NDOR

MAPA — UNL

OMAHA METROPOLITAN AREA

Intelligent Transportation Systems

Early Deployment Planning Study

Strategic Deployment Plan

Appendix D

SYSTEM ARCHITECTURE AND COMMUNICATION MASTER PLAN REPORT

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APPENDIX D

System Architecture and Communications Master Plan

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1. SYSTEM ARCHITECTURE BACKGROUND

A system architecture is a framework that describes how system components interact and work together to achieve total system goals. The primary objective of the system architecture development process for the Omaha Metropolitan Area is to develop an open[1] architecture that describes the system operation, what each component of the system does, and what information is exchanged among the components. The system should function smoothly with systems used by other jurisdictions and be capable of expansion to future capabilities.

To assure a national capability between various regional ITS architectures, Congress, in ISTEA, directed the U.S. Department of Transportation to promote national ITS compatibility. The Department, with advice from ITS America, has responded by leading an effort to develop a national ITS architecture. In addition, ITS standards development is proceeding and new standards will be identified with the architecture development. Telecommunications systems are an important aspect of ITS and play a key role in the development of a national ITS architecture. Together, these activities represent the first steps toward a nationally compatible ITS.

2. THE NATIONAL ITS ARCHITECTURE

The development of a national ITS architecture will provide a framework that describes how ITS components interact and work together to achieve total system goals *(1).* It will be an open system architecture, and modular, allowing for and facilitating the introduction of new technologies and system capabilities over time. The architecture is different from a system design. Within the framework of the architecture, many different designs can be implemented. Using an analogy of the home stereo system, the architecture defines the functions of various components --receivers, compact disk players, etc. -- and specifies how they will be interconnected. Consumers are able to put together their own system design with products of various capabilities and options with confidence that they will work together. Manufacturers adhering to architectural standards are assured that their products will be acceptable in the marketplace alongside other competing consumer products.

The development of the national ITS architecture is a top-down, systematic process. It involves an understanding of system goals, the functions and functional requirements necessary to achieve those goals, and the different operational concepts and enabling technologies that can be used to build a system that meets those functional requirements. In ITS, the 29 user services are regarded as the functional requirements of the ITS architecture. The architecture is one step on the road to a nationally compatible ITS as illustrated in Figure 1.

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1 An architecture can be either "open" or "closed." An architecture is open if its documentation is in the public domain. An open architecture encourages competition among multiple vendors, with their success determined by capability, cost, and innovation. Supporting information in a "closed" architecture usually is proprietary and consequently does not encourage competition among suppliers.

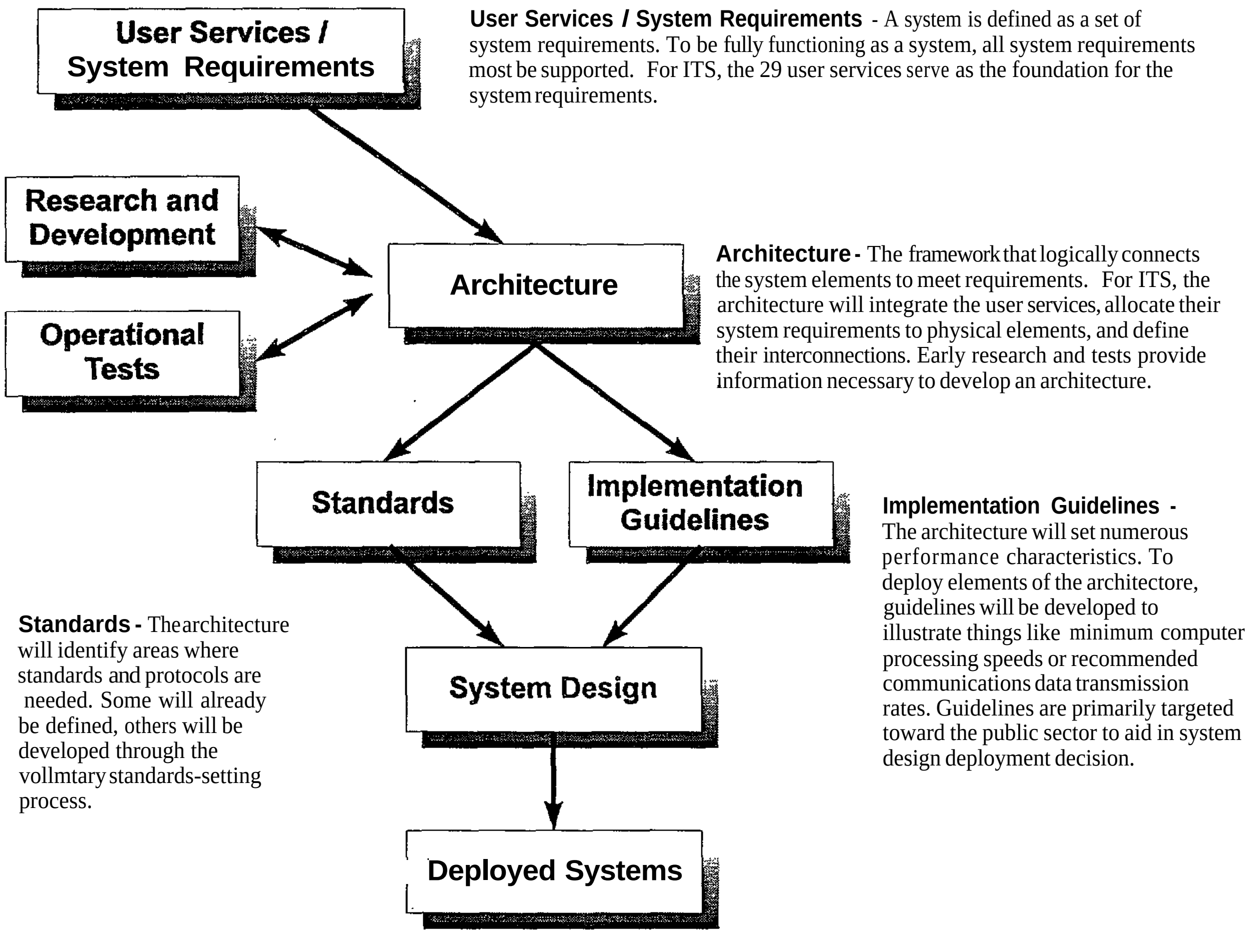


Figure 1 National ITS Architecture and ITS Deployment

2.1 The National ITS Architecture Development Program

Initiated in September, 1993, the U.S. DOT is leading a 34-month, two-phase program to define a national ITS architecture. The first phase of the program, completed in January 1995, involved the development of four architectures developed in parallel by consortia teams led by Hughes, Loral, Rockwell International, and Westinghouse. These architectures were developed in a competitive environment and were evaluated for technical soundness and desirability to stakeholders. The most promising approaches were down-selected for continuation in Phase II.

The teams selected to continue to Phase II were those led by Loral and Rockwell International. Phase II of the architecture development will involve the two selected teams working together in a non-competitive environment to refine the Phase I architectures into a single national ITS architecture. This phase began in February 1995 and is scheduled for completion in July 1996.

2.2 Synopsis of National ITS Architecture

Figure 2 shows the high level ITS subsystems, terminators and dataflows between them. In particular, Figure 2 shows the high level inter-subsystem and terminator messages which identify for each message the subsystem or terminator originating the message and the subsystem or terminator receiving the message.

As the legend in Figure 2 shows, the central four boxes represent the ITS subsystem in four classes (or groups): Center subsystems, Roadside subsystems, Vehicle subsystems and Remote Access subsystems. The ITS subsystems that constitute each of these groups are shown in Figure 3 and described in more detail in subsequent sections. Around the perimeter of the four subsystem groups in Figure 3 are the terminator groups. The terminators have been grouped into four categories: Users, Systems, Environment and Other Subsystems.

Users. These are the personnel at Centers and Roadside as well as Drivers and Travelers who interact with ITS subsystems.

Systems. These are the ITS Centers (e.g., Government Agencies), Roadside systems (e.g., traditional signals and sensor) and Vehicle Systems (e.g., braking and steering systems) that ITS will interact with.

Environment. The environment is sensed by ITS subsystems. Examples are air quality and obstacles.

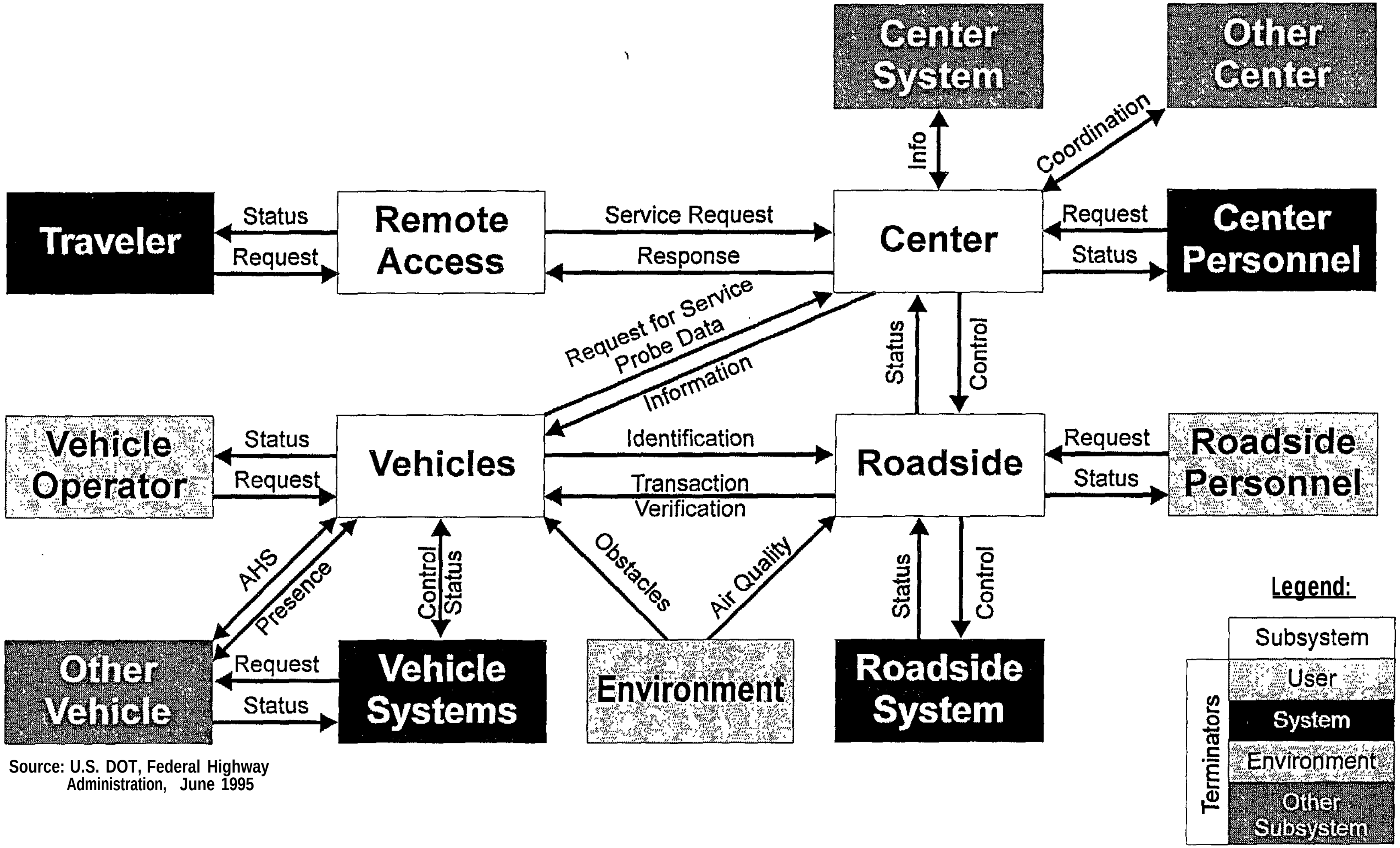
Other Subsystems. Interactions between multiple subsystems. For example, vehicle-to-vehicle messages and Traffic Management Center-to-Traffic Management Center messages.

Subsystem Background

The specific choice of subsystems represent a decomposition of the ITS architecture that captures all expected or likely subsystem boundaries for the near 20-year future. In this way, the intersubsystem boundaries identify the likely candidates for message standard interfaces between subsystems. The choice of subsystems and the logical process specifications assigned to them are based on current institutional responsibilities and the assumption that in the next 20 years, the current institutions and general types of responsibilities will continue.

In many deployments, several of the apparently separate subsystems may be deployed in a single "agglomerated" subsystem. For example, the Traffic Management and Emissions Management subsystems may be deployed as a single subsystem in some regions. In those cases, the total number of physical subsystems actually deployed would be fewer than shown in Figure 2.

The ITS subsystems communicate with each other using the communication elements and architecture interconnect channels shown in Figure 3, a version of the ITS Architecture Interconnect Diagram (AID). In Figure 3, the subsystems are shown as white boxes, the communication channels are shown as lines and the communication elements are shown as "sausages."



Source: U.S. DOT, Federal Highway Administration, June 1995

ITS Architecture High Level Subsystems and Terminators Flow Diagram

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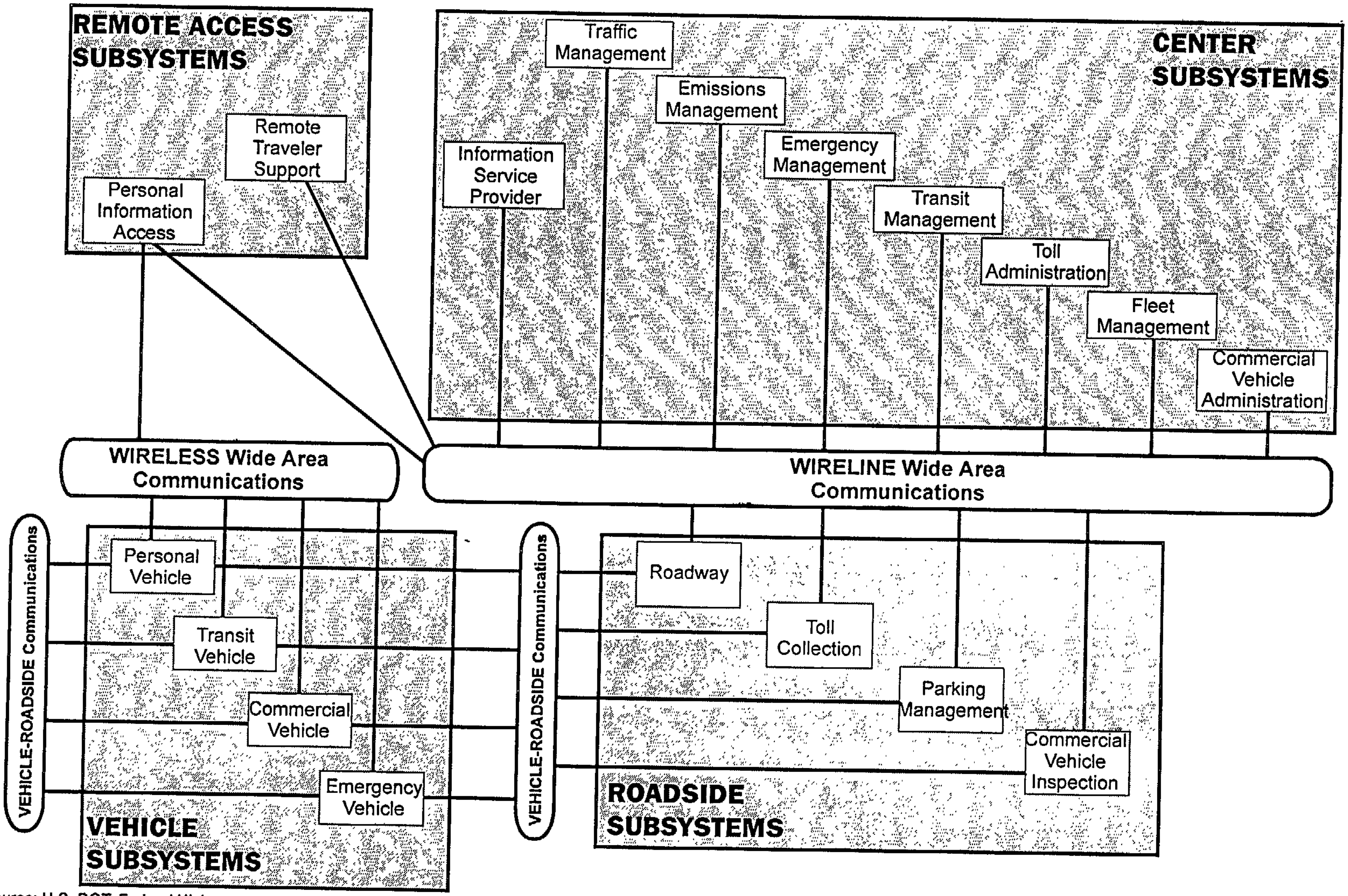
Figure 2



Source: U.S. DOT, Federal Highway Administration, June 1995

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National ITS Architecture Subsystem Interconnect Diagram

Figure 3

Subsystem Multiplicity

The subsystems shown as single entities in Figures 2 and 3 are representative of multiple instances of the specific subsystem. For example, several Traffic Management subsystems in a region, each with their own jurisdiction, may communicate with each other (and each with their many Roadway subsystems) to implement regional ITS policies.

The multiplicity expressed for ITS subsystems extends to the hardwire and wireless communication elements as well. In the previous example, the Traffic Management subsystems may communicate with each other using a commercial wireline data communications service provider, but may have their own dedicated wireless communications elements for data communications with their many Roadway subsystems.

ITS Subsystem Classes

The ITS architecture subsystems of Figure 3 are further grouped by classes where the subsystems may share common communication elements, deployment and institutional characteristics. The ITS subsystems in each class are shown in a common shaded box in Figure 3. The four classes of subsystems are Center Subsystems, Roadside Subsystems, Vehicle Subsystems and Remote Access Subsystems.

Center Subsystems. These subsystems are typically fixed, and can be located almost anywhere. To the extend that they communicate with other subsystems, they need access to wireline communications.

Roadsicle Subsystems. These subsystems typically include some function that requires convenient access to a roadside location for deployment of sensors, signals, programmable signs, or some other interface with travelers and/or the vehicle. Roadside subsystems generally need wireline communications for messages to/from one or more Center subsystems, and possibly toll-tag or beacon communications to some or all vehicles passing the specific roadside location where the subsystem is deployed.

Vehicle Subsystems. These subsystems are installed in a vehicle and will be common across the various vehicle types in some areas (e.g., navigation and Mayday functions). In addition to toll-tag or beacon communications, the vehicle may be equipped with WAN (Wide Area Network) wireless communications equipment to enable data communications with specific Roadside subsystems (e.g., Parking Management for a parking reservation prior to arrival at a parking lot) or for one-way (e.g., link-times to the vehicle) or two-way communication with one or more Center subsystems (e.g., Commercial Vehicle to Fleet Management messages). Finally, the vehicle subsystems may be equipped with vehicle-to-vehicle data communications in support of the AVCS (Advanced Vehicle Control Systems) services (e.g., high density platooning).

Remote Access Subsystems. This subsystem represents the "personal" and portable platform for ITS functions of interest to a traveler for support of multimodal traveling. The Personal Information Access (PIA) subsystem in this class may have WAN wireless communication capability similar to the capability in vehicles as well as the ability to access the same information services over a wireline communications element (e.g., when the PIA is "docked" at home, work or at a kiosk).

Physical Architecture Communication Elements and Modalities

The Architecture Flow Diagram (AFD) of Figure 3 includes additional communication elements. These communication elements are a part of the interconnect channel architecture, and appropriately are not included in the AFD of Figure 2 because these entities do not do any ITS processing. That is, there are no Logical Architecture Process Specifications (PSpecs) assigned to them. Their role is to facilitate the transfer of data messages between ITS subsystems where ITS processing does occur.

2.3 FHWA "Core Infrastructure" Concept

U.S. DOT has defined seven elements which form the "core infrastructure" for deploying Intelligent Transportation Systems (ITS) traffic management and traveler information services in a metropolitan area (2). These definitions constitute today's "state-of-the.-art" implementation of ATMS/ATIS, of ITS user services to be provided by both public and private sector entities.

The metropolitan area ATMS/ATIS core infrastructure consists of the following seven elements:

1. Regional Multimodal Traveler Information Center
2. Traffic Signal Control System(s)
3. Freeway Management System(s)
4. Transit Management System(s)
5. Incident Management Program
6. Electronic Fare Payment System(s)
7. Electronic Toll Collection System(s)

In defining these core infrastructure elements, the following principles were followed:

- Deployment of the element(s) will enable meaningful implementation of metropolitan area ATMS/ATIS user services and facilitate deployment of many other ITS user services.

- Each element could be deployed independently of the others, but concurrent implementation would significantly increase overall benefits and/or decrease incremental costs.

- The element(s) can be readily deployed in the near term using "state-of-the-art" concepts and technologies (versus existing "state-of-the-practice"), and would typically be eligible for Federal aid funding.

- Varying technologies, from "low-tech" to "high-tech" can be used to deploy/implement each element.

- The definitions should account for different' institutional environments, varying spacial/ geographic relationships among centers of activity (i.e., as with CBD / ring city / suburb relationship), and recognize that system(s) will evolve over time to provide for greater benefits/lower costs.

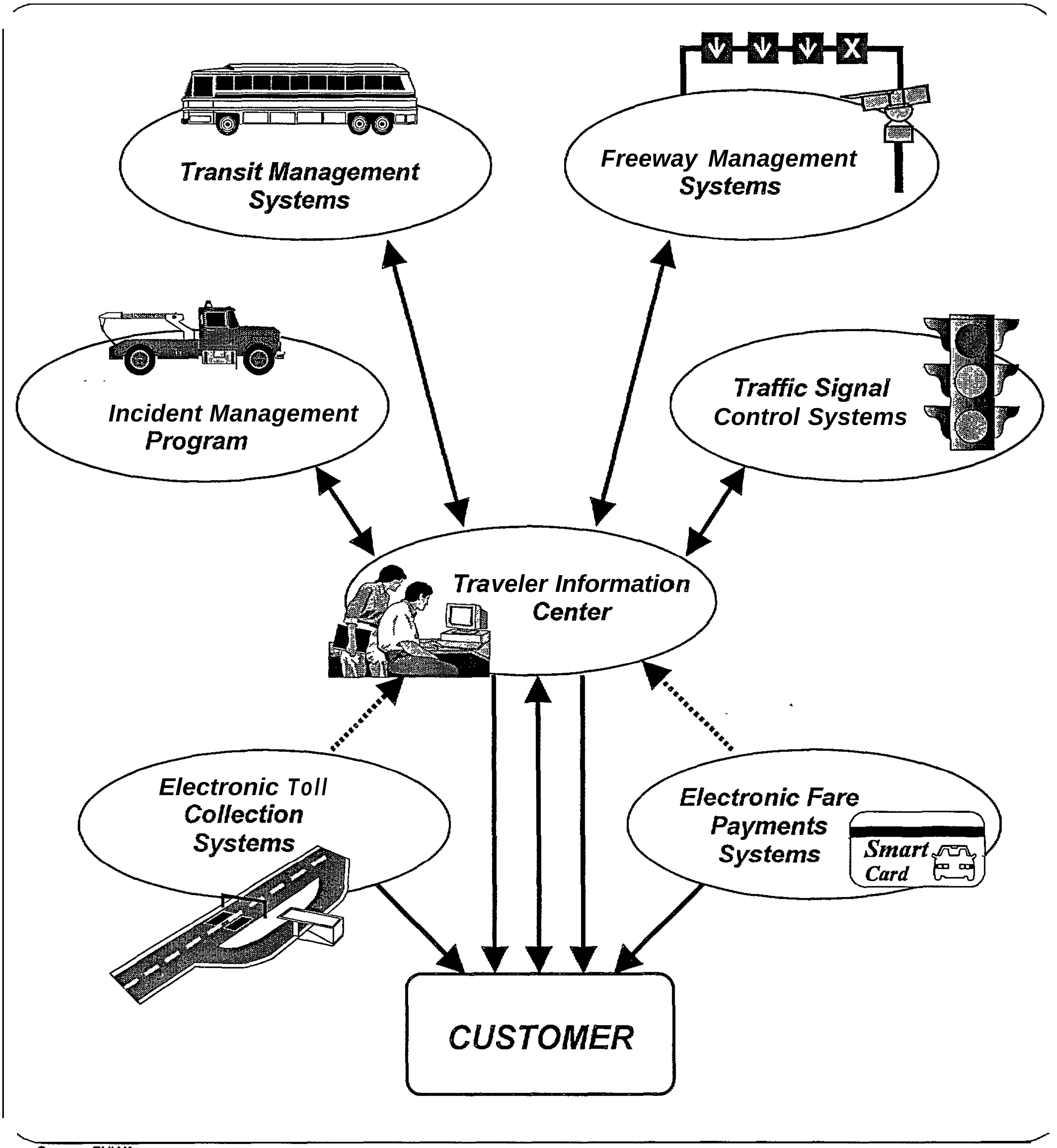
- Private sector participation in delivering ATMS/ATIS user services will be encouraged to the maximum extent possible, particularly in the collection and dissemination of traveler information The private sector is also encouraged to participate in development of the core elements.

The relationship between the seven system elements as defined by FHWA is shown in Figure 4.

2.4 References

1. *ITS Architecture, Theory of Operations,* Joint Architecture Team, Eoral Federal Systems and Rockwell International, U.S. Department of Transportation, Federal Highway Administration, June 1995.

2. *Core ITS Infrastructure Elements for Metropolitan Area AKMS/ATIS Deployment,* FHWA/HTV-10: Version 1, March 9, 1995.



Source: FHWA

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Metropolitan Area ITS Core Infrastructure for ATMS/ATIS Deployment

Figure 4

3. KEY CONSIDERATIONS IN ARCHITECTURE DEVELOPMENT

A well-defined system architecture wilI accommodate different levels of implementation, different system designs and flexibility to allow system evolution over time. This allows different goals to be supported across many jurisdictions.

Following is a list of key fundamentals for developing the Omaha Metropolitan Area System Architecture:

- Capability to distribute multimodal traveler information to the general traveling public.
- Surveillance and detection capability; resulting in current, comprehensive, and accurate traffic and transit system performance information.
- Infrastructure-based communications systems linking field equipment with central software/database systems.
- Communications (routine information sharing) among jurisdictions, between traffic and transit agencies, and between the public and private sectors; without necessarily relinquishing control responsibility (i.e., "share information but not control") - This may entail formal interagency agreements for incident response and information sharing.
- Proactive management of roadway and transit resources.
- Sufficient resources for continuing support of system operations and maintenance needs, including personnel and training requirements

3.1 Considerations in the Omaha Metropolitan Area System Architecture

The Omaha metropolitan area ITS architecture has been developed by considering the following elements. It should:

- Be consistent with National ITS architecture.
- Be consistent with FI-IWA "Core Infrastructure" concept.
- Provide the overall structure for a transportation management system to improve mobility within the metropolitan area.
- Provide for future growth in a modular fashion and incorporate advances in new technologies.
- Be service driven, not technology driven Both proven technologies and state-of-the-art technologies should be considered.
- Utilize existing resources and assets,

- Foster opportunities for private/public partnerships.
- Utilize National Traffic Control and IVI-IS Communications Protocol (NTCIP) for communications.
- Implement the system cost-effectively.

4. EXISTING SYSTEMS

The Omaha metropolitan area currently has several systems that could be incorporated into the system architecture to the greatest extent possible. These systems were reviewed during the inventory task and documented in the "Inventory Report", April 28, 1995. The existing systems include the following elements.

▪ Freeway Traffic Management Systems

The Nebraska Department of Roads (NDOR) currently operates a SCAN system, which consists of weather data collection stations, along the freeway system. There are approximately six portable changeable message signs (CMS) currently in use by the NDOR.

▪ Traffic Control Systems

There are three communities within the Omaha study area which operate closed loop systems. They are Omaha and Bellevue, Nebraska, and Council Bluffs, Iowa.

- **Omaha, Nebraska.** The City of Omaha operates a closed loop system with on-street masters which communicate to the City Hall via dial-up 1200 and 2400 baud modems.

- **Council Bluffs, Iowa.** The City of Council Bluffs, Iowa, also operates a closed loop system, similar to that of Omaha, although using NEMA (Eagle) controllers.

- **Bellevue, Nebraska.** The City of Bellevue operates three closed loop systems throughout the City.

▪ Communications

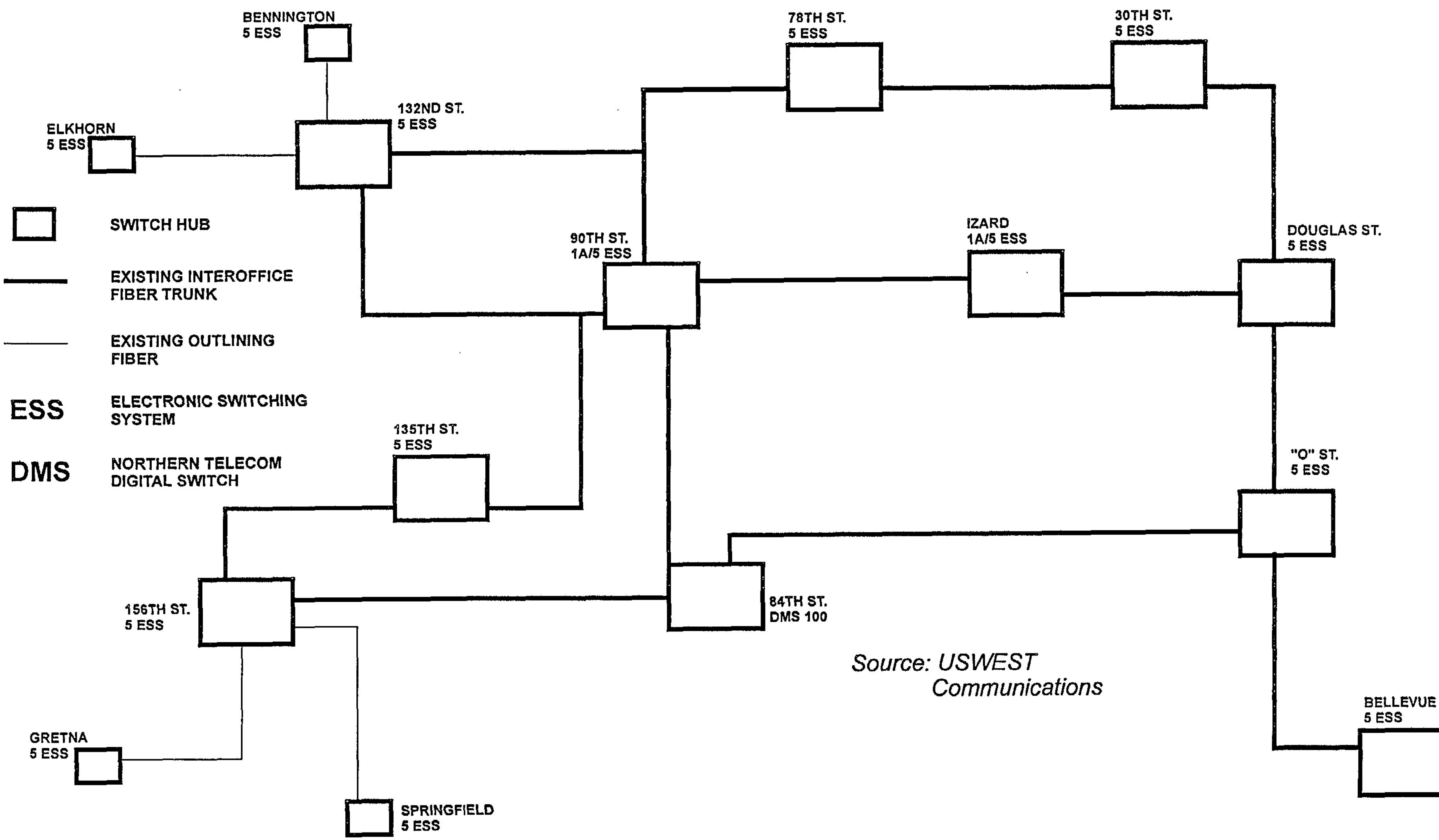
In the Omaha metropolitan area, the primary communications media for traffic signals are hardwire copper cable and dial-up telephone, which transfer data/commands from the central traffic control offices to intersection field masters and local controllers. Currently all three jurisdictions which operate closed loop systems (Omaha, Bellevue, and Council Bluffs) use the same basic framework.

▪ Travelller Information Systems

Metropolitan Omaha currently uses the media quite extensively to inform the public of freeway and/or arterial roadway incidents.

▪ Other Systems

- US **West Communications.** The US West communications network consists of area-wide fiber optic cable (see Figure 5).



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USWEST COMMUNICATIONS PLANTS

Figure 5

- **Cox Cable.** Cox Cable has installed a significant network of fiber/coaxial cable reaching 97,000 homes, primarily within the metropolitan area.

- **TCI Cable of the Midlands** The TCI Cable network consists of approximately 560 miles of cable serving Bellevue, Papillion, Offut Air Force Base, La Vista, Ralston, Milland, and Sarpy and Douglas Counties.

- **Sky Cable** TV. The Sky Cable TV System is a relatively new wireless microwave system serving the west Omaha area and the cities of Millard, Ralston, Papillion, La Vista and other communities.

▪ State. Communications Network

The State Division of Communications manages communications services. The division negotiates rates with utility companies (primarily phone) on behalf of groups of agencies. A total of 42 companies are involved in providing services for the state.

▪ Computer Networks

Area computer networks include:

- **Omaha Free Net.** The Omaha Free-Net links people by computer with information provided by local schools, hospitals, government, and health and human service organizations.

- **Husker Net/UN0 Net.** Husker Net is a campus computer network restricted to the University of Nebraska at Lincoln. A similar network, called "UN0 Net", is providing services to the University of Nebraska Omaha campus.

- **Sarpy County Communications System.** Sarpy County is implementing a new communications system which will be a combined county-wide communications system operated on an 800 megahertz trunk communications system serving the cities of Gretna, Papillion, Bellevue, La Vista, Springfield and Sarpy County.

- **Applied Information Management Institute (AIM).** AIM is involved in applied research, continuing education, and employment services, recruitment and placement of information management professionals for area businesses. AIM has gone "on-line" with a schedule of current and upcoming Continuing Education conferences and training opportunities.

- **MidNet.** MidNet is a computer network serving several Midwestern university campuses with the local hub at the University of Nebraska-Lincoln.

- **Synergy Communications**. Synergy is a privately owned, Omaha area, Internet service provider.

- **Monarch.** Monarch **is** a multi-use electronic bulletin board that provides and distributes information and schedules to area residents via computer and modem.

5. SYSTEM COMPONENTS

This section presents an overview of the major components of the Omaha Metropolitan Area Intelligent Transportation System as described below:

5.1 Area-Wide Traffic Management and Information Center (ATMIC)

The ATMIC will provide a foundation for metropolitan area-wide ITS activities and will provide a focal point of data collection, information dissemination, traffic management, and incident response activities It directly receives roadway and transit system surveillance and detection system information from a variety of sources provided by both public and private sector entities. To a larger degree, these sources of information are the other metropolitan core infrastructure elements. The ATMIC is the key element of the system, either in a single physical facility or an interconnected set of facilities, which provides a bridge between the general public and the transportation system managers.

5.2 Traffic Signal Control Systems

Traffic signal control systems include existing and future jurisdictional systems such as the City of Omaha's signal control system. Signal control systems have the capability to adjust the amount of green time for each street and coordinate operation between each signal to maximize the person and vehicular throughput and minimize delay through appropriate response to changes in demand patterns. At a minimum, these coordinated systems will provide for a selection of "time-of-day" signal timing patterns which optimize operations along major arterial routes and throughout signal networks. The capability to adjust the traffic signal timing may include computer-generated timing plans and/or manual operation by skilled and knowledgeable operators. The hardware/software systems are designed to be upgraded in capability as required for future operations with an "open architecture" which enables relatively inexpensive and efficient installation of improved'products, and potential coordinated operations with adjacent freeway and arterial systems.

The various jurisdictional systems are capable of electronically sharing traffic flow data with the signal systems of adjoining jurisdictions in order to provide metropolitan-wide signal coordination.

5.3 Freeway Management System

The freeway traffic management system will have the capability to monitor traffic conditions on the freeway system; identify recurring and non-recurring flow impediments; implement appropriate control and management strategies (such as ramp metering and/or lane control); and provide critical information to travelers through infrastructure-based dissemination methods, such as changeable message signs and highway advisory radio.

The freeway management system will include a Freeway Management Center (or multiple centers where responsibility for the freeway system is shared by more than one jurisdiction) and information links to the ATMIC and other management and control systems in the metropolitan area. These capabilities can encompass and/or expand to provide for coordination of response to emergency and special event situations.

5.4 Transit Management System

The transit system will include hardware/software components on buses and in dispatching centers, communications, operator training, and maintenance. Depending upon needs, the system would utilize automatic vehicle location, include advanced voice and data communications, automatic passenger counting, driver information (voice and visual), vehicle diagnostics, linkage to geographic information systems, and computer-aided dispatching.

The system will provide reliable bus position information to the dispatcher. The dispatcher or a central computer will compare the actual location with the scheduled location, enabling positive action to improve schedule adherence and expanded information for transmission to the ATMIC and for direct customer information. In addition, on-board sensors will automatically monitor data such as vehicle passenger loading, fare collection, drive-line operating conditions, etc., providing for real-time management response. In the event of an on-board emergency, the dispatcher can inform the police of the emergency situation and direct them to the vehicle's exact location.

5.5 Incident Management Program

The Omaha metropolitan area will have an organized and functioning system for quickly identifying and removing incidents that occur on area freeways and major arterials. The roadway is cleared and flow restored as rapidly as possible, minimizing frustration and delay to the traveling public while at the same time meeting the requirements and responsibilities of the agencies and individuals involved,

6. OVERALL SYSTEM ARCHITECTURE

The ultimate architecture for the Omaha metropolitan area system is consistent with the national architecture and FHWA core infrastructure concept. It consists of an Advanced Traffic Management and Information Center (ATMIC) which will provide a bridge between the general public and transportation system managers. Through linking data from the other elements into a comprehensive regional information system, the center will exemplify movement towards advanced ITS user services.

Each of the traffic management centers (TMCs) will be connected to the ATMIC through a wide-area computer network (WAN) using the fiber optic communications backbone network. The WAN will provide for the complete integration of all system elements in a single environment. Although each agency will have control over its signals and operations, the system will permit an agency to monitor operation of any system in the region.

Figure 6 shows the long-term system architecture while Figure.7 illustrates the basic data flow between various components of the system.

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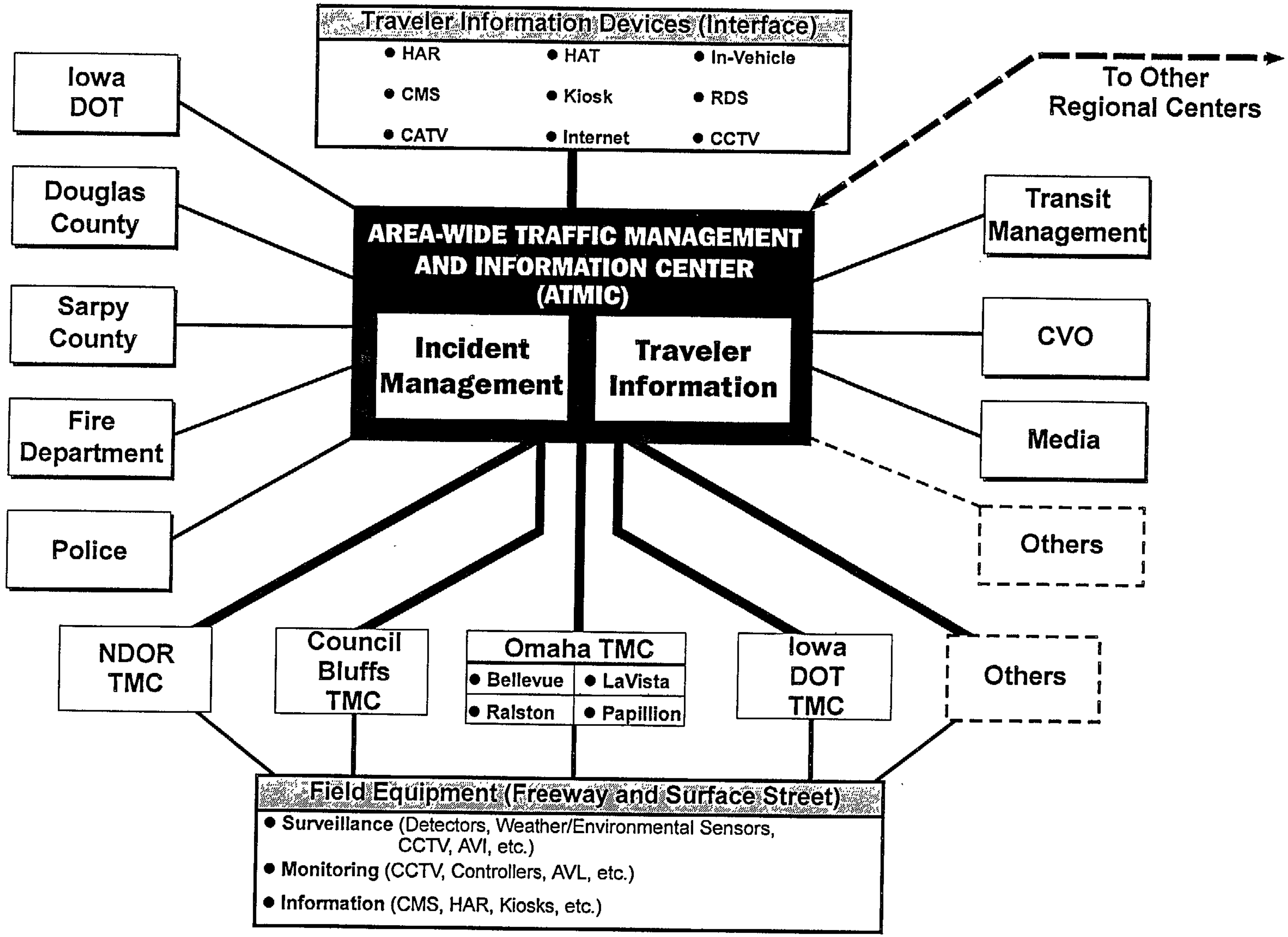

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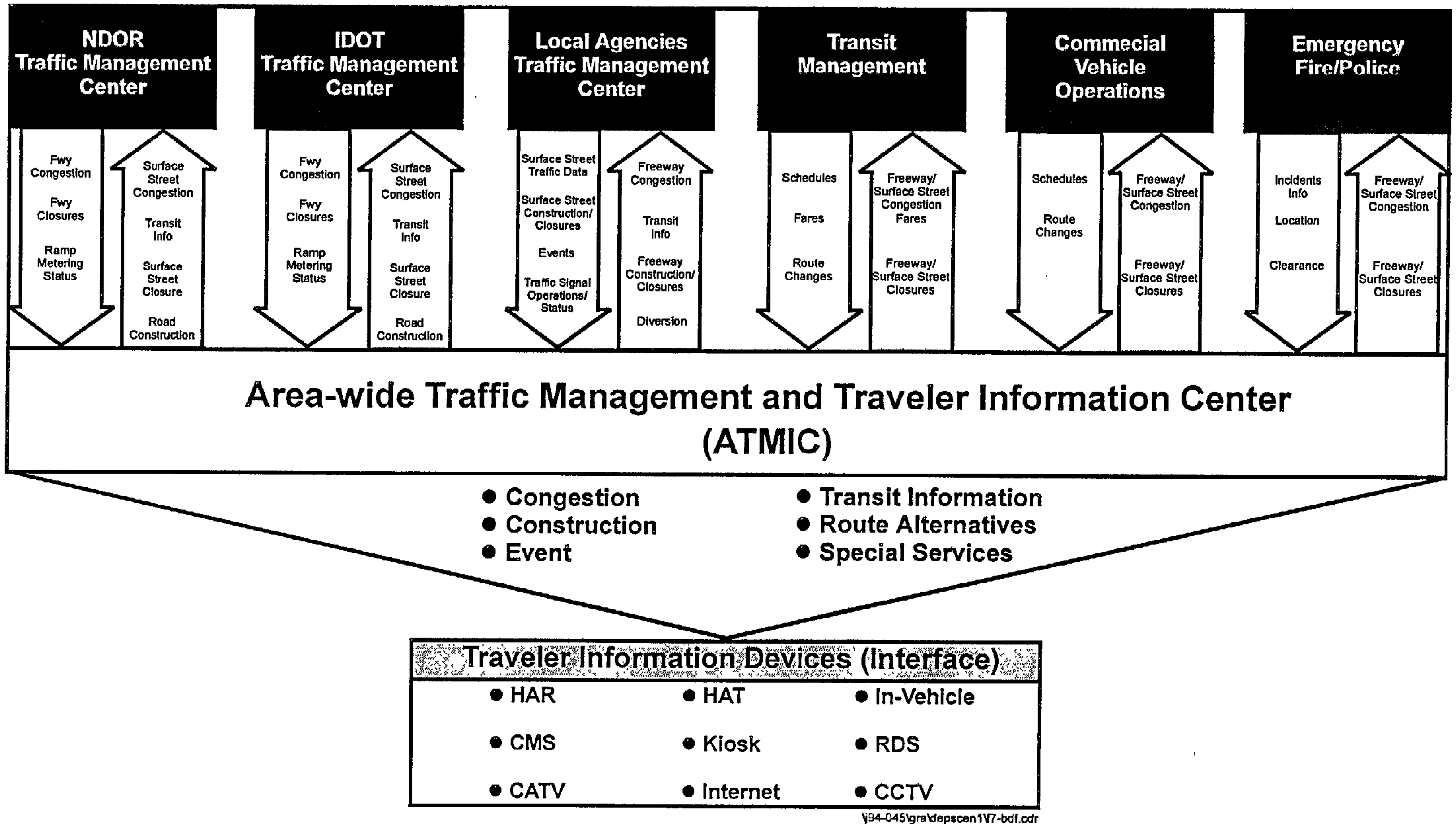
Long-Term System Architecture

Figure 6



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Basic Data Flow

Figure 7

6.1 Operational Overview

This section describes the operation of the Omaha metropolitan area ITS architecture. The physical architecture of each subsystem is defined by the flow diagram and information flow.

6.1.1 Traveler Information

Traveler information services will be performed as a subsystem of the total ATMIC function and includes obtaining traffic information, transit information, commercial vehicle information, and other (e.g., yellow page services, etc.) information. This information can be accessed by travelers at kiosks, in-transit vehicles, home or office computers, highway advisory radios and other traveler information interfaces. Traffic information will be sent to the system from jurisdictional traffic management centers; transit information will be sent to the system from the MAT system; commercial vehicle information will be sent to the system from isolated or central CVO operation systems; and yellow page services will be sent to the system (or to the user directly) by independent service providers in the area. The physical architecture is shown in Figure 8.

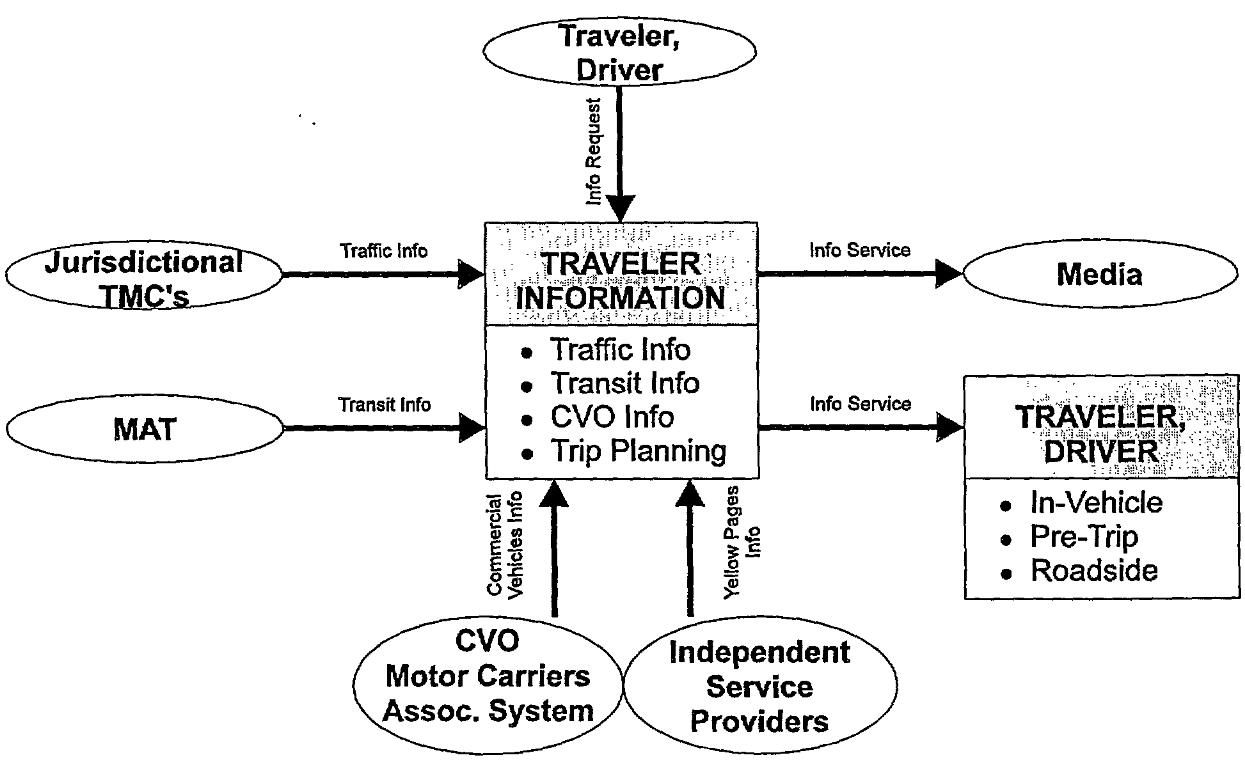


Figure 8. Architecture for Traveler Information

6.1.2 Incident Management

Managing the transportation network to minimize the impacts of recurring and non-recurring incidents is a primary function of the ATMIC. The ATMIC correlates information from a variety of sources: jurisdictional TMCs through roadway infrastructure sensors such as loops and video cameras; motorist reports; transit and commercial vehicle agencies; emergency agencies (police and fire). Once the data is used by the ATMIC to detect and classify the incidents, an incident response plan will be initiated and information about the incident will be shared with the appropriate agencies. As part of the incident response, HAR, HAT and CMS data messages will be sent to the roadway devices to alert the traffic control or to present information to drivers and travelers. Figure 9 shows the architecture of incident response and flow of information.

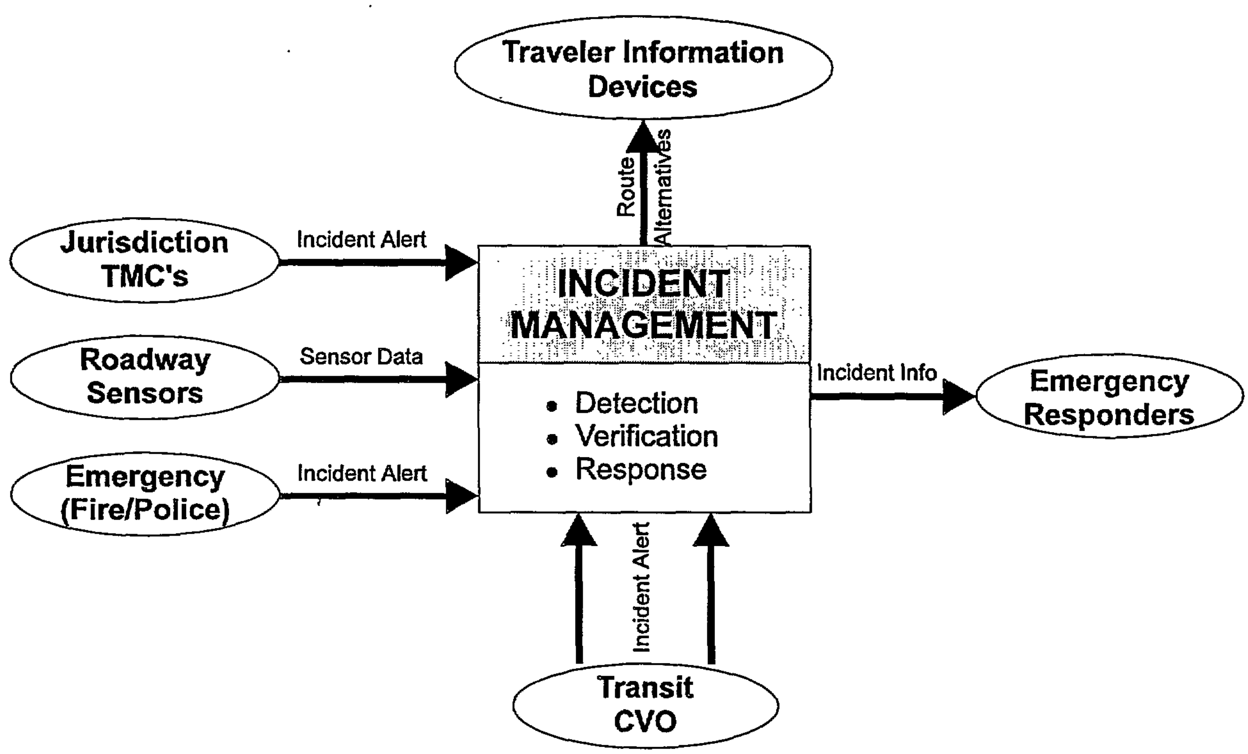


Figure 9. Architecture for Incident Management

6.1.3 Jurisdictional Traffic Management

Local traffic management and control will be performed by jurisdictional TMCs, including the City of Omaha TMC, City of Council Bluffs TMC, Iowa TMC, and NDOR (Freeway) TMC. Each of the traffic management centers will be connected to the area-wide traffic management and information center using the area-wide communications network. The WAN will provide the complete integration of all of the region's TMCs in a single environment. Although each agency will have ultimate control over all its signals and operations, the system will permit an agency to monitor system operation of any system in the region and share information and data between operators and other personnel of the connected agencies.

The TMC will use surveillance data from detectors to determine the state of the transportation network and create the signal timing and phasing messages used to control traffic. This control can also include CMS or any other roadside traffic control feature. The transit center (MAT) can request signal priority and emergency vehicles can also request signal preemption. The TMC, with its knowledge of vehicle routes and expected turning movements, can give vehicles class selective signal priority with minimum disruption to the surrounding traffic. The TMC architecture is shown in Figure 10.

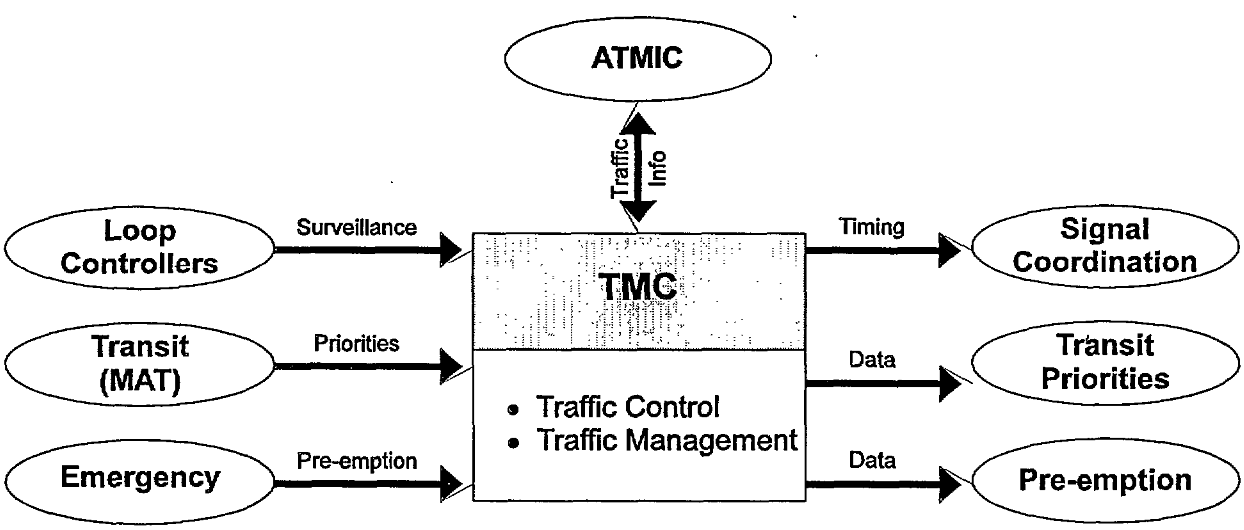


Figure 10. Architecture for TMC

6.2 Institutional Issues

Although there are good working relationships between the jurisdictions involved in this study process, there are some institutional issues that need to be addressed before the system can be implemented. Primarily, these issues deal with the operation of the system components, maintenance of the system components, and issues that will likely be encountered in the future as the system expands in functionality. How jurisdictions communicate with one another and their relational responsibilities, have a significant impact on the step-by-step implementation of the system.

The current institutional opportunities and constraints were documented in the "Inventory Report", dated April 28, 1995. Highlights of the issues, problems, concerns and opportunities are described below.

- **Traffic Control Systems**. NDOT District 2 performs the required maintenance for freeways and several of the state routes and signalized intersections along those routes. The accidents and incidents clearance and management is performed based on primarily informal agreements. The freeway police enforcement is provided via the Omaha Police Department.

The City of Omaha maintains and operates the traffic signals within the City and Douglas County. Smaller cities with few signalized intersections work with NDOR, City of Omaha, or Douglas County for operation and maintenance of their signalized intersections

Existing traffic control systems could be used as elements of the future computerized signal system and TMC's of the system architecture. The proposed ultimate architecture is flexible to accommodate existing systems at various steps of implementation.

There exists an opportunity for an organized incident management team concept where in case of such events, depending upon their nature, pre-existing arrangements and agreements would be made where involved entities would have a clear understanding of their responsibility and their required action plan.

The implementation and expansion of traffic management centers (TMCs) should be made in phases with clear definition of operational and maintenance requirements and responsibilities.

Operational issues to be resolved include how information is transmitted from one jurisdiction to another to coordinate signal operations, diversion routes, incident responses, and other situations, especially during the short and medium term of implementation.

Clearly, the involved entities in the ITS process are key players capable of penetrating through the institutional barriers. The Steering Committee and focus groups have demonstrated a sincere desire in building relationships at higher levels and have been involved throughout the project development process. As this process continues, the institutional issues should be the key element subject to discussion and the consensus building process.

6.3 Deployment Scenarios

The deployment scenarios "discussion" report identified a series of ITS projects and programs based on which deployment scenarios have been developed for three timeframes: short term, medium term, and long term. The phasing allows a building block approach of implementing the system architecture over time as technologies and funding become available.

- **Short-Term Deployment** Scenario-Projects and programs which can begin immediately and be implemented within five years. The short-term plan also provides infrastructure for some of the projects included in medium and long-term plans.

- **Medium-Term Deployment** Scenario-Projects and programs to be implemented within five to 10 years in the future.

- **Long-Term Deployment** Scenario-Projects and programs to be implemented beyond ten years in the future.

Each scenario has been the basis for development of the corresponding operational and physical system architecture. The overall integration of the architectural scenarios will be consistent with the ultimate architecture for the Omaha metropolitan area system.

6.3.1 Short-Term Scenario

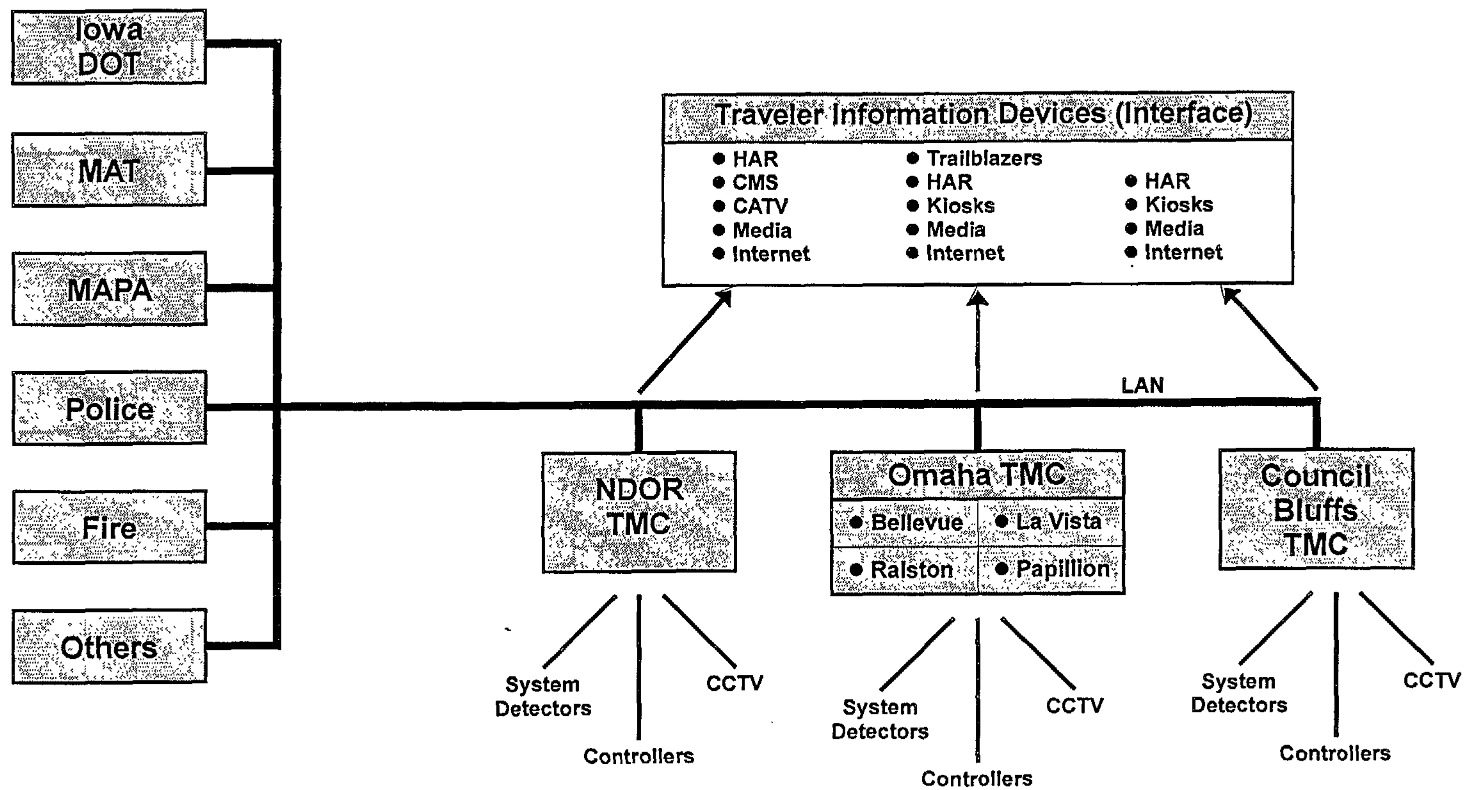
The focus of the short-term scenario will be on existing assets, expansion of the existing features and introduction of foundations for application of ITS technologies during the medium and long-term scenarios

Short-Term Scenario System Architecture

Figure 11 shows the physical architecture of the short-term ITS deployment scenario. Although the three existing control systems will be linked for data sharing via a Local Area Network (LAN), the systems will get their information from field devices independentIy, disseminate it and use the processed information independently to traveler information devices. This is the first step toward the implementation of the ultimate architecture. All other projects and programs identified for implementation during this scenario will be toward supporting the completion of the system shown in Figure 6.

6.3.2 Medium-Term Scenario

The medium-term scenario will build upon the foundation established in the short-term scenario. The major component of this scenario is the implementation of the ATMIC which is critical to the advanced traveler information system and traffic incident management system. The architecture of this scenario is a transition between the short-term and long-term architecture of the entire system as shown in Figure 6. Figure 12 shows the physical architecture of this scenario.



Short -Term Scenario System Architecture

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Figure 11

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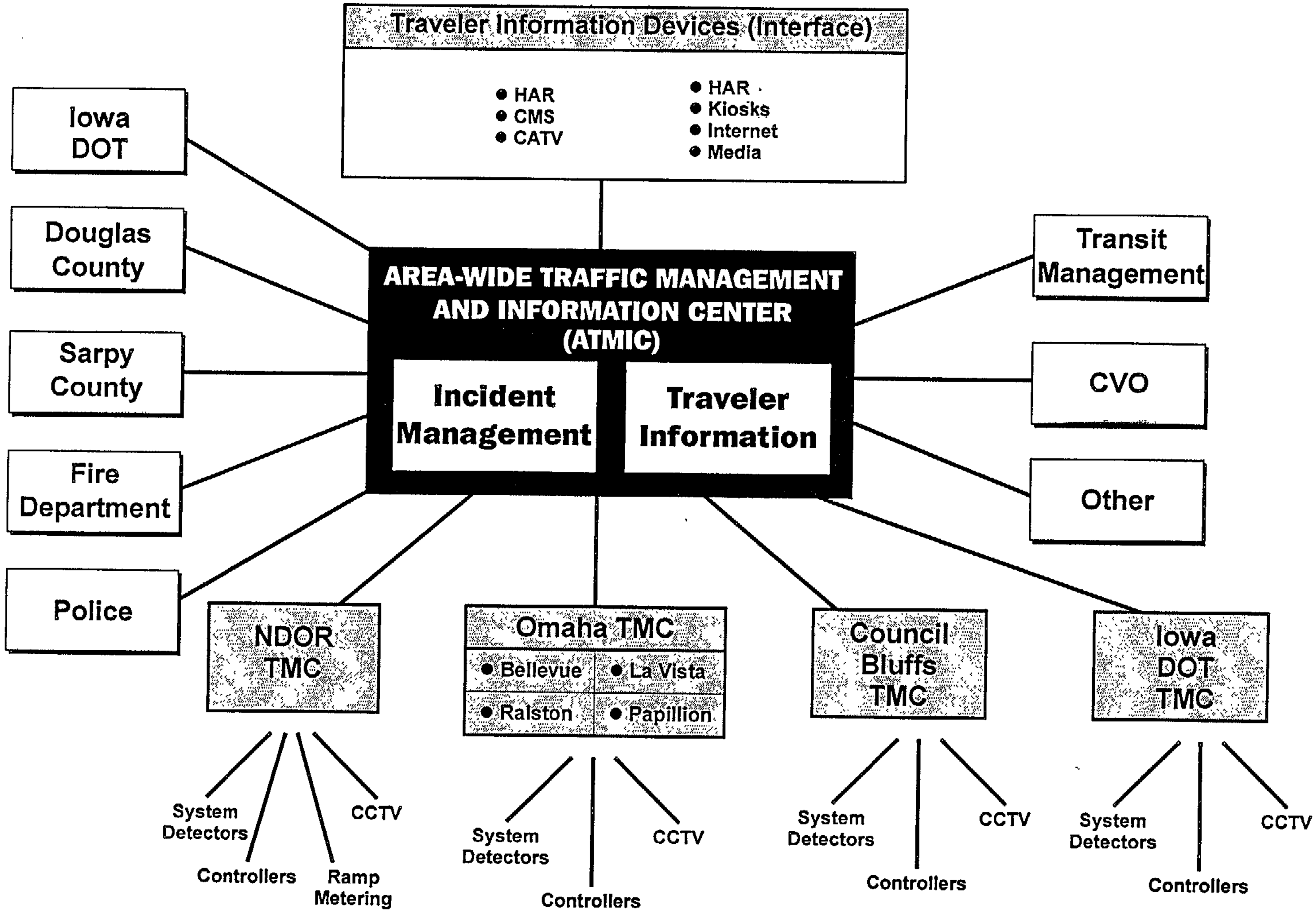

Mid-Term Scenario System Architecture

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Figure 12

4. Other Interfaces

Interface capabilities will be provided with transit facilities (advanced transit system, ATS), commercial vehicle facilities (commercial vehicle operations systems, CVO), and with a number of interested private sector organizations such as radio stations, TV stations and traffic management services.

- **Links Outside Infrastructure**

  Longer-term requirements might include the capabilities to provide en-route information to motorists and links between in-vehicle information systems.

The type of information transferred and the flow of data for the communications component of the system is shown in Figure 13.

Omaha Metropolitan Area ITS EDP Study

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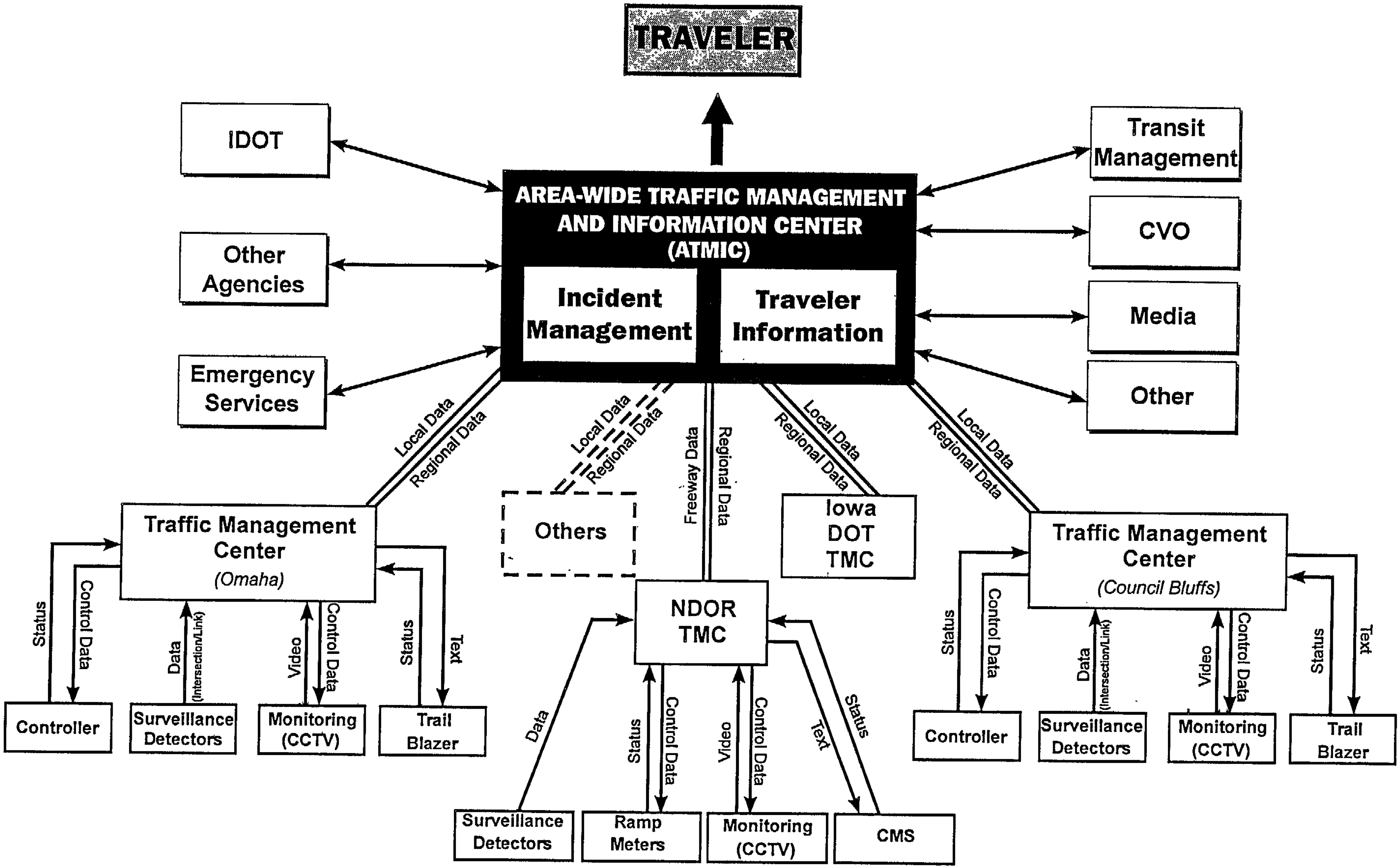

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Data Flow

Figure 13

8. INFORMATION REQUIREMENTS

The overall goal of the ITS communications system is to provide networked communications service for traffic operations, enforcement, motorist aid, emergency services, transit, traveler information, and maintenance activities.

The communications network will be an integral part of ITS in that it will affect (and be affected by) the system architecture, configuration, and operational strategies. In addition, the design of the communications network must be robust to provide reliable service for long-term strategies. Currently, the extent of technology change and market restructuring present real problems of potential system obsolescence in a relatively short-time frame. With obsolete systems, comes either high maintenance costs or premature replacement of equipment. Accordingly, the communications system for the Omaha ITS must provide a flexible, open architecture and conform to major trends in the market.

The information and communications requirements for the metropolitan Omaha communications network are summarized below.

- **Support of Wide Range of Uses** -The communications network will have a number of separate voice, data, and video systems each with separate requirements.
- **Support of a Wide Range of Data Systems** -There will be several different types of data communications systems both at the outset and especially in the future, all of which must provide compatibility with the ITS network.
- **Support of a Wide Range of Topologies-**The network topology is determined by the need for field equipment at particular locations and by the availability of agency facilities and existing systems.
- **Use of Communications-** Standards-Standards are critical to the use of the network by diverse equipment and to future enhancements and migration.
- **Robustness--**Even as important as the basic availability requirement, the ITS communications network must be suitable for operation in unusual and disaster circumstances.
- **Reliability-**A level of redundancy is required which allows for basic functions (traffic control, essential traveler information) to be carried out at all times.
- **Maintainability-**The effort of maintaining the system must be in line with available agency staffing and resources.
- **Network Modularity-**The communications system must allow for a phased implementation, and cost-effective location of facilities.

- **Future Enhancement Capability-**The network will need to handle equipment and messages for future technologies, many of which are as yet undefined or undeveloped. There must be a high probability that new designs will interface into this network.

8.1 Communications Functions

The following communication links are required in the proposed ITS architecture.

Area-Wide Traffic Management and Information Center (ATMIC)

The ATMIC will serve as the central clearinghouse of information regarding the area's transportation network. Thus the ATMIC must be serviced by a communications network capable of both receiving and transmitting data from and to individual agencies including NDOR, IDOT and other regional centers.

These communications links may consist of existing leased lines or fiber optic links, microwave radio, or satellite links. It will be desirable for several agencies to have the capability to transmit and receive CCTV images, thus, those links must have the capability to handle video with a minimum data rate of 112 Kbps for compressed video transmission, and a minimum data rate of 56 Kbps channel without video transmission

Additionally, the ATMIC will disseminate information to the various traveler information stations. These may include Community Access Television (CATV) broadcasts, kiosks, Highway Advisory Radio (HAR), Highway Advisory Telephone (HAT), Changeable Message Sign (CMS), etc.

Traffic Operations/Management

A typical reliable, cost-effective communications architecture must be designed to accommodate the connection of thousands of field devices to the state and local TMC's These devices are distributed over , several miles and are often not in close proximity to the existing communications networks.

The general design of the traffic operations architecture consists of trunk communications which connect the TMCs to communications hubs located in the field, and local area communications which connect each field device to a communications hub. The trunk communications may consist of a combination of leased lines from US West and TCI (Telecommunications International), agency-owned twisted pair and fiber optic cable. These lines range in capacity from 64 Kbps to 44 Mbps (DS3) and beyond, depending on the requirements of the devices which are connected to the local hub. Local area communications may be accomplished using twisted pair cable, fiber optic cable, and networked spread spectrum radio. The data rate on these links is low, and typically consists of 1200 to 9600 baud rate circuits.

Transit Operations

Transit operations requires the transmission of data both between stationary locations (e.g., vehicle service center and MAT central) and between mobile and stationary (e.g., transit vehicle and central). These links may consist of leased lines, agency-owned cable, and a variety of wireless communications such as two-way radio and satellite (supplying AVL information).

Communication with Enforcement Agencies

The ATMIC will provide information to enforcement agencies using both computer and voice links. These links can be either dedicated or dial-up, depending on the nature of the equipment at each end of the link.

Communication with Emergency Services

Information exchanges between the ATMIC and the TMC's and Police, Fire, Hazardous Material, and Service Patrols will use both direct voice links and data links via the ATMIC. Either dial-up or dedicated links could be established, depending on the requirements of the individual agencies.

Communication to Traveler Information Devices

Traveler information equipment includes changeable message signs (CMS), highway advisory radio (HAP), information kiosks, radio data systems (RDS), Internet devices, and highway advisory telephone (HAT). Test equipment is considered as field devices and communications from/to the equipment and will use the traffic operations links as discussed above.

Interagency Communication

Dependent upon the local and subregional traffic control configurations, links would be established between local agencies and regional hubs, with similar links between the regional hubs and the ATMIC. Assessment of required data transfer requirements must be done as part of a detailed system design effort. As a minimum, however, these links must be standardized in terms of data structure and protocol. A desirable standard to use is Ethernet.

Field Device Considerations

The communication system must accommodate a variety of field devices. The data rates and frequency of communications varies greatly among the devices. The design of the communications systems must take into account the requirements of each connected device, as well as the number and types of devices in a local communications hub.

Detection Station, Traffic Signal, and Ramp Controllers

Detection stations, traffic signals, and ramp controllers use the same controller hardware, typically a Type 170 controller or NEMA equivalent. They will be located at freeway interchanges and at intervals along the freeway as well as at each signalized intersection along the major arterials. These devices will communicate with processors in the communications hub on a regular, polled, full-time basis, and require two-way communications.

These controllers will require a 1200-9600 bps data circuit which can be in a multi-dropped configuration on a single channel (full-duplex). However, the new NTCIP standard specifies, as a minimum, use of 1200 baud communications link between the TMC and each field device.

Changeable Message Signs

Both full matrix changeable message signs and limited message changeable message signs (trailblazers) use the same type of data channel as the detectors, signals, and ramp meter controllers, communicating at 1200-9600 bps. The communications requirement for CMS is a low rate, on demand type link. Dial-up leased line or cellular links are ideal, since the actual use of these communications paths will probably be less than 10 percent.

Highway Advisory Radio

Highway advisory radio (HAR) communications require a clear voice channel or medium high rate data channel. Typical HARs support the broadcast of both pre-recorded messages and messages which are sent to the HAR by the TMC's Either a cellular telephone or wire communications is used to transfer messages to the HAR. Leased 65 Kbps digital circuits are now used by commercial broadcast radio with special equipment for 7.5 KHz voice ("broadcast quality voice") and could be used for the HAR. The HAR communications requirement is for 100 percent availability, but not necessarily a constant connection.

Video Equipment

The major purpose of video surveillance is incident verification, which requires only short duration visual information. However, the video network will have to be available 100 percent of the time for incident verification and other surveillance functions. Some individual cameras may only be used a relatively small percentage of the time.

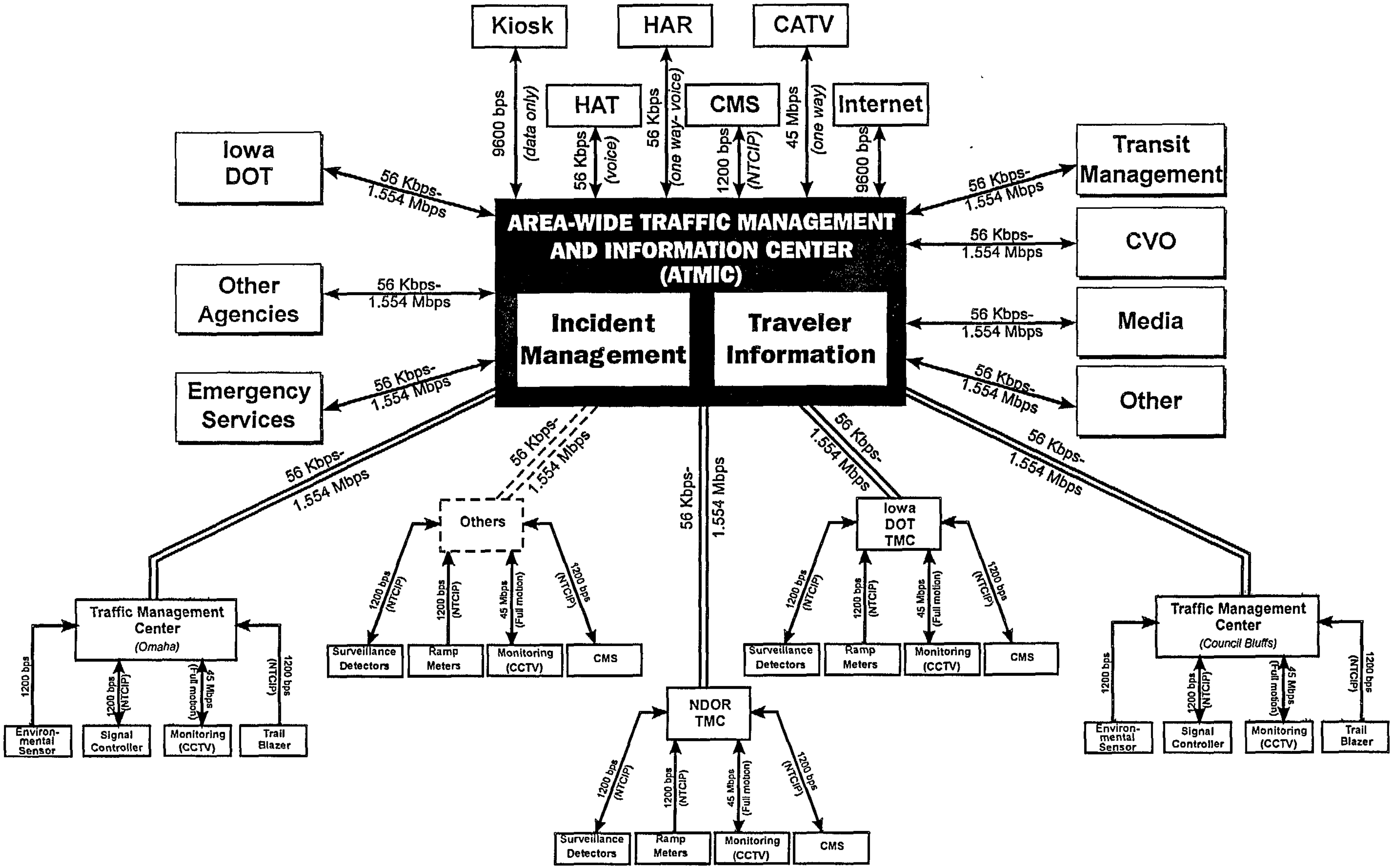
Two different types of video communications circuits are envisioned for the TMCs. In those areas where a fiber optic backbone is installed, the video transmissions will be full motion analog. The video signal will be multiplexed onto the backbone fiber network. In those areas where other types of trunk communications must be used (e.g., leased line networks), compressed digital (i.e., CODEC) video at a rate of 112 Kbps will be used. Two switched 56,Kbps lines will be installed at these communications hubs to provide a cost-effective communications path from the hub to the TMC. Camera control from the TMC to the video equipment will also be required. The control will require a low data rate (about 1200 bps) communications link when the cameras are active to support camera positioning (pan, tilt, zoom, etc.).

Table 1 shows a summary of ITS equipment data/video transmission requirements and Figure 14 illustrates the required data rate flow between components of the system.

TABLE 1. EQUIPMENT DATA/VIDEO TRANSMISSION

Equipment	information Flow Direction	Interface Data Rate	Length of Exchange	Frequency
FREEWAY EQUIPMENT				
Detection Stations	To TMC	***1200-9600*** bps	100-200 bytes	***15-30*** seconds
Lamp Meters	To and from TMC	***1200-9600*** bps	**< *20*** bytes	On Demand
Changeable Message Signs	To and from TMC	1200-9600 bps	10-100 bytes	On Demand
Highway Advisory Radio	From TMC	56 Kpbs ***(30-3000*** Hz)	**< *30*** seconds of audio	On Demand
Jideo Surveillance - Full Motion - Compressed	To TMC' To TMC'	Analog 6 MHz bandwidth Digital 45 Mbps 112 Kbps-1.544 Mbps (depending on number of frames per second)	Duration of Incident	On Demand
MAJOR ARTERIAL EQUIPMENT				
Detection Stations	To TMC	1200-9600 bps	***3*** bytes control ***+3*** bytes/detector	Every 30 seconds
Traffic Signal Controller	From TMC	1200-9600 bps	Bi-directional 8 bytes to/from TMC	Once/second
Full Matrix Changeable Message Signs	From TMC	1200-9600 bps	***250*** bytes Max	On Demand
Video Surveillance Full Motion Compressed	To TMC' To TMC'	Analog 3 MHz bandwidth Digital 4.5 Mbps 56 Kbps-1.544 Mbps (depending on number of frames per second)	Duration of Incident	On Demand
Highway Advisory Radio	From TMC	56 Kbps ***(30-3000*** Hz)	**< *30*** seconds of audio	On Demanc
Limited Message CMS (Trailblazer)	From TMC	1200-9600 bps	***250*** bytes Max	On Demanc

Notes:
1. Camera control information (pan, zoom, etc.) jiows from TMC to video equipment.



/j94-045/gra/finalrpt/f12-req cdr

Communication Requirements

Figure 14

9. COMMUNICATIONS REQUIREMENTS

This section describes the data, voice and video communications analysis to determine the network requirements for the Omaha metropolitan area ITS communications system. Several criteria relative to this analysis are described below.

- **Data Requirements.** Information required to determine the design capacity and data transmission rate of the various elements of the communications system are the amount of information to be transmitted and the frequency of transmission.

- **Latency.** Latency is best described as how long it takes for the transmission of data to occur from the originating source to the destination source including processing. This is generally measured in micro or nano seconds. There are several different elements of delay that define the overall latency of a network, sub-network or communications link.

  Many transportation strategies and algorithms are delay sensitive. The amount of latency in a physical network must be understood and quantified. Even though different networks may use the same processing and communications hardware, the amount of delay inherent in each of them may differ.

  Latency in a public network can present much different issues than those of a private network. In a private network, the majority of the data placed on the network is known and quantifiable. In a public network service environment, where many different customers access the same network, the loading of that network at any given moment in time is variable and mostly unpredictable. While this issue is important, it should not preclude the use of dedicated and virtual leased network services.

- **Throughput.** Throughput is the measurement of the amount of data that passes through all or part of a communications system when that system is working at optimum capacity. Throughput may be expressed in bits, bytes, characters, words, blocks, messages or any other data unit per unit of time. The most common throughput measurement is in bits, kilobits, or megabits per second.

  Measurement of throughput through modeling and statistical analysis in conjunction with data loading and latency delay calculations will provide the network designer with invaluable information.

- **Network Topology.** There are a number of varying topologies that are used in designing a communications network. Topologies include:

  - Star
  - Mesh
  - Ring
  - Tree
  - Backbone

Selecting the optimum topology to support the application ensures the highest transmission speed and fastest routing which maximizes the efficiency of the communications network.

- Redundancy. The communications subsystem is a critical component of the Omaha system. Since it supports the entire ITS infrastructure, consideration must be given toward developing a "fault tolerant" system in which a failure of a portion of the network can be circumvented using backup communications media or redundant communications paths. The following paragraphs outline the available options for redundancy within communications network:

  Functional Redundancy. Functional redundancy means that the communications system has simultaneous dual transmission capabilities. Essentially, there are separate communication lines for each function-one mainline connection and one backup mode. However, these lines may be contained within a single cable, so that if the cable is intentionally or accidentally cut, both lines are severed.

  Physical Redundancy. Physical redundancy is a further form of redundancy where the mainline and backup connections are physically separated in different conduits. These may be spaced a few feet apart, or installed on opposing sides of a roadway.

  Staggered Redundancy. This method of redundancy selectively alternates (or staggers) individual equipment components onto separate communication lines. Therefore, if a particular communications link fails, communications with the entire section would not be lost.

  Ring Diversity. Ring diversity involves a loop network with primary directional flows, usually along the same communication line(s). If communications are lost in the primary direction, then all communications will run in the opposite direction on the loop.

  Route Diversity. Route diversity is slightly different from ring diversity in that is automatically reroutes communications onto a new line when the usual link fails. The communication signals do not have to "piggyback" on the fibers in the opposite direction. Route diversity is appropriate for networks that contain more routing options than a simple ring system.

- **Standards and Protocols.** Protocols define sets of rules that are used to coordinate conversations between two or more devices on a network. The devices may be Data Terminal Equipment (DTE) such as computers, terminals, facsimiles, etc. or Data Communications Equipment (DCE) such as modems, radios, multiplexers, routes, bridges, switches, etc., capable of peer-to-peer communications. Communications networks are designed using communications protocols for DCE equipment and physical interface standards required to support the integration of DCE and DTE equipment.

  Protocols are either open, ***de facto*** or proprietary.

  Open protocols are created by collaboration of multiple organizations, vendors and individuals working in conjunction with a standard body that ultimately sanctions the work completed by the committee, forum or group. In the simplest of terms, open protocols create a transparent network regardless of equipment or applications.

De facto protocols are generally open in that they are released to the world for consultant and collaboration. ***De facto*** protocols may have been created by an individual or single organization such as a manufacturer or a forum of interested parties. These protocols may be sanctioned by a specific group or through widespread common use become ***de facto*** protocols.

Proprietary protocols are developed by individual companies or organizations and are not released for consultation or standardization.

- **NTCIP.** The National Traffic Control and ITS Communications Protocol (NTCIP) committee, established to define a standard protocol for two-way communications for traffic control systems, is using the three lower layers of the OSI model for development of the NTCIP standard. This standard will support manufacturer's interchangeability of controller units in traditional traffic signal control systems.

  The NTCIP committee has defined two physical layer standards for communicating with controllers, RS-232C and FSK modems. RS-232C is the most common method of interfacing to external communications equipment. The FSK modem is specified because it is the typical method by which current traffic control systems implement communications.

  The new physical layer standard requires controllers to be equipped with an RS-232C DTE interface configured to support the byte structure of 1 start bit, 8 data bits, and 1 stop bit operating at a minimum of 1,200 bps. Controllers will also be equipped with a modem interface capable of two-wire or four-wire full duplex communications using an unconditional Type 3002 voice grade circuit or equivalent customer-owned cable. The NTCIP committee defined 1,200 bps as the minimum data rate which is used nation-wide for traffic signal control.

- **Transmission** Media. The transmission media is the lowest layer of the physical network. Transmission media is an individual component part of the overall physical network and not a separate network component. Therefore, there is flexibility to choose the appropriate transmission media to support the applications at each of the three levels.

  For definition purposes, transmission media can be placed into one of the two groups which can be owned or leased:

  -Bounded. Includes wires, fibers and cables.
  -Unbounded. Includes all wireless transmission technologies

  When practical, existing communications infrastructures will be used to support the requirements of the Omaha project. A brief comparison of various media is presented in Section 10.

- **Installation** Costs. Installation of a privately owned communications network requires infrastructure investments with costs dictated by the size of the area to be interconnected. Where no infrastructure or services exist, installation costs for a conduit and cable system would be several million dollars. This expense can be avoided with the use of wireless technologies such as microwave or spread spectrum radio. There are some one-time installation costs associated with leased services that are standard throughout the industry.

- **Monthly Recurring Costs.** Installation of ‘a privately owned and maintained communications network has its advantages in that recurring costs associated with leased services and maintenance contracts can be avoided, however, monthly operating costs for self-maintenance is required. Leased services have higher monthly operating costs than those of a privately owned and maintained network.

  Monthly recurring costs for leased services can be avoided if there is sufficient and adequate communications infrastructure that could be used to integrate each sub-network into the physical network architecture via surface street right-to-way.

  Employing services already in use should cause little or no increase in monthly recurring costs.

- **Equipment Costs.** Installation of a privately owned network requires the purchase of communications equipment. Communications equipment costs vary according to the degree of technical sophistication and bandwidth supported. The requirement to transport real-time data at the Local level dictates use of a more sophisticated communications equipment configuration, resulting in a larger investment.

  Existing traffic control systems will have no requirement for new telecommunications equipment. Where no traffic control systems exist, new equipment will be required.

- **Maintenance.** Maintenance is an essential element of all networks. Generally, maintenance on privately owned networks is performed by the technical staff of the owning agency. Self-maintenance is generally more costly than contracted maintenance. However, with self-maintenance comes ownership which can be an important issue. Performing self-maintenance is generally based on the criticality of the service and the operating budget.

  Leasing equipment and services relieves the lessor of the responsibility to perform maintenance. Unfortunately, having to reply on an outside source to restore outages often times result in long delays due to non-availability of vendor technicians and parts which can be costly.

- **Staffing.** The level of staffing required to continually operate and maintain the overall network is an important factor in selection and design of the communications system. A complete owned system may require staffing much beyond the capabilities of the agencies. A hybrid system comprised of both private and public ownership may be more cost-effective.

10. COMMUNICATIONS MEDIA

This section identifies and examines the capabilities and characteristics of various communications media which are being considered for implementation in the Omaha metropolitan area ITS communications network. A more detailed discussion of various communications media technologies could be found in the Support Technology Report.

10.1 Communications Media Capabilities

Numerous communications media exist for use in ITS applications, each with inherent characteristics such as bandwidth, repeater spacings, transmission rates, and number of data, voice and video channels. In addition, several qualitative characteristics of these media determine their suitability for use in specific architectures. For the Omaha Metropolitan Area ITS Study, several types of communications media are considered to be practical, including:

- Fiber Optics
- Twisted Pair
- Radio (800 and 900 MHz)
- Satellite
- Microwave

The quantifiable features of each of these communications media are summarized in Table 2. Qualitative features are briefly discussed in the following sections.

- Fiber Optics. Fiber optics technology transports information by sending light waves through the glass strands of a fiber optic cable. Therefore, in order to install a fiber optic network, a communications conduit and fiber optic cable information must be available.

  If not owned by the Agency, it may be possible to lease fiber optic cable from private communications providers.

  Fiber optic cable requires the use of fiber optic equipment to convert the digitized data signal into a fiber optic analog signal. This equipment ranges in price depending on the amount of bandwidth required and number of channels to be used. The fiber optic cable could be terminated and connected to the fiber optic communications equipment at each location, i. e., controller cabinet, TMC, or communications room.

- Twisted Pair. Twisted pair cabling can be used to support any existing communications technology, however, as in the case of fiber optics, a communications conduit and copper cable infrastructure must be available. These include dedicated circuits capable of transporting data at rates of 300 bps to full Tl 1.544 Mbps.

  Twisted pair cabling would be terminated and connected to communications equipment at each location, i.e., controller cabinet, TMC, or communications room,

TABLE 2

COMMUNICATIONS MEDIA CHARACTERISTICS

Communications Media	Characteristics						Comments
	Bandwidth	Repeater Spacing	Transmission Rate	Voice Channels[6]	Video Channels’	Date Channels[6]	
Single-Mode Fiber optics (SMFO)	< Several GHz[1]	40-50 miles	<Several Gbps	100	<16	100	Number of channels influenced by multiplexing capabilities
Multi-Mode Fiber optics (MMFO)	500 MHz[1]	1-12 miles	<Several Gbps	100	<16	100	Number of channels influenced by multiplexing capabilities
Copper Wire Twisted Pair Cable)	2.7 KHz	9-15 miles	<9.6 Kbps	24	1[10]	[5] 5	Not suitable for full motion video transmission
Coaxial Cable	<300 MHz	l-3 miles	< 10 Mbps	100	<50	[5]	Typically installed for one-way communications only
Radio (800 MHz)	25 KHz	15-30 miles[8]	<9.6 Kbps	1	---	[5]	Requires FCC license
Cellular Radio/Phone	30 KHz	N/A	1.2 Kbps (9.6 Kbps data)	1	---	[5]	
Packet Radio	<25 KHz	up to 43 miles[7]	< 1.2 Kbps	1	---	[5]	Requires FCC license

Communications Media	Characteristics						Comments
	Bandwidth	Repeater Spacing	Transmission Rate	Voice Channels[6]	Video Channels[6]	Date Channels[6]	
Broadcast Subcarriers AM	Not determined (typ. <50 Hz)	N/A	30 bps to 200 bps	[4]	---	[4]	No FCC license
FM	53 KHz to 99 KHz	NIA	2.4 Kbps to 9.6 Kbps	[4]	---	[4]	No FCC license
TV	16 KHz to 120 KHz	N/A	2.4 Kbps to 19.2 Kbps	[4]	---	[4]	No FCC license
Satellite	[3]	N/A	<50 Mbps	100	1	[5]	This is basically microwave to and from satellite
Terrestrial Microwave	10 MHz[9]	40-50 miles[2]	<40 Mbps	100	< l 6	[5]	Requires FCC license
Spread Spectrum Radio	(902-928) - 26 MHz total	5-10 miles	200 Kbps (typical)	Varies	<4	Varies	No license in the 902-928 MHz band is required

1 Bandwidth for fiber optic is indirectly proportional to transmission distance.
2 Repeater spacing for terrestrial microwave is indirectly proportional to frequency. Upper limits of range also depend on frequency.
3 Bandwidth for satellite microwave varies depending on service.
4 Channels for all broadcast subcarriers reflect a trade-off between available bandwidth, typical signal/noise ratio (dB) and the number of applications (clients) to be served.
5 The number of data channels available reflects a trade-off between the achievable transmission rate, message size and format, as well as the number of applications (clients) to be served.
6 The number of available channels (voice, video, data) does not reflect simultaneous transmission of each per communication media type.
7 Requires line-of-sight for **low** power (1 watt or less) transmissions over long distances.
8 Range depends largely upon line-of-sight.
9 Up to 200 MHz possible but bandwidths above 10 MHz require special waiver from the FCC.
10 Compressed only. Have one T-l capability on copper wire and compressed video can provide good operation on as little as l/2 of a T-1.

- **Single Channel Radio.** Operating frequencies for this equipment are regulated by the Federal Communications Commission (FCC) and therefore require a license. This is a problem in the project area due to the non-availability of frequencies.

  Single channel radio would not require installation of a communications conduit and cable infrastructure. Radios would be installed at each location, i.e., controller cabinet, TMC or communications room. Antennas would be installed on roofs, towers, or signal poles.

- **Spread Spectrum Radio.** Spread spectrum radio (SSR) is the newest of the wireless technologies. It is a non-licensed technology that uses radio broadcast power of less than 1 watt. The functional operation of a SSR is identical to that of a modem.

  Unlike single channel radio, SSR is sensitive to line-of-sight antenna propagation. Although not as critical as that of satellite or microwave (narrow beams), antenna alignment is an issue. This is generally overcome by the use of directional antennas.

  SSR's come in two different configurations. With either separate antenna or fully integrated antenna, SSR's with a separate antenna would be installed at each location, e.g., controller cabinet, TMC, or communications room. Antennas would be installed on roofs, signal poles, or towers. SSR's with an integrated antenna would be installed at each location, e.g., signal poles, roofs, or towers. SSR's would not require installation of a communications conduit and cable infrastructure.

- Satellite. Very Small Aperture Terminal (VSAT) is the industry standard for satellite technology. VSAT technology is unique in that it requires line-of-sight antenna propagation from the earth station to the satellite. Often times this presents problems in placement of equipment.

  Satellite transponder channels (air time) would have to be leased from one of the existing satellite companies or a leasing company. VSAT does not require an FCC license.

  VSAT would not require installation of a communications conduit and cable infrastructure. VSAT transmitters/receivers would be installed at each location, e.g., controller cabinet, TMC, or communications room. Antennas would be installed on roofs, towers, or signal poles.

- **Microwave.** Microwave signals are transported identical to satellite signals with one exception. The signals are transmitted from antenna to antenna versus antenna to satellite to antenna. Microwave technology requires line-of-sight antenna propagation between antennas which can present problems in the placement of equipment.

  Microwave equipment is rated as either licensed or non-licensed depending on transmitter power and bandwidth. An FCC license may be difficult to obtain due to the high usage of microwave in the Omaha area.

Microwave transmitters/receivers would be installed at each location, e.g., controller cabinet, TMC, or communications room. Antennas would be installed on roofs, towers, or signal poles.

Microwave would not require installation of a communications conduit and cable infrastructure.

10.2 Data Transmission Technologies

- **T1 Technology.** T1 technology is the oldest form of high speed digital data service, providing data rates from the basic Tl (1.5544 Mbps) to T3 (44.736 Mbps) using twisted pair cable for lower rates and fiber optic cable for higher rates. Tl technology uses individual digital service channels of 64 Kbps, each which can easily be mulitplexed and demultiplexed. This technology is limited to a point-to-point or point-to-multi-point topology only. This limitation requires installation of separate circuits between each agency.

- **Integrated Services Digital Network (ISDN).** ISDN is built on Tl technology, 1.544 Mbps, with one advantage and one disadvantage. The advantage of ISDN is that is uses a circuit switched technique, and therefore is not limited to any certain topology. The disadvantage is it can only be leased at 128 Kbps or 1.5444 Mbps data rates. All nodes subscribing to ISDN services have a unique network address which is required for call set-up. With ISDN, each regional corridor and agency would require a single connection to the network. Data can then be transferred by "dialing" a system. Once the information is received, the call can be terminated. Or the connection can be maintained for as long as it is required, however this prevents access by others.

  ISDN was developed for use as a "bandwidth on-demand" network with a pricing incentive for infrequent use. In a network requiring continuous communication, a dedicated circuit is preferable. Use of, ISDN for dedicated services has a higher rate than dedicated Tl service.

- **Frame Relay.** Frame relay is a technology that transports data in frames which is more efficient than T1 technology. Frame relay is available at data rates of 56 Kbps, 128 Kbps, 256 Kbps, 384 Kbps and 1.5544 Mbps. Frame relay provides permanent virtual circuits between network nodes, which can be configured as either point-to-point or point-to-multi-point. There is no additional costs for usage or distance which makes frame relay an attractive alternative to T1 networking.

11. MASTER PLAN REQUIREMENTS

One objective of the communications system master plan is to provide guidelines for future communications infrastructure deployment. The Omaha metropolitan area communications system is envisioned as a multi-jurisdictional network encompassing data processing and transmission, vi&o transmission, as well as voice transmission, for emergency entities and advisory radios.

It is clear that in order to undertake state-of-the-art traffic/incident management strategies, the communications network should be able to meet current communications requirements as well as provide ample capacity for future expansion to support the development of advanced traffic technologies. In Table 1, the data transmission requirements for Omaha's future ITS equipment is presented, and in Table 2, various communications media characteristics are outlined. These tables, as well as the overall system architecture, highlight the following master plan requirements for the Omaha metropolitan area's ITS needs That is, the architecture must:

- Be compatible with high capacity, high data transmission rate communications system such as SONET and ATM.

- Provide a backbone and distributed architecture utilizing communications hubs at appropriate locations.

- Provide a high data rate backbone that will connect the communications hubs to the ATMIC or TMCs.

- Provide equipment at each hub to transform high data rate channels into low data rate distributed channels.

- Utilize both agency-owned communications infrastructure as well as carrier providers in the area.

The development of the communications master plan was based on an analysis of communications requirements of the three deployment scenarios and individual ITS projects/programs identified in previous reports.

Thirteen communications hubs were identified and selected to interconnect the high data rate backbone to the rest of the ITS system's field components. Table 3 shows the identified hubs and their characteristics for the three deployment scenarios.

Communications hubs 1, 2 and 3 are designed for state equipment along the freeways. At the hubs, combined signals from the NDOR TMC via high speed trunk will be resplit and transmitted to the field equipment. Similarly, the responses from the field equipment will be gathered at the hub locations, multiplexed and transmitted via the backbone to the NDOR TMC where they are split and read by the system. Fiber optic installation along I-80 as freeway construction activities progress, will connect these three hubs together and transmit the multiplexed data to the, NDOR TMC via the communications network of the private service providers.

TABLE 3

COMMUNICATIONS HUBS

Communications Hub	Short-Term Scenario	Mid-Term Scenario	Long-Term Scenario	Combined
Hub 1 Approximate Location: I-80 and I-680	***Devices*** CCTV - 5 CMS-4 HAR-3 ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:*** 5 DS-3 for video 7 DS-0 for data and voice	***Devices:*** HAR-2 ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:*** 2 DS-0 for voice	***Devices:*** CCTV - 1 CMS-1 HAR-1 ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:*** 1 DS-3 for video 2 DS-0 for data and voice	***Devices:*** CCTV - 6 CMS-5 HAR-6 ***Information Flow Direction*** To and from NDOR ***Information Combined Data Rate:*** 1 DS-4 for video 1 DS-1 for data'and voice
Hub 2 Approximate Location: I-80 and Kennedy Expressway	***Devices*** CCTV - 5 CMS-5 HAR-3 Signal - Kiosk - ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:*** 5 DS-3 for video 8 DS-0 for data and voice	***Devices:*** CCTV - 4 CMS-3 HAR-2 Signal - Kiosk - ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:*** 4 DS-3 for video 5 DS-0 for voice	***Devices:*** CCTV - 1 CMS-1 HAR-1 Signal - Kiosk - ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:*** 1 DS-3 for video 2 DS-0 for data and voice	***Devices:*** CCTV - 10 CMS - 9 HAR-6 Signal - Kiosk - ***Information Flow Direction;*** To and from NDOR ***Information Combined Data Rate:*** 1 DS-4 for video 2 DS-3 for data and voice 1 DS-1 for data and voice

Communications Hub	Short-Term Scenario	Mid-Term Scenario	Long-Term Scenario	Combined
Hub 3 Approximate Location: I-80 and Highway 192	***Devices*** CCTV - 1 CMS - 1 HAR-1 Signal - Kiosk - ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:*** 1 DS-3 for video 2 DS-0 for data and voice	***Devices:*** CCTV - 3 CMS - HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:*** 3 DS-3 for video	***Devices:*** CCTV - CMS-1 HAR - Signal - Kiosk - ***Information Flow Direction:*** To and from NDOR ***Information Combined Data Rate:***	***Devices:*** CCTV - 4 CMS-2 HAR-1 Signal - Kiosk - ***Information Flow Direction*** To and from NDOR ***Information Combined Data Rate:*** 1 DS-4 for video 2 DS-1 for data
Hub 4 4pproximate Location: W. Center Road and 90th Street	***Devices*** CCTV - 1 CMS-2 HAR - Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 2 DS-0 for data	***Devices:*** CCTV - 2 CMS-4 HAR-2 Signal - 43 Kiosk - 5 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 2 DS-3 for video 17 DS-0 for and voice . . . signals	***Devices:*** CCTV - 4 CMS-2 HAR-3 Signal - 4 Kiosk - 2 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 4 DS-3 for video 7 DS-0 for data and voice 1 DS-0 for signals	***Devices:*** CCTV - 7 CMS-8 HAR-5 Signal - 47 Kiosk - 7 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-4 for video 2 DS-1 for data and voice

Communications Hub	Short-Term Scenario	Mid-Term Scenario	Long-Term Scenario	Combined
Hub 5 Approximate Location: 72nd Street and Dodge Street	***Devices*** CCTV - 4 CMS-3 HAR-1 Signal - Kiosk - 1 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 4 DS-3 for video 5 DS-0 for data and voice	***Devices:*** CCTV - 2 CMS-5 HAR-4 Signal - 40 Kiosk - 6 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 2 DS-3 for video 20 DS-0 for and voice	***Devices:*** CCTV - CMS - HAR- Signal - Kiosk - 4 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 4 DS-0 for data	***Devices:*** CCTV - 6 CMS-8 HAR-5 Signal - 40 Kiosk - 4 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-4 for video 2 DS-1 for data and voice
Hub 6 Approximate Location: Highway 92 and 72nd Street	***Devices*** CCTV - 1 CMS-3 HAR- Signal - Kiosk - ***Infomtion Flow Direction:*** To and from City of - Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 3 DS-0 for data	***Devices:*** CCTV - 1 CMS-1 HAR- Signal - 53 Kiosk - 1 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 2 DS-0 for voice 7 DS-0 for signals	***Devices:*** CCTV - 4 CMS-1 HAR-2 Signal - 5 Kiosk - 4 ***Information Flow Direction:*** To and from City of Omaha ***Infomtion Combined Data Rate:*** 4 DS-3 for video 7 DS-0 for data and voice 1 DS-0 for signals	***Devices:*** CCTV - 6 CMS-5 HAR-2 Signal - 58 Kiosk - 5 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-4 for video 1 DS-1 for data and voice

Communications Hub	Short-Term Scenario	Mid-Term Scenario	Long-Term Scenario.,	Combined
Hub 7 Approximate Location: Dodge Street and 42nd Street	***Devices*** CCTV - 1 CMS-1 HAR-1 Signal - Kiosk - 1 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 4 DS-0 for data	***Devices:*** CCTV - 1 CMS - 1 HAR-2 Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 3 DS-0 for data and voice	***Devices:*** CCTV - 3 CMS-3 HAR-2 Signal - 63 Kiosk - 1 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 3 DS-3 for video 6 DS-0 for data and voice 8 DS-0 for signals	***Devices:*** CCTV - 5 CMS-6 HAR-5 Signal - 63 Kiosk - 2 ***Information Flow Direction*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-4 for video 1 DS-1 for data and voice
Hub 8 Approximate Location: Sorenson Parkway and 30th Street	***Devices*** CCTV - CMS-1 HAR - Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-0 for data	***Devices:*** CCTV - 1 CMS - HAR- Signal - Kiosk - 1 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 1 DS-0 for data	***Devices:*** CCTV - CMS-1 HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-0 for data	***Devices:*** CCTV - 1 CMS-2 HAR- Signal - Kiosk - 1 ***Information Flow Direction;*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 1 DS-1 for data and voice

Communications Hub	Short-Term Scenario	Mid-Term: Scenario	Long-Term Scenario	Combined
Hub 9 4pproximate Location: 3. Murphy and 13th Street	***Devices*** CCTV - 1 CMS-3 HAR - Signal - Kiosk - 1 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 1 DS-0 for data	***Devices:*** CCTV - CMS - 1 HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-0 for data	***Devices:*** CCTV - CMS - HAR- Signal - Kiosk - 1 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-0 for data	***Devices:*** CCTV - 1 CMS-1 HAR- Signal - Kiosk - 1 ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-3 for video 1 DS-1 for data
Hub 10 Approximate Location: Ft. Crook and Bellevue Boulevard	***Devices*** CCTV - CMS - HAR - Signal - Kiosk - ***Information Flow Direction:*** To and from City of Bellevue ***Information Combined Data Rate:***	***Devices:*** CCTV - CMS - HAR- Signal - 10 Kiosk - 1 ***Information Flow Direction:*** To and from City of Bellevue ***Information Combined Data Rate:*** 1 DS-0 for data 2 DS-0 for signals	***Devices:*** CCTV - CMS - HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from City of Bellevue ***Information Combined Data Rate:***	***Devices:*** CCTV - CMS - HAR - Signal - 10 Kiosk - 1 ***Information Flow Direction:*** To and from City of Bellevue ***Information Combined Data Rate:*** 1 DS-1 for data

Communications Hub	Short-Term Scenario	Mid-Term Scenario	Long-Term Scenario	Combined
Hub 11 Approximate Location: Willow and Broadway	***Devices*** CCTV - CMS - HAR- Signal - Kiosk - 1 ***Information Flow Direction:*** To and from City of Council Bluffs ***Information Combined Data Rate:*** 1 DS-0 for data	***Devices:*** CCTV - 1 CMS - 1 HAR- Signal- Kiosk - 1 ***Information Flow Direction:*** To and from City of Council Bluffs ***Information Combined Data Rate:*** 1 DS-3 for video 2 DS-0 for data	***Devices:*** CCTV - CMS - HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from City of Council Bluffs ***Information Combined Data Rate:***	***Devices:*** CCTV - 1 CMS-1 HAR- Signal - Kiosk - 2 ***Information Flow Direction*** To and from City of Council Bluffs ***Information Combined Data Rate:*** 1 DS-3 for video 1 DS-1 for data
Hub 12 Approximate Location: 30th Street and California	***Devices*** CCTV - CMS - HAR - Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:***	***Devices:*** CCTV - CMS-1 HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-0 for data	***Devices:*** CCTV - CMS - HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:***	***Devices:*** CCTV - CMS - 1 HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-1 for data

Communications Hub	Short-Term Scenario	Mid-Term Scenario	Long-Term Scenario	Combined
Hub 13 4pproximate Location: Northeast corner of Maple Street and Highway 133/9th Street	***Devices*** CCTV - CMS - HAR- Signal - Kiosk - ***Information Flow Direction:*** To and from City of Omaha ***Information Combined Data Rate:*** 4 channels each 9600 bps	***Devices:*** CCTV - CMS - HAR-1 Signal - Kiosk - 2 ***Information Flow Direction:*** To and from City of Omaha To and from City of Council Bluffs ***Information Combined Data Rate:*** 2 DS-0 for data	***Devices:*** CCTV - CMS-1 HAR- Signal - Kiosk - 2 ***Information Flow Direction*** To and from City of Omaha ***Information Combined Data Rate:*** 3 DS-0 for data	***Devices:*** CCTV - CMS-1 HAR- Signal - Kiosk - 4 ***Information Flow Direction*** To and from City of Omaha ***Information Combined Data Rate:*** 1 DS-1 for data
Isolated Devices	***Devices*** CCTV - CMS - HAR- Signal - Kiosk - 4 ***Information Flow Direction:*** ***Information Combined Data Rate:*** 4 channels each 9600 bps	***Devices:*** CCTV - CMS - HAR- Signal - Kiosk - ***Information Flow Direction:*** ***Information Combined Data Rate:***	***Devices:*** CCTV - CMS - HAR- Signal - Kiosk - ***Information Flow Direction:*** ***Information Combined Data Rate:***	***Devices:*** CCTV - CMS - HAR- Signal - Kiosk - ***Information Flow Direction:*** ***Information Combined Data Rate:***

The concept of the overall communications master plan is illustrated in Figure 15. As is shown, a total of 13 communications hubs constitute the modular design elements of the system. These hubs could consist of agency-owned elements containing fiber optic devices owned by the agencies connected to privately-owned communications service providers, and which comply with standards normally applied to telephone company equipment to provide high reliability and multi-role (voice, data and video) communications service in all. environments.

11.1 Non-Trunk Connection

Some field equipment components such as traffic signal controllers require low speed data transmission systems. Furthermore, the City of Omaha currently has a significant interconnect network for the operation of its closed loop subsystems. This existing hardwire network could be utilized, at least initially, during the short-term deployment scenario for non-trunk connections between field controllers and communications hubs. However, with the addition of other field devices such as CCTVs, which required higher speed and higher capacity transmission media, other transmission means such as fiber optics (owned or leased) will be needed for non-trunk connections. The connections could be made from the device to the center directly, or via the communications hubs.

12. COMMUNICATIONS ALTERNATIVES

The development of communications alternatives builds upon available information from regional and local private communications system providers (US West Communications and TCI Cable of Midlands), including their capabilities and their tariff rates for high speed data channels. Three alternatives have been considered for evaluation. These are:

1. Alternative 1. Agency-owned network
2. Alternative 2. Private carrier network
3. Alternative 3. Hybrid: a combination of agency-owned and proviate carrier network.

12.1 Alternative 1. Agency-owned Network

Under this alternative, the communications system will utilize single-mode fiber optics cable for its backbone ITS communications trunk network. This system will offer multiple data-type transmission capabilities, high data transmission rate, noise/interference immunity and high capacity.

The fiber optics trunk system will provide links between the ATMlC and TMCs and communications hubs as well as between the hubs themselves.

The backbone network will be designed to accommodate the use of alternative media for other connections, such as field equipment connections to controllers and controllers to communications hubs. The complete system will be designed within SONET system architecture standards.

Fiber optic conduits will be installed along freeways and major arterials. For functional redundancy purposes, additional fiber wil1 be allocated for each fiber required and for physical redundancy, two fiber lines could be allocated for each fiber required. This will provide a further safety measure to guard against loss of communications by providing a counter rotating redundancy concept.

This alternative will possess a high initial cost, but lower monthly cost relative to Alternative 2. A sound design with redundancy provision will provide a reliable system for the short, medium and long-term deployment scenarios.

Agency-owned alternative wil1 require trained technicians for maintaining the system.

12.2 Alternative 2. Private Carrier Network

This alternative will rely heavily on private communications carriers for both the backbone trunk network and non-trunk connections. The data transmission requirements of the ITS components will be determined and the detailed design and implementation will be done in conjunction with private carriers. The system will have identical features and characteristics as Alternative 1. It will have very low initial cost, but significantly high monthly installments for DS channels and fiber optic equipment to be placed at communication hubs.

Several options exist within the Omaha metropolitan area for implementing this alternative. The US West communications network consists of area-wide fiber optic cable with DS-1 and DS-3 service, which will provide a significant communications infrastructure for the metropolitan area at established tariff rates.

12.3 Alternative 3. Hybrid Network

A hybrid system, a combination of agency-owned and private carrier network is the recommended network for the Omaha metropolitan area ITS. With the availability of private service providers in the area and existing interconnect network within the City of Omaha, this alternative possesses the advantages of both Alternative 1 and Alternative 2. The implementation cost of this alternative will be lower than Alternative 1 and the monthly installments lower than Alternative 2. Under this alternative, the majority of backbone trunk connections will be leased channels. Fiber optic installation along the I-80 freeway will be gradually implemented as an agency-owned network and, except for the remote field equipment, other field equipment will utilize leased data and video channels connected to either the communications hubs or directly to the ATMIC. This alternative will be developed in phases as the deployment scenarios are implemented.

12.4 Preliminary Cost of Alternatives

Table 4 shows the preliminary implementation costs of the three alternatives. The costs are rough and approximate and should be used for a comparative analysis at this stage. A more detailed cost estimate should be performed for the preferred alternative as the design elements become more definite. The costs are shown in current 1995 dollars and include construction, operations and maintenance costs for an analysis period of 20 years.

TABLE 4

PRELIMINARY COST ESTIMATE

Alternative	Capital Cost	Operational and Maintenance Cost	Leased cost	Total
Alt. 1 - Agency-Owned System	16,000,000	9,520,000	700,000	26,220,000
Alt. 2 - Private Carrier System	5,850,000	3,200,000	12,950,000	22,000,000
Alt. 3 - Hybrid System	11,700,000	4,760,000*	7,100,000	23,560,000

** Operational and maintenance cost of Altenative 3 is assumed to be 1/3 of total O&M cost of the ITS components.*

12.5 Master Plan Implementation

Implementation of the communications system master plan will be performed parallel to the deployment scenarios of other ITS components.

During the short-term scenario, the initial part of the overall preferred communications system will be implemented. The design of the communication improvements will be performed during the first and second years and the implementation will start the second year and will be gradually completed during a three-year time period. Figure 16 illustrates the concept of communications improvements of the short-term deployment scenario. Table 5 is a preliminary cost estimate of communication improvements during the five years of the short-term deployment scenario.

TABLE 5

SHORT-TERM SCENARIO
COMlMUNICATIONS IMPROVEMENTS

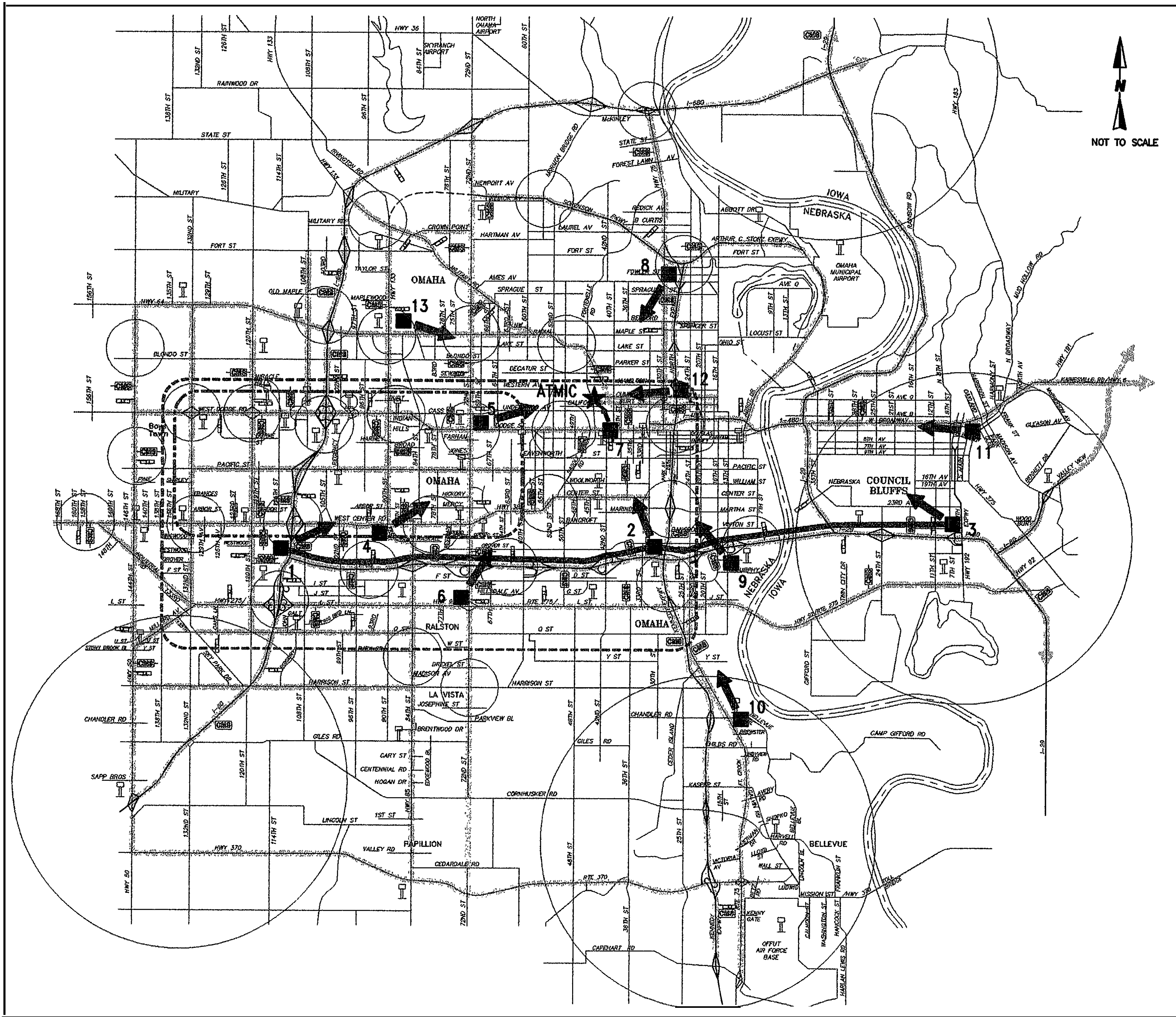
Design	$333,050
Initial Improvement Cost	3,010,200
Annual Cost (Two Years)	3 17,600
TOTAL	$3,657,850

The implementation of the communications improvements during the medium-term deployment scenario will support the requirements of the medium-term data, voice and data communications. During the first two years of this scenario, the design of the system will be performed and concurrently, different elements of the communications system will be implemented. Table 6 is a preliminary cost estimate of the medium-term communications improvements and Figure 17 illustrates the concept of the improvements.

TABLE 6

MEDIUM-TERM SCENARIO
COMMUNICATIONS IMPROVEMENTS

Design	$472,000
Initial Improvement Cost	4,155,000
Annual Cost (including annual cost associated with short-term scenario)	1,134,800
TOTAL	$5,761,800



OMAHA METROPOLITAN AREA ITS

NDOR
MAPA
UNL

COMMUNICATION MASTER PLAN

LEGEND

- PRIMARY CORRIDOR
- FREEWAY
- CITY STREET
- CMS (FREEWAY)
- CMS (ARTERIAL TRAILBLAZER)
- CCTV
- KIOSK
- HAR
- SMART CORRIDOR DEMO
- ADAPTIVE TRAFFIC CONTROL
- COMMUNICATION HUB
- OC-12/OC-48 CHANNELS TO ATMIC
- F.O. ALONG I-80

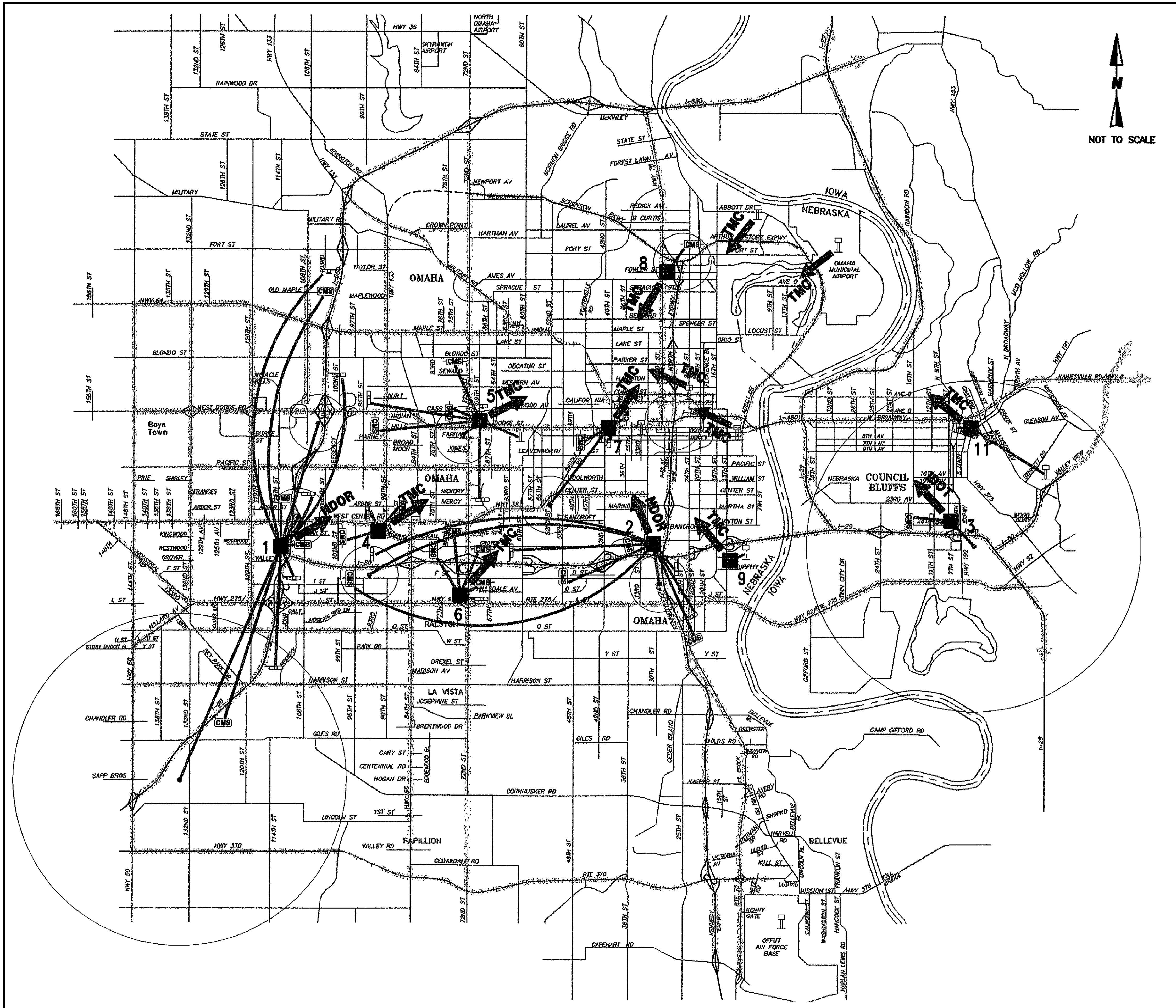
FIGURE 15

University of Nebraska Lincoln

Meyer, Mohaddes Associates, Inc.

IOWA STATE UNIVERSITY

NEBRASKA MOTOR CARRIERS ASSOCIATION



OMAHA METROPOLITAN AREA ITS

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SHORT-TERM COMMUNICATIONS SCENARIO

LEGEND

- PRIMARY CORRIDOR
- FREEWAY
- CITY STREET
- CMS (FREEWAY)
- CMS (ARTERIAL TRAILBLAZER)
- CCTV
- KIOSK
- HAR
- COMMUNICATION HUB
- CONNECTION TO CENTER
- CONNECTION TO HUB

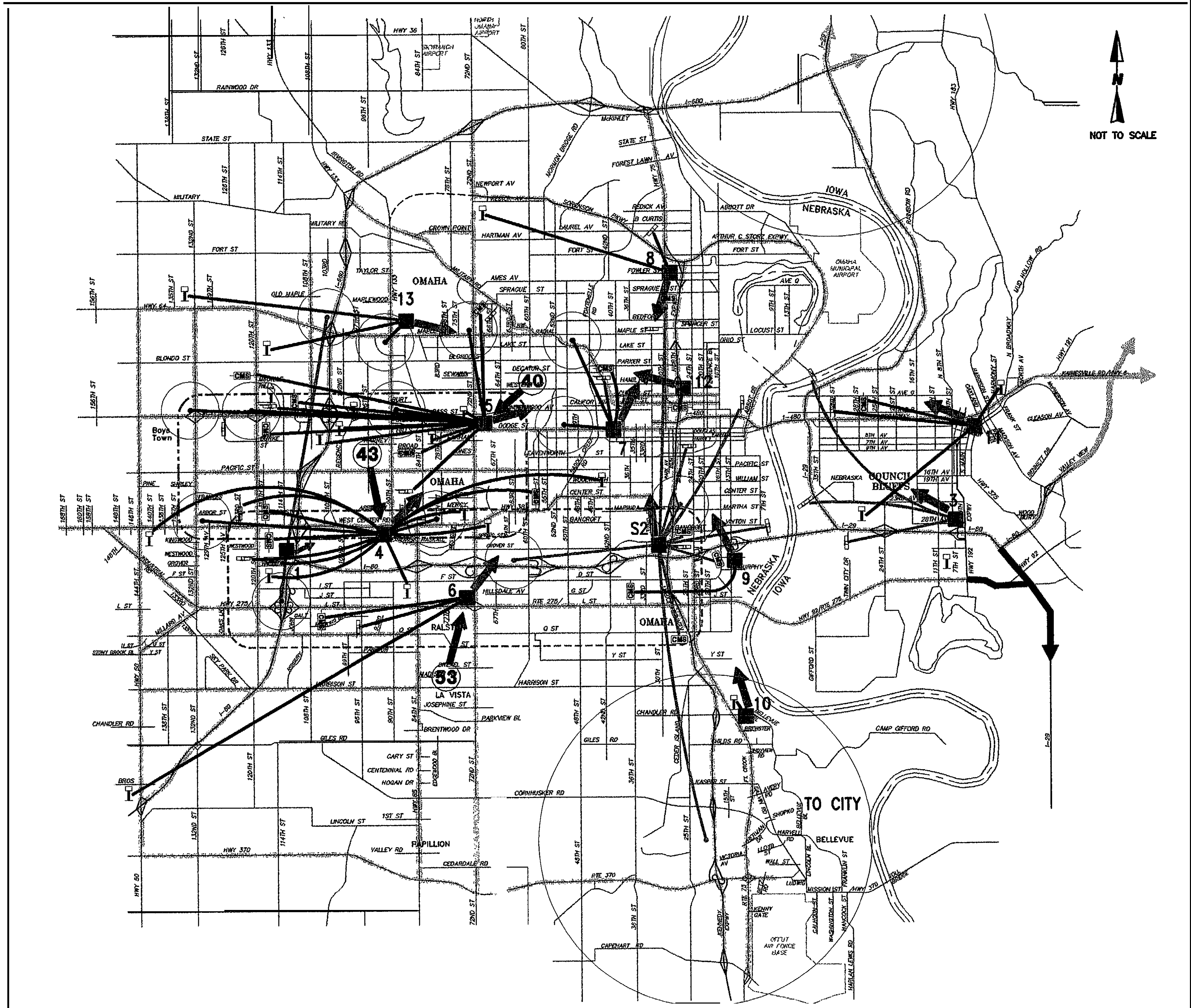
FIGURE 16

University of Nebraska Lincoln

Meyer, Mohaddes Associates, Inc.

Iowa State University

NEBRASKA MOTOR CARRIERS ASSOCIATION



OMAHA METROPOLITAN AREA ITS

NDOR

MAPA — UNL

MID-TERM COMMUNICATIONS SCENARIO

LEGEND

- PRIMARY CORRIDOR
- FREEWAY
- CITY STREET
- CMS (FREEWAY)
- CMS (ARTERIAL TRAILBLAZER)
- CCTV
- KIOSK
- HAR
- SMART CORRIDOR DEMO
- ADAPTIVE TRAFFIC CONTROL
- 3 COMMUNICATION HUB
- 40 NUMBER OF SIGNAL CONTROLLERS
- CONNECTION TO HUB (STATE)
- CONNECTION TO HUB (CITY)
- CONNECTION TO CENTER

FIGURE 17

University of Nebraska Lincoln

Meyer, Mohaddes Associates, Inc.

IOWA STATE UNIVERSITY

NEBRASKA MOTOR CARRIERS ASSOCIATION

:94-45\CAD\FIGURE\DRFTSCEN\ITS-MTS.DWG 11-1-95

Implementation of the long-term communications improvements will complete the master plan as shown in Figure 15. Table 7 is a preliminary cost estimate associated with communications improvements of the long-term scenario.

TABLE 7

**LONG-TERM SCENARIO
COMMUNICATIONS IMPROVEMENTS**

Design	$390,000
Initial Improvement Cost	3,325,000
Annual cost (including annual cost associated with short- and medium-term scenario)	7,843,400
TOTAL	$11,558,400