

CASE STUDY REPORT

NTCIP 9004 v01.05

City of Phoenix, Arizona
Phoenix Advanced Transportation
Management System

Version 01.05, November 16, 1999. A Recommended Information Report of the Joint Committee on the NTCIP.

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1. PURPOSE OF THE CASE STUDY

1-1 INTRODUCTION

Field deployment of NTCIP-Conforming equipment has begun. State and local Departments of Transportation and their consultants are aware of the interoperability and interchangeability features promised by the NTCIP, and are including references to the NTCIP in their procurement documents. For all but a few, this is their first experience with the NTCIP.

The purpose of this project, sponsored by AASHTO, FHWA, ITE and NEMA, is to prepare a series of case studies that describe the lessons-learned by vendors, agencies, and consultants during three of the early projects that required NTCIP compliance. The objective was to compile an unbiased investigation of each case study that incorporates the perspectives from different implementation positions.

Two Dynamic Message Sign (DMS) projects and one traffic signal control project were selected for this study during 1999. Additional projects may be investigated in FY 2000. The material for these case studies were drawn from interviews with individuals who were directly involved in the NTCIP implementation and from project-related documents such as specifications, test plans, and procurement documents. At least three individuals in different roles, such as agency champion, procurement specification writer, agency field technician and vendor representative was interviewed. The interviews, conducted by individuals familiar with the NTCIP, were structured around a survey prepared for these case study investigations. Whenever possible, relevant project documents for each project are included in that case study report.

This document focuses on the implementation of devices using the NTCIP. It does not attempt to explain the details of the NTCIP. Additional information on the NTCIP, including specific NTCIP standards, is available on the NTCIP Website (www.ntcip.org)¹.

2. THE CASE STUDY

In 1996, the City of Phoenix initiated a project to enhance their traffic signal system. This project included two distinct parts, the replacement of the central traffic control system, and the upgrade and purchase of additional traffic signal controllers. The NTCIP was specified as the communications protocol of choice for both. The central system (termed Phoenix Advanced Traffic Management System or Phoenix ATMS) was also required to control additional field devices, however, without the requirement to utilize the NTCIP communications protocol.

The project schedule is summarized in Table 1. Phase 3 (of four) was underway when the interview was conducted.

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|----------|--|
| Phase 1: | Phoenix ATMS developed to control AB 3418 ² -compliant signal controllers to be installed at 57 downtown intersections ³ . |
| Phase 2: | Phoenix ATMS development continued. Second-by-second communications and NTCIP, download/upload capabilities were added. VENDOR traffic signal controllers were integrated. |
| Phase 3: | Integration continued. Second-by-second communications and upload/download functionality to be added to allow communication with controllers from a second vendor. |
| Phase 4: | Bids to be solicited for an additional set of signal controllers from a third vendor. |

Traffic signal controllers at more than 1000 signalized intersections and approximately 350 traffic cabinets will be replaced in a staged effort over multiple years and purchases. The City is transitioning from the existing UTCS-based system installed in the 1970s, to a new distributed control system. With the new system, local intersection control will be provided through timing plans resident at the traffic signal controller that are selected primarily from time-of-day (TOD) schedules. Existing NEMA TS 1 traffic signal controllers will be replaced with NEMA TS 2 signal controllers capable of Type 1 and Type 2 actuated configurations from a single controller unit. The communications media consists of several half-duplex 1200-baud leased lines and two full-duplex 9600-baud fiber optic channels. The existing and new devices are described in Table A-1⁴. The Phoenix ATMS will also control CCTV cameras, ramp meter controllers and variable message signs (VMS).

This case study focuses on two NTCIP-compliant components of that project. The VENDOR and SYSTEM INTEGRATOR for this study were Econolite and TransCore, respectively. Another vendor, PEEK Traffic Systems, was added to the project later, but integration of these new controllers was not finished when the interviews were conducted. The City of Phoenix also plans to purchase approximately 200 additional field controllers from a third vendor.

The objectives of the AGENCY in implementing this project were:

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- 1 The White Paper "Understanding the NTCIP Class Profiles from an End User's Perspective," prepared by the NTCIP Profiles Working Group is an excellent example.
 - 2 California Assembly Bill 3418 (AB 3418) requires all new or upgraded traffic signal controllers installed in California after January 1, 1996, to incorporate a standard communications protocol. The protocol behind AB 3418 is considered the precursor to the NTCIP Suite of Protocols containing definitions for the communications within a multidrop environment and a set of fixed communications messages.
 - 3 This was due to the opening of the ballpark stadium and availability of the AB3418-compliant controllers. The development of a device driver for a static protocol was much faster than for a highly flexible protocol such as the full NTCIP.
 - 4 See Annex A of this report

- To create a system that will allow traffic signal controllers to be procured from multiple vendors without the need to develop a device driver for every controller model.
- To replace the mainframe-based central system with a modern PC-based system to ensure that the system can be upgraded in the future.
- To cover the city with one control and monitoring central system (the first system only covered 480 of the existing 820 signal controllers).
- To implement distributed intersection control technology within the city in order to reduce the effects of communications failures.

The SYSTEM INTEGRATOR's goal was to facilitate the development and acceptance of the NTCIP by demonstrating its feasibility within an implementation.

This project is one of the first NTCIP deployments to use equipment from more than one vendor⁵.

Table 1: Project Timeline

AGENCY	VENDOR	NTCIP Standards Status	Date
Feasibility Study Development			1993
Began writing RFP			7/ 94
RFP published			1/ 96
Proposals due			3/ 96
Contract Award	Contract Awarded		9/96
		NTCIP Standards approved (TS 3.2, TS 3.3)	5/97
		NTCIP Standards approved (TS 3.4, TS 3.5)	11/96
Phase 1 initiated - (development of Phoenix ATMS and implementation of VENDOR traffic signal controllers, AB 3418)			12/96
		NTCIP Standards published (TS 3.1, TS 3.2, TS 3.3, TS 3.4, TS 3.5)	1/97
		Modifications to TS 3.2, TS 3.3 and TS 3.4 published as Recommended Technical Revisions	5/97
Phase 1 completed	Phoenix ATMS installed to control 57 signal controllers in the downtown area using the AB 3418 protocol		8/97
Phase 2 initiated (NTCIP)			12/97
		Additional amendments recommended and incorporated with previous Technical Revisions (i.e., OER, time differential, dynObj Table)	11/98
Phase 2 completed			12/99

⁵ Ablett, Matthew; "NTCIP Lessons or Making the NTCIP Work", TransCore, 1998.

AGENCY	VENDOR	NTCIP Standards Status	Date
			(expected)
Phase 3 initiated (Second vendor)			Not yet initiated
Phase 3 completed			Not yet completed
Phase 4 initiated			Not yet initiated

3. PROJECT PROCUREMENT

3-1 PRE-QUALIFICATION

The Prequalification RFP for the Traffic Signal Controllers⁶ was published in January 1996; proposals were due in March 1996. Proposers were required to supply the AGENCY with one complete controller assembly configured for testing with the new traffic signal system. These signal controllers were required to comply with the NEMA TS 2 specification. The AGENCY required the VENDOR to upgrade the controllers to comply with the final version(s) of the NTCIP. The AGENCY received one (1) proposal for the controller upgrade in January 1996.

No pre-qualification was required for the Phoenix ATMS.

3-2 ADVERTISEMENT / REQUEST FOR PROPOSAL(RFP)

Because only the VENDOR responded to the pre-qualification RFP, only they were eligible to respond to the Invitation to Bid⁷ (the actual RFP) for the traffic signal controller upgrade project. The vendor selected for Phase 3 of this project also had to meet the requirements stated in the IFB, and was required to use the same objects supported in the Phoenix ATMS.

The Phoenix ATMS RFP was published in January 1996. Proposal responses were due in March 1996. The bid and award procedure for the implementation of the Phoenix ATMS consisted of a two-stage submittal process. In the first stage, contractors submitted a functional proposal without a cost estimate. These proposals were essentially a technical response to the Phoenix ATMS RFP⁸ and a statement of qualifications. Six (6) proposals were received for the Phoenix ATMS⁹.

3-3 SELECTION & AWARD

The only VENDOR to respond to the RFP for the traffic signal controllers was selected.

Two of the 'Phoenix ATMS'-respondents were disqualified because of non-compliance with the required proposal format. The remaining four system integrators were invited to submit an amended final Proposal. The AGENCY selected the SYSTEM INTEGRATOR from this group of proposals based on qualifications, experience, and thoroughness of the proposal. A scope of services and a price was

⁶ See Annex A

⁷ See Annex C

⁸ See Annex F

⁹ NET, Gardner+ CompuTran; Holmes&Narver [+ Sonic]; TransCore + Econolite as well as 2 other teams (disqualified and not named here)

negotiated with that SYSTEM INTEGRATOR. The requirements specified within the RFP and the proposal responses were amended during the contract negotiations with a “supplementary conditions” clause because of actual and future anticipated modifications to the NTCIP standards.

The SYSTEM INTEGRATOR and VENDOR for both the central system and traffic signal controller procurements were selected because they were the low bidders. Selection of the second vendor was based on low bid as well as the AGENCY’s desire to integrate different equipment into the system.

4. SPECIFICATIONS

The AGENCY learned about the NTCIP and made the decision to specify it during development of a feasibility study. At that time (December 1993) the relevant NTCIP standards were in a very early draft form. The AGENCY understood that these standards could, and most likely would, change.

The plans and specifications, the functional specification and the RFP for the controller upgrade were developed by the AGENCY without outside assistance. The traffic signal control equipment VENDOR was required to identify any vendor-specific standard NTCIP object ranges¹⁰ as part of the RFP response, and any object definitions to be used in addition to the standard mandatory Conformance Groups and mandatory objects

The Phoenix ATMS (central system) hardware specifications were developed in conjunction with the software and NTCIP portions of the specifications. The hardware specifications included several different platform choices. Although the AGENCY felt its staff had the capability to assemble the functional specifications for the Phoenix ATMS, the AGENCY needed assistance in certain areas. Consequently, some parts of the specifications were developed jointly by an Information Technology specialist firm and a Communications Infrastructure specialist firm.

According to the specifications, the VENDOR and SYSTEM INTEGRATOR were required to provide upgrades to the signal control system and to the field controllers for a period of 36 months following acceptance of the deployed system. The VENDOR and SYSTEM INTEGRATOR were also required to provide add-on (or on-call) services to address changes in the NTCIP suite of protocols following system acceptance and the 36-month warranty period. The specification wording aside, both the VENDOR and the SYSTEM INTEGRATOR were committed to work with the AGENCY to provide a working implementation of the NTCIP. This commitment included overcoming problems and inconsistencies within the standards, and modifying the implementation if the standards were changed during the course of the project.

The actual wording within the “IFB for Traffic Signal Controller” were indicated in Section 2.0 (Scope), Item 4, heading N¹¹:

The successful bidder shall provide a software update(s) for the controller units based on an agreed upon or final revision of the NTCIP protocol. In addition, the successful bidder shall provide the city with all information identifying manufacturer specific features and functions beyond those specified and required by the NTCIP definition.

The AGENCY considers the RFPs used for this project satisfactory at the time they were developed, and the process used to develop the specifications was generally effective. However, the AGENCY indicated that this specification would be inappropriate for any new purchase. The AGENCY anticipated modifications to the NTCIP suite of protocols during the project. Instead of spelling out the NTCIP object definitions, the RFP described a framework-type specification indicating the functional requirements for

¹⁰ See Annex A, Table A-3 of this report

¹¹ See Annex B of this report

the central system and the traffic signal controllers. Consequently, the protocols described for this project was much less specific than they otherwise would have been.

Early in the project, it was determined that the traffic signal controllers at 57 downtown intersections and the Phoenix ATMS had to be installed prior to the opening of the downtown baseball stadium. A fully NTCIP compliant system could not be implemented to meet this deadline. There was not enough time to modify the signal controller and ATMS software to support SNMP (see the discussion below). Fortunately, the SYSTEM INTEGRATOR and VENDOR determined that they could meet this deadline by implementing the Californian AB3418 protocol in these 57 signal controllers and the ATMS. These signal controllers and the ATMS were later upgraded to meet NTCIP standards.

4-1 PROJECT-RELATED NTCIP STANDARDS STATUS

The NTCIP standards relevant to this project are shown in the table below.

Table 2: NTCIP-Related Standards & Specifications for the “Phoenix ATMS” Implementation

Standard	Description
AB 3418	The State of California passed a law that requires all new traffic signal controllers implemented in the State of California after January 1, 1996 to comply with the standard protocol defined in Assembly Bill 3418 (AB 3418). AB 3418 incorporates concepts of the NTCIP, but pre-defines a set of “dynamic objects” ¹² .
<i>VERY early Draft NTCIP Standard</i>	<i>May 5, 1995 NTCIP - Working Draft marked “For Committee Reference Only”¹³</i>
NEMA TS 3.2 1996 and Amendment 1	Simple Transportation Management Framework (STMF) Conformance Level 2 ¹⁴ .
NEMA TS 3.3 1996 and Amendment 1	Class B Profile
NEMA TS 3.4 1996 and Amendment 1	Global Object Definitions
NEMA TS 3.5– 1996	NTCIP Actuated Signal Controller Object Definitions

¹² The concepts of dynamic objects are defined in TS 3.2-1996 and were amended in TS 3.2-1996 Amendment 1. A dynamic object provides a means for related managed objects to be operated on as a group. The goal is to minimize the bandwidth requirements when communicating frequently requested sets of objects between a management station and remote devices.

¹³ This “very early draft NTCIP Standard” is shown in italics to emphasize the influence this draft had on the development of the NTCIP specifications, even though it was not the basis for the implementation of this system.

¹⁴ Initially, only STMP (Conformance Level 1 of the published TS 3.2-1996) was to be implemented. However, changes in the standard required the support of SNMP; essentially requiring conformance level 2 to be implemented.

In the early stages of the project, the AGENCY attended NTCIP-related working group (WG) meetings and had a very good understanding of the protocol and their implications. The AGENCY referred to the May 5, 1995 NTCIP - Working Draft marked "For Committee Reference Only" during the specification development. This very early version of the NTCIP standard was still organized in one document and it included only object definitions for traffic signal control¹⁵. The VENDOR began work on the project using draft standards¹⁶ and subsequent Technical Revisions¹⁷.

There were several significant changes in the NTCIP that impacted this project. NTCIP TS 3.3 was approved as a NEMA Standard in May 1996. This version of TS 3.3 required the use of STMP¹⁸; the use of SNMP¹⁹ was optional. In May 1997, modifications to TS 3.2, and to TS 3.3 were published as Recommended Technical Revisions, which reversed the requirements for SNMP and STMP. Consequently, both central and field device codes were re-written. While this did not result in a change order to the contract, it did result in increased costs.

5. NTCIP FUNCTIONS AND FEATURES

This section discusses the NTCIP functions and features implemented. NTCIP Conformance Groups and Optional Object Definitions are listed in ANNEX A. Additionally, a number of proprietary objects to address special functions and the once-per-second communications requirement were created by the VENDOR and implemented within the ATMS and the signal controllers.

5-1 OBJECTS & CONFORMANCE GROUPS

All of the controllers integrated into the system for this project are "NTCIP-compliant". This implementation conforms to "Conformance Level 2" as defined in Amendment 1 of TS 3.2-1996²⁰. SNMP could not be used because of bandwidth limitations and because it would not support once-per-second control.

The specifications did not define the objects or conformance groups to be implemented. During the course of the project, and after consulting with and agreement from the City of Phoenix, VENDOR and SYSTEMS INTEGRATOR agreed on a set of object definitions to be implemented.

The list of standard objects implemented for this project is included in Table A-2²¹; Table A-3 shows the object value ranges supported. This object definition set included most of the objects defined within the mandatory and optional conformance groups of TS 3.4-1996 and TS 3.5-1996. All optional data elements of the conformance groups were implemented. Proprietary objects were implemented in order to address several functional requirements that were not provided by the standard object definitions. These proprietary objects addressed some optional conformance group functionality differently than defined in the NTCIP standards.

¹⁵ This version also included concepts of the X.25-format (a network layer protocol) instead of the Internet Protocol (IP), which was specified in later versions of the NTCIP standards. However, no network protocol was used in this implementation.

¹⁶ TS 3.1, 3.2, 3.3 (4-17-96), TS 3.4, TS 3.5 (7-13-96).

¹⁷ The Amendments to TS 3.2, TS 3.3, TS 3.4 and TS 3.5 were approved in 1998.

¹⁸ Simple Transportation Management Framework (STMF) describes the organization of the information within devices and the methods of retrieving or modifying any information within the device. STMF also explains how to generate and utilize computer readable information organization descriptions.

¹⁹ Simple Network Management Protocol - A communications protocol developed by the IETF (define), used for configuration and monitoring of network devices.

²⁰ Conformance Level 1 requires support of SNMP, while Conformance Level 2 additionally requires the support of STMP.

²¹ See Annex A

The proprietary objects also provided additional functions to the mandatory and optional conformance groups as extensions to the standard tables. The VENDOR added so-called “block objects” for database management^{22 23}. The SYSTEM INTEGRATOR required status objects such as a “transition/offset seeking” object and the download/upload feature.

The data elements to control these features were developed by the VENDOR. The AGENCY had considered developing its own objects to address these functions but decided against it. The unique object identifiers (OIDs) for these data elements controlling the non-standardized features are located at the VENDOR’s NEMA node address. The AGENCY has the right to re-use the VENDOR-provided MIB for future contracts within the City²⁴. These non-standard features will be used in future applications for the AGENCY, as well as for future implementations by the SYSTEM INTEGRATOR and by the VENDOR²⁵.

5-2 INTERCHANGEABILITY & INTEROPERABILITY

This system provides interoperability among traffic controllers manufactured by different vendors. At the time of the interview, devices from two vendors were being integrated into the system. The AGENCY anticipates the addition of equipment from a third vendor during Phase 4.

Interchangeability is being achieved to some degree. In part, because the AGENCY developed an agency-specific set of dynamic objects that are used to populate some of the 13 dynamic objects. These objects are setup using the STMP-defined mechanism²⁶.

5-3 THE LEARNING CURVE

The AGENCY staff had participated actively in the development of early NTCIP versions, and was very knowledgeable about those versions. Work assignments limited their participation in the development of later NTCIP versions. Consequently, their knowledge of later NTCIP versions was limited.

The VENDOR continues to be an active participant in the development of all versions of the NTCIP documents.

Definitions

Interchangeability: the capability to exchange devices of the same device type (e.g., a signal controller from different vendors) without changes to the software beyond updating the appropriate parameters and variables. Some non-standard functions and features might not be available.

Interoperability: the capability to operate devices from different manufacturers, or different device types (e.g., signal controllers and VMS) on the same communications wire/channel.

²² Database management is one of the most important features within a field device. Within a signal controller, manipulating several data elements as a group is critical since the contents are interrelated. Within the NTCIP, there is a standardized mechanism to achieve this, but the implementation provided an additional proprietary mechanism using “block objects”. This is a mechanism where objects are defined using the MIB OBJECT TYPE Macro, but where the value of an object contains a proprietary “message”. These “message” setups are such that each byte, or bit within a byte, or several bytes have a particular meaning. This setup is very similar to the messages used in traditional traffic signal communications protocols.

²³ The “block objects” are specific to each vendor, and each vendor’s controller uses a different set of “block objects.” This means that the central system software must be changed every time a new controller is being added to the system.

²⁴ Locating object OIDs under the vendor’s node is appropriate and feasible. However, if an agency requires the development of ‘special’ objects and/or entire MIBs, it may be more feasible to place them under an agency node to ensure that the control of the object remains with the agency. If objects are under the vendor’s node, the AGENCY might need an agreement with the VENDOR to maintain the objects until both sides agree to dismiss them.

²⁵ The VENDOR and SYSTEM INTEGRATOR used the same software for another implementation.

²⁶ The STMP mechanism is as defined in TS 3.2-1996, not as modified in TS 3.2 Amendment 1.

Therefore, they were very knowledgeable about the objects, their meaning and interpretation. The VENDOR's continued participation on these NTCIP Working Groups was valuable in another respect. Implementation and interpretation issues that arose during this project were discussed during the course of the Standards development. These discussions contributed to the development of the Amendments ²⁷.

The SYSTEM INTEGRATOR has significant experience develop device drivers to communicate with various proprietary protocols. They were very aware of the emerging NTCIP suite of protocols, and reviewed and had commented on various standards. During the development of the central system, the SYSTEM INTEGRATOR used Internet pages and several books to learn about ASN.1, HDLC ²⁸ and SNMP in addition to the NTCIP Guide (of 1995) and the NTCIP standards publications.

6. TESTING COMPLIANCE

The RFP defined NTCIP compliance in a very general way ²⁹. During the project, the VENDOR defined a set of objects the AGENCY, VENDOR and SYSTEM INTEGRATOR agreed would become the "de-facto" compliance statement ³⁰.

The AGENCY was satisfied with the testing process. The SYSTEM INTEGRATOR and the VENDOR developed the software code independently, and began integration testing after testing of the individual components was completed. The VENDOR and the SYSTEM INTEGRATOR developed the testing procedures collaboratively. The process was essentially an informal exchange of information between the VENDOR and SYSTEM INTEGRATOR where in the SYSTEM INTEGRATOR and the VENDOR discussed and worked out problems as they were discovered. In most cases, problems resulted from interpretation of the standards rather than from bad frame constructs. Textbooks and the Exerciser were used to resolve frame construction issues. This process worked well and contributed to the development of an integrated system/product ³¹.

6-1 TESTING TOOLS

The NTCIP Exerciser was not available with the RFP was developed, and consequently was not required within the specifications, but it was used for certain testing procedures. No other testing procedures and tools were defined or described in the RFP.

The VENDOR conducted compliance testing using several different tools, including DataScan, a 'GET NEXT' tester and a 'suitcase tester'. The VENDOR designed the 'GET NEXT' tester, which automatically sequences through all objects, and the 'suitcase tester' ³², which uses dynamic objects to read signal indications, set parameters, and to read or set other objects. The suitcase tester was also used to test non-standard NTCIP functionality.

²⁷ Errors and inconsistencies identified by the VENDOR during software development were recorded and presented to the appropriate NTCIP WGs. The VENDOR's recommendations were incorporated in Amendment 1 of TS 3.2-1996 and of TS 3.4-1996. The VENDOR and the SYSTEM INTEGRATOR made the appropriate modifications to ensure a successful implementation.

²⁸ HDLC – High-level Data Link Control = Data Link Layer protocol

²⁹ See Annex B, Scope, Item 2, Bullet N.

³⁰ This does not necessarily mean that every implementation can, or should, implement all of the proprietary objects used in this implementation. The interview did not reveal whether the system could be operated without using these proprietary objects.

³¹ Leaving it up to the VENDOR and SYSTEM INTEGRATOR could lead to problems when other devices or device types are being added to the system. The interpretation of the NTCIP has to be unambiguous to guarantee that systems can provide interoperability and interchangeability.

³² A 'suitcase tester' is a testing tool contained in a briefcase or suitcase for portability.

The VENDOR used the NTCIP Exerciser when questions related to frame constructs arose. The VENDOR and the SYSTEM INTEGRATOR compared the frames generated by the NTCIP Exerciser to the ones they developed. The NTCIP Exerciser was also used during development of the testing tools mentioned above.

The VENDOR chose to develop their own testing tools because the NTCIP Exerciser did not meet their needs. They needed a more sophisticated testing tool with a better user interface. At that stage, the setup and the code (software) needed work. The VENDOR found it far easier to form frames manually than to use the Exerciser.

The AGENCY plans to purchase and use a Line Analyzer to verify selected bit/byte patterns to ensure that future vendors interpret the NTCIP the same way the VENDOR and SYSTEM INTEGRATOR have for this project.

At the time of the interview, acceptance testing had not yet been performed.

7. USING THE NTCIP

The AGENCY, SYSTEM INTEGRATOR and VENDOR representatives were asked to briefly describe their "NTCIP experience".

7-1 FROM THE AGENCY'S PERSPECTIVE

The AGENCY described their experience "on the bleeding/leading edge" as painful but very interesting. From the AGENCY perspective, the standards were not specific enough to provide a "standard" implementation. For example, all devices added to the system require proprietary items such as "block objects" and upload/download mechanisms. These proprietary objects are likely to be different for each vendor's equipment.

The AGENCY learned of the NTCIP while developing the feasibility study. While this study did not mention the NTCIP, the AGENCY decided to implement an NTCIP compliant system at that time. The AGENCY was not comfortable specifying NTCIP in the RFP because of potential changes in the standards during and after the project. Instead, the AGENCY decided to use 'framework-type' terminology and required a commitment by the VENDOR and SYSTEM IMPLEMENTOR to ensure a successful implementation. Once the RFP was released and the negotiation was concluded successfully, the implementation of the NTCIP proceeded as expected (which does not mean that there were no problems).

The AGENCY, aware that the NTCIP protocols were in the draft standard stage, anticipated some changes. The AGENCY's primary concern was that the cost of addressing dramatic changes in the NTCIP would exceed the budget. AGENCY staff were also concerned the download time requirement for database contents would increase dramatically.

The available NTCIP Standards address the AGENCY's existing and planned communications infrastructure. In hindsight, the AGENCY's main objective of achieving interoperability³³ among controllers was realistic and has been achieved. The AGENCY was also able to reduce the number of proprietary objects by defining and requiring the use of specific dynamic object setups in each controller. While it would have been much easier to implement a proprietary protocol, this project helped to advance the standardization effort. The next implementation of the NTCIP should be even smoother. The project, for example, requires another round of software upgrades/revisions that will not be required for later implementations.

³³ Interchangeability was dropped after it became clear that each vendor would use proprietary objects to achieve some functionalities.

7-2 FROM THE VENDOR'S PERSPECTIVE

The VENDOR was committed to the implementation of the NTCIP, although they expected interface issues to arise from the onset of the project. The VENDOR's primary concern in implementing the NTCIP was bandwidth availability. The NTCIP Class B protocol, designed for use with slower communications links, requires more overhead than most of the proprietary protocols in use today. This made it unlikely it would be possible to maintain the same polling cycle time with the same number of controllers per channel and the same data rate. While the VENDOR developed Upload/Download functionality (block objects) to overcome some of the limitations of the 1200 bps communications rate, dependence on the use of these proprietary objects runs counter to the objective of the NTCIP. The number of controllers on each communication line dropped from 8 controllers (using the proprietary protocol) to 4 controllers (using the NTCIP). However, this fact was known at the on-set of the project.

While the level of effort required to implement the NTCIP was much higher than anticipated, the implementation itself went smoother than anticipated.

The VENDOR encountered errors and problems with the balloted standards. In particular, there were errors in the NEMA PER³⁴ encoding, dynamic objects were poorly defined³⁵, and the design of the upload/download mechanism for the database³⁶ was not as efficient and clear as it could have been.³⁷

7-3 FROM THE SYSTEM INTEGRATOR'S PERSPECTIVE

The SYSTEM INTEGRATOR saw the concern trying to implement evolving standards realized. However, due to the commitment to ensure a successful implementation, changes and modifications were implemented.

Other concerns included:

- a) The overhead associated with SNMP and usage of standard NTCIP object definitions prohibited communications over 1200 bps communications lines (even 9600 bps) proved inconvenient. To work around this, a great deal of work was required (development of specific block objects), and it led to the decrease of the number of controllers per communications channel.
- b) The standard object definition sets (TS 3.4 and TS 3.5) did not support all the operations of the controllers due to proprietary features. This affected virtually every group of objects within TS 3.5 and led to the creation and implementation of proprietary (VENDOR) MIBs, which will require an adjustment of the software for each controller type.

³⁴ Packed Encoding Rules (PER) was developed for use on low bandwidth communications links, as specified in NEMA TS-3.2. In the later version "TS 3.2-1996 - Amendment 1" these encoding rules were renamed Octet Encoding Rules (OER) because, unbeknownst to each other, the International Standards Organization (ISO) also developed a set of encoding rules they also referred to as PER.

³⁵ Author's Note: The dynamic objects were not as "poorly designed" as a comparison between the first version and the version within Amendment 1 might indicate. The DynObj table was split in two, because it was felt that there would only be one owner of a dynObj. Additionally, some objects that might have been queried using SNMP but contain the STMP dynObj values have been deleted.

³⁶ See TS 3.4-1996 under Database Management Conformance Group, and TS 3.2-Amendment 1 under Database Management Conformance Group.

³⁷ Author's Note: These issues have been addressed in Amendment 1 of TS 3.2 (STMF), TS 3.3 (Class B Profile) and TS 3.4 (Global Object Definitions).

8. LESSONS LEARNED

8-1 FOR AGENCIES

During the interviews, the following recommendations were made for an AGENCY preparing for an implementation:

- Gain a thorough understanding of the NTCIP ³⁸.
- Consider hiring a knowledgeable consultant to guide NTCIP implementation
- Understand the interchangeability and interoperability effects of NTCIP.
- Have realistic objectives and goals.
- Provide a definition of "NTCIP-compliance" in RFPs. No "one-liners" requiring NTCIP compliance.
- Include the latest versions of NTCIP standards in your NTCIP specifications.

8-2 FOR VENDORS / SYSTEM INTEGRATORS

Purposely left blank.

8-3 RECOMMENDATIONS FOR IMPROVEMENTS TO THE NTCIP STANDARDS

- **Revert decision to eliminate use of the 'NEMA node' mechanism** in conjunction with STMP.
- **Develop another object set for a separate time source**, i.e., WWW clock, to allow queuing of time and distribution of this time to all other devices (communications using NTCIP standard objects).
- **Develop standards for fiber-optic communications.**
- **Standardize the block objects** or, as a minimum, the approach to block objects.
- **Improve the NTCIP Exerciser.**
 - ⇒ Consider modifying the Exerciser to perform communications testing, and to help construct frames and setup frame sequences. ³⁹
 - ⇒ Improve the user interface and make the Exerciser more user-friendly.
- **Develop standard or universally accepted test procedures** to aid in compliance testing and in defining compliance.
- **Develop Compliance Levels** that allow a specifications writer to pick 'low level' conformance groups that represent specific functions.

³⁸ The documents posted on the NTCIP web-site, and attendance at the NTCIP WG Meetings helped the AGENCY understand the NTCIP.

³⁹ Author's Note: the functionality to perform communications testing and to help construct frames is, and was always, included in the NTCIP Exerciser.

8-4 THE NTCIP JOINT COMMITTEE AND FHWA

- **Publish and maintain a list of all Working Group work items** including descriptions in layman's terms".
- **Increase outreach and education** to inform customers.
- **Present a realistic picture of the NTCIP** in outreach programs; avoid presenting the NTCIP with a "marketing" spin.
- **Complete NTCIP Guide** as soon as possible. Include a general discussion of data exchange with respect to data rate, system status and upload/download. Specifically, discuss and define latency issues and bandwidth capabilities ⁴⁰.
- **Maintain the standards and provide funding** to support this maintenance effort. Integrate implementation findings into the standards as quickly as possible.
- **Develop realistic test-plans** or testing procedures to help compliance testing and conformance.

⁴⁰ The new version of the NTCIP Guide is available on the NTCIP homepage and addresses these issues.

ANNEX A: NTCIP EQUIPMENT DESCRIPTIONS

Table A1: Existing and New Equipment

Equipment information	Before project non-NTCIP	After project Non-NTCIP	After Project NTCIP
Number of devices	810	N/A	860
Device Types	SIGNAL CONTROLLERS: NEMA TS1, Solid State Fixed Time controllers	CCTV, VMS, RAMP METER CONTROLLER	SIGNAL CONTROLLERS: Econolite ASC/2, PEEK M3000
Controller Connection	Multi-drop, UTCS mainframe based System (and stand alone)	N/A	Multi-drop, Distributed PC-based System

Table A2: NTCIP Conformance Groups Implemented for Signal Systems

Conformance Group	Reference Standard	Conformance Status	CAPABILITIES	
			Requested	Implemented
Configuration	TS 3.4	Mandatory	Not specified	V=Y / SI=Y
Database Management	TS 3.4	Optional		V=Y
Time Management	TS 3.4	Optional		V=P / SI=Y
Timebase Event Schedule	TS 3.4	Optional		V=P
Report	TS 3.4	Optional		V=P
STMP	TS 3.4	Optional		V=Y
PMPP	TS 3.4	Optional		V=N
Phase	TS 3.5	Mandatory		V=Y / SI=partially
Detector	TS 3.5	Mandatory		V=Y / SI=partially
Vehicle Occupancy Report	TS 3.5	Optional		V=Y / SI=Y
Unit	TS 3.5	Optional		V=Y / SI=partially

Annex A – Project-Specific NTCIP Items

Conformance Group	Reference Standard	Conformance Status	CAPABILITIES	
			Requested	Implemented
Special Function	TS 3.5	Optional		V=Y / SI=partially
Coordination	TS 3.5	Optional		V=P / SI=partially
Time Base	TS 3.5	Optional		V=P
Preempt	TS 3.5	Optional		V=P
Ring	TS 3.5	Optional		V=Y
Channel	TS 3.5	Optional		V=Y
Overlap	TS 3.5	Optional		V=Y / SI=partially
TS 2 Port 1	TS 3.5	Optional		V=Y

Note 1: V=Vendor, P = Private objects, SI=System Integrator, partial=a mix of mandatory and optional objects of a conformance groups were used, but not all mandatory objects were needed and therefore not supported.

Note 2: Portions of Coordination objects were supported (being able to command coordination were implemented using standard objects)

Table A3: ECONOLITE ASC/2 Series Controller NTCIP Support

In addition to the above description, the VENDOR provided the following information (*excerpt without any changes*) regarding the objects and the object ranges that are supported in this implementation. While providing this information deviates from the approach taken in other case studies, the authors felt this information was too important. However, the implementation also implemented a large number of proprietary objects, which are not provided due to intellectual property rights issues.



Econolite is currently supporting NTCIP Class B communications in the ASC/2 Series controllers. The level of NTCIP support is as defined in the new NEMA TS2 specification recently approved by NEMA. The specification defines NTCIP Level 1 and Level 2 compliance for actuated controllers. A summary of the NEMA Level 1 and Level 2 compliance for actuated controllers, as set forth in the new TS2 standard, is included as an attachment to this document.

The ASC/2 controller can support system operation using the ASC/2 Level 1 NTCIP objects plus the ASC/2 private objects. Econolite NTCIP software for the ASC/2 controller is currently NEMA NTCIP Level 1 compliant (ASC/2 NTCIP software is currently undergoing integration testing for the Phoenix, AZ; Lakewood, CO; and Salt Lake City, UT ATMS projects). The ASC/2 Level 1 NTCIP software also supports the following optional conformance groups: Database Management as defined in TS 3.4, and Volume Occupancy Report, Unit, Special Function, Ring, Channel, Overlaps and TS2 Port 1 as defined in TS 3.5. Attached is a list of objects currently supported by the ASC/2 NTCIP Level 1 controller software.

The NTCIP optional Coordinator, Preemption and Timebase conformance groups are not supported with ASC/2 NTCIP Level 1 compliant software. However, all ASC/2 Coordinator, NIC, Time-of-Day, Holiday and Preemption functions are supported using private objects.