters are almost universally disdained; Columbus is the only exception in Ohio. The problem is that the traffic control measures that are the most beneficial to the public at large are also the measures that are the most unpopular in a political sense.

Dissemination of Traveler Information

As with traffic control, traveler information can be provided through a variety of formats: the media, dynamic message signs, or highway advisory radio. The *function* of traveler information is separated to make a message signs, or highway advisory radio, to name a few. The *function* of traveler information is separated to make a distinction from traffic control; regardless of the technology deployed, there could be traffic control without traveler information (e.g., ramp meters). Traveler information usually provides a somewhat limited form of traffic control (e.g., drivers might divert if warned of an incident).

Traveler information represents a higher level of service that can be offered by a transportation agency. For example, agencies could provide *only* incident management and still be providing great benefit to the traveling public.

Data Collection: Synergistic Opportunities

Thus far, the discussion of required functions has focused on data related to freeway traffic surveillance and control. There are other, significant sources of data and data requirements for other sections of the Department, as summarized in **Table 1**.

Table 1 Responsibilities of ODOT Units	
Organizational Unit	Responsibility
Freeway Operations	Generally speaking, both directly and indirectly guiding motorists to achieve less congested travel on Ohio's freeways.
Signal Operations	Traffic signal systems at freeway ramps and on rural, state/US-numbered routes are the responsibility of ODOT.
Maintenance Management	Responsible for the ongoing maintenance of interstate, state and US-numbered routes in non-incorporated areas, including snow and ice removal. Major technology applied includes weather information systems and radio communications with field units. Incident response and freeway service patrols.
Technical Services	Responsible for traffic data collection, including count, classification and weigh-in-motion.

Expressed in a matrix format (**Table 2**), there are some commonalities between these work units, in terms of data needs and/or data collection methodologies.

Table 2 Needs for Data by ODOT Offices				
Monitoring Functional Requirements	Technical Services	Freeway Operations	Signal Operations	Maintenance Management
Occupancy/ Presence in the loop			Required for signal activation	
Speed	Minimal need	Yes	Yes	Yes (for snow and ice removal)
Volume	Yes	Minimal need	Yes	
Classification	Yes			
Weigh-in-Motion	Yes			Yes
Weather		Yes		Yes
Video Images		Yes		

Taking the matrix analysis one step further, the potential for shared data and technologies to improve the efficiency of data collection, as well as the operations of ODOT work units (**Table 3**). These relationships are an appropriate foundation for the detailed assessment of technologies. Capitalizing on these opportunities will depend on cooperation in planning and deployment, and keystone decisions made regarding telecommunications.

Table 3
Synergistic Opportunities Among ODOT Offices

Data to: / Data from:	Technical Services	Freeway Operations	ODOT Signal Operations	Maintenance Management
Technical Services		Retrofit ATR stations to provide real-time traffic data to TMC		Potential to provide real-time speed data for quality monitoring of snow and ice control
Freeway Operations	Format data to be useful for count and speed; some installations have potential for classification and WIM		Interface between freeway and arterial operation, particularly at ramps, and alternate routes	(Same as above)
Signal Operations	Transfer counts from signal operations to Technical Services			Speed data from signal detectors
Maintenance Management		Weather; Radio communications from maintenance vehicles to TMC		

5.0 BEST ITS PRACTICES — FREEWAY OPERATIONS

Based on anecdotal experience, ODOT's executive management has been dissatisfied with the reliability and expense of the components associated with ITS. For the most part, executive management's impressions stem from experiences with the ARTIMIS program in Cincinnati. ARTIMIS gained a somewhat unfortunate image due to some missteps in system development. For example, dynamic message signs were installed prior to electrical/communication connections, and thus did not seem to work well. But this was due to procurement issues, not technology. However, the die was cast, with a general impression left that ITS technologies were both expensive and unreliable.

The irony is that some of the technologies deployed in ARTIMIS, and criticized by executive management for their unreliability, are deemed perfectly acceptable for other purposes. For example, the use of inductive loop detectors in the ARTIMIS project became suspect for their failure rate and associated downtime. Meanwhile, other sectors of the Department rely on loops almost exclusively as detectors for traffic signal control and automatic traffic recording, but without a negative image.

The positive effect is that determining best ITS technologies became a primary motivation for this study. While such an effort may seem pedestrian to ITS professionals, the fact is that policy makers– non-practitioners–have not been afforded good information on the subject, stated in a policy sense. The authors see this as a great failing of the ITS movement as a whole.

Surely, there are tradeoffs between cost and functionality of the technology choices made by state DOTs. Policy makers deserve well-articulated information on the subject. Based on the priorities identified in this research, this section of the report provides a discussion on the range of technology options that exist for each function. Functions are grouped into categories as shown in **Table 4**.

Table 4 Functional Categories and Descriptions	
Function Name	Function Requirement
Multi-agency Traffic Management	Collocation of more than one agency; or “Hard wire” communications connection
Incident Detection	Identifying incidents as quickly as possible to ensure fast response/clearance
Traffic Monitoring	Detecting and measuring traffic flow
Traffic Surveillance	Receiving and using visual images for traffic and incident management
Traffic Control	Directly influencing route access, speed, etc.
Traveler Information Dissemination	Provision of traffic information to indirectly influence route selection, flow, speed, etc.
Data Collection, Analysis, and Planning	Development of strategic and tactical plans for managing Macro System traffic with a more cost effective and efficient use of available resources

5.1 Recommendations for Multi-agency Traffic Management

The collocation of state and local personnel has proven to be one of the primary benefits of ITS deployments across the country, *regardless of technology.* Inter-agency communication is strengthened, and bonds are forged to improve traffic operations.

It is recommended that collocation of police and fire agencies be integral to ITS investments in urban areas of Ohio. Optimally, police and fire dispatch offices would be collocated with traffic management. However, even the physical presence of a police and/or fire department representative in a regional traffic management center will provide significant benefits to all agencies involved in emergency response.

Recognizing the multitude of local police and fire jurisdictions, it will be impossible to locate all local agencies together. However, care should be taken to involve the major local agencies, for example, the city of Columbus Police and Fire Departments with ODOT in the CORTRAN Traffic Management Center. In some cases, the larger police and fire departments in the State have mutual aid agreements that will increase the effective freeway coverage of a given agency.

Another option for collocation is the distribution of data and video images to the many and various local agencies, such as police, fire, and transit. This option would provide partnering agencies with information but lack the *interaction* necessary for optimal traffic management.

When discussing multi-agency traffic management, ODOT should not ignore intra-DOT collaboration and cooperation, specifically the inclusion of the DOT maintenance dispatching function within a traffic management center (TMC). There are many advantages to this. The DOT maintenance forces are called out to respond to many incidents, such as when traffic control is required for long closures, or when there is damage to the roadway or its appurtenances. Maintenance forces are also responsible for snow and ice removal, a key operational function. With radio communication, these forces can also serve as “eyes and ears,” or real-time probes, to provide incident and traffic condition reports.

Finally, cost is a key consideration in the development of traffic management centers. The issue is especially critical for the Ohio context, with eight significant urban areas. Experience from across the country suggests that too much effort and expense goes into the physical structure for a traffic management center, instead of the institutional partnership.

This misapplication of management attention results in compulsory design: two-story video walls and long rows of computer workstations reminiscent of 1960s-era NASA space launches. In fact, such extravagant traffic management center design does more to impress political leaders than to address traffic and incident management. Construction of new buildings for TMCs is not always necessary or recommended.

Instead, ITS planning efforts should seek to identify space within a partner agency’s facility, (i.e. dispatch office of a police, fire, or the State Highway Patrol). In the case of the ITS Strategic Assessment for the Eastgate Development and Transportation Agency in the Youngstown-Warren area, the research team recommended looking at an option of collocating a Regional TMC in a transit agency’s facilities. The effort to identify shared-space opportunities will not only save money, but will also build the partnerships that are critical to multi-agency traffic management.

5.2 Recommended Incident Detection Strategies

Assuming collocation of agency personnel, the next function is incident detection to improve and reduce response and clearance times. The early years of ITS focused on the intelligence made available by advances in information technology and telecommunications. With the ability to transmit and process real-time traffic data, traffic management centers could take in streams of traffic sensor data and create algorithms to automatically detect slowdowns and incidents. Per the guidelines of the late 1980s, this method of detection required the spacing of traffic detectors every one-third to one-half mile on a freeway system.

Interestingly, the roadway technology designed for incident detection has been trumped entirely by the technology in the hands of private individuals: cellular telephones. Detection via ITS infrastructure could take two to five minutes, and produced numerous false alarms while not detecting incidents if traffic was light. Meanwhile, calls to 9-1-1 provided nearly instantaneous incident detection; in Cuyahoga County, for example, the 9-1-1 call center will receive up to 90 calls within the first two minutes of a highway crash.

9-1-1 calls are routed to Public Service Answering Points (PSAP), which generally cover a large geographic area. For example, there is one PSAP for Cuyahoga County. Call takers determine if the emergency requires a police or fire response; if the call is emergency related, the call takers will record the information on a computer aided dispatch (CAD) system, allowing the emergency dispatcher for each jurisdiction to direct equipment and personnel to the scene.

Some emergency agencies have been reluctant to make CAD information available to transportation agencies, but newer systems have incorporated "filters" to screen out traffic-related calls (as coded by the call taker) for transmission to a traffic management center. In addition to the functionality of CAD information for incident detection, dialogue with emergency management agencies for use of the data also increases cooperation and partnering for traffic management. For cost, effectiveness, and partnering purposes, the best technology for incident detection relies on the private traveler's cell phones, and traffic management center links to CAD systems.

5.3 Recommended Traffic Monitoring and Surveillance Strategies

As used in this report, "traffic monitoring" refers to the function of detecting traffic flow characteristics, through infrastructure in or near the pavement.

In Cincinnati and Columbus (as in many cities), traffic detection was intended to serve the duel function of traffic monitoring and incident detection. Detectors (no matter the type) are placed every third- to half-mile. With 9-1-1 as a recommended means of incident detection, the functions required from traffic detectors are reduced, which consequently changes the type and density of detection required.

As discussed previously in this report, it is imperative to have traffic monitoring on alternate routes prior to diverting traffic to those routes. Data is also important to provide real-time information to travelers, and to provide archived information for post hoc analysis. To serve these purposes, detectors can be placed at much greater intervals than what is needed for incident detection.

Data requirements for this function are limited: speed, and perhaps volume. Loop detectors currently provide the most accurate measures, but other detection technologies are closing rapidly. However, accuracy is of relative importance to this function. Speed and volume data, at plus or minus five percent accuracy, is adequate to meet the demands of traffic management.

Another concern is reliability and maintainability. Inductive loops are not necessarily unreliable if installed correctly, but they are susceptible to damage and their repair is disruptive to traffic. Because of these concerns, the best technology for traffic monitoring in a freeway environment is non-intrusive: acoustic, radar, or microwave detectors installed in the right-of-way but not imbedded in the pavement. These technologies are accurate enough to serve their intended purpose, and their maintenance, repair, and replacement will not burden traffic due to their location off the roadway.

Video surveillance can serve up to three distinct functions: traffic management, incident response, and traveler information. For traffic management, TMC personnel view images from around a freeway system in order to activate responses (e.g., changes in dynamic message signs or ramp metering). The video images are critical for verification, reducing reliance on detector data.

In theory, emergency dispatch personnel collocated in a TMC will have the ability to view incidents in order to determine their exact nature and location. The incident response functionality implies that reliability, quality, and coverage of the video surveillance are critical. Generally, specifications for this function call for full-motion video, with the cameras having the ability to pan, tilt, and zoom (PTZ). These PTZ commands require two-way communication from the control center to the camera. Such functions need to be carefully analyzed before installing PTZ cameras.

Traveler information is generally a secondary benefit of the two functions above. Images can be easily ported to a website, and incident information verified through CCTV surveillance can be disseminated to travelers through media such as dynamic message signs and highway advisory radio. Television media are especially interested in video images, for use in broadcasts in the morning and evening rush hours. Media prefer very high quality, full-motion images that are comparable to their own television broadcasts.

ODOT has had great success installing web cams for its I-70 work zone in Columbus, at a very modest cost ($17,000 for eight cameras), and porting these images to its website. This type of temporary installation has proven to be very beneficial in assessing how well the maintenance of traffic plans are performing during construction projects. However, these types of configurations are not recommended for permanent CCTV installations. They typically lack the ability to achieve the desired coverage area and image stability that can be achieved with static poles that are designed to minimize deflection at the greater heights necessary to maximize coverage area. In addition to the structural inadequacies, the electronic equipment (camera and communications) often found within temporary installations often cannot support the environmental standards (i.e. NEMA environmental standards) that have been established over the years in transportation applications of field equipment.

Communications technologies used in traffic surveillance applications offer the greatest tradeoff between functionality and cost. The camera and components in and of themselves are not a great cost consideration. Rather, the communications implications drive the level of functionality and quality that can be achieved in deploying a CCTV surveillance system. CCTV requires transmission of both bi-directional data communication and uni-directional video communication. Because video communication requires substantially higher signal rates than data communications, CCTV requirements are typically the central factor in the communication network design. Compressing video to 1.5 Mbps (equivalent to a T-1 telephone line) will allow for transmission of 30 frames per second (fps) back to the TMC. This rate is typical for standard video broadcasts and is also acceptable for traffic surveillance. Bandwidth could be increased as high as six Mbps at a substantial increase in cost, but would have little or no noticeable difference in picture quality to the remote user. **Figure 7** shows examples of CCTV bandwidth needs.

Figure 7
CCTV Bandwidth Needs for Agency Interface

Interface Description	Bandwidth Requirement
Video (30 fps – full motion, one way)	1,536 kbps
Video (30 fps – full motion, each way)	3,088 kbps
Video (15 fps one way)	128 kbps

It is recommended that a communications master plan be developed for each region that weighs functionality, performance, and desired/acceptable quality against realistic capital and operational budget projections. The greatest incident management benefits of a CCTV surveillance system will be realized in combination with a local commitment to interagency cooperation, and more specifically with the collocation of police and fire dispatch personnel. Although the media are important partners, media demands for high-quality video should not be the driving factor in traffic surveillance design (unless they contribute to cost). Relatively speaking, television media reaches only a small percentage of the traveling public, and the quality and timeliness of their service is out of a Department's control.

5.4 Recommended Traffic Control and Traveler Information Strategies

The lines between traffic control and traveler information blur. For example, merely providing traveler information can also serve a control function, when travelers avoid a route due to information on congestion or incidents.

Traffic control and traveler information functions are very closely related. A primary function of traveler information dissemination is indirect traffic control by impacting travel demand. For the purpose of this research, traffic control and traveler information methods were grouped under either traffic control or traveler information as shown below.

Traffic Control

- DMS
- Lane Control Signals
- Variable Speed Limits
- Ramp Metering

Traveler Information

- Media
- Highway Advisory Radio
- 5-1-1 Telephone
- Web page (and internet enabled devices)
- Alerts to travelers via email, cellular phone, pager, personal digital assistants
- Kiosks in high traffic areas

Traffic Control

Once the DOT is able to monitor real-time traffic conditions, a key benefit to the public is providing control measures to influence demand and route choice. For example, in the event of an incident, the goal is to reduce demand on the facility by providing alternate route or modal information.

Dynamic Message Signs (DMS) — DMS are one of the most visible components of freeway management systems. They range from simple, trailer-mounted message boards to large, complex devices mounted on overhead trusses. At best, these DMS provide timely, point-specific information. But there are limitations to their functionality and cost considerations in the selection of the technology. At worst, they become a public relations nightmare due to perceived inaccuracy or disuse. Descriptions of DMS types with cost/performance characteristics, and photos illustrating a fiber optic, a LED, and a hybrid fiber optic sign, each with a different mounting system, are shown in Section 6.3.

While DMS are a popular feature of freeway management systems across the country, and a feature included almost by default in most ITS regional architectures, DMS have limits to their functionality. Foremost among these limitations is their point-specific nature. They can only serve travelers passing by one point on the roadway system, so each sign has perhaps six to ten seconds of utility per driver. Secondly, drivers may actually be distracted by the messages, having to slow down to read them. Related to the point-specific nature of DMS coverage, they are also unable to reach the multitude of drivers approaching a freeway facility from an arterial.

There is also a functionality issue in the "downstream coverage" of the DMS: how much information can be conveyed regarding the multitude of destinations available to drivers who pass the sign? And, for how long will that information be accurate for drivers continuing a long way downstream from the DMS? In fact, downstream information coverage, in a geographic and temporal sense, is limited.

It is suggested that ODOT place due diligence on relying on DMS for traffic control (and traveler information). DMS are appropriate where there is a clear need and benefit to point-specific information, such as a diversion point that is logical and has utility for traffic control. It is recommended that ODOT conduct individual cost-effective analyses in cases where specifications for large, over-the-roadway DMS mounted on trusses that span the roadway are being considered. Where DMS are appropriate, it is recommended that ODOT specify smaller sized signs that have equal utility (i.e. visibility) but are not a preponderant visual image over the freeway. While message length may be compromised, smaller signs may actually be more commensurate with the value of the information provided by these devices. Moreover, highway aesthetics may improve and the smaller signs may be less a public relations issue.

Lane Control Signals — A cost-effective technology is lane control signals. Installed over each travel lane, these signals display the message that indicates if the lanes ahead are closed (red "X"); open to traffic (green down arrow); or if traffic should merge from its current lane (yellow slanted arrow). San Antonio and Charlotte have used such signals on freeways and surface arterials, respectively, with significant benefits to traffic flow. In the photo shown at right, the lane control signs are augmented by a flashing light and a small electronic sign.

Lane control signals have most of the same limitations as DMS. That is, limited geographic coverage area and information conveyance. They must be installed at a greater density than would DMS, and their utility is somewhat constrained by the geometric design of the highway section being covered. They are cheaper in capital cost and maintenance, and their simple logic makes them much less of a public relations issue when compared to a higher order of magnitude for the cost of installing overhead message boards. It is recommended that the Department specify lane control signals to control reversible lanes. Specific designs are needed for surface arterials and for freeways.

Variable Speed Limits — European cities have found a high level of success with variable speed limits. On the M25 in England, detectors measure traffic density and speed, and change the speed limit in increments. Smoother traffic flow resulted in decreased average travel times, as well as traffic accident decreases of 28 percent on the M25 motorway according to the British Ministry of Transport. France, Germany, and Sweden have also found success with similar systems.

Data on variable speed limits in the United States is limited. The New Jersey Turnpike utilizes a simplified system in the southern part of the state, varying speeds from 45 to 65 miles per hour, usually in response to weather conditions. While it is probable that there would be political resistance to variable speed limits in Ohio, they appear to be effective for managing traffic and improving safety. It is recommended that ODOT discuss variable speed limit functionality with local governments during ITS deployment planning.

Ramp Metering — Ramp meters (traffic signals on ramps) regulate the number of vehicles entering the freeway during periods of peak flow. The objective is to reduce demand on the freeway or regulate the flow to ease merge maneuvers on the main line. Ramp meter systems can be isolated to operate by time-of-day protocols, or tied into software that monitors traffic in real-time to adjust the signals accordingly.

Ramp meters have been found to be beneficial to freeway traffic flow. As a traffic control device, the effectiveness of ramp metering for reducing freeway congestion and accident rates is well documented. A recent Minnesota DOT (MnDOT) study found that without ramp meters in Minneapolis, travel times increased 22 percent, average speeds decreased 14 percent, and accidents increased 26 percent. After utilizing the ramp meters for several years, MnDOT found that the public actually requested that they be activated again after a period of not using them.

There are negative impacts of ramp metering. One is that ramp queues can back up onto the arterial that feeds a freeway. A second negative impact is that local governments often see ramp meters as a strategy that makes freeways less attractive to drivers, who opt for city arterial routes instead (thus creating congestion on city streets). Notwithstanding the situation (previously related) describing Minnesota motorists, the traveling public in general is resistant to traffic control measures, and there are few more direct control mechanisms for freeway operations. Finally, ramp metering has been tied to spurious "environmental justice" issues, in that signals are normally deployed in or nearer to the central city and not the more affluent suburban developments.

In summary, wherever feasible and beneficial, the Department should continue to consider ramp meters as part of the traffic control strategy for urban freeway systems. Resistance groups may increase public objections to the widespread deployment of such devices. Currently, only Columbus, among Ohio's cities, has demonstrated a general political acceptance of ramp metering, while other major Ohio cities have rejected this function.

Traveler Information

In reviewing traveler information functions, it is instructive to include a public survey of Cincinnati-area travelers, related to their awareness of traffic information services. The study asked respondents, with unaided recall, to state their preferred sources of traveler information. As shown below, traditional media are preferred over publicly provided information sources. However, media information improves through links to the public agency-maintained freeway management system, as shown in the data from this May, 2000 "Awareness of Traffic Information Sources" survey by ARTIMIS.

• Radio	81%
• Television	48%
• DMS	8%
• Internet	7%
• 5-1-1 telephone	6%
• HAR	4%
• Newspaper	4%
• Other	7%
• None/Don't know	7%

The findings above provide insight into determining the most effective policy choices for disseminating traveler information.

Broadcast Media — As seen from the ARTIMIS evaluation, traditional media sources are foremost in the mind of travelers in the Cincinnati region. Eighty-one percent cited radio and 48 percent cited television as sources for traveler information, with no prompting. This is not surprising, as electronic media has long been identified as a key partner in developing traveler information systems.

Broadcast media, especially radio, is very attractive to the traveling public for two reasons. One, it is readily available in the vehicle, so that real-time information has immediacy to drivers. Secondly, radio broadcast reports are bundled with entertainment programming, which meshes well with the experience of commuting: passive, not requiring visual reception. Television reports are limited in their immediacy, but are valuable for conveying some information (e.g., prior to peak AM commuting times).

Strong institutional linkages with television and radio media should be a primary focus of all ODOT ITS deployments. Such linkages can be both human and technological. On the side of personal communications, TMC operators and managers should be on familiar terms with radio, television, and newspaper traffic reporters, interacting with these individuals on a daily basis and through special events such as TMC tours. The DOT should also consider office provisions for the media in the TMC itself, for live broadcasts and for building "brand recognition" of the program with the public. On the technology side, traffic systems should be made compatible with media broadcast systems, in order to facilitate public dissemination of data.

Highway Advisory Radio (HAR) — HAR provides drivers with timely information on road conditions and accidents. The technology has been available and in use for years, but is generally not considered "high-tech." HAR systems transmit low-power AM or FM radio signals, with coverage varying in relation to station wattage. The systems must be licensed by the FCC, and advertising is prohibited.

The advantage of HAR (compared to DMS) is its broad coverage area, and amount of information that can be conveyed. In contrast to a DMS, drivers can receive several minutes worth of data, with a high level of content, but only if messages are updated regularly and are accurate. However, small DMS can be used to alert travelers to HAR broadcasts during incident-caused traffic congestion.

A negative is that drivers do not readily tune to HAR stations. Their lack of popularity might stem from several factors. One, some systems simply do not work well due to their low power output and typical one-mile broadcast radius. Secondly, HAR has been both misused and underused by highway agencies, particularly in not updating messages in a timely fashion. Finally, HAR is not always well publicized by DOTs. It is important to provide signing (including flashing beacons) to alert drivers of the presence of a message.

Specifying a higher-power system and making provisions for testing/acceptance in the procurement phase of a project easily overcomes the technical faults of HAR systems. ODOT must commit to a high service level in maintaining and updating the messages being broadcast over the system. It is recommended that in all cases, signing and flashing beacons be used to alert drivers of the presence of HAR messages. When used properly, HAR becomes an invaluable, cost-effective method of delivering near real-time traveler information to a wide audience.

5-1-1 Telephone — ARTIMIS is a pioneer in the use of three-digit telephony for traffic information, receiving approximately 900,000 calls per year. This service has many of the same advantages as highway advisory radio, plus some others. The systems offer customized route and mode information. The disadvantage of the service is its expense, approximately $100,000 per month in Cincinnati, and the lack of participation by all cellular companies in the service area. Verizon does not currently participate in ARTIMIS, although it will in the future. GTE and Cingular wireless customers can use the 511 now, as well as Cincinnati Bell customers from both landlines and wireless. Most other wireless providers are negotiating with ARTIMIS for future 511 service.

Web and Internet-enabled Wireless Devices — These devices may become the future for traveler information dissemination. Web pages offer an inexpensive method of providing traveler information. Video stills, streaming video, and other traffic information can be easily ported to a website. However, Internet communication is generally limited to the home or office, so receiving en-route information is even more restricted.

Wireless devices allow traffic information to be provided in many cities via cellular telephone and pager devices. It is probable that these wireless devices (and others) will increasingly have Internet connectivity, thus increasing their ability to convey real-time traffic information. Moreover, the Internet will be moving into the vehicle as standard equipment, providing another medium for traveler information dissemination, including real-time video, to the driver. Foreseeing these changes in information delivery, ODOT should design all ITS deployments to capitalize on Internet protocols for delivery of traffic information.

Interactive Traveler Information Kiosks — Kiosks offer another method of providing traveler information, especially in areas with a large amount of foot traffic, such as malls, central business districts, and highway rest areas. Despite providing a valuable service to tourists and visitors, interactive traveler information kiosks reach a relatively small portion of the traveling public. Rest areas, visitor information centers, and other locations such as malls provide much less coverage in comparison to the number of travelers who receive broadcast information while enroute. Kiosk designs that provide only one terminal can only serve a few people at a time, and queues formed at kiosks are equally as frustrating as queues formed on the freeway. Because of these drawbacks, the market that uses these devices will probably limit their deployment, as in most states, to Interstate Welcome Centers, high-use truck stops, and other high-use markets such as (in Ohio) Cedar Point, the Cleveland riverfront and the "Flats," and perhaps major university centers.

6.0 RECOMMENDED TECHNOLOGIES— A DETAILED ASSESSMENT

Detailed assessments were made in this study for four different aspects of technology in which ODOT expressed specific interest. Those technologies are:

- Vehicle detection
- Traffic controllers
- Dynamic message signs
- Communications technologies

These four categories of ITS deployment and operations are contained in this section. A note regarding this section follows: *In Sections 6.1 through 6.4, as well as in the appendices, there are references to specific technologies by trade name, and to specific vendors. Neither the inclusion nor the omission of a specific product by trade name or vendor is an indication of an endorsement of those products and vendors that are included, nor is it intended to be an overt act to exclude any specific product by trade name or by vendor. Names of products and vendors are listed to be illustrative only.*

6.1 Vehicle Detection

Perhaps the basic function performed by a traffic management system, whether applied to freeways or major arterials, is vehicle detection. The ability to collect vehicle counts, measure detector occupancy, estimate vehicle speeds, and classify vehicles allows a TMC manager to evaluate the performance of the transportation network as well as monitor the system for irregular conditions and levels of congestion.

Detection Functions

The four primary detection functions are: vehicle counts, vehicle presence (occupancy), vehicle speed estimation, and vehicle classification. Each of these functions requires a different type of detector field measurement. How these parameters are measured is described below.

To perform a vehicle **count**, a detector needs only to register that a vehicle has entered its detection zone. Some of the difficulties encountered with vehicle counts include double-counting of tractor trailers, counting non-vehicles, and missing vehicles due to vehicle lane-changing or a lane of traffic being obscured by a large vehicle.

To perform vehicle **presence** detection, a detector must be able to determine when a vehicle enters and exits its field of focus and how long it stays in the field.

There are essentially four ways to determine **speed**:

- Use magnetic probes in a trap configuration.
- Use the Doppler frequency shift effect (i.e. RADAR) to determine the speed of vehicles when using active range-finding devices.
- Assume an average vehicle length and take the time a detector field is occupied to determine speed.
- Use an object-tracking algorithm.

Three methods of **classification** are used:

- Identify vehicles with long occupancies and attempt to segregate vehicles on the basis of vehicle length (usually limited to two or three times the length of an average automobile); this method uses either intrusive or non-intrusive detection.
- Use a range-finding device to scan a detector field and determine a vehicle profile based on length, height, and width dimensions of a vehicle (acoustic, microwave, or infrared).
- Use video-based vehicle pattern matching.

Intrusive Vehicle Detection

The standard for *intrusive* (i.e. buried in the pavement) vehicle detection in the traffic industry has been the **inductive loop** detector. An inductive loop is an effective means of determining vehicle counts and occupancy. When used in a trap configuration, the loops are effective at determining speed. Furthermore, when used in conjunction with an embedded weigh-in-motion device such as a piezoelectric strip, they form an accurate vehicle classification station.

The following are advantages of inductive loops:

- Extensive deployment nationwide
- Proven performance
- High accuracy
- Compatible with most field hardware
- Performance in any type weather
- Good presence detection
- Size and shape of the detection zone can be customized

The following are disadvantages of inductive loops. These disadvantages are typically associated with the installation of the wire loops rather than the sensor unit.

- Require saw cutting pavement for installation (costly and time consuming)
- Require lane closures for installation (safety concern for workers/disruptive to traffic)
- Tend to fail frequently resulting in repeating the installation process
- Detection accuracy significantly impacted by the quality of the installation
- Detector life span limited by the pavement life span
- Susceptibility to degradation in deteriorating pavements
- Tendency to double-count trucks
- Invalidated data due to traffic control involving lane shifts and closures
- Frequent loop replacement resulting from poor scheduling of construction and maintenance activities

Piezoelectric sensors are a specific type of inductive loop designed to provide vehicle classification in addition to volume and speed. The following are advantages of piezoelectric sensors:

- Communication requirements similar to those of inductive loops
- Relatively easy installation of sensors
- Vehicle classification information obtained from the detected axle weight when used in combination with inductive loops
- Substantially lower capital cost when compared to other classification technologies

The following are disadvantages of piezoelectric sensors:

- Speed and accuracy not measured directly when used as a single sensing element
- Subject to mechanical stresses associated with measuring axle weight, thereby limiting its life span
- Lane closures required for installation (disruptive to traffic)
- Detection accuracy significantly impacted by the quality of the installation
- Detector life span limited by the pavement life span
- Susceptibility to degradation in deteriorating pavements
- Traffic control involving lane shifts and closures often render data from piezoelectric sensors meaningless
- Construction and maintenance activities often result in piezoelectric sensor replacement

Non-intrusive Detection

A variety of non-intrusive detectors have emerged to compete with the inductive loop over the last several years. The leading non-intrusive candidates emerging from the technology assessment are evaluated in this report:

- Passive acoustic detectors
- Microwave sensors
- Active infrared sensors

These devices operate using a variety of methods, but all allow installation and maintenance to be performed outside of the roadway.

The **passive acoustic detector** is a non-contact and non-radiating sensor intended to be a practical alternative to in-pavement inductive loops. Each acoustic detector operates from overhead structures or roadside mounting positions and processes the acoustic signals radiated by vehicles as they pass through the detection zone. The signals from the vehicles passing through the detection zone are passed to the controller card unattenuated for detection processing. The signals for vehicles outside the detection zone are heavily attenuated and therefore filtered out.

The following are advantages of passive acoustic detector technology:

- Detection zones can be established
- No damage to the pavement surface
- Completely passive detectors emit no potentially controversial energy
- Lane closure usually not needed for installation
- Detectors can be adjusted to provide useful detection data during lane shifts and closure
- Construction activities generally do not impact these or other non-intrusive detectors
- Can be configured to emulate inductive loop output

The following are disadvantages of the passive acoustic detector technology:

- Inaccurate vehicle classification due to the great variability in road noise associated with tire pressure pavement surface conditions, and vehicle loads
- Requires an existing sign/bridge structure or new pole for mounting application

A **microwave sensor** is an advanced self-contained device that detects and monitors road traffic. It is a true-presence detector that can provide presence indication as well as volume, lane-occupancy, speed, headway, and limited classification information for up to eight discreet detection zones. The information is provided to existing controllers by contact closures and to other systems by serial communication lines.

The following are advantages of microwave sensors:

- Detects up to eight lanes and 200 linear feet of lane with a single unit
- Can collect data regardless of direction of travel
- No damage to the pavement surface
- Lane closure not necessarily needed for installation
- Units can be adjusted to provide useful detection data during lane shifts and closure
- Construction activities generally do not impact microwave detectors
- Can be configured to emulate inductive loop output

The following are disadvantages of microwave sensors:

- Less extensively tested technology at this point in time for ITS applications
- Requires a new or existing sign/bridge structure or new pole for mounting application
- Complicated establishment of detection zones

The **active infrared detector** is a diode-laser-based vehicle detector/classifier. The detector employs a scanning laser rangefinder to measure three-dimensional vehicle profiles that can be used for very accurate vehicle classification. It has an increased scan angle and higher angular resolution for multiple lane coverage. The narrow laser beam width permits the detection of closely spaced vehicles moving at high speeds; even a two-inch-wide tow bar can be detected. This sensor is the only known non-intrusive sensor that may classify up to 11 vehicles using standard FHWA classifications.

The following are advantages of the active infrared technology:

- Determines vehicle classification compatible with FHWA classification
- No damage to the pavement surface
- Lane closure may not be needed for installation
- Construction activities generally do not impact installations

The following are disadvantages of the active infrared technology:

- Very expensive
- At this point, active infrared technology needs further field tests
- Requires an existing or new sign or overhead structure for mounting

Detection Summary and Costs

Table 5 summarizes functional performance of various detectors. The following cost estimates show only the cost of the detector unit and, where required, the cost of the detector amplifier card for detection of two lanes. It is assumed that all devices require a conduit run with loop lead-in, communications, and/or power cable to be installed from the controller cabinet to the device. Some devices have wireless communications options; however, these tend to be very site specific and are not easy to generalize.

Inductive Loop Detectors: **Approximate cost**

- Single Loop Detector
- Loop Detector (Trap Configuration) Range from $2,000 to $4,000 for all three types
- Loop Detector (Classification Station)

Non-Intrusive Detectors (Two lanes of detection, not including overhead structure)

- Passive Acoustic Detector $5,000
- Microwave Unit $5,500
- Active Infrared $20,000

These costs are meant for comparison only. Acoustic and microwave units are approximately twice the cost of the loop detectors, and the active infrared sensor is approximately four times the cost of the acoustic and microwave units.

Table 5
Detector Functionality Segregated by Technology Class

Technology Class	Function			
	Count	Presence	Speed	Classification [b]
Single Inductive Loops	X	X	X [a]	
Inductive Loops (Trap Configuration)	X	X	X	
Inductive Loops w/ Piezoelectric Sensor (Classification)	X	X	X	X
Passive Field (Overhead Mount)	X	X	X	
Passive Field (Sidefire Mount)	X	X	X	
Microwave (Overhead Mount)	X	X	X [c]	
*Microwave (Sidefire Mount)	X	X	X [a]	
Active Infrared	X	X	X	X

a Assumes a vehicle length to obtain calculated speed.

b Classification refers to sensors that may provide eleven of the FHWA classifications.

c The RTMS unit can provide accurate speed (as opposed to calculated speed) only in an overhead mount with one detector per lane.

Table 6 lists typical vendors, vendor contacts, and user contacts for each detector technology class.

Table 6
Vendors and Reference Contacts

Technology Class	Vendor Contact	User Contact
Inductive Loop Detectors	Canoga 3M Doug Henderson (612)737-1581	All DOTs.
Passive Acoustic Detectors	International Road Dynamics Jim Alexander (612)931-9026	Arizona DOT Tim Fletcher (602)220-0869
Remote Traffic Microwave Sensors	Electronic Integrated Systems, Inc. Dan Manor (800)668-9385	Wisconsin DOT Steve Young (414)227-2160
Active Infrared Detector	AutoSense II Schwartz Electro-Optics, Inc. Terry Myers (407)298-1802	North Carolina DOT C.E. Vance (919)733-7102

Inductive loops have excelled in five critical areas as compared to non-intrusive technologies:

- Lower equipment costs
- Reduced maintenance staff training due to familiarity with system
- Negligible impact on loop performance and accuracy from environmental factors such as fog, rain, temperature, ambient lighting conditions, and wind
- Easily obtainable, proven technology
- Currently in widespread usage

Non-intrusive technologies have outperformed inductive loops in three important areas:

- Capable of producing multiple direct and indirect measures of effectiveness with one sensor device, such as speed, volume, density, vehicle classification, queue length, travel time, etc.
- Easier and less expensive to install when considering impacts to existing freeways/infrastructure, traffic disruption, mounting requirements (i.e. ability to mount on existing poles and crossing structures), and time required for installation
- Good reliability (higher mean time between failure)

The key concerns with non-intrusive technologies include:

- Availability and vendor support of the products
- Lack of widespread deployment
- Susceptibility to the weather and surrounding environmental factors
- Accuracy of the data obtained

Of the non-intrusive technologies, based on the analysis shown above concerning advantages and disadvantages of each technology, passive acoustic detectors and microwave show the most promise and are recommended for general use. For a classification station, inductive loops with piezoelectric sensors in a trap configuration are recommended.

6.2 Traffic Controllers and Cabinets

The purpose of traffic controllers is to process the inputs from field devices, such as CCTV and DMS, and serve as a communications node for polling by the central computer. Currently in the traffic control industry, new generations of controllers are emerging to meet the needs of intelligent transportation systems.

Field Controller Alternatives

The most appropriate controller for any application will depend on the communications architecture employed. There are three options for processing the field data:

- Process field inputs and transmit processed data to the central computer
- Employ field devices with internal/external intelligence, controller serves as a serial communications hub
- Utilize the vendor-specific controller to process field data and transmit processed data to central computer

Of the technologies available, the most viable controller alternatives are listed below:

- Caltrans-specified Model 170E
- Caltrans-specified Model 170E with enhanced PROM module
- Caltrans-specified Model 2070 “Lite” ATMS controller

- NEMA-specified TS-2 controller
- Vendor-specified controllers (for DMS, CCTV)

A brief description of each of these five controllers, and estimated costs, are provided below. It should be noted that the estimated cost for the 170E and 2070 controllers do not include software costs.

Caltrans-specified Model 170E Controller

The basic features of the 170 family of controllers are modularity and standardization. Standard pin assignments and cabinet wiring facilitate the mapping of cabinet inputs and outputs. Multiple vendors exist for model 170 components. The Model 170E controller operates using the 8 bit, Motorola 6800 family of microprocessors. The controller has four ACIA communication ports for serial communications. Software for the 170E is typically supplied on a removable PROM chip, which mounts on a removable PROM board (the 412C). The approximate cost of the 170E controller is $1,000 to $1,300.

The following are advantages of the Caltrans-specified Model 170E Controller:

- Field proven for several years
- Several vendors, competitively priced
- Software can be replaced independently of hardware
- Can interface with Caltrans-specified cabinets and cabinet accessories
- Open architecture

The following are disadvantages of the Caltrans-specified Model 170E Controller:

- Inadequate processing power to operate the National Traffic Control and Incident Protocol (NTCIP) high-speed, class A protocol in a multi-device configuration
- Production of the Motorola 6800 processors currently being phased out
- Caltrans is no longer refining the 170E specification, and focusing on the 2070 controller

Caltrans-specified Model 170E Controller with an enhanced PROM module

To address the processor speed issues of the Model 170E controller, several vendors have developed an enhanced PROM module. These modules fit in the 412C PROM module slot of the 170E controller, but contain enhanced processor and communications capabilities. Among others, two of these devices are the 417/ip produced by Antares and the 470i produced by Safetran. Both units have the processor capability to handle NTCIP protocols.

417/ip

The 417/ip features the 32-bit Motorola 68360 microprocessor, 25-MHZ motherboard (the same chip used in the 2070) with four external serial ports. Utilized with a Model 170E, a total of 8 serial ports are available. The ports are user configurable, and can support EIA-232, EIA-422, and EIA-485 communications.

The cost of the 417/ip is approximately $1,000. The combined cost of the 417/ip and the Model 170E controller would be about $1,850.

Vendor Contact: Gordan Dale, Antares, (503) 315-9899
User Contact: Charles Vidrine, City of Norfolk, VA, (757) 664-7300.

470i

The 470i features an Intel, 16-bit, microprocessor with four serial ports. The ports are user configurable, and can support EIA-232, EIA-422, and EIA-485 communications. The 470i contains operational, multi-tasking firmware for software development that are compatible with central control communication, ramp metering, incident detection, and dynamic message sign control.

The cost of the 470 is about $2,000. The combined cost of the 470i and the Model 170E controller would be about $2,850 (the price of the 412C PROM module which is being replaced is deducted from the price).

Vendor Contact: Ron Johnson, Safetran, (719) 599-5600
User Reference: Jeff Barney, ODOT District 8, Lebanon, OH; and Glenn Anderson, Kentucky Transportation Cabinet, Frankfort, KY, (503)564-3020

The following are advantages of the Caltrans-specified Model 170E Controller with an enhanced PROM module:

- Increased processor capabilities at a lower price than a 2070 controller
- Existing 170E controllers could be retrofitted with enhanced communications modules
- NTCIP compatibility

The disadvantage of the Caltrans-specified Model 170E Controller with an enhanced PROM module is that it is a relatively new technology with very little deployment history nationwide. Caltrans does not specify enhanced modules and to date has not tested or prequalified them for use.

Advanced 2070 Family of Controllers

The Caltrans specification for the 2070 controller has been undergoing modification since the mid-1990s. Currently, the latest-referenced Caltrans specification is the November 19, 1999 TEES available on the website, http://www.dot.ca.gov/hq/esc/ttsb/electrical/electrical_index.htm. The National ATC Committee has put the specifications for the 2070 controllers out for balloting as a national standard.

In addition to the 2070 Lite, the 2070 controller is available in several variations. The customer can select from the option of a VME assembly and/or a NEMA TS-1 adapter as well as the CPU-type board, the input/output type, the front panel display, and the power supply. **Table 7** describes the component configurations defined by Caltrans for the 2070. The 2070L, 2070LC, and 2070 LCN versions are the so-called “Lite” versions of the 2070 family of controllers.

Table 7 2070 ATC Controller Configurations						
Component	**Description**	**Unit Version ***				
		2070	**2070N**	**2070L**	**2070LC**	**2070LCN**
Unit Chassis		X	X	X	X	X
Model 2070-1A	Two Board CPU	X	X			
Model 2070-1B	One Board CPU			X	X	X
Model 2070-2A	Field I/O for 170 Cabinet	X	X	X		
Model 2070-2B	Field I/O for ITS Cabinet/NEMA TS-2		X		X	
Model 2070-3A	4x40 Front Panel Display	X	X			
Model 2070-3B	8x40 Front Panel Display			X		
Model 2070-3C	Blank Front Panel				X	X
Model 2070-4A	10 Amp Power Supply	X	X			
Model 2070-4B	3.5 Amp Power Supply			X	X	X
Model 2070-5A	VME Cage Assembly	X	X			
Model 2070-8	NEMA Interface Module		X			X
Model 2070-9	2070N Back Cover					

Source: Caltrans 1999 TEES

**** Descriptions of various unit versions:***
2070 – full unit paired with 170 cabinet family
2070N – full unit paired with TS-1 cabinet family
2070L – LITE unit paired with 170 cabinet family
2070LC – LITE unit paired with ITS and TS-2 cabinet family
2070LCN – LITE unit paired with TS-1 cabinet family

Caltrans-specified Model 2070 "Lite" ATMS Controller

The 2070 Lite controllers (including the 2070L, 2070LC, and 2070LCN) operate using the 32 bit, Motorola 68360 chip. The 2070 may come equipped with an industrial VME bus and supports four high-speed serial ports as well as a Synchronous Data Link Control (SDLC), multi-drop serial port for the connection of field peripheral devices via EIA-485 connections. The controller uses the OS/9 multi-tasking operating system. Any cabinet I/O can be specified (i.e., TS1 w/ ABC connector), TS2 and ITS cabinet (sdlc), and 170 cabinet w/C1 connector). Cost range for the 2070 "Lite" is $2,900-$3,000 ordered with a TS-1 input/output. Ordered with a TS-2 connector it will be $400 - $700 cheaper since it will only need a SDLC port for input/output.

The following are advantages of the Caltrans-specified Model 2070 Lite ATMS Controller:

- Versatile operating platform
- Can serve as communications hub or processor for field devices

- If ordered with a VME bus, provides for parallel expansion capabilities; Lite version without the VME bus provides for serial expansion
- NTCIP compatible
- Open architecture
- Several vendors (Safetran, Eagle, Econnolite, Naztec, McCain, US Traffic, Peek, and others)
- Significant cost advantage over previous 2070 models
- Can be used for signal control, freeway operations (meters), and ITS operations
- Physically compatible with NEMA TS-2 controller

Vendor Contact: Baldwin and Sours, Inc., 5263 Trabue Rd., Columbus 43228; (614) 851-8800
User Contact: John Renfro, Kentucky Transportation Cabinet, (503) 564-3020

NEMA TS-2 Controller

The National Electrical Manufacturers Association (NEMA) TS-2 standard is an overhaul of the NEMA TS-1 traffic control equipment specification. The standard promotes interchangeability of NEMA equipment between cabinets. Cost: about $2,000

The following are advantages of the NEMA TS-2 Controller:

- Uses SDLC serial bus and EIA-485 for communication between field device and controller and for intra-cabinet components
- NTCIP compatible (applications program specific)
- Supports increased serial communications speeds over other NEMA controllers (TS-2 is the only serial NEMA controller)

The disadvantages of the NEMA TS-2 controller are:

- Proprietary system with merged hardware and software
- Likely short-lived TS-2 standard (NEMA is currently drafting the TS-3 and TS-4 standards)

Vendor-Specific Controllers for Dynamic Message Signs and Closed Circuit TV

The vendor-specific controller is designated as the field controller that works in conjunction with individual field devices, such as CCTV and DMS. It is developed primarily to suit the intended functionality associated with the field device. For example, a CCTV camera controller has indicator lights and switches that allow local testing and activation of the camera's pan, tilt, and zoom functions. Other specific user-assigned options and alarm responses are easily selected through the available software and communication protocol distributed by the vendor. By interfacing a vendor-specified controller such as this to a 170E controller with enhanced PROM, the field device link back to central would be readily NTCIP-compatible. However, this compatibility comes at the cost of purchasing two controllers.

The other option is the sole use of the vendor-specific controller connected directly to the communication link back to central. This option is cheaper and cleaner, but will cause compatibility issues in the future if software upgrades are not developed to make it an open system.

It may also be desirable to employ 2070 Lite controllers at CCTV and DMS locations. However, additional research is needed to determine the viability of this approach. Vendor controllers that come as a package with CCTV or DMS hardware represent the predominant part of this market at present.

There are currently no known suppliers manufacturing CCTV or DMS controllers that are NTCIP compatible. However, it is anticipated that the vendor specific controllers will be NTCIP compatible in the future.

Cabinet Alternatives

There are several available cabinet alternatives, including:

- Caltrans 334 Cabinet (for freeway applications)
- Caltrans 336 and 332 (for signals)
- NEMA TS-2 Cabinet
- New Caltrans-specified ITS cabinets (being procured in 2001)
- Other Cabinets, although none that meet national standards

Recommendations

The field controller type is highly dependent on the communication architecture chosen. Due to acceptance of the 2070 family of controllers by the traffic engineering profession, and a number of other factors, it is recommended that ODOT move toward conversion to the 2070 "Lite" controllers (particularly the 2070LCN which provides interface with NEMA connectivity). The following are additional reasons for recommending the 2070 Lite controller:

- Complete interchangeability of modular controller parts including the boards that may be purchased from various manufacturers
- A stable standard with more than 5,000 units deployed
- Highly competitive with a large number of manufacturers
- Large number of software choices
- Open architecture, with site license available to program all controllers under the same license
- Multitasking available where needed
- Supports ITS architecture requirements of FHWA
- Interfaces with all existing cabinets that meet national standards

6.3 Dynamic Message Signs

Dynamic message signs (DMS) are designed to inform drivers of delays and to suggest alternate routes. DMS are one of the primary means of communicating traffic conditions to motorists. The technology assessment addressed the following technologies:

1. Light reflecting DMS
2. Light emitting DMS
    - Light Emitting Diode (LED)
    - Shuttered Fiber Optic
3. Hybrid
    - LED Reflective/Flip Disk
    - Fiber Optic Reflective/Flip Disk

Photos showing examples of these signs are on the following pages.

Each character displayed on a DMS sign is formed by a group of pixels. There are three basic pixel types typically used on DMS signs: light-reflecting, light-emitting, and hybrid. Light-reflecting DMS are made of materials that reflect light back to motorists from external sources, such as sunlight or vehicle headlights. Light-emitting pixels incorporate light generated by the sign or pixel itself. Hybrid pixels emit light from internal sources and reflect light from external sources.

Light-Reflecting Dynamic Message Signs

Light-reflecting technology utilizes shuttering devices such as flip-disk, cube, or rotating drums at each pixel in either an "on" or "off" configuration. In the "on" position, highly reflective sheeting is positioned facing on-coming traffic. In the "off" position, the sheeting is rotated to face away from traffic (into the pixel), and a non-reflective black surface faces traffic.

The most common technology for the shuttering device uses interaction between magnets and closely coupled electromagnetic coils. Current pulses are directed through the coils by control signals, establishing the direction of the magnetic field in the coils. The magnet inside the disk is either attracted or repelled by the field produced in the coil. The disk is magnetically held in its latest position until the coil field is reversed.

Advantages of light-reflecting signs include:

- Established technology
- Multiple vendors
- Low initial cost
- Low operating cost (power consumption)
- Last message retained in the event of power failure
- Will not wash-out when sign face is subjected to direct sunlight

LED overhead sign, cantilever mount from freeway shoulder

Shuttered fiber optic, overhead sign,
Mounted in median

Disadvantages of light-reflecting signs include:

- Low intensity
- Poor visibility compared to other technologies
- Visibility greatly reduced by back-lighting
- Moving shutter/disks prone to failure
- Considered as obsolete for permanent installation in a traffic management system

Additional features of light-reflecting signs include:

- Text and graphics capabilities
- Power required only when message is changed
- Signs are available with either the modular character matrix, the continuous line matrix or full matrix design
- Flip disks have life span of approximately 7 years
- Square flip disks have sloping sides and are "3-dimensional," providing some depth to the message element

Hybrid Fiber Optic Flip Disc, with fixed fiber insert, mounted on Sign Bridge Truss

Light-Emitting DMS

There are two main types of light-emitting signs: light emitting diode (LED) and shuttered fiber optic. Through these technologies, messages are created by lighted pixels or characters against a black background. Generally, light-emitting signs employ one or more photocells to determine ambient light conditions. The sign then automatically controls the light output to maintain constant intensity levels. The following two subsections give brief descriptions of the LED and shuttered fiber optic signs.

Light Emitting Diode — Clusters of LEDs make up each pixel on an LED sign. Characters are formed using a matrix of pixels, each of which can be turned on or off. LED clusters feature low power consumption (drive current less than 30 milliamp) for both day and night operation. Factory testing of LEDs suggests that they have a useful life in excess of 100,000 hours. Typically, DMS employed for traffic systems utilize a 50mm AllnGAP amber LED cluster for 450mm-character generation.

Advantages of the LED signs include:

- Low operating cost (power consumption)
- High reliability, low maintenance requirements due to absence of moving parts and halogen bulbs
- Excellent free-text capability
- Easily obtainable positive feedback of message status
- Better visibility during back-lighting than light-reflecting

Disadvantages of the LED are:

- Ultraviolet rays cause pixel degradation
- Adversely affected by high ambient temperature (decreased light intensity, quicker aging)
- Fans, venting, and/or refrigeration required under high ambient temperature conditions
- Individual LEDs degrade at different rates, possibly causing uneven message illumination
- Replacement of failed LED module may result in uneven illumination
- Poor performance under wash-out conditions
- Complex arrangement of sunvisors and louvers required to maintain contrast ratio/legibility and to protect from sun's ultraviolet rays
- Limited viewing angle

Additional features of the LED are:

- 100,000-hour average LED life (around 10 years)
- Three colors: red, amber, green
- Multi-sided displays (with different messages running simultaneously on each side)
- Text and graphics capabilities

- Legends displayed statically, in flash-mode, or sequenced
- Viewing angle: 10-16 degrees

Shuttered Fiber Optic — Fiber optic signs utilize bundles of smooth optical glass strands (essentially non-aging), which conduct light with little transmission loss from a point source to pixels on the sign face. The matrix-form pixels on the sign remain lit continuously, while pixel shutters mounted behind the sign face control each pixel's emission of light. Characters are formed by shuttering some pixels to block light, and others to permit light emission.

There are two technologies available for shuttering the fiber optic pixel. An electromagnetic shutter technology, described under light-reflecting technology, is utilized by most vendors to close and open each pixel. Another shutter technology (offered by a single vendor) utilizes an electronically-controlled shutter that rotates axially in the pixel.

Typical light sources for fiber optic signs are two quartz or tungsten halogen lamps. A 50W, 12V-tungsten halogen lamp can produce a luminous intensity of up to 4,000 candela, with a life expectancy of 2,000 hours. The life expectancy can be increased to 6,000 hours by underdriving the lamp at 10.8 V. A stand-by lighting system allows a secondary lamp to be switched on automatically if the primary lamp fails. The second lamp can also be used in “overbright” mode to increase the intensity when needed.

Advantages of shuttered fiber optic signs include:

- High reliability, low failure rate if electrically controlled axial shutters are employed
- Proven technology with extensive use in the past
- Excellent quality color/light output
- Primary and secondary light sources
- Not adversely affected by high ambient temperature
- Performs well with back-lighting and fair during wash-out
- Relatively user-friendly/bug-free software
- Flexibility to customize viewing angle by location depending on geometric and field conditions
- Instantaneous display if electrically controlled axial shutters are employed

Disadvantages of the shuttered fiber optic sign include:

- Periodic halogen bulb replacement
- Limited viewing angle
- Moving shutter/disks prone to failure if electromagnetic flip disks are employed

Additional features of the shuttered fiber optic sign include:

- Halogen cycle lamps with average life in the field of one year
- Text and graphics capabilities
- Legends displayed statically, in flash-mode, or sequenced
- Viewing angle: 10-16 degrees

Hybrid DMS

Hybrid DMS technologies combine the attributes of both light-reflecting and light-emitting technologies.

LED Reflective/Flip Disk — The LED flip disk sign combines the technologies of light-emitting and light-reflecting disk displays. The LED's emit light through openings in the reflective fluorescent yellow disk surfaces of the flip disk.

Advantages of the LED reflective/flip disk DMS include:

- Enhanced viewing angle (as compared with pure LED and shuttered fiber optic) during daytime
- Low operating cost (power consumption)
- Saves energy during daylight hours, when direct sunlight illuminates the characters
- Improved visibility under wash-out conditions over pure LED sign

Disadvantages of LED reflective/flip disk sign are:

- When initially installed, visibility compares favorably to fiber optic flip disks, but reliability and appearance consistency not yet evaluated
- Display speed slower than pure LED signs
- Moving shutter/disks prone to failure

- Significant reflective glare at nighttime
- LED is adversely affected by high ambient temperature

Additional features of the LED reflective/flip disk DMS include:

- Legends displayed statically, in flash-mode, or sequenced
- Need rigid performance standards and specific type of LED for both intensity and color
- Fans used to combat moisture build-up
- Viewing angle: 12 to 160 degrees

Fiber Optic Reflective/Flip Disk — Like the LED flip reflective/flip disk design, the fiber optic reflective/flip disk sign combines the concepts of light-emitting and light-reflecting disk display. The reflective disk surface, which has a fluorescent yellow appearance, has an opening to pass light emitted from the end of an optical fiber bundle; the fiber terminates just behind the disk. The other side of the disk completely blocks light from passing when the disk is in the off state. Messages can be changed or removed almost instantaneously.

Advantages of fiber optic reflective/flip disk include:

- Highest legibility
- Excellent quality color/light output
- Good resolution, depending on number of pixels in legend
- Primary and secondary light sources
- Simple contrast ratio control
- Enhanced viewing angle (as compared with pure fiber) during daytime
- Flexibility to customize viewing angle by location depending on geometric and field conditions

Disadvantages of the fiber optic reflective/flip disk DMS include:

- All legends predetermined with each legend requiring individual light sources and fiber harnesses
- Display speed slower than shuttered fiber signs
- Moving shutter/disks prone to failure, except for electrically-controlled disks

Additional features of the fiber optic reflective/flip disk DMS include:

- Alpha numeric and graphics capability
- Alternative colors available
- Legends displayed statically or in flash-mode
- Fans used to combat moisture build-up
- Viewing angle: 11 to 75 degrees

Table 8 shows the top two technologies under each attribute category.

Table 8
DMS Technology Attributes

Attribute	Best Technology	Second-Best
Reliability	LED	Fiber optic
Legibility	Fiber reflective/flip disk	LED reflective/flip disk
Degradation from heat/sunlight	Fiber reflective/flip disk	Fiber optic
Proven technology in field	Fiber optic	Fiber reflective/flip disk
Washout/backlighting	Fiber reflective/flip disk	Fiber optic
View angle flexibility	Fiber reflective/flip disk	Fiber optic
Capital Cost	LED flip disk	Fiber reflective/flip disk
Operating Cost	LED flip disk	LED
Maintenance Cost	LED	LED reflective/flip disk

Cost Comparison

Table 9 shows a cost comparison for the five sign technologies discussed in this assessment. Capital cost is given as estimated by vendors, and as an average. This estimation covers the cost of a 3-line (18 characters per line), amber-colored sign with 450mm-inch characters, including individual sign controller In addition, the annual operating and maintenance costs per sign for each technology are included.

Some states have a requirement that a DMS must maintain its message even if power is lost dictates that a light-reflecting sign be used. It is recommended that Ohio follow this trend and implement LED reflective/flip disk technology wherever possible.

Table 9
DMS Technology Cost Comparison

Technology	Capital Cost[1]	Annual Operating Cost[2, 3]	Annual Maintenance Cost[2]
Light-Reflecting Mark IV	 $50,000		
LED Vultron Daktronics Skyline Hi Tech Average	 $87,000 $90,000 $80,000 $70,000 $82,000	$1,300	$1,250
LED Flip Disk Vultron Mark IV Average	 58,000 65,000 62,000	$760	$2,000
Fiber Optic Flip Disk Vultron Mark IV Axial Shutter FDS Average	 $75,000 $85,000 $95,000 $85,000	$1,850 $1,850	$2,370 (4) $2,000 (4)
Hybrid Fiber Optic Vultron Telespot Mark IV Average	 $75,000 $84,000 $75,000 $78,000	$1,880	$4,200 (4)

1. Capital costs are based on vendor-provided estimates to generic sign requirements and do not reflect contractor mark-up or installation.
2. Operation and maintenance costs are from the Final Technical Report prepared for the I-595 Dynamic Message Sign System provided by the Florida Department of Transportation.
3. Additional research is needed to develop operational costs based on vendor supplied information and review/revise maintenance cost projections.
4. Fiber optic signs require replacement of bulbs approximately every eight months.

Table 10 lists the vendors and user contacts for each DMS technology.

Table 10
Vendors and User Contacts

Technology	Vendor Contact	User Contact
Light-Reflecting	Mark IV F.P. Electronics (905)624-3025 Daktronics, Inc. (888)325-8766	Virginia DOT Morris Pearson (757)627-6206
LED	Daktronics, Inc. (888)325-8766 Skyline Products, Inc. (800)759-9046	Virginia DOT Morris Pearson (757)627-6206 Washington DOT Gilbert Bjorge (509)575-2822
Shuttered Fiber Optic	Fiber Display Systems, Inc. (800)252-6220 Mark IV F.P. Electronics (905)624-3025	North Carolina DOT Mohd Aslami (919)715-5721 South Carolina DOH Eugene German (803)740-1660
LED Flip Disk	Mark IV F.P. Electronics (905)624-3025 Vultron, Inc. (810)853-2200	Wisconsin DOT John Corbin (414)227-2166 Florida DOT George Gilhooley (904)943-5309
Fiber Optic Flip Disk	Vultron, Inc. (810)853-2200	Maryland SHA John Young (410)787-5869

6.4 Communications Technologies

Communication technologies are comprised of wireline and wireless solutions. Wireline solutions can be comprised of agency-owned copper or fiber systems, or leased-lines from a telephone service provider, or a mixture. Similarly, wireless systems that constitute microwave (high-bandwidth), spread-spectrum, and even cellular can also be agency-owned or leased from a service provider. The following section discusses the merits of each media technology and their potential applications.

Leased Lines

Leased lines are usually an existing alternative to the placement of a new agency-owned cable network. Leased lines can provide viable communications between agencies for data, voice, and video (with sufficient bandwidth). Leased communication networks are typically provided by the Local Exchange Carrier (LEC) in a region, who normally provides local telephone service as well as access to the Public Switched Telephone Network (PSTN). Until recently, these companies were restricted by federal law to offering wide area communications services within a designated zone, known as a Local Access and Transport Area (LATA). However, due to the telecommunications deregulation, LECs are now permitted to compete with long-distance carriers, TV cable providers, and value-added services.

Leased lines are somewhat attractive from the maintenance standpoint since the majority of the communication network is owned/operated and managed by others. However, the operational costs are high and remain high in perpetuity. There is also a distinct reliance on others for repairing/restoring communications in the event of a public network outage. Other public agencies have encountered slow response times for maintenance/repair requests. There are a host of services available through leased-line communication networks, some of which are described below.

- *Analog Plain Old Telephone Service (POTS)*

  POTS is the acronym assigned to the analog lines that serve the majority of homes and businesses throughout the country. It is capable of standard data rates up to 56kbps, although the FCC limits the throughput to 53kbps. Analog telephone services are widely available. Field-hardened modems above speeds of 33.6kbps are generally hard to find, which limits the applications that POTS can handle. Typical analog dial-up telephone services are approximately $20-25 per month. A dedicated 56kbps leased-line would generally run about $200 per month.

- *Integrated Services Digital Network (ISDN)*

  In contrast to Plain Old Telephone Service (POTS), which is analog by nature, ISDN is a digital telephone service. ISDN can handle data more rapidly and more effectively not only since it has speeds up to 128kbps, but also because it does not have to convert digital data to analog form. The added costs of ISDN, however, can present added operational implications since the cost of ISDN lines are typically $100 per month (roughly five times the cost of an analog circuit). Standardization for video encoder/decoder (CODEC) applications over ISDN has improved ISDN's viability for videoconferencing and remote video surveillance.

- *Digital Subscriber Line (xDSL)*
  xDSL technology enables existing copper wires to deliver affordable high-speed remote access to the Internet, corporate networks, and on-line services over ordinary twisted-pair phone lines. xDSL also enables new applications that require real-time, interactive multimedia and broadcast-quality video (i.e. collaborative computing, video conferencing, and distance learning). xDSL service, whether leased or privately developed, can operate at speeds up to 100 times faster than 56 Kbps modems; however, it will generally support voice communications in the publicly switched telephone network only. xDSL modems are currently priced at about $600-1000 for each end, and MPEG-2 codecs typically run about $6000 for each end.

- *Packet/Frame Relay*
  Frame Relay is a packet-switching data service that is similar to ISDN with transmission rates up to 45 Mbps. Unlike T-1 or T-3 services that "nail-up" a service connection for use by one user only, frame-relay circuits can be shared by multiple users and thus are more cost-effective. Frame Relay is priced according to a "committed information rate" or CIR. Frame-relay has recently increased its capabilities and more manufacturers have introduced encoder/decoder (CODECs) for transmitting voice and video over the public packet networks in addition to the current data transport.

- *Asynchronous Transfer Mode (ATM) over wireline*
  Asynchronous Transfer Mode (ATM) is similar to Frame Relay except that it switches "cells" instead of packets. ATM circuits are available with a T-3 interface or fiber OC-3 interface. ATM circuits, due to their varying bandwidth requirements, are generally more cost-effective than dedicated T-3 services. ATM integrates multiplexing and switching functions and is specifically structured to accommodate the time-sensitive needs of multimedia, voice, and video applications. ATM circuits typically range from $700 for 1.5Mbps up to $4500 per month for 25 Mbps data rates.

Fiber Optics

Fiber optic cables coupled with fiber optic transceivers provide digital high-speed capability for the transmission of voice, data, and video. Fiber optic systems are generally the most costly to deploy. However, they also have the most versatility over any other medium. Fiber optic systems are also the most reliable. Fiber is not susceptible to EMI/RFI like twisted-pair/leased-lines or wireless systems. Fiber capacity continues to increase with a constant evolution of multiplexers. The biggest downside to fiber-optic deployment is that it is a fixed capital infrastructure along the highway that is subject to utility relocation as roadways are widened or structures are modified. The number of field technicians in the industry that are capable of supporting fiber optic systems is far greater than the number for wireless infrastructure. The capacity (both bandwidth and distance) and flexibility of application afforded by fiber optic cables far exceeds the higher cost when the decision is made to install wireline infrastructure.

Two types of fiber optic cables are generally used for ITS applications: single-mode and multimode. Single-mode fiber is typically recommended because it is two- to five-times less expensive compared with multimode fiber cable, and has significantly less signal attenuation which allows coverage over greater distances. It does not have a MHz-km frequency attenuation characteristic as compared with multimode fiber. Because of these factors, single-mode fiber offers significantly less risk for future expansion and build-out. The optical modems and fiber connections are more expensive for single-mode, but the fiber cost-savings generally negate this difference.

- *Low-Speed Optical Technologies*

  Optical networking at data levels below those carried by SONET share very few standards aside from the types of fibers that are used. Typically, low-speed optical technologies are used to interconnect simple data/controller devices such as traffic signal controllers, system detection controllers (e.g. 170, 2070, TS-1, TS-2), DMS controllers, HAR, and in some cases ramp meters. These devices and controllers generally have a serial communication channel, or RS-232 port, that is used to interface the field controller with a central management system. An optical transceiver (OTR) for data applications over single-mode fibers typically ranges between $1400 to $2000 each. A video optical transceiver (VOTR) is comparably priced between $1000 to $1500 each. In addition to single-channel serial and video fiber distribution modems, there are also several multiplexing devices that can provide substantial fiber capacity utilization despite their lack of standards.

- *SONET*

  SONET is the single-most prevalent broadband fiber-optic communication technology in use today, particularly by telephone, long-distance, and cable TV companies. SONET was designed to replace its twisted-pair predecessors with much more capacity, increased flexibility to administer changes, and increased capability to manage the network from one location. SONET standards provide both forward-compatibility with future equipment as well as backward-compatibility with existing telephone carrier equipment, protecting long-term investment. SONET establishes fixed bandwidth channels that can be terminated anywhere around the ring. In comparison, ATM effectively takes over the responsibility for managing the network capacity by establishing multiple communication paths inside of a large optical path.

- *ATM over SONET*

  Asynchronous Transfer Mode (ATM) is very effective in complex networks such as telephone networks where there are many alternate paths between one hub and another. In ATM, communication paths can be established and broken down on demand as the capacity is needed. ATM has primarily found its best market opportunities in wide area networks. The higher cost of ATM equipment has generally not been as conducive for deployment in LANs. In wide area network implementations, ATM switches generally use SONET for the fiber optics transport in order to cover greater distances compared to a twisted pair medium. For a traffic management system, the communication paths are not complex. They include integrating field hubs with the Traffic management center and perhaps integrating other traffic operation centers and other centers such as emergency services in peer-to-peer fashion. While ATM technology will certainly support traffic management systems' communication requirements, the question is generally cost versus benefits.

  For real-time continuous video transmission, there is no clear benefit to utilizing ATM. To make more efficient use of bandwidth, video codecs can be directly connected to SONET interfaces. Both ATM and SONET require video codecs, but SONET codecs are generally less expensive. ATM becomes cost/effective when a large number of LANs (10 to 15) are to be virtually distributed (shared by many groups). Bandwidth management between LANs becomes effective, justifying cost. Another important point to consider in ATM is embedding (integration of SONET and ATM into one piece of hardware). The majority of ATM switch manufacturers provide SONET interfaces and some market them heavily as a backbone solution. This style of ATM deployment bypasses many of the important fault-tolerant SONET network management features.

- *Internet Protocol (IP) Packet over SONET*

  Internet Protocol (IP) or Packet over SONET (POS) reduces the amount of overhead that is required to transport data over an ATM network. Overhead consists of control, routing, and error-checking information that goes beyond the user-transmitted data. ATM networks typically waste about 10 percent of usable bandwidth, and can potentially consume up to 15-20 percent of bandwidth in the form of overhead. In comparison, POS generally can access all but one percent of a channel. One potential problem with using POS for video/multimedia applications is that there are fewer guarantees on quality of image transmission than with ATM. (Standards bodies are working to resolve this problem.)

Wireless Media

Although the relative costs for an agency-owned wireless system may seem attractive in comparison to the other scenarios, other factors must be taken into consideration that cannot be enumerated. These factors include the potential for:

- FCC frequency re-allocation rendering acquired infrastructure no longer viable
- Electromagnetic/radio-frequency interference (EMI/RFI) causing communication failures
- Degraded reliability under severe weather conditions (heavy rain, hail, snow)
- Public sentiment making it increasingly more difficult to deploy new towers (as seen with cellular tower construction activities)

On the positive side, wireless systems do provide a great deal of field element portability in comparison to leased lines and fiber optics. A field element can be re-located a few feet or several hundred yards away and generally a re-alignment of antennas is all that is needed to restore communications. However, this becomes more complicated when licensed frequencies are used since it may be necessary to re-apply for the new location.

- *Microwave*

  Traffic control applications have used microwave links primarily as a communications trunk between points to carry video, voice, and data. Microwave signals radiate through the atmosphere along a line-of-sight path between transmitting and receiving antennas. Because microwave is a point-to-point media, it is generally not as cost-effective as fiber for applications requiring several closely-spaced elements along freeways or arterial roads.

  The Federal Communications Commission (FCC) makes several frequencies available for private service ranging from 928 MHz to 40 GHz. Considering a five-km length of highway with five elements equally spaced, an 18 GHz microwave solution would cost approximately $325,000 versus a single-mode fiber cost of $300,000. Furthermore, adding additional elements for microwave distribution would cost $65,000 per element, whereas the fiber solution would only require splicing equipment and modems to tie-in to the network at even more substantial savings over microwave. Microwave does show cost-savings over fiber when used for trunk backbone communications between two hub facilities. Additionally, microwave can be more cost effective if difficult conditions are present that would drive up the cost of trenching a conduit system. The limiting factor is the bandwidth that it can support, which is typically 622 Mbps per link.

- *Spread Spectrum*[1]

  Spread spectrum radios use transmitters that spread a signal bandwidth over a wide range of frequencies, while the receiver acquires the signal bandwidth and compresses it back to its original frequency range. This process, known as Code Division Multiplexing (CDM), encodes data by using a specified binary sequence for each channel. This technique makes spread-spectrum less susceptible to jamming, weather interference, and neighboring user interference. Although spread spectrum radio, like microwave, adheres to line-of-sight restrictions, some level of bending around obstacles is possible in the 902-928 MHz frequency range. Since FCC approval is not required in the 902-928 and the 2400-2483.5 frequency bands, spread spectrum can be implemented rather quickly. However, since it operates in unprotected channel space, it can be shared with other users without any regard for interference between them. Also, the FCC could re-assign new uses to these frequency ranges at a later date.

  [a] *Federal Highway Administration, "Communications Handbook for Traffic Control Systems", Sterling, VA, April 1993.*

- *Cellular*

  Cellular telephone is a two-way communication technology. North American analog cellular networks are based on the Advanced Mobile Phone Service (AMPS) standard. Digital cellular and Personal Communication Service (PCS) implementations vary, but the two most prevalent are time-division multiple access (TDMA) and code-division multiple access (CDMA). The use of cellular service has so far been limited to maintenance personnel communications, and small-scale and/or short-term projects relating to traffic control applications. Digital cellular and PCS services have yet to offer data capabilities in most markets. Current data capabilities over analog cellular are limited to 9.6kbps.

- *Cellular Digital Packet Data (CDPD)*

  CDPD is a wireless data network and an industry standard for data transmission. It uses the Analog Mobile Phone Service (AMPS) networks already in place in the United States. The system does require specialized electronics at each AMPS cell site location at additional cost to the provider, which means CDPD coverage is not necessarily equivalent to AMPS. CDPD provides two-way data communications for users of devices such as notebook computers and Personal Digital Assistants (PDA). AMPS has been modified to allow digital information to be transmitted in packet form on a "not to interfere" basis with voice. Digital data packets fill the time slots where voice is not transmitted, and this service can support transmission rates up to 19,200 bps (AMPS only supports up to 9,600 bps). This capability is available in selected urban areas; however, the amount of data transfer to occur and the corresponding operational cost of service may become an issue. CDPD can be an effective medium for semi-urban (or possibly rural) data communication distribution links by using several low-cost remote radio modems to connect controller cabinets to a slightly higher cost master modem at a communication hub or at the TOC. The data throughput for CDPD is enough to support data communications for the National Transportation Communication for ITS Protocol (NTCIP), but it can not provide an acceptable level of quality for video demands.

Summary of Media Attributes

A comparison of the respective media attributes is shown in **Table 11**.

Fiber optics is a highly reliable medium with significantly more capacity and usefulness than copper-based systems. In the fiber versus copper debate, fiber has a performance edge, whereas copper is a more widely understood and accepted technology. More important, the costs of fiber components have become competitive with their copper counterparts. If life-cycle costs are considered, including the costs of downtime and possible obsolescence, fiber is the better value.

Table 11 Summary of Media Attributes				
Attributes	**Twisted-Pair**	**CDPD**	**Digital Microwave**	**Fiber Optics (Single-Mode)**
Ability to carry full-motion video	Limited with xDSL	No	Yes	Yes
Fault tolerance capabilities	No	No	Yes	Yes
Bandwidth capacity	1.5Mbps	19.2kbps	155Mbps	40Gbps +
Susceptibility to interference	Moderate	Fair	Fair	Low
Recurring maintenance requirements	Moderate/High	N/A	Moderate	Low
Distance range supported (in kilometers)	4	Urban coverage from cellular providers	Line of sight (≈5 km)	30+
Typical life expectancy (in years)	15-20	N/A	10-15	25+
Relative cost per bit per second (bps)	Moderate	High	Moderate	Low

There are some wireless solutions that can accommodate some of the needs of a traffic management system. Wireless systems, whether privately held or leased from a provider, face one of two situations: 1) cost-effective broadcast solutions are bandwidth constrained; and 2) point-to-point architectures with higher bandwidth are not cost-effective for densely-placed field devices.

Table 12 provides information on various macro-level or communications systems components. These components, assuming they are utilized in a communications network design that serve a number of ITS field devices, have been evaluated on the following factors:

- the general cost range of each component
- the bandwidth or application
- the number of service providers or vendors in that market
- an assessment for their potential deployment in Ohio

The latter factor is based on the current capability and capacity to support those technologies and maintain them as part of an on-going freeway operations and management program.

Table 12
Detailed Assessment of Communications Components

Transmission Technology	Band Width or Application	Cost Range	Names of service providers/ vendors (selected items)	Potential for deployment in Ohio
Ethernet	10 Mbps	$20 - $200 per interface	Cisco 3Com	High (H)
Synchronous Optical Network (SONET)	51.84 Mbps to 13.27 Gbps; OC-1 thru OC-256	$20k to $120k per network node	Cisco/Nortel Sumitoma Electric Texas Instruments Fujitsu	H (will be common in metro area systems)
Asynchronous Transfer Mode (ATM)	Optimized bandwidth utilization for asynchronous data interchange	Adds $40k to $60k to a SONET node	Cisco/Nortel	Moderate (M)
DS-X or OC-X Digital Microwave	155.52 Mbps (max.); Wireless extension of SONET link	Terminals: $20k to $100k; Towers: $20k to $120k	General Data Company	M
Integrated Services Digital Network (ISDN)	112 Kbps	$15 k per link to install $50 to $100 per month per connect.	All major telephone companies	H
T-1 line T-3 line	1.5 Mbps 45 Mbps	$400 - $700/mo.; $2,000 - $6,000/mo.	All commercial phone companies, Coastcom	H M
Serial Control and Data Acquisition (SCADA)	Controls sensors for remote monitoring	$1500 - $5300	Transdyne	Low (L)
Low power AM Highway Advisory Radio	Remote controllable thru EIA 232 link	$16k - $32k on trailers, generator or solar-powered	Digital Recorders, Inc. ISS/Information Station Specialists	Low, except in work zones in tandem with portable VMS
FM Subband, Radio Digital Data System (RDDS)	1200 baud digital broadcast link; Typical at 57KHz	Add $50 to $80 to cost of vehicle radio	Modulation Sciences Seiko Communications Systems CRL Systems	H (market driven, in-vehicle system)
Digital Short-Range Communications (DSRC)	900 MHz; 500 Kbpa; Typical for toll tag systems	$15k for readers; Tags from $35 (Type I) to $45 (Type III)	Cisco/Nortel	H (for commercial veh. Applications)
Infrared Optical Wave Length Communications	Emergency vehicle preemption for traffic signals	Similar cost to RF tags		M

Table 12
Detailed Assessment of Communications Components

Transmission Technology	Band Width or Application	Cost Range	Names of service providers/ vendors (selected items)	Potential for deployment in Ohio
Cell Phones and Digital Cellular Service (DCS)	Traveler info. provided cell center for dissemination	$25 to $125/mo., depending on minutes	Motorola Ameritech AT&T Sprint	H for both 911 (emergency) and 511 (travel info.) calls
Land Mobile	Supports 4800, 9600, & 19200 Kbps full duplex	$20 k for transceiver site; $2 k for vehicle terminal	AT&T Quest GE/Ericsson Icon America, Inc	M
Personal Communications Service (PCS)	Supports 9600 Kbps to 2.4 Mbps	$30 / mo. (plus)	Compac Philips Palm Pilot	H (market driven)
Private Packet Network Radio	9600 Kbps to 19.2 Mbps	$0.0002 per character transferred		M
Switched Public Telephone Service (also called POT, "plain old telephone")	Leased interconnect to a switched public network service	$300 per year per each low-speed interconnect	All commercial phone companies	H
Digital Spread Spectrum Radio	Network communication to 2 Mbps	$1600 per controller plus $320 to $480 per relay	Cylink Corp. Hughes, Temex Telecom Persoft, Pinnacle	L
Optical Transceivers	Receive/transmit data thru fiber; EIA232/422/485	$300 - $2500 per transceiver	Stratos Lightwave LLC American Fibertech Opcom, Optelecom	M
Video Optical Transceivers (VOT/VOR)	Receive/transmit video signals thru fiber lines	$600 - $2500 per transceiver	OPTEL, Orchard/Phillips	M
Video Multiplexer	Multiplexes 4 - 8 video signals thru a single fiber	$4k - $5k per 4 – channel transcvr; $6k - $8k per 8 – channel transcvr	Silicon Graphics Nortel, Imux Pelco Orchard/Phillips	M
Road Weather Information Systems (RWIS)		Approx. $75 k ea.	GTE Government Systems	M
Fiber Illuminated Signs			National Sign and Signal	M
Single mode/ Multi mode Fiber ("backbone" fiber plant)	Applications in: AM video FM video CATV HDTV	$30 k to $70 k / kilometer	SIECOR Force, Inc. Alcatel Pirelli Lucent Tech./AT&T Sumitoma Electric	H

Table 12
Detailed Assessment of Communications Components

Transmission Technology	Band Width or Application	Cost Range	Names of service providers/ vendors (selected items)	Potential for deployment in Ohio
800/900 MHz and 1900 MHz system	Applications in: Common emergency vehicle communications	Approx. $9 k/ link	NEXTEL Motorola	H will become standard with MARC communications
Satellite communications (GPS, VSAT, other)	Applications in: Fleet commo. In-vehicle commo. CVO commo.		QualComm DATASAT Global One Magellan Garmin Lawrance OmniSTAR	H (commercial vehicles primarily)
Twisted copper wire	Applications in data transmission	$12 k/ kilometer	Used commonly in signal systems, ACR's, other communications plants throughout the nation	H (will continue to furnish short-range connectivity for traffic systems)

For each of the three extended metropolitan regions (Northeast, Central, and Southwest), including ODOT Districts 6, 8, 12 and 4, it is important that a common ITS communications architecture be developed for cost effective deployments and operations of field devices and TMC components. The communications technologies most needed in Ohio should focus on meeting the following recognized needs throughout the state:

- Common communications channels and protocols
- Common database
- Adequate bandwidth
- Clearinghouse for information dissemination coordinated with Metro Area TMCs

Appendix F contains a Technical Memorandum summarizing options for installing communications conduit. The summary includes general conduit installation and placement information, installation alternatives and costs, example details, and information about pull boxes, manholes, and splice closures.

ITS BEST PRACTICES — ORGANIZATIONAL

ODOT has made an important leap of faith into the world of real-time traffic operations. The creation of the Office of ITS Program Management, with staffing, provides an unprecedented central office level of commitment. However, institutional considerations serve as a cautionary tale for ITS program management, and the department has much work to do in aligning staffing and resources to support a real-time operations mission.

7.1 Organizational Structure

Like all of ODOT, the Office of ITS Program Management is a lean structure. Reporting directly to the Deputy Director of the Division of Planning, the Office consists of the ITS Program Coordinator, the Senior ITS Engineer and the ITS Implementation Engineer. A college intern position is also approved for the Office. In terms of skill sets, the Office is well represented and its personnel have a high-degree of interaction and communication. One deficiency is telecommunications expertise, which can be filled by the Division of Information Technology or through training programs.

ITS projects and activities touch upon a variety of ODOT divisions and offices. It is the coordination of this technology that creates the need for the Office of ITS Program Management. In and of itself, the Office does not operate these systems, but should rather coordinate deployment and develop operations policies. Thus, the Office should serve as an umbrella that oversees the following work units and activities:

Office of ITS Program Management

ODOT Divisions and Offices

- Office of Traffic Engineering
- Office of Maintenance Administration
- Division of Information Technology
- Office of Urban and Corridor Planning
- Office of Technical Services
- Office of Real Estate
- District Offices
- Other state and local agencies

Activities (non-exhaustive)

- Traffic signal controller policy
- Freeway management systems
- Traveler information/data dissemination
- Weather information systems
- Hardware/software support
- MPO/local government coordination

For the future, it is reasonable to consider a change in the makeup of the Office and its possible repositioning with the department. First and foremost, the ITS Program Coordinator is an unclassified position, meaning that the position's tenure is tied to the current administration. This provides an advantage in terms of executive visibility for the program, but that advantage might be unnecessary as the program matures. If this is the case, it might be reasonable to change the skill set of the ITS Program Coordinator, or change the position altogether to transition into more telecommunications, operations/maintenance, or other expertise as deemed appropriate. Depending on the viability of the program at that time, the position should be reconstituted into a classified status.

As to positioning within the organization, it is entirely appropriate that the Office is now located in the Division of Planning, since that is the posture of the program at this time. In the future, however, it is recommended that the Office of ITS Program Management be melded into the Office of Traffic Engineering–a position more reflective of the program's mission, and more in alignment with district counterparts.

7.2 District ITS/Operations Staffing

District level staffing and support can alone determine the success or failure of the department's ITS program. Currently, there is inadequate attention to traffic engineering and freeway operations in general, a situation that does not bode well for successful deployment of freeway management systems.

Elements of proper ITS/Operations staffing are evident in many districts. All districts have an adequate focus on snow and ice removal; and districts eight, six, and twelve are active in implementation of freeway service patrols. With the notable exception of district six, however, no district has designated an ITS coordinator or equivalent position to manage these systems.

District eight has avoided the need to staff such a position by abdicating ARTIMIS management to the Kentucky Transportation Cabinet. This situation must change, however, with ODOT's assumption of managerial responsibilities in 2002–thus, it is recommended that district eight designate a full-time program manager to the ARTIMIS contract (it should be noted that district eight will be providing staff for some of the ARTIMIS operations functions.)

For large urban areas, there will need to be at least two or three management positions to supervise the operation and maintenance of freeway management systems (and attendant integration of other systems). District signal maintenance personnel should be cross-trained to maintain, repair and replace ITS field devices–it is possible that some of this activity could be limited to replacement, with field devices sent to the central office signal shop for repair. The other major maintenance area involves computer hardware and systems, which should be maintained by district systems managers (DSMs).

There will also need to be operator positions for ITS. These operator positions are notorious for their tedium, with high turnover in some environments. This becomes an acute problem for the public sector, as employment and hiring practices are not geared toward flexibility, and retaining employees through high financial reward is not prudent public policy. Other agencies have had success with employing college engineering students in these positions, which provides them real-world experience while meeting public sector objectives. Alternately, agencies have found success in employing retired state police (or other retired law enforcement) in these positions, which provides flexible (part time) hours and a generally motivated workforce with ties to emergency operations.

Flexibility is the key to district staffing levels during these early years of ITS deployment in Ohio. District six seems to have embraced such flexibility as it implements the freeway management system, freeway service patrols, incident management and other operational improvements.

7.3 Budget Considerations– Capital

Currently, capital budgeting provisions for ITS projects reside with the Department's Transportation Review and Advisory Committee, or TRAC. With no criteria, TRAC reviews ITS project requests and approves funding through very public and very formal deliberation processes. Although most ITS proposals to TRAC have been flawed, to date the TRAC has never approved a request for ITS funding.

For ITS, the TRAC process is flawed because it doesn't recognize operational improvements, instead being geared toward capital improvement projects. The only commonality between ITS and traditional highway and bridge projects is the cost. Optimally, the department should eliminate ITS projects from the TRAC process and set aside a separate, multi-year budget for capital funding of the systems. In lieu of such action, the Office of ITS Program Management should work with the TRAC to develop reasonable criteria for ranking and selection of ITS projects.

7.4 Budget Considerations– Operating and Maintenance

ITS operation and maintenance funding has not been a large problem for the department as a whole, but looms as an issue for widespread deployment. To date, only district eight has had to shoulder the burden of operations and maintenance funding–for ARTIMIS.

Current policy calls for ITS operation and maintenance funding to come out of district funding allocations, the same funds that are used for pavement maintenance, bridge maintenance, and other operations activities. This puts an undue burden on district eight, since it is the only district with a functional freeway management system. It is easily seen that funding ITS operations and maintenance takes away from bridge and pavement funding, but the corollary is less obvious: That taking funding from bridge and pavement maintenance activities reduces district enthusiasm and support for ITS programs. This is especially true, given that ITS is not evenly deployed across the state at this time.

To address equity issues, ODOT should centralize ITS operations and maintenance funding until ITS deployment becomes more widespread. While this would decrease the overall amount available to district maintenance allocations, it would reduce equity considerations during these crucial early years of ITS development.

Appendix

APPENDIX A
PROJECT ADVISORY COMMITTEE

Name	Unit	E-Mail
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APPENDIX B
ROLE OF ITS TECHNOLOGIES IN OVERCOMING CURRENT PROBLEMS

Overview

In order to understand and quantify the role of ITS technologies in overcoming the identified problems that currently exist in managing traffic and improving safety on Ohio's highways, three basic approaches were taken. The first approach was to evaluate problems and opportunities for improvement, as well as current deficiencies in ODOT's ability to deliver its services, in the three basic program areas of concern:

(1) Recurring congestion
(2) Safety (specifically incident management)
(3) Traveler information

Initially, the consultant team developed a set of eight functions that are addressed by each of these three program areas. The eight functions that define each of the three major program areas are identified in **Table B-1**. These 24 functions are all within the mission of the Ohio DOT, with either primary responsibility to carry out those functions, or major supporting responsibility to another agency, such as the Ohio State Highway Patrol. Within each of these functions, the consultant then developed a list of problems and a list of deficiencies in resources currently available to ODOT to carry out its mission. These initial lists were developed based on the consultant's research, and then reviewed and further developed during the first meeting of the Project Advisory Committee on October 25, 2000.

Table B-1
Functions addressed by ITS Program Areas

Program Areas	Functions
1.Managing Recurring Congestion	NS Network surveillance and congestion verification CM Construction/maintenance operations CMF Corridor congestion management – freeways and major arterials CMS Congestion management – surface streets/intersections CP Crash prevention SE Special event management MM Multi-modal coordination PL Planning for improvements
2. Incident Management	DV Detection and verification ER Emergency response SM Site management VCC Vehicle clearance/site clean-up SCP Secondary crash prevention OTM Overall traffic management PIE Post-incident evaluation PFI Planning for improvements
3. Traveler Information	MAC Motorists' assistance communication (i.e., the public's information sent **<u>to</u>** a motorist assistance center) IS Information sharing among agencies TI Traffic and travel time information II Incident information TTI Traveler, tourism, and special event information WI Weather information ICV Information on commercial vehicles PI Planning for improvements

At the second meeting of the Advisory Committee on January 23, 2001, these lists of problem areas and deficiencies were further reviewed for each major category (recurring congestion, incident management, and traveler information). The 20 members of the Committee gave attention to these three program areas. The members of the Committee initially addressed in one of three working groups. Further specific problems and deficiencies were added, and each of the 24 functions were further defined by the identification of "minimum essential ITS technologies required to overcome the problems and deficiencies." Finally, the Advisory Committee met as a whole to review the work of the working groups and verify/validate, or change, the output of each separate group. The work of the Committee is shown in **Tables B-2, 3, and 4**.

In each of the three major program areas addressed by this study, the break-out groups at the January 23 workshop also provided their evaluations of the urgency and importance of the Ohio DOT addressing each of the 24 functions of the state's basic ITS program. Each member provided an independent rating of the functions' urgency and importance. All individual ratings were then analyzed for all 20 Committee members involved in the meeting.

The analysis consisted of plotting all data on a four-cell "matrix analysis" diagram, compiling the individual evaluations, and computing the means, medians, and standard deviations. Elliptical graphs were then plotted as a "pattern diagram" representing one standard deviation of the mean for the collection of eight functions representing each of the three program areas. These standard deviation-of-the-mean plots are shown in **Figures B-6, 7 and 8**. A description of the roles that ITS can play in solving transportation problems in Ohio is related in the following three sections.

The deficiencies that that can be addressed by deploying ITS technologies in each of the three program areas cover a broad range of issues and potential technology applications. For all three program areas, the deficiencies most often cited by the committee include:

- A clearinghouse for traffic and travel information
- Common communications channels and protocols
- Common database for units within ODOT and other involved agencies
- Adequate bandwidth to meet the requirements of all public sector users
- Clear responsibility for carrying out required functions

Congestion Management

To meet the needs of managing recurring congestion, the one most often identified deficiencies are the common communication channels and common databases. **Figure B-6** reveals a slope on the axis of the means of the eight functions of approximately 45 degrees, indicating that there is a very high relationship between urgency of addressing a function and the importance of addressing that function. The most important and most urgent congestion management function, according to ODOT managers, that needs action by ODOT is network surveillance (coded as "NS" on the chart). The fourth column of **Table B-2** identifies that to implement a program of network surveillance on Ohio's urban freeway system, the following technologies are most needed:

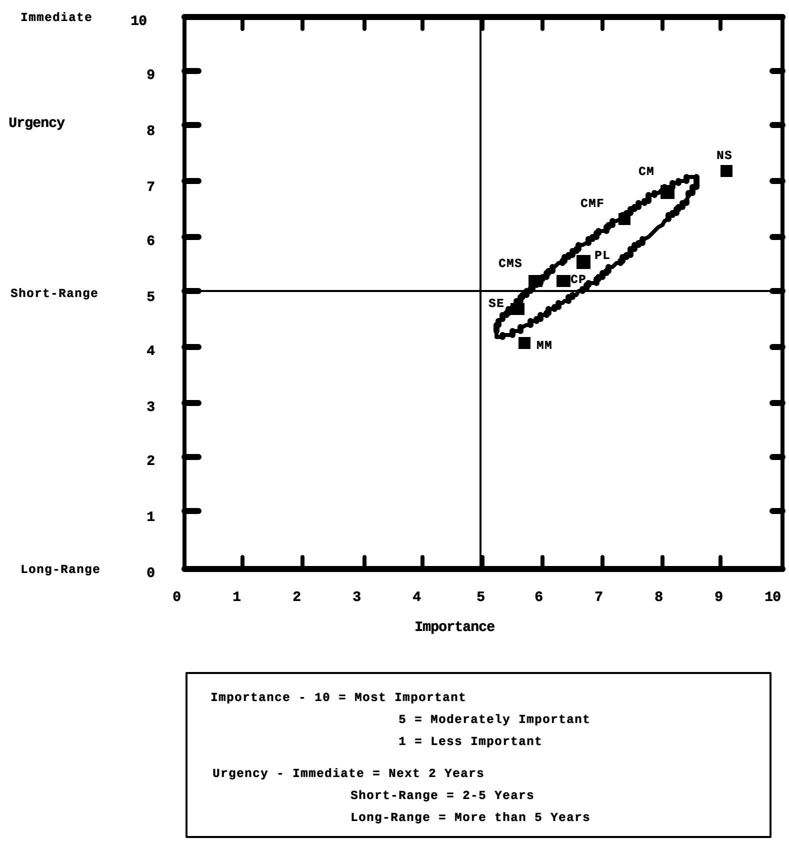
- A central Traffic Management Center (TMC)
- Fixed Variable Message Signs (but utilizing technologies that are smaller and less costly than typically deployed in the past)

- Freeway Service Patrols (also called "Crewzers") deployed by ODOT maintenance personnel that work with SHP in managing traffic on-scene at crashes and other incidents

Figure 6

Rankings of ITS Functions

Mean Scores for Functions Involved in Managing Recurring Congestion



- Probe vehicles, which may be any type public or private vehicle whose drivers are equipped to monitor traffic flow while enroute and report to a Traffic Management Center
- Closed Circuit Television (CCTV), utilizing fixed focus cameras for wide area surveillance rather than major use of pan-tilt-zoom technology
- High bandwidth communications backbone

Table B-2
Essential ITS Technologies for Application in Ohio for Managing Recurring Congestion
(Developed at January 23, 2001 workshop conducted with the Advisory Committee)

Function	Problems	Current Deficiencies in Resources Available	Minimum Essential ITS Technologies Required
Network Surveillance and Congestion Verification (NS)	• Timeliness of data • Insufficient details • Multiple reports	• Single source information clearinghouse/dispatch for jurisdiction • Adequate bandwidth	• Data collection: — Fixed lens camera — Probe vehicle — CCTV • Data reduction and processing • Central TMC by mode • High bandwidth commo. Bandwidth • Data dissemination — Telephone — Broadcast media — VMSs — Internet — HAR — DMS — EMS — Ramp metering
Construction/ Maintenance Operations (Work Zone Traffic Control) (CM)	• Separation of agency functions • Agencies PIO functions not connected to operations	• Expanded access to real time traffic data • Expanded access to real time construction and maintenance schedules • Connectivity to districts' TIPS – expanded information to PIO/District offices/TMCs • Educational program	• Wide area surveillance • Highway reporting and closure system with automated notification • Web-based PSAs
Corridor Congestion Management (surface streets/ intersections) (CMS)	• Signal timing • Resource management • Centralized control • Cross-jurisdictional data exchange	• Hardware/software compatibility • Standards for signal timing • Surveillance on arterials • Continuation of timing patterns across jurisdictions	• Adequate signal control system • CCTV (leverages signal control information)

Table B-2
Essential ITS Technologies for Application in Ohio for Managing Recurring Congestion (continued)

Function	Problems	Current Deficiencies in Resources Available	Minimum Essential ITS Technologies Required
Crash Prevention (CP)	• Lack of information to upstream traffic • Queueing due to poor highway geometrics	• Communications channel • Positive identification of responsibility	• Dynamic message signs (specific critical locations) • Pager activated flashing beacons • COBRA safety warning systems • Signal preemption subsystem
Special Event Management (SE)	• Lack of adequate capacity • Lack of knowledge of available alternate routes • Excess VMT due to lack of knowledge on parking available • Diversity of driver skills	• Surveillance on arterials and surface streets • Broad area wireless media connectivity to real-time data • Common communications protocols	• Parking management systems • Wide area surveillance systems - Kiosks - Travel Info. Displays (TID) - "Diamondvision"
Multimodal Coordination (MM)	• No information exchange among modes	• Management structure • Common database • Standards and protocols for data exchange • Integration approach (physical, data)	• Speech to text/ text to speech protocols • Common radio frequency
Planning for Improvements (PL)	Inadequate data Inappropriate/ not useful data Common data format	• Management structure • Funding for responsible database manager • Common architecture for data collection • Integration approach	• Geographic information systems

Incident Management

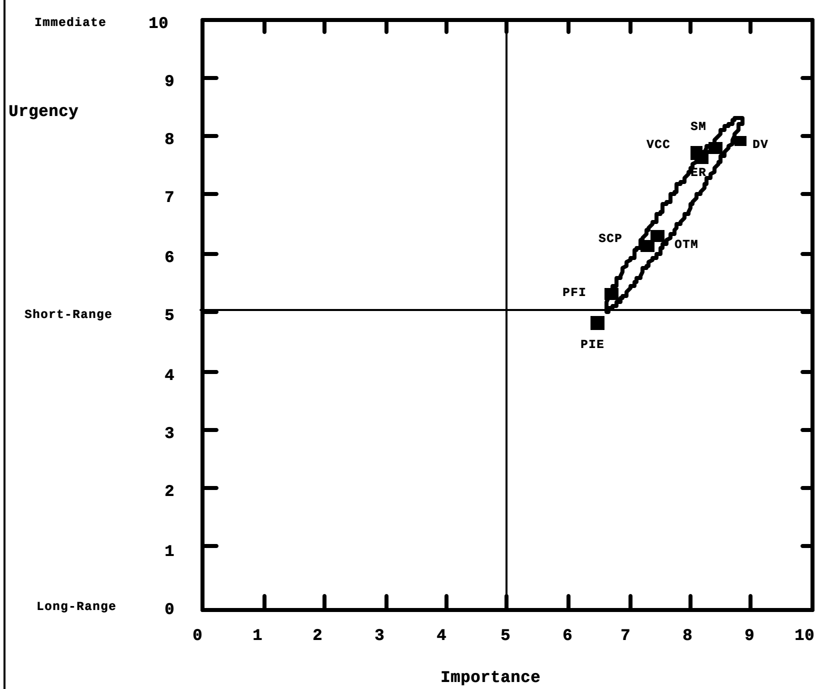
In contrast with the "pattern diagram" defining the evaluation of the eight recurring congestion functional areas (Figure 6), the pattern diagram defining incident management **(Figure 7)** is somewhat steeper and with higher values of urgency than exhibited by the recurring congestion functions. This would seem to indicate that managers in ODOT view incident management as having a greater degree of urgency in managing Ohio's highways, and that urgency of deployment of ITS technologies should first address incident management needs.

Deficiencies that more often surface in the evaluation of Ohio's incident management program **(Table B-3)** tend more to represent the institutional area rather than the technology area, with "clear responsibility" being more often cited. There are two functions that are very close in describing the highest rated functions that affect the incident management program.

Figure 7

Rankings of ITS Functions

Mean Scores for Functions Involved in Incident Management



Importance - 10 = Most Important
5 = Moderately Important
1 = Less Important

Urgency - Immediate = Next 2 Years
Short-Range = 2-5 Years
Long-Range = More than 5 Years

Essential ITS Technologies for Application in Ohio for Incident Management

(Developed at January 23, 2001 workshop conducted with the Advisory Committee)

Function	Problems	Current Deficiencies in Resources Available	Minimum Essential ITS Technologies Required
Detection and Verification (DV)	• Inaccurate location • Insufficient details • Multiple reports	• Single source information clearinghouse/dispatch for jurisdiction • Adequate bandwidth • Positive location method	• Reference markers • Motorist assistance patrol "crewzers" • Fixed lens cameras for CCTV • Better use of 1-877-7PATROL and 911 call centers • Better use of CB or cellular calls from truckers
Emergency Response (ER)	• Too much response • Redundant response • Slow response • Site inaccessibility • Traffic mgmt. in both directions	• Common communication channels • Use of fire trucks as crash barriers	• Common communications channel • Common database **Tier 2** • Portable CCTV
Site Management (SM)	• Multiple agency coordination • Inter-agency communication • Resource management • No quick clear policy for PDO crashes	• Team building across operations/ enforcement/ environmental personnel • Command and control functions (Fire Depts. commonly in charge of scene) • Communication of quick clear of PDO crashes to the public	• Message boards on maintenance vehicles • Lane closure signs to advise of lane blockage
Vehicle Clearance/Site Clean-up (VCC)	• Lack of adequate policy directives • Lack of clear control responsibility • 40 min. to 2 hrs. for cleanup	• Timing of arrival of needed resource • Personnel/ equipment • Qualifications of responders (training)	• CDPD – images of incidents to tow companies • AVL on emergency vehicle responders

Table B-3
Essential ITS Technologies for Application in Ohio for
Incident Management (continued)

Function	Problems	Current Deficiencies in Resources Available	Minimum Essential ITS Technologies Required
Overall Traffic Management (OTM)	• Decisions on lane closures • Lack of adequate diversion routes • Lack of knowledge of available diversion routes • Lack of traffic conditions on alternate routes • Lack of information dissemination to all parties	• Surveillance on arterials and surface streets • Broad area wireless media connectivity to real-time data • Jurisdictional control issues • Rural incident notification on major arterials (e.g., at rest stops, truck stops, etc.) – further upstream of traffic than in urban areas	• Permanent and portable (temp.) dynamic message signs • Video cameras in police cruisers and/or freeway service patrol vehicles • Short-range radio and use of cell calls • Regional data coverage **Tier 2** – Ramp meters in selected locations
Post-Incident Evaluation (PIE)	• Timeliness and timing of coordination effort	• Management structure • Use of data collected for accident prevention	• Automate/ simulate future response • Prediction capability
Planning for Improvements (PFI)	• Inadequate data • Inappropriate/ not useful data	• Management structure • Funding for responsible database manager	•

These are detection and verification (DV) and site management (SM). Common communications channels would help reinforce each of these functions. The panel that worked through the details of analyzing incident management needs identified the following technologies as most needed:

- Reference markers
- Crewzers with portable message boards
- Fixed lens cameras for CCTV coverage
- Better use of existing notification methods (e.g., 911, 1-877-7PATROL, CB radios, cell phones)
- Message boards on other maintenance vehicles (other than Crewzers)
- Lane change signs (mounted on Crewzers and other maintenance vehicles)

It is suggested that to improve Ohio's multi-agency responsibilities in the area of incident management, a program of incident management "team building" among incident management responders in each of the major metropolitan areas be initiated, or aggressively continued where they already exist. A separate section of this research report will address in more detail recommendations for improving Ohio's incident management program.

Traveler Information

While traveler information covers a broad range of types of data and information provided to the traveling public, the panel addressing this program identified incident information as by far the most urgent, and slightly more important than the other functions (**Figure B-8**). The slope of the pattern diagram describing the relationship among the various incident management functions is approximately the same slope as for incident management.

With the exception of incident information, however, the functions involved in the traveler information program are valued slightly less urgent than the incident management functions. This would seem to indicate that ODOT managers feel that there is a greater need to address internal (i.e., public agency) communications and management functions before expanding the broader program in traveler information. However, traveler information functions are viewed as equally important as the other functions. The priority deficiency that needs to be overcome in addressing traveler information **(Table B-4)** is a common communications channel and common protocols. It would seem that a statewide ITS communications strategic plan would help prioritize budget needs among the various agencies in order to acquire this capability.

Figure 8

Rankings of ITS Functions

Mean Scores for Functions Involved in Traveler Information

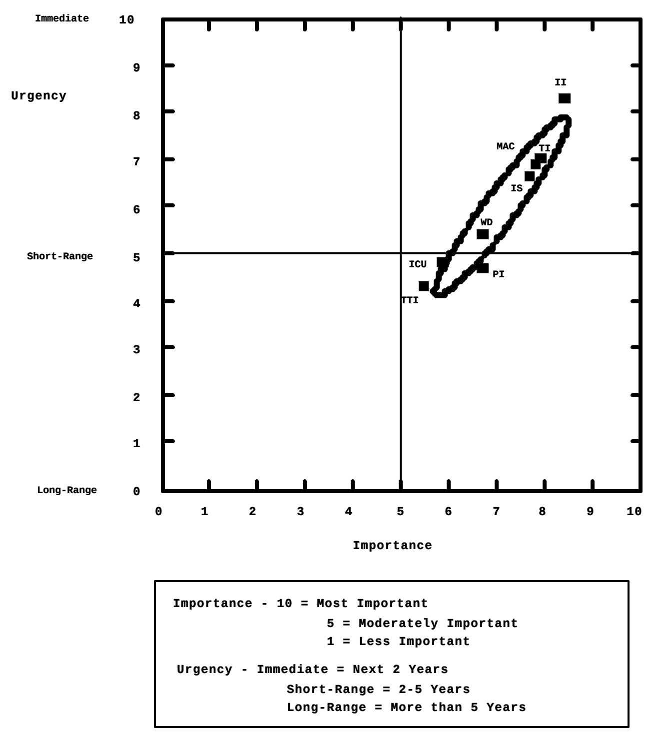


Table B-5 also indicates that the minimum essential technologies that are required to implement a program of improving the flow of providing incident information to the public, to ODOT units, emergency responders, and law enforcement, are as follows:

- “E-tools” – Web pages, OTIS, pagers, e-mail alerts, etc.
- FM Traveler Information Radio
- Broadcast media connections
- Low power AM Highway Advisory Radio
- Interactive, touch-screen electronic Traveler Information Kiosks

- Small scale, fixed Variable Message Signs
- Ramp metering (recommended only in strictly warranted situations in high density corridors)

Table B-4
Essential ITS Technologies for Application in Ohio for
Traveler Information
(Developed at January 23, 2001 workshop conducted with the Advisory Committee)

Function	Problems	Current Deficiencies in Resources Available	Minimum Essential ITS Technologies Required
Motorists assistance communication (public info. To motorist assistance center) (MAC)	• Long breakdowns lead to incidents • Motorists don't know where to call for help • Default notification system is cell phone	• Single source information clearinghouse/ dispatch for jurisdiction • Adequate bandwidth	• Signs including 511 notification and mile markers • Call protocols for resource center • Common 511 center • Links to 911 call center, OSP, other law enforcement
Information sharing among agencies (ODOT, local jurisdictions, travel and tourism, etc.) (IS)	• Home rule "culture" • Separation of agency and unit functions • Compatible data protocols among agencies • Agencies PIO functions not connected to operations	• Common communications channels • Common database	• Communication policies and protocols • Operations and management policy • Common statewide ITS architecture • Integrated statewide ITS communications system • MOU's to deal with immediate problems
Incident information (to public, ODOT, emergency responders, law enforcement) (II)	• Timeliness of reports • Reliability of information • Jurisdictional responsibility • *Ad Hoc* nature of reports	• Connection to multiple media outlets • Sharing of on-line info.	• E-tools (as above) • Travel Advisory Radio (FM) • Broadcast news/ traffic stations connection **Tier 2** - Dynamic Message Signs
Traveler, tourism, and special event information (TTI)	• Lack of economic development or tourism promotion involvement	• Connection to multiple media outlets • Sharing of on-line information	• E-tools (as above) • Travel Advisory Radio (FM) • Broadcast news/traffic stations connection • Variable message signs (essential for this function)

Table B-4
Essential ITS Technologies for Application in Ohio for
Traveler Information (continued)

Function	**Problems**	**Current Deficiencies in Resources Available**	**Minimum Essential ITS Technologies Required**
Information on commercial vehicles (ICV)	• Separation of agency functions • Lack of trucking companies • Lack of coverage of non-permitted trucks • Parking availability along Interstates	• Connection to state commercial vehicle enforcement unit • Sharing of information from state-to-state on all Interstate routes • Advance notification system on all Interstates on permissible parking availability	• Pre-pass on all interstates • Parking information systems • Integrated weigh stations and inadequate coverage.
Planning for improvements (PI)	• Inadequate data • Inappropriate/ not useful data	• Management structure • Funding for responsible database manager	•

Summary

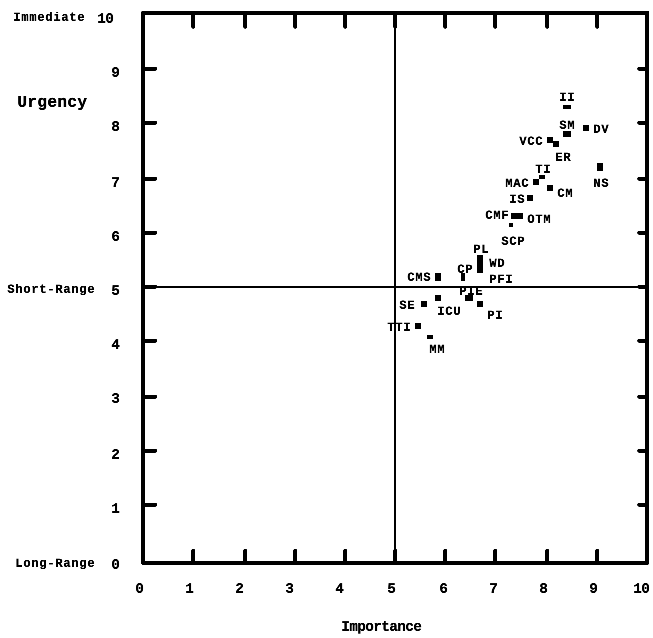
Summary tables illustrating the data from which the above analyses were derived are shown in **Figures B-9 and B-10**. Those figures illustrate that there is a wide variation on the part of ODOT managers in their perceptions of the importance and urgency of addressing the various functions. **Figure B-9** shows that all of the 24 separate functions (actually 22 functions, since "planning for improvements" is a function in all three program areas) are on average considered at least moderately important and should be implemented in the short term (within the next five years).

Figure B-10, on the other hand, reflects the "raw data" from the independent evaluation of all 24 functions by the 20 participants in the exercise that was conducted on January 23,2001. This figure reveals that there is a wide disparity among ODOT managers in their assessment of the urgency and importance of implementing certain functions. For example, approximately eight percent of the independent evaluations were rated as a "10/10," which indicates an immediate need to deploy those technologies (within next two years), and are the most important to the overall ITS program. Those evaluations that considered functions at least as high as a "8/8," which still indicates a high level of importance and urgency, totaled approximately 23 percent.

Figure 9

Rankings of ITS Functions

Mean Scores for All ITS Functions



Importance - 10 = Most Important
5 = Moderately Important
1 = Less Important

Urgency - Immediate = Next 2 Years
Short-Range = 2-5 Years
Long-Range = More than 5 Years

At the other end of the scale, however, approximately 12 percent of all the ratings placed values on the urgency and importance of some functions as low importance and long-range in deployment urgency. Beyond the results of this analysis that are portrayed in Figures 6 – 10, further analysis of these rankings was not carried out in this research. The implication of what has been done, however, is that the results of the research should be used to stimulate further dialogue and obtain consensus on which functions are the top priority items to the Ohio DOT.

Clearly, the top-rated functions in each of the three program areas should be receiving the most attention by ODOT in setting these priorities. Those three top-rated functions are:

- For recurring congestion management — Network surveillance
- For incident management — (a) Detection and verification, and (b) Site management
- For traveler information — Incident information to the public, to ODOT, and to other emergency responders

All of these four functions are interrelated, and therefore the deployment of ITS technologies as well as operations and management improvements are recommended as the highest priorities for implementation by ODOT.

Rural vs. Urban Needs

While state highways and other streets in the urban areas of the state, which include all counties within the 17 MSA's in Ohio, will ultimately be within the monitoring capability of a regional TMC, it is simply not cost-effective for ODOT to provide the same type of electronic surveillance of less densely traveled corridors.

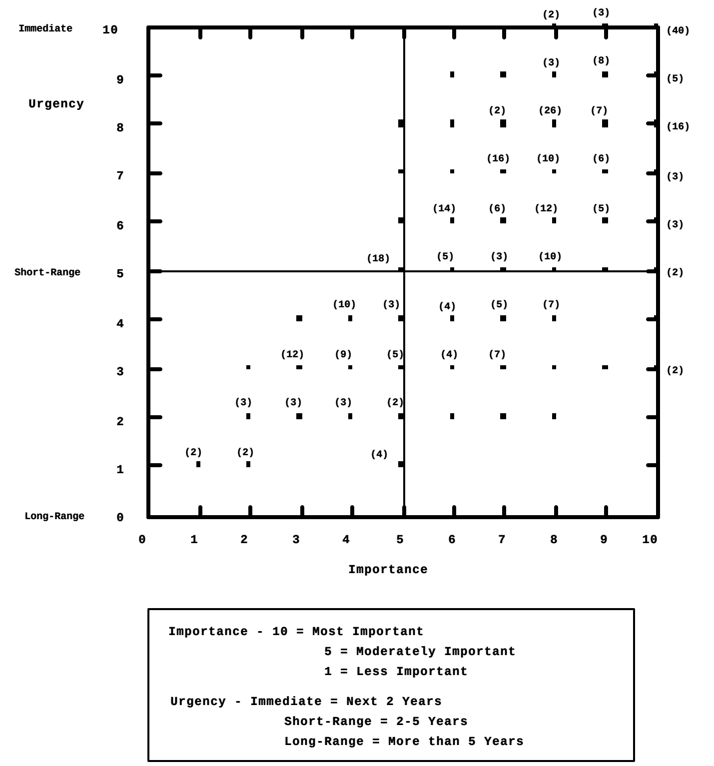
For purposes of this research, however, and in the planning for a statewide ITS Strategic Plan, the inclusion of all highways on Ohio's Macro Corridor system (Figure 1) is useful. The 2500 route miles in rural areas on the Macro Corridors include all Interstates, the Ohio Turnpike (again, not under ODOT's jurisdiction), and selected State routes.

In extremely lightly traveled portions of the Macro Corridor routes, it may be sufficient to continue to rely on the OSP (Ohio State Patrol), ODOT maintenance units, and other motorists, for incident observation and reporting. Of course, in-vehicle location identification and emergency notification systems such as "On-Star" and similar systems, will continue to increase in the personal vehicle and commercial vehicle markets.

Figure 10

Rankings of ITS Functions

Raw Scores for All ITS Functions



However, in some parts of the rural Macro Corridors, such as all rural Interstates, it may be that the development of the ITS network surveillance system would include locating a non-intrusive detection device between each interchange. On the approximately 100 miles of rural I-71 between Columbus and Cleveland, for example, this would mean approximately 20 sensors be deployed.

This would provide feedback to one of the regional TMCs about major changes in traffic flow between segments in the event of dramatic events such as a lane blockage or complete shut-down of a particular segment. OSP cruisers could then be notified by the TMC. This type information would greatly augment the expected reporting of major incidents on rural highways that would be made via cell phone calls from motorists involved in the situation.

There are approximately 160 interchanges statewide on the 720 centerline miles of rural Interstate highway. This would mean a total of 320 detection devices to cover both directions of each segment between interchanges. Other ITS infrastructure that would be required in rural areas to complete this level of coverage may include the following:

- Video surveillance at all Welcome Centers and rest areas in the state
- Traveler information kiosks at each Welcome Center and major truck stops in the State
- Overhead variable message signs between every fourth interchange (approximately 40 statewide – one every 18 miles, on average)
- Communications network, presumably wireless for most areas
- Video surveillance at all interchanges with periodic or regular high volume traffic (such as the two interchanges that serve the Mid-Ohio Raceway or the Polaris interchange for periodic use, or all interchanges serving major truck stops for regular use)

APPENDIX C
TECHNOLOGY ASSESSMENT ¾ VEHICLE DETECTION

(Survey of deployment of specific technologies/vendors in other states – updated 04/06/01)

Technology	Examples of Vendors	States in which vendors have deployed technology	Cost Range	Current potential for deployment in Ohio
Inductive Loops	• 3M • Microloop • Nu-Metrics • Safetran •Reno A&E •Peek Traffic •US Traffic Corp.	Nationwide MN	• $5 k to $8 k for 4 loops with controller • O&M approx. annual $400 to $800 / loop	High (H)
Video Imaging	• Autoscope/ISS • Traffic Cam • Vantage •Diamond Traf. Products •Enerdyne •Transformation Systems	GA, MN, MD Nationwide Nationwide Nationwide 10 states	• $25 k to $50 k for typical 4-camera installation	Moderate (M)
Infrared	• Autosense • ASIM Engr., Ltd. • Grumman • IR224 • Microsense • SEO • Swartz Electro-Optics	FL, OK	•$6k to $10 k per installation	Mod. to High
Acoustic (Sonic and Ultrasonic)	• Lucent Technol./AT&T • IRD (International Road Dynamics) • Sumitoma Electric USA	NY, VA	•$4.5k to $10k for four-sensor system • O&M approx. annual $200 - $400	Mod. to High
Microwave	• Beatrics • Microwave Sensors, Inc. • Peek Traffic, Inc. • Whelen Engineering, Inc. •KSI, Inc.	MD	$6 k for one ea., two-way sensor $18 k for 4-leg intersection	H
CCTV (Closed Circuit Television)	• Cohu •American Dynamics • Odetics/Iteris • Panasonic • VTDS •OMTV Systems •Philips •Pulnix	CA, PA, NJ, CO, MD, NC Nationwide CO FL, CA, CO	$7 k to $60 k for color video $18 k to $50 k for tower $0.6 k to $1.7 k /yr. For O&M	H

RADAR (Radio Detection and Ranging)	• EIS Electronic Integrated Systems • RTMS XI •American Traffic Systems •Scientex •GMH Engineering	NC, SC, NY, MD MD MD, KY	$3 k to $30 k	M
LIDAR (Light Detection and Ranging)	• EIS, Inc. • RTMS XI •American Traffic Systems		$4 k to $6 k	L
Pan/Tilt/ Zoom (PTZ) Cameras	•Cohu •Detection Systems & Engr. • Pelco •Panasonic	MI, PA, IN, OR CO, FL	Dual channel models 5000 & 6000 – cost $20 k to $60 k	M
"Webcam" Fixed Image Cameras	•Javelin	CA, CO, TX	$8 k to $17 k	H
Portable Traffic Management System (TMS)	•Santa Fe Technologies	10 (+) states	$3.0 to $40.0 k	L
Laser-Scan Detectors	•Schwarz Electro-Optics	FL, OK		M
Ramp Meters/ Signals			$15 k to $65 k per ramp $1.5 to $3.5 k/year for O&M	L
License Identifier	Raytheon Northrup Grumman Scientific Technologies			

APPENDIX D
TECHNOLOGY ASSESSMENT ¾ TRAFFIC CONTROL

(Examples of specific deployments of technologies/vendors in other states; updated 04/17/01)

Technology	Examples of Vendors	States in which vendors have deployed technology	Cost Range	Current Potential for deployment in Ohio
Closed Loop Signal System	Econolite Eagle Peek/Transyt Bitrans	CA, CO, WA, FL, MD, MN, Nationwide Widely used, esp. in SE	Varies with size of system Typically $30k - $40k for PC software	High (H)
Urban Traffic Control System (UTCS)	Transcore Control Technologies	FL, GA, VA, TX	Several hundred thousand dollars for central hardware and software; ($180 k to $220 k for integration software)	Low (L)
Dynamic, Adaptive Control System	SCOOT SCAT RT-TRACS	MI, MN MI, MN	Several hundred thousand dollars for central hardware and software	L
Distributed Processing Control	Aries Monarch MIST ESCORT System 2000	MD Widely throughout US TX, PA, Canada	Typically $100 k to $300 k for Software	H
NEMA TS-1, TS 2 Controller	Econolite Eagle Peek/Transyt Naztec	All used widely throughout US	$1,500 - $2,000 per controller unit; $6 k to $8 k for TS-1, and $8 k to $10 k for TS02 (fully equipped cabinet w/ controller); $200 - $500 annual O&M	H
170 Controller	McCain(hardware) NOVAX (hw) Safetran (hw) Naztec (hw) Bitrans (software)	CO, MN	$900-$1,300 for 170 controller and software $6,000-$8,000 for fully equipped cabinet	M
2070, 2070 Lite Controllers	Eagle Econolite Safetran Naztec	CA, CO, FL, NY, WA, MN	$2,500-$5,000 for 2070 controller and software $10,000-$15,000 for 2070L (fully equipped cabinet + software)	L
Manual Override of Traffic Signals	Emergency Preemption Systems	10(+) states	$100-$500 per intersection	M

Radar Intersection Control	EIS Electronic Electronic Control Measurements	NC, SC, NY 10 states	Approx. $4 k per unit	M
Infrared Intersection Control			$5,000 per intersection	L
Lane Control Signals			$130 k to $210k for software, gates, signals (freeways)	M

APPENDIX E
INCIDENT MANAGEMENT TECHNOLOGIES AND PRACTICES

To achieve an understanding of the current status of how incidents are managed by emergency responders in Ohio, a number of interviews were conducted. A cross section of incident management and response agencies in various jurisdictions created a baseline understanding of current practices (**Table E-1**). These interviews were conducted during late March and early April 2001, with ODOT central office staff, District offices, Ohio State Highway Patrol (OSP), local police and fire departments in Columbus, and others.

Telephone interviews were conducted and each was based on a written "guideline" document identifying topics to be discussed. The primary focus of these interviews was on anecdotal information rather than quantifiable data collection, although the basic results are depicted in the table. Separate results from these interviews were recorded for the three larger metro areas in the state, and for other field districts of ODOT and OSP.

A detailed assessment of Incident Management technologies is related in **Table E-2.**

Based on the interview results, and a summary of current incident management practices in the state of Ohio and elsewhere, suggestions on how to change the highway incident management programs in Ohio's metropolitan counties, as well as other jurisdictions, include the following observations:

- Jurisdictional considerations: Ohio's Corporation Limits and Home Rule legislation are well entrenched in a strong local governance history, including traffic enforcement on state highways inside Corporation Limits. Therefore a more substantial coordination effort is required to establish a higher degree of communications among emergency response agencies, and to decrease congestion caused by extended time to clear the scene after both major and minor incidents occur on the highway.

- ODOT role in a coordinated incident management program: In order to make an impact on improving incident management, ODOT should commit resources to work with MPOs (in the planning phase) and law enforcement and other emergency response agencies (in the operations phase). Common training programs and "incident management team building" are, at best, scattered in Ohio's metropolitan counties. In order to establish a concerted effort to increase these common training and team building programs, ODOT must partner with the FHWA Division Office and take the lead in this area. No other agencies at the state or local level have the statewide mission or responsibility for managing traffic on state highways. This state system effort will have a "spillover" effect on municipal and county streets and highways.

- Legal authority: Fire departments throughout Ohio, including both paid and volunteer organizations, have the undisputed authority of on-scene command and control. Local fire and police departments, along with ODOT and local highway O&M units, have recognized the need for several years to establish "clear the scene" time reduction measures. Reference material on this issue from the City of Columbus, OSP, and other localities is contained in the Appendix. It is suggested that a major information dissemination effort be conducted to establish common approaches to on-scene management in metropolitan areas across the state. As a matter of policy, ODOT and the OSP should also update their interagency working agreements that provide guidelines for on-scene management.

Incident management priorities are focused on the implementation and improvements of the following subsystems, rather than specific technologies:

- Incident notification subsystem
- Emergency responder dispatch and operations subsystem
- Enroute traveler information subsystem

Table E-1
Summary of Incident Management Program Status

Incident Management Activity	Cincinnati Metro Area	Cleveland Metro Area	Columbus *Metro Area	Statewide-ODOT/ OSP outside Corp. Limits
Service Patrols				
1. Operational	Public & Private	Public	Public	Public
2. Schedule	16 hrs/5 days	16/5	24/7	24/7
3. Communication w/ police	Yes	Planned	Yes	Yes
4. Cell phones and/or pagers	No	No	Yes	Yes
5. Arrow boards	Yes	Yes	Yes	No
6. Other traffic control devices	Yes	Planned	Yes	Yes
Interagency Activities				
1. Published interagency agreements	No	Yes	Planned	No
2. Regular meetings w/ I.M. Team	Yes	Yes	No	Yes (quarterly)
3. Joint training	Yes	No	One course	No
4. Joint participation in disaster drills	Yes	Planned	No	Yes
5. Written response criteria	No	No	No	No
Incident Clearance				
1. Quick clearance policy	No	Planned	Yes	No
2. Clearance time criteria	No	No	No	No
3. Use Total Station approach	Yes	Yes	Yes	Yes (Districts 6&9)
4. ODOT or City has active role in scene clearance and clean-up	No	Yes	Yes	Yes
5. Evaluation of Incident Management performance	Yes	Yes	Yes	No
6. Evaluation of equipment deployment	Yes	Yes	Yes	No
Design and Construction				
1. Incident response considered in early design stage	No	Planned	Yes	No
2. Detection and verification technology used	Cameras	No	Yes	No
3. Video used by emergency agencies	Planned	Planned	Planned	No
4. Use permanent or portable DMS	Permanent	No	Planned	Yes (portable)
5. Use temporary access or "turn-arounds" during construction	No	Yes	No	Yes (limited)
6. Temporary accident investigation sites available	No	Yes	No	No
7. Mile post reference markers	Yes	No	No	Yes (Cincinnati)
Incident Management Leadership				
1. Top management involved in developing guidelines	Yes	Yes	Yes	Yes
2. Top management involved in Incident Management activities	Yes	Yes	Yes	No

* Response by City only

Table E-2
Technology Assessment - Incident Management
(Examples of deployment of specific technologies/vendors in other states - updated 04/17/01)

Technology	Examples	Examples of Vendors	States in which vendors have deployed technology	Current potential for deployment in Ohio
Notification Subsystem	Cell phones Roadside call boxes Motorist Assistance Patrols CB Radio MayDay (etc.)	Miland Cobra Astropower Comarowireless Tech Mark IV Industries	GA NJ, NY, PA	High (H)
Emergency Response Dispatch/Operations	E911 ETS	Teledent McKenzie Engr. Baker Geo Research ETC911 Motorola Orion	MI, MD MD	H
Emergency Vehicle Fleet Subsystems	Heads-Up display 800/900 MHz radio	Teletrac GE/Ericsson NEXTEL	MI MI	M (market driven)
Traffic Diversion Routes	Broadcast On-site, portable message signs Truck-mounted msg. Boards/arrow boards	American Signal Co. Guardian	NE, KY, IL, MD	M (demand is high, but opportunities for viable diversion routes, especially off rural freeways, is limited)
Enroute Traveler Information	Dynamic Message Signs	Guardian Transtar American Signal Co. Voltron Addco Telespot	MI MD MD	H (for shoulder and median-mounted signs)
On-Site Management Subsystem	Two-way radio 800/900 MHz	ICOM America Audiovox Motorola	Nationwide	H

Table E-2, continued
Technology Assessment - Incident Management
(Examples of deployment of specific technologies/vendors in other states - updated 04/17/01)

Technology	Examples	Examples of Vendors	States in which vendors have deployed technology	Current potential for deployment in Ohio
In Vehicle Navigation Subsystem	Global Positioning Satellite Differential GPS	ETAK ARINC Clarion Auto PC CSE Computronics Trimble	Nationwide VA, MD, CA MN	H (market driven)
Broadcast Information Subsystem	Wide Area/Regional FM FM Subband Radio Data System	Cue Network Delco	Nationwide Nationwide	H
Dynamic Message Signs (also called Changeable Message Signs, or Variable Message Signs)	Overhead, Permanent signs	American Signal Co. Daktronics Fiberoptic Display Systems Tele-Spot VULTRON American Electronic Signs Mark IV Skyline Products	NE, KY, IL, MD 10 (+) states AZ, TX, NC MN, FL, SD DE, FL, MD, MI, MN, NY, OH AL, FL, NC, NY WA	High for moderate priced assemblies. Overhead Signs: $50 k - $150 k; Typical installation cost for overhead signs is $85 k to $150 k on freeway; and $35 k to $95 k in median or shoulder; $30 k to $40 k for smaller signs used in Parking Management, special uses.
	Portable signs	American Signal Co. American Electonic Signs	Nationwide	Typical cost for portable signs is $30 k to $40 k, with trailer, either solar panel or generator powered.

Appendix F

Technical Memorandum – Communications Conduit Installation

KHA OF OHIO, INC.
An Affiliate of KIMLEY-HORN AND ASSOCIATES, INC.

Technical Memorandum

To: Howard Wood

From: Amy Massey

Date: May 24, 2001

Subject: Best ITS Management Practices and Technologies for Ohio
Task 5 Results

The purpose of this technical memorandum is to present the results of Task 5, as described in our letter dated April 19, 2001.

1. INTRODUCTION

A key element in achieving typical freeway management objectives is development of a conduit and pull box infrastructure that will facilitate a field communication network. The field communications plan requires a distribution system that would facilitate the installation of all required communication cables and power conductors.

This technical memorandum identifies options and discusses various considerations in selecting and designing a system to provide the conduit and pull box infrastructure for the ODOT ITS system. The focus of this technical memorandum is on the infrastructure needs specific to fiber optic cable. This background technical memorandum describes technical options, location requirements, and evaluates the costs associated with the different options.

2. GENERAL CONDUIT INSTALLATION AND PLACEMENT

Many freeway management systems employ two different conduit systems: one for communication cables and another for power conductors. A conduit system for communication cables should be able to handle both fiber optic cable and twisted pair cable. Other cables that potentially could share the communication conduit include control cables, loop detector cables, and other low voltage cables.

One of the goals of a robust communication infrastructure is to minimize tension on the cable during pulling. This in turn will maximize the length of cable that can be installed in a single pull, resulting in lower installation cost and greater spacing for pull boxes. Fewer pull boxes has the added benefit of fewer locations where the cable integrity is at higher risk due to rodents, ants, water infiltration, and other environmental actions. Communication cables are typically designed with a strength member that allows for pulls over greater distances than power conductors.

Power conductors typically require shorter conduit runs than communication cables. In addition, tighter pull box spacing is common practice. Also, many agencies prefer not to have communication cables and power cables in the same conduit system.

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When considering conduit placement, it is important to understand the system architecture and needs of the communication system. Most freeway management systems use a trunkline cable between a traffic center and hubs (also called nodes) located in the field. The field hubs are then linked together in either a linear or "ring" configuration to provide one or more communication paths between hubs and the traffic center. These rings allow communication to sections of freeway that are generally not located on or near the communication trunkline. Typically, the trunkline is accessed only at the hubs and traffic center.

A separate communication or distribution system is established from the hub, or in some cases, the traffic center, to the individual field elements, such as closed-circuit television (CCTV), dynamic message signs (DMS), and detector stations. If cable is utilized, there will be access points at each device.

Conduit that will be used for fiber optic cable should be installed as straight as practical to minimize the amount of pulling tension and maximize the length of cable installed with each pull. As a general rule, fiber optic conduit systems should not exceed 270º of cumulative bending between pull boxes. The total number of bends may reach 360º for short runs of 100 feet (30 meters) or less. Bending of the conduit should be accomplished by deflecting the run no greater than one foot for every ten feet (one meter for every 10 meters) in either the horizontal or vertical directions. At locations that will not permit a 10:1 deflection, factory bends may be used, with the flattest bend available (typical bends range from 11 1/4º to 90º). The number of 90º bends should be minimized. When used, fiber optic conduit bends should be gradual and of a large radius. Current ODOT fiber optic cable installation specifications (intended for providing a fiber optic communication link between intersections in an interconnected traffic signal system) call for the following minimum bend radii:

- 10 times cable diameter under no load (up to 180 lb or 82 kg)
- 20 times cable diameter under applied load (181-400 lb or 83-182 kg)

Main line fiber optic cable should enter and leave a pull box on opposite walls through factory-installed side knockout hole. If necessary, entry can be accomplished from beneath the pull box using 45º, large radius sweeps. The side entry method reduces the number of bends for the run, thus enabling longer pulls at lower friction. The 45º sweep approach provides greater flexibility in placement of conduit and pull box.

Different types of conduit systems should be evaluated in order to select what best suits the needs of the ODOT ITS system. The design options include the use of single conduits or multiduct conduit. Typical multiduct applications include the use of four one-inch (25-mm) diameter innerducts encased and protected by a four-inch (100-mm) Schedule 40 or 80 PVC outerduct, or the use of a number of 1-inch (25-mm) Schedule 40 PVC conduits locked together in formation (i.e. four conduits quad-locked in a square configuration). Quad-locked multiduct runs approximately $0.75 less per foot (300 mm) than multiduct with an outerduct.

Multiduct will allow for installation of future fiber optic cable(s) without removing or damaging existing cable. On the average, the installation of multiduct conduit with four ducts will cost on the order of $2.00 to $4.00 per foot (300 mm) more than standard three-inch (75-mm) conduit. Once trenching costs are considered, the order-of-magnitude cost of standard conduit verses multiduct is often insignificant. Depending on the type of conduit selected, various other issues should be addressed including inner conduit, duct plugs, expansion fittings, conduit terminations, and bends.

Installation of multiduct will give the communication system added spare capacity, depending on the number of cables installed. Typically, one cable is installed in one inner conduit. Most systems use one to three fiber optic cables. Accordingly, there are up to three spare inner conduits. The addition of a second multiduct greatly increases the capacity with only an incremental increase in cost.

Buried conduit is typically PVC or rigid metal. Most agencies are using PVC for fiber optic cable due to substantial cost savings and longer life; however, rigid metal provides greater protection and may be more appropriate in some installations. Conduit that will be exposed or placed in bridge structures should be either fiberglass or rigid metal.

3. COMMUNICATION CONDUIT INSTALLATION ALTERNATIVES

Alternatives for the deployment of fiber optic communications cable are included in the following categories:

1. Trenched or drilled
2. Direct-buried
3. Installed in median wall
4. Attached to bridges
5. Installed aerially

Each alternative is described below. Section 6 includes a comparison of rough order of magnitude (ROM) costs.

3.1 Trenched or Drilled Conduit

In locating the trench for conduit, many considerations should be evaluated prior to arriving at a recommended strategy. While an installation behind the shoulder is preferred, limiting factors in the field could make it necessary to install the conduit in the median area. Also, the conduit could be installed under pavements (typically in the shoulder area) by saw-cutting the pavements. The lateral distance between conduit and the edge of the roadway should be reviewed to determine the optimum path. This offset should consider existing and proposed utilities as well as ODOT facilities. Maintenance of the roadway as well as future system maintenance functions and potential freeway widening should also be considered. In some instances the terrain can dictate the trench location. Unless the median area is wide, traffic control is typically more extensive during installation and maintenance than it would be for conduit trenched along the shoulder.

An alternate method that is sometimes employed for areas with significant surface obstructions or crossings is directional drilling. Depending on soil conditions, directional drilling can install up to 600 feet (180 meters) of PVC conduit or rolled polyethylene conduit without disturbing the surface. The results are similar to that of jack and bore methods, except longer runs can be achieved at greater cost efficiency. Specialized equipment is needed to install conduit by directional drilling, so this alternative may not be practical.

Both the trunkline and the distribution cables should be installed in the same trench when possible to conserve construction cost. The most common shoulder conduit placement strategies are:

- *Main line trench on one side of freeway*
  This approach will yield consistency. Movement of people and vehicles during installation and maintenance activities relating to the main line trench can be accomplished in a sequential manner starting at one end and working to the other. An exception applies if an obstruction or physical constraint is identified rendering it unfeasible or cost-prohibitive to maintain trench on one side of the freeway. Thus, there may be select locations where the main line trench will move to the opposite side of the freeway for a relatively short distance in order to bypass an obstruction. Lateral conduit runs are necessary to cross the roadway to reach equipment on the opposite side of the roadway. Location of field devices can be weighted to the side with the main line conduit run to minimize the number of freeway crossings and associated costs for the communication system.

- *Main line trench on both sides of freeway*
  In the second approach, main line conduit is installed on both sides of the freeway between the traffic center and a hub, and between two hubs. While this approach typically yields a higher construction cost, the benefits include:

  - System redundancy by providing two communication paths between hubs.
  - Reduced need for distribution conduit crossings. (Distribution cabling is installed on both sides, and field devices will access the closest distribution cable.)
  - Greatest flexibility for system expansion.

The depth of conduit in trench should be held constant at 24 inches (600 mm). If a non-metallic conduit is used, a locator wire or detectable locator tape is needed to assist location efforts.

The trench configuration and backfill material should be investigated to determine what best meets the needs of ODOT. Some agencies have specified a slurry backfill to reduce settlement of the trench area and to provide additional protection against accidental damage from work performed after the conduit has been installed. Current ODOT fiber optic cable installation specifications (intended for providing a fiber optic communication link between intersections in an interconnected traffic signal system) require the placement of three-inch (76-mm) wide orange dielectric polyolefin film tape directly above all new conduit containing fiber optic cable as a warning. **Figure 1** is an example trunkline trench detail.

The National Electric Code (NEC) requires that conduit for communications be filled no more than 54% for a single cable.

Figures 2 and **3** are example details of conduit installation in fill sections. **Figures 4** and **5** are example details of loop detector/conduit and ramp metering controller/conduit installations along ramps in fill sections, respectively.

Figures 6 and **7** are example details of conduit installation in cut or flat sections. **Figures 8** and **9** are example details of loop detector/conduit and ramp metering controller/conduit installations along ramps in cut or flat sections, respectively.

Figure 10 is an example detail of conduit installation at overpass bridge structure (passing over crossroad).

3.2 Direct-Buried Conduit

Given the right soil conditions (loose, sandy, loam, etc.), it is possible to directly plow one-inch (25-mm) to two-inch (50-mm) polyethylene conduit (stored on reels) to an acceptable depth. Specialized equipment is needed to plow conduit, thus it may not be an option for small projects or local contractors. In addition, flat open space without crossing utilities or other conflicts is needed to accommodate the equipment and installation process.

3.3 Conduit Installed in Median Wall

For new construction projects, it is possible to install conduit within median walls and barriers that are formed in the field. Pull boxes can be built into the face of the barrier or wall or placed at grade. In either case, it is important to design the conduit in accordance with the radius and degree of bend criteria identified earlier in this document. ODOT Surveillance Junction Box Details include details on installing conduit, surveillance pull boxes, and lighting pull boxes in 50-inch (1270-mm) vertical top, battered top, and single slope barriers.

Although the use of conduit imbedded in a median wall can be advantageous in some situations, consideration must be given to the following complexities of this method:

- To conform to the size of the median wall, many barrier pull boxes have two dimensions that are 11 inches or shorter. If fiber is to be coiled or turned in the box, then the requirement for fiber optic cable minimum bending radius (10- or 20-times outside diameter) may be violated.
- Because of the size of median wall pull boxes, it is not feasible to install facilities for splicing fiber optic cable in the pull box.
- To access the trunk line cable, roadside devices will require a lateral conduit to be routed to the median. The installation of a lateral conduit typically requires directional drilling, which likely will dictate the closure of multiple travel lanes (to set up equipment) for an extended period of time.
- Careful planning of the placement of roadside devices is required to minimize the number of lateral crossings.

3.4 Conduit Attached to Bridges

Placement of the communications conduit across overpass structures should be evaluated to establish the most suitable location and means of supporting the conduit. When possible, the elevation of the conduit through the structure should be approximately the elevation of the conduit placement in the trench in order to avoid sharp directional changes. Long bridges may require equipment for various field devices and require special routing of conduit.

As shown in Figure 9, it is possible to install conduit down the embankment and beneath a crossing facility. However, conduit installations along a mainline over railroads and waterways typically require one of three methods:

- Installed within a cavity or cell of the bridge
- Attached to the underside of the bridge
- Attached to the parapet or side of the bridge

Figures 11, 12, and **13** are example details of conduit installations in/along overpass structures (I-beam and box girder). Aside from the installment method, other design decisions that will be necessary include:

- Steel versus fiberglass
- Aesthetics (if attached to the side or bottom)
- Expansion (need for one or more expansion couplings)
- Entry and exit points to and from the structure to minimize bending

It is fairly typical to place a pull box on both sides of a structure. If the degree of bending will exceed the 270º or 360º thresholds, then additional structure-mounted pull boxes (or junction boxes) will be needed.

3.5 Fiber Installed Aerially

Standards and guidelines for the aerial installation of fiber optic cable are articulated by ODOT (intended for providing a fiber optic communication link between intersections in an interconnected traffic signal system). Aerial installation is not commonly used for freeway communications systems.

4. PULL BOXES AND MANHOLES

Pull boxes are the primary access points for conduit and any cable housed in the conduit. The size and configuration of pull boxes should be determined based on the conduit configuration, type, size, quantity of conduit, splicing method, and required amount of spare cable.

A good design policy is to avoid installing pull boxes in the traveled way. Not only do these pull boxes require heavy-duty construction, but they also require traffic control to install and maintain. In all areas where there is a risk of heavy truck loading on the pull box and lid, they must be rated for AASHTO H20-44 loading. Typical reinforced concrete pull boxes are not rated for heavy truck loading, and at best may be able to sustain an infrequent loading when equipped with a steel lid.

If reinforced concrete pull boxes are used in areas that could potentially be subjected to infrequent vehicular loading, then a special concrete footing extending 6 inches (150 mm) around the outside of the box bottom should be considered to give added strength. Heavy-duty pull box lids should be considered even for areas not subjected to vehicular traffic to minimize maintenance activities and exposure of the communications system.

Composite pull boxes should be considered for fiber optic conduit runs. These boxes tend to cost more than reinforced concrete pull boxes, but offer a number of advantages including:

- More durable
- Less prone to cracked lids
- No metal reinforcing to rust
- Lighter weight (easier to store and install)

Composite pull boxes come in different load ratings. The concrete collar described above may not be necessary for composite boxes depending on the load rating of the box and the anticipated frequency of vehicle loading.

Pull boxes should not be located in drainage swales; pull boxes located on slopes should be placed horizontally and designed not to expose the side of the pull box that might be a hazard to traffic. Maximum pull box spacing criteria should be maintained for conduit installed on bridges. At each end of bridge structures, a pull box should be placed to facilitate the installation of cable and conductors. For communication cables, maximum pull box spacing of 1,000-1,500 feet (300-450 meters) is adequate for pulling purposes. Additional pull boxes should be installed sparingly, but in the vicinity of all field devices to provide communication access. Placement of pull boxes should also consider the conduit routing at the interchanges and potential splice points.

The minimum bending radius for fiber is approximately 13 times the outside cable diameter. (ODOT specifies 10-20 times cable diameter depending on applied loads.) The minimum pull box size should be determined in part by the minimum bending radius of the largest fiber optic cable, since excess cable is required in most pull boxes. To achieve consistency and provide flexibility for future growth, all pull boxes used for fiber optic runs should be sized to accommodate a splice closure as well as the minimum bend radius of the fiber cable. ODOT specifications call for a 24-inch (610-mm) X 35-inch (890-mm) X 26-inch (660-mm) pull box and indicates specific models and vendors.

In general, the use of a pull box will accommodate nearly all anticipated scenarios in routing conduit or cable for the ODOT ITS system; however, there are isolated cases that may warrant the use of a manhole or vault, including:

- Access required in non-freeway travel lane
- Frequent heavy vehicle loading
- Merge point for multiple branches and expansion
- Storage location for significant amount of slack cable

A manhole typically consists of a pre-cast concrete 4-foot (1.2-meter) diameter vault or ring(s) with base and cast iron frame ring and cover. Each manhole should conform to AASHTO HS20-44 standards. The manhole cover and frame should have a minimum diameter clear opening of 24 inches (600 mm) to 36 inches (900 mm). The cover should be secured to the manhole to discourage unauthorized entry or movement.

5. SPLICE CLOSURES

Fiber optic communication cables require an access point at each field device. At these locations, individual fibers of the fiber optic cable are either spliced or terminated in a manner that leaves the remaining fibers of the cable intact. Splicing and termination of the individual fibers can be housed either above or below ground.

Above ground splices are typically housed in a rack-mounted fiber distribution unit with a patch panel located in an equipment cabinet. Jumpers are utilized between the communication equipment and the patch panel. Fiber optic cable is either field terminated at the patch panel, or fusion spliced to a factory pigtail that is terminated at the patch panel. A comparison of the advantages and disadvantages associated with above ground splicing shows the following:

Advantages

- Easier access to fiber
- Less susceptible to moisture intrusion
- In smaller systems, all fibers in a cable can be terminated at the patch panel to provide greater flexibility (This approach would induce excessive signal loss in larger systems.)

Disadvantages

- More susceptible to dust and grime
- Communication cables are at-risk of vehicle knockdown
- Consumes cabinet space
- Increased handling of fiber optic cable

Below ground splices are housed using watertight underground splice closures. The fiber optic cable is fusion-spliced to a fiber optic pigtail (short run of fiber that is bare on one end for splicing, and terminated on the other) for patching or connection to communication equipment. A comparison of the advantages and disadvantages associated with below ground splicing shows the following:

Advantages

- Communication cables are not at-risk of vehicle knockdown
- Less complicated installation resulting in lower construction cost
- The fiber optic cable is not pulled into, and then out of each field cabinet
- Does not consume cabinet space
- Fusion splicing and the use of fewer terminations result in less signal loss/degradation

Disadvantages

- Poor construction methods can result in water/moisture infiltration
- Difficult to access fiber

Many freeway management systems utilize the underground splice approach at field cabinets and an aboveground approach at hub locations and traffic center. This combined approach offers flexibility for rerouting communication paths at the hub building while capitalizing on the benefits of an underground approach at field cabinets where flexibility is not generally needed, or could be provided on a case-by-case basis.

6. FIBER INSTALLATION COST COMPARISION

Table 1 includes a rough order of magnitude (ROM) comparison of costs associated with the various fiber installation alternatives discussed.

Table 1
ROM Costs per Linear Foot of Conduit

Method	Trenched in Dirt	Drilled	Plowed in Dirt	Installed in Median Wall*	Aerial
In Conduit					
4-inch PVC Multiduct w/ Outerduct	$16.50	$22.50	N/A	$14.50	N/A
4-inch PVC Multiduct (4 1-inch conduits)	$15.75	$22.50	N/A	$13.75	N/A
4-inch PVC Conduit	$14.00	$20.00	N/A	$12.00	N/A
4 1-inch Polyethylene Conduits	N/A	N/A	$13.00	N/A	N/A
Overhead Using Existing Poles					
Lashed to stranded messenger	N/A	N/A	N/A	N/A	$3.00

* Does not include the additional cost of laterals that will be required for roadside devices.

The following assumptions were made in developing the ROM costs:

- Pull box, splice closure, cabinets, fiber optic cable, splices, and other costs that will not vary between installations will cancel out and thus are not included in the above values.
- Trench is assumed to have no slurry.
- Costs include delivery and installation given a large quantity and could be substantially higher for small jobs.
- It is assumed that the Contractor mark-up will be equal to the suppliers discount, thus list price is used.

The following unit-cost assumptions were made:

- Trench $12/ft
- Drill $18/ft
- Plow $11/ft
- Attach $20/ft
- In median wall $10/ft
- Conduit $1.00/ft
- Multiduct $2.00/ft
- Polyethylene $0.50/ft
- Conduit (delivered, list price) $1.00/ft
- Multiduct w/ Outerduct (delivered, list price) $2.50/ft
- Multiduct w/o Outerduct (delivered, list price) $1.75/ft
- Dielectric, Single Mode Fiber Optic Cable, $2.00/ft
- Stranded messenger, $1.00/ft

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