Final Draft

October 1995

Tasks 6 and 7 - Technical Memorandum

- Identify Functional Requirements to Support User Services and Define System Architecture
- Identify and Screen Alternative Technologies and Related Issues

ITS Strategic Plan

The Early Deployment of Intelligent Transportation Systems (ITS) In Maricopa County

Maricopa County Department of Transportation

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Steering Committee Agencies

AAA	Glendale	Phoenix	UPS
ADOT	MAG	RPTA	
ASU	Maricopa County	Scottsdale	
Chandler	Mesa	Sky Harbor	
DPS	Motorola	SRPM Indian Comm.	
Federal Express	PAG	Swift Transportation	
FHWA	Peoria	Tempe	

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1. Introduction and Summary of System Functional Requirements (from Task 5)

1.0 Introduction

This Technical Memorandum presents the results of the architectural design and technology assessment (Tasks 5 and 7) and associated logical and physical architecture recommendations for the Maricopa County, Arizona integrated Intelligent Transportation System. Tasks 6 and 7 were combined since they are highly interrelated and involve iterative analysis and trade-offs of functional architectures and technology implementation alternatives.

The foundation for the logical architecture analysis is the combined preceding tasks which identified user needs and functional requirements. Functional requirements can be defined as logical requirements and information flow not allocated to a physical architecture. Function needs (requirements) were derived from stakeholder(s) inputs and represent the basis for system architectural analysis and recommendations. **Figure 1.0-1** represents the foundation for Tasks 6 and 7.

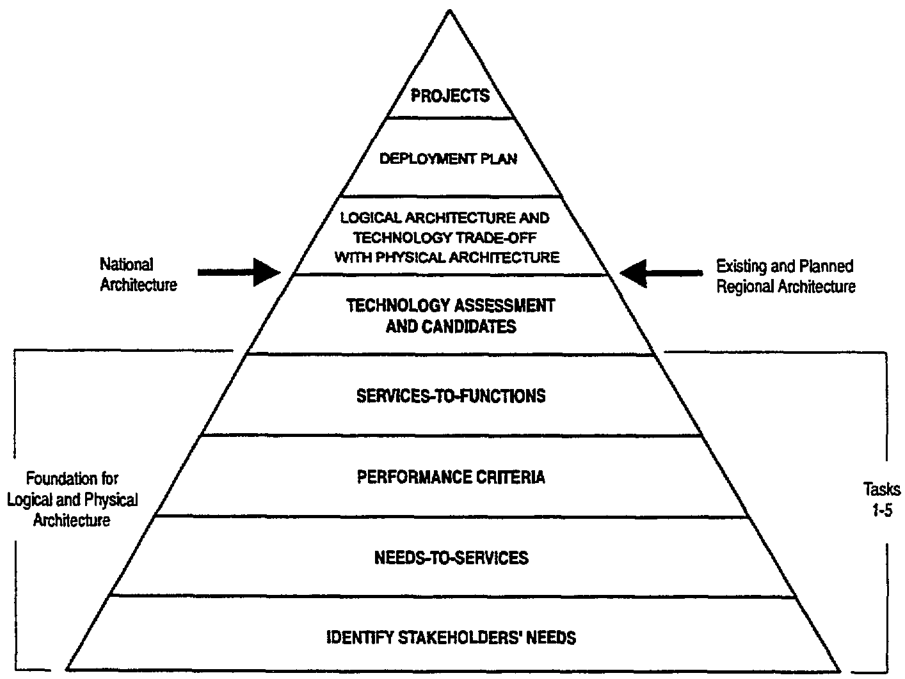


Figure 1.0-1 Basis for Architecture

Task 2 identified the following ITS user service needs as candidates to be met with a systems architecture. These include:

- Pretrip travel information
- En-route driver information
- Traveler services information
- Route guidance
- Enroute transit information
- Emergency notification and personal security
- Traffic control
- Incident management
- Emergency vehicle management
- Emissions testing and mitigation
- Public travel security
- Ride matching and reservations
- Demand management and operations
- Public transportation management
- Personalized public transit
- Electronic payment
- Commercial fleet management.

Several automated-vehicle-control/automated-highway-system services were also identified, including longitudinal collision avoidance, intersection collision avoidance and vision enhancement for collision avoidance.

Task 3 Technical Memorandum provides a bundling of user services based on the needs of Maricopa County **(see Table 1.1).**

Table 1.1
User Services Bundling Based on Needs of Maricopa County

User Service Bundle	Sub-bundle	Service Need
Traveler and Transportation Management	Traveler information and Safety support	. Pretrip travel information . Enroute driver information . Route guidance . Traveler service information
Traffic Management	Traffic and Incident Management	. Traffic Control ■ Incident management . Emergency notification and personal security
Public Transportation Operations	Public Transportation Management	. Public transportation management services . Public travel security
	Special Transit Services	. Personalized public transit

Task 4 Technical Memorandum defines recommended performance measures, which are summarized in **Table 1.2.** While performance measures are more suitable for operational testing, where quantitative data can be obtained, they form a qualitative basis for evaluating architectures and technology.

Task 5 Technical Memorandum defines the functional areas that best support user services. Functional areas are mapped into user services as illustrated in **Table 1.3. Table 1.4** from maps specific stakeholders' requirements to functional areas.

Table 1.5 is a summary of technology areas expanded from Task 5. These technology areas are analyzed for suitable candidates for inclusion in the recommended architecture.

Table 1.2
Recommended Performance Measures

ITS Services	Recommended Performances Measures	
	Primary	Secondary
Region-Wide Traveler Information	. Availability/accessibility of traveler information . Total incident clearance time . Availability of real-time traffic date between agencies . Public acceptance/reaction . Maintenance/operations requirements	. Number of congested locations . On-time transit arrivals
Public Transportation Management	. Transit ridership . Maintenance of headways . Number of on-time arrivals . Maintenance/operations requirements . Public acceptance/reaction	. Transit travel time
Personalized Public Transit	. Number of on-time arrivals	. Travel time . Duration of congestion
Enroute Driver Information	. Response/conformance to messages . Amount of diversion . Public acceptance/reaction . Maintenance/operations requirements	. Travel time . Duration of congestion
Route Guidance	. Response/conformance to messages . Level of participation/usage	. Travel time
Traffic Control	. Availability of real-time traffic data . Maintenance/operation requirements . Staff utilization . Travel time . Travel speed . Public acceptance/reaction	. Number of congested locations . Duration of congestion . Level of service . Delay . Fuel consumption
Incident Management	. Total incident clearance time	. Delay . Vehicle emissions . Fuel consumption
Pretrip Traveler Information	. Level of participation/usage . Availability/accessibility of traveler information . Public acceptance/reaction	. Operations/maintenance requirements

Table 1-3
Matching Functional Areas to Local User Services

		FUNCTIONAL AREAS																		
		Surveillance				Traveler Interface		Navigational Guidance		In-Vehicle Sensors		Communi-cations			Control Strategies		Data Processing			
USER SERVICES		Traffic	Vehicle	Weather	Hazard	Out-of-Vehicle	In-Vehicle	Real-time Position	General Guidance	Navigation	Driver Safety	1-Way Mobile	2-Way Mobile	[illegible]	Signalized	Restrictive	Traffic Prediction	Traffic Control	Routing	Database
Traffic Control	Traffic Flow Optimization																			
	Traffic Surveillance																			
	Device Control Function																			
	Control Information Sharing																			
Pre-Trip Travel Information	Available Services Information																			
	Current Situation Information																			
	Trip Planning Service																			
	User Access																			
Route Guidance	Provide Directions																			
	Static Mode																			
	Real-Time Mode																			
	User Interface																			
En-route Driver Information	Driver Advisory																			
	In-vehicle Signing																			
Incident Management	Schedule Planned Incidents																			
	Identify Incidents																			
	Formulate Response Actions																			
	Support Coordinated Response																			
	Predict Hazardous Conditions																			
Public Transportation Management	Automated Operation																			
	Automated Planning/Sched.																			
	Automated Management																			
	Communications																			
Personalized Public Transit	Rider Request																			
	Vehicle Assignment																			
	Data Collection																			
	Information Processing																			
	Communications																			

Table 1-4
Transportation Needs in Maricopa County

	Locally Identified User Services						
	Traffic Control	Pre-Trip Travel Information	Route Guidance	En-Route Driver Information	Incident Management	Public Transportation management	Personalized Public Transit
Transit Needs							
More Routes						X	X
Express Routes to non-downtown locales						X	X
More frequent service						X	X
More hours of service						X	X
Reduced trip time							X
Real-time information on schedule		X					
Transit/shuttle busses for special events		X	X	X	X		
Coordination of smart hwy/traveler info system w/transit and ride share				X			
Improve efficiency of existing bus routes and system				X		X	
Additional, more accurate real time info on transit locations, efficiency and ridership						X	
Automatic vehicle location for buses						X	
Institutional							
Coordination between agencies	X				X		
Valley-wide uniformity of traffic control	X				X		
More focus on moving people not autos	X	X					
Traffic Management							
Accurate, timely reports to public			X	X	X		
Freeway call boxes					X		
Incident detection and notification to motorists	X	X	X	X	X		
Central clearinghouse for incident detection	X	X		X	X		
More highway advisory radio				X	X		
Quicker incident removal	X		X	X	X		
Real-time in-vehicle display of vehicle information	X		X	X	X	X	
Reduced "rubbernecking"				X	X		
Special event control	X		X		X		
More traffic signals in suburbs and rural areas	X						
Traffic Signals							
Computerized traffic signals	X						
Regional signal coordination	X				X		
Coordination between FMS and city signals	X				X		
Implement MAGIC findings	X						
Regional uniformity of emergency pre-emption	X						
Improve bandwidth of communications infrastructure	X				X		
Arterial management system	X						
Bus pre-emption	X					X	
Traveler Information							
Better highway identification				X			
Better detour signing				X	X		
More information on street operating conditions		X	X	X			
Route/destination information		X	X	X			
Parking information		X		X			
High water crossing warning and detour			X	X	X		
Fleet Management							
May Day alert capability					X		
Other Needs							
More consideration for pedestrians at signals	X						
Regionwide Dial-A-Ride						X	X
Congestion pricing for commercial vehicles	X						
Reduced congestion at airport	X	X	X	X			
Tie Dial-A-Ride into regional bus service						X	X
Needs Indentified in Studies							
Reduce accidents at intersections	X						
Inter-agency coordination	X				X	X	
Improve regional mobility	X			X	X		
A traffic status map of the region	X	X	X	X			
Reduce number of incidents	X						
Provide motorists on arterials with extra traffic info during special events			X				
Reduce congestion on streets and freeways	X						
Arterial network coordination	X						
Reduction in congestion and delay	X				X		
Valleywide uniformity of traffic control	X				X		
Accurate, timely reports to public		X	X	X	X		
Incident detection and notification to motorists	X	X	X	X	X		
Regionwide communications infrastructure	X						
Enhanced incident management at freeway interchanges					X		
Regional sisgnal system database	X						
Alternative communciations technologies for deployment of ITS	X						

Table 1.5
Summary of Technology Areas

Surveillance

- **Traffic surveillance**
  - **Volume**
  - **Speed and travel time**

- **Vehicle**
  - **Classification**
  - **Pollution**
  - **Safety**

- **Weather**

- **Hazardous road conditions and other hazards**
  - **Road repair and obstruction**
  - **HAZMAT**
  - **Flooded road**
  - **Rock Ice**
  - **Ice**
  - **Toxic fumes**

Traveler Interface

- **Out-of-vehicle**
  - **Walking**
  - **Home**
  - **Office**
  - **Public infrastructure**

- **In-vehicle**

Navigation and Guidance

- **Real-time positioning**
  - **Private vehicle**
  - **CVO**
  - **Public transportation**

- **General Guidance**
  - **Position fix service**

In-vehicle Sensors

- **Navigation**
  - **GPS**
  - **Dead reckoning with updates**

- **Driver Safety**
  - **Safety monitoring and alarm**
  - **Impact detection and reporting**
  - **Fire detection and reporting**
  - **Gas leak detection and reporting**
  - **Mayday**

Communications

- **Mobile**
  - **Infrastructure-to-vehicle**
    - **1-way mobile**
    - **2-way mobile**

- **Stationary**
  - **Infrastructure-to-infrastructure**
  - **Infrastructure-to-other-agency**
  - **Intra-TOC**

Control Strategies

- **Signalized**
  - **Standard**
  - **Adaptive**
  - **Preemptive**

- **Restrictive**

Data Processing

- **Traffic prediction**
- **Traffic control**
- **Routing**
- **Database**

Requirements define necessary functions in a system. In many cases, functions have geographic location contraints: by the laws of physics, by architecture which has evolved and is in place, by cost and by the very nature of the function. For instance, vehicle sensors by definition are in the vehicle while field controllers are generally located near the field control point and/or sensing point. Functional requirements can always be mapped into an architecture as well as information flow

between functions. In some cases, logical architecture can be geographically allocated; however, in many cases physical architecture may dictate the geographic locations of the logical functions and provide a functional architecture. When technology is added, a physical architecture is created by the final mapping of logical architecture into physical subsystems; specific signals and interconnects are defined; and specific information processing, display, storage, and retrieval interrelationships are defined. Thus, the physical architecture of the system evolves.

This report presents the logical architectural candidates with trade-off analysis for possible system architectures. The recommended final system architecture is presented along with technology assessments. Technology recommended for deployment is emphasized and justified. Mapping of the technology into a physical architecture, based on selected system architecture, is thus provided.

The ITS National Architecture has provided a general framework of information requirements with modern network technology literally capable of integrating "any communications link" with "any communications link," and with the basic requirements of cost effectiveness dictating use of any usable/supportable, existing infrastructure. A national physical architecture is not a significant issue, what is important is the information flow between logical ITS functions which is supported with cost/effective communications network technology suitable to integrate existing usable infrastructure with new infrastructure. The actual architecture of the region is thus dictated by:

- What logical ITS functions are required
  - Area needs
- Where these functions geographically reside
  - ITS service support area (dictating communications coverage)
- Usable existing infrastructure
  - Functionality to meet needs and supportability
- Policy and Standards (or absence of standards) employed in the region (in this case, Maricopa County, associated jurisdictions, and ADOT)
- Maintenance and operational philosophies and consensus, and
- Supportability of the architecture by jurisdictions.

What has been accomplished in this study is the use of National Architectural functional information flows and associated architectural concepts to define the specific architectural needs of this project with the technology survey providing the best choice technology to employ, thus forming the physical architecture.

2. Define System Architecture in Functional and Logical Attribute Form

2.0 Approach

Functions derived from functional requirements, defined by stakeholders, form a logical architecture for the system. The logical architecture identifies each of the functions required to meet user needs and to implement the associated ITS user services. These user services were identified in Task 3, and documented in the *User Service Plan Technical Memorandum*, along with functional relationships and interfaces. This data flow model is complemented by an integrated control flow model which provides a description of the behavior of the system and identifies the external events and system states which affect the system behavior. It is also illuminating to consider what is NOT included in the logical architecture analysis. Neither functional allocation to physical subsystem (where the functions are performed) nor implementation of the subsystems themselves (how the functions are performed) is specified within the logical architecture. These items are covered within the physical architecture section of the memorandum.

The format and content of the logical architecture section reflect the real-time structured analysis methodology applied in this development. The structured analysis approach was originally set forth by Tom De Marco and later enhanced to include real-time extensions by a host of other authors, notably Hatley and Pirbhai in *Strategies for Real-time System Specification*. In this application of the methodology, data and control flows are integrated within a single set of diagrams rather than partitioned onto separate data flow and control flow diagrams as recommended by Hatley and Pirbhai.

The structured analysis model was generated using Cadre Technologies' *Teamwork/SA* Computer Aided Software Engineering (CASE) tool.

2.1 User Service Plan to Context Diagram

The User Service Plan developed in Task 3 identifies user services with functionalities addressed by the logical architecture. These are:

- Traffic Control,
- Pretrip Traveler Information,
- Route Guidance,
- Driver Information,
- Incident Management,

- Public Transportation Management, and
- Personalized Public Transit.

In addition, Task 3 identified the need to better address incident management with respect to emergency management. Thus, the user service:

- Emergency Notification and Personal Security

was also addressed by the logical architecture.

The first step in developing the logical architecture was to understand the context of the system required to fulfill the functionalities necessitated by these user services. A context diagram was created to provide a definition of the Maricopa County architecture boundary. The single process bubble on the diagram, Figure 2.1-1, represents all the functionality required to support all eight user services listed above. All data and control flows which are generated or consumed by the architecture are shown, along with the external sources and sinks for the conveyed information and control.

Depending upon perspective, many of the elements depicted as "system externals" in the diagram may be considered part of the architecture. For instance, human operators, travelers, and vehicles may all be considered part of the architecture and yet they are presented as system externals on the diagram. The reason for this representation is that while these entities are certainly relevant to Maricopa County transportation, they are not completely encompassed by it. For example, humans perform functions that fall outside of the scope of the user services. The following is a brief description of various externals as identified on the system context diagram.

2.1.1 Humans

Humans who interface with the system can be grouped into two general categories: 1) system users (drivers and travelers), and 2) system operators (traffic operations personnel, transit operators, emergency dispatchers, and construction and maintenance personnel). The data flowing from the various users/operators represent queries and requests for architecture services. The flows to them represent responses and unsolicited notification of system status. Although humans are shown as external to the system, all ITS functionalities have been included within the boundary of the system.

2.1.2 Vehicles

Vehicle interfaces to the system are shown in several contexts to support the specific vehicle by user services. The various types of individual vehicles (emergency, transit, and personal) are included as interfaces to illustrate their unique connectivity to the architecture. Another class of vehicle externals represented on the context diagram is alternate mode vehicle (e.g., ships, rail vehicles, airplanes). This class is not directly controlled by the ITS services. These vehicles are interfaced as multi-modal crossings and intermodal transportation providers.

2.7.3 List of Externals

The following list, **Table 2.1.3-1,** includes all externals represented on the context diagram. Accompanying each external name is a brief description and its relationship with the architecture.

Table 2.1.3-1. Maricopa County ITS Architecture External

External	Description
Construction and Maintenance Personnel	Construction and Maintenance Personnel are defined as those tasked to build and maintain the roadway infrastructure. These include roadway maintenance personnel, roadway construction personnel, or other work crew personnel assigned to highway construction and maintenance. Coordination with construction and maintenance personnel allows the architecture to rapidly correct deficiencies noted through its advanced surveillance capabilities and also improves the quality and accuracy of information available to travelers regarding closures and other roadway construction and maintenance activities.

External	Description
Driver	The operator of a licensed vehicle on the roadway. Included are operators of private, transit, commercial, and emergency vehicles. This user originates driver requests and receives driver information which reflects the interactions potentially useful to all drivers, regardless of classification. information and interactions which are unique to a specific vehicle type (e.g., fleet interactions with transit, commercial, or emergency vehicle drivers) are covered separately.
Emergency Dispatch	A dispatcher managing an emergency fleet (police, fire, ambulance, HAZMAT, etc.) or a higher order emergency manager who provides response coordination during emergencies.
Emergency Vehicles	Police, fire, ambulance, towing, and other special response team vehicles (e.g., HAZMAT clean-up) which respond to emergencies. In the context diagram, the emergency vehicle external is also treated as the source and destination for interactions with the emergency vehicle driver.
Entertainment System	The on-board entertainment system of a private vehicle which must be interfaced and considered in developing advanced driver information systems. This external represents the control interface necessary for integration of driver information and entertainment programming.
Environment	Environment is defined as the operational setting in which the ITS interfaces and operates. This setting consists of weather effects such as snow, rain, fog, pollution, dust, temperature, humidity, solar radiation, and man-made electromagnetic (RF) effects. Environmental conditions must be monitored by the architecture so that travelers may be informed and control strategies can reflect adverse environmental conditions in a timely fashion.
Financial Institution	The financial institution handles all electronic fund transfer requests to enable the transfer of funds from the user of the service to the provider of the service.
Info Service User	Reference to anyone who requires ITS information services. This category includes all travelers (transit users, drivers, and pedestrians) in both pretrip and en-route settings.
Intermodal Transportation Providers	The integrated information services and intermodal operations supported by the architecture will require interface with operators of non-roadway transportation systems (e.g., airplanes, ships, heavy rail). This two-way interface enables coordination for efficient movement of goods across multiple transportation modes and also enables the traveler to efficiently plan itineraries which include segments using modes not directly included in the user services.
Map Update Provider	Third-party developer and provider of map databases used to support the user services.
Media External Sources	Media is defined as the entities from which traffic flow information, incident information, or any other travel-impacting events are collected. These sources may include television/radio broadcasters, traffic reporting services, private citizens, or any other information gathering or using body external to the architecture.
Multimodal Crossings	Multimodal crossings are defined as the specialized roadway lane crossing areas spanning the roadway surface specifically designed for travel modes other than roadway vehicles. These crossings are in the same planar dimension as roadway vehicles. These include light rail, heavy rail, marine ferries (movable bridges), non-motorized vehicles (bi-, tricycles), specialized transit buses, and surface street rail, etc.

External	Description
Other Jurisdictions/ Agencies/ TMCs	Other jurisdictions, agencies, and TMCs are defined as those entities which interface with the architecture, i.e., road use permitters, traffic information providers and users, regulatory agencies, and other jurisdictional authorities (policy authorities). When the architecture impacts multiple jurisdictions, agencies, and TMCs, then these entities are replicated within the architecture.
Other Response Agencies	Agencies and service providers who may be called upon to participate in an emergency response. Agencies include police departments, highway patrol, fire departments, search and rescue, emergency medical services, environmental protection agencies, HAZMAT teams, and towing services. Within the system boundary are all functions required to coordinate across multiple agencies as well as the functions necessary to manage an emergency response within a particular agency. This external is used to model the information flows which will cross jurisdictional boundaries to enable a coordinated multi-agency response to emergencies.
Pedestrian Crossings	Pedestrian crossings are defined as the specialized roadway lane crossing areas spanning the roadway surface specifically designated for pedestrians. The most common crossings are found at surface street intersections. These crossing locations can be equipped with manual or automatic sensors to signal pedestrian right-of-way requests to traffic control systems. The traffic control service support must account for pedestrian right-of-way requests in developing the overall information and control architecture supporting traffic operations.
Position Fix Provider	The "position fix provider" references an external function which generates or recalculates accurate position information. External systems which use GPS, terrestrial trllateration, or driver inputs are potential examples. This external implies that the functionality associated with developing an absolute position is outside the system and will not be directly modeled by the logical or physical architecture representations of the system.
Roadway	Roadway is defined as the surface on which vehicles travel from an origin to a destination. Roadways can vary in type, such as surface streets, arterials, highways, expressways, tollways, freeways, or any other vehicle travel surface. Roadways can also depict travel networks, such as surface street networks, arterial networks, or freeway networks. The condition of the roadway must be monitored by the architecture to enable corrective action and information dissemination regarding roadway conditions which may adversely affect travel.
Special Event Sponsors	Special event sponsors are defined as external information entities which have cognizance over events which may impact travel on roadways or other modal means. Examples of special event sponsors include sporting events, conventions, motorcades/parades, and public/political events. These sponsors interface with the architecture to provide event information such as date, time, estimated duration, location, and any other information pertinent to traffic movement in the surrounding area.
Traffic	Traffic is defined as the body of vehicles which travel on surface streets, arterials, highways, expressways, tollways, freeways, or any other vehicle travel surface. Traffic depicts the body for which traffic flow surveillance information is collected (average occupancy, average speed, total volume, average delay, etc.), and traffic control indicators are applied (intersection signals, stop signs, ramp meters, lane control barriers, variable speed limit indicators, etc.).

External	Description
Traffic Operations Personnel	Traffic Operations Personnel are defined as the human entity which directly interfaces with vehicle traffic operations. These personnel are interactive with traffic control systems, traffic surveillance systems, incident management systems, work zone management systems, and travel demand management systems. They provide operator data and command inputs to direct the systems' operations.
Transit Driver	Transit driver represents random route drivers, flexible fixed route drivers and fixed route drivers. The fixed route drivers require minimal information such as run times and passenger loading. The flex fixed and random route drivers require additional information such as dynamically changing routes.
Transit Operator	Transit operator is responsible for monitoring, controlling, and planning the transit fleet route schedules and the transit fleet maintenance schedules.
Transit User	Transit user represents those in the act of embarking or debarking transit vehicles for the purpose of determining passenger loading and fares.
Transit Vehicle	Monitoring of transit vehicle mechanical condition and mileage provides the major inputs for transit vehicle maintenance scheduling.
Travel Service Provider	Provider of any service oriented towards the traveler. Example services which would be included are gas, food, lodging, vehicle repair, points of interest, and recreation areas. Interface with the service provider is necessary so that accurate, up-to-date service information can be provided to the traveler and so that electronic reservation capabilities can be included in the user services.
Vehicle Dynamics	The physical movement and orientation of the vehicle which may be monitored and measured to support some forms of vehicle determination.
Weather Service	An external source of current and forecast weather conditions. This externally derived weather data is integrated with the other information collected and disseminated by the architecture to support travel planning.

2.2 Functional Decomposition

The level-0 diagram, **Figure 2.2-1,** presents the first order decomposition of the ITS architecture for Maricopa County into four major functions. This decomposition reflects a clustering of the eight user services into these four groupings. Within each user service grouping, the individual user services have relatively high connectivity as compared to the connectivity between the groupings themselves. The data and control flows presented on the level-0 diagram reflect the high level interfaces between the groupings. As a small departure from the standard structured analysis techniques, the external entities depicted on the context diagram are repeated on the level-0 diagram. This approach more clearly documents the relationships between the user service groupings and the external world.

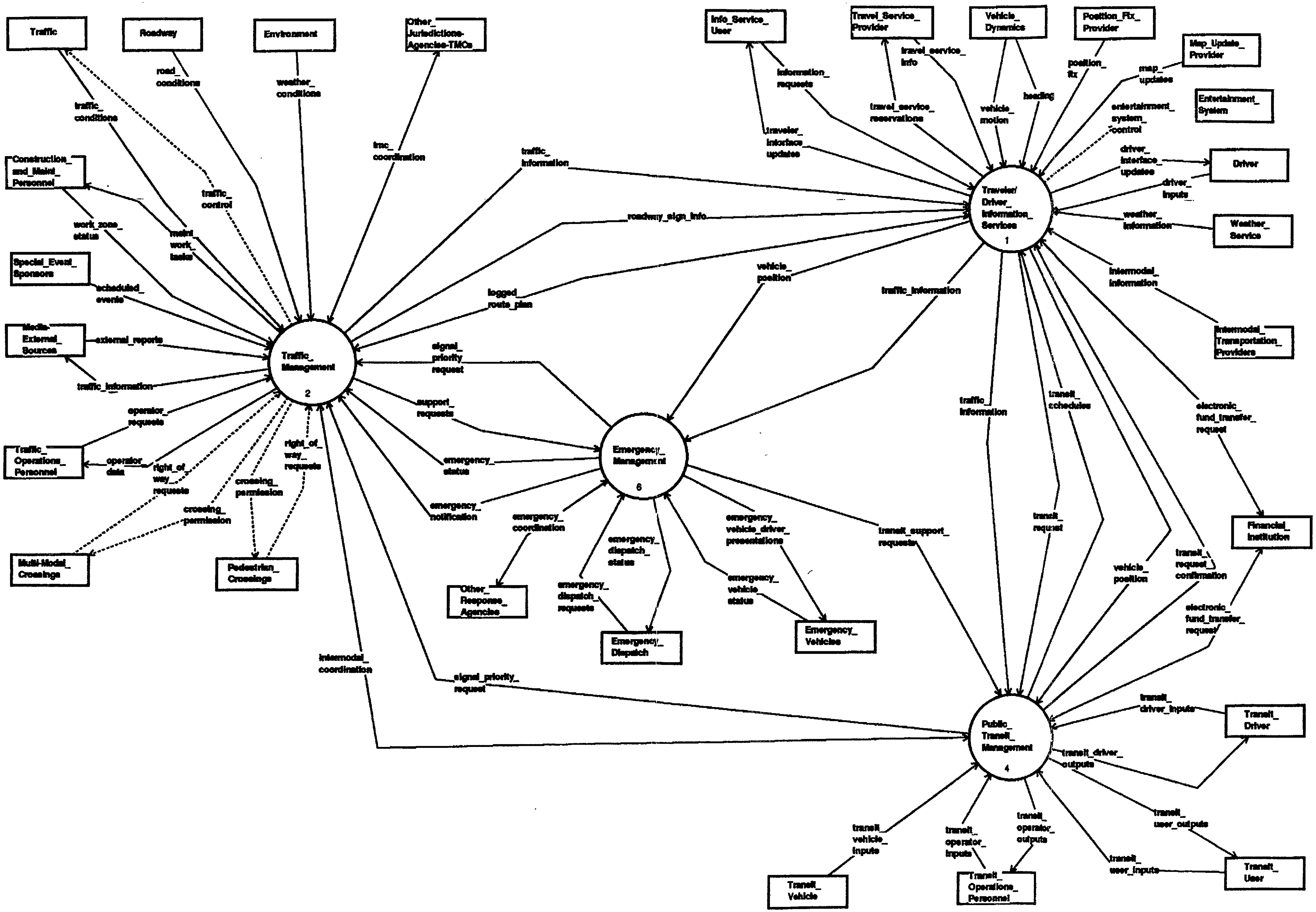


Figure 2.2-1 User Service Plan

In this study, the level-0 data flow diagram for the Maricopa County ITS Logical Architecture is decomposed into four level-l data flow diagrams. The following paragraphs highlight the fimctionalities implied by each of the four groupings and list the associated user services.

2.2.1 Traveler/Driver Information Services

The **Traveler/Driver Information Services** process includes all functionalities required to interact with the end users of the ITS services, principally vehicle drivers, travelers, and transit users. The user services encapsulated in this process are:

- Pretrip Planning
- En-route Driver Information
- Route Guidance

As illustrated in **Figure 2.2.1-1,** the three user services addressed in Traveler/Driver Information Services can be performed by the following four functions:

- Position Determination
- Trip Planning/Route Selection
- Driver Presentation and Command Receipt
- Traveler Information Services

Position Determination is the process that provides the activities to determine position location. It accepts position fix, heading, and vehicle motion to calculate the vehicle position for the Trip Planning/Route Selection and Driver Presentation and Command Receipt processes. This process also provides the vehicle position to the Public Transit Management process.

Trip Planning/Route Selection is the process that provides the activities to facilitate trip planning and route selection. It accepts traffic information, transit schedules, route criteria and vehicle position to develop trip itineraries, including identification of the route plan that conforms to route criteria. It also provides for Driver Presentation and Command Receipt and Traveler Information Services.

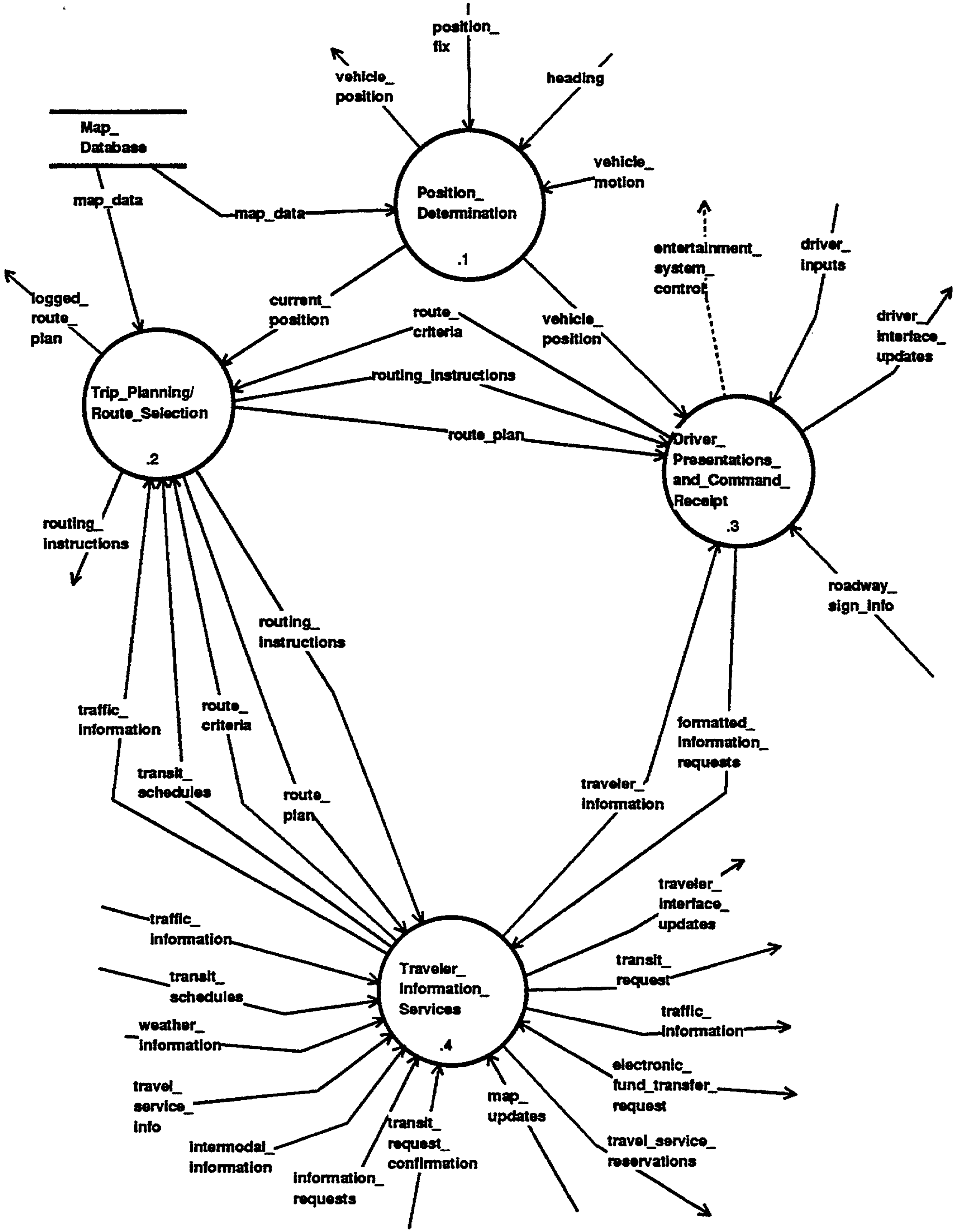


Figure 2.2.1-1 Traveler/Driver Information Services

Driver Presentation and Command Receipt is the process and activities that provide system-related information to drivers and travelers and accepts commands and inputs from system users. It accepts traveler information, roadway sign information, route plan, and driver inputs to assimilate, correlate and present to system users (drivers, travelers, operators, etc.). This process also provides an interactive functional interface with system users. Once user inputs are received, this process determines the nature of the inputs and issues entertainment system control, formatted information requests, or defines route criteria to other appropriate processes. This process also issues information (roadway sign information, transaction status, vehicle position, and route plan) to system users through driver interface updates.

Traveler Information Services is the process and activities that allow management and dissemination of travel-related information to system users and processing entities. It accepts traffic information, transit schedules, weather information, travel service information, intermodal information, transaction status, and map updates for assimilation, correlation, storage, and dissemination. This process also accepts information requests to initiate servicing for the request. In response to the accepted requests, this process provides traffic information, transit schedules, route criteria, and traveler information, and also issues requests to other processing entities. In addition, this process provides travel-related information to system users through traveler interface updates.

2.2.2 Traffic Management

The Traffic Management process includes all functionality required for management of the traffic network. Included are traffic surveillance, traffic control, incident management, and all associated capabilities. The user services included in this process are:

- Incident Management, and
- Traffic Control.

As illustrated in **Figure 2.2.2-1,** the two user services addressed in Traffic Management can be performed by the following five functions:

- Monitor Traffic Flow and Roadway Status,
- Manage Incidents,
- Control Area Wide Traffic Flow,
- Manage Traffic Demand, and
- Manage Work Zones.

Monitor Traffic Flow and Roadway Status is the process that determines the measured traffic network status of the instrumented system. It measures weather conditions, road conditions, traffic conditions, and collects and correlates regional traffic flow from other TMCs, external reports, and traffic control preemptions for assimilation into traffic network status information available to the Traffic Operations Personnel, and the processes for Manage Incidents and Control Area Wide Traffic Flow. It also facilitates storage of information in a Traffic Flow Archive.

Manage Incidents is the process and activities to manage traffic incidents on the highway network. It collects traffic network status, external reports, incident network status, and scheduled events information for analysis and identification of potential or predicted incidents by comparison with historical traffic flow. In addition, it facilitates incident management through coordination with the Emergency Management and Control Area-wide Traffic Control processes. This process also interacts with Traffic Operations Personnel for presentation of incident data and acceptance of incident commands.

Control Area-wide Traffic Control is the process and activities to manage the control implements of the traffic system. It uses the traffic network status, incident coordination data, work zone coordination data, and traffic flow demand information to provide traffic control, intermodal coordination, and coordination between TMCs. In addition, it accepts signal priority requests, right-of-way requests, and traffic control commands to provide traffic control, crossing permission, traffic control preemptions, maintenance requests, and general Traffic Operations Personnel system commands. This process also configures traffic controls based upon predictive aspects applied to incidents and work zones. Furthermore, this process provides user-presentable roadway sign information, advisories, and traffic reports to the Traveler/Driver Information Services process.

Manage Traffic Demand is the process and activities to manage traffic demand on the roadway network. It provides the prediction management for incident and work zone management by accepting traffic flow control requests, demand management commands, traffic conditions, historical traffic conditions, traffic network status, scheduled closures, and potential traffic controls, and provides demand management strategies through assessment of transit schedules, logged route plans, traffic network status, and roadway information.

Manage Work Zones is the process and activities to manage work zones occurring on the traffic network. It provides work zone coordination data and work zone advisories by analyzing the work and construction zone effects on traffic flow. This analysis is conducted through the monitoring and coordination of work zone activities from work zone status, predicted traffic flow, and work zone management commands. It also processes maintenance requests issued by the Control Area Wide Traffic Control process resulting in maintenance work tasks issued to Construction and Maintenance Personnel and provides scheduled closures information to the Manage Traffic Demand and Control Area Wide Traffic Control processes.

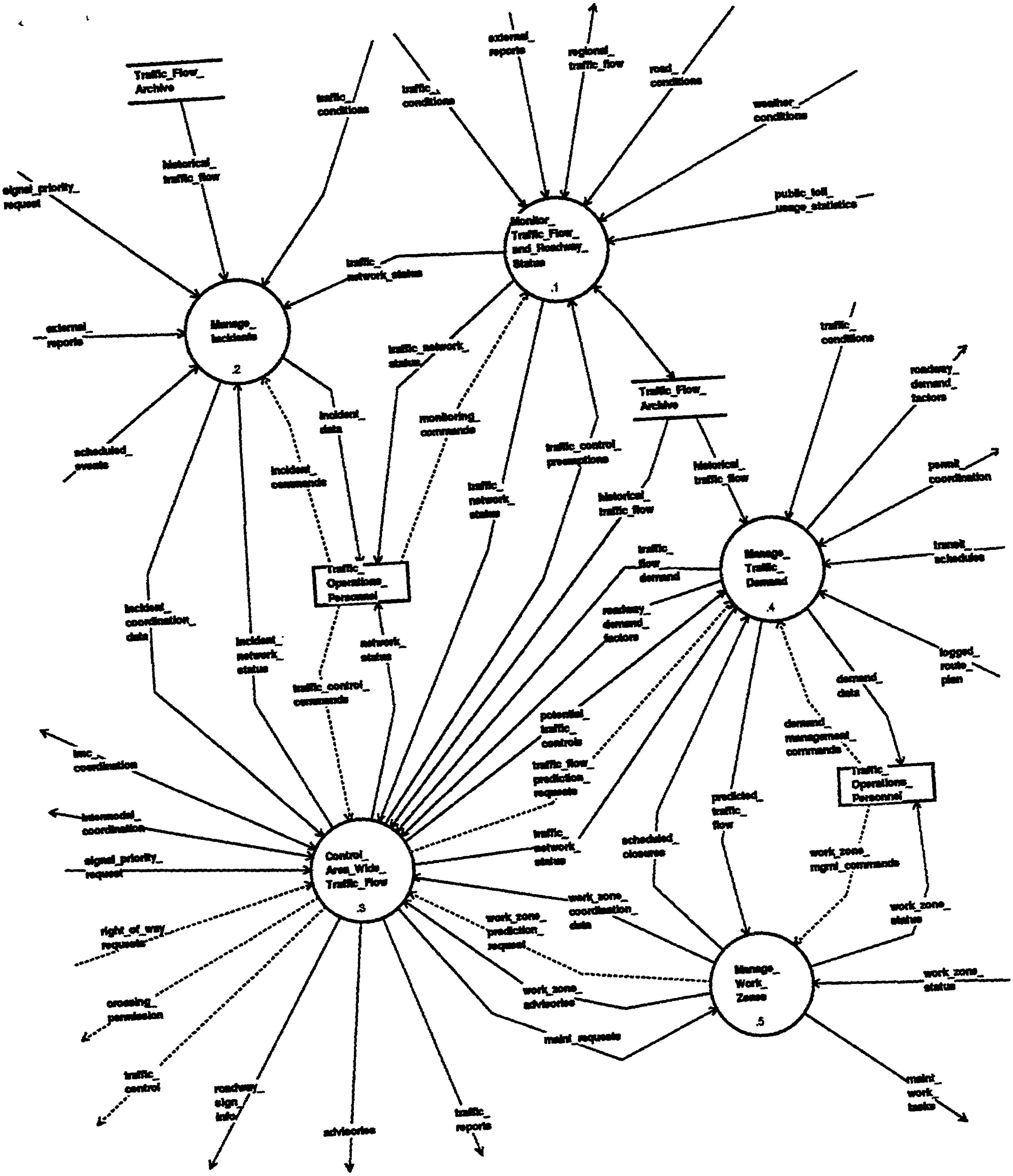


Figure 2.2.2-1 Traffic Management

2.2.3 Public Transportation Management

The Public Transportation Management process includes the functions necessary to manage both fixed and flexibly-routed transit vehicles. Transit information is provided to the transit driver via the Traveler/Driver Information process. Interactions with this process also accept requests for transit service and convey current transit information to prospective transit users. Interactions with Traffic Management are modeled to support priority routing and reflect overall coordination between transit and traffic management services. User services included are:

- Public Transportation Management, and
- Personalized Public Transit.

As illustrated in **Figure 2.2.3-1,** the two user services addressed in Public Transportation Management can be performed by the following three functions:

- Monitor and Control Transit Schedules,
- Monitor and Control Transit Maintenance, and
- Monitor and Control Transit Fare Collection.

Monitor and Control Transit Schedules is the process that provides transit scheduling activities. These activities include performing fixed-route planning and scheduling, performing demand response route planning and scheduling, monitoring transit schedule adherence, generating driver route assignments, disseminating schedules to travelers and traffic management centers, updating transit schedule information, reporting transit schedule information to transit operations personnel and transit drivers, updating traffic information, updating vehicle position information, reporting traffic information to transit operations personnel and transit drivers, and reporting vehicle position information to transit operations personnel and transit drivers.

Monitor and Control Transit Maintenance is the process that provides transit maintenance activities. These activities include monitoring the transit vehicle condition during operation, generating transit vehicle maintenance schedules, generating technician work assignments, monitoring and verifying maintenance activities, reporting transit vehicle maintenance information, and updating transit vehicle maintenance information.

Monitor and Control Transit Fare Collection is the process that provides transit fare collection activities. These activities include updating transit fare information, reporting passenger loading and fare information, generating passenger fare and loading statistics, generating transaction data necessary to complete a financial transaction between the transit user and transit providers, detecting and counting embarking/debarking passengers, and selectively controlling passenger embarkation based upon the success or failure of the fare collection transaction.

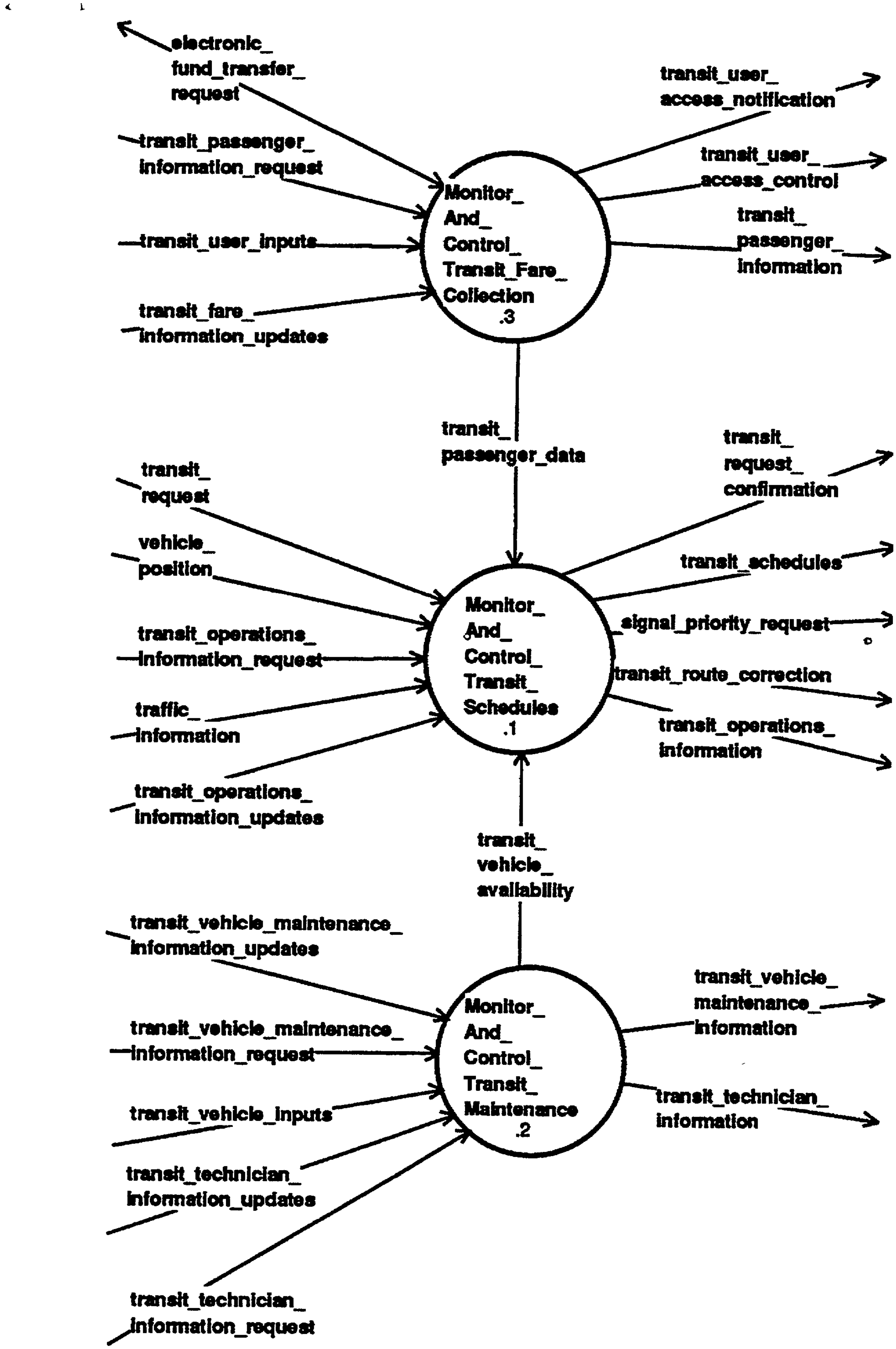


Figure 2.2.3-1 Public Transit Management

2.2.4 Emergency Management

The Emergency Management process provides interface with emergency services personnel. The user service allocated to this process is:

- Emergency Notification and Personal Security.

As illustrated in **Figure 2.2.4-1,** the two user services addressed in Emergency Management can be performed by the following functions:

- Coordinate Emergency Response, and
- Manage Emergency Vehicles.

Coordinate Emergency Response is the process that provides notification requiring response from emergency services, appropriately coordinated with response information provided to the proper agencies, traffic management, and those who had requested assistance. In addition, coordination with emergency vehicles is provided.

Manage Emergency Vehicles is the process whereby emergency support is provided through the acceptance of requests for support and status of the support. The management of emergency vehicles is supported through acceptance of dispatcher inputs, status back to dispatchers, presentation of information to the emergency vehicle driver, and location and status of the emergency vehicles. In addition, traffic coordination is supported through reception of traffic data and request for priorities.

2.3 Major Data Flows and Databases

This subsection is actually a precursor to the physical architecture section. A major part of the development of the physical architecture is the allocation of functions to physical entities; however, this process is greatly influenced by data requirements. These data flows and databases drive the identification of interconnections and functional allocations. A brief description and discussion of some of the major data flows and databases, and their impacts on the physical architecture development, is presented.

The process of decomposing the context diagram into the level-l data flow diagrams provides much illumination with respect to required functional requirements. In addition, data and control flows and data storage are identified. The major data flows and databases that influence development of the physical architecture are:

- TMC to TMC Coordination,

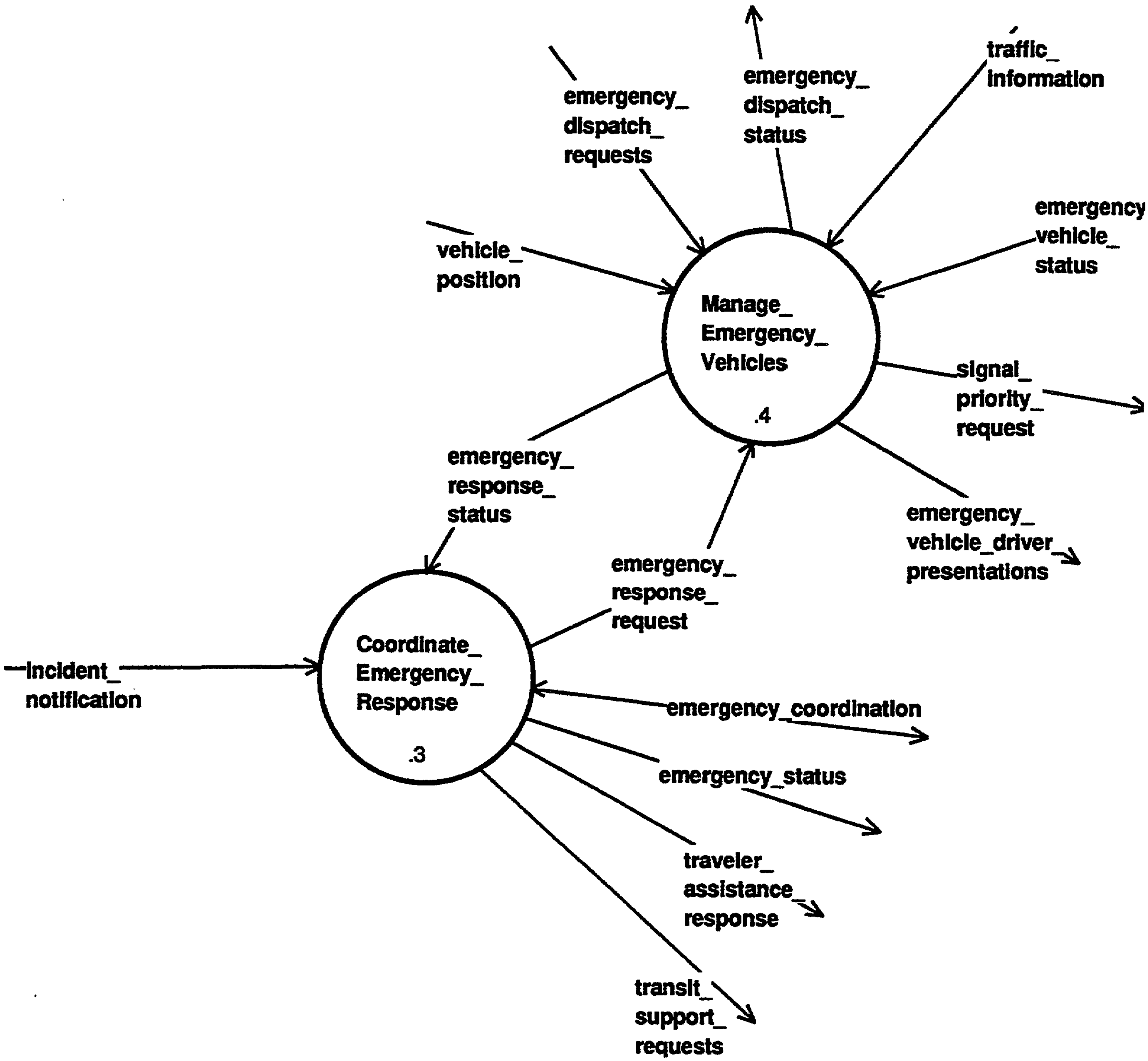


Figure 2.2.4-1 Emergency Management

- Traveler Information, and
- Driver, Traveler, and Transit User Inputs and Outputs

A major data flow in the logical architecture is TMC Coordination from the Traffic Management process to the external entity Other Jurisdictions/Agencies/TMCs. TMC Coordination is currently under examination by the National ITS Architecture program for standardization recommendation. Due to potential regional diversification, it is reasonable to believe that inter-regional transmission of this data flow might require a "national" standard. In regions such as the I-95 and Southern California corridors, traffic information requirements encompass multiple regions with potentially cascading effects transgressing multiple states. A standardization of this information might greatly influence interconnection requirements between the regions and the TMCs. Expected data components of this data flow include TMC identification code, regional traffic information flow data, advisories, regional surface street status, regional freeway status, and permits coordination.

In Maricopa County, this TMC Coordination is more intra-regional and thus, driven by local requirements, i.e., the region is somewhat self-contained with the interconnection to Pima County potentially the only major inter-regional connection consideration. The problem is not necessarily simplified by this containment as the region is large and diverse. The interconnection might be driven by the largest requirements such as those for video images. This concern about potential interconnection bottlenecks versus overkill is addressed in the alternative architectures discussion that is part of the physical architecture section of this report.

Both Traffic Information and Traveler Information are provided definitions in the National ITS Architecture program. To distinguish between the two, Traffic Information data flow is described as congestion, pricing, and incident information. Traveler Information data flow is described as traveler routing, yellow pages, etc. As seen in the level-O diagram presented herein, Traffic Information is transformed into Traveler Information by the Traveler/Driver Information Services process. The major considerations of this process are the information requirements of the users in Maricopa County. During the development of the physical architecture, considerations generated from the focus groups and regional meetings conducted during this study and from other surveys such as those performed during the MAGIC study are analyzed. Issues addressed include whether a TMC is sufficient to provide Traveler Information, and localized versus regional information needs.

Major databases include:

- Traffic Flow, Control, and Information,
- Traffic Incident and Demand,
- Roadway Conditions,
- Yellow Pages,

- Maps,
- Transit Operations,
- Emergency Response Plans, and
- Special Events Plans.

As with the major data flows, the major databases are examined as to how they influence the physical architecture development. Traffic-related databases will most probably remain the responsibility of traffic management centers, yet map and yellow pages data might be privatized to information providers. Questions about map standardization and whether it will impact the architecture will be examined. The relationship between traffic and transit operations might be separate or become redundant backup systems, such as is the case in Houston. The impact of regional databases, especially with respect to regional plans such as emergency response and special events, will impact the physical architecture development.

3. Define Candidate Physical Architectures

3.0 Approach

The physical architecture identifies the physical subsystems, architecture flows between subsystems, and architecture interconnects between subsystems that will implement the processes and support the data flows of the logical architecture.

The process of developing the physical architecture begins with the identification of Maricopa County's physical transportation entities. This naming and categorization of physical entities started with the identification of existing systems. The existing and additionally identified physical subsystems were then grouped using the template developed in the ITS National Architecture program. (During the ITS National Architecture program, physical architecture development analyses resulted in four classes of ITS subsystems. These four groupings are used to develop the physical architecture: centers, roadway elements, vehicles, and traveler locations.

Once the physical subsystems have been identified, physical partitioning is performed to allocate the logical architecture functions to physical subsystems. The result is a physical architecture. Within a physical architecture, each of the subsystems has been allocated functionalities and associated input and output data requirements. Implicit in these data requirements are interconnection requirements and an overlying communication architecture. Physical partitioning is by no means unique and several partitions may result in several physical architecture candidates.

The development of candidate physical architectures is based upon a set of simple design axioms formulated during the ITS National Architecture program. These axioms are relevant to local deployment. In fact, this premise itself is embedded as one of the axioms. As these axioms are used to develop the architectures, they provide criteria against which the candidate architectures are evaluated. In addition, initial technology assessments are performed as part of the development of candidate architectures. (This is discussed in more detail later in this section.) The final product of the process is a recommended physical architecture.

3.1 Physical Subsystems

As part of the development of the ITS National Architecture, a rigorous analysis of user services was performed. One byproduct of this analysis is the ***Mission Definition*** document provided to FHWA as an ITS National Architecture program deliverable. On the basis of functional requirements derived from this analysis along with examination of the existing and required transportation system entities, four distinct groupings of these entities have evolved. These groupings of centers, roadway, vehicles, and the traveler locations are used as the basic foundation of any ITS physical architecture.

3.7.7 Subsystem Groupings

The center subsystems provide management, administration, and support functions for the transportation system. Each center subsystem communicates with other centers to enable coordination between modes and across jurisdictions within a region. The center subsystems also communicate with roadside and vehicle subsystems to gather information and provide information and control, coordinated by the center subsystems.

The roadside subsystems provide the direct interface to the roadway network, vehicles traveling on the roadway network, and travelers in transit. Each of the roadway subsystems includes functions that require distribution to the roadside to support direct surveillance, information provision, and control plan execution. All roadside subsystems interface to one or more of the center subsystems that govern overall operation of the roadside subsystems. The roadside subsystems also generally include direct user interfaces or support for interfaces to drivers and transit users. Roadside subsystems may include short range communications interfaces to the vehicular subsystems to support on-board operations and interoperability with ITS operations centers.

The vehicular subsystems associated with ITS are vehicle-based and include general driver information, vehicle route guidance, safety and hazard warning, and communications linkage with the fixed, ITS infrastructure. The vehicular subsystems communicate with the roadside subsystems and center subsystems to provide information to the driver and to provide dispatching and management centers with location and status information for fleet management. Vehicular subsystems may communicate with traffic operation centers for Mayday and to provide probe “vehicle of opportunity” information to support corridor congestion assessment and travel time predictions.

The traveler subsystems include the equipment that is typically owned and operated by the traveler. Though this equipment is often general purpose in nature and used for a variety of tasks, including gaining access to traveler information within the scope of the ITS architecture. Special equipment, uniquely tailored to ITS requirements and providing travelers with ergonomically designed interfaces for traveler information are available. These include the new class of in-vehicle traveler information subsystems and special hand-held radio digital data terminals utilizing FM subband communications for traveler information. These subsystems interface to the information provider (one of the center subsystems, most commonly the Information Service Provider Subsystem) to access the traveler information. A range of service options and levels of equipment sophistication are considered and supported. Specific general purpose equipment included in this subsystem class includes personal computers, cellular telephones, personal digital assistants (PDAs), televisions, and any other communications-capable consumer products that can be used to supply information to the traveler.

There is growing deployment of ergonomically designed, private (for profit) and publicly owned kiosk terminals to support travelers in public locations, such as convention centers, transportation terminals (airports, train stations, bus terminals, etc.), hotels, amusement parks and park-and-ride centers.

3. 1.2 Maricopa County Existing/Planned Sysfems

Task 1 reviewed the existing and planned ITS systems including projects and studies. The results of this task are documented in ***Technical Memorandum I.*** **Table 3.1.2-1** provides a brief summary of this review. As evidenced by the items listed in this table, Maricopa County presents diverse needs and various distributed systems.

Table 3.1.2-l. Maricopa County Existing/Planned Systems

Project/Study	System
FMS	ADOT FMS first phase completed with TOC; planned to ultimately serve more than 200 miles
Phoenix Transit	Bus Card Plus Program including debit and VISA cards for electronic payment; AVL with GPS; on-board automatic voice announcement
MAGIC	Regional signal system coordination; integration of regional system with ADOT FMS; Development of a regional ATIS
Highway Performance Monitoring System	MAG database system with GIS
Rhodes-ITMS	University of Arizona algorithm development for coordinated freeway/surface interchange signals and ramp meters
City of Scottsdale	Leased telephone alternatives evaluation; vehicle detection and CCTV evaluation; motorist information subsystem evaluation; city traffic control center planned; regional TOC interface evaluation
City of Glendale	ATIS under design
City of Phoenix	New city-wide computerized traffic signal system under design; fiber-optics in downtown area; cooperative public/private project with fiber optics providers under evaluation for downtown
City of Tempe	Special event control system funding requested

The MAGIC regional signal system coordination analysis conducted in 1994 by JHK and Associates identified the existing signal systems. **Table 3.1.2-2** provides a summary of their findings.

Table 3.1.2-2. Maricopa County Existing Signal Systems

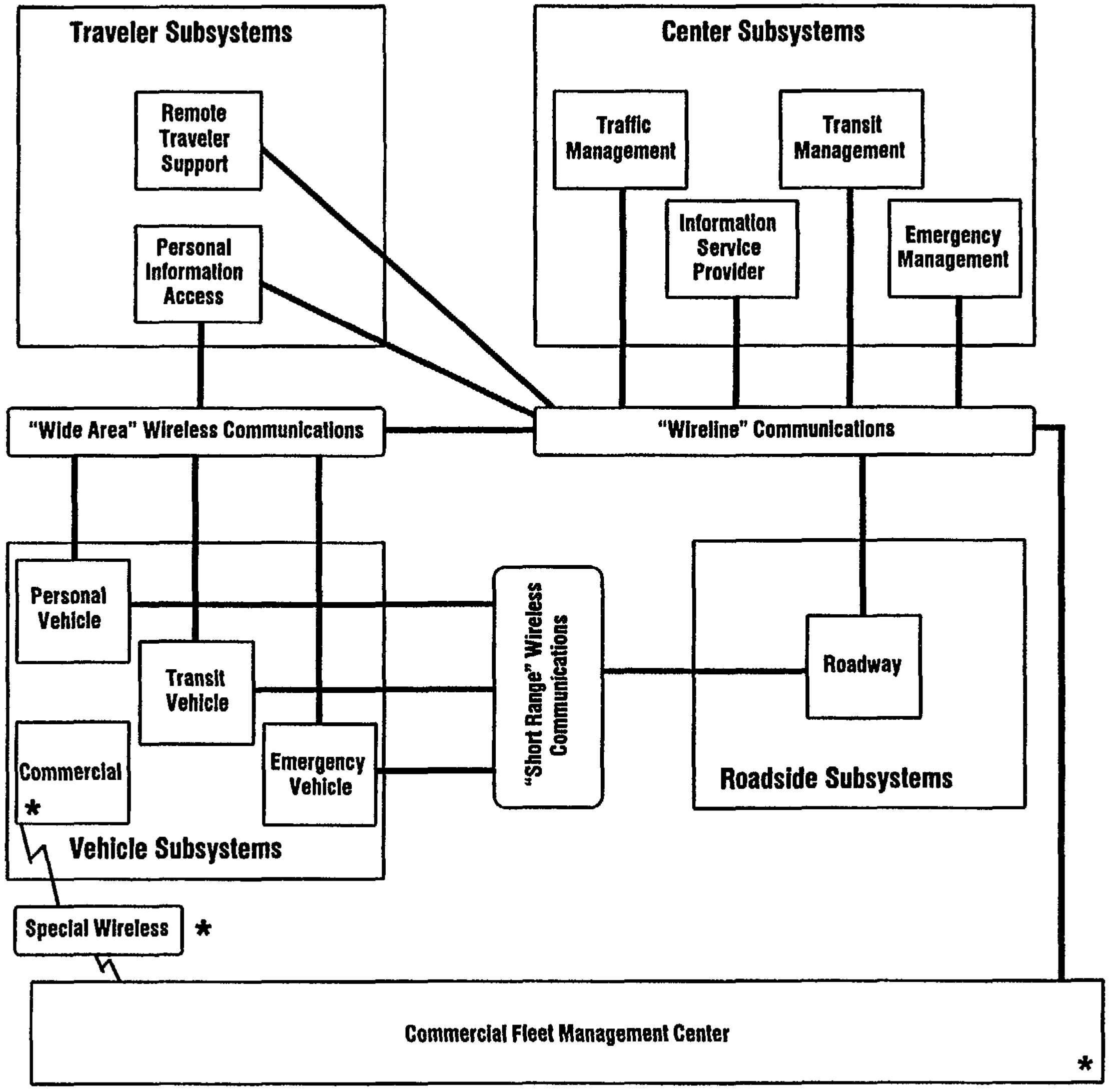
City	Control System	Controllers	Communications	Comments
Tempe	**Computran-ATCS**	**NEMA TS-1 (planning NEMA TS-2)**	**Leased lines (considering wireless)**	**Some emergency Vehicle pre-emption**
Mesa	**SONEX ZDC**	**NEMA**	**Leased lines, some twisted-pair**	**Maintains signals for Gilbert, some emergency vehicle pre-emption**
Glendale	**Time-based with some closed-loop**	**NEMA**	**Closed-loop uses twisted-pair and dial-up**	**Some emergency vehicle pre-emption; currently being updated**
Scottsdale	**JHK Series 2000**	**Type 170 and some time-based**	**Leased lines**	
Peoria	**Isolated**	**NEMA**	**None**	**Some emergency pre-emption**
Phoenix	**Computran-CTCS with some time-based**	**NEMA and fixed-time**	**Leased lines F/O for downtown TWP at 4 downtown intersections**	**Some coordination with Tempe and Glendale on border intersections**
Chandler	**Eagle-Marc closed-loop with some time-based**	**NEMA**	**Twisted-pair (planned leased-line)**	**Nearly all intersections with emergency pre-emption**
ADOT	**Isolated with two closed-loop, FMS**	**NEMA**	**Closed loop use leased line and twisted-pair, fiber optics**	
Paradise Valley	**Isolated intersections**	**NEMA**	**None**	**Scottsdale maintains signals, only one of 12 signals has emergency pre-emption**
Maricopa County	**Isolated , some time-based, and closed loop**	**NEMA**	**Dial-up and hard-wired**	
Gilbert	**Isolated with one time-based**	**NEMA**	**None**	

3.1.3 Architecture Interconnection

The ITS National Architecture program focuses on the interconnections between the four groupings and between the subsystems within groupings. Thus, an important step in maintaining compatibility with ITS National Architecture is achieved by developing the Maricopa County physical architecture from this set of groupings. Figure 3.1.3-1 illustrates this interconnection diagram between the four groupings.

As shown in **Figure 3.1.3-1,** embedded in the four groupings are the physical subsystems identified for Maricopa County. These subsystems have been identified on the basis of existing systems and analysis of the logical architecture functional requirements. Four center subsystem functional types are identified: traffic management, transit management, emergency management, and information service provider. One roadside subsystem is identified: roadway. Three vehicle subsystems are identified: personal vehicle, transit vehicle, commercial and emergency vehicle. (Note that commercial vehicle is added since CVO was separated from the National Architecture study and recently defined by Johns Hopkins, Applied Physics Lab under contract to FHWA.) Two traveler subsystems are identified: remote traveler support and personal information access.

Three types of communications are also shown in **Figure 3.1.3-1.** The term “wireline” communications is used to describe fixed communications networks including the public-switched telephone network, public integrated services digital network, Internet, jurisdictional owned networks (including LAN, MAN, WAN), and wireless packet data network. Typically, these networks consist of twisted-pair, coaxial, microwave, satellite, and fiber-optics. The term “wide area” communications describes a cell-based network involving mobile users. These networks include cellular telephone, data network, and specialized mobile radio. The term "short-range" communications is used for transmissions of generally less than 200 feet which involve mobile users and include Radio Frequency (RF) toll tags, IR communications links, optical links, and micro-cellular (RF) links.



NOTE: Revised per Johns Hopkins University's National CVO Architecture

Figure 3.1.3-1 Maricopa County Physical Architecture Interconnection Diagram

3.1.4 Subsystem Definition

The Maricopa County identified subsystems are defined in **Table 3.1.4-1.**

Table 3.1.4-1. Maricopa County Subsystems.

Subsystem	Definition
Emergency Management	The Emergency Management Subsystem operates in various emergency centers supporting public safety including police and fire stations, search and rescue special detachments, and HAZMAT response teams. This subsystem interfaces with other Emergency Management Subsystems to support coordinated emergency response involving multiple agencies. The subsystem creates, stores, and uses emergency response plans to facilitate coordinated response. The subsystem tracks and manages emergency vehicle fleets using automated vehicle location technology and two way communications with the vehicle fleet. Real-time traffic information received from the other center subsystems is used to further aide the emergency dispatcher in selecting the emergency vehicle(s) and routes that will provide the most timely response. Interface with the Traffic Management Subsystem allows strategic coordination in tailoring traffic control to support enroute emergency vehicles. Interface with the Transit Management Subsystem allows coordinated use of transit vehicles to facilitate response to major emergencies.
Information Service Provider	This subsystem provides the capabilities to collect, process, store, and disseminate traveler information to subscribers and the public at large. Information provided includes basic advisories, real-time traffic condition and transit schedule information, yellow pages information, ride matching information, and parking information. The subsystem also provides the capability to provide specific directions to travelers by receiving origin and destination requests from travelers, generating route plans, and returning the calculated plans to the users. Reservation services are also provided in advanced implementations. The information is provided to the traveler through the Personal Information Access Subsystem, Remote Traveler Support Subsystem, and various Vehicle Subsystems using available communications links. Both basic one-way (broadcast) and two-way (personalized) information provision is supported. The subsystem provides the capability for an informational infrastructure to connect providers and consumers, and to gather the market information needed to assist in planning service improvements and in operations maintenance.
Traffic Management	The Traffic Management Subsystem operates within a traffic management center or other fixed location. This subsystem communicates with the Roadway Subsystem to monitor and manage traffic flow. Incidents are detected and verified and incident information is provided to the Emergency Management Subsystem, travelers (through Roadway Subsystem Highway Advisory Radio and Variable Message Signs), and to third party providers. The subsystem monitors and manages maintenance work and disseminates maintenance work schedules and road closures. The subsystem communicates with other Traffic Management Subsystems to coordinate traffic information and control strategies in neighboring jurisdictions.

Subsystem	Definition
Transit Management	The Transit Management Subsystem provides the capability for determining accurate ridership levels and implementing corresponding fare structures. The fare system supports travelers using a fare medium applicable for all surface transportation services. The subsystem also provides for optimized vehicle and driver assignments, and vehicle routing for fixed and flexibly-routed transit services. Interface with the Traffic Management Subsystem will be integrated with traffic signal prioritization for transit schedule adjustments and transit vehicle maintenance management will be automated with schedule tracking. The Transit Management Subsystem also provides the capability for automated planning and scheduling of public transit operations. The subsystem will also provide the capability to furnish travelers with real-time travel information, continuously updated schedules, schedule adherence information, transfer options, and transit routes and fares.
Commercial Vehicle Fleet Management Center	The specific privately-owned commercial vehicle dispatching and management center responsible for a specific commercial vehicle. Size of the commercial vehicle operations generally defines automated services including automated vehicle location (AVL) and real-time monitoring of vehicle status, including company leased communications between the Fleet Management Center and vehicles using cellular, satellite, and other mobile communications services.
Roadway	This subsystem includes the equipment distributed on and along the roadway that monitors and controls traffic. Equipment includes highway advisory radios, variable message signs, cellular call boxes, CCTV cameras and video image processing systems for incident detection and verification, vehicle loop detectors, signals, and freeway ramp metering systems. This subsystem also provides the capability for emissions and environmental condition monitoring. HOV lane management and reversible lane management functions are also available.
Personal Vehicle	This subsystem resides in an automobile and provides the sensory, processing, storage, and communication functions necessary to support efficient, safe, and convenient travel by personal automobile. Information services provide the driver with current travel conditions and the availability of services along the route and at the destination. Both one-way and two-way communications options support a spectrum of information services from low-cost broadcast services to advanced, pay-for-use personalized information services. Route guidance capabilities assist in formulation of an optimal route and step by step guidance along the travel route. Advanced sensors, processors, enhanced driver interfaces, and actuators complement the driver information services so that, in addition to making informed mode and route selections, the driver travels these routes in a safer and more consistent manner. Pm-crash safety systems are deployed and emergency notification messages are issued when unavoidable collisions do occur.
Emergency Vehicle	This subsystem resides in an emergency vehicle and provides the sensory, processing, storage, and communication functions necessary to support safe and efficient emergency response. The Emergency Vehicle Subsystem includes two-way communications to support coordinated response to emergencies in accordance with an associated Emergency Management Subsystem. Emergency vehicles are equipped with automated vehicle location capability for monitoring by vehicle tracking and fleet management functions in the Emergency Management Subsystem. Using these capabilities, the appropriate emergency vehicle for response to each emergency is determined. Route guidance capabilities within the vehicle enable safe and efficient routing to the emergency. In addition, the emergency vehicle may be equipped to support signal preemption through communications with the roadside subsystem.

Subsystem	Definition
Transit Vehicle	This subsystem resides in a transit vehicle and provides the sensory, processing, storage, and communication functions necessary to support safe and efficient movement of passengers. The Transit Vehicle Subsystem collects accurate ridership levels and supports electronic fare collection. An optional traffic signal prioritization function communicates with the roadside subsystem to improve on-schedule performance. Automated vehicle location functions enhance the information available to the Transit Management Subsystem enabling more efficient operations. On-board sensors support transit vehicle maintenance. The Transit Vehicle Subsystem also furnishes travelers with real-time travel information, continuously updated schedules, transfer options, routes, and fares.
Commercial Vehicle	This subsystem resides in the commercial vehicle and provides sensory processing, storage, and communications capability to support automated vehicle clearance, safety status assessment and reporting, automatic vehicle locator, vehicle performance monitoring (maintenance), and other functions important to commercial vehicle management.
Personal Information Access	This subsystem provides the capability for travelers to receive formatted traffic advisories from their homes, place of work, major trip generation sites, personal portable devices, and over multiple types of electronic media. These capabilities will also provide basic routing information and allow users to select transportation modes that allow them to avoid congestion, or more advanced capabilities to allow users to specify transportation parameters unique to their individual needs and receive travel information. This subsystem will provide capabilities to receive route planning from the infrastructure at fixed locations such as in the home, the place of work, and at mobile locations such as from personal portable devices and in the vehicle, or perform the route planning process at a mobile information access location. This subsystem will also provide the capability to initiate a distress signal and cancel a prior issued manual request for help.
Remote Traveler support	This subsystem provides access to traveler information at transit stations, transit stops, other fixed sites along travel routes, and at major trip generation locations such as special event centers, hotels, office complexes, amusement parks, and theaters. Traveler information access points include kiosks and informational displays supporting varied levels of interaction and information access. At transit stops, simple displays providing schedule information and imminent arrival signals can be provided. This basic information may be extended to include multimodal information including traffic conditions and transit schedules along with yellow pages information to support mode and route selection at major trip generation sites. Personalized route planning and route guidance information can also be provided based on criteria supplied by the traveler. In addition to traveler information provision, this subsystem also supports public safety monitoring using CCTV cameras or other surveillance equipment and emergency notification within these public areas. Fare card maintenance, and other features that enhance traveler convenience, may also be provided at the discretion of the deploying agency.

Table 3.1.4-2 presents the subsystems identified for Maricopa County by group.

Table 3.1.4-2. Maricopa County Group/Subsystem

Group	Subsystem	Acronym
Center	Emergency Management	EMS
	Information Service Provider	ISPS
	Traffic Management	TMS
	Transit Management	TNMS
Roadside	Roadway	RWS
Vehicle	Personal Vehicle	PVS
	Emergency Vehicle	EVS
	Transit Vehicle	TVS
	Commercial Vehicle	CV
Traveler Location	Personal Information Access	PIAS
	Remote Traveler Support	RTSS

While Commercial Fleet Management Centers are associated with Maricopa County, these are private facilities. What is important to this project is commercial vehicle-to-infrastructure communications.

3.2 Physical Partitioning

Physical partitioning is the process in which functional requirements identified in the logical architecture development are allocated to physical subsystems. The physical partitioning process for Maricopa County is based upon examination of the level 1 architecture data flow diagrams. Listed in Table 3.2-1 are the functional requirement number, its name, and the set of possible subsystems to which it may be allocated. (Note: the numbering of the functional requirements is not necessarily sequential due to database management compatibility with the ITS National Architecture database.)

Table 3.2-1. Maricopa County Functional Requirements Allocation

Number	Functional Requirement	Subsystem
1.1	Position Determination	PVS, EVS, TVS, PIAS, RTSS
1.2	Trip Planning/Route Selection	EMS, ISPS, TMS, TRMS, PVS, EVS, TVS, PIAS, RTSS
1.3	Driver Presentations and Command Receipt	PVS, EVS, TVS,
1.4	Traveler Information Services	ISPS, TMS, TRMS
2.1	Monitor Traffic Flow and Roadway Status	TMS, RWS
2.2	Manage Incidents	TMS, CV, RWS
2.3	Control Area-wide Traffic Flow	TMS, RWS
2.4	Manage Traffic Demand	TMS
2.5	Manage Work Zones	TMS
4.1	Monitor and Control Transit Schedules	TRMS, TVS
4.2	Monitor and Control Transit Maintenance	TRMS, TVS
4.3	Monitor and Control Transit Fare Collection	TRMS, TVS
6.3	Coordinate Emergency Response	EMS, RWS
6.4	Manage Emergency Vehicles	EMS, EVS

Each possible combination of allocations defines a potential physical architecture. On the basis of these combinations, candidate architectures are selected.

3.3 Candidate Architectures

3.3.1 Considerations

In developing candidate architectures, there are many considerations that bridge Maricopa County transportation, communication and socio-economic concerns. The relationship of the socio-economic, transportation, and communication elements can be represented as shown in **Figure 3.3.1-1.** Each element includes a distinct subset of people, capabilities, and constraints associated with individual ITS user services. These elements together provide the required user services and satisfy the ITS goals and objectives. The foundation of the concept is an understanding of the bottom layer, the socioeconomic element.

The socioeconomic element highlights the institutional issues related to ITS which must be addressed by the architecture. The socioeconomic element reflects the jurisdictional boundaries and organizational boundaries within jurisdictions, and includes private companies and public/private ventures. It is in this element that funding is acquired for user services that are implemented. This element is reflected by examination of the diverse signal systems depicting individual jurisdictional considerations. **Figure 3.3.1-2** presents a pictorial representation of the various centers involved.

Analyses performed in earlier tasks of this project and previous Maricopa County studies provide a foundation that the physical architecture development must build upon. Please refer *to Technical Memorandum I, Technical Memorandum* 2, and the MAGIC report for more details. The following is a summary of findings reported in those documents:

- Maricopa County requires diverse data collection and processing and real-time database capabilities.
- Interjurisdictional coordination and cooperation will be required.
- There is agreement that information sharing is needed, but control of traffic systems is parochial.
- Early public/private partnerships are required here as with almost any other region.
- Maricopa County's public transit systems need increased standardization of mapping and graphic applications.
- Different transit payment and fare box equipment exists; this creates a need to standardize regional electronic fee collection.
- Some transit radio systems differ and no data links have been established.
- No information exchange between transit service providers currently exists.
- Local traffic management agencies need real-time information in the form of freeway traffic conditions, incident clearance operations, and FMS operational status.

- ADOT FMS needs real-time information in the form of arterial traffic conditions, and arterial control system operational status.
- Regional database needs include access to arterial and freeway regional information, information on timing plans and schedules, CMS message library, current or planned arterial and freeway construction information, and traffic volumes.
- Regional database should be updated weekly or as needed, and should be accessible via dial-up modem (optimally, both data and video real-time accessible), and location and maintenance responsibility should be identified.
- Traveler information should be regional in nature for "benefit of travelers."
- Initial traveler information efforts should be focused on regional communications network and standardization of data formats and protocols.
- Concern exists about the collection of unneeded data.
- Central ATIS regional center is needed.
- Public/private partnerships need to be established. Where the public should focus on data collection/processing and information dissemination, private sector involvement should be only in dissemination of processed traveler information.

3.3.2 Architecture Alternatives

Five ITS system level architecture alternatives are presented plus a representation of the existing architecture.

The existing architecture consists of local traffic agencies managing their own field controllers with some exceptions. As previously mentioned, Mesa maintains Gilbert's controllers and Scottsdale maintains those in Paradise Valley. Some intejurisdictional coordination exists, e.g., between Scottsdale, Tempe, and Mesa. Coordination is based upon agreements as no computer-to-computer communications exist between the centers. No formal concept of an ATIS exists. Commercial television and radio stations provide traveler advisory information supported by Sky Watch and other private sources of traveler information. Cellular service companies also support speed-dial/no-cost traffic status and "Mayday" as an incentive for service use. Transit services provide travelers with scheduled service information but it is not based on real-time status. For travelers, there is no single point of contact for traffic and transit status information. While ADOT Freeway Management Center supports ATIS through use of variable message signs, Highway Advisory Radio and Direct Traveler Interface using Autovoice and other automatic request/response technologies are scheduled for later phases of implementation. Transit systems are not electronically sharing data; however, Phoenix Transit has implemented its own electronic fare collection. Thus, the architectural representation for the existing systems is a loosely connected, dial-up public telephone network for voice information exchange, as shown in **Figure 3.3.2-l.**

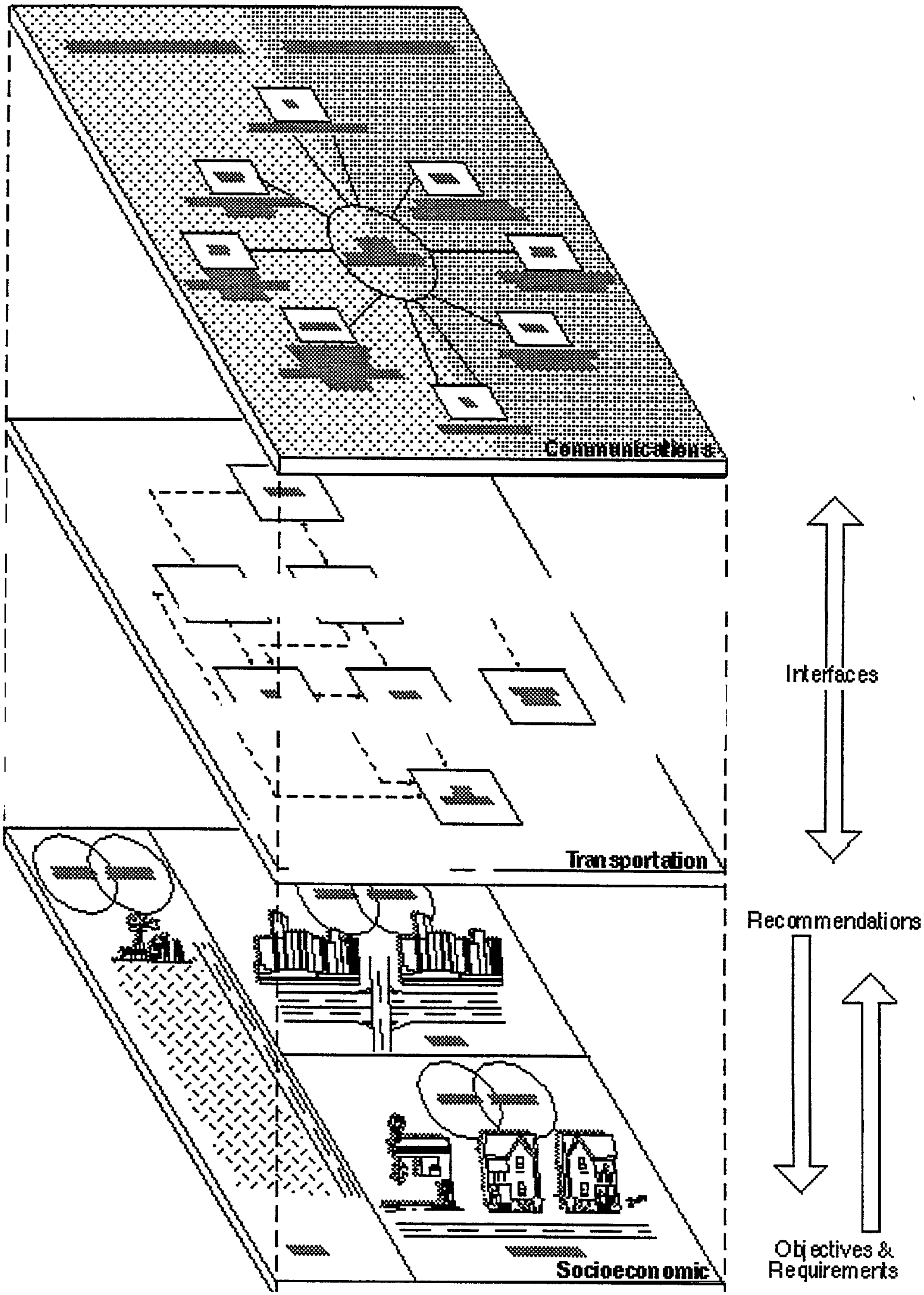


Figure 3.3.1-1 Multi-layered ITS Architectural Concept

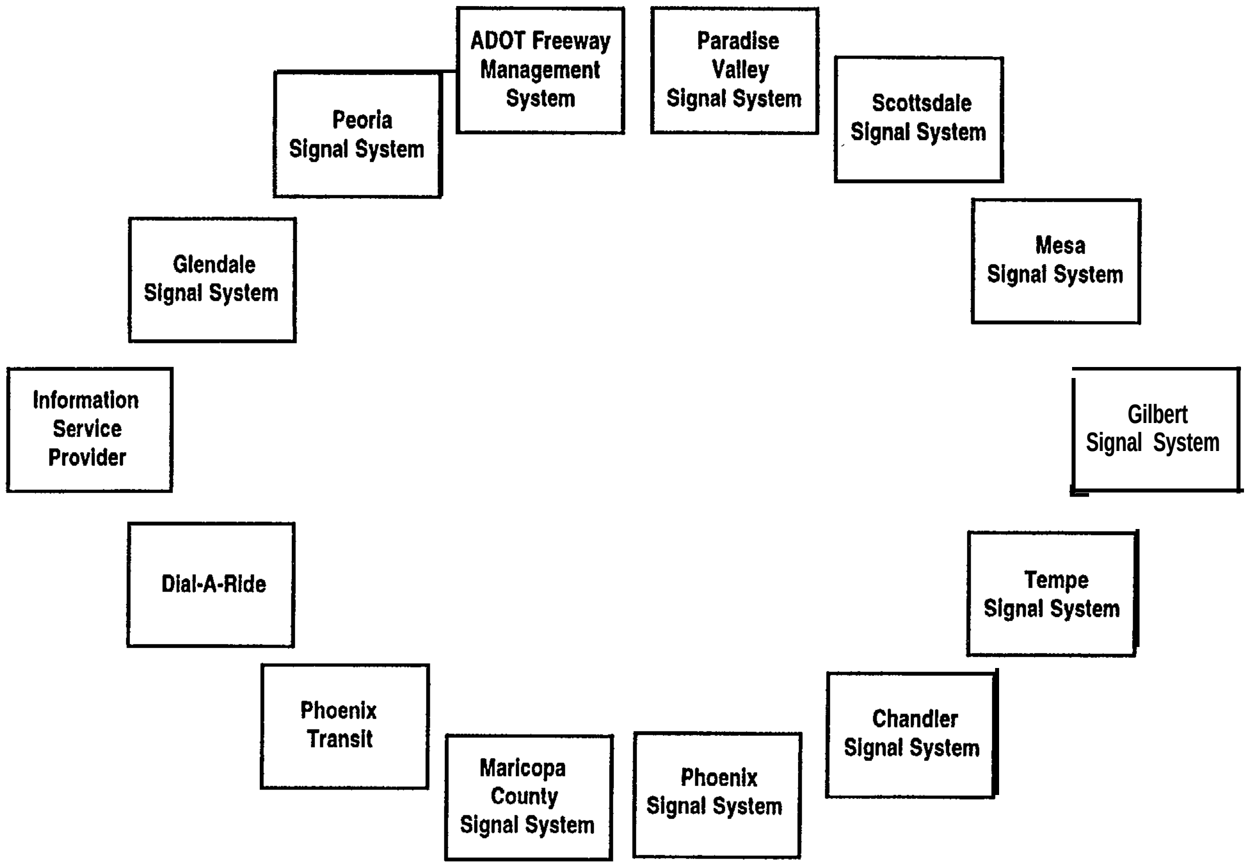


Figure 3.3.1-2 Maricopa County Center Subsystems

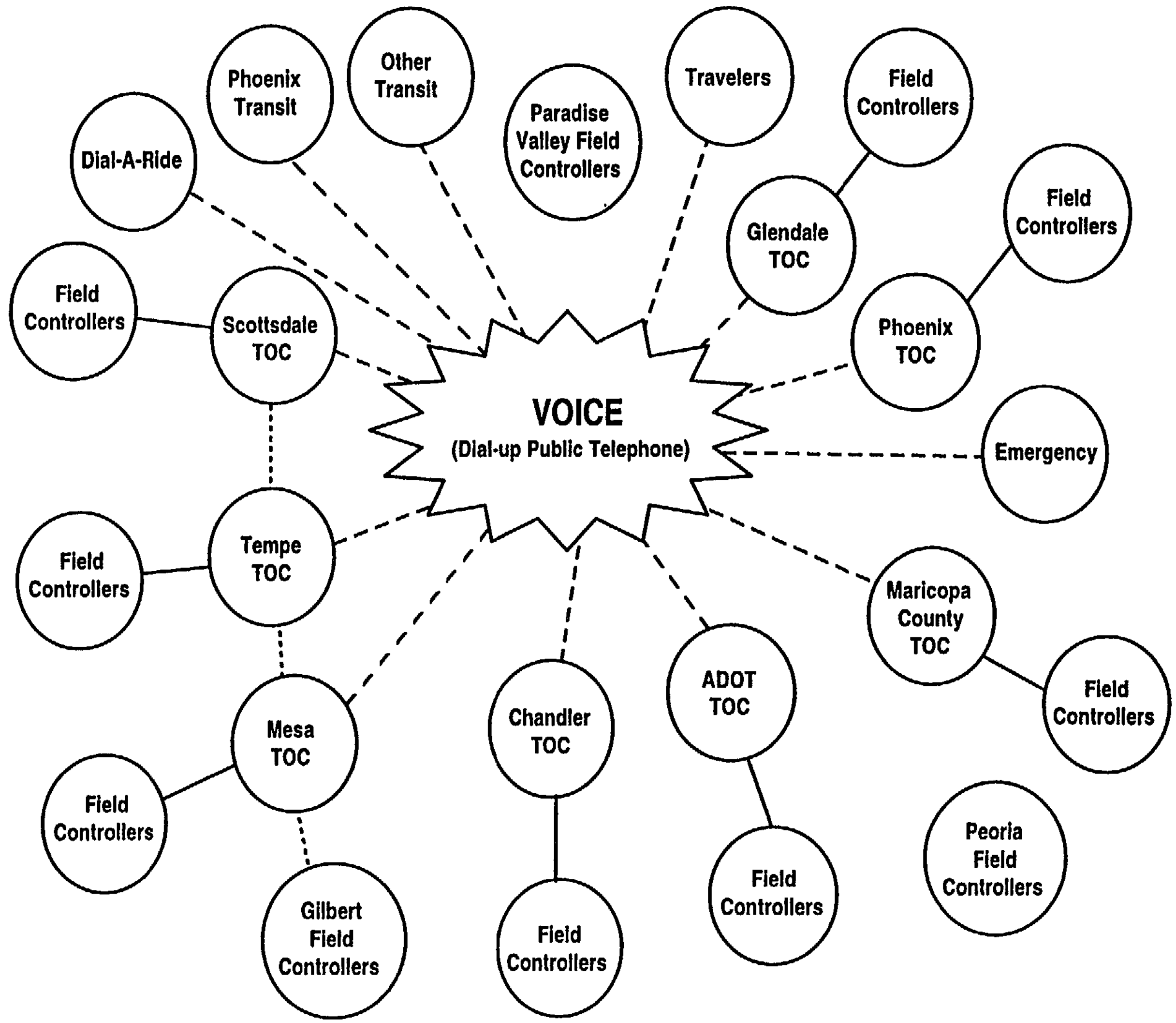


Figure 3.3.2-1 Existing Maricopa County Architecture

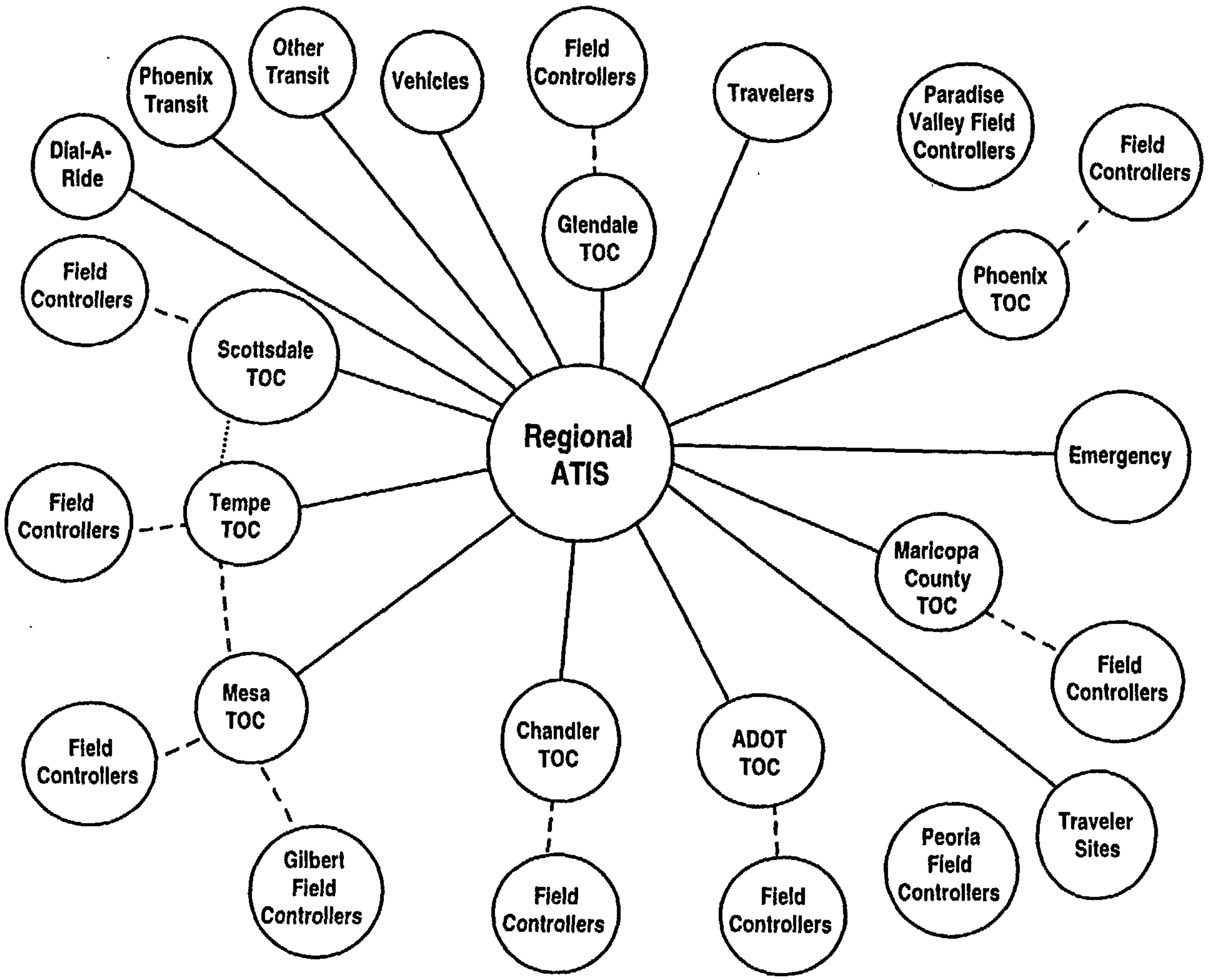


Figure 3.3.2-3 Centralized ATIS with Distributed Control Maricopa County Architecture

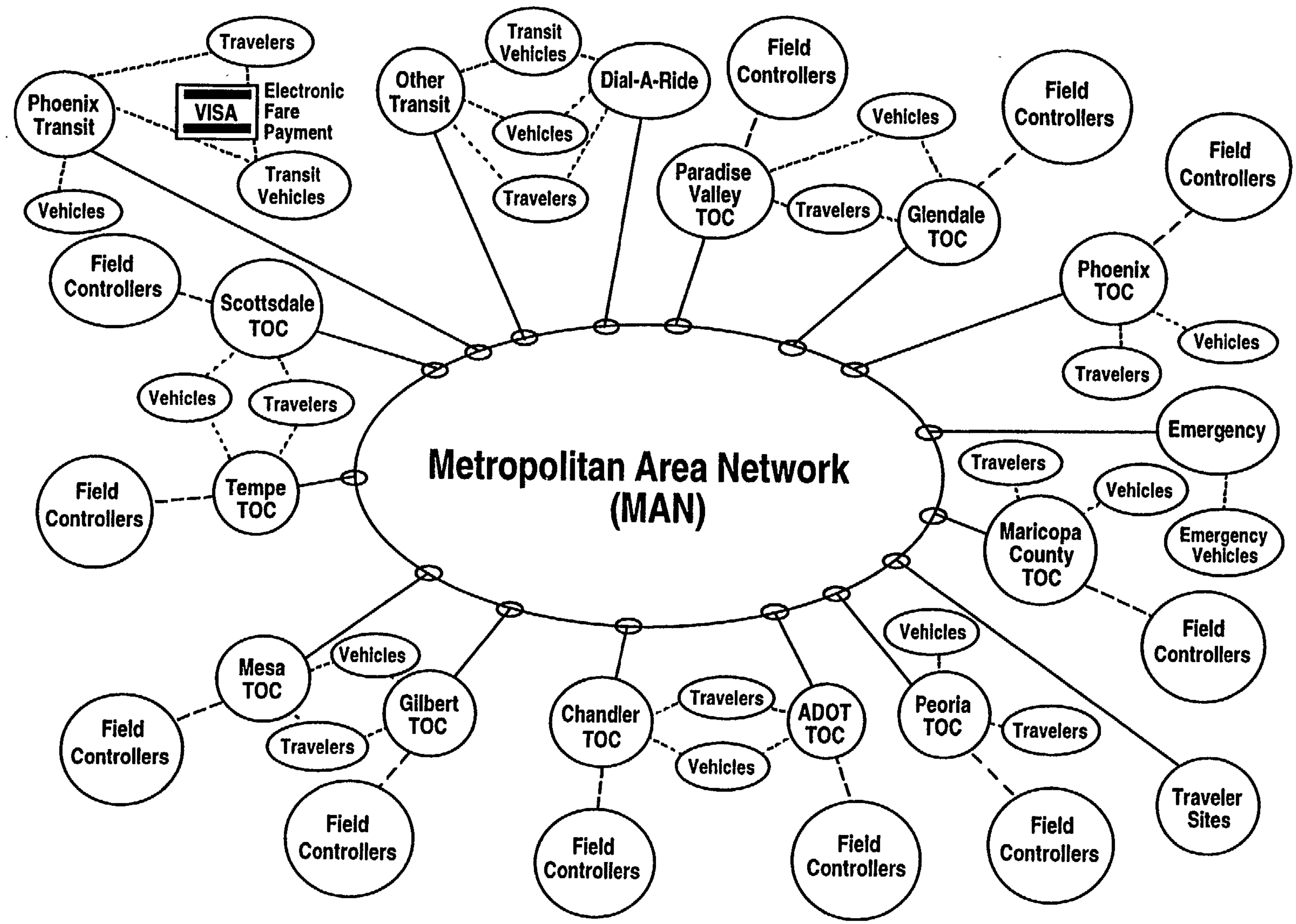


Figure 3.3.2-4 Peer to Peer with Distributed ATIS Maricopa County Architecture

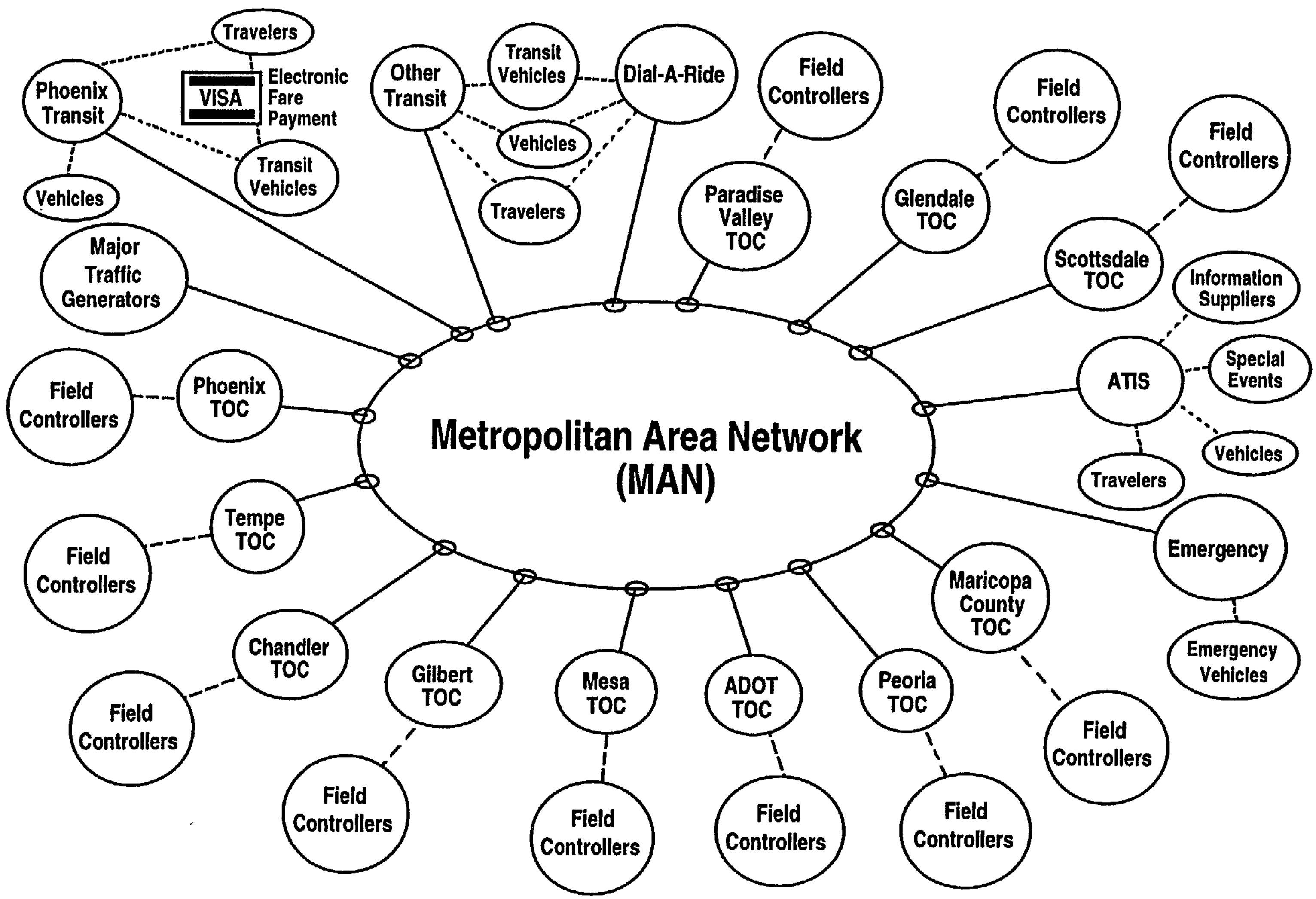


Figure 3.3.2-5 Peer to Peer with Centralized ATIS Control Maricopa County Architecture

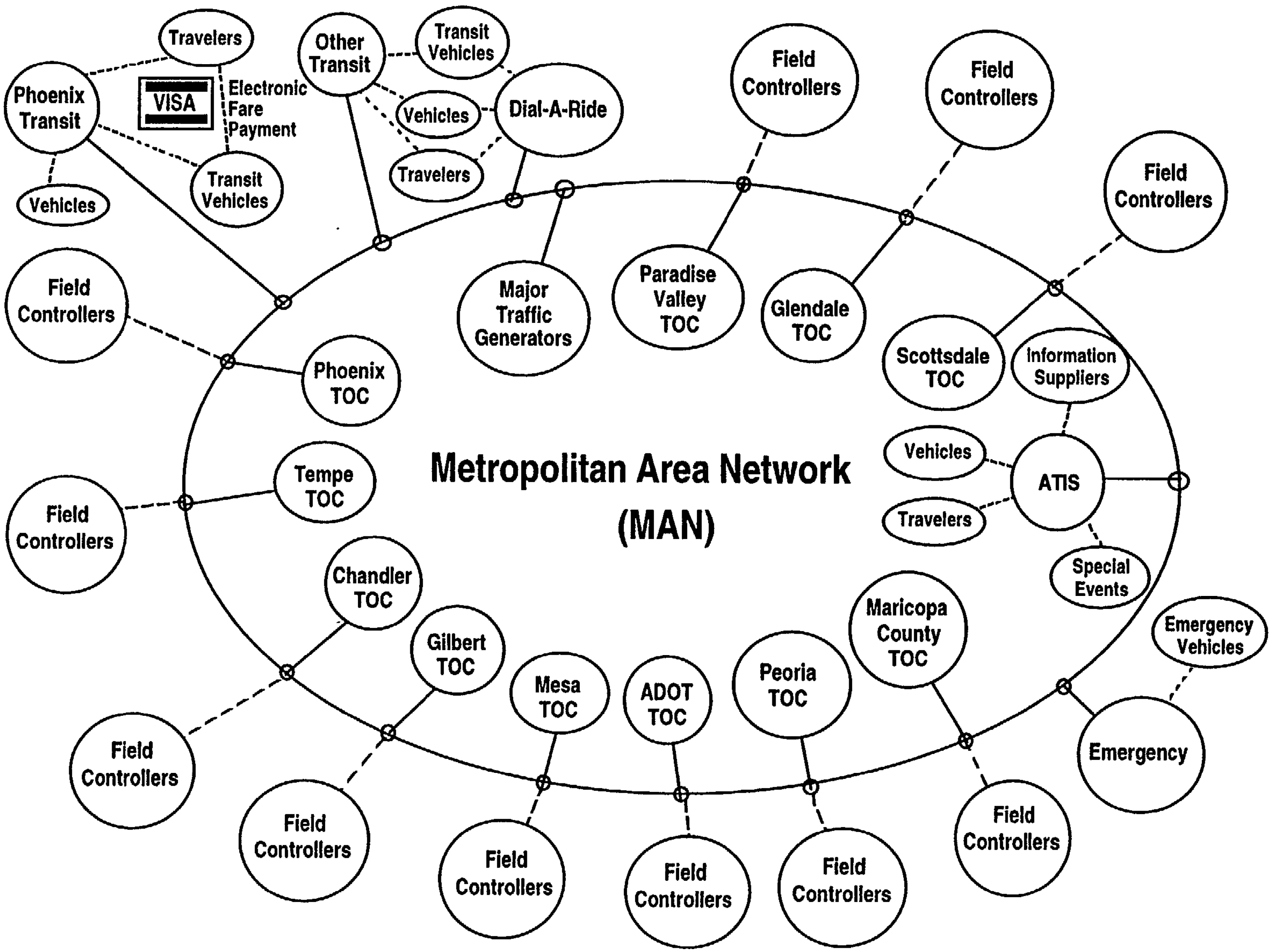


Figure 3.3.2-6 Peer to Peer with Permissive Control and Centralized ATIS Maricopa County Architecture

4. Trade-off of Physical Architectures and Architecture Recommendation

4.0 Architecture Development Axioms

As mentioned in section 3 of this technical memorandum, development of candidate physical architectures does not rest solely upon considerations and judgment. A basic set of axioms has been created specific to the development of an ITS architecture. The Maricopa County ITS architecture alternatives were developed with these axioms in mind. They are:

- Low entry cost,
- Provide choices in price/performance for travelers to receive user services,
- Provide travelers with privacy,
- Accommodate increasing levels of system integration,
- Assure equity,
- Detailed open standardization to maximize interoperability and reduce market entry risk,
- Leverage the existing and emerging infrastructures,
- Facilitate profitability for private industry to speed early deployment,
- Architecture that is open and not biased toward any particular products,
- Encourage public/private infrastructure cooperation,
- Enhance traveler safety, and
- Provide locally determined management capabilities.

4.1 Recommended Architecture

An analysis of the candidate architectures was performed. A summary of this analysis is presented in **Table 4.1-1** where, comments on the pros and cons of each alternative architecture, are listed.

Table 4.1-1. Alternative Architectures Pros/Cons

Alternative	Pros	Cons
Fully Centralized	. Single standard communication channel to/from central facility . Efficiency an cost of staffing . Single standard interface to support . Consistent user interfaces across region	. Autonomy sacrificed . Local TOCs become obsolete . Susceptible to failure . Consensus building most difficult
Centralized ATIS with distributed control	. Local signal control retained by individual agencies . Consistent ATIS user interfaces across region with regional information . Information dissemination via common, standard channels and interfaces . Makes use to existing infrastructure	. Central ATIS facility to operate and maintain . Inherently a publicly funded ATIS . Consensus building difficult due to ATIS coordination versus management issue
Peer-to-peer with distributed ATIS	. No additional facilities to operate or maintain . Full ATMS autonomy maintained . Peer-to-peer communication can be hybrid . Inherently fault tolerant	. Regional traveler information difficult to gather . Duplicate data processing and display equipment . Added complexity . Additional manpower supporting distributed operations
Peer-to-peer with centralized ATIS	. Full ATMS autonomy maintained . Consistent ATIS user interfaces across region . Information dissemination via common standard channels and interfaces	. Duplicate data processing and display equipment . Added complexity . Additional manpower supporting distributed operations . Central ATIS facility to operate and maintain
Peer-to-peer with permissive control and centralized ATIS	. Full ATMS autonomy maintained . Control functions inherently fault tolerant . Most conducive to regional emergencies . Conducive to jurisdictional, operational and maintenance preferences . Flexibility to expand and add areas/jurisdictions/ transit facilities . Consistent ATIS user interfaces across region . Information dissemination via common standard channels and interfaces	. Duplicate data processing and display equipment . Added complexity . Additional manpower supporting distributed operations . Central ATIS facility to operate and maintain

On the basis of these analyses, the alternative architectures were presented to the Maricopa County ITS Strategic Plan steering committee on August 10, 1995. The peer-to-peer with permissive control and centralized architecture was recommended to the steering committee. The decision was made to select this architecture and continue performing technology assessment to support this architecture.

4.2 Architecture Evaluation Criteria

While axioms provide focus for the development of an architecture, a formal set of criteria is needed to evaluate the architecture, especially with respect to its deployment. For the Maricopa County ITS Maricopa County ITS architecture development, evaluation criteria from the Phase I National ITS Architecture development program are used. (While these criteria are used to evaluate the architecture, they do not provide measures of benefit. The performance measures are provided under separate cover in *Technical Memorandum 4.)* Table 4.2-1 lists these evaluation criteria.

Table 4.2-1. Maricopa County ITS Architecture Evaluation Criteria

Evaluation Criteria	Description
Technical/Performance	
Support of ITS Services	**Implementation of the User Service within the architecture**
System Flexibility and Expandability	**. Support for geographic growth and for a variety of technologies as they evolve** **. Potential implementations of data sharing between TMCs**
Performance of Variously Equipped Vehicles	**. Description of functions supported by variety levels of in-vehicle equipment** **. Magnitude of benefits for users with varying levels of in-vehicle equipment**
Multiple Levels of System Functionality	**. Support for implementation of a broad range of functions** **. Identification of system functions which can be modularly implemented**
Incremental Installation	
Evolutionary Implementation	**. Support a wide range of logical evolutionary implementation strategies both in terms of geographic expansion and upgraded system functionality** **. Growth process and coordination with adjacent jurisdictions** **. Identification of likely functional upgrades**
Existing Infrastructure	**. Ability to be integrated with existing roadway, TMC, and communication infrastructures and be upgraded without major reconstruction work, disruption of roadway capacity, or lengthy delays to develop and deploy new communication infrastructures**
Operational Characteristics	
Efficiency of Traffic Monitoring and Control	**. Monitoring of network traffic conditions and detection of incidents, demand spikes, infrastructure failures, and unpredictable lane closures** **. Efficient implementation of identified control strategies**
Efficiency of Traffic Management Center	**. Time interval required to receive updated traffic reports, analyze this data, compute predicted link times, and disseminate route guidance, link times, or signal control information across network** **. Frequency of traffic report update (data or video)** **. Communication system and route guidance computation latencies**
Accuracy of Position Location	**. Desired accuracy of determining place of vehicle in network** **. Cost of position location technologies**

Evaluation Criteria	Description
Effectiveness of Information Delivery Methods	. **Ability to deliver time-critical information effectively to the vehicle/user** . **Communication link and aggregate system delay statistics** . **Communication system utilization** . **User interface device and its ease of use** . **Effectiveness of incident information** . **Ability to support well defined logical interfaces consistent with industry requirements**
Adequacy of Communication System Capacity Vis-a-vis Demand	. **Ability to handle transmission and reception of wide range of ITS messages with different sizes, frequencies of use, and priority levels** . **Communication system throughput, coverage, availability, and ubiquity** . **Adequacy of utilized bandwidth**
Security Safeguards	. **Ability to prevent of detect system subversion, misuse, cloning/ fraud** . **User confidentiality and anonymity** . **Authentication and non-repudiation**
Map Update	. **Location of map function for user** . **Type of changes required of map (road closure, new roadways), method for update**
Operational	
System Robustness-Reliability and Maintainability	. **Continued provision of benefits to users for all time frames under environmental stress or infrastructure failures** . **Performance in diverse terrain and in various weather conditions** . **System availability during maintenance**
System Safety in Degraded Mode Operation	. **Safety of User Services under failure of in-vehicle components, communications system, TMC operations, or hardware/software systems** . **Availability of User Services under failure of in-vehicle components, communications system, TMC operations, or hardware/software systems**
Risk	
Equipment or Service Not Provided	. **Expected risk that provider cannot or chooses not to market a service because an issue cannot be overcome given the proposed architecture** . **Service not offered by potential providers (no adequate return on required investment)**
Service Not Implemented by Traffic Managers	. **Complexity of TMC** . **Timeliness of information** . **Jurisdictional issues** . **Availability of qualified personnel for implementation or maintenance**
Service Not Purchased by End User	. **Risk that the driving public will not choose to purchase or implement the service supported because of technical, financial, or other grounds (e.g., perception of risk to user privacy**
Technology Places Limits on Size of Market	. **Spectrum availability, use rules, etc., for communication within the architecture** . **Inability to offer certain services at a given time frame** . **Technology limitations in supporting existing demand**
Potential Market Acceptance	. **Commercial viability**

Evaluation Criteria	Description
Penetration Levels for Effective Performance	. Risk that only a limited fraction of the potential market may use services or in-vehicle equipment, thus not allowing full benefits to materialize . Very infrequent use of services . Limited penetration of certain in-vehicle equipment
Human Factors	. Support implementation of easy-to-use interfaces for motorists of all age groups
Costs	
Vehicle Costs	. Capital costs . Operating and maintenance costs
Communication System Cost	. Capital costs . Operating and maintenance costs
Traffic Management Center	. Capital costs . Operating and maintenance costs
Cost Distribution	. Effectiveness of cost allocation between drivers, commercial vendors, and government agencies
Benefits	
Improved User Travel Performance	. Reduction of user travel time and queue time through traffic management, techniques during recurrent and non-recurrent congestion, by time frame
Improved Traffic System	. Reduced congestion measures including system travel time and VMT, by time frame . Impacts on energy consumption . Reduction in pollutant emissions
Net Safety Improvements	. Net impact of architecture on overall safety, including improvements and governmental agencies, by time frame
Institutional and Economic Issues	
Potential Acceptance of ITS Technology	. Ability to promote acceptance among a variety of commercial and governmental agencies, by time frame . Acceptance by US culture, by time frame . Acceptance of value of various user services . Acceptance of cost . Ease of use of new technologies
Equitable Allocation of Costs And Benefits	. Distribution of costs for development and implementation . Distribution of costs for operation and maintenance . Distribution of benefits among individuals, organizations, society
Ability to Support Pay-for-Use	. Stability of funding sources over time . Diversity of funding sources
First User Benefits	. Range of near-term User Services . Likely first user benefits
Expected Market Penetration	. Expected size of market . Range of User Services

Evaluation Criteria	Description
Legal Issues	. **Legal/liability exposure for ITS provider**
Privacy Issues	. **Legal issues dealing with anonymity and protection of individual privacy** . **Protection of privileged information (e.g., user/use profiles, location, etc.)**
Inter-jurisdictional Issues	. **Local issues** . **State issues**

As a first step in evaluating the entire recommended architecture, the five architecture alternatives were evaluated individually using the evaluation criteria. A qualitative assessment using L (low), M (medium), and H (high) was used. This is an assessment of how well the architecture is rated in the specific category with an H (high) the best achievable ranking. The architectures are assessed in an absolute sense, i.e., the architectures are not rated against each other. Table 4.2-2 presents the results of this assessment.

The evaluation of these architectures is not intended to be quantitative. It again presents the five alternative architectures and an assessment of the architectures in seven criteria areas. No weighing of the criteria are presented. What is provided, however, is a baseline evaluation such that an architecture re-evaluation can be performed in a consistent manner. In addition, if evaluation criteria weighing factors are assigned and/or addable, a re-evaluation can be performed.

Table 4.2-2. Alternative Architectures Evaluation

Evaluation Criteria	Alternative Architecture				
	1	2	3	4	5
Technical/Performance	L	M	M	H	H
Incremental Installation	L	L	H	H	H
Operational Characteristics	H	H	M	M	M
Operational	L	L	H	H	H
Risk	H	M	L	L	L
Costs	L	M	L	L	L
Institutional and Economic Issues	L	L	M	H	H

As seen in Table 4.2-2, a peer-to-peer architecture with centralized ATIS is the desired architecture for Maricopa County. Furthermore, detailed evaluation shows that providing permissive control is desirable as additional performance can be achieved with impact to other criteria.

It is necessary to keep in mind that these evaluation criteria not only address they physical architecture, but also evaluate actual deployment, the technologies used in that deployment, and the resulting operations, risks, costs, and other issues.

5. Identification of Physical Architecture Technology Candidates

The technology survey has been prepared with survey forms for each specific technology included in Appendix 1. Within Appendix 1, information is categorized by technology classifications developed by Kimley-Horn and Associates, Inc., to reflect the migration from existing traffic control systems to future ITS implementation, and it is specific to Maricopa County deployment needs. The process of determining the functional technology application includes a high level ITS technology area categorization with subsections based on architecture, traffic management strategies, and traffic related needs. Specific vendors are not included unless they have unique technology which is not classifiable as a “general” technology. Identification of specific candidate technology is based on the category subsection heading. The Maricopa County ITS Architecture Assessment matrices presented in Section 6 were developed to evaluate candidate technologies and describe deployment need, risk, architectural compatibility, cost, Organizational Administrative Maintenance and Provisioning (OAM&P) issues, functionality, performance attributes, and technology limitations. This section discusses the categorization, classification, and order of the technology surveys located in Appendix 1.

5.0 Technology Functional Areas

Table 5.0-l lists the contents of Appendix 1 through high level ITS communications area, functional subsection classifications, and candidate technology nomenclature.

Information related to candidate technology provided in the Appendix 1 matrices was developed by evaluating manufacturer specifications of commercially available products, and reviewing internationally approved standards and specifications. Section 5.1 provides a description of the subsections (found in Appendix l), which detail each candidate technology in terms of its suitability for ITS applications as well as its history of ITS deployment.

Table 5.0-1
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Communications	Infrastructure-to-Infrastructure (Backbone)	Backbone/Metropolitan Area Network • Synchronous Optical Network (SONET) • Asynchronous Transfer Mode (ATM) • Fiber Data Distribution Interface-l (FDDI-1) • Fiber Data Distribution Interface (FDDI-2) • DS-X or OC-X digital microwave • Non-standard fiber optic links using frequency and time division multiplexing • Integrated Services Digital Network (ISDN)
Communications	Infrastructure-to-infrastructure (Field-to-Backbone)	• Digital spread spectrum packet radio • Digital spread spectrum frequency-hopping packet radio network • Point-to-point digital wireless, Serial Control and Data Acquisition (SCADA) • Optical transceivers (EIA 232, EIA 485, DS-1, DS-3, etc.) • Short-haul Microwave Video • Short-haul LASER • Video Optical Transceiver (VOTR) Simplex Video with fully duplexed camera and pan/tilt control • Video 4-channel multiplexer over 1 single mode fiber • Short-haul microwave
Communications	Video CODEC/ Infrastructure-to-Infrastructure	• Video CODECs 1) H.261 2) H.263 3) MPEG-I 4) MPEG-II 5) MPEG-IV 6) JPEG 7) M-JPEG 8) Vector-Horace

Table 5.0-1, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Communications	Infrastructure-to-Vehicle (One-way)	▪ Highway Advisory Radio (HAR) ▪ Broadcast AM/FM radio ▪ Radio Digital Data System (RDDS), Radio Data System (RDS), and .subband FM digital ▪ Radio Digital Data System (RDDS) AM subband ▪ Enhanced paging service ▪ Variable Message Sign (VMS) ▪ Broadcast television
Communications	Infrastructure-to-Vehicle (Two-way)	▪ Radio frequency toll tags, Radio Frequency Identify (RFID), Heavy Equipment License Plate (HELP) – CVO RF intelligent tag, Advantage RF tag (CVO Advantage I-75 project) ▪ Infrared optical wavelength communications; EUROSCOUT - Siemens ▪ Cellular telephone, AMPS, CDPD, or digital voice ▪ Cellular telephone, Cellular Digital Packet Data (CDPD), or new digital service ▪ Land mobile ▪ Personal Communications Service (PCS) ▪ Citizens-band radio ▪ Private packet network radio, ARDIS, RAM mobile, etc.

Table 5.0-1, cont.
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Communications	Infrastructure-to-Other Agency	. Switched public telephone dial-up . Integrated Services Digital Network (ISDN) . Synchronous Optical Network .(SONET) interconnects . Cellular telephone voice
Communications	Intra-TOC	. Private Branch Exchange (PBX) . ETHERNET - 10 BASE-T, 10 BASE-FL . ETHERNET - 100 BASE-T, 100 BASE-FL . Fiber Data Distribution Interface (FDDI-I) . Fiber Data Distribution Interface (FDDI-II) . Token ring . 100 VG-ANYLAN . Fiber link . Wireless LAN - ETHERNET . Asynchronous Transfer Mode (ATM)

Table 5.01, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Traffic Surveillance and Monitoring	Speed/Travel Time	▪ Inductive loop detectors ▪ Fiber optic loop detectors ▪ Video image detection systems (low end) ▪ Video image detection systems (medium) ▪ Video image detection systems (high end) – includes license plate reading capability ▪ Infrared sensors ▪ Acoustic sensors ▪ Microwave sensors ▪ Radar ▪ LIDAR
Traffic Surveillance and Monitoring	Classification	▪ Inductive loop ▪ Video image processing (medium) ▪ Video image processing (high) ▪ Infrared ▪ Acoustic ▪ Microwave ▪ LIDAR ▪ Strain gauge weigh-in-motion ▪ Fiber optic weigh-in-motion

Table 5.0-1, cont.
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Traffic Signal Control	Software/Control Strategy	. Conventional . Closed loop . UTCS . Hybrid
Traffic Signal Control	Software/Control Strategy	. Adaptive . SCOOT . SCATS . Alcatel (adaptive) . ITS New Development (FHWA)
Traffic Signal Control	Controller Devices	. NEMATS-2 . 170 Controller . 179 Controller . 2070 Controller
Traffic Signal Control	Emergency Vehicle Preemption	. Panic button (fire department) . Infrared detection systems . Optical (flashing light) detection system
Alternate Route	Pathfinder Signs	. Pathfinder Signs . Variable Message Signs (VMS)

Table 5.0-1, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Navigation	Real-time (in-vehicle)	. Global Positioning Service (GPS) . Differential GPS (DGPS) . Dead reckoning with GPS update . Dead reckoning with sign post update . Inertial navigation
Navigation	Dispatching Center Oriented	. Time difference of arrival . Direction Finding (DF)/Cross Correlation
Navigation	General Guidance	. Map matching . Cellular phone
Route Guidance	In-vehicle	. Data link with communications to "Yellow Page" service center . "Yellow Page" database (in-vehicle) . Delco Telepath™ (DT) – subband FM one-way communications . Area FM broadcast station

Table 5.0-1, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology

Mayday	Traveler Safety and Security	· Emergency roadside telephones
		· Cellular telephone
		· Mobile radio to central dispatch
		· Citizens band radio
		· Motorist Assistance Patrols (MAPs)
		· In-vehicle sensors linked to route guidance for reporting position and crash severity to a center
		  · Impact sensors
		  · Fire sensors
		  · Gas leak sensors
		  · Occupancy sensors
		· Manual panic button - request for mechanic services
		· Cellular provided as an additional service by Westinghouse Security, etc.

Traveler Information	Walking	· Pager · AM/FM radio · Portable television · Cellular telephone · Kiosk terminal · PDA/digital cellular · SMART call box

Table 5.0-1, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Traveler Information	Home/Office/Hotel	▪ Broadcast radio ▪ Broadcast TV ▪ Cable TV ▪ Interactive cable TV ▪ Cellular telephone ▪ Computer/modem ▪ PDA/modem ▪ Interactive hotel TV/video system
Traveler Information	Public Transportation Vehicle	▪ Cellular telephone ▪ Broadcast radio receiver (portable) ▪ Broadcast TV receiver (portable) ▪ Personal digital associated/digital cellular ▪ Kiosk on bus ▪ Automated announcement ▪ Variable message signs (out window)
Traveler Information	In-vehicle (private)	▪ Integrated vehicle information system (part of Route Guidance) ▪ Broadcast radio ▪ Variable Message Signs (VMS) ▪ Cellular telephone ▪ Personal digital assistant ▪ Paging terminal ▪ Pathfinder signs ▪ RF tag (Type III with display) ▪ RDDS stand alone terminal
Traveler Information	Commercial Vehicles	▪ Same as private vehicle ▪ Computer aided dispatching link ▪ Call box/SMART call box

Table 5.0-1, ***cont.***
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Vehicle Air Pollution Monitoring	Infrastructure Installed	. SMOG DOG - Remote emissions sensor . Marksman 660 Traffic pollution monitor . AT&T Acoustic sensor
Vehicle Air Pollution Monitoring	In-vehicle System	. Engine performance monitoring
Hazardous Conditions Sensors and Surveillance	Weather	. Wind direction and speed . Weather sensor systems (ALERT) . Visibility detectors
Hazardous Conditions Sensors and Surveillance	Ice on Bridges/Roadway	. In-pavement weather conditions sensor . Video (CCTV) . IR ice detection
Hazardous Conditions Sensors and Surveillance	Flooded Road Areas	. Fiber optic and infrared level sensor . Flood level switches
Hazardous Conditions Sensors and Surveillance	Pot Hole and Potential Pot Hole Detection	. Radar

Table 5.0-1, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Hazardous Conditions Sensors and Surveillance	Toxic Fumes/Fire in Tunnel	. Diffusion type electrochemical sensors . Infrared gas sensors . IR fire sensors . Smoke
Hazardous Conditions Sensors and Suweillance	Rockfall/Slide	. Wire grid with strain gauges . Video . Laser light beam
Hazardous Conditions Sensors and Suweillance	Snow Avalanche	. Ultrasonic sensor . IR sensor
Hazardous Conditions Sensors and Suweillance	Hazardous Material Spills and Warning	. Diffusion type electrochemical sensors . Infrared gas detectors . Video (CCTV) . Video image processing . CVO RF intelligent tag (HAZMAT warning)
Hazardous Conditions Sensors and Suweillance	Nuclear Radiation	. Geiger Counter

Table 5.04, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Hazardous Conditions Warning to Drivers	Communications (Infrastructure-to-Vehicle)	. Portable signs . Fixed signs . Highway Advisory Radio (HAR) . Variable Message Signs (VMS) . In-vehicle route guidance systems . Special low-power hazard beacon
Electronic Toll and Traffic Management	Electronic Toll/Fee Collection	. Magnetic card reader . Type I through III toll tags
Electronic Toll and Traffic Management	Commercial Vehicle Operation	. Radio frequency toll tags, Radio Frequency Identify (RFID), Heavy Equipment License Plate (HELP) – CVO RF intelligent tag, Advantage RF tag (CVO Advantage I-75 project)
Enforcement Support	Speed	. Doppler Radio Detection and Ranging (RADAR) . Light Detection and Ranging (LIDAR)
Enforcement Support	Signal Violation	. Video image processing . Vehicle detector providing trigger for CCTV

Table 5.04, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Enforcement Support	Vandalism of Infrastructure	. Digital Signal Processing (DSP) Closed Circuit Television (CCTV) . Access sensors
Enforcement Support	Pollution	. SMOG DOG with automobile license plate reader
Enforcement Support	Fee payment and CVO inspection violation	. Payment sensing and CVO vehicle inspection station entrance sensor with automated license plate reader/CCTV video of violators
Vehicle Safety Sensors	Mayday	. Impact sensors, airbags front/side, seatbelts . Vehicle condition sensors

Table 5.04, *cont.*
Technology Functional Areas

Technology Area	Functional Subsection	Candidate Technology
Vehicle Safety Sensors	Any Vehicle	· Collision Avoidance - acoustic obstacle detection, ultrasonic obstacle detection, microwave radar, millimeter wave radar, LIDAR, wide-band radar · Over speed limit, infrastructure-to-vehicle reporting and vehicle-to-driver alarm system identifying violation · Night vision enhancement · Anti-lock Brake System (ABS) · Traction control system, anti-wheel spin regulation, road environment sensor, intersection sensors · Restraint system - Infrared sensors, machine-vision sensors, acoustic sensors, heating elements · Magnetic lane control, visual TV lane control, infrared imaging lane control, radar and reflectors
Vehicle Safety Sensors	Commercial Vehicle Operation	. Airbrake pressurization alarm . Steep hill (infrastructure-to-vehicle) . Acoustic tire wear sensor . Type Ill toll tag . Monitoring mechanical performance of public transit and commercial vehicles

5.1 Description of ITS Matrix

Functional Classification — Technology functional area and sub-classification that applies to the candidate technology, such as communications, infrastructure-to-vehicle.

Technology Classification — This is a high level classification describing basic technology application. For example - wire line, fiber optic, wireless, Local Area Network (LAN), Public Switched Telephone Network (PSTN), video, etc.

Industry Designation — Provides the product or system nomenclature as typically described by the technology industry. Example - Fiber Distribution Data Interface (FDDI), Remote Emissions Sensor (RES), Closed Circuit Television (CCTV), etc.

Functions Performed — Describes explicit function and range of operating performance that is provided by the technology. Example - radio voice communications, vehicle speed detection, Origin/Destination tracking and reporting, weigh-in-motion, percent relative humidity, automatic vehicle location, etc.

Technology Status — Refers to ITS deployment status of a particular candidate technology. Describes technological deployment risk by determining actual ITS field deployment compatibility and development status. Pilot program locations and known agency support are listed where identified.

Environmental Compatibility — Describes configurations of equipment which may be suitable for outdoor environment (i.e. NEMA TS-1 and TS-2 compatible) or office environment, or both.

Interface and Operational Standards — Describes known standards which specify operational performance, physical layer interconnection, communications protocols, network management, man-machine interface, hardware/software compatibility, reliability, Electromagnetic Interference (EMI)/Electromagnetic Compatibility (EMC), communications licensing (FCC Part 15, etc.), and human safety. Example - ANSI, IEEE, IEC, EIA, CCITT/ITU UL, FCC, and FDA (Laser Safety).

Reliability — Describes built-in product features that allow extended operational performance as a result of hardware, firmware and software quality and design. Intent for product deployment in ITS is not to allow a single point of failure within the communications network. Mean Time Between Critical Failure (MTBCF) is determined as the inability of the product to perform to specification, providing that all necessary input power, connections, data, communications protocol(s) and operating environment meet the operating specifications of the unit. Example - modular construction, hot-swappable module replacement, hot stand-by, redundant power supplies, and redundant communications path support high MTBCF.

Maintainability — Maintainability is defined as design features which allow jurisdictional maintainability. These include built in text, fault detectionlreporting, network management features with graphical user interface, etc. Maintenance is typically described in terms of Mean Time To Repair (MTTR) and is defined at the module or component replacement/repair level.

Jurisdictional Supportability — Define the ability of the jurisdiction to maintain the technology. Describes the technical repair experience level, Test Measurement and Diagnostic Equipment (TMDE), and Preventative Maintenance Checks and Services (PMCS) necessary to maintain operations and repair the equipment to specified performance criteria. Includes mention of new test equipment that may be needed and training courses to provide jurisdictional members the skills to operate and maintain the candidate technology. Includes need for contract maintenance at various levels through depot.

Architectural Compatibility — Addresses compatibility with ITS architecture.

Cost — Technology cost on a functional per unit basis. Where several candidate technologies are compared, the comparison reflects equivalency regarding installation, features and options. Indoor, outdoor and portable versions are included.

Comparative Features with Conventional Technology — Describes improvements that exceed capabilities provided- by conventional technology. Example: less installation time, higher communications bandwidth, adaptation to multimedia, automated features, built-in-test (BIT), environmental compatibility and advanced/remote management capability, etc.

Benefits of Features — Describes how features incorporated into the technology will benefit ITS operations. Application of the technology may provide a dynamic change in the way the communications, man-machine interface, organizational operation, network management, etc., are performed after installation.

Application Pro's — Indicates positive aspects of the candidate over rival technologies that may serve as incentive for deployment.

Application Con's — Pertains to the issues of cost, reliability, high maintenance, obsolescence of technology, etc., that may limit consideration for ITS deployment.

6. Technology Candidate Analysis

6.0 Technology Candidates

Appendix 1 presents the key technology candidates surveyed. The matrices presented in Appendix 1 provide an overview of the technology.

6.1 Communications Technology

There are a variety of communications requirements for the architecture including:

- Infrastructure-to-Infrastructure
  - Network backbone supporting communications with field devices and between operations centers
  - Interconnect links to the backbone
- Infrastructure-to-Vehicle
  - One-way to the vehicle
  - Two-way to/from the vehicle
- TOC to Other Agencies
  - Typically dial-up modem or leased service
- Intra-TOC
  - Local area network
  - Voice

Within each of the communications categories reviewed, recommendations are made for technology implementation within the system architecture.

6.1.7 Key Factors in Evaluating Communications Technology

Important factors to be considered in selection of a technology for the system architecture include:

- Nationally recognized, approved standards compliant with International Standards Organization's seven-layer architecture
  - Not considered open architecture if technology does not meet this criteria

- Supported by commercial industry
  - If the standard is not supported by competitive technology, it presents risks in technology cost and future supportability

- Availability of the technology with fault tolerance and a standard network management protocol
  - If not available, presents reliability and maintainability risk

- Ability to modularly expand as bandwidth requirements and interface requirements expand
  - If not expandable, the technology presents cost and obsolescence risks

- Compatibility with multimedia which requires synchronous or isochronous capability
  - If not compatible, special overlay links are required for voice and video, and the system will be subject to obsolescence as technology rapidly transitions into complete multimedia

- Field equipment should be compatible with area commercial buildings (i.e. outdoor environment). If not compatible, problems will include:
  - Cost to place in an environmentalized shelter
  - Reliability dependent on air conditioner reliability
  - Reliability of semiconductor greatly impeded by temperature overstressing

6.1.2 Communications Backbone Technology Trade-off

The recommended architecture for the Maricopa County ITS System is a Synchronous Optical Network (SONET) architecture which conforms to Bellcore GR-253-CORE, *SONET* Transportation *Systems: Common Generic Criteria, American* National Standards Institute (ANSI) TI.105-1991, *American National Standards for Telecommunications, Digitai Hierarchy: Supplement for Optical Interface Protocol and Format S*pecifications and ANSIT1 .102-1989, *American NationaI Standards for Telecommunications, Digitai Hierarchy: Electrical Interfaces.* An add/drop capability in accordance with Bellcore TR-NWT-000496 should be included for each communications hub supporting ITS functions. Fault tolerance through use of line-switched or path-switched technology should be used. Physical optical ring diversity is recommended for the highest reliability. Inter-working ring technology may also be used to support reliability and modular network expansion.

SONET is the most appropriate choice for Maricopa County backbone communications because:

- It complies with open architecture recommendations for national ITS architecture including seven-layer International Standards Organization Communications model;

- It supports multimedia communications;

- Significant competition exists and is growing with cost continuing to go down;

- Hardware is available compatible with outdoor environment as well as commercial building environment;
- Using Bellcore Standards, the equipment is reliable and maintainable, including fault tolerance, built-in automated text, and status reporting via network management protocol;
- It supports modular expandability both in bandwidth and interfaces;
- It is inherently compatible with Broadband ISDN and Asynchronous Transfer Mode switching (bridging capability);
- It literally can support connecting any form of LAN, MAN, and WAN communication through appropriate application of bridges and routers;
- It has the lowest lifecycle cost;
- It offers many maintenance options; and
- With SONET, the deployment risk is low.
- Institute of Electrical and Electronic Engineers (IEEE) ITS Standards Group is in the process of developing network standards for ITS applications based on SONET.

SONET allows a variety of build-out options including use of SONET digital microwave links and use of ISDN, DS-1, and DS-3 circuits. Without a detailed design, it is difficult to determine the exact amount of bandwidth required for the network. An OC-12 SONET network would accommodate the basic communications requirements facilitating center-to-center backup and peer-to-peer sharing of compressed digital video; however, OC-12 would not facilitate significant bandwidth for expansion and assumes selective distribution of ADOT freeway video when fully expanded. An OC-24 network would accommodate spare bandwidth for growth. **Table 6.1.2-1** presents a high level estimate of SONET network load. The integrated system assures multiple interoperable LANs (10 each) using ATM communications technology between centers.

Specifics of candidate technologies considered are included in Appendix 1, Infrastructure-to-Infrastructure Communications. These are summarized in **Table 6.1.2-2.** Short range communications devices were not considered in this trade-off. These devices are more suited to low speed controller-to-communications-backbone interface; also, the effort of IEEE 802.14 Forum on digital network standards over CATV network was not considered since this standards effort is in its infancy and no standard nor supporting hardware or software exists at this time.

Table 6.1.2-2 presents the trade-off analysis using (to the extent applicable) performance measures defined in Task 4. SONET and ATM are the technologies receiving the highest evaluation. Since SONET is inherently compatible with ATM, a combination of the technology is recommended.

Table 6.1.2-1
Backbone Loading Communications (DS-1 Increments)
Based on Future Requirements (Estimates for Fully-Integrated System with interoperability)

Jurisdiction	Controller/ Center-to-Center	Video Channels	Voice Channels	Total
City of Phoenix	3	40	1	44
City of Tempe	1	20	1	22
City of Chandler	1	10	1	22
City of Gilbert	1	10	1	12
City of Mesa	1	20	1	22
City of Peoria	1	20	1	22
City of Scottsdale	1	20	1	22
City of Glendale	1	20	1	22
Paradise Valley	1	IO	1	22
Maricopa County	2	40	1	43
State/ADOT	6	40	1	47
Integrated System	28	--	1	29
				329

(_ oc -12)
NOTE: DS-1 = 1.54 Mbps

Table 6.1.2-2
Communications Backbone Technology Trade-off

Evaluation Criteria (See Task 4)	SONET	ATM	FDDI-I	FDDI-II	Digital Microwave	Non-standard Fiber Video/ Voice/Data Multiplexers	ISDN
1. Open Architecture (Approved Standards = 10)	10	10	10	4	10	0	10
2. Modular Expandability (Interface and Bandwidth = IO)	10	10	0	0	4	10	6
3. High Availability for Real-time Operations (99.98% = IO)	10	10	10	10	10	5	8
4. Supports Traveler Information Distribution (yes = 10)	10	10	10	10	10	10	10
5. Low Maintenance (Low = 10)	10	10	8	8	6	5	10
6. Recommended Architecture Compatibility (Compatible = 10)	10	10	2	2	6	2	5
7. Lifecycle Cost (Low = 10)	10	10	10	5	6	2	4
8. Public Telephone Network Compatibility (Full = 10)	10	10	5	5	10	10	10
9. Multimedia Compatible (Full = 10)	10	10	0	10	10	10	10
10. Deployment Risk (Minimal = 10)	10	6	10	3	8	5	10
(100 = Fully Compatible) Totals	100	96	65	58	80	59	83

6.1.2.1 SONET and ATM Applications

Within the recommended architecture, the SONET add/drop hubs will provide a means of peer-to-peer sharing of video. Video will be compressed and distributed to all peers. It will be on the network and available based on interest and needs. There is no reason to use ATM for video since it must be present on the network or selected DS-1 channels for access by those who require it. Thus, ATM provides no optimization of video bandwidth since it is synchronous and would receive priority under isochronous signal distribution rules of ATM.

ATM is recommended for establishing functional, virtual, local area networks between operations centers. This provides easy-access ATIS information, coordination information, transit information, etc., as necessitated by the operation.

6.1.2.2 SONET with Digital Microwave

Available on the market in 1995 are several products integrating digital microwave with SONET, operating at the OC-3 SONET rate. Digital microwave with SONET compatibility, while not the primary choice for the communications backbone, can be used in a build-out plan or to provide interworking ring topology to support greater network reliability and performance. SONET microwave is available with compatible fault tolerance and network management features with “all optical” SONET. It complies with SONET network and American Digital Hierarchy Standards as specified by ANSI.

6.1.2.3 SONET Bandwidth

SONET is available in bandwidth increments from OC-1 through OC-192. OC-96 (4.976 gigabits/second) and OC-192 (9.952 Gbps) are operational today. OC-48 (2.488 Gbps) are widely deployed on an international basis. Most ITS freeway systems are deploying between OC-12 (622 Mbps) and OC-48 SONET systems depending on length (number of miles and associated sensor deployment).

SONET uses single mode fiber which is the prevalent fiber technology (in terms of fiber-miles) being deployed today. Because of the significant demand for single-mode fiber to replace copper, coax, and microwave links, a number of manufacturers have focused on supporting this market. Thus, single-mode fiber has continued to come down in price to where it is now of comparable cost with copper and 2.5 to 3.0 times less expensive than multimode fiber. On a $/bps/mile bases, single mode fiber is the cheapest form of communications medium available today.

Bandwidth capacity of single-mode fiber is very significant (over 100 GHz). SONET lab technology (i.e. Bell Labs) has conducted tests at 100 Gbps over significant distances proving the usefulness of single-mode fiber bandwidth. Thus, once single-mode fiber is installed, the capacity of the fiber is hardly used with today's SONET technology. In addition, fiber, once installed, has significant "built-in" growth capacity, requiring only higher speed communications electronics to realize the potential.

The significant feature of SONET is that it is designed on modular optical increments. Thus, four (4), OC-3 channels can be integrated with an OC-12 optical shelf. Similarly, four (4) OC-12 optical channels may be integrated to form an OC-48 network. Essentially, the network capacity can grow without replacing existing infrastructure. Obviously, it is less expensive to install a fully-integrated SONET terminal initially; however, the ability to expand in OC-4 increments is an alternative with SONET technology.

The cost of higher-data-rate SONET terminal equipment continues to come down as more competition emerges. The demand for higher-data-rate SONET equipment has increased exponentially in the past two years, as has manufacturing emphasis on competition. In 1995, cost has decreased as much as 40% for high-data-rate SONET equipment (OC- 12,OC-24, and OC-48). Cost differential in an OC-3 versus an OC-12 communications hub is only about 22% making it reasonably uneconomical to wait to install expanded capability. The trend toward lower cost SONET electronics will continue, making it an even more cost effective communications network technology.

6.1.2.4 ATM

Asychronous Transfer Mode (ATM) has been defined as part of Broadband Integrated Services Digital Network (B-ISDN) for more than ten years as has SONET. The ATM Forum, supported by Bellcore and other standards groups, developed ATM Standards Bellcore TA-NWT-001113, *Asynchronous Transfer Mode (ATM) and ATM Adaptation Layer (AAL) Protocols, Generic Requirements,* and ANSI T1 S1.5/92-002R3, *Broadband ISDN ATM Aspects, ATM Functionality and Specifications.* These specifications have only been approved for the past two years. In 1995, ATM equipment started emerging on the market in compliance with these standards. Some aspects of ATM standards are still in an approval stage related to specific features of the technology. Standard ATM interfaces are at the OC-1 and OC-3 SONET data rates with a 25 Mbps IBM standard emerging in 1995 as a LAN standard. The disadvantage of the 25 Mbps standard is that it is incompatible with a MAN/WAN transport by SONET.

ATM provides optimized use of synchronous network channels for signals which are non-continuous (i.e. Asychronous). ATM switch technology can significantly improve connectivity of LANs, MANs, and WANs, with use of edge routers. ATM offers no significant benefit for transport of continuous, real time video information.

ATM technology is currently rather expensive compared with other alternatives. Where bandwidth is available, ATM offers a potential for conserving bandwidth, however, cost versus need must be the decisive factor.

When the detailed design of the system is initiated, ATM technology cost should be reviewed in relation to the very low cost bridge/router circuit boards available for ETHERNET, and Token Ping. A DS-1 bridge/router module can establish effectively virtual ETHERNET between field devices and centers. When ATM technology becomes competitive, then establishing ATM links from field equipment to the jurisdictional TOC, and between TOCs within the County, becomes a cost effective possibility.

Currently, a DS-3 (or an OC-3) ATM switch with ETHERNET edge router module, is an economical approach to establishing area-wide virtual ETHERNETS, functionally allocated. This is a current trend in ITS to support center-to-center interoperability with "computer interface friendliness." Standard software and low cost ETHERNET interfaces are available to support implementation.

In summary, ATM communications technology is recommended, integrated with SONET. Cost of ATM is expected to decrease; therefore, detailed system design should review cost status and justifiable extent of technology deployment within the communications network.

6.1.3 Communications Technology to Link Low-Speed and Video Devices

Several technologies are suitable for low-speed communications links to communications hubs. These include:

- Twisted pair copper with wireline modems
  - Multidropped
  - Point-to-point
  - Leased dial-up or dedicated circuits

- Wireless
  - Packet radio/spread spectrum
  - SCADA

- Fiber optic optical transceivers available with EIA 232, EIA 485, DS-1 and DS-3 compatibility
  - Typical of current ITS deployments
  - Available in fault-tolerant, and point-to-point configurations
  - Available with outdoor environment (NEMA T1) compatibility

Short-haul video interfaces are supported by:

- Short-haul microwave;
- Laser communication;
- Low-cost optical transceivers with integrated CCTV control and video, over a single fiber; and
- Low-cost video multiplexers (4-channel) with optical transceivers, using a single fiber.

Coaxial cable is considered to be obsolete technology and of significantly limited capability and lower reliability compared with fiber optic communications. Coax is only recommended for consideration where existing coax is installed and available. New video communications interfaces should consider only fiber unless installation restrictions exist, dictating wireless solutions.

6.7.3.1 Fiber Selection

Single-mode fiber has become significantly less expensive compared with multimode fiber, and is generally less expensive, even considering differences in electronics cost. When standardization for all installations is considered, lifecycle cost savings dictate use of all single-mode fiber. About the only place where multimode fiber becomes economical, compared to single mode, is “in-building” cabling and “around campus” (i.e. short-distance) cabling.

Similarly, the lower loss single-mode fiber provides more flexibility in locating communications nodes and hubs. In reality, fewer concentration points are required, especially those driven by the limited communications lengths of multimode fiber.

Finally, multimode fiber has a Km-MHz factor which limits distance based on bandwidth. This can become a problem at high data rates or on links where many video channels are multiplexed, requiring wide bandwidth. For this reason SONET systems typically require single mode fiber.

6.1.3.2 Video CODEC

Video distribution can be accomplished in several ways:

- Analog Distribution — typically using 10 MHz or 15 MHz bandwidth per channel.

- Digital Distribution — using non-compressed techniques, typically at 16 MHz sample rate (8 bits per sample), requiring a 128 Mbps data channel.

- Digital Distribution — using data compressor at various compression ratios depending on the quality of video image desired and degree of change from video frame to frame.

Older ITS systems used analog video distribution. Analog video signals were multiplexed into 32 to 64 channels and distributed using coax. Coax was replaced with multimode fiber. With 32 multiplexed channels and 15 MHz per channel, 480 MHz of bandwidth is required. Typically multimode fiber has a 500 MHz-Km specification limiting transmission distance. Thus, to achieve distance and bandwidth required for 64 channels, single-mode fiber is necessary.

Typically analog video distribution systems cost $4,000 per video channel. Being analog, they are susceptible to signal-to-noise, differential phase errors and differential gain errors, degrading the quality of the signal.

Complying with EIA 250C requirements for medium haul video transmission from a signal source (i.e. CCTV camera), to a display in the TOC is difficult. Add/drop capability, while accomplishable, requires special adapters for band filters, allowing certain channel frequencies to be dropped and unused frequencies to be added. Built-in test and automated reporting of failures are not available. Therefore, a signal "lost" isolation to point of failure must be manually identified through use of separate test equipment. Thus the network is not "self determinant" from a performance standpoint.

Digital video distribution maintains signal quality (assuming adequate digital bandwidth is available) and can achieve EIA 250C requirements. This digital television has a significantly higher signal/noise ratio and resulting image quality. This is comparable to the difference between analog audio tapes and "CDs" in the quality of the resulting signal.

With digital signals, video information may be transmitted over modem communications networks (assuming isochronous) complete with the following benefits:

- Ability to easily distribute the signals to multiple user;
- Ability to maintain signal quality during the signal distribution process;
- Ability to use modem network monitoring and management protocol enhancing maintainability;
- Ability to use fault-tolerant, high-reliability communications equipment for video distribution, proven in general communications; and
- Elimination of the need to service and maintain several communications technologies.

Both commercial and consumer markets are rapidly transitioning to multimedia and digital television. CCTV cameras are merging with digital signal processors. RCA and Sony now support digital broadcast television via their Digital Satellite Systems (DSS) service. In fact, the DSS uses compressed digital video.

The consumer market will make a major transition to digital video when the high-definition TV (HDTV) standard is approved. Format and resolution options are perhaps the current consensus problem with HDTV. The Motion Picture Experts Group's (MPEG) MPEG-II compression and decompression algorithm seems to be the acceptable standard for conversion. The need for digital broadcast television is not an issue. DSS utilizes the MPEG-II compression and decompression algorithm.

To achieve compatibility and bandwidth conservation on communications networks, video CODEC transmitters and receivers are necessary. These devices perform as follows:

- Video Transmitters:
  - Interface with analog video;
  - Compress the digital video using intraframe and interframe compression technologies;
  - Format the compressed information; and
  - Provide physical and link interfaces for transmission

- Video Receivers:
  - Receive the serial digital information;
  - Combine received information to form a frame of video;
  - Decompress the digital information;
  - Form an uncompressed digital version of the frame; and
  - Convert the uncompressed digital video into an EIA 170 compatible signal with appropriate synchronization. (In the future, HDTV video decompressed output signal will be provided.)

While, today, video CODECs are separate electronic units, in 1996 one major CCTV manufacturer will offer the video CODEC transmitter as an integrated capability with its camera. Technology will continue to evolve to where all devices supporting video will include integrated CODEC. Large-scale Integrated Circuit (LSI) chips are available on the market today for MPEG-II compression and decompression, assuring that these LSI chips will be in equipment emerging on the market by 1997.

There are a number of CODEC standards which are available including those presented in **Table 6.1.3.2-1** on the following page.

Table 6.1.3.2-1
Video CODEC Standards

Standards Group	Standard Number	Approximate Age/Maturity (Years)	Purpose
ITU	H.261	15	Video Teleconferencing
ITU	H.263	2	Video Teleconferencing
MPEG	MPEG-I	6	Video CDs
MPEG	MPEG-II	2	Motion Picture Digital Distribution and HDTV
MPEG	MPEG-IV	0	Improved Performance of MPEG-II
JPEG	JPEG	6	Still Photo Digital Distribution
JPEG	M-JPEG	0	Adaptation of JPEG to Motion
DOD	Vector Horace	8	Airborne Video Surveillance — High Motion

ITU = International Telecommunications Union (formerly Consultative Committee International Telephone and Telegraph - CCITT)
MPEG = Motion Picture Expert Group
JPEG = Joint Photographic Experts Group
DOD = Department of Defense

Tests conducted by Kimley-Horn and Associates, Inc., using CODEC equipment with the above algorithms (except MPEG-IV) and CCTV cameras, viewing high-speed traffic on a freeway at various viewing angles, provided the results presented in **Table 6.1.3.2-2.** Tests were conducted to determine at which communications data rate acceptable quality video would be displayed from outputs of the CODEC receiver. When jurisdictions invest $10,000 to deploy a CCTV surveillance camera, an acceptable and usable video image should result. Tests resulted in superior performance with algorithms that emphasize intraframe compression for high motion imaging. At dual DS- 1 data rates, the M-JPEGS algorithm, even though not a formalized standard, had excellent performance as did the Vector Horace algorithm, which was developed by the U.S. Army's Fort Monmouth Laboratory. MPEG-II algorithm also performed well at dual DS-I data rates. No algorithms performed acceptability at DS-1 to justify deployment of a quality, CCTV camera. At quad-DS-1 data rates (= 6.18 Mbps) most algorithms performed acceptably.

Table 6.1.3.2-2
Test Results of Video CODEC Algorithms for Freeway Applications

Standards	Data Rate and Results			
	F-T1 56 Kbps	DS-1 1.54 Mbps	Dual DS-1 3.08 Mbps	Quad DS-1 6.16 Mbps
H.261	R, B, CJ	R, B, J	B, J	A
H.263	R, B, CJ	R, B, J	B, J	A
MPEG-I	R, B, CJ	R, B, J	B, J	A
MPEG-II	R, B, CJ	R, B, J	A	A
Vector Horace (DOD)	R, B, J	R, B, J	A	A
M-JPEG (Draft) Specification	R, B, J	R, B, J	A	A

A = Acceptance full-motion quality
B = Periodic blocking of image
CJ = Continuous jumping of image
J = Periodic jumping of image
R = Poor resolution

While DS-3 (44.73 Mbps) CODECs performed outstandingly, seeking a conservation of communications bandwidth and the ability to flexibly distribute video to any user in need of it, DS-3 CODECs do not become the best choice.

For this project, a compression standard technology is recommended which operates effectively at dual DS-1. The DS-1 signals should be integrated with the network and dropped to any TOC or other agency having an interest. These may include emergency services, law enforcement, transit, and even public works. Either integrated real-time, digital, cross-connect switches within the SONET terminal or external digital switches associated with video selection and distribution should be used at each TOC, with inputs from the DS-1 circuits. Many of the video switch companies are now offering switches compatible with digital video.

A further issue with CODEC, is that the transmitter must be independent of the receiver allowing any transmitters to communicate with any, or many, receiver(s). While some CODECs include a camera control channel, in a distributed system, camera control should be a separate function with priority assignment. The owning jurisdiction would always have priority for use of its own camera.

6.1.4 Infrastructure-to-Vehicle Communications

6.1.4.1 *Roadside-to-Vehicle (one-way)*

There are several communications technologies which can support one-way, infrastructure-to-vehicle communications. Appendix 1 summarizes these technologies. **Table 6.1.4.1-1** presents a comparison of various technologies.

Radio Digital Data System (RDDS) or digital information moderated on an FM broadcast signals subband (FM Subband) is ranked the highest. It is now being deployed in General Motors (GM) automobiles in support of route guidance. Being FM, it provides superior performance compared to AM, and it provides digital corridor status data to the route guidance system within vehicles. It is recommended that a RDDS with GM compatibility be included in the provision of the Maricopa County ITS. Business forecast indicate that most major car manufacturers will follow GM's lead with RDDS radios.

Variable Message Signs (VMS) rank second. ADOT has deployed VMS, and VMS is in Glendale's plans. Variable message sign provisions should be an included technology for Maricopa County.

Highway Advisory Radio (also called Metropolitan Advisory Radio) was a stated requirement and should be included. 'Unfortunately, FCC limits HAR to AM frequencies with low priority. Therefore, it is highly subject to interference. Broadcast radio is normally provided by public broadcast media and will remain a privatized source of traveler information. Provisions to share data with public broadcast media should be included in the design. HAR provides a localized corridor status and hazards warning compared with area wide commercial broadcast radio.

Broadcast TV will also continue to be a privatized source for traveler information dissemination. Television has limited use in vehicles, however hand-held TVs are a source of ATIS information for non-vehicle travelers and travelers in public transit vehicles. Interface with broadcast TV media is recommended for coordination.

6.1.4.2 Bidirectional Infrastructure-to-Vehicle Communications Links

Table 6.1.4.2-1 presents the comparison of two-way vehicle-to-infrastructure communications technologies. The most prevalent two-way communication technology is land-mobile. Commercial vehicles, and public transit vehicles, as well as private providers of transportation to the public (i.e. taxies, dial-a-ride services, etc.), use land-mobile communications. This technology is proven and it can communicate with vehicles over the region, if properly engineered.

Obviously, commercial vehicles and transit vehicles will continue to use this technology which can support voice and data. For operational tests of ITS services related to infrastructure-to-vehicle communications, use of a common mobile radio channel would be reasonably easy to implement.

Table 6.1.4.1-1
Infrastructure-to-Vehicle Communications One-Way

Evaluation Criteria	Broadcast Radio HAR	Broadcast Radio	RDDS FM	RDDS AM	Paging	Variable Message Signs (Visual)	Broadcast Television
1. Open Architecture (Open = 10)	0	0	5	5	5	6	0
2. High Reliability (High = 10)	5	9	9	9	7	7	5
3. Low Maintenance Cost to Jurisdiction (Low = 10)	4	8	8	8	8	5	4
4. Low Operations Cost to Jurisdiction (Low = 10)	6	8	6	6	6	6	6
5. Reaches Wide User Base (Wide = 10)	10	10	2	0	3	10	4
6. Low Cost to User (Low = 10)	10	10	9	1	4	10	8
7. Jurisdictional Control of Information Transfer (Full Control = IO)	10	0	8	8	10	10	0
8. Compatible with Route Guidance System (Supports = 10)	0	0	10	10	5	0	0
9. ITS Deployment Proven (Proven = 10)	10	10	10	1	2	10	10
10. Seamless for Traveler (Full Seamless = 10)	10	10	8	5	8	10	10
(100 = Perfect) Totals	65	65	75	53	58	74	47

Table 6.1.4.2-1
Infrastructure-to-Vehicle Communications

Evaluation Criteria	RF Tags	IR	Cellular Telephone Voice	Cellular Telephone Data	Land Mobile Radio	PCS Microcellular	Citizens Band Radio
1. Open Architecture (10 = Open)	9	3	10	5	8	8	0
2. High Reliability (10 = High)	6	5	8	8	9	7	1
3. Low Cost to User (10 = Low/Affordable)	10	5	3	3	5	8	10
4. Reaches Wide User Base (10 = Wide)	3	2	10	5	10	9	5
5. Jurisdictional Control of Information (10 = Control)	5	5	5	5	10	10	5
6. Compatible with Route Guidance System (10 = Compatible)	5	10	0	5	10	10	5
7. Low Cost to Jurisdiction (10 = Low)	2	2	10	5	1	0	9
8. Supports Mayday (10 = Yes)	0	0	8	10	10	10	7
9. ITS Proven (10 = Proven)	10	10	10	2	10	2	1
10. High Probability of Wide Acceptance (10 = High)	10	3	10	6	5	6	3
(100 = Perfect) Totals	60	45	74	54	78	70	46

Cellular telephone is a high ranking technology. Cellular telephone components have speed-dial (*) for Mayday reporting and access to traffic and weather conditions. Some cellular companies have the ability to automatically locate a vehicle within a sector of a cell site. A new time-difference of arrival (TDOA) positioning technology is being used for automated vehicle location utilizing the time of arrival of a signal at various cell sites.

Digital Cellular (CDPD) is also emerging. It allows digital data to be transmitted in time slots where voice is not transmitted. This capability is available; however, operational cost of service is an issue.

Siemens has an IR communications link which is used to update their route guidance system and to preempt traffic signals for emergency vehicles. This communication technology is closely coupled to Siemens' products.

RF tag readers can provide communications between vehicles and infrastructure. Type three RF tags, which would cost the user approximately $50.00, can support communications up to l/4 mile. Passive tags (Types 1 and 2) have limited communications range (less than 100 feet). Preferred tags are those which can handle high density traffic [such as a Type 3 tag with Time Division Multiple Access (TDMA) technology as accommodated by the Advantage 75 CVO tag]. But, unless the correct type is selected, implementing RF tag readers with a density to provide Mayday and other support services would be cost prohibitive.

Similarly, use of microcellular technology and digital PCS communications would be cost prohibitive. Thus, the following technology is recommended to support vehicle-to-infrastructure communications.

Technology	***Reason***
Digital Mobile Radio	. Already in use by CVO and transit
Cellular Telephone (Voice)	. Already in use . Encourages Mayday and traffic report services (privatized function)
RF Tag	. Can be used at strategic entrances to corridors . Assures CVE compatibility . Includes HAZMAT reporting to the system . Used for probe vehicles of opportunity

6.1.4.3 Summary of Vehicle-to-Infrastructure/Infrastructure-to-Vehicle Communications

Radio Digital Data Service (RDDS) for communicating traffic conditions on corridors to vehicular route guidance systems and portable subband receiver/displays is recommended.

Mayday reporting is recommended via cellular services with a private/public partnership for coordination. Private cellular systems should report emergency service requests to the jurisdictional system.

Consideration to establish a common ITS frequency, using existing mobile radio infrastructure, is recommended. This common frequency could be used by commercial vehicles to receive traffic reports and corridor conditions as well as to provide Mayday reports.

Yellow Pages services should be provided by a private service using cost effective communications technology-perhaps digital cellular.

RF tag readers should be installed in major routes used by commercial vehicles. The primary purpose would be to receive HAZMAT reports and alert jurisdictions to the presence of HAZMAT within the area. Strategically placed RF tag readers should be considered for determining progress of a HAZMAT vehicle and also to be used to support probe vehicles of opportunity. Corridor travel time and Origin Destination (OD) modeling for traffic conditions prediction can be supported.

Obviously, law enforcement and emergency vehicles will continue to use mobile radios (digital and voice) for dispatching and status.

6.1.5 Infrastructure-to-Other Agency Communications

As provided in Appendix 1, there are several technologies which would be used for interfacing the Maricopa County system with other agencies. These typically would be:

A) Dial-up Plain Old Telephone System (POTS)
- With V.XX modem for digital communications

B) Leased ISDN service, fractioned T-l to T-l, as required
- Isochronous service would be used for any compressed video distribution

C) Direct Drops from the recommended County ITS network for voice and data

Where wireless voice or data communication is permitted, (such as for law enforcement or emergency services) this service would be provided, as determined to be permissible and useful during the detailed design. Policy may dictate that only dispatchers use wireless frequencies associated with law enforcement and emergency service vehicles. It is recommended that a coordination link be established (to the extent allowable) to provide on-scene feedback for incident clearance prediction.

6.1.6 Intra-TOC Communications

Intra-TOC Communications includes video, voice, and data. Thus multimedia capability is required.

A PBX is required to support voice communications. The PBX should be interconnected via a DS- 1 channel (or multiple DS-0 channels) to the network for voice channel services between TOCs and other ITS-related centers associated with the network. PBX trunk lines would be tailored to the needs of the specific jurisdiction, as would local office and workstation voice service.

In addition, the central ATIS center could include PBX trunk lines designed to meet user interface traffic.

Table 6.1.6-1 presents a comparative evaluation of Local Area Network technology. ETHERNET (10 Base XX) is the LAN of choice for the evaluation, followed by ATM, 100 Base XX ETHERNET, and Token Ring. ATM is ranked high because of its market emphasis and flexibility. Token Ring is a proven and reasonably widely deployed LAN technology. The 100 Base XX ETHERNET and 100 VG-ANYLAN are emerging technologies and will be contenders for the future LAN market; thus, their costs are expected to decrease. Fiber Data Distribution Interface (FDDI) is a reasonably widely used LAN technology because it can be extended to MAN; however, it is 15 to 20 times more expensive compared with ETHERNET (10 Base XX). FDDI provides 100 Mbps interface and supports counter-rotating ring fault tolerance. It is based on a token ring principle.

FDDI-II is a new draft standard that endeavors to add isochronous capability to FDDI-I and to increase its data rate to 155 Mpbs (same as ATM). Industry predictions are that FDDI-II will not survive with perhaps ATM and either 100 VG-ANYLAN or an isochronous version of 10/l 00 Base XX ETHERNET dominating the future LAN market. The standards which dominate the market will drive prices down and make the technology affordable, with adoption by PC manufacturers.

Table 6.1.6-1
Intra-TOC Communications

Evaluation Criteria	ETHERNET 10 BASE T/FL	ETHERNET 100 BASE T/FL	FDDI-I	FDDI-II	Token Ring	100 VG-ANYLAN	Fiber Link	Wireless LAN (ETHERNET)	ATM
1. Open Architecture (10 = Open)	10	10	10	2	10	10	10	10	10
2. High Reliability (10 = High)	6	5	**10**	**10**	10	5	5	3	5
3. Low cost (10 = Low)	10	3	4	2	8	3	2	1	2
4. High Efficiency/ Low Overhead (IO = High)	5	5	8	8	8	8	9	4	5
5. Isochronous (10 = Full)	0	10	0	10	0	10	10	0	10
6. High Industry Product support (10 = High)	10	5	5	2	6	3	2	3	4
7. Easy to Interface with MAN (10 = Easy)	10	10	10	5	10	6	2	5	10
8. Supports Flexible Interface (10 = High)	6	2	2	1	3	2	1	10	5
9. Supports Built-in-Test (10 = Excellent)	10	10	10	10	10	10	10	10	IO
10. Provides Growth Margin (10 = Growth)	5	10	10	10	5	10	10	3	10
(100 = Perfect) Totals	72	70	69	60	70	67	61	49	71

As presented in **Table 6.1.6-1,** Candidate LAN Technologies, ETHERNET is the lowest cost technology and obviously wireless ETHERNET provides the most flexibility. Unfortunately, ETHERNET, in its open architecture standard, does not support multimedia; however, under 100 Base T/FL an isochronous standard is in draft. FDDI-II supports isochronous multimedia capability; however, it too is a draft specification without significant industry support. Most likely, industry will support ATM (which is isochronous) and 100 Base XX (XX = fiber or wire standard) ETHERNET (because of the popularity of ETHERNET.) 100 VG-ANYLAN is an isochronous standard, in its infancy and, as stated, may overcome the popularity of ETHERNET.

ETHERNET (either 10 BASE T or 10 BASE FL, copper or fiber operating at 10 Mbps) is the most prevalent local area network technology deployed today. It was developed by Xerox, Inc., in the early 1980s in competition with IBM's Token Ring. The Institute of Electrical and Electronic Engineers (IEEE) developed standards for ETHERNET (IEEE 802.3) and Token Ring (IEEE 802.4) in the early 1980s, in support of LAN technology. Today, ETHERNET interfaces are available from ports on single computer boards, to PCMCIA small modular interface circuit cards. ETHERNETS are available in office and environmentalized configurations.

The 10 Mbps ETHERNET is suitable for most information exchanges between servers and workstations. LAN performance is reasonably good if not overloaded by a significant number of workstations. The collision detection/fairness access scheme used for ETHERNET impacts throughput of the network as workstations and interconnected devices start growing on a LAN. With 20-30 connected devices, ETHERNET performs adequately unless multimedia is added. Multimedia can add significant communications, data processing, and data storage/retrieval load to a system. Isochronous capability is also required to support motion video processing and transfer via a LAN. Frame-grabbed (single frame) video can be handled on standard ETHERNET without isochronous information; however, when large pix files are transferred, this places a large, instantaneous load on a 100 Base ETHERNET. Where a TOC has two to four workstations, a 10 Base ETHERNET with single-frame (compressed) video transfer is suitable. For larger TOCs with perhaps eight to ten workstations and a number of office PCs interconnected to the LAN, a 100 Base XX ETHERNET is more appropriate. Furthermore, 100 Base XX ETHERNET has a draft standard for isochronous operation. Alternatively, 100 VG-ANYLAN standard is already released and is isochronous, supporting multimedia.

IEEE 802.9 standard covers a 10 Mbps ETHERNET with an integral 6 Mbps isochronous capability, which can support MPEG-II video compression. Thus a single channel of full motion video may be supported. This standard is in its infancy with product cost still high.

From a cost standpoint at this time of this report, virtual 100 Base ETHERNET is recommended for the Maricopa County network. Cost of ATM versus 100 VG-ANYLAN versus 100 Base ETHERNET should be reviewed during detailed design. An isochronous 100 Mbps LAN is recommended to support multimedia interoperability within an operation center. The most cost effective of the LAN technologies should be selected.

Within an operation center, a video signal of interest to operational personnel will be selectively "dropped." Through use of CODEC receivers, this video will be converted to conventional form for display, processing, and storage by conventional CCTV video equipment. HDTV is not an available technology at the time of this report. Should it become available, digital video to the monitor may be a cost effective option; however, until HDTV becomes an approved standard and well established within the market, the most cost effective approach is to use conventional NTSC video recorders, monitors, frame grabbers, etc. The best industry estimate is that HDTV, with supporting peripheral devices, will not be a viable option before 2000.

SVGA video is the standard for most workstations. Operation centers require wall displays for management and coordination. Typically, color-coded maps of the infrastructure are used for wall presentation, illustrating congested corridors, location of incidents, location of construction, routes for special events, and other information providing overview comprehension of infrastructure status. Thus, there is a requirement to support SVGA video distribution using a graphics generator with a color graphics projector or a projector with an integral graphics generator which can refresh/generate graphics or images from information received via a common LAN. The physical architecture of the TOC must consider state-of-the-art color graphic projection technology. The Texas Instruments micromirror light value projector may be the next generation wall display technology.

To summarize Intra-TOC communications recommendations, LAN technology is currently in transition to multimedia. Until industry selects the "favorite" technology (as they did with ETHERNET) and prices come down, the best choice cannot be made. ATM will be a major contender as well as 100 VG-ANYLAN and 100 Base XX ETHERNET. FDDI-II looks like it may be on the trailing edge of success probability. The need for 100 Mbps LAN technology is a size issue. Small TOCs that can adequately operate by displaying CCTV video on separate monitors, using only a single-frame for archiving, can adequately use 10 Base XX, which is working well today in TOCs across the country. There is no question that today, 10 BASE XX LANs are the best value for performance.

Use of copper versus fiber is again, installation dictated. In large TOCs where there is a significant amount of electronic equipment, use of fiber optic LANs (XX = FL) minimizes problems with electromagnetic compatibility. Fiber LANs also offer a degree of protection against lightning strikes which can destroy LAN interface circuits. For small TOCs, with just a few workstations, copper LANs (XX = T) are suitable.

It should be noted that TOC guidelines for future architectural commonality should include the ability to share technology (software and hardware) in order to reduce TOC modernization costs and assure that communications interoperability goals are met. It is not intended that TOCs immediately adopt the common architectural "guide" for TOCs, but would evolve over a period of time to the standard.

6.2 Traffic Surveillance and Monitoring Technology Selection

Traffic surveillance and monitoring technology matrices are included in Appendix 1. This section summarizes the technology and presents the recommended technology for deployment.

Classically, inductive loops with traffic signal controllers have been used for traffic surveillance. Loops, when deployed with appropriate geometry, can detect presence of vehicles, measure velocity, classify vehicle by length, and essentially provide key information on low congestion and average flow rate. When properly installed, loop sensors have proven to be reasonably reliable and accurate. In areas where ice causes cracks in road materials, and in areas where clay soil has a high compression and expansion ratio based on soil moisture control, loop reliability problems have been reported. Loops are still the basis of reference for evaluation of competitive sensors such as image analysis (i.e. Autoscope TM). Loops are currently deployed in the County area and should continue to be used, with maintenance provided by the jurisdictions which have them deployed.

Microwave and radar sensors have been developed and are deployed in ITS systems. Glendale, California has microwave sensors which do not reliably operate. Reliability problems exist with Radio Frequency (RF) sensors related to RF interference, multipath, and impact of weather conditions on RF propagation.

Laser sensors operated as radar comprise a reasonably new technology. Having a much more narrow beam, LIDAR is less susceptible to interference; however, multipath can be a problem, as well as signal transmissions deterioration during heavy rain.

IR sensors are an emerging option; however, reliability of these sensors has not proved to exceed that of loops. The advantage of IR sensors is perhaps that they do not have to be embedded in the pavement.

The AT&T acoustical sensor has excellent performance compared with loop sensors. ITS tests have proved that they operate on freeways and within traffic grids. They are designed for interface compatibility with 170 and 2070 controllers. Experimental tests in the AT&T Virginia laboratory indicate that the sensor has the potential to:

- Classify a vehicle;
- Determine velocity;
- Provide a vehicle weight estimate; and

- Provide an indication of unsafe tires.

Acoustic technology is well proven in the military, being a key element in the Army's REMBASS technology. The military technology has proved to be able to classify vehicles and aircraft and even to determine the maintenance status of vehicles. If AT&T continues to perfect this sensor for ITS use, it should provide substantial capability in systems. ADOT currently plans to deploy the AT&T SMARTSONCI™ technology in 1996.

Video image analysis has also emerged from DOD and is now deployed in ITS systems. Autoscope ™ in the United States and Siemen's ARTEMIS in Europe are perhaps the better known technologies. The Peek Video Trak 900, Visitech VT-4000, and Golden River, Inc., Marksman CCATS are reasonably new competitors to Autoscope™. All include the ability to set up "virtual loops" in multiple lanes, including along the roadside. All can extract vehicle presence, count, and velocity, and can classify vehicles by length. The Peek Video Trak 900 is designed to be used with a pair/tilt-mounted camera, providing additional flexibility. These units cost around $5,000 per lane, including camera cost.

Rockwell International has introduced Traffic Cam™, which is advertised to cost $3,500 (non-installed). A single Traffic Cam* includes camera, digital signal processor and video CODEC integrated into a weatherproof housing, perhaps smaller than current CCTV technology. While the compressed video image is of poor quality, it is essentially a by-product of the image analysis processor. Thus, the primary purpose of Traffic Cam™ is not video surveillance, but to automatically measure presence, count, velocity, and vehicle classification in up to four lanes. The camera is reasonably easy to install and is an ideal candidate for deploying video analysis technology on corridors within the county.

CCTV surveillance is very important for traffic management analysis, and incident assessment. CCTV supports functions such as:

- Current congestion assessment;
- Potential congestion assessment;
  - Surveillance of entertainment centers, shopping malls, universities, community colleges, convention center parking, parks, etc.;
- Incident evaluation and clearance;
- Hazard detection and determination;
- Verification of messages on variable message signs;
- Queue build-up behind incidents with assessment of congestion clearance time; and
- Security of deployed equipment in the field.

CCTV surveillance should be included in this system with cameras located as follows:

- Surveillance of major corridors;
- Surveillance of complex intersections; and
- Surveillance of areas funneling large amounts of traffic to corridors.

Table 6.2-l prevents a survey of surveillance technology and the basic functions which it can perform. Controllers also can provide average flow rate and volume and can combine statistics.

Since the sensors use various ways of classifying vehicles, **Table 6.2-2** is provided to illustrate those differences. Vehicle classification provides the TOC with the specific mixture of commercial vehicles, public transit vehicles, and private vehicles which provides a parameter for congestion assessment. The length and size of commercial vehicles impacts traffic flow.

Table 6.2-3 provides an evaluation of surveillance technology. This table indicates that inductive loop technology should continue to be deployed. Acoustic technology is a second choice. While IR and microwave ranked higher than Traffic Cam™, here are two reasons why Traffic Cam™ is recommended. These are:

- It offers microwave reporting of performance problems, and

- It can potentially provide more information to the TOC for very little additional cost (i.e. low resolution video).

Thus, to summarize, the following surveillance sensors are recommended:

- CCTV,

- Loop for control, incident detection, counting, and classification,

- Traffic Cam™ to compliment loop deployment on a non-intrusive basis, and

- Acoustics to complement loop on a non-intrusive basis.

In addition, use of RF tag readers to provide probe vehicle of opportunity information and HAZMAT Alert (CVO tag compatibility) is recommended. Public transit and jurisdictional vehicles should be provided with RF tags to complement private tag use. Compatibility with Sky Harbor Airport RF tags is also necessary.

Table 6.2-1
Functional Performance Comparison of Surveillance Technology

Technology	Function Performed (with Controller)						
	Presence Detection	Count	Velocity	Vehicle Classification By Length	Vehicle Classification By Axle Count	On-shoulder Vehicle Stopped	Queue Length
Loop Inductive	✔	✔	✔	✔	✔		
Loop Fiber Optic	✔	✔	✔	✔	✔		
Video Image Analysis							
Low End (Traffic Cam™)	✔	✔	✔	✔		✔	
Medium (Autoscope™)	✔	✔	✔	✔		✔	✔
High End (ARTEMIS™)	✔	✔	✔	✔		✔	✔
IR	✔	✔	✔	✔			
Acoustic	✔	✔	✔	✔			
Microwave	✔	✔	✔	✔			
Radar	✔	✔	✔	✔			
LIDAR	✔	✔	✔	✔			

Table 6.2-2
Vehicle Classification Comparison

Types of Technology	Vehicle Classification Approach					
	Classification by Characteristic Recognition	Classification by Axle Count	Classification by Axle Count and Weight	Classification by Axle Separation Distance	Classification by Vehicle Length (bumper to bumper)	Classification by Length and Width
Loop		✔			✔	
Image Analysis	✔				✔	✔
IR					✔	
Acoustic	✔				✔	
Microwave					✔	
LIDAR					✔	
Strain Gauge Weigh-in-Motion		✔	✔	✔		
Fiber Optic Weigh-in-Motion		✔	✔	✔		

Table 6.2-3
Evaluation of Traffic Surveillance Technology

Evaluation Factors	Technology								
	Inclusive Loop	Fiber Optic Loop	Imaging Low End	Imaging Medium/ High End	IR	Acoustic	Microwave	Radar	LIDAR
1. Compatibility with Existing Controllers (10 = Full)	10	0	5	5	10	10	10	5	5
2. Low Cost (10 = Low)	10	6	7	3	8	8	5	4	4
3. Multiple Function (1 Point per Function)	7	8	9	10	6	8	6	4	5
4. Measurement Reliability (10 = 99%)	10	10	9	9	8	9	6	8	8
5. Complexity of Technology (10 = Simple)	10	7	6	1	7	4	4	3	3
6. All-weather/Day-night (10 = Best)	10	10	7	8	8	10	8	8	8
7. Non-intrusive on Road; Easy to Install (10 = Easy)	0	0	10	6	10	8	9	9	9
8. Capable of Being Maintained by Jurisdiction (10 = Fully Capable)	10	8	6	2	7	7	5	3	3
9. ITS Proven (10 = Most Proven)	10	1	3	5	5	2	8	7	3
10. Ease of Interface with Communications Network (10 = Easy)	10	3	8	5	6	10	10	5	5
(100 = Best) Totals	87	53	70	54	75	78	71	56	53

6.3 Traffic Signal Control

As the MAGIC Survey indicated, the prevalent technology deployed by jurisdictions is NEMA. There are various vintages and manufacturers of NEMA equipment already deployed. ADOT has selected 179 controllers for traffic signal control as well as standard ITS controllers. Both closed loop and UTCS signal system architectures are deployed within the area. ADOT perhaps has a hybrid control strategy where intelligent controllers are monitored on a frequent basis (once per 20 seconds) with control strategies downloaded as signal plans and selected as traffic conditions and predictions dictate.

There are a number of standard controller technologies available including:

- NEMA (TS-1 and TS-2)
- 179
- 170
- 2070

Within each standard, some manufacturers include features over and above those required by the basic specifications.

The 2070 and NEMA TS-2 are the newest controller specifications. NEMA TS-2 stresses more open architecture for sensor and signal device interface, as well as conflict detector interface, while maintaining a standard interface between controller and TOC. The 2070 controller, under Caltrans development sponsorship, stresses:

- Open architecture at the circuit card level;
- Improved processing capability;
- An architecture supporting a standard, real-time, multitasking operating system (OS-9);
- 170 interface (facilitating direct replacement with existing 170 controllers);
- Improved time clock stability;
- Built-in test and test reporting features;

- Complete flexibility in communications options using open architecture VME-compatible communication circuit cards;

- Significant memory improvement and expandability; and

- Higher-order programming language support.

Manufacturers of 2070 hardware have also developed a NEMA interface, facilitating direct replacement of NEMA TS-1 or TS-2 controllers with the 2070, this configuration of the 2070 is being referred to as "NEMA TS-3" even though there is no supporting NEMA TS-3 specification.

A further feature of the 2070 is that it can support the National Traffic Control ITS Protocol (NTCIP), both heavy and light versions. The advantage is in the ability to extend network management and failure reporting to the controller.

There is no question that the 2070 controller is a far superior and capable controller compared with any of its predecessors. Because of its input/output channel flexibility, processing capability and memory capability, the 2070 can easily be adapted to control variable message signs, accomplish traffic surveillance in support of incident and congestion management, and provide interfaces with weather, hazard detection, and other sensors.

The FHWA has funded software development for the 2070 to support traffic signal control. It is well suited to a hybrid control architecture where the controller reports status once per second but initiates local control from downloaded timing plans. It is further well suited to support advanced adaptive control strategy algorithms.

Conventional and adaptive control options exist. The British and Australian SCOOT and SCATS systems are examples of deployed adaptive control. ALCATEL has a hybrid adaptive control system, an extension of SCOOT, which is operating in Europe. In the ALCATEL system, segments of the system can be placed in adaptive control or returned to a conventional programmed timing plan.

In addition, FHWA has an adaptive control software development project. No published reports have been reviewed related to the success of this project.

It is the belief of many traffic engineers that, perhaps, real-time adaptive control negatively impacts traffic flow, and the frequent perturbations of traffic timing does not allow the traffic flow to adequately adapt. Similarly, communication between traffic signals, adjusting adaptive algorithm inputs in real-time, is perhaps beyond the capability of existing deployed communications infrastructure.

The 2070 controller is uniquely suited for adaptive control, should it be desired, because:

- Processing resources available include:
  - 32-bit processors, and
  - Significant memory, and

- It offers a variety of communications options.

Thus, by deploying 2070 controllers, upgrade to adaptive control is facilitated.

Changing controllers is not recommended until jurisdictional modernization is planned. What is recommended, is that each participating jurisdiction agree, when they upgrade, to use the area standard, with a standard protocol. The 2070 controller is recommended, provided in a NEMA interface compatible with existing signal heads and sensors. The NEMA cabinet should be reusable. NTCIP protocol is recommended with network management implemented, and hybrid control strategy is recommended.

6.4 Navigation, Route Guidance, and Mayday

This section describes technologies related to vehicle navigation, route guidance, and Mayday. Communications technology supporting these functions was described under Section 6.1.

6.4.1 Navigation Technology

Table 6.4.1-1 presents a trade-off of navigation technologies as detailed in Appendix 1. Global Positioning System (GPS) and GPS with dead reckoning are considered to be the superior technologies. These navigation technologies used are for commercial vehicle Automated Vehicle Location (AVL) as well as transit vehicles. The dead reckoning capability provides continued navigation when buildings or maintenance "shadow" the GPS satellite communications line-of-sight path to the GPS receiver.

Differential GPS is preferred over standard GPS since it is far superior in accuracy. With differential GPS, positioning within a lane is possible; thus commercial vehicle operators and transit vehicle operators are transitioning to differential GPS, which requires a separate reference link to the vehicle to provide the differential correction.

Table 6.4.1-1
Navigation Technology Evaluation

Evaluation Criteria	Navigation Technology								
	Real-time In-vehicle					Dispatching Center Oriented		General Guidance	
	GPS	Differential GPS	Dead Reckon-ing/GPS Update	Dead Reckon-ing/Sign Post Update	Inertial	Time Differ-ence of Arrival	DF/Cross Correlation	Map Matching	Cellular Tele-phone
1. Open Architecture (10 = Open)	10	10	10	5	3	1	1	3	3
2. Hardware Affordable to User (10 = Least Cost)	8	5	5	8	1	8	8	8	10
3. High Accuracy (10 = Position in Lane)	9	10	10	7	5	8	4	3	1
4. Self Determinant Location (10 = Self)	10	9	10	5	10	0	0	8	0
5. Sharable with Operations Center (10 = Sharable)	10	10	10	5	3	3	3	0	0
6. High Reliability (10 = High)	8	8	10	6	5	8	5	4	3
7. Integratable with In-vehicle Route Guidance (10 = Integratable)	10	10	10	10	10	0	0	10	1
8. Integratable with Computer Dispatching System (10 = Yes)	10	10	10	10	8	10	10	1	1
9. Low Operational Cost (10 = Low)	10	5	10	5	8	2	2	8	3
10. Database Map (10 = Full)	10	10	10	10	10	5	5	10	3
(100 = Perfect) Totals	95	87	95	71	63	45	38	55	25

Dead reckoning with sign post updates is a very old technology, having been deployed as early as the 1960s. Cost of sign posts to provide updates plus maintenance of sign posts is a main issue. New technology includes use of an RF tag reader for dead reckoning navigation system updates, as well as obtaining vehicle identity for use as probe vehicles of opportunity. Unfortunately, commercial dead reckoning systems are not being produced with a toll tag interface. Siemens offers a dead reckoning navigation system with IR signpost updates.

Time Difference of Arrival (TDOA) is a precision location technology using a cellular network. Teletrak™ uses this technique. A dispatching center pays for position reporting service. Only a cellular transceiver is required in the vehicle. The TDOA processing center provides position reports to the dispatching center over leased lines. TDOA technology is reasonably new and is relatively expensive if frequent location reports on a fleet of vehicles is required.

Direction Finding (DF) with Cross Correlation is supported by General Motors Corporation and Hughes. They offer tracking of toll tags utilizing DF technology. Similarly, commercial positioning service is available using mobile radio transmissions. This technology was originally deployed by Hazeltine Corporation in the early 1970s in Dallas, Texas to locate and track police cars. Reports on position of vehicles are communicated to the dispatching center. The problem with TDOA and DF/Cross Correlation is that position information is not available in the vehicle to support route guidance, and payment for continued operation becomes expensive. Similarly, masking of vehicle communications equipment by buildings in downtown area makes both DF and TDOA technologies somewhat unreliable.

Internal guidance has been used in aircraft for years. It is essentially a dead reckoning system with significantly more accuracy. New progress in fiber optic gyros is providing lower cost, internal guidance systems. A combination of fiber optic gyro with GPS would be very accurate but too costly for general ITS use.

Cellular telephone service can provide crude location of a vehicle within a sector of a cell. It is low cost but generally not considered accurate enough for route guidance support. In its current deployed form, cellular telephone networks do not support real time reporting of vehicle location within a cell since this is not the primary function of the system and there is no user demand for the "crude" location service. Vehicle locations have to be determined in police investigation by reviewing logs maintained at cells which include signal level received.

Map matching is basically a form of route guidance. Initial location of the vehicle is entered and essentially a dead reckoning system is used to determine vehicle position on an electronic map. Its accuracy is crude, but when combined with GPS or sign post updates, it becomes a full capability route guidance system. Dispatching centers include a GIS map and "plot" location of their responsible vehicles as position information is received (either from the vehicles' navigation systems or from an external location system). The dispatching computer determines average travel time and interpolates position along the route map. Logically the vehicle must travel along the corridor until a "turn decision" is necessary, based on trip plan. The database map and correlated position of the vehicle is then displayed on the dispatching console and wall displays. Dispatching logic determines location of the vehicle versus time and compares this with schedule to determine "time late" or "time early." Auto link feedback to the transit or commercial vehicle provides feedback information to the driver related to performance against schedule.

With high-accuracy navigation and timing, a new concept is to allow transit vehicles to preempt signals only if they are late. This is accomplished by real-time coordination between transit dispatching and traffic control and generally includes:

- GPS time coordination between vehicle and traffic control
- Accurate vehicle location
- Knowledge by the traffic system if the transit vehicle is behind schedule by an amount to justify traffic perturbation

Navigation support is a necessity for a modern transit system, especially if it supports accurate traveler information. GPS updated dead reckoning is recommended for transit vehicles, operating within the county area and providing status and schedule information to area travelers. Similarly with "personalized public transit" (dial a ride), it is very important that the dispatching system know vehicle location and load status in order to make an optimized decision relative to vehicle assignment to a ride request.

6.4.2 Route Guidance

Route guidance technology is basically associated with vehicles. The basic functions of the route guidance system are to:

- Receive navigation subsystem input;

- Locate vehicles on the GIS database of the road infrastructure;

- Determine progress along the planned route; and

- Display alerts to the driver of upcoming intersections with cues to proceed ahead, turn right, or turn left.

- Display alerts to the driver about an upcoming hazard (which has been communicated to the vehicle from the ITS infrastructure).

The interface between the route guidance system and the ITS infrastructure provides intelligence on:

- Route segment congestion and travel time estimates;
- Location of hazards along the route; and
- Closed route segments.
- Recommended alternate routes.

With this information, the traveler can "plan" a route based on "least time" or "shortest route" using the route guidance system. Once the driver defines destination and travel route (least time or shortest distance) the trip plan is made. It may be changed if route conditions change while enroute In the same manner that the route guidance system advises the driver of an upcoming turn, it also advises him/her of upcoming road hazards.

Some of the more sophisticated in-vehicle ITS systems include either a data link to a "yellow page" service center or a detailed database within the in-vehicle ITS computer which includes yellow page addresses (and telephone numbers for cellular access). As part of the route planning function the driver can call up the location of a public or commercial building and the route guidance computer will provide best routing (based on shortest time or shortest distance). Where an external yellow page service is provided, location is extracted from the data link message received in response to a request.

The Delco Telepath (DT) radio supports FM subband digital link to the (DT) in-vehicle traveler information and route guidance system. This is the critical link to support basic route guidance functionality. It is a one-way link and provides corridor status and hazards warning to drivers. This link is recommended to be incorporated into the system.

Incorporation of route guidance into vehicles will be the responsibility of individual owners and commercial vehicle owners (including leasing/rental agencies for private vehicles, such as Avis, Hertz, etc.). The system planning issue is related to supporting the route guidance system with corridor status and hazards data. With the emergence of FM subband digital communications as a normal production feature of automobiles, it is prudent to plan to support this link, which will require support of an area FM radio broadcast station.

6.4.3 Mayday

"Mayday" is an ITS function which provides positive messaging of an accident from the vehicle to a center which is responsible for responding to the emergency. Emergency roadside telephones are a form of "Mayday" which requires a driver to walk (up to l/3 mile) to the telephone and report the emergency. Of course in the case of a serious accident., the driver (or his passenger) could not walk to an emergency telephone (which could be 2,000 feet away). Wired and cellular emergency telephones are typically deployed along freeways and are now emerging in tourist areas and on college campuses.

Another form of "Mayday" is use of a cellular telephone to report an accident and request emergency service. Many cellular telephone companies are providing speed-dial emergency reporting and dispatch service coordination for their customers. Again, use of this function requires the driver (or a passenger) to be able to make the call for help. It also assumes that the cellular telephone was not damaged in the mishap.

For any vehicle which has a mobile radio and is in communication with a central dispatching center, this radio becomes a link for "Mayday." In fact, this form of accident reporting (as well as corridor status condition) is very prevalent, especially with dial-a-ride service such as Super Shuttle. In a similar manner, truckers with Citizens Band radios communicate traffic status and accidents.

Any passing vehicle can, if they take time, report an incident. Motorist Assistance Patrols (MAPS) on freeways provide accident surveillance service and reporting. Of course, they also rely on the incident detection capability of the freeway system to identify assistance needed by drivers.

The "Mayday" concept which is arising in ITS is for real-time reporting of an accident to emergency services centers and/or to a traffic operations center. The concept is to integrate safety sensor and associated alarm signals with a "Mayday" automated reporting system much like a home security system with remote monitoring. In-vehicle route guidance systems would provide location of the emergency and in-vehicle sensors would provide an assessment of the seriousness of the emergency. In-vehicle sensors may include:

- Impact sensors and release airbags;
- Fire sensors;
- Gas leak sensors; and
- Occupancy sensors;

With:

- Time;
- Location;
- Vehicle occupants; and
- Seriousness of the accident.

When incidents are reported in real-time to a TOC, an incident manager can reduce response time for emergency services dispatching. There is further consideration for including a "manual panic button" for robbery attempts (such as a happened in Miami), and a manually-activated request for mechanic services. The problem with manual activations is false alarms. Fines for false alarm reporting and interlock keys to prevent children from issuing false alarms is an alternative.

While automated "Mayday" is a beneficial ITS service because it:

- Can save lives;
- Can clear incidents quicker, reducing congestion; and
- Improves security of drivers and passengers on the roads;

It requires:

- An integrated vehicular information system where sensors are automatically monitored, and
- A vehicle-to-infmstructure data link.

Cars are only now being designed to include this capability and standards for communications are not in place.

Perhaps the in-vehicle "Mayday" service can be privatized in Maricopa County in a manner similar to the way that homeowners pay $20 to $30 per month for a monitoring service (such as Westinghouse Security) to monitor homes, plus paying a $30 to $50 yearly licensing fee to support cost of police dispatching. Since the trend in home security monitoring is transition to a cellular telephone interface (to prevent cutting of copper telephone lines), the same wireless digital service can support "Mayday" monitoring of vehicles. In fact, Ford Motor Company will provide a capability in their 1996 Lincoln called Remote Emergency Satellite Cellular Unit (RESCU). RESCU utilizes an in-vehicle route guidance systems (GPS based) with a real time cellular link to the Westinghouse Emergency Response Center (Irving, Texas). This center originally was developed to support home security.

The recommendation for this system is to include real-time "Mayday" monitoring as a privatized service offered preferably by an established security service; altematly by the ATIS center. A communication link will be provided with the SONET network for coordinating emergency services and managing incident clearance.

6.5 Advanced Traveler Information Services Technology

6.5.1 Overview of Advanced Traveler Information Service Technology

ATIS services are categorized by the location of the traveler that they serve. These are:

- Travelers in private vehicles;
- Private travelers out of vehicle (walking);
- Private travelers at home or office;
- Private travelers on public transportation vehicle;
- Commercial driver in vehicle;
- Commercial/transit operations out of vehicle.

Each of the above categories includes unique requirements. This section addresses the terminal device. Section 6 of this report addresses communications.

6.5.2 Technology Trade-off for Traveler in Private Vehicle

Table 6.5.2-l presents the devices which support in-vehicle ATIS. Evaluation ranking is as follows (most effective/desirable to least):

- Enroute guidance and passenger information system
  - Supported by radio digital data service
- Variable Message Signs
  - Supported by direct interconnect with systems ATIS center and TOCs
- Broadcast radio
  - Supported by ATIS communications links to public media for traffic status
  - Highway advisory radio
- Cellular Telephone
  - Supported by the cellular telephone traveler information service interfaced with the system's ATIS service link
- Path finder signs on intelligent corridors
  - Controlled by ITS
- Toll tags with alarms and displays (Type 3):
  - Supported by direct links to ITS
- Public cellular digital
  - Supported by digital links to cellular interfaced with the ITS ATIS center for **support**
- Paging
  - Paging service traveler information supported by available service link from ATIS

Technology recommended includes all but paging and toll tags. Toll tags for enroute traveler information are worthy of testing but not as a massive deployment of technology due to cost. Paging is not recommended due to the limited information available to the traveler.

The following additional recommendations are made:

- Privatized services supported by available digital link from the ITS ATIS operations center:
  - Broadcast radio
  - Broadcast radio FM side band RDDS
    - Project (ITS) will develop standards; not left to the radio station
  - Cellular telephone service, traveler rapid dial
  - Cellular digital service using traveler's private personal digital assistant or laptop computer with wireless modem

- ITS services
  - Variable message and path finder signs
  - Highway advisory radio
  - ATIS broadcast service to private suppliers for corridor status, incident notification, and transit schedule/status

Table 6.5.2-1
Traveler Information Service for Private Mobile (In-vehicle Traveler)

Evaluation Criteria	Technology							
	Vehicle Information System/ Route Guidance	Broadcast Radio	Variable Message Sign	Cellular Telephone (Voice)	Public Cellular Network (Digital*)	Paging with Traveler Service	Pathfinder Signs	Toll Tags with Displays
1. Cost to Driver (10 = Low)	2	10	10	7	6	8	10	8
2. Lifecycle Cost to Jurisdiction to Support (10 = Low)	9	10	6	10	9	9	9	3
3. Overall Effectiveness to Driver (10 = Best)	10	5	8	6	5	4	8	8
4. Best Technology for Trip Planning (10 = Best)	10	5	0	8	9	4	0	3
5. Best Service for Hazard Warning (10 = Best)	10	9	9	4	2	3	0	10
6. Accuracy and Reliability of Information (10 = Best)	10	7	10	7	8	7	10	10
7. Most Likely to be Used by Drivers (10 = Most)	10	5	10	9	2	2	10	4
8. Proven in ITS (10 = Well Proven)	6	10	10	10	3	2	5	1
(80 = Best) Totals	67	61	63	61	44	39	52	47

*Includes Personal Digital Assessments and Laptops

6.5.3 Technology trade-off for out-of-vehicle, mobile (walking) travelers

Table 6.5.3-1 presents a summary of technology available to the traveler which is not in a vehicle, in his home, or in his office. Ranking of this technology is as follows (highest recommended to least recommended).

- Cellular Telephone
  - Private service supplied by an ATIS link

- Personal digital assistant or laptop PC with wireless modem interconnected to a cellular service
  - Private service supported by an ATIS link

- Broadcast radio
  - Public media ATIS link should be offered

- Portable broadcast TV
  - Public media ATIS link should be offered

- Public kiosk
  - Privatized deployment should be encouraged, providing corridor and transit status from ATIS center .

- Pager
  - Not recommended at this time due to limited information that can be transferred and the fact that interactive paging systems are not widely deployed at this time.

Table 6.5.3-1
Traveler Information for Mobile Traveler — Non-vehicle (Walking)

Evaluation Criteria	Technology					
	Broadcast Radio (Portable)	**Broadcast TV (Portable)**	**Cellular Telephone**	**Personal Digital Assistance/ Digital Cellular**	**Public Kiosk**	**Pager**
1. Cost to User (10 = Low)	10	10	7	6	0	9
2. Convenience to User (10 = Most Convenient)	10	10	10	9	8	7
3. Cost of Special Service to Jurisdiction (10 = Low)	10	10	10	9	5	9
4. Effectiveness of Support for Vehicle Trip Planning (10 = Most Effective)	4	5	8	10	10	3
5. Most Likely to be Used by Travelers (10 = Most Likely)	10	5	10	3	2	1
6. Reliability of Information to Traveler (10 = Most Reliable)	5	6	9	10	10	2
7. Best Service for Transit Trip (10 = Best)	0	0	10	10	10	0
8. Proven in ITS (10 = Most Proven)	10	10	10	2	5	1
(80 = Best) Totals	59	56	74	59	50	32

6.54 Private Traveler at Home, Office, or Hotel

Table 6.5.4-1 presents technology considered for the private traveler at home, office, or hotel. It assumes that telephone service and interacted TV are linked to an ATIS support center and that public media is offered access to corridor and public transit information. There is, of course, no assurance that public media nor CATV will broadcast traveler information. A public service channel or CATV is an exception. The following ranking results from the evaluation:

- Plain Old Telephone Service
  - Dial-up interactive voice (Auto-voice) with an ATIS center.

- Cellular telephone
  - Dial-up to the cellular traveler information service supported by ATIS link

- Interactive hotel television
  - Deployed in some modem hotels
  - Encourage adding on traveler information channel which is serviced from the ATIS center, perhaps, on a fee per use basis for added service to the hotel's customers

- Interactive cable TV
  - Same as hotel but on an area basis
  - In its infancy in deployment
  - Should plan a support link

- Broadcast TV

- Broadcast Radio
  - Offer ATIS link to improve accuracy of traffic reports

- Plain Cable TV (non-interactive)
  - Offer an ATIS link or use a public service channel

Table 6.5.4-1
Traveler Information Service for Traveler in Home, Office or Hotel

Evaluation Criteria	Technology								
	Broadcast Radio	Broadcast TV	Cable TV	Interactive Cable TV**	Interactive Hotel TV Cable Service**	Home/Office Computer/ Modem*	Fax*	Cellular Tele-phone	Plain Old Telephone Service*
1. Cost to User (10 = Low)	10	10	5	4	4	5	5	7	9
2. Convenience to User (10 = Most)	10	9	9	8	10	4	8	10	10
3. Effectiveness for Private Vehicle Route Planning (10 = Most)	4	8	9	10	10	10	10	10	10
4. Effectiveness for Public Transit Route Planning (10 = Most)	0	0	1	10	10	10	8	10	10
5. Effectiveness for Yellow Page Services (10 = Most)	0	0	0	10	10	10	8	10	10
6. Reliability of Information (10 = Most)	5	6	6	10	10	10	10	10	10
7. Likely to be Used by Traveler (10 = Most)	10	9	8	5	10	4	4	10	10
8. Proven in ITS System (10 = Most Proven)	10	10	10	1	1	4	4	10	10
(80 = Perfect) Totals	49	52	48	58	65	57	57	77	79

* Assumes dial-up voice, fax, and data access to ATIS Center
** Assumes ATIS Interface

6.5.5 Traveler in Public Transit Vehicle

Table 6.5.5-l presents the technology options to a traveler in public transit vehicles. They are similar to those of a walking traveler; however, adding kiosk terminals in the bus is being tested, under "SMART Bus" technology. The kiosk terminal would be serviced via digital link(s) to the bus which support AVL/AVM; a separate interactive link would be required. Alternatively, a private service may be interested in funding kiosk terminals in public transit vehicles for advertisement and fees from yellow page customers. A private digital network or digital cellular link could support ATIS distribution to the vehicle. Common technology in public vehicle is an announcing system tied to vehicle location. It provides the traveler with the identification of the next stop. This is not considered to be advanced technology and it does not specifically respond to a traveler's needs.

It is recommended that the in-vehicle kiosk terminal be a privatized function with ATIS information support provided by the ITS system to the privatized center.

Ranking of technology include:

- In-transit-vehicle kiosk/terminal
- Cellular telephone
- Broadcast radio (portable)
- Portable TV
- Personal digital assistant/laptop computer with wireless digital modem and cellular interface
- Variable message signs
  (Listed because this mode is an available information source, but not preferred for this application)
- Paging terminal with traveler information.

6.5.6 Traveler Information Service for Commercial Vehicle Driver

Table 6.5.6-l presents options for traveler information within commercial vehicles. This would also apply to transit vehicle drivers. Ranking is as follows:

- Vehicular information system with route guidance
- Radio link from dispatching center (voice or digital)
- Variable message signs
- Broadcast radio including HAR
- Cellular telephone
- Pathfmder signs
- Toll tag alarm and display (Type 3 tags)
- Digital cellular with personal digital assistant or laptop computer

Table 6.5.5-1
Traveler Information For Public Transit Module Passenger

Evaluation	Technology						
	Broadcast Radio (Portable)	Broadcast TV (Portable)	Page Terminal	Cellular Telephone Voice	Cellular Telephone Digital*	In Bus Kiosk	Variable Message Signs
1. Cost to Passenger (10 = Low Cost)	10	10	9	7	6	10	10
2. Lifecycle Cost to Service Provider/Jurisdiction (10 = Lowest Cost)	9	9	9	10	9	5	5
3. Usefulness for Trip Planning While Riding (10 = Most Useful)	8	9	3	5	9	10	1
4. Accuracy and Reliability of Information (10 = Highest)	7	7	7	7	9	10	10
5. Most Likely to be Used by Traveler (10 = Most Likely)	10	5	1	10	5	10	2
6. Proven in ITS (10 = Most Proven)	10	10	2	10	3	3	10
7. Most Useful for Transit/ Public Transportation only (10 = Most Useful)	0	0	0	8	10	10	0
8. Most Convenient for Rider Use (10 = Most Convenient))	10	5	5	10	3	8	0
(80 = Best) Totals	64	55	36	67	54	66	38

Table 6.5.6-1
Traveler Information Service for Commercial Vehicle Driver (in-vehicle)

Evaluation Criteria	Technology							
	Vehicle Information System/ Route Guidance	Broadcast Radio	Mobile Radio with Dispatcher	Cellular Telephone (Voice)	Cellular Telephone (Digital*)	Variable Message Signs	Pathfinder Signs	Toll Tags with Displays
1. Cost to CVO Operator (10 = Low)	2	10	2	7	6	10	10	7
2. Lifecycle Cost to Jurisdiction to Support (10 = Low)	9	10	10	10	9	6	9	3
3. Overall Effectiveness to Driver (10 = Best)	10	5	10	6	5	8	8	8
4. Best Technology for Route Planning (10 = Best)	10	5	10	8	9	0	0	3
5. Best Service for Hazards Warning (10 = Best)	10	9	5	4	2	9	0	10
6. Accuracy and Reliability of Information (10 = High)	10	7	10	7	8	10	10	10
7. Most likely to be Used by CVO (10 = Most)	10	5	10	9	2	10	10	10
8. Proven in ITS (10 = Proven)	6	10	10	10	3	10	5	1
(80 = Best) Totals	67	61	67	61	44	63	52	52

*Includes Personal Digital Assessments and Laptop Computers

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It is recommended that commercial vehicles be supported with RDDS traffic conditions plus offer communications interfaces to ATIS on a per fee basis. The commercial user pays for communications cost; however, ATIS data should be available on a computer-to-computer basis using the public telephone network.

6.5.7 Traveler information for CVO and Transit Dispatching

Table 6.5.7-1 surnmarizes technology available to support a CVO and/or transit dispatching center related to route planning, hazard advisories, and conditions impeding current schedule progress.

A direct link to ATIS service information is the best technology with the ability to add real-time traffic reports received from drivers over their in-vehicle voice links . Implementing the technology is the responsibility of the CVO organization or transit company. ITS service should be to move available information with the private company paying communications cost. Communications interface would be via the public telephone network.

6.5.8 Summary of ATIS Technology Recommendation

Table 6.5.8-1 sumrnarizes ATIS technology recommended. Recommended are:

A) Plan for full service ATIS in region

- Include integrated traffic conditions and public transit schedules/status
- Offer ATIS service link interface to interested users including:
  - Privatized ATIS service centers
  - Public broadcast and CATV media
  - Cellular telephone and data services
  - Vehicle dispatching centers (CVO and transit)
- User-paid communications service
  - Leased public telephone lines, broadcast, digital service
- Interactive services provided to users by private ATIS information suppliers

B) Plan for deployment of limited public kiosk terminals

- Number and location will depend on privatization interest in ATIS
- Plan for deployment in airports (possibly funded by airport authority and rental car companies), convention centers, etc.
- Use as demonstration project to encourage private partnership; objective will be to transition to privatization

Table 6.5.7-1
Commercial and Transit Operations Out-of-Vehicle Traveler information Service

Evaluation Criteria	Traveler* Information Integrated with Computer and Dispatching System	Broadcast Radio	Broadcast TV	Cable TV	Interactive* Cable TV	Cellular* Telephone	POTS*	Fax*	Mobile Radio Reports From Drivers
1. Cost to User (10 = Lowest)	5	10	10	5	3	7	9	8	5
2. Convenience to User (10 = Most)	10	3	4	4	8	7	7	6	8
3. Effectiveness for Pretrip Planning (10 = Most)	10	3	4	4	10	5	5	6	6
4. Effectiveness for Enroute Planning (10 = Most)	10	3	4	4	8	9	5	4	10
5. Effectiveness for Yellow Page Services (10 = Most)	10	0	0	0	10	10	10	5	0
6. Cost to Support by Jurisdiction (10 = Lowest)	0	10	10	10	5	8	5	5	10
7. Most Likely to be Used by CVO if Available (10 = Most Likely)	10	9	9	9	7	7	10	7	10
8. Proven in ITS System (10 = Most Proven)	4	10	10	10	1	10	10	5	10
(80 = Perfect) Totals	59	48	51	46	52	63	61	46	59

* Supported by ATIS System Interface

Table 6.5.8-1
ATIS Technology Summary

ATIS Technology Recommended	ATIS Terminal	ATIS Terminal Finance	ATIS Communications Link	ATIS Communications Link Facilitating Service Finance	ATIS Communications Link Operations Finance
Broadcast Radio Terminal	Standard radio	User	Broadcast radio station and HAR	ITS project	Radio station and jurisdictions for HAR
Broadcast Radio FM Subband Digital	FM radio with subband modification (Delco)	User	Broadcast radio station	ITS project	Radio station and ITS project
Broadcast TV	Standard TV set; home/office, and portable	User	Broadcast TV station	ITS project	TV station
Cable TV (CATV)	TV with CATV adapter	User	CATV	ITS project	CATV station or public channel, if available
Interactive CATV	TV with interactive CATV adapter	User	CATV	ITS project	CATV station and/or hotel
Variable Message and Pathfinder Electronic Signs	Electronic signs	Jurisdictions	ITS system link	ITS project	ITS project

(Continued on next page)

Table 6.5.8-1, *cont.*

ATIS Technology Recommended	ATIS Terminal	ATIS Terminal Finance	ATIS Communications Link	ATIS Communications Link Facilitating Service Finance	ATIS Communications Link Operations Finance
Kiosk Terminals	Kiosk terminals	Private and jurisdiction	Private links to terminal, private terminals, and public link to public-supported terminals	ITS project	Private funding for private links, public funding for public link
RF Tag Link (ETTM)	Toll tag in-vehicle/ Type III, with display	User	RF tag link	ITS project	ITS project (experimental limited basis)
CVO and Transit Dispatching Systems	Integrated real-time traffic conditions	User	Data link from ITS system	ITS project	Users: CVO and transit
Dial-up Digital Service: PDA and Computer Support	PDA with modem and computer with modem	User	POTS/Dial-up direct or via cellular telephone	ITS project	User pays via software charge; privatized ATIS with yellow page advertisers providing funding
Dial-up Voice Service	Autovoice via standard telephone or cellular telephone	User	POTS or cellular	ITS project	Cellular telephone private service or privatized ATIS service funded by yellow page advertisers

- Integrate, to the extent possible, with the system communications backbone to minimize communications cost
- Public kiosks should not provide yellow page services. Electronic yellow pages should be privatized.
  - Provide corridor conditions and transit schedule/status.

C) Jurisdictions deploy variable message signs, pathfinder signs, and WAR supported by the ITS system and communications network.

D) Radio digital data service should be implemented by partnering with a local FM station with full area broadcast coverage. The RDDS link information should be planned to be created by the ITS system and supplied to the radio station. Radio station will broadcast information as a public service. This is perhaps the most important ATIS service which is emerging.

E) Partner with an area major cellular service company and security monitoring service to support Mayday. "Mayday" is a highly visible ITS service to users and deployment encourages tax payer's support for ITS projects.

An experiment with the effectiveness of a vehicle RF tag for hazard warning and traffic conditions information transfer is recommended, pending Sky Harbor Airport's implementation of RF tags for commercial vehicle management and fee collection.

The RF tag reader experiment could be conducted in conjunction with HAZMAT warning and probe vehicle of opportunity tests. Larger deployment of the technologies would be based on test results. One key to success is the wide use of versatile RF tags within the region.

6.6 Air Pollution Monitoring

One objective of stakeholders is to reduce air pollution. The "Smog Dog" is a transportable, roadside pollution monitoring system which is currently under test in the Phoenix area. This unit can automatically survey traffic, locate a vehicle which exceeds pollution standards, and capture a video image of the vehicle and license plate with pollution measurements recorded. Capability can be integrated with the system through wireless digital communication link. Once integrated, the address of the owner of the vehicle can automatically be retrieved from a digital link to the state auto license computer. A notice to repair the vehicle can be automatically prepared. A second detection after the grace period by "Smog Dog" could create an alarm condition for ticketing.

Public Works reports on construction and street repair	Obstruction of lanes	Common practice

In addition, there are a number of other sensors which may be deployed to support hazardous conditions detection and reporting. These are summarized in **Table 6.7-2.**

Table 6.7-2
Specific Hazards Sensors

Sensor	Hazardous Conditions Sensed	Comment
Wind velocity/direction, temperature, precipitation, and barometric pressure	Weather conditions which may adversely impact driving	Proven technology deployed in a number of ITS projects
IR and embedded moisture/ temperature sensors	Ice conditions on bridges	IR is a non-contact sensor. Provides a hazards warning signal to TOCs. Deployed in northern U.S. ITS systems
Water level sensors	Road flood conditions	Measures water level in dip of a road susceptible to flooding conditions. May also control a pump station. Deployed as part of the ADOT Freeway Management System.
Radar	Pot hole and potential pot hole detection. Detects voids under concrete. Also detects moisture in surface asphalt and overlay delamination.	Technology, called subsurface Interface Radar (SIR), operates at 1 GHz and 800 MHz in R&D under strategic highway research program.
Toxic fume sensors	A variety of toxic fume sensors may be deployed, especially in tunnels, to detect carbon monoxide, methane, carbon dioxide	Toxic fume sensors are utilized in tunnels to assume ventilation system is working and to detect a hazardous condition

IR Fire	Used in tunnels to detect vehicle fires	Fire detection in tunnels that could result in explosion(s)
Smoke	Used in tunnels in conjunction with fire detection sensors	Part of hazard warning for fire and decreased visibility in tunnels
Visibility sensor	Used in areas susceptible to heavy fog. Typically a transmitting sensor is used.	Typically deployed in valley areas and bridges where fog may be a problem
Rock fall/slides	Used to detect rock fallen on to the road from an adjacent cliff. Sensor varieties include a wire grid with strain gages, video sensors, laser light beams, etc. The rock slide condition is reported to the TOC.	Typically deployed along mountain roads where falling rock is a problem
Snow Avalanche	Sensors are used in areas where snow slides could potentially block a road. The sensor measures snow depth and reports it to the TOC.	Typically deployed in mountainous areas
Hazardous Agent Detectors (chemical warfare agents)	Special sensors deployed for detection of military nerve gas and other chemical warfare agents. They detect hazardous materials accidents and leaks.	Typically deployed in areas, such as Portland, known to have military storage of chemical agents
Nuclear Radiation	Special sensors deployed in areas around nuclear power generators and military nuclear material storage areas. These sensors detect high radiation levels and provide an alarm to TOCs.	Sensors determine hazardous corridors and best evacuation route

Other sensors are used in support of environmental protection including ozone level sensors and pollution sensors such as the Smog Dog. Generally, pollution sensors are deployed by the Environmental Protection Agency and support smog/ozone alerts and execution of discount fares on public transportation.

Another technology that senses hazardous materials is receiving interest in the ITS community. Since only Class I hazardous material must be reported for transit through an area, Class III and Class II are not reported. This means jurisdictions are not aware that certain hazardous chemicals and biological agents may be present. Using the commercial vehicle RF tag reader strategically deployed on main commercial corridors, the presence of a vehicle with any hazardous material (Class I to III) may be detected upon entering and exist from the jurisdiction. This provides a "potential hazards warning" to the jurisdiction. If the vehicle is involved in an accident, the jurisdictions is then better prepared to quickly and effectively deal with the clean-up.

Obviously, as in-vehicle safety sensors emerge and Mayday reporting capability is facilitated by vehicular technology, a near instantaneous knowledge of an accident with injury, fire, or potential fire (gas leak) will be available to the jurisdiction. This, too, is a form of hazards warning.

Hazards warnings to the driver are accomplished in a number of ways as summarized in **Table 6.7-3.**

Table 6.7-3
Hazards Warning to Drivers

Warning Method	Used for	Comment
Portable signs	Road work, ice conditions, etc.	Classically used
Fixed signs	Utilized to advise drivers of hazards under certain conditions such as rain (i.e. slippery when wet)	Classically used
Highway advisory radio (HAR)	Alerts drivers to upcoming hazards of any nature including accidents	Effective only if driver turns on vehicle radio
Variable message signs	Alerts drivers to upcoming hazards of any nature including accidents	More effective than HAR
In-vehicle route guidance systems	Can specifically locate a hazard in the route guidance database and warn drivers within approaching vehicles	Most effective hazards warning
Special low-powered hazards beacon	Placed at a hazard, it communicates with a receiver	

	in the vehicle. Could use a Type III RF toll tag with toll tag reader at the hazard.	Under ITS test; requires the driver to buy a special device for the vehicle.

Hazards sensors and warning technology recommended for this project are summarized in **Table 6.7-4.** Ice and snow conditions within the area do not justify sensors for these hazards. Rock slides are also not considered a significant hazard. Nuclear radiation, based on of the area's nuclear power plant, could be considered a potential hazard; however, current alarm signals within the power plant are integrated with the area emergency alert network. The TOCs should include capability to monitor public media traffic, weather, and emergency reports.

Tunnel sensors are currently accommodated by DOT and should be deployed as necessary in tunnels. There are no known chemical warfare agents, such as nerve gas, stored within the area to justify special sensors. Radar "pot hole" detectors are not developed sufficiently to recommend deployment. Fog is not known as a significant enough problem in the County to justify visibility sensors. Thus, the main hazards to consider are:

- Road debris;
- Road construction and repair;
- Vehicle accidents (normal);
- Vehicle accidents with fire and fuel spills;
- Flooding; and
- Hazardous material accidents.

Sensors and hazards reporting technology presented in **Table 6.7-4** support these main hazards.

Table 6.7-4
Hazardous Conditions Technology Recommended

Technology	Where to Deploy	Connect or Technology Needed
Sensors:		
▪ CCTV	▪ Along major corridors	▪ Uses DSP camera technology
▪ Incident Detection	▪ Along major corridors	▪ Includes loop, acoustical, or video sensors
▪ Human Eye	▪ Partner with cellular company for no cost speed-dial of hazards reports	▪ Excellent source of information if made convenient
▪ Flood Conditions	▪ Road areas susceptible to flooding	▪ ADOT has currently deployed
▪ HAZMAT presence	▪ CVO RF tag readers on major commercial routes	▪ Must have compatibility with CVO tags
▪ Tunnel Sensors	▪ In major tunnels of the area	▪ ADOT has currently deployed
Information Dissemination:		
▪ Highway Advisory Radio (HAR)	▪ Area coverage	▪ Managed by County ITS
▪ Broadcast Radio and TV	▪ Links to broadcast media	▪ Served by ATIS center
▪ RF tag in-vehicle warning	▪ Portable at hazard	▪ Managed by jurisdiction
▪ Radio Digital Data Service (RDDS)	▪ (FM subband) directly to route guidance system of vehicles	▪ Served by ATIS Center
▪ Variable Message Signs	▪ Along major corridors	▪ Managed by jurisdictions
▪ Fixed and Portable Signs	▪ Along major corridors, as needed	▪ Managed by jurisdictions

6.8 Electronic Fee Collection

Electronic Fee Collection on Public Transit Vehicles is an objective. This is a technology which should be implemented by the Transit Authority. It involves use of a "Smart Card" either readable by RF interrogation or readable through use of a magnetic reader or the bus. Standardization of the card is the main issue. The Transit accounting system must be modified to accommodate the electronic transactions with interface with the financial broker associated with paying the Transit Company from the traveler's account.

Electronic toll tags are under design consideration at Sky Harbor Airport. These toll tags will be utilized for parking fee collection, employee parking security, security control of commercial vehicles on the airport and management of taxi cabs. It is important that a common toll tag standard be adapted for the area. Currently there are many competing standards. While a draft National standard on Electronic Toll and Traffic Management tags exist, it has major problems with International Standards Organization Level 1 layer interface. It is important that the area toll tag standard comply with the new commercial vehicle electronic tag, which most likely will evolve as the National CVO Standard.

Where the jurisdictions requires electronic fee collection for parking, corridor use (congestion pricing) or use of a toll tag for probe vehicles of opportunity, a common standard should be utilized. Readers are recommended for use on main CVO corridors to identify presence of HAZMAT in the area.

Type III (Intelligent Active) Toll Tags provide the most flexibility for multiple application within the area. Type III toll tags can provide feedback to drivers not only for low account balance but also for road hazards warning. They can be adapted for "sign post" updates of route guidance, dead reckoning navigation subsystems.

They further have the capability of operating over multiple lanes as is accomplished on the Advantage 75 project.

6.9 Electronic Enforcement

Electronic enforcement technology includes:

- Automated sensing of a violation and logging of the violation event, time, and location;
- Automatic capture of an image of the license plate (and driver if state law requires);
- Automatic extraction of the license plate number and state (manual assistance if necessary);
- Capture of other key vehicle features (for automatic identification and tracking);
- Automatic access to state vehicle registration database for copying of vehicle owner's name and address;
- Automatic generation of violation notice or fine; and
- Automatic transmission of violation parameters to a law enforcement officer, if supporting near real-time apprehension and ticketing.

Typically electronic enforcement is associated with:

- Automated CVO vehicle inspection stations;
- Electronic fee collection stations; and
- Automatic safety and pollution violation stations.

Where toll tags are used, electronic enforcement is recommended. It is an integrated part of "SMOG DOG" pollution detection technology.

Electronic enforcement is generally negatively viewed by the public. It should be prudently used, otherwise, public support for ITS is lost. With automated surveillance and electronic enforcement comes the public concern over Orwell's *1984* "Big Brother is watching" syndrome. This could lead to public objections to using vehicles as probe vehicles of opportunity.

6.10 Vehicle Safety

Vehicle safety sensors are beyond the scope of this project. They involve:

Mayday:

- Impact sensors (associated with air bag Release)
- Under-hood fire detection sensor
- Under-hood trunk-area gas leak sensor

Any Vehicle Safety:

- Collision warning
- Over speed limit
  - Speed limit for corridor transferred via infrastructure-to-vehicle data link
  - Vehicle information system advises driver of speed violation
- Night vision enhancement

CVO Safety:

- "Air break pressure loss" warning
- "Steep hill ahead" warning
  - Through hazards warning link from infrastructure-to-vehicle route guidance and driver information system.

Early research by AT&T on its acoustic sensor indicates the possibility of detecting excessive tire wear. Thus a hazards warning signal could be generated and conveyed to the commercial vehicle via infrastructure-to-vehicle data link. A Type III CVO tag would accommodate this communications link.

For public transit rider safety, typically SMART buses include a "Mayday" alarm from driver to transit dispatching in case of an accident, mechanical problems, or robbery. Many "SMART Bus" projects include automatic monitoring of the bus's mechanical performance as part of a preventative maintenance program. The data link that supports automatic vehicle management and monitoring is part of the transit infrastructure. It interfaces with both transit dispatching and transit maintenance management.

Some CVO operations include real time monitoring of the fleet's mechanical status. Again, this information is communicated to CVO dispatching and/or maintenance management.

In-vehicle sensors are considered to be the responsibility of the owner of the vehicle. In-vehicle information, route guidance, and communications transceivers are also considered to be the responsibility of the vehicle owner. Link to the vehicle for hazards warning and corridor conditions is recommended for inclusion in this project.

6.1 1 Operations Centers

6.11.1 Architecture of Operations Centers

As previously discussed, the architectures of existing TOCs vary. The objectives of this ITS project should be:

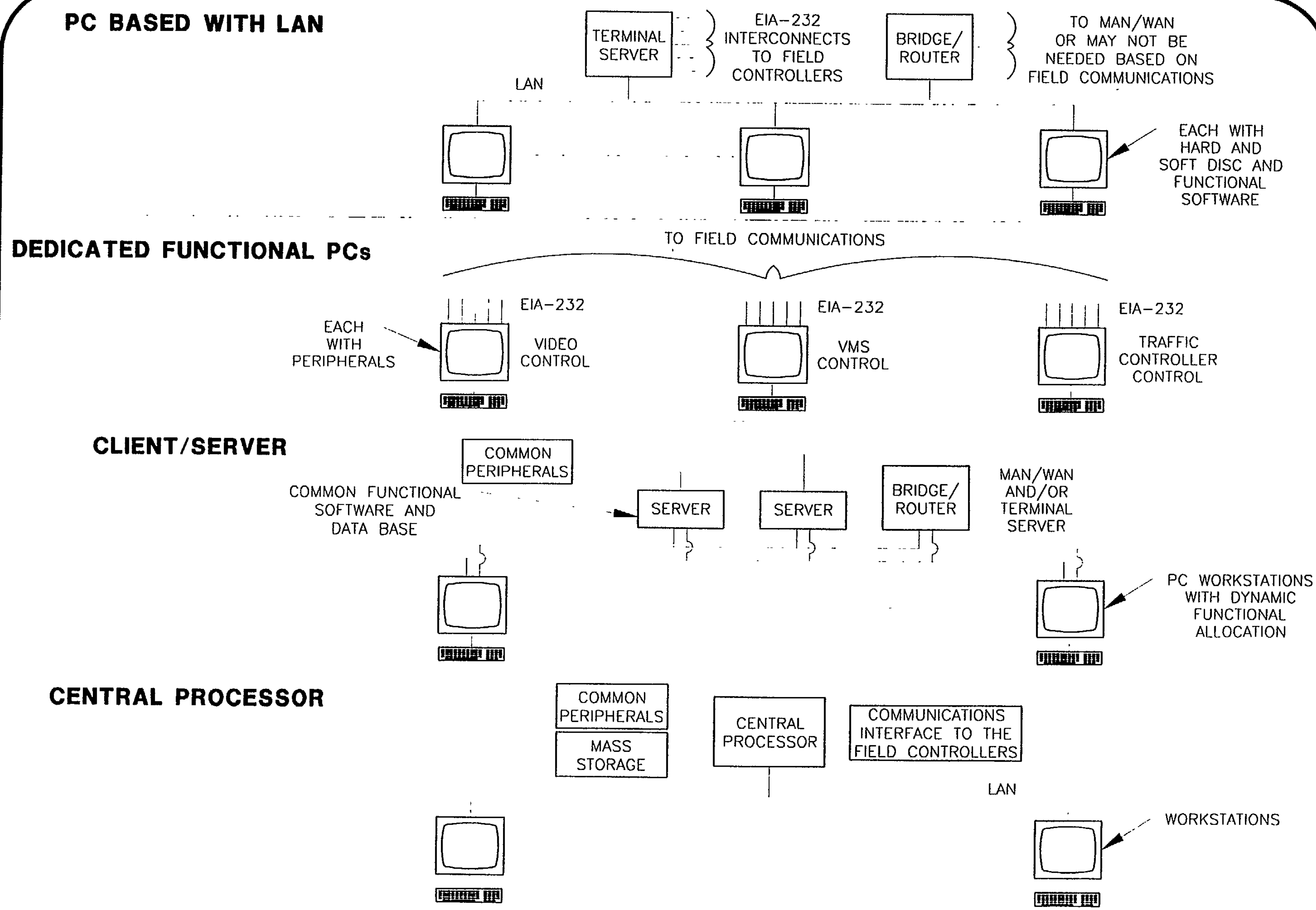
- Evolutionary transition of all peer operation centers to a common architecture to minimize acquisition and operational cost to each jurisdiction, and to facilitate implementation of backup fault tolerance.
- Implementation that emphasizes an open communications network as the first step.
- Integration of jurisdictional field communications and associated controllers into the network via a jurisdictional controlled gateway to the network, as the second step of the program.
- Addition of key ITS field controllers and sensors to meet operational needs and ITS service deployment.

There are four basic architectural options for TOCs and other centers. These are summarized in **Figure 6.11.1-1. Table 6.11.1-1** provides a comparative evaluation of architectures. Ranking is as follows:

- Client/server using PCs
- Networked PCs
- Central processor with workstations
- Functionally dedicated PCs.

Therefore, the architecture recommended for TOCs is client/server, including fault tolerant servers.

Figure 6.11.1-2 illustrates the recommended architecture for integration of the client/server architecture with communications, video, network management, and management information presentation equipment. The following comments apply.

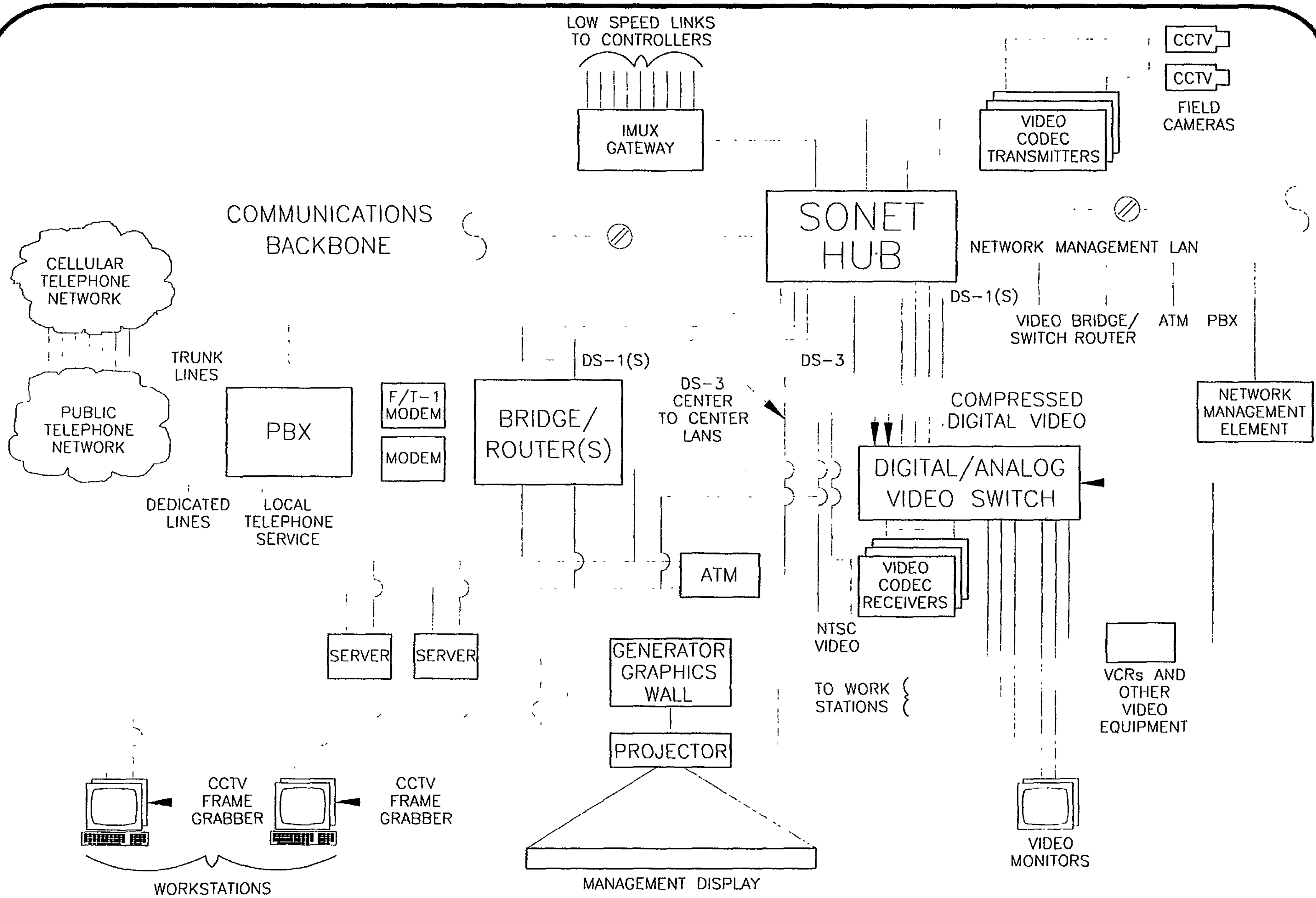


BASIC ARCHITECTURAL OPTIONS FOR TOCs

FIGURE 6.11.1-1

Table 6.11.1-1
Comparative Analysis of TOC Architectures

	PC-based with Local Area Network	PC-based with Dedicated Functional Links	Client/ Sewer with PC-based Architecture	Central Processor with Work-stations and LAN
1. Cost (10 = Low)	9	10	8	3
2. Real-time Interoperability Between Functions (10 = Best)	8	0	10	10
3. Ease of Ability to Add New Hardware and Software Functions (10 = Easy)	8	5	10	10
4. Ability to Support Dynamic Task Allocation and Workload Balancing (10 = Highest)	3		10	10
5. Supports High System Reliability (10 = High)	10		10	2
6. Lowest Cost Maintenance (10 = Low)	9		10	8
7. Responsiveness (10 = Most Responsive)	7		10	4
8. Most Compatible with Communications Backbone interface (10 = Most Compatible)	8		10	9
9. Most Compatible with Multimedia (10 = Most Compatible)	6	2	10	9
10. Modern Architecture Being Deployed in New Systems (10 = Modern}	6	0	10	2
Totals	74	32	98	67



GENERIC OPERATIONS CENTER SCALED TO SPECIFIC TOC NEEDS

FIGURE 6.11.1-2

SONET Hub

- SONET Hub is part of the communications subsystem architecture.
- It provides peer-to-peer communications between centers.
- An ATM linkage supporting interoperable virtual LANs between centers is recommended. Functionally-oriented LANs should be used to facilitate ease of evolution.
- Virtual ETHERNETs are established with field gateways using bridge/router technology (multiple DS- I to ETHERNET).
- Video interface with the TOC is DS-1 compressed video (3.08 Mbps/dual) with any center having access to any video within the region.

Video

- Video is digital compressed.
- A video switch that can accommodate DS-1 digital and NTSC video is recommended, to conserve cost (lower cost than integrated digital cross connect switch within SONET).
- All video should be color.
- Standard NTSC video devices are recommended unless:
  - HDTV standards are approved and
  - HDTV hardware is affordable and comparable in price.
- Video monitors should be sized to operation center needs. Console monitors should be 19” and wall monitors should be 25-38 inches (diagonal).
- Frame-grabber interface is recommended from NTSC video to the processing environment.
- A graphics projection unit is recommended for larger centers capable of SVGA color graphics and NTSC video projection (selectively).
- Control of jurisdictional CCTV cameras is through the gateway.

Voice Communication

- PBX is recommended, interfaced with SONET for Center-to-Center and Center-to-Field voice communications.
  - Trunk lines to the public telephone network are required, sized to the needs of the TOC.
  - Internal voice communications with workstations and offices should be provided as required.
  - Voice messaging (mail) may be maintained within the PBX, or the PBX may be integrated with the LAN and messaging accomplished via the workstation.

Local Area Network:

- ETHERNETs are recommended for Center-to-Gateway
  - Compatible with available bridge/router technology (ETHERNET-to-Multiple DS- 1)

- Server-to-Workstation LANs are recommended to be ETHERNET
  - 10 BASE XX without real-time multimedia, and
  - 100 BASE XX (or 100 BASE VG any LAN) if real-time multimedia is used

6.11.2 Specific Technology Recommended for TOCs

6.11.2.1 Servers

Servers should be 32-bit architecture PC technology, operating at 90+ MHz or Reduced Instruction Set Computer (RISC) technology, similar to that used by SUN. Memory should be sized to applications needs; however, 20 mbytes of RAM, minimum, should be provided. Redundant local LANs and servers are recommended for reliability.

6.11.2.2 Peripherals on Sewers

The following peripherals are recommended:

- Hard Copy
  - For TOCs, two laser printers are recommended providing redundancy. One should be associated with each LAN or redundant LAN interfaces used.

- Mass Memory
  - Operational Database
    - Hard disk should be used, sized to database needs (500 mbyte minimum)

- Archiving and Backup Database
  - Optical disk write-once/read-many (WORM) or newer read/write technology (if available) should be used. Redundant disk should be provided. Size should accommodate a minimum of one week's statistical data collection to minimize operator activities.

- LAN Hubs
  - LAN hubs should be used to facilitate installation and maintenance of equipment.

- Scanner
  A document scanner is recommended to facilitate data entry, including software to support optical character recognition.

6.11.2.3 Workstations

Workstations should be of a technology common with servers. Servers should be essentially workstation processors without keyboards and monitors, sized to support all workstations. Workstations should include:

- SVGA color graphics
- Keyboard
- Trackball with function keys
- Hard disk
- Soft disk
- CD Rom.

A trackball is recommended rather than a mouse because of reliability and workspace conservation. Workstation should include a video frame grabber and dual LAN interface for reliability.

Workstation software should:

- Include graphics user interface functionality,

- Include windowing,

- Stress graphic communications with the operator rather than alphanumeric,

- Not require function CODEC for operator selection but use icons for operations and point/click selection,

- Include an operating system that is compatible with the servers and:
  - Supports multitasking
  - Supports multiple workstation interoperability
  - Is responsive for real-time operational needs
  - Supports graceful recovery from faults.

All of the above technologies are deployed in ITS systems. Projection cubes are reasonably expensive ($1504250 thousand). Wall monitors with matrix video generator are less expensive but this setup includes wider matrix borders (3" to 5" matrix element seams for mounting, versus 1" for projection cubes). Monitors and projection cubes provide the highest brightness, followed by light value projections. Light value projections and wall matrix displays using monitors are $50,000 to $80,000. Smaller TOCs generally use the LCD projection displays that cost $8,000~$10,000 and support NTSC video and SVGA graphics projection. Smaller TOCs display NTSC video on wall monitors and typically use the projector for color graphics map presentation of the street/road/freeway infrastructure status.

In large TOCs (such as the County and ADOT) light value projection displays, which provide much higher light output and support improved display accuracy and linearity, are recommended. For smaller TOCs the lower cost LCD-projectors are suitable. It should be noted that Texas Instruments is nearing perfection of a solid-state micromirror array technology which will represent a major technology improvement in projection displays. Status of this Texas Instruments micromirror technology should be reviewed prior to projector procurement.

6.11.2.4 Wall Displays

The following wall display technologies are available:

- Projection Cube
  - Stackable cubes with integrated projectors and projection screens. (Includes a common video generator and presentation manager.)

- Wall monitors with matrix video generator/manager.

- Graphics/video projectors
  - Low end, using LCD array and overhead projector
  - Integrated LCD array with projection optics
  - Light value.

7. Recommended Physical Architecture

7.0 Overall Network Architecture

Figure 7.0-l illustrates the overall physical network architecture. This architecture is based on future build-out. Note that it is possible to integrate several "gateways" into a single SONET Hub. Thus, the architecture is considered to illustrate a generic build-out without consideration of possible consolidation at SONET Hubs.

7.1 Gateway Architecture

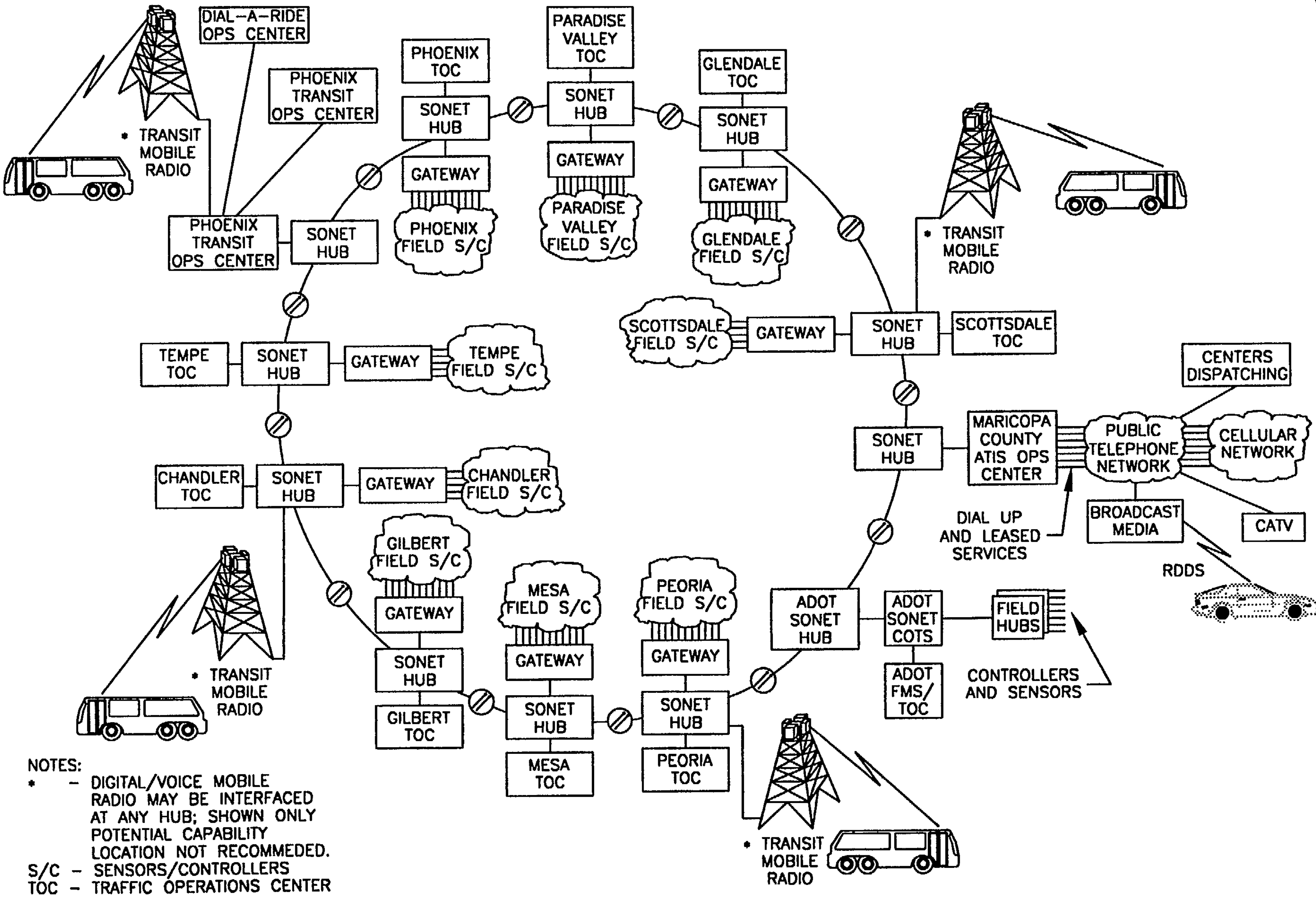
Figure 7.1-1 presents the Gateway Architecture. The gateway is an intelligent multiplexer which controls access to the jurisdictional low-speed controller links (i.e. EIA 232 multidropped or point-to-point). It is designed to Federal Information Processing Standard (FIPS) 46-2 and ANSI x9.42. An encryption key controlled by the jurisdiction can open the gateway for another to receive controller information and to issue controller commands (timing plan selections, variable message detectors, CCTV PTZ commands, etc.). The gateway complies with NEMA TS-2 environmental requirements and is fault tolerant. It includes an internal bridge/routing capability which:

- Grooms all EIA 232 into ETHERNET and vice versa,
- Bridges and routes ETHERNET to DS-1 channel(s), and
- Interconnects the gateway to SONET.

Existing copper infrastructure communications with 400 multidrop modems may be integrated with the gateway. In addition, as shown, counter rotating ring optical transceivers should be used for new construction and new additions to an existing jurisdictional field environment.

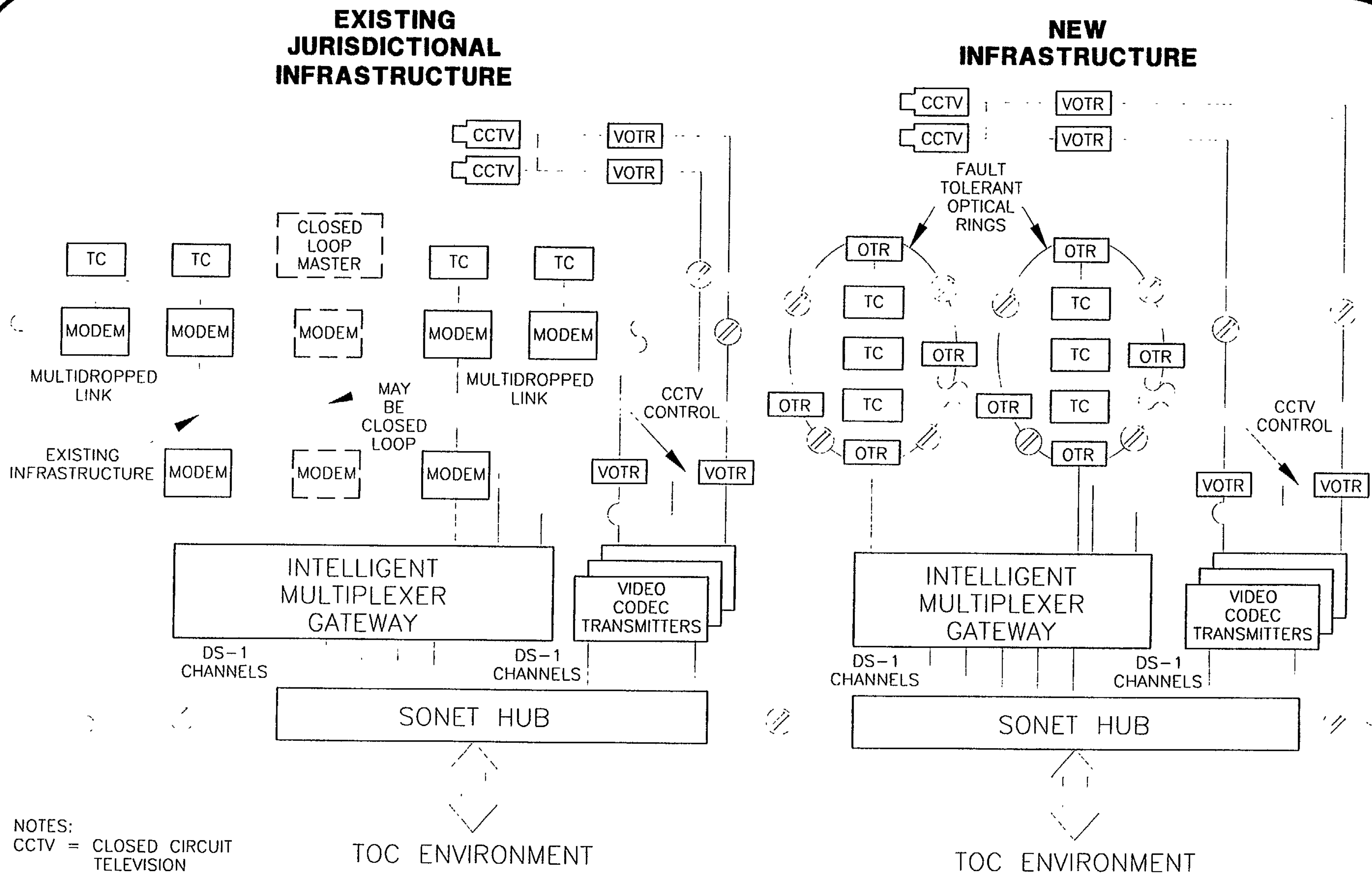
Some jurisdictions are operating closed-loop systems. These may be interfaced directly with the gateway's low-speed link interfaces.

The gateway is modular and is configured in groups of eight low-speed channels to a maximum of 96 channels. Network management protocol and NTCIP protocol is recommended; however, the intelligent multiplexer is capable of supporting protocol conversion with a smaller number of links supported. The objective should be conversion at controller level to a common area wide protocol, which should be based on NTCIP.



OVERALL PHYSICAL NETWORK ARCHITECTURE

FIGURE 7.0-1



NOTES:
CCTV = CLOSED CIRCUIT TELEVISION
OTR = OPTICAL TRANSCEIVER
TC = TRAFFIC CONTROLLER
VOTR = VIDEO OPTIC TRANSCEIVER

GATEWAY ARCHITECTURE

FIGURE 7.1-1

Where a common protocol is not implemented, the responsible jurisdiction can still operate its TOC in a normal manner. Backup will only be possible by:

- Converting to a common protocol, or
- Designing the backup system to be capable of operating with a second protocol.

In addition, CCTV cameras interface at the gateway through video CODEC transmitters. CCTV video already available at the gateway site will be interfaced directly with video CODEC transmitters. For new CCTVs, video optical transceivers which support video and EIA 232 control over a single fiber should be used to bring the CCTV from the camera site to the gateway site. Control for the CCTV is accomplished via the gateway which can provide priority control access to a jurisdictional camera. Priority control scheme assures that the owner jurisdiction always gets control when required and when a desired preset is selected and needed for traffic management, it may be "locked" until no longer needed by that jurisdiction.

Outputs of video CODECs are dual DS-1 channels which may be viewed by any TOC on the network. Video is available on the total SONET ring for use as needed.

Major features of the "gateway" are:

- Standard SONET network interfaces,
- Any TOC can share video since DS-1s are add/dropped. (Control of cameras is on a not-to-interfere basis with the owner jurisdiction.),
- Fault tolerant, as is the SONET hub,
- Supports network management protocol, and
- 2070 controller commonality is facilitated.

7.2 SONET Hub

The SONET hub features standard Bellcore and ANSI specification-compliant hardware. Fault tolerant ring architecture is used. Primary add/drop is at the DS-1 level with a DS-3 electrical port for ATM. **Figure 7.2-l** illustrates the physical SONET hub. DS-1 interfaces are defined by:

- Number of video channels on the network,
- Number of gateways to backup, and
- Number of voice channels supported on the network.

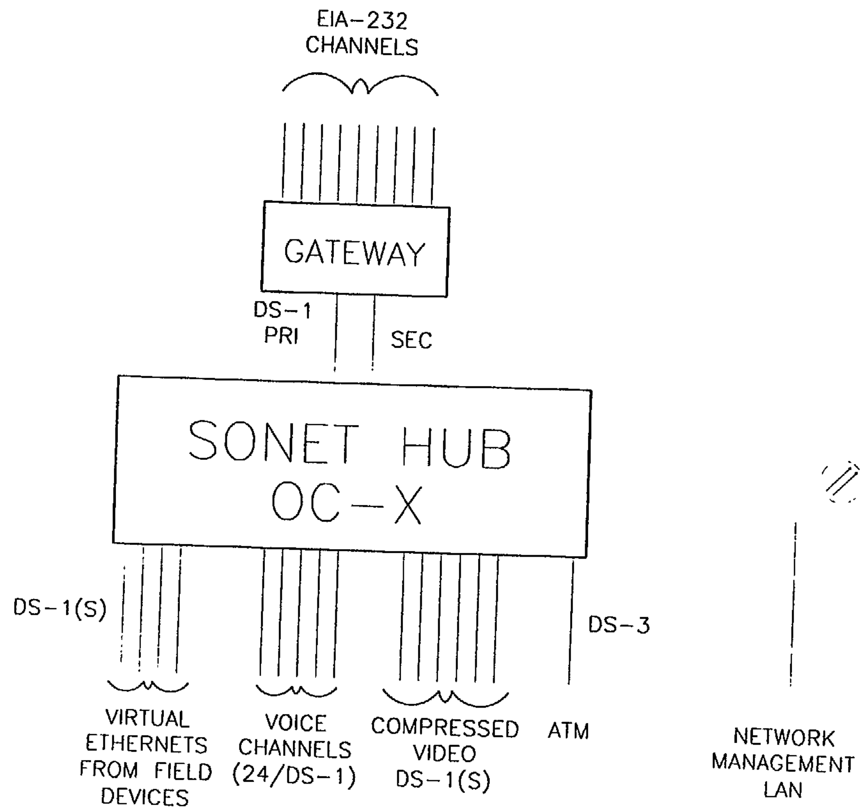
The ATM DS-3 channel supports center-to-center virtual LAN communications. The number of channels depends on type of LAN with up to 10 ETHERNETs (10 BASE X) supported.

7.3 TOC Physical Architecture

Section 6.11 presented the technology options and physical architecture of a generic TOC. **Figure 7.3-l** presents an overview of this architecture, which uses a Client/Server configuration. The subsystems include:

Video:

- CODEC Receivers.
- Digital/Analog video switch (LAN control compatible).
- Video Monitors (console mounted and wall mounted).
- Video Recorders (minimum of two).
- Broadcast/cable TV channelized receivers and radio for monitoring traffic and weather reports from public media.
- Special video processors (quad combiners).
- Wall Display Projector (NTSC?SVGA).
- Server
  - Applications servers
  - Peripheral and database servers



SONET HUB

FIGURE 7.2-1

- Workstations
  - Color graphics with keyboard, trackball, and disk memory (hard, CD, and soft)
  - Same technology as server
  - Graphics generator for projection display
    - Same as workstation technology
    - Projector replaces monitor
    - No keyboard.

Communications:

- PBX
- ATM Switch (TOC-to-TOC virtual functional LANs).
- DS-l(s)-to-ETHERNET Brouter (Virtual ETHERNETs with gateways).
- LAN-to-FTl Brouter (Other Agency interface via leased line or dial-up line).

Network Management Element:

- Network management workstation

7.4 Open Architecture Standards

All physical interfaces are open architecture national standards.

8.1.2 Operational Staff for Jurisdictional TOCs which Back Up other TOCs

Where the agreement is reached that one TOC will back up another, or take over operations nights and weekends, adequate staff should be planned to accommodate this back-up. Depending on activity within the backed up jurisdiction, perhaps no additional operational personnel will be needed. At worse case, no more than one additional operator should be required to accomplish back-up for most jurisdictions.

It is recommended that the County's TOC include the capability to back up a minimum of the small jurisdictions or one large jurisdiction in case of natural or man-made disaster. This will require perhaps two additional workstations. Manpower for these workstations can be from management staff in case of a major emergency.

The economics of the County TOC supporting operations in other jurisdictions during nights and weekends should be considered and staffplanning perhaps based on agreements between the County and peer jurisdictional members of the network.

8.1.3 ATIS Staffing

There is, currently, no ATIS center. Based on the SMART Routes ATIS center in Boston, the operational staffing requirements recommendation for Phoenix area would be:

- Peak hour staff 3 operators
- Off-peak staff 2 operators
- Operational service 14 hours/day

SMART Routes uses additional personnel (4 per peak hour and 3 per off-peak). They also use part-time staffing. Permanent staff includes 7 operators with 6 part-time operators plus 3 administrative staffers. All maintenance is contracted; no maintenance staff is maintained.

SMART Routes in Boston is a private/public partnership. If it is not possible to obtain a private partner for the ATIS center, then operational manpower could be reduced by co-locating the ATIS function at the ADOT FMS or the County's TOC. Functions could possibly be shared in off-peak hours reducing operational staffrequirements and ATIS management functions could be shared with other TOC management functions.

8.2 Maintenance

System architecture and subsystem architecture recommended is fault tolerant. Built-in test and test reporting via the network management is included. Maintenance of the architecture is simpler than that associated with conventional systems. Graphic displays of fault identification and location should be automatically provided.

In addition, hardware and communications medium (fiber) are more reliable than conventional hardware (copper, wireline, modems, etc.). Thus, the reliability of modem technology is significantly greater than older technology. Therefore, frequency of failure should be much lower.

Depot maintenance of circuit cards is recommended. Complexity and construction of modem circuit boards make it advisable to use depot maintenance resources.

Assuming the use of depot resources for printed circuit board repair, conventional maintenance staff should be able to maintain the system. Where contract maintenance services are used today, they may be continued.

Users are responsible for ATIS terminal equipment. ATIS communications links are via leased lines, dial-up telephone, broadcast radio (FM), existing mobile radio links, or other established, privately owned links. This ATIS service will have little maintenance impact, except for ATIS center equipment.

If ATIS is privatized, center maintenance will be the responsibility of the private operator. It is possible that the County or ADOT maintenance can support the ATIS function. Network management technology supports remote monitoring of the ATIS center's equipment, if it is not co-located.

In summary, additional maintenance may be required for ATIS. Card level replacement maintenance is achievable by current maintenance staff.

8.2.1 Pooling Maintenance

With integrated network management, it is possible for jurisdictions to pool maintenance resources for cost savings.

9. Funding

9.0 General Comments

The potential funding sources for ITS projects can be grouped into four areas:

- Federal ITS Funds
- Other Federal Funds
- Local Funds
- Private Funds

Federal ITS Funds

The picture of federal funding for transportation is changing rapidly. Congress is currently debating issues which may dramatically affect the availability of federal money for ITS projects. There are two federal ITS-specific funding sources as shown below with their FY 1996 budgeted amounts:

- ISTEA ITS funds	$113 million
- General Operating Budget	$238 million

Congress is debating how much, if any of the $113 million ITS budget will actually be appropriated. Congressional action is expected in September or October, 1995. The $238 million General Operating Budget includes the $100 million Trailblazer program. The likelihood of the Maricopa County area finding a meaningful revenue source in the ITS-specific ISTEA funds is remote for the following reasons:

- There is only $113 million nationwide, and
- Congress may not appropriate all (or any) of it

It is also unlikely that any meaningful funding opportunity will come from the General Operating Budget. Although the funding for the development of this Strategic Plan comes from that source, these funds are primarily intended for FHWA use.

Other Federal Funds

The following presents the FY 1995 Arizona allocations of federal programs, most of which are eligible for ITS activities.

- National Highway System (NHS) - Arizona has been allocated $43 million for FY 1995. If these funds are not appropriated by Congress by September 30,1995, they will revert back to the Trust Fund.

- Highway User Revenue Funds (HURF) - These funds are allocated by the state legislature to ADOT, cities and counties. These agencies have demonstrated needs beyond available funding. If the legislature were convinced of the benefits of ITS, perhaps additional funding could be provided. The HURF Legislative Study Committee is meeting to discuss funding needs at the time of the preparation of this technical memorandum. If desired, Maricopa County could use a portion of their HURF allocation for ITS projects.
- Local Sales Tax or Gas Tax - If a project or projects utilizing ITS technology could be identified which would garner public support, it could be funded with a local sales tax. It must be recognized that sales tax approvals are difficult to develop grass roots support. The ITS project would have to meet specific perceived needs by the general population.
- Lottery Funds - Another possible funding source is the lottery. Again, ITS would have to compete with other state needs to receive these funds.

Private Funding

The Federal Highway Administration encourages private funding and public-private funding of ITS projects. Certainly, for the private sector to invest in ITS projects, there must be a profit or marketing potential. The paradigm shift to joint public-private projects will require some time and creative planning. Arizona has already begun to plan and implement such ventures, including the CVO Expedited Crossing at International Borders (EPIC) and the ATIS project Radio Broadcast Data Systems (RBDS).

ITS Funding Plan for Maricopa County

In order for funding to be obtained for ITS projects in Maricopa County, projects must be identified with regional appeal and acceptance. The various governmental entities must agree on the need for and mutual benefit of the proposed project. These agencies must depart from the past practice of competition among regional agencies and identify potential projects with citizen support across political boundaries. The proper forum for this process is the Maricopa Association of Governments (MAG).