Understanding the NTCIP Class Profiles from an End User's Perspective

July, 1998

Prepared by: Albert J. Bonificio, New York State Department of Transportation and Joseph R. Herr, Vanasse Hangen Brustlin, Inc.

Technology advancements in computing, electronic communications, and control systems are accelerating at a blinding pace and affecting more areas of our professional and personal lives everyday. This is especially true in transportation systems, where digital technology is opening new horizons of capabilities and interconnectivity that were not feasible only a few years ago. State-of-the-art transportation control and monitoring components that make use of digital technology are moving from the demonstration arena to real-world applications. These components include:

- Microcomputer based Traffic Signal Controllers
- Dynamic Message Signs (DMS)
- Highway Advisory Radio (HAR) Controllers
- Automated Vehicle Identification (AVI) controllers
- Weigh-in Motion (WIM) controllers
- Ramp Meters
- Traffic Management Centers
- Vehicle Detection Stations
- Video Camera Control
- Traffic Sensors
- Intelligent Grade Crossing Devices
- Environmental Sensor Stations (ESS)

However, no matter what new capabilities that technology brings forward, there will be a fundamental need to exchange information among the hardware, software, and end-users that interact with our transportation infrastructure. This exchange of information requires a common communications capability that works seamlessly with multiple devices at multiple locations.

Recognizing both the needs and potential difficulties in creating common communications, the American Association of State Highway Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), the Institute of Transportation Engineers (ITE), the National Electrical Manufacturer's Association (NEMA), various government agencies, software developers and consultants began working together on this common goal. NEMA began development of the National Traffic Control / IVHS (Intelligent Vehicle Highway Systems) Communications Protocol Standard (NTCIP) in May of 1993 and the first version of NTCIP was created in December of 1995. In 1996 a consortium consisting of AASHTO/ITE/NEMA was formed to continue and expand on the development of the communications protocol standard and the NTCIP acronym was renamed to the National Transportation Communications for ITS (Intelligent Transportation Systems) Protocol.

This paper is broken into four sections. The first section discusses NTCIP applications that are currently being implemented or are planned to be developed. The second section explains NTCIP experiences and concerns, emphasizing the lessons learned from current implementations. Next the paper includes an NTCIP overview and the development effort of the Profiles Working Group. The final section discusses system implementation.

TRANSPORTATION APPLICATIONS USING NTCIP

One of the primary goals of the transportation engineering community is to improve overall traffic flow and reduce congestion via the application of traffic management systems. These management systems may include highly specialized subsystems designed to accomplish specific traffic management tasks; advanced traffic signal systems are examples of such a specialized traffic management subsystem. It is normally the intent of such traffic management systems to provide an integrated architecture where data can be easily transmitted and control functions shared between subsystems when required by system operations. In addition, these traffic management systems must be capable of seamlessly sharing information across jurisdictional boundaries and even regional boundaries. To effectively work, these systems must communicate with all components in a given region. When all field processing devices can communicate with each other, one of NTCIP's goals will be fully realized. Consider the NTCIP as the Transportation Industry's Internet.

NTCIP defines a family of general-purpose protocols that support all types of devices used in transportation management systems. It is the goal of NTCIP to allow all field processing devices to communicate via the NTCIP standard regardless of type or brand. It should be noted that not all existing field devices will be able to support an NTCIP based communications standard. Due to the level of processing power and transmission requirements, the hardware in the field devices will need to be of a particular level to support NTCIP. A typical example is a traffic signal system that utilizes controllers owned by different agencies and supplied by different vendors. NTCIP can be implemented so that typical traffic signal system functions such as remote monitoring, remote system control and data upload/download can be achieved irrespective of manufacturer.

NTCIP is a flexible protocol. The structure of NTCIP can support communications for almost any type of field device designed with an NTCIP interface. Messages can be device specific or global in nature. Since all devices use the same fundamental protocol, different types of devices can be mixed on the same communications channel. For example, the same communications channel can support different vendor’s traffic signal controllers, a dynamic message sign, a video camera controller and an Environmental Sensor Station. NTCIP will support virtually any type of dedicated or as-needed communications link including twisted pair, coaxial cable, optical fiber, radio (spread spectrum, microwave or narrow band) or telephone lines. In fact, the type of communications medium is not an issue in the use of NTCIP, nor is the ownership of the communications channel be it agency owned, leased or dial-up. NTCIP is also independent of the way in which a transportation management system is configured, be it central control, distributed control or a hybrid configuration.

The following are example NTCIP applications that are planned or are currently being implemented.

New York State Department of Transportation

As a real world example, consider the following. The New York State Department of Transportation is spearheading an Intelligent Traffic Systems project in conjunction with the Long Island Rail Road. Currently, when a train approaches an intersection, a track circuit that is hard wired into a signal cabinet input triggers a preemption service request in the traffic signal controller. The controller begins a sequence in which the tracks that cross the intersection are cleared of vehicles. Next, the controller allows traffic, which is parallel to the tracks to be served. Finally, when the train passes the intersection, normal intersection control is returned to the controller. Unfortunately, due to hardware constraints, this scenario is very rigid and its timing is inflexible.

The new project will use an Intelligent Grade Crossing Device (IGC) to enhance this scenario. An IGC will be a field-hardened, track-side controller (field management station) that in the future will communicate over a network with other roadside traffic control devices via NTCIP. Among its many jobs will be to activate the gates. A train signals the IGC, when it is approaching an intersection. As it approaches, it sends a message that includes the speed of the train, an id number, etc. It is anticipated that once the IGC receives the message that a train is approaching, it will send a message to an ITS controller, using NTCIP, that may include such information as the expected arrival time and length of train. Based on the information that it receives, the ITS controller would have the ability to adjust its preemption sequence. The IGC may also send a message to a dynamic message sign using NTCIP that would display messages such as “TRAIN APPROACHING”, which warns motorists before the gates descend. The IGC may also update information to a remote central monitoring and control computer station for display purposes. The IGC may send information to other controllers or other IGC’s down the line to inform them about the upcoming train. Possible messages sent back to the IGC may include information that the gates are down, a car is stuck on the track, the dynamic message sign is displaying the proper message and traffic delays or backups have occurred.

Future features may include communications between the IGC and Environmental Sensor Stations (ESS). The data from an ESS may indicate weather conditions so that the IGC can safely adjust train braking distances. Also, the IGC may be able to send back a video image of the track to the approaching train from a video detector. NTCIP will simplify many of these communications tasks and make it possible for different devices to seamlessly exchange information.

City of Phoenix, Arizona

The City of Phoenix, Arizona is currently implementing a distributed traffic control system using the NTCIP Class B Protocol, as explained later in this paper. The city has approximately 850 intersections that utilize traffic signal controllers from two different manufacturers. The communications infrastructure consists of fiber optic cable, twisted pair copper wire and unconditioned half-duplex leased lines. This system has no on-street master controllers and is totally controlled from a central location. The city's goal is to allow a central user access to any one of the intersections. This access will allow the engineer or technician to view real-time traffic control, manually change timing plans to better coordinate traffic throughout the city and allows uploading and/or downloading of specific data such as timing.

Each manufacturer of signal controllers will be required to have software in place that uses the NTCIP Class B Protocol as their communications protocol. Each signal controller contains descriptions of data elements (called object definitions) that allow the setting and retrieval of function parameters. The object definitions are organized in one or more Management Information Bases (MIBs) that allow each vendor's controller to communicate with the central control facility. From the central facility, the user can manually send which timing plan he/she would like to use or watch traffic at a specific intersection. This information exchange takes place regardless of the manufacturer. If a controller breaks down, the signal crew can replace it with a "NTCIP-compliant" signal controller from any vendor. Once replaced, mandatory NTCIP objects such as Phases allowed, Initial timing, or Maximum Green time can be downloaded to the controller from the central database.

Since NTCIP mandatory objects cover only a portion of the controller database, manufacturer specific MIBs were supplied that provide access to the entire database. Additionally, special manufacturer MIBs may be used to significantly reduce database upload/download times. By Mid 1998, the City will have central control using controllers and software from multiple vendors. Interoperability and limited interchangeability of signal controllers within this system have been made possible by the NTCIP.

State of North Carolina, Department of Transportation

The State of North Carolina Department of Transportation realized the importance of using NTCIP. Use of the NTCIP Class B Protocol is a requirement in the specifications for a central traffic control system to be implemented in the City of High Point for approximately 165 intersections. The architecture is similar to what is planned for the Phoenix application described above. The end result will be a centrally controlled traffic system with no on-street masters.

Since Class B was still in a development stage at the time of specification, there were some limitations. For example, there is only one type of signal controller that will be used in the field in the short term. The NTCIP Standard MIBs only define about one-third of the object definitions that are in the manufacturer's controller database. The central control facility will be able to download all mandatory NTCIP standard object definitions. In addition, the controller manufacturer converted all the controller's database to a MIB compatible format that can be uploaded and downloaded with the standard protocols. Twenty percent of the controller's proprietary messages were also converted. These represent most of the prior, once-per-second command and response message. Intersection control can now be handled through the Class B Protocol. Even with the above limitations, the State is confident that the decision to deploy NTCIP will prove to be a wise choice.

State of Delaware DOT and the I-95 Corridor Coalition

A project to use NTCIP with Dynamic Message Signs (DMS) is being partnered by the Delaware Department of Transportation and the I-95 Corridor Coalition. Slated to be completed in August of 1998, this project will allow the Transportation Management Center in Wrangle Hill to centrally send messages to two different vendors supplied Dynamic Message Signs using NTCIP software via a compliant controller. Although this is a pilot project, the State is optimistic that NTCIP will simplify the task of sending messages as well as eliminate the need for redundant equipment (PC's) and software.

State of Virginia Department of Transportation (VDOT)

VDOT's need for interchangeable Dynamic Message Signs has generated a project to install up to 75 Dynamic Message Signs (17 per year) in the state using NTCIP. The state uses the low bid process in all purchases. To ensure that the equipment that they were going to purchase would properly utilize NTCIP, the vendor had to be prequalified before bidding. Part of the prequalification procedure was to test the DMS data strings using the NTCIP exerciser. Four out of ten vendors were able to prove that their signs were NTCIP compatible using the exerciser. The project is slated to be field tested in the late Fall of 1998.

NTCIP EXPERIENCES AND CONCERNS

Although the NTCIP implementation process is just beginning, there are already some lessons learned from current implementations. Both the High Point and Phoenix projects were started before the NTCIP Class B profile was fully developed. This has necessitated close communications among the central system software manufacturer, controller vendors and the agency. Without keeping the lines of communications open and the agency's long-term needs and usage in the forefront, the development effort could backfire.

In North Carolina, one of the lessons learned was that there are limitations with the current Class B Profiles. Class B works well with centralized systems where the central system is directly connected to each signal controller. However, the current set of object definitions was never planned to be used with all types of traffic signal systems. It was quickly realized that standardized system MIBs (i.e. MIBs that control coordination and uploading and downloading features) have to be created, tested and/or expanded to allow for interchangeability. One of the purposes of the Profiles Committee is to help realize this goal.

Although the ultimate goal of NTCIP is to allow seamless communications between various types of equipment, the reality of the matter and the desired effect is that each piece of equipment can have its own proprietary enhancements and is not totally independent. Each piece of equipment may have its own proprietary MIB's and Dynamic Object setups that allow it to handle field situations, like traffic flow, in its own way. End users should recognize that many features available in today's field control devices are indeed proprietary items that are not covered by NTCIP object definitions. Inclusion of these features in a system design may result in device non-interchangeability (or worse, non-interoperability) for those areas of the system using such special, proprietary features. However, these special features that are today manufacturer specific could become standards tomorrow if the demands of the end user so dictate.

The agency should be as clear and detailed as possible when writing NTCIP specifications. The specifications should explain the agency's physical and functional needs at the time that the specification is written. To help develop a solid specification, the agency may want to consider a team approach by working with engineering consultants, hardware vendors and software vendors with proven experience. The agency must consider writing specifications that contain functional requirements such as NTCIP compatibility. It is important to hold to the original specification requirements during equipment/system development. Often during the development process, different opinions or ideas come into play that may seem to be totally necessary at the time, but in reality can tremendously complicate the process. NTCIP by its nature is not trivial and is dependent upon many parties to reach a final product. By not straying from specifications, unless the situation warrants change, the user or agency has a good chance of getting the interoperability that is desired. Keep in mind that as more parties get involved with NTCIP, it becomes important that the user is selective in deciding what is essential. Again, a team approach will help realize this goal. Initially, NTCIP will have a high overhead because of the development effort that must be done. Once you choose a path that utilizes NTCIP, you must stick with it or it will be extremely costly to change direction.

A major obstacle that must be overcome is that of testing the equipment to assure NTCIP compliance. Although an NTCIP exerciser is available, it is still in a development stage. As VDOT realized with their DMS test procedures, staff has to knowledgeable of how the exerciser works down to the bitstream level. As more vendors and software developers come on board, interoperability testing will be of equal importance with NTCIP compliance. Without a well thought out method to guarantee compliance with NTCIP, as well as testing interoperability of components and the interrelationships between the different objects defined by NTCIP, users will be getting a product that will not deliver the desired results.

Finally, an agency must use caution in a phased deployment of an NTCIP based system. After a first phase deployment is installed, any second phase expansion contract that is negotiated, must be very clear as to the specifics of the NTCIP protocol in place. What needs to be avoided is a different vendor supplying their "version" of NTCIP that differs from the first phase equipment and results in the loss of interchangeability and interoperability that led to the deployment of NTCIP in the first place.

NTCIP OVERVIEW

A communications protocol is a set of rules that indicate how messages are coded and transmitted between electronic devices. Although equipment at each end of the data transmission may have different electronic characteristics, such as utilizing different microcomputers, they must use this same protocol to communicate successfully. The NTCIP is being developed as a suite of standard communications protocols that will be used for data transmission within and between all processor-based devices that make up the transportation infrastructure. Under the NTCIP effort, the format and the meaning of the messages, or better the smallest units (the data elements), are being defined and standardized. This is important because both ends of the communications link need to have a common understanding of the data being exchanged. Take for example the concept of timing plan “offset”. The NTCIP will choose and standardize the message format for “offset”. The protocol may choose that both communications endpoint devices must agree that the “offset” of a timing plan is referenced to the beginning of green of the first main street phase, and not at some other point as it is currently done in several other implementations. Or it may choose another reference point. However, once chosen, the standard will not vary. Remember, the NTCIP standard is concerned with the transmission rules, the format and the meaning of the standardized messages being sent between devices using those rules. As such, this development effort is concerned with utilizing communication protocols that can easily be migrated to existing field and central hardware. Where possible, NTCIP uses the existing protocol standards in the telecommunications and computer industries.

The NTCIP structure is based on the current topologies (architectures) of traffic management systems. Currently, the two most common system architectures for field device control currently being used in the transportation industry are the centralized system and the distributed system. In a centralized system, a central computer directly communicates with all field controller units under its control. Connections are hard-wired and are permanently dedicated. However, all the equipment in the system does not have to be on the same communications channel. In a distributed system, the central computer communicates directly with an intermediate unit called either a link controller, or a communications controller or a field master. This intermediate unit is directly connected to all local field controller units. Thus with a distributed system, there doesn’t have to be a permanent link between the central computer and the field masters or the local controllers. If a connection is necessary, a link can be established to or by the central using the communications controller for remote monitoring and control operations.

In addition to center-to-field communications, NTCIP seeks to define the framework for communications between traffic management centers. This will enable adjacent ITS facilities, that may perform different functions (e.g. ATMS, APTS, ATIS, ARTS, etc.) and/or be under different operation and control jurisdictions, to exchange system data on a constant basis allowing seamless transportation management across system boundaries. Another consideration used in developing NTCIP was that NTCIP followed the International Standards Organization's (ISO) Open Systems Interconnect (OSI) seven-layer model. Each layer separates certain communications functions. The layers are as follows:

Layer	Description (Function)
Application	Interacts with the actual application program that is performing a specific function.
Presentation	Formats the data properly for system to system communications.
Session	Provides multiple communications channels within a device to allow multiple applications to operate simultaneously and not interfere with each other.
Transport	Organizes the data that is passed back and forth from the lower layers. This layer, which is the lowest to deal with end-to-end communications, dissembles and assembles packets for use by the lower layers.
Network	Controls how packets of data are routed from source to destination. It ensures that data sent through several physical links arrive intact.
Data Link	It transforms the data that came in over the physical connection (wire) into data that appears to be free of transmission errors.
Physical	How the bits of information are transmitted over a communications channel, electrical & mechanical interfaces and the physical transmission medium.

The OSI model allows NTCIP to deliver interoperability. NTCIP defines the various layers to enhance the interoperability of devices that share a communications link. Interchangeability is provided by defining a standard Applications Layer and Data Dictionary for device control. A major goal of NTCIP is to enable users to buy any off-the-shelf product and be assured of interoperability. This means that when a user purchases a piece of transportation equipment that uses NTCIP, it will be able to communicate with any other device in the transportation network that also uses NTCIP, providing there is enough available bandwidth. Interoperability will allow utilization of a communications link regardless of the type of device. For example, if a DMS, HAR and a Ramp Meter Controller uses the same NTCIP protocol (in fact utilizing only the **same** lower two OSI layers should be enough), it can use the same communications wire to communicate with a central system, without currently having the ability to communicate with each other. Be aware that current NTCIP standards are focusing on center-to-field and center-to-center activities. NTCIP utilizes existing common base standards to the extent possible so that vendors and system developers can buy proven and reliable off-the-shelf software packages, which effectively reduces the price of a system to the purchasing agency. However, these base standards have been chosen to provide flexibility during both deployment and operation.

NTCIP PROFILES WORKING GROUP

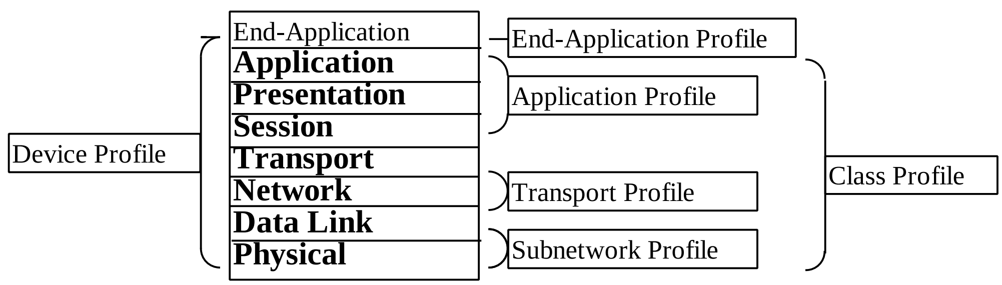
In 1996, the NTCIP Steering group created documents related to the development of the NTCIP standard. One of the documents, NEMA Standards Publication Number TS 3.3 described the Class B Communications Profile. The profile establishes a method of linking field devices, defines the protocol and procedures necessary to link field devices, defines the procedures and protocols necessary to provide communications between such devices, and defines a common set of operation information variables.

A profile is important when specifying the requirements for devices that will operate within a system. The Class B Profile was developed for use with existing systems where communications bandwidth is limited by legacy equipment and the controlling unit (central or field master) is directly connected to the field devices. It has been optimized for use on existing 1200 baud FSK data communication links. An overview of the Class B Profile in reference to the OSI model is as follows:

Layer	CLASS B Profile	
Application	Simple Transportation Management Framework (STMF).	
Presentation	None	
Session	None	
Transport	None	
Network	None	
Data Link	HDLC-modified or Point to Multi-point Protocol (PMPP)	
Physical	EIA/TIA-232 Bell 202	(RS-232 Interface) (FSK Modem Interface)

In September 1997, the NTCIP Profiles Working Group was formed to create profiles for Class A and Class C communications. The Class A Profile was intended to provide an enhancement of the Class B Profile by adding support for network communications through the use of the Internet and User Datagram Protocols (IP and UDP). A second Profile, Class C, was to provide a further enhancement by providing a more reliable communications facility and file transfer capabilities. However, after much discussion, the group realized that by using Class Profiles as originally planned, redundant documentation would have resulted. Instead the group decided that it would combine the requirements of the various Layers of the OSI Model by using the Profiles as defined in ISO TR 10,000.

A simplified block diagram illustrating the seven layer OSI model and the different aspects/functions (in the following, called Profiles) is shown below.



As such, standardized profiles for NTCIP fall into one of the following five categories.

1) Device Profile (DP) - references the informational and communications standards that apply to a specific device such as a traffic controller or a variable message sign.

2) End Application Profile (EP) - references standards and/or profiles that are applicable to the structure, content and meaning of the information related to an end application such as a traffic controller or a variable message sign. Potential EP's include EP-ASC, the Actuated Traffic Signal Controller Profile and EP-DMS, the Dynamic Message Sign Profile.

3) Application Profile (AP) - references a set of standards and/or profiles that apply to the Application, Presentation and Session Layers of the communications stack. It defines all information management services. Potential AP's include AP-STMF, the Simple Transportation Management Framework Profile and AP-FTP, the File Transfer Protocol Profile.

4) Transport Profile (TP) - provide a mechanism for the exchanges of data between end or host systems. It defines the appropriate combinations of connection-oriented and connection-less transport and network protocols. Potential TP's include TP-UDP/IP, a connection less Transport and network Service Profile and TP-TCP/IP, a connection-oriented Transport Service over a connection-less Network Service Profile (we have combined these two into one called TP-Internet).

5) Subnetwork Profile (SP) - references protocols and/or other profiles related to the Data Link and Physical Layers. Potential SP's include SP-PMPP/RS232 a Point-to-Multi-point over RS-232 Service protocol and SP-PPP-Bell202, a point-to-point over Dial-up Service protocol.

To emphasize again, prior to this meeting, the sixth category, the Communications Class Profile (CP), was discussed. The CP encompassed all seven OSI layers when defining a set of communications standards. The use of a CP is now discouraged.

As of May 1, 1998 the Profiles Working Group has developed the following draft profiles that will be submitted to the Joint Committee for approval and user comments.

- TS3.CLA-199x, National Transportation Communications for ITS Protocol (NTCIP) - Class Profiles
- TS3.FTP-199x, National Transportation Communications for ITS Protocol (NTCIP) - File Transfer Protocol-Application Profile
- TS3.TFTP-199x, National Transportation Communications for ITS Protocol (NTCIP) - Trivial File Transfer Protocol-Application Profile
- TS3.STMF-199x, National Transportation Communications for ITS Protocol (NTCIP) - Simple Transportation Management Framework - Application Profile
- TS3.INTERNET-199x, National Transportation Communications for ITS Protocol (NTCIP) - Internet (TCP/IP and UDP/IP) Transport Profile
- TS3.PMPP232-199x, National Transportation Communications for ITS Protocol (NTCIP) Point to Multipoint Protocol Subnetwork Profile Using RS232 Connections (SP-PMPP232)

USING NTCIP TO MEET SYSTEM NEEDS

On March 3, 1997, the NTCIP Joint Standards Committee prepared a draft document entitled the " NTCIP Guide". Although some of the information contained in the document is now obsolete due to recent changes in the communications profiles, it provides a good base understanding of the technical issues that need to be examined during the NTCIP design, procurement and deployment process. It is intended to provide an overview and explanation of the NTCIP standard and guidance to those intending to use the communications protocol.

As a standard, NTCIP has a base structure that all protocols conforming to it must meet. Where applicable, individual NTCIP standards contain Performance Implementation Conformance Statements (PICS). These PICS are a set of tables where protocol questions, elements and features are defined. These items are either mandatory or optional. Mandatory items are required for the protocol to be defined as NTCIP. Optional items allow the end user to customize the protocol to meet the specific requirements of their own system.

In addition to protocol elements, specific system operations or management objects can be defined to meet the particular requirements of a system. These management objects are defined in a Management Information Base (MIB) that uses a hierarchical type of numbering system to define each object. Listings of NTCIP objects are contained in several different documents, such as, NEMA TS 3.4 that defines Global Objects and TS 3.5 that defines objects germane to Actuated Traffic Signal Controllers. Similar to the customization available with PICS requirements for profiles, the end user can define objects within the MIB's that are suited to that particular system. Objects are categorized as mandatory, optional or proprietary. The mandatory and optional types are listed within the specific system areas of the NTCIP standards documents. The proprietary types are defined by each individual manufacturer and would allow the end user to utilize system features that are beyond those defined under the NTCIP base standard.

In summary, as transportation professionals it is our duty to constantly improve the transportation infrastructure through the use of the best and most appropriate technology. An important tool that we can use to fulfill this duty is the NTCIP, Transportation Industry's future Internet.

Bibliography

1) "Issues for the National Traffic Control/IVHS Communications Protocol (NTCIP) Workshop", February 1995 White paper, Prepared for the Federal Highway Administration by Farradyne Systems, Inc.

2) "The National Transportation Control/ITS Communications Protocol", July 1995, Federal Highway Administration.

3) "The National Transportation Communications for ITS Protocol (NTCIP) Guide", March 1997, The NTCIP Joint Standards Committee.

4) "The NTCIP-Protocol Details", January 1996, ITE Journal, The NTCIP Steering Group.

5) National Transportation Communications for ITS Protocol (NTCIP) Overview, NEMA Standards Publication, TS 3.1-1996

6) National Transportation Communications for ITS Protocol (NTCIP) Simple Transportation Management Framework, Nema Standards Publication, TS 3.2-1996

7) National Transportation Communications for ITS Protocol (NTCIP) Class B Profile, Nema Standards Publication, TS 3.3-1996

8) National Transportation Communications for ITS Protocol (NTCIP) Framework and Classification of Profiles, Joint AASHTO/ITE/NEMA Standards Publication TS 3.PRO-1997

9) "NTCIP-How it can be used", April 1996, ITE Journal, The NTCIP Steering Group.

10) "The National Transportation Control/ITS Communications Protocol: An Introduction" , December 1995, ITE Journal, The NTCIP Steering Group

11) National Transportation Communications for ITS Protocol (NTCIP) GUIDE, Draft Document, The NTCIP Joint Standards Committee, March 3, 1997

12) "TCP/IP Explained", Philip Miller, Digital Press, Boston, Massachusetts,