Colorado Department of Transportation

Colorado Springs TOC to CDOT CTMS Interface

NTCIP Center-to-Center Protocol Analysis

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1. INTRODUCTION

Currently, the Colorado Springs Traffic Operations Center (TOC) operates intelligent transportation devices within the city limits, and along thirteen miles of the El Paso County section of I-25. The TOC controls a local area traffic signal system that includes city and state traffic signals. In addition, the TOC monitors and controls closed circuit television (CCTV) cameras, automatic traffic recorders (ATRs), variable message signs (VMSs), and weather sites. In the future, operations of ramp meters will also be included. The Colorado Springs TOC hours of operation are extended business hours. During off-hours, the signal system operates predetermined signal timing plans.

The Colorado Department of Transportation (CDOT) Colorado Transportation Management Center (CTMC) currently operates devices on state highways outside of Colorado Springs. This includes VMS, highway advisory radio (HAR), CCTV cameras, and ramp metering. CDOT also provides a "traffic conditions" web site. Traveler information services are being expanded with the deployment of a statewide electronic Traveler Information Center (TIC) and an updated CDOT Web Site. The CDOT CTMC is staffed twenty-four hours a day, seven days a week.

The establishment of a direct, electronic link between the CDOT CTMC and the City of Colorado Springs TOC would enable the joint sharing of control, data, and images from roadside equipment. Creating an electronic interface between these two centers serves to accomplish two primary objectives.

1. Create a broader southern I-25 corridor management system to improve traffic safety and flow.

2. Allow CDOT to manage Colorado Springs devices during the hours when the TOC is not staffed.

The functional requirements for this direct center-to-center (C2C) interface have already been developed.[1] The functional requirements define the operational and technical functionality of the interface.

The purpose of this document is to analyze and recommend which National Transportation Communications for ITS Protocol (NTCIP) C2C is best suited for the interface between the Colorado Springs TOC and CTMC. The two protocols developed by the ITS community are based on ***Data Exchange Between Systems*** (DATEX) and ***Common Object Request Broker Architecture*** (CORBA). Many factors are considered in making this decision because this choice will have far reaching implications for the future direction of ITS deployments in the state.

The NTCIP protocol, which is being developed specifically for center-to-center communications, is *TS 3.CLE National Transportation Communications for ITS Protocol - Class E Profile for Center-to-Center Communications*. According to the National Electrical Manufacturers Association (NEMA), "this communications protocol profile is established to connect a

[1] Prepared by IBI Group, Colorado Springs TOC To CDOT CTMS Interface Functional Requirements, prepared for Colorado Department of Transportation, April 2000.

transportation management center (TMC) to other TMCs and information service providers. The profile will include a data transmission protocol and a message set standard."[2]

This document assesses which protocol is better suited for this particular application. The availability of two protocols implies that one protocol is better suited to certain circumstances. In this document, the comparison criteria are clearly identified and analyzed to determine the best choice for Colorado's NTCIP center-to-center requirements. Factors considered included:

- Characteristics of systems to be linked
- Functions to be supported
- System life cycle considerations
- System performance
- Communications infrastructure and demand

Each of these factors is discussed in the document. An overview of NTCIP is provided first.

[2] http://www.nema.org/standards/ntcip/devel.html, *Joint AASHTO/ITE/NEMA Committee on the NTCIP's Working Group on Center-to-Center (C2C) Communications, chaired by Warren Tighe, DKS Associates*

2. NTCIP CENTER-TO-CENTER PROTOCOLS

> *"The primary objective of NTCIP is to provide a communications standard that ensures the interoperability and interchangeability of traffic control and Intelligent Transportation Systems (ITS) devices. The NTCIP is the first protocol for the transportation industry that provides a communications interface between disparate hardware and software products. The NTCIP effort not only maximizes the existing infrastructure, but it also allows for flexible expansion in the future, without reliance on specific equipment vendors or customized software."*[3]

NTCIP provides two alternative protocol choices for center-to-center communications. One is called DATEX and the other is called CORBA. Two different protocols were found necessary to meet the variety of requirements for inter-system data exchanges. It is feasible to use both protocols in the same network, with some centers acting as a bridge, or translator, between the two. The key is in determining where to deploy each protocol.[4]

After providing some background on the purpose and origin of the NTCIP protocols, the report provides descriptions of both DATEX and CORBA.

2.1 PURPOSE OF NTCIP PROTOCOLS

> *"In early 1993, the U.S. Department of Transportation's Federal Highway Administration (FHWA) brought together transportation industry representatives to discuss the obstacles in the way of installing equipment for new Intelligent Transportation Systems (ITS). The representatives said that the number one priority was the need for an industry-standard communications protocol. Since the National Electrical Manufacturers Association (NEMA) Transportation Section members had already started a part of a new industry standard, they offered to expedite and expand the scope of their activities.*
>
> *Thus was born the National Transportation Communications for ITS Protocol (NTCIP). The key objects of the new protocol are the interchangeability of similar roadside devices, and the interoperability of different types of devices on the same communications channel.*
>
> *The development of the NTCIP standards documents branched off in two directions. Some of the documents were "object definitions" for particular types of roadside devices and control products, such as traffic signal controllers or dynamic message signs. (An "object" is an abstract computer term, which represents a range of values, or functions that can be accessed or remotely controlled. The object is "defined," like in a dictionary, so that everyone uses the same spelling of its name.) And the other documents were "communications profiles" for standardized groupings of layered profiles, which are in turn based on international communications standards.*

[3] http://www.ntcip.org/index.html, NTCIP Website, May 3, 2000.

[4] Published by American Association of State Highway and Transportation Officials (AASHTO), Institute of Transportation Engineers (ITE), and National Electrical Manufacturers Association (NEMA), THE NTCIP GUIDE - National Transportation Communications for ITS Protocol, September 1999.

The FHWA sponsored a Steering Committee to help guide the development of the NTCIP. Volunteer contributions to the standards-making effort came from public sector agencies, consulting firms, nonmember manufacturers, and the NEMA Section's member companies.

In 1996, the FHWA suggested a partnership of standards developing organizations to expand both user and industry involvement. The American Association of State Highway and Transportation Officials (AASHTO) and the Institute of Transportation Engineers (ITE) signed an agreement with NEMA to establish the Joint Committee on the NTCIP, and to work together on completing the NTCIP. Many of the members of the former Steering Committee were appointed to the Joint Committee.

The purpose in having a national standard is simple: Any traffic management center (TMC) that conforms to the standard will be able to exchange information with any other TMC that also conforms to the standard. Sharing information across jurisdictional boundaries is imperative during certain critical times (storms, incidents, route diversion, stadium evacuation, etc. to assist the operators in making better operational decisions".[5]

2.2 DATEX

DATEX is a message-based protocol. Systems exchange information using messages that provide information (publish) and messages that request information (subscribe). This is the *publish and subscribe* approach. The systems interact using a client-server style relationship. The client system requests information from the server (subscribe) and the server provides that information to the client (publish). Subscriptions may be a single one-time request or a periodic request for data to be sent on a periodic basis or on an event driven basis. Like most protocols, DATEX includes error-checking mechanisms to insure that the information was passed correctly from the server to the client.

The messages are exchanged according to a data dictionary. This data dictionary provides some commonality so that both systems reference the information in the same way. The data dictionary gives common names and attributes to anything referenced by the systems. For example, both Colorado Springs and CDOT must agree on the attributes (properties or commands) of a VMS.

It is recommended that an industry standard data dictionary be used for exchanging information. The Traffic Management Data Dictionary (http://www.ite.org/tmdd/) is ideal for these purposes.

The NTCIP DATEX center-to-center protocols are nearing finalization. At present, the DATEX version of the protocol is further ahead than the CORBA version.

[5] Excerpt from http://www.nema.org/standards/ntcip based on the article "Petal to Metal on Traffic Standards" by Paul R. Bell, P.E.

2.3 CORBA

"The Common Object Request Broker Architecture (CORBA) is the Object Management Group's answer to the need for interoperability among the rapidly proliferating number of hardware and software products available today. Simply stated, CORBA allows applications to communicate with one another no matter where they are located or who has designed them. CORBA 1.1 was introduced in 1991 by Object Management Group (OMG) and defined the Interface Definition Language (IDL) and the Application Programming Interfaces (API) that enable client/server object interaction within a specific implementation of an Object Request Broker (ORB), adopted in December of 1994, defines true interoperability by specifying how ORBs from different vendors can interoperate.

The (ORB) is the middleware that establishes the client-server relationships between objects. Using an ORB, a client can transparently invoke a method on a server object, which can be on the same machine or across a network. The ORB intercepts the call and is responsible for finding an object that can implement the request, pass it the parameters, invoke its method, and return the results. The client does not have to be aware of where the object is located, its programming language, its operating system, or any other system aspects that are not part of an object's interface. In so doing, the ORB provides interoperability between applications on different machines in heterogeneous distributed environments and seamlessly interconnects multiple object systems.

In fielding typical client/server applications, developers use their own design or a recognized standard to define the protocol to be used between the devices. Protocol definition depends on the implementation language, network transport and a dozen other factors. ORBs simplify this process. With an ORB, the protocol is defined through the application interfaces via a single implementation language-independent specification, the IDL. And ORBs provide flexibility. They let programmers choose the most appropriate operating system, execution environment and even programming language to use for each component of a system under construction. More importantly, they allow the integration of existing components. In an ORB-based solution, developers simply model the legacy component using the same IDL they use for creating new objects, then write "wrapper" code that translates between the standardized bus and the legacy interfaces.

CORBA is a single step on the road to object-oriented standardization and interoperability. With CORBA, users gain access to information transparently, without them having to know what software or hardware platform it resides on or where it is located on an enterprises' network. The communications heart of object-oriented systems, CORBA brings true interoperability to today's computing environment."[6]

When NTCIP for Center-to-center was being developed, an object oriented approach was considered. At that time, CORBA was an emerging industry standard. In recent years however, other approaches to Center-to-center interfaces have emerged. These include Distributed

[6] http://www.omg.org/corba/whatiscorba.html, Object Management Group, Inc.

Component Object Model (DCOM) and Extensible Markup Language (XML). At this time, it is not clear what the future computer industry standard will be for Object Oriented communications.

2.4 GATEWAYS AND BRIDGES

A *gateway* is used to port data from one center-to-center protocol to another. Once the CORBA and DATEX NTCIP Center-to-center protocols have been clearly defined, the CORBA/DATEX Gateway will be developed. This will allow NTCIP compliant systems to share information regardless of their choice of CORBA or DATEX.

Bridges are used to get data into and out of non-NTCIP compliant systems. As the name implies, the bridge spans the gap between new and old technologies providing a simple, seamless solution without having to rebuild the existing transportation management systems.

2.5 NETWORK LAYERS

Typically, network communication is discussed using the seven-layer model. The NTCIP protocols of CORBA and DATEX are primarily concerned with the first three layers (Application, Presentation and Session). These top three layers define the procedures for data exchange, the syntax and establish the dialog between client and server.

Because the network model uses this layered approach, the choice for the bottom four layers (Transport, Network, Data Link, and Physical) is independent of the upper layers. This implies that as new technologies become available for the lower layers, the upper layers can remain unaffected.

The goal of the NTCIP protocols is to share information amongst the TMCs so the interface should be independent of operating system, platform, or choices for the communications network.

OSI LAYERS	DESCRIPTION	DATEX	CORBA
Application	Define procedure for file transfer, access methods and management of messages	DATEX	CORBA
Presentation	Define syntax and semantics for transmission	Per ISO	CORBA-GIOP
Session	Establish dialogues	NULL	NULL-IIOP
Transport	Break long message in packets and organize passing between high and low layers	TCP	TCP
Network	How packets are routed from source to destination.	IP	IP
Data Link	Ensures Data Integrity (error correction)		
Physical	Mechanical and electrical interfaces and the transmission medium	Fiber	Fiber

3. CHARACTERISTICS OF TMC SYSTEMS

This interface will be used to connect the CTMC to Colorado Springs and other traffic management centers operated by CDOT regions and local jurisdictions across the state. The nature of each center is an important consideration in selecting an appropriate NTCIP protocol for center-to-center interface.

3.1 POTENTIAL SYSTEMS TO BE LINKED

3.1.1 Colorado Transportation Management System (CTMS)

The Colorado Transportation Management System (CTMS), which supports the functions of the CTMC is being designed. The timing of the implementation of the center-to-center interface fits well with the emerging schedule for deployment of the CTMS. The developers of the system have experience with both DATEX and CORBA. The use of CORBA could require additional time for development of the interface because of the increased complexity of CORBA.

3.1.2 Colorado Springs

The Colorado Springs Intelligent Transportation Management System (CSITMS) system software is based on Arizona Model Deployment Initiative Software Architecture. The system employs Distributed Object-Oriented knowledge-based software architecture. The system does not use CORBA. It includes a multiple distributed and configurable client/server, server/server software interfaces. Currently defined message protocols that run over TCP/IP. Currently defined message formats include: Event Data, Data Transfer, CCTV Control Request Message, VMS Control Request Message, Request Response Message, Schedule Adherence Data Message, Client Register Message, Client Unregister Message, and others.

The system is flexible and could be adapted to either choice of DATEX or CORBA. However, based on the system architecture and the developer’s previous center-to-center communications experience, the developer has indicated that DATEX would be their preferred choice.

3.1.3 Other Traffic Management Centers

In the near future, the CTMC will interact with other TMCs across the state. Most of these centers operate traffic control signal systems using centralized or street-master control software from a range of different developers. Many of these systems are moving toward the incorporation of NTCIP protocols. However, their initial focus has been on center-to-field communications and not center-to-center communications. Recent experience in San Jose by the IBI Group with some of these same traffic control systems indicates that DATEX offers proven route for the deployment of a center-to-center interface.

3.2 FACTORS TO CONSIDER

3.2.1 Need for A Standard Interface

The immediate plan is to connect the CTMC with the systems at Colorado Springs, Lakewood, and other Denver area traffic control centers. From a technical standpoint, these interconnections are relatively straightforward. If the goal was to simply share data between these centers, some very simplified communications could be built into these systems. If this were the only goal, national standards would not have to be utilized to simply pass some simplified messages between the systems. However, the goal is to prepare for the future. If the CTMC is to be connected to several other systems, some type of standard protocols should be used.

The future goals of the system are to include other TMCs as well as to connect to Colorado's neighboring states. This is why a national standard should be adopted. Instead of trying to adapt the CTMC to each new integrated system, all of the systems should be able to speak the same "language". Both DATEX and CORBA will meet this requirement.

3.2.2 System Development Approach (Object Oriented)

The CORBA protocol is an Object Oriented approach to inter-process communications. CORBA allows the systems to define *objects* that have methods and properties. When discussing an object-oriented approach, phrases such as data encapsulation, inheritance, and polymorphism are used to describe the characteristics of these objects. These fundamental concepts of object oriented design yield great dividends when designing a system that is very complex and will potentially evolve over time.

Although the DATEX approach is not object oriented, the protocols developed by the ITS community are thorough, complete, and operational. DATEX will not require a major paradigm shift on the part of the other center software developers to provide this interface.

3.2.3 User Interface

Minor changes would be required in the user interfaces of the existing TMC systems. The existing systems will have to accommodate the new data available from the other systems. Further, the ability to issue commands to these new remote devices must be in an intuitive manner to the user.

The selection of DATEX or CORBA will be transparent to the operator so the user interface modifications will be identical regardless of the protocol selection.

4. FUNCTIONS TO BE SUPPORTED

The purpose of the interface is to primarily support the exchange of information and the sharing of control.

4.1 INFORMATION EXCHANGE

The primary goal of the center-to-center system is to exchange information between centers. This information exchange will allow operators to make better decisions. The choice of CORBA or DATEX will not have a significant impact on the exchange of information and will be transparent to the operator.

4.2 DEVICE CONTROL SHARING

A secondary goal of the center-to-center system is to control remote devices that belong to other TMCs, beyond jurisdictional boundaries. This ability will give operators new abilities to control devices, which will be particularly important during after-hours operation. The choice of CORBA or DATEX will not have a significant impact on the control of devices and will be transparent to the operator.

4.3 VIDEO

It’s important to note that the NTCIP protocol for center-to-center communications does not include any protocols regarding the sharing of video images. However, CCTV camera status and control commands are included in the protocol if centers wish to share camera control.

The center-to-center system adds some additional time delay to the system. When controlling devices such as VMSs, this minor increased delay is incidental. When controlling CCTV cameras that will respond in real-time, this delay can be problematic. For example, the delay between the *rotate-left* command issued by the operator and then actually seeing the video image rotating left could be frustrating and cause the operator to buffer several more commands to the camera. For this reason, it is recommended that the cameras be controlled with preset camera locations. When an operator at a remote site wishes to move a camera they send a command to the camera to move to a preset PTZ (pan-tilt-zoom) location.

5. LIFE CYCLE DEVELOPMENT

The life cycle development of a complex computer system includes a wide range of factors. The issues of potential concern for NTCIP center-to-center deployment are discussed below.

5.1 DEPLOYMENT TIMING

The deployment timing of this project requires a risk assessment. Colorado will be on the cusp of incorporating the newly developed NTCIP center-to-center protocols into the CTMC software. The addition of the center-to-center functions while the CTMC system is still in development is favorably timed as well. The additional center-to-center functions in the new software will be easier at this point in time, than if the system was an older, legacy system.

5.2 EASE OF IMPLEMENTATION

Since both of the available NTCIP center-to-center protocols will perform the communications function equally well after they are implemented, one of the primary considerations is the ease of implementation. Once implemented, the choice of communications protocol will be transparent to the operators. This means that the primary consideration should be the effort involved in the implementation.

To date, DATEX has been easier to implement than the CORBA protocol. One reason is that the DATEX NTCIP protocol is much farther along than the CORBA protocol. The CORBA protocol has yet to be finalized. So at this time, DATEX offers a more mature solution.

The majority of the software at the other TMCs is inwardly focused. Thus, integrating legacy systems with NTCIP protocol object libraries would be a daunting task if CORBA were chosen. By its simplified nature, the DATEX would be easier to implement than the CORBA protocol. Simple message passing is relatively straightforward compared to the complexity involved in implementing the object-oriented approach.

5.3 SCALABILITY

Each of the NTCIP center-to-center communications protocols is scaleable. That is to say, they will work equally well with three centers as they would with 30 centers. However, the CORBA protocol may lend itself better to large-scale implementations. For example, this was one of the deciding factors for using CORBA in the Showcase system in southern California. There was a large number of existing, large-scale, freeway management centers involved and the likelihood of expansion.

5.4 MAINTAINABILITY

Once the center-to-center system is implemented, it should be relatively maintenance free. One aspect of the system to be addressed is how to make new devices, data, or functions available to the system without large impacts. For example, if a new VMS were added in Colorado Springs and that device needed to be included in the center-to-center system, how much effort would be involved in incorporating that new device into the system?

The choice of CORBA or DATEX will have little impact on the maintainability of the system, but it is an aspect that should be considered.

5.5 FUTURE PREVALENCE

An important factor when deciding on a new technology is it's future prevalence, i.e., staying power. Without clairvoyance, this is the most difficult aspect of new technologies. One reassurance is that both DATEX and CORBA NTCIP systems are currently being implemented and will be supported in the future. There are some factors that could give clues to the future prevalence of this technology.

- **Origin**: CORBA is North American and DATEX is European. Traditionally, a new technology gets a foothold in its place of origin. This would give an edge to CORBA.
- **Industry Standard**: Outside of the realm of NTCIP, CORBA seems to be more widely utilized in North America than DATEX.
- **ITS Examples**: There are ITS examples of implementations of both DATEX and CORBA throughout the ITS community. The Silicon Valley Smart Corridor project utilized DATEX and connected seven state, county and local systems. Washington State DOT has chosen DATEX for its near-term C2C deployment efforts. The Showcase system in California is using CORBA to connect eight primary TMCs and several satellite centers.
- **Object Orientation**: Object Oriented Programming has made a significant impact on software development. Object Orientation is increasingly becoming more widespread throughout the industry. This would favor using CORBA for the communications protocol because it's object oriented.
- **Competing New Technologies**: The most difficult aspect of new technology is predicting if it will be in use in the near future. The CORBA protocol is receiving some serious competition from new technologies (DCOM, XML, etc.) It is impossible to assess the commitment that the ITS community has to CORBA if one of these new technologies becomes an industry standard.

6. PERFORMANCE

Key to any real-time system performance is responsiveness and reliability.

6.1 RESPONSIVENESS

Responsiveness of the protocol is another consideration. Because of additional overhead, CORBA responses tend to be slower than DATEX. There are no sources that quantify this additional overhead but it's assumed for the requirements for Colorado, the additional bandwidth required for CORBA would not be prohibitive. This may not be a significant consideration, to the nature of the information involved. For example, if a sign responds to a command in 1.1 seconds instead of 0.85 seconds, it doesn't really matter.

6.2 RELIABILITY

Once the protocol is established, there wouldn't be any noticeable difference in reliability. Both CORBA and DATEX have error checking and error correction built into the protocol. The reliability of the protocol isn't a significant factor for consideration in choosing between CORBA and DATEX.

7. COMMUNICATIONS

Due to some additional overhead, CORBA requires some extra bandwidth than DATEX. The information packaged by the CORBA objects will have more header information. There are no sources that quantify this additional overhead. But given the large amount of bandwidth being installed as part of CDOT communication projects, the additional bandwidth required for CORBA would not be prohibitive.

8. RECOMMENDATION

At this point in time, DATEX is recommended for deployment as the NTCIP Center to Center protocol in Colorado. The simplicity and ease of implementation are the primary considerations in this decision. The current status of the DATEX NTCIP protocol is further ahead than the CORBA version, which is another strong consideration. Further, the DATEX protocol will be able to be implemented by the developers at all sites without difficulty. The CORBA protocol has more unknowns and an increased risk during deployment.