PILOT Deployment of the Center-to-Center Reference Implementation C2C RI – TRANSCOM

FINAL REPORT

Prepared for

Federal Highway Administration

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Abstract

Understanding the Big Picture of Why Test C2C Deployments

Over the years, agencies have spent valuable resources building complex systems that seek to be able to communicate with other systems in the region. However, these legacy systems cannot communicate with each other because the format of the messages are either proprietary or are non-standardized in structure. Therefore, in order for centers to exchange information, dedicated data translation software is needed to facilitate this critical exchange of information. This requires additional operations and maintenance efforts for this dedicated software.

As demand for the exchange of this information increases, the systems will become more complex and reliant upon each other. These two challenges have brought about a need for a standardized message format that each system can share.

The USDOT's ITS Standards Program has recognized this dilemma and has taken the proactive step to work with standards development organizations (SDOs) which include technical experts, deployers and systems integrators, representing both public and private entities on a standards based solution that can be applied to these legacy systems in the hopes of facilitating greater communication between systems.

ITE, AASHTO and NEMA have been assigned the task of developing standards for communication between centers (center to center).

This work has been highlighted by the creation and ongoing support of the Traffic Management Data Dictionary (TMDD) and the National Transportation Communications for ITS Protocol (NTCIP) 2306 XML. However, the one thing that these standards have not addressed up to this point is, how are systems to be aligned, or, "*conformant*" to the various ITS standards?

Case Study of TRANSCOM C2C Deployment

The Federal Highway Administration (FHWA), through its participation in the standards development efforts, as well as oversight of numerous systems integration projects throughout the country, identified the need for a tool that would allow agencies to assess the level of conformity with the TMDD standard for their systems.

In 2015, the FHWA sought participants willing to work on a project with FHWA and the Center to Center Reference Implementation (C2C RI) Maintenance Contractor and project development team to support the configuration and testing of a tool to test system conformance to ITS standards.

This project would include two distinct parts. First it would address the training and implementation of the C2C RI tool with an agency's data exchange system. Second, it would ascertain that the

requirements necessary to interface with the C2C tool, as well as, the review and implementation of any system changes are defined from the test results of the C2C tool.

In the northeast, the Transportation Operations Coordinating Committee (TRANSCOM) and its member agencies faced a problem that was uniquely aligned with what the FHWA had recognized.

One of TRANSCOM's roles is to be a repository and distribution point for data exchange between member agency disparate legacy systems and the need to support regional technology efforts such as integrated corridor management and active traffic management initiatives. In TRANSCOM's effort to align these systems to better communicate with each other, they built a system called the TRANSCOM *Middleware* system. The overall goal and output of this system would be to help standardize the messages from these legacy systems and to share this data to support these ITS initiatives as well as share the data between the 100+ operations centers located at a wide range of multimodal agencies in the New York/New Jersey/Connecticut three state region.

These circumstances presented both parties the unique opportunity to test the FHWA C2C tool to assess the conformance of TRANSCOM's Middleware system at both the Information layer and Application layer together.

Thanks to the coordinated efforts of FHWA and TRANSCOM, the testing of the TRANSCOM Middleware system using the C2C RI tool has been tested successfully. During the testing process, we were able to answer the following questions (objectives):

- Is the TRANSCOM Middleware system conformant to the TMDD v3.03c and NTCIP 2306 XML v1.69 standards?
- Is the C2C RI tool v1.07 deployable? Can it work with NRTM (TMDD) and PRL (NTCIP 2306)?

Both questions have been answered "YES" by testing the TRANSCOM Middleware system with the C2C RI tool.

This report will supply pertinent, usable information to readers so that they can understand what is needed to utilize the C2C RI tool to answer similar questions about their own systems.

Overview of Project Testing Activities and Findings Outcomes

In five chapters, this report hopes to convey the following activities that occurred at the TRANSCOM testing site, described in the order, starting with:

1. Training Session on March 21, 2016
2. Pre-test Activities
3. Conformance Test 1 on April 22, 2016
4. Post-Test Activities for Conformance Test 1 as well as Pre-Test Activities for Conformance Test 2

5. Conformance Test 2 on August 9, 2016
6. Test results and conclusions reached that day

This report will also present what worked, what didn't work and outline the key issues identified through the testing process aligned with the TRANSCOM NRTM, the Test Plan, the Test results, the Anomalies and impacts. It will also highlight the resolutions.

The C2C RI tool does *not* support testing for Owning Center's Extensions.

Five key discoveries we found that would enhance the future use of the C2C RI tool:

- The initial use of the C2C RI tool proved to be a valuable validation of several components of the TRANSCOM Middleware system. However, based on an iterative dialogue between the C2C RI Maintenance team and the TRANSCOM Team, several "bugs" were discovered and addressed. This collaborative approach led to the development of a more user friendly product that will provide significant benefits to future users of the tool. In addition, it also provided critical feedback to FHWA and the C2C RI Maintenance Contractor for future iterations of the tool. (i.e. v2.0 and beyond)

- As future owning operations centers begin to use the C2C RI tool to test their system, they should remain flexible to making modifications to their system(s) to proceed with the C2C RI tool testing process.

- The owning operations centers should plan to allocate resources and support from in-house staff or contracted support; to prepare for the test, conduct the test, interpret test results and possibly schedule additional Conformance tests based on their specific results.

- The TRANSCOM Middleware system testing also discovered:
  - what steps users (TRANSCOM) must take to conduct follow up testing;
  - what updates the C2C RI Maintenance Contractor tool developer must do to address TMDD related bugs.
  - what SDOs (ITE-AASHTO-NEMA) must do to correct conflicts/discrepancies in both TMDD v3.03c at the Information layer and NTCIP 2306 XML v1.69 at the Application layer to make (foster use of) standards usable for interoperability.

For the C2C Testing process to be successful, it will require teamwork and close coordination among stakeholders, in-house technical support, contracted system developers to resolve local system issues.

Recommendations

Recommendations are organized below. They are broken out by specific user group.

For FHWA/C2C RI Tool Developers

Based upon the testing and lessons learned during the initial testing of the C2C RI tool against the TRANSCOM Middleware system, it is suggested that C2C RI tool be made available through a secure web portal. Items to be included, along with the C2C RI tool itself, should be installation guides, case studies, user and training manual and all appropriate testing requirements for IEEE 829-2008.

- FHWA should consider providing an extended tool for testing communications capability for NTCIP Center to Field (C2F) devices such as DMS, ESS, CCTV etc. as part of development stage and further added value. This will work towards fostering the use of standards as well as ease of the testing process and IEE 829-2008 formats.

For Standards Developing Organization (SDOs): ITE/ASSTO/NEMA

- ITE/AASHTO as concerned SDO for TMDD should consider addressing the issues found at TRANSCOM testing site while using TMDD v.3.03c. Should future updates to the TMDD be released, the comments listed below should be considered:

- Modification needed: At this time, NTCIP 2306 requires that the SOAP Subscription use both Subscription-Publication and Request Response messaging. TMDD only requires Request Response Messaging. This finding was discovered during the TRANSCOM Conformance Testing process as TRANSCOM has implemented Request Response Messaging only. As an outcome of the conformance testing process, TRANSCOM suggests that the SDOs consider modifying the standard to make SOAP requirements as OPTIONAL for Subscription-Publication.

- Correction needed: Currently, TRANSCOM uses the TMDD “dl” style for dialogs in the WSDL, while NTCIP 2306 v1.69 specifies the prefix “OP_” for dialogs. This inconsistency results in the C2C RI failing one of the NTCIP 2306 requirements. We recommend that the SDOs documentation be updated to work around this.

- Guidance needed: Definition or direction is needed to articulate what defines conformity. Is this a percentage of passed tests, or, is there criteria that is being considered to meet the conformance accreditation?

- Recommendation: As illustrated through the testing of the C2C RI Tool, where a conflict between TMDD v3.03c and NTCIP 2306, of the two standards were discovered, as noted above, TRANSCOM is suggesting a follow up test between

two Owning Centers that have successfully passed the conformity test of the C2C RI Tool. The purpose would be to conduct a follow up test to verify the ability to freely exchange data between the two Owning Centers.

For C2C Deployment and Testing Locations

- Testing Site Preparation: Assemble testing documentation beforehand. Have copies of the Test Plan, NRTM, TMDD v3.03c, NTCIP 2306 v1.69 ready and available. Also, set up the test laptops to act as External Centers with secured power sources as well as the Native system interface (like Middleware). Rehearse with the testing engineer to ensure the smooth function and plan for any unanticipated results.

- As a pre-test activity: A thoroughly developed and vetted NRTM is critical aspect to the pre-test activity. Once agreed upon, ensure that you secure in-house and or contracted.

- Be sure to allocate sufficient time and resources to make changes identified during the testing process to the affected agency systems, should additional tests be needed.

- Use the available C2C RI tool (now v1.07.) Take full advantage of the readily available FHWA tools and supporting documentation instead of developing a costly testing tool.

- It is recommended that all testing results, log files and other documents be stored on a dedicated testing computer. All logs reports must be signed (Passed-failed) by your test engineer. Additionally, hard copies of all test results and other documents should be generated for storage and submittal to any applicable parties. These could be, but not limited to: FHWA, Owning Centers and or any other pertinent parties that may be needed for billing or contracting purposes.

Conclusion

The TRANSCOM Middleware system was tested by the C2C RI Maintenance Contractor with representatives and staff from the FHWA, TRANSCOM, and NJDOT present.

The test engineer used the C2C RI tool v1.0.7 to test conformity of the TRANSCOM Middleware system against TMDD v3.03c and NTCIP 2306 v1.69.

Two conclusions were identified:

- *The TRANSCOM Middleware system is conformant with TMDD v3.03c.*
- *The TRANSCOM Middleware is conformant with NTCIP 2306 v1.69, acknowledging that TRANSCOM uses the TMDD 'dl" style for dialogs in the WSDL, while the NTCIP 2306 Specifies the prefix 'OP_' for dialogs. This difference in dialogs causes the NTCIP 2306 v1.69 standard to be in conflict with TMDD v.3.03c. (A Suggested resolution was identified in the five discoveries listed above.)*

List of Acronyms

This report contains a significant number of acronyms. We have added the list of acronyms at the beginning of the report in order to provide the reader with a quick reference guide.

AASHTO	American Assoc. of State Highway and Transportation Officials
API	Application Programing Interface
C2C	Center to Center
C2F	Center to Field
C2CRI	Center to Center Reference Implementation
DMS	Dynamic Message Sign
EC	External Center
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
FHWA Maintenance Contractor	Transcore
FHWA Technical Advisor	NOBLIS
FHWA Test Engineer	ConSysTec
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
NEMA	National Electrical Manufacturers Association
NRTM	Needs to Requirements Traceability Matrix
NTCIP	National Transportation Communications for ITS Protocol
OC	Owning Center (Native System)
PRL	Protocol Requirements List
SDOs	Standards Developing Organizations
SUT	System Under Test
SOAP	Simple Object Access Protocol
TMDD	Traffic Management Data dictionary
TRANSCOM	Transportation Operations Coordination Committee
TRANSCOM Team	TRANSCOM Staff, Infosenseglobal (Middleware Developer)

USDOT	United States Department of Transportation
XML	Extensible Markup Language
WSDL	Web Services Description Language

1. Introduction

1.1 Purpose of this Report

This final report for the project called *Pilot Deployment of the Center-to-Center Reference Implementation* (DTFH6116H00005) aims to describe the activities, proceedings and processes used to test conformance of the TRANSCOM Middleware system to the TMDD v3.03c and the NTCIP 2306 XML v1.69 system interface standards using C2C RI (Center to Center Reference Implementation) testing tool. It also covers the interpretations and decisions made relative to the use of these standards and the testing tool, and provides a set of recommendations as to how the process may be further improved to refine the use of the tool and the testing methodology.

The report provides background on FHWA's efforts to develop a Center to Center (C2C) tool that enables agencies and system developers to test and validate conformance to the Traffic Management Data Dictionary (TMDD) and the National Transportation Communication for Intelligent Transportation Protocol (NTCIP) 2306 XML and standards. FHWA also undertook an initiative to deploy the tool and use it to test conformance and validate operational messages (using TMDD) in the real-world environment at TRANSCOM.

The purpose of this report is to convey information to interested parties, system developers and implementers as pertains the activities undertaken (e.g. pre-test preparation, extensions handling etc.) by the C2C RI Maintenance Contractor for the System Under Test (SUT)-TRANSCOM Middleware system, and to document the key findings (what worked-what didn't), share lessons learned and present recommendations to FHWA, SDOs (Standards Developing Organizations), transportation agencies, system developers and testing professionals.

Additionally, the content and references provided by the report will aid in the future C2C testing efforts to assess the testing resources needed and the C2C expertise support needed to prepare a thorough NRTM and SUT set up, and prepare a testing schedule, including all after test activities like system modifications. This will help to successfully complete the C2C testing for compliance to both of the standards. The report will help create a better understanding of the need to be flexible to allow potential modification of the native system environment subject to initial test results.

The following two bullets document the two active projects by FHWA and TRANSCOM. Based on these parallel efforts, a unique opportunity came together to facilitate and conduct conformance testing for the applicable standards.

- **Development of a C2C System Testing Tool**: Center to Center Reference Implementation (C2C RI v1.07) testing software tool was developed by the FHWA to test and validate a user supplied Needs to Requirements Matrix (NRTM), a component of the TMDD

standard. Each C2C system has its own native NRTM derived from the standard and outlines user needs/requirements for request-response messages among centers.

- **Deployment of a C2C RI Tool and Conformance Testing of the TRANSCOM Middleware system using the C2C RI Tool:** TRANSCOM Middleware system, which was completed in 2015, is the preferred interface to exchange data between TRANSCOM and all of its affiliated operations centers using TMDD v3.03c and NTCIP 2306 XML v1.69 standards-based communications interface. This system is driven by the TRANSCOM NRTM that covers the C2C messages such as center active verification, organization, node inventory, node status, link inventory, link status, route inventory, route status, DMS Inventory, DMS Status, CCTV, event information and event action logs. The system deploys TMDD v3.03c at the Information Layer and NTCIP 2306 XML v1.69 at the Application Layer Web Services.

1.2 Development of the Center-to Center Reference Implementation (C2C RI) TOOL

FHWA fully supported the C2C RI tool as a way to promote the wide-scale deployment of the TMDD v3.03c and NTCIP 2306 v1.69 XML standards. The tool would verify a target system's conformance to designated Intelligent Transportation System (ITS) C2C standards. Furthermore, it would also provide a consistent and repeatable approach to verifying a target system's implementation of the standard.

FHWA also recognized the need to conduct a pilot deployment test in order to validate the C2C RI tool and to document and develop "lessons learned" while testing in a real-world operational environment where centers were attempting to communicate with each other using TMDD and NTCIP standards.

Benefits of the C2C RI Tool

- Improves the efficiency of system data exchange and development.
- Allows for a uniform data exchange protocol test tool between disparate systems. These systems may have been developed, operated and or maintained by more than one vendor.
- Stratifies data interpretation tasks when interfacing between systems. Allows the C2C RI tool to arbitrate system modification disputes between disparate vendors.

1.3 C2C Deployment at TRANSCOM

TRANSCOM is a coalition of 16 transportation and public safety agencies in the New York – New Jersey – Connecticut metropolitan region located at Jersey City, NJ. It was created in 1986 to provide a cooperative, coordinated approach to regional transportation management. As a successful regional leader in information sharing and coordination, TRANSCOM has developed a gateway to their systems called the TRANSCOM Middleware system. The purpose of the TRANSCOM Middleware system is to improve the mobility and safety of the traveling public by supporting its member agencies through interagency communication and the enhanced utilization of their existing traffic and transportation management systems. Figure 1 below shows TRANSCOM's System Architecture - Middleware and other native systems.

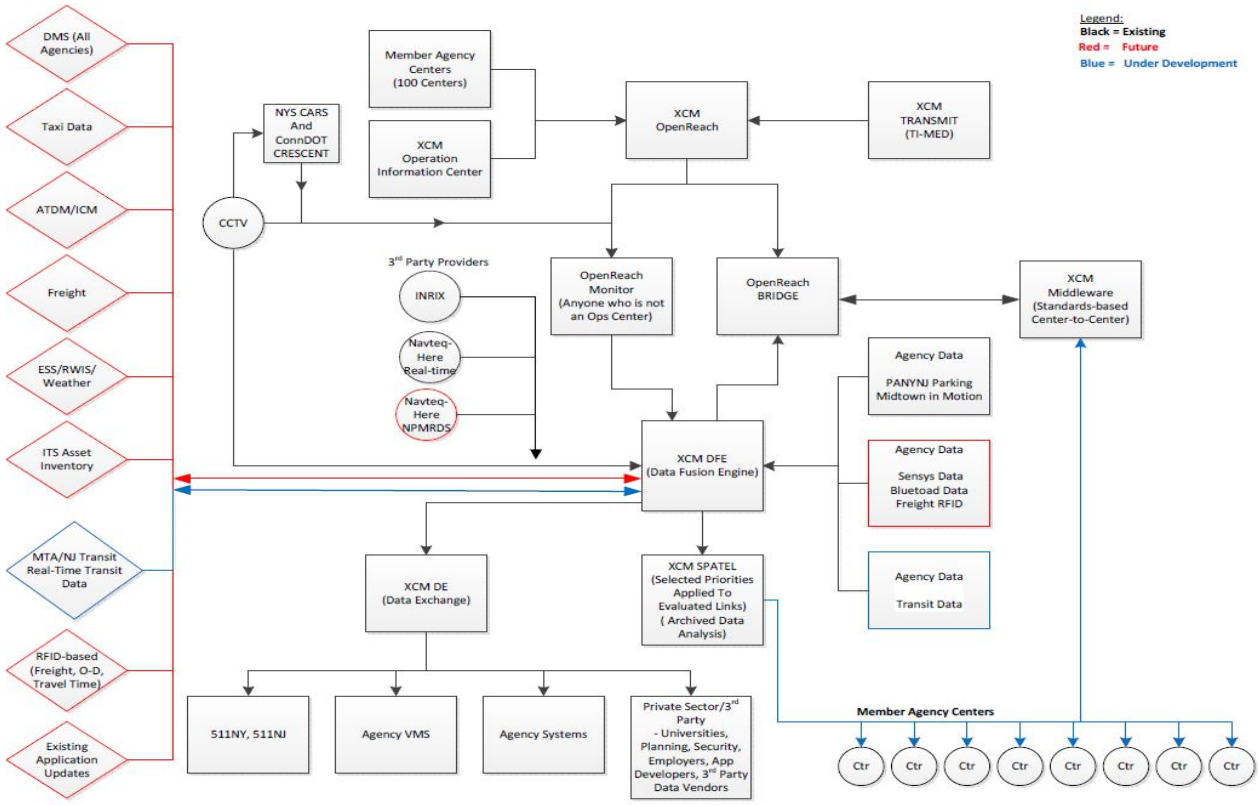

Figure 1: TRANSCOM System Architecture - Middleware and other native systems

1.4 C2C RI Tool Testing Process

Figure 2 below, provides an overview of the process that has to be followed for the C2C tool test to ensure overall testing objectives of checking the efficacy of the C2C RI testing tool in the real-world C2C deployment test of the TRANSCOM Middleware system. This testing experience and resulting lessons learned will shed light to other agencies and developers who can readily adopt and freely use the available tool to test their NRTM and NTCIP 2306 XML standard without having to develop their own costly testing tools.

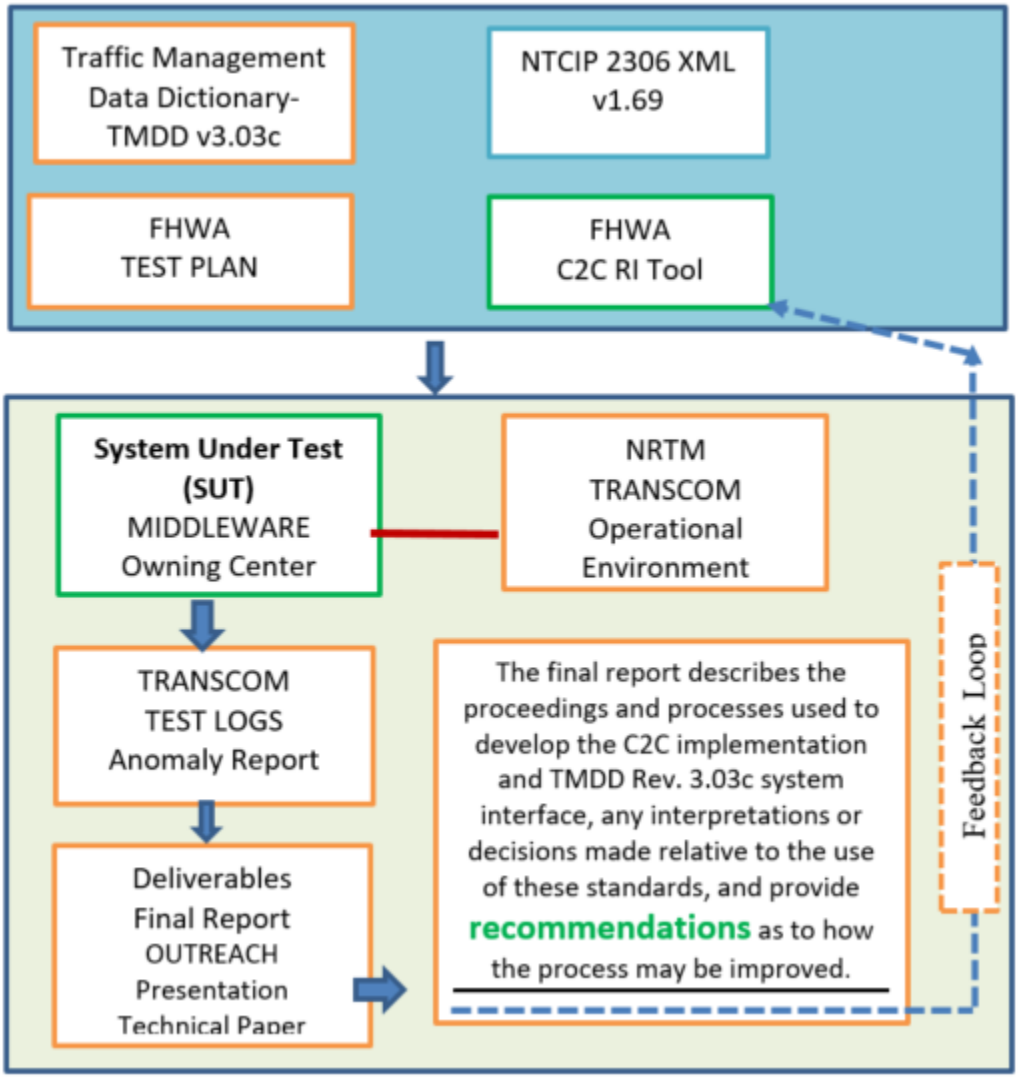

Figure 2: C2C Overview of the C2C RI Testing Tool Process

Under the terms of the agreement with FHWA, the TRANSCOM team would support the initial testing, make modifications to the TRANSCOM Middleware system as defined by the test results. This support would continue should any supplemental tests need to be conducted on the TRANSCOM Middleware system.

The C2C RI tool facilitates the validation of conformance to both standards; an achievement of national significance for real-time communication among transportation agencies.

On August 9, 2016 TRANSCOM successfully completed the conformance testing of their Middleware system using C2C RI testing tool (v1.07).

- Note that the C2C RI tool has built-in test cases and procedures to test a native system.
- TRANSCOM Extensions were not tested for functionality usage. However, the tool did confirm the sequence or placement of extensions were in order.

2. C2C Deployment Testing Methodology and Test Environment

2.1 General Background

Through their efforts to implement the TRANSCOM Middleware system, the TRANSCOM Team (includes Infosenseglobal) went through an iterative set of tests using the existing off-the-shelf product (SOAP UI) to assess and verify that the TRANSCOM Middleware system was generating and ingesting the appropriately structured messages.

As noted in the Introduction, the project testing methodology included two conformance tests. Conformance Test 1 used the agreed upon TRANSCOM Middleware NRTM matrix and the approved test plan to configure the FHWA C2C RI tool and allow communications with the TRANSCOM Middleware system. Testing was performed by the FHWA C2C RI Maintenance Contractor using the FHWA C2C RI tool.

The goal of Conformance Test 1 was to assess the conformance of the TRANSCOM environment via the TRANSCOM Middleware system with the TMDD Rev. 3.03c Standard and NTCIP 2306 v1.69.

Based on the results from Conformance Test 1, a second "Conformance Test 2" was conducted. Updates that addressed these findings were made to the TRANSCOM Middleware system per results that were generated from the C2C RI tool in Conformance Test 1. As part of the update process, TRANSCOM documented all the system updates and the reasons for making them so that other system integrators in the future may be made aware of the types of activities and changes to be expected when conducting systems testing via C2C RI tool.

The iterative testing processes from Conformance Test 1 and Conformance Test 2 formed a methodology that illustrated the approach to carrying out the necessary pre-test preparation to be ready to use the C2C RI tool, make modifications to the NRTM, perform system updates and generate the follow up analysis through the C2C RI tool as intended.

The testing was completed based upon the C2C RI – TRANSCOM Deployment Test Plan had been developed in accordance with their existing standards that define the content and processes for test documentation. The IEEE Std 829-2008, IEEE Standard for Software and System Documentation. IEEE Std 829-2008, provides a comprehensive overview of the processes and documentation for testing.

During the collaborative development process, the following sections highlight key areas that required discussion and consensus in order to ensure that all parties were in agreement regarding the methodology of how both Conformance Test 1 and 2 were to be conducted and the interpretation of the results of these tests.

For a complete list of items that were addressed during this process as well as the official Test Plans, see Section 6, C2C References and links.

2.2 Approach

Testing was carried out in a two-phase process. The phases for testing are described as follows:

- **Pre-test Test Phase.** The pre-test test phase verified that the TRANSCOM Middleware WSDL was correct, and that the C2C RI and TRANSCOM system were able to connect and exchange messages, prior to the commencement of the Conformance Test phase. The pre-test phase ensured that the center being tested had the ability to send and receive each message in accordance with the WSDL that was being specified. A limited number of test cases were identified. At a minimum, these included the test cases for: Center Active Verification, Node Inventory, and Link Inventory.
- **Conformance Test Phase.** The Conformance test phase ensured that for the center being tested, the full set of requirements specified by the TRANSCOM Middleware NRTM were fulfilled, and that the messages sent conformed to the requirements of TMDD v3.03c and NRTM v1.69. This included testing of error handling by the center.

The TRANSCOM Middleware system conformance test was conducted twice. The period between the two tests allowed for the C2C RI Maintenance Contractor and/or TRANSCOM Team to make any applicable adjustments to their respective systems based on the outcome of the test.

2.3 Item Pass-Fail Criteria

The C2C RI tool determined whether a test case had passed or failed. The pass/fail results were recorded in an automated test log which was generated from the C2C RI tool during testing. In the event a test case failed, a test anomaly report should be completed.

The test anomaly report should indicate whether the anomaly identified pertains to:

- TMDD v3.03c
- NTCIP 2306 v1.69
- C2C RI
- TRANSCOM Middleware system
- Operator Error

2.4 Suspension Criteria and Resumption Requirements

During the TRANSCOM Middleware system test, the following test case dependencies were identified:

- All test cases were dependent on the WSDL SUT test case. NOTE: An anomaly in the way that TMDD references a NTCIP 2306 requirement would ensure that one of the WSDL SUT tests procedures shall fail, that being the test for the prefix "OP_" in the names of all operations defined in the WSDL. All other test procedures of the WSDL SUT must pass prior to the start of any other test cases.
- The Information Layer Test Cases were not dependent upon passing of the WSDL SUT test (Application Layer Test Cases).
- All other test cases were unrelated and do not depend on each other. If a test case failed, another may commence.

A test case may fail, but the parties present may determine that a parameter was not set properly (for example a password or username has been misspelled). In this case, a test case that has failed may be run again.

If the problem was likely to be caused by a problem that requires a software modification, the test case remains as failed, but the testing may continue in accordance with the dependency rules outlined at the beginning of this section.

2.5 Test Deliverables

The following identifies the documents that were required to be available to conduct testing of the TRANSCOM Middleware system.

- Test Plan
- Test Case Specifications (managed within the C2C RI)
- Test Procedure Specifications (managed within the C2C RI)

The following identifies documents that were required to be available after testing was conducted on the TRANSCOM Middleware system:

- Test Anomaly Reports
- Test Summary Report (Provided by C2C RI)
  - Configuration Detail Report (includes Test Case Traceability)
  - Conformance/Compliance Report
  - Test Case Summary Report

- Test Case Detail Report
- Message Summary Report
- Message Detail Report

The following identifies documents that should be available, but not required:

- TMDD V3.03c
- NTCIP 2306 v1.69
- C2C RI User Manual

2.6 Environmental/Infrastructure

In order to conduct the testing, a set of environmental needs had to be identified to ensure testing could start and progress smoothly and consistently as possible. These needs are outlined below:

- **Test Laptop.** The test laptop will need to be configured to serve as a virtual external center, and be configured to: a) send and receive messages to/from the TRANSCOM Middleware system; and b) contain test software necessary to execute tests and verify conformance with standards.

- **Test Software.** The laptop was also configured with most recent version of the C2C RI tool, prior to the test to reflect the needs and requirements identified in the TRANSCOM Middleware system NRTM – 2016. Note that two versions of the C2C RI tool were used for Conformance Test 1 and Conformance Test 2.

- **Test Facility.** A test facility, for example a conference room, was located at the owner center (TRANSCOM Offices) with sufficient room for all test equipment and staff. It was desirable for the owner center to have the capability for remote access into the system to facilitate pre-configuration of test software ahead of formal testing. The test facility had a comfortable table and chairs for 6 persons (2 test engineers, 2 owner center staff, and 2 system contractor staff). Table space was required within the test facility for the test laptop, and test documentation. The test facility provided a projector to allow clear view of the test laptop display during testing. The test facility had a laptop projector system, however, if yours does not, the test engineer may provide a projector. (Though not required, if the owner center staff would like to include staff that are remotely located, they may provide a teleconference/webinar capability so remote staff may participate or witness the test.)

- **Network Connection to the TRANSCOM Middleware system.** The test facility had a network connection and security access for the test laptop to communicate with the SUT.

- **Block Diagram of Test Equipment and System Under Test.** The block diagram below shows the relationship of the test laptop that ran the C2C RI tool to TRANSCOM Middleware system.

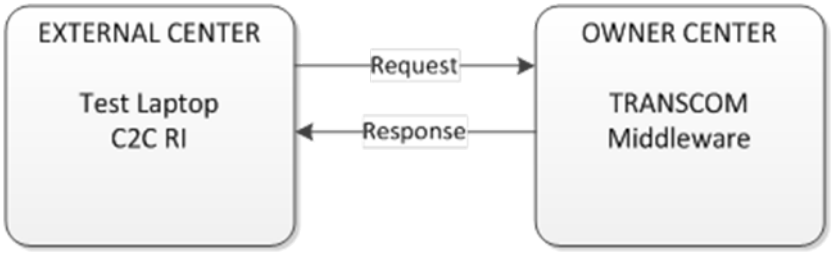

Figure 3: Configuration of Test and System Software for C2C RI – TRANSCOM Deployment Testing

2.7 Responsibilities and Authorities

The following staff roles and responsibilities applied to this set of tests:

- **FHWA Test Observers:** These are the FHWA representatives/contractors who witnessed and provided advice and guidance during testing. They also provided feedback back to FHWA C2C RI Maintenance Contractor regarding potential changes required in the C2C RI tool and to the SDOs.
- **FHWA C2C RI Maintenance Contractor:** These are FHWA representatives/contractors who configured the C2C RI test software, performed tests, identified anomalies, generated anomaly reports and generated the C2C RI test reports.
- **TRANSCOM Project Manager:** This is the staff member from TRANSCOM or designated representative that authorized, witnessed, and approved the test results.
- **TRANSCOM Center Staff:** These are the staff of the organization that provided the system under the test. They were responsible for securing an adequate test facility, and were present during testing.
- **TRANSCOM Contractor Staff:** These are the contractors who developed the TRANSCOM Middleware system operated by TRANSCOM. They were responsible for resolving any issues which arose during testing and reported them as an anomaly in the test anomaly report.

2.8 Interfaces Among the Parties Involved

The means of communication between the individuals from organization involved in the testing is shown in the diagram below (Figure 4).

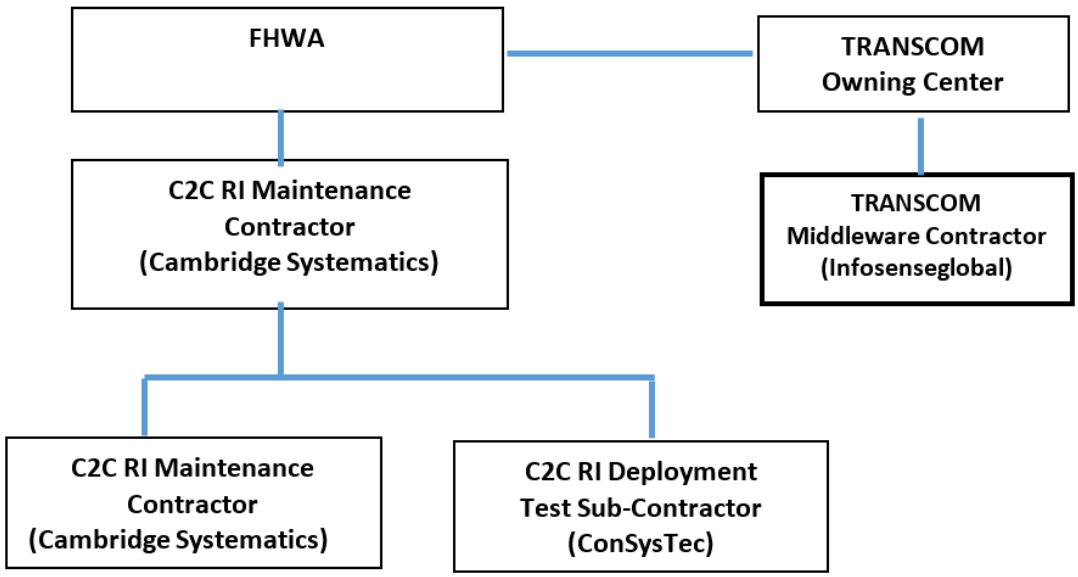

Figure 4: Team Communications Pathway

2.9 Risks and Contingencies

The risks of this testing process impeding the system under test's operations were minimal. The test cases involved a series of requests for information – no new information was being added to the SUT. There were no modifications done to the TRANSCOM Middleware system during testing. Updates to correct anomalies occurred outside of testing and in accordance with the TRANSCOM's methodologies and procedures.

2.10 Training for Testing Process Requirements

Training for the C2C RI – TRANSCOM Middleware system test was expected to take a full day. Training included:

- C2C RI Project Overview
- Center-to-Center Reference Implementation (C2C RI) Overview
- TRANSCOM Systems Overview

- Walkthrough of TRANSCOM User Needs
- C2C RI tool User Training
- Hands-On Training and Demonstration

3. Testing Process Activities and Findings

3.1 Introduction

This section presents a summary of the three key activities that occurred during the C2C RI tool testing at the TRANSCOM Offices including the training session prior to the preparation for the testing process on March 21, 2016, for Conformance Test 1 on April 22, 2016, and for Conformance Test 2 on August 9, 2016.

The purpose of the section is to provide essential information in the form of a summary for each activity to highlight key issues and findings discovered, and document suggestions that were made by the team and actions taken by concerned parties. Coverage is given to testing process, and test results. Details on each activity are well-documented and presented in Section 6, C2C References and links.

3.2 Summary of User Training Session

3.2.1 Participants

Owning Center operation and system staff (TRANSCOM), C2C RI tool developers and FHWA team, and testing engineer and his team, and the TRANSCOM Middleware system developer, Infosenseglobal.

Agenda:

- Project Training
- C2C RI Overview
- TRANSCOM System Overview
- Walkthrough of the TRANSCOM TMDD System Requirements (NRTM)
- C2C RI User Training
- Hands-on Training & Demo

The following sections presents the summary of training session.

3.2.2 Key Findings from Training Sessions

- The current version of C2C RI tool does not support validation for section 1201, Therefore we did not test TRANSCOM TMDD for section 1201 conformance.

- The Test Engineer performed a walkthrough of the TRANSCOM NRTM. He has provided the user training followed by a hands-on training for C2C RI testing tool.
- The TRANSCOM NRTM was used for this project.
- Test cases generated by the C2C RI testing tool were considered as test cases for the C2C RI tool project testing work.
- The C2C RI testing tool is considered a TMDD *conformance* tool and not a TMDD *compliance* tool.
- The current version of the C2C RI testing tool did not support testing for TRANSCOM TMDD extensions. So TRANSCOM TMDD extensions were excluded from this testing.
- The C2C RI testing tool was considered as an external center.
- The dialog naming conventions in TMDD v 3.03c and NTCIP 2306 v 1.69 did not match. For example: TMDD dialog name: dlDialogName; NTCIP dialog name; OP_DialogName. TRANSCOM has implemented TMDD dialog name (dl) semantics.

3.2.3 Discussion on the Benefits of the C2C RI Tool noted during C2C RI hands-on training

- The C2C RI tool could streamline user testing time and effort by automating the TMDD conformance testing process.
- The C2C RI tool can provide a consistent testing approach across the multiple TMDD implementations as it generates automated test cases which will be uniform as long as requirements match.
- The C2C RI tool can provide a platform to test both TMDD and NTCIP standards in one place**.** It can also provide easy to use NRTM configuration options as per user testing needs.
- It provides the capability to view checksum and ensures that configurations are not changed as compared to previous testing cycle runs.

3.2.4 Discussion and Suggestions to FHWA/C2C RI Tool Developers

- The TRANSCOM Middleware system is secured by a username and password authentication. TRANSCOM TMDD request messages require a username and password along with other request parameters. The C2C RI testing tool does not provide a system level general configuration option to pass the username and password for TRANSCOM TMDD messages. In order to test the TRANSCOM

Middleware system, individual C2C RI test cases had to be modified by inserting a username and password. This was a tedious testing process from an end-user point of view. In order to make the C2C RI tool user-friendly, TRANSCOM suggested to provide a system level configurable option to pass required authentication. In addition, the C2C RI tool should implicitly apply user provided authentication details to all request messages/test cases.

- Currently, the C2C RI testing tool does not provide an option to test TMDD extensions. This could be desirable in future testing.
- As a part of the testing process, it was discovered that the C2C RI testing tool requires a WSDL to match NTCIP 2306 specifications. This should be conveyed as well as pre-requirements to the end user community
- While configuring the information layer test cases during training with the C2C RI tool, the Test Engineer tried to edit the source path of the test case file and clicked the "Save" button in C2C RI testing tool. It did not save user changes.
- In a second try, the Test Engineer repeated the same action, clicked on another row in the data grid (just to give it a try) and then clicked "Save" the button. This resolved the issue.
- The C2C RI testing tool should display more user-friendly error messages instead of code level exception messages. More technical error details can be displayed on further user actions.
- The C2C RI testing tool should provide a reporting option to generate test script *only* for user selected needs from the NRTM. Currently, it generates test scripts for *all* TMDD needs irrespective of user selected needs.
- The C2C RI testing tool should provide an option to print a user manual or alternatively be supported by a separate PDF copy of the user manual.
- The C2C RI testing tool should include access to user manuals with hands-on training videos. This will help to make it more user friendly.

3.3 Summary of Conformance Test 1 Conducted on April 21, 2016

3.3.1 Pre-testing Activities Performed and Changes Made to the TRANSCOM Middleware system

The following is a high-level snapshot of tasks that were completed prior to the start of Conformance Test 1. To view the full documentation of the Pre-test activities as well as the changes that were made prior to the Conformance Test 1, please see Section 6, C2C References and links.

- Acquire and Install the C2C RI.
- Acquire Connection Parameters for SUT.
- Configure the C2C RI with Connection Parameters.

3.3.1.1 Execute Test for WSDL Conformance

- The C2C RI tool requires a WSDL to be in conformance with NTCIP 2306 v 1.69. We have modified the TRANSCOM Middleware system to use a WSDL which is in conformance with NTCIP 2306 v 1.69. The Middleware system uses both standards (TMDD and NTCIP 2306).
- The original build of the TRANSCOM Middleware system used an extended version (tailored version) of TMDD schema. The C2C RI tool requires a standard TMDD schema to be used irrespective of the extension added to the original TMDD schema; and suggest to add each extension under another namespace. The C2C RI tool will ignore validations for all those elements as it is defined as processContents="lax" in TMDD schema. The TRANSCOM Team modified the TRANSCOM Middleware system to use the standard TMDD schema to be referenced from the WSDL file.
- Added a SOAP Action in the WSDL to distinguish the actual request message. e.g. Node Inventory, Node Status, Link Inventory, Link Status, Route Inventory and Route Status share a common request message called “Traffic Network Information Request”. The TRANSCOM Team also added different SOAP Actions for each method which is in conformance with NTCIP 2306 v 1.69. The SOAP Action had to be in a URL format as per NTCIP 2306 v 1.69.
- NTCIP 2306 v 1.69 requires all messages to have <soap:Header> tag included in it. Prior to the test, all versions were not validating the SOAP Header conformance. In order to use the C2C RI tool for Conformance Test 1, the TRANSCOM Team added an empty <soap:Header /> tag in each IN and OUT messages from the TRANSCOM Middleware system.

3.3.1.2 Execute Test for Center Active Verification

- The TRANSCOM Middleware system is secured and one has to provide a valid user-id and password in order to request the information. As the C2C RI generates test cases based on NRTM configurations, the Test Engineer was not able to control the attribute values to be passed into the request messages. As a result, the TRANSCOM Middleware system sends an authentication not recognized error report back to the C2C RI tool. Working with the C2C RI Maintenance Contractor, we were directed to implement the following to address the required username and password functionality.

```
#PARAMETER TYPE = String
#EDITABLE = true
#DOCUMENTATION = tmdd:centerActiveVerificationRequestMsg.authentication.user-id
tmdd:centerActiveVerificationRequestMsg.authentication.user-id = newUser

#PARAMETER TYPE = String
#EDITABLE = true
#DOCUMENTATION = tmdd:centerActiveVerificationRequestMsg.authentication.password
tmdd:centerActiveVerificationRequestMsg.authentication.password = newUser
```

- Once the message string was added to each test case, a valid test message was passed from the C2C RI tool into the TRANSCOM Middleware system.
- When the Test Engineer tried to run a valid center active verification test from the C2C RI tool, it was discovered that a data type and enumerations mismatch for center-type attribute under centerActiveVerificationRequestMsg.organization-requesting.center-contact-details occurred. The TRANSCOM Middleware system was modified to handle this error.
- The C2C RI tool automatically generates all valid (positive) and invalid (negative) test cases based on the configured NRTM. The Test Engineer observed that for invalid test cases, the tool deliberately generated invalid XML request files having any one of the following:
  - With wrong request message name
  - With restricted character set as a parameter values
  - With missing attributes
  - With out of range attribute values
  - With invalid user-id and password
  - With Valid user-id and password that does not have privileges to access the messages

  A few of these messages have been handled correctly by the TRANSCOM Middleware system but certain test cases were failing. Based on feedback from the C2C RI Maintenance Contractor, TRANSCOM Team modified the TRANSCOM Middleware

system to handle all TMDD defined error message as a request message from the C2C RI tool.

3.3.1.3 Execute Remaining Test Case Groups

- The C2C RI tool requires standard TMDD schema to be used regardless of the extension added to the original TMDD schema and suggest to add each extension under ##other namespace. The C2C RI tool will ignore validations for all elements defined as processContents="lax" per TMDD schema.
- Lastly, as part of the Pre-test activities, it was discovered that the TRANSCOM Middleware system was not configured to handle extensions as defined in TMDD and validated through the C2C RI tool. The TRANSCOM Team agreed to update the extensions in the TRANSCOM Middleware system as per TMDD standards in order to validate against the C2C RI tool. This issue was vetted and agreed by all parties to be excluded from Conformance Test 1 and will be addressed in the TRANSCOM Middleware system changes before Conformance Test-2 is scheduled.

3.4 Conformance Test 1 Findings

This section describes key activities of the testing process and outlines findings from the Conformance Test 1. A full report and list of documents are presented in Section 6, C2C References and links.

3.4.1 Preparation

On April 21, the Conformance Test 1 was conducted at the TRANSCOM Offices in Jersey City, NJ as outline in the approved Test Plan as noted in Section 2 above. Prior to initiating the test, a brief summary of the pre-test activities and findings were outlined for all attendees in order to ensure that all attendees were brought up to speed on the issues and resolutions that took place. The TRANSCOM Team agreed to provide anomaly reports for all findings in the pre-testing. The Testing Engineer also indicated that all of the test logs and test reports for all pre-test activities will be collected and will create a summary report.

3.4.2 Testing Process

The TRANSCOM Middleware system was tested in accordance with the Test Plan to evaluate conformance to TMDD v3.03c and NTCIP 2306 v 1.69, as noted in Section 2, above.

3.4.3 Findings from the Conformance Test 1

The following is a summary of findings from the Conformance Test 1:

- The C2C RI should enable the user to download and print-out Test Procedures and Test Cases to serve as proof of deliverables.
- TRANSCOM questioned the necessity of the "other" category within the list of the invalid categories of messages within the TMDD.
- During testing of the Node Inventory group, issues were identified and anomaly reports were generated concerning the C2C RI stripping off SOAP tags (headers, body, and envelope) associated with the TCS-10-dlNodeInventoryRequest-OC-Valid message. During troubleshooting, it was found that when two sets of SOAP tags were used in the configuration files, the test passed. The TMDD standard only requires one set of SOAP tags. Anomaly reports were generated and will be provided to the C2C RI Maintenance Contractor.
- In order to facilitate the filtering of data for the TRANSCOM member agencies, TRANSCOM was extending inventory request messages by adding state and facility tags as an extension. Even though the TMDD allows for extensions, it was never envisioned that requests would be extended. A collective examination of the TMDD elements took place to see if any other fields could be used that would allow TRANSCOM to serve its member agency needs as well as future ITS related needs. It was also discovered after looking at what was extended, TRANSCOM could use the existing TMDD fields for organizations or networks that do the same thing as the redundant extensions (identifiers for states and facility). The TRANSCOM Team agreed to rework the logic to use the network fields to limit the need for "extensions" in requests.
- During the node inventory request the user message content verification window in the C2C RI tool had rows that were highlighted in yellow while others were not. This issue was not defined in the C2C RI user manual.
- The TRANSCOM team noted that while using the C2C RI tool it would be helpful to add a window that displays the purpose of the Test Case.

- Testing was stopped in the *Link Inventory Request* group. Since no modifications had been made to the rest of the configuration files, the remaining group tests would have failed.

3.4.4 Remedial Actions Taken by the Team and Anomalies' Status from Conformance Test 1

The following was discussed after the test was terminated and necessary remedial actions were taken by the team.

TRANSCOM Team Action Items (As denoted in the Conformance Test 1 Anomaly Report)

- Change the logic in the request messages so extensions are not required.
- When extensions are used, TRANSCOM agreed it will follow TMDD/C2C RI extension tag. Extensions will only be used on response messages, if necessary.

C2C RI Development Team Actions Items

- Solve the SOAP tag issue as discussed above.
- Look into the "other" category of invalid messages to determine if it is a real issue or not.
- Look into why some rows in the "User Content Verification" windows were highlighted. Add an explanation in the User Manual.
- Include version control information for the C2C RI tool.
- Possibly add a Test Case Description window for each Test Case being run.
- Provide user access to printable Test Case Specifications and Test Procedures.

At the conclusion of Conformance Test 1, the TRANSCOM Team agreed to complete the modifications to the TRANSCOM Middleware system and the Test Engineer updated the NRTM. In addition, the C2C RI Maintenance Contractor agreed to update the C2C RI tool.

The consensus amongst the attendees of Conformance Test 1, was that these issues should be resolved. Once completed, the TRANSCOM Team and the C2C RI Maintenance Contractor requested permission to schedule a second Conformance Test 2. Understanding the significance of the efforts involved with the project, FHWA granted approval for the Conformance Test 2 and it was scheduled accordingly.

Lesson: Act fast. Keep an open-minded approach and work to resolve issues while the whole team is in one place.

3.5 Summary of Conformance Test 2

This section provides background regarding the updates conducted by the TRANSCOM Team based on the agreed upon action items denoted in the Conformance Test 1 findings summary which was conducted in April 2016. These findings, which were presented previously in this report, centered on a series of changes to the TRANSCOM Middleware system to accommodate how extensions should be handled to support both the design of the C2C RI tool as well as to align properly with the specifications of TMDD ver. 3.03c.

3.5.1 Pre-test activities for C2C RI Conformance Test 2 and changes made to the TRANSCOM Middleware system

Based upon the findings of Conformance Test 1, FHWA approved moving forward with the system update activities in order to conduct a system retest effort (Conformance Test 2). In parallel with the TRANSCOM Team activities, the C2C RI Maintenance Contractor undertook efforts to update the C2C RI tool per the findings from Conformance Test 1. It is important to note that these parallel actions occurred due to the ongoing upgrade of the C2C RI Tool. Under normal circumstances, end users performing conformance testing on their system would be following the iterative test process defined in Section Two above.

The TRANSCOM Team updated the TRANSCOM Middleware system to align its extensions to map directly with TMDD v3.03c since that is the only format that is operable with the current version of the C2C RI Tool. This change was applied to all messages that TRANSCOM utilizes for its environment that are exchanged.

Additionally, the TRANSCOM Team updated and verified that this schema change was applied to the WSDL file for each response dialog. For all request messages, the TRANSCOM Team also removed the extension requirement from the TMDD messages to support the C2C RI Tool.

A detailed description of the activities conducted by the TRANSCOM Team on the TRANSCOM Middleware system is provided in the “Pre-test activities performed for the C2C RI Test 2 and changes made to the TRANSCOM Middleware” report referenced in Section 6, C2C References and links.

Lastly, per feedback from the FHWA Technical Advisor, it was identified that the following user needs denoted within the TRANSCOM Middleware NRTM included inaccurate titles. The C2C RI Maintenance Contractor (Test Engineer), working with the TRANSCOM Team, updated the NRTM to correctly align with the TMDD definitions.

UN ID	User Need
2.3.4.3	Need to Share Link Data

Should state:

2.3.4.2.1	Need to Share Link State

UN ID	User Need
2.3.4.4	Need to Share Route Data

Should state:

2.3.4.2.3	Need to Share Route State

This revised NRTM was reflected in the Conformance Test 2 Test Plan and was also used to configure the C2C RI tool to conduct Conformance Test 2.

As noted previously, the C2C RI Maintenance Contractor generated a series of iteration updates to the C2C RI Tool in order to address functionality issues identified during Conformance Test 1. The TRANSCOM Team worked with the C2C RI Test Contractor team as part of the pretest activities to review and, when applicable, verify status of updates provided. Below is synopsis of the update activities conducted as related to the C2C RI Tool.

- Legacy versions of the C2C RI Tool required invalid 1 test case to be passed in order to successfully complete and pass the Conformance Test 2. As invalid 1 refers to "unknown processing error", of which it is fundamentally almost impossible to trap the scenario. The TRANSCOM Team suggested making invalid 1 test case as optional for all dialogs in the C2C RI tool. The updated C2C RI Tool has accommodated this change.
- Legacy versions of the C2C RI Tool require "TCS-1-dlCenterActiveVerificationRequest-OC-InValid-8" test case to be passed in order to successfully complete and pass the Conformance Test 2. As invalid 8 refers to "no valid data available" of which it is fundamentally almost impossible to generate the scenario. The TRANSCOM Team has suggested making the "TCS-1-dlCenterActiveVerificationRequest-OC-InValid-8" test case as optional in C2C RI tool. The updated C2C RI Tool has accommodated this change.
- Legacy versions of the C2C RI Tool allowed a user to override/set error type and error code which was expected to be returned by owner center when invalid test cases were conducted. The updated C2C RI Tool has been updated to restrict the override

error type and error code for invalid test cases. The TRANSCOM Team modified the TRANSCOM Middleware System to accommodate this change. This allowed all invalid test cases to be passed when the updated C2C RI Tool was used.

- Legacy versions of the C2C RI Tool had an issue as it related to performance and memory allocation/usage during pre-test configuration for Conformance Test 2. The TRANSCOM Team had noticed this issue and recommended addressing it. Both the performance and memory allocation/usage issue were addressed and resolved in the updated C2C RI Tool.

- Legacy versions of the C2C RI Tool had an issue with the conformance report generated from the C2C RI tool. It was not reflecting the appropriate test result on the report though the TRANSCOM Team had run all test cases for a dialog. For some of the user needs, it is either showing “Not Fully Tested” or “Not Tested”. The TRANSCOM Team recommended addressing it. The updated C2C RI Tool has accommodated this change.

- The TRANSCOM Team identified a possible issue with a release of the updated C2C RI Tool when it was used for the event test case against preconfigured parameter values. To overcome the problem, the TRANSCOM Team modified the Middleware system to provide all live events from the system to the C2C RI tool when executing the test case. Since there could be more than 500+ events in a result set, the C2C RI tool took more than 25+ minutes to validate the data. The C2C RI Maintenance Contractor, in response to this feedback, recommended to use the USERDEFINED# parameter in the data configuration file to overcome the issue. The TRANSCOM Team revalidated and advised and it worked fine.

3.5.2 Test Plan for Conformance Test 2

In accordance with the test process defined as part of the TRANSCOM Pilot Test Project for the C2C RI Tool, a dedicated Test Plan was generated for Conformance Test 2. The structure and format of the test mirrored that which was used for Conformance Test 1, which was developed in accordance with IEEE Std 829-2008. A copy of the full test plan for Conformance Test 2 is available in Section 6, C2C References and links.

Subject to updates conducted on the TRANSCOM Middleware system and the C2C RI Tool, as well as, the format update associated with the TRANSCOM Middleware NRTM, the following updates were added to the Conformance Test 2 Test Plan:

A list of the specific C2C RI Test Cases was added to the Test Plan. These updates documented the order by which each test was to be executed along with specifically including the positive and negative test cases to be conducted in accordance with TMDD v3.03c in order to appropriately validate conformance. Additionally, the order of tests conducted was defined with application layer tests done first and followed by information layer tests.

Based on this guidance and configuration in the C2C RI Tool, the following order of tests were conducted:

- Application Layer – NTCIP 2306 v1.69
  - Web Services
- Information Layer – TMDD v3.03c
  - Center Active Verification
  - Node Inventory
  - Link Inventory
  - Route Inventory
  - Node Status
  - Link Status
  - Route Status
  - CCTV Inventory
  - DMS Inventory
  - DMS Status
  - Organization Information

- Event Information
- Action log

All remaining elements of the original test plan were not changed, such as features to be tested and not to be tested, pre-testing, anomaly reporting, etc.

3.6 Findings from Conformance Test 2

Based upon review of the post Conformance Test 1 activities by both the TRANSCOM Team and the C2C RI Maintenance Contractor along with pre-test activities orchestrated by the C2C RI Maintenance Contractor (Lead Engineer), all parties reported that they were ready to proceed with the conduct of Conformance Test 2. This information was shared with FHWA, the FHWA Maintenance Contractor and the FHWA Technical Advisor as part of the monthly project status reviews which were conducted throughout the Pilot Project and by consensus, it was agreed to schedule Conformance Test 2.

The following sections provide an overview of the results of the Conformance Test 2 as well as findings from the testing process.

3.6.1 Findings and Anomalies

The TRANSCOM Middleware system was tested for conformance with TMDD v3.03c and NTCIP 2306 v1.69 using the C2C RI Tool by the C2C RI Maintenance Contractor (Test Engineer) with representatives from the FHWA, TRANSCOM, and NJDOT in attendance at TRANSCOM's offices. All testing was conducted in accordance with the methodology defined in the Conformance Test 2 Test Plan summarized above.

The results of the test generated two expected anomalies and three unexpected anomalies highlighted below:

- A WSDL dialog configured in the TRANSCOM Middleware Project to support TMDD 'dl' style did not align with the NTCIP specified dialog of "OP_" prefix.
- An NTCIP defined SOAP Subscription-Publication requirement was being defined as "FAIL" for a request-response only request that does not mandate the use of the NTCIP SOAP requirement.
- The title in the log of the C2C RI Conformance Report bled over to the next line, which made reading the test report difficult.
- If a user selected "Create PDF" in the Report Generation Tool of the C2C RI Tool and the user accidently selects "Create PDF" again, it generated a second report request that failed to complete and required the user to manually close out the open panel.

- If a user selected an Information Test Layer Test Case and then moved to the Application Test Layer Test Case and selected it, both test cases began to run simultaneously. The C2C RI Tool showed Application Layer test as "running" and failed the Information Layer Test Case.

The top two anomalies mirrored findings of Conformance Test 1 and were expected as these are direct conflict issues between NTCIP and TMDD that will suggest an update to the NTCIP 2306 standard.

The remaining three anomalies were identified as bugs in the C2C RI Tool that were to be investigated by the C2C RI Maintenance Contractor for resolution.

3.6.2 Conclusion of Testing Process

Per the documented results that were generated from the C2C RI Tool, it was identified that:

- *The TRANSCOM Middleware system is conformant with TMDD v3.03c.*
- *The TRANSCOM Middleware system is conformant with NTCIP 2306 v1.69, acknowledging that the NTCIP 2306 v1.69 standard is in conflict with TMDD v.3.03c, and that the NTCIP 2306 v1.69 PRL contains an error. The TRANSCOM Middleware system passed all Application Layer Tests, with the exception of the inconsistency problem between the TMDD and NTCIP 2306 standard regarding naming of dialogs in the WSDL.*

4. Lessons and Recommendations

4.1 Lessons

4.1.1 User Friendly C2C RI tool

As part of the Pilot Study that the TRANSCOM Team supported for the C2C RI Tool, an iterative process was conducted in parallel for both the interface needs of the TRANSCOM Middleware system and also to support troubleshooting and system review for the C2C RI Tool. While future users of the C2C RI Tool should not anticipate this, since a fully vetted version of the C2C RI Tool shall be released for general use, the TRANSCOM Team was able to provide unique insight based on its role as a consensus-based organized comprised of 16 public agencies. In this role, the TRANSCOM Team was able to provide guidance based not on its personal perspective, but rather from the viewpoint of the desires and expectations of multiple agencies.

4.1.2 Flexible Approach

It is important for any organizations (public or private) seeking to align the data exchange capabilities of their system to conform to TMDD and NTCIP 2036 standards that they should anticipate that modifications will be needed on their native system. The C2C RI tool is a reporting system that identifies the non-conformant elements of an end user's native system; it is not a troubleshooting and/or analysis tool that specifies the exact error and potential changes that may be needed.

Any interested organization should expect to allocate dedicated resources to address both the legacy system updates needed, as well as, utilized and interpret the results generated via the C2C RI Tool.

Lastly, as noted previously in this report, the standards conformity activity is an iterative process and all participating parties should be fully aware and understand their respective roles throughout the entire initiative and ensure that the entirety of the approach is presented and fully explained to the participants' respective management so that they have a very clear understanding of what is required.

4.1.3 Understanding Roles and Responsibilities

The TRANSCOM Middleware system testing (with two successive tests) using the C2C RI tool has *discovered*:

- what type of activities prospective users (TRANSCOM) shall expect if they want to conduct testing;

- what level of refinement the C2C RI tool developers (C2C RI Maintenance Contractor) should expect when generating a product with strict definitions, such as TMDD v3.03c and NTCIP 2306 version 1.69;
- what SDOs (ITE-AASHTO-NEMA) should expect to need to address from a conflicts/discrepancies/interpretation perspective as organizations undertake the system interoperability stage of a standard lifecycle.

4.1.4 Teamwork/Coordination

Based upon the collective experience of the TRANSCOM Team undertaking the Pilot Test of the C2C RI Tool, it is vital to the success of the project that all participants are fully engaged and willing to support the iterative test process. Coordination between all parties is key and no 'walls' or barriers can exist, either on a technical or institutional level.

If any one partner in the process does not fully support, the probability of data conformity being achieved is significantly diminished and future integration efforts *will be* impacted.

4.2 Recommendations

Recommendations are organized per concerned organization and contacting parties as follows:

4.2.1 For FHWA/C2C RI Tool Developers

- FHWA should continue with the efforts it has taken to lead the development and pilot deployment of standards-based conformity tools. Specifically, for the C2C RI tool, these activities could include such efforts as the public deployment of the tool, along with resources that will support the end user's ability to take advantage of the capability of the tool. These items could include but not be limited to: training manuals, case studies, help guides, and video aides that highlight functions/features of the tool.
- In order to be more beneficial to user-specific needs, the C2C RI Tool should allow for the ability to only generate the test scripts that are configured into the C2C RI Tool. This would allow for level of customization that many end users would be expecting when utilizing the tool.
- The TRANSCOM Team recognizes the benefits that can be yielded from this type of tool. Therefore, the TRANSCOM Team suggests that FHWA might consider developing a parallel tool that would allow for testing capability for NTCIP Center to Field (C2F) devices such as DMS, ESS, CCTV etc. This is part of the natural evolution of the standards conformity effort being sought by multiple entities that are undertaking

future deployments such as the Integrated Corridor Initiative along with the autonomous vehicle initiatives.

- Allow for a period of time between tests. This will allow the participants to make any applicable adjustments to their respective systems based on the outcome of the test.
- For Standards Developing Organizations (SDOs): ITE/ASSTO/NEMA
- Through their efforts undertaken during the standards conformance process, the following have been identified as key items for the SDOs to consider as they pertain to the implementation and utilization of standards.
  - The question of "conformance" was raised amongst the project participants and no clear answer was available regarding what defines a standards conformant data exchange. Is it a 100% yes/no statement or some percentage of conformance. A clear definition is needed to ensure that all system owners clearly understand the baseline that needs to be achieved.
  - The issue of alignment between standards was discovered during the C2C RI Tool Pilot Test, which found incompatibilities between the NTCIP and TMDD standards. It is suggested that the applicable SDOs review the standards which they are responsible for and either address the conflict, or, provide clear guidance regarding the process by which acceptance is defined for a legacy system when a standards-based conflict arises.
  - Among the benefits of the C2C RI tool is its ability to determine the conformance needs for each owning center's legacy system. However, the potential exists whereby two centers use the C2C RI tool and are reported to be conformant to the TMDD and NTCIP standards but when the systems are directly connected together, the two centers *cannot* communicate. What is the role/responsibility of each owning center and what role does the SDO play in addressing this potential issue.

4.2.2 For C2C Deployment and Testing Locations (Owning centers)

- **Test Site Preparation**: Assemble all necessary testing materials in advance of the scheduled test and ensure that all key participants are available to be present throughout the entire test process. It is vital that all parties are viewing the tests and the results in order to reach consensus on issue resolution. It is advisable to rehearse with the C2C RI Test Engineer to ensure that all critical testing issues such as networking and system accessibility type items are fully addressed and plan for any potential unanticipated situation or side-effects if any shows up.

- **Pre-test activity**: As noted within this report, the pre-test activities can actually take more resources and time to conduct prior to the actual standards conformity test. Therefore, it is important to conduct all the tasks that are necessary to prepare for the test process, including but not limited to: securing necessary expertise (testing, system integrator, etc.), clearly designating roles and responsibility among test participants, ensuring that the NRTM matches and clearly reflects both the system elements applicable for testing and the TMDD/NTCIP defined elements to ensure all tests are correctly developed and configured in the system test plan. Lastly, plan and align all necessary resources for an interactive test process, subject to test results.

- **Use available C2C RI tool (now v1.07):** Do not indulge in developing costly testing tools. Take advantage of FHWA-led tools and services (as available and applicable) to support the data conformity initiative.

- **Test Results:** Per the functionality of the C2C RI Tool, both electronic (PDF) and hard copies should be produced. These results should be shared with all test participants in order to clearly view the results for any needed follow-up activities (as applicable). The hard copy should be maintained by the owning center for both their records as well as for proof of testing status as may be needed for any applicable contracting needs.

5. Conclusions

5.1 Project Conclusion

This project was undertaken at the request of FHWA who has been working, as part of the ITS Standards Program, on the development of a tool that allows for organizations to ascertain their level of conformity to the TMDD v3.03c and NTCIP 2306 v1.69 standards. FHWA recognized the need to conduct a real-world assessment of the C2C RI Tool that was under development by the C2C RI Tool Maintenance Contractor.

TRANSCOM, in its role as the information clearinghouse among its 16 Member Agencies, understood the need to be able exchange data in a structured and easily understood format had undertaken a project to develop a standards-based system, the TRANSCOM Middleware system.

FHWA, understanding the benefits to be acquired by working with a system that supports multiple agencies entered into an agreement with TRANSCOM in February 2016 to conduct a two-fold assessment. The key items to be addressed included: the needs/requirements for an owning center to exchange data through a defined set of ITS Standards and to provide a testbed for a system testing of an under-development data conformity tool (C2C RI Tool).

Through the dedicated efforts by all project participants, both areas of FHWA interest have been able to be investigated and positively addressed.

TRANSCOM has been recognized as being fully conformant with TMDD v3.03c and NTCIP 2306 v1.69 and significant real-world experience was provided to the C2C RI Maintenance Contractor Team that allowed them to implement key modifications necessary to release the tool for use by organizations around the country.

5.2 Concluding Thoughts

The following is a list of concluding thoughts and are presented here to highlight the value added and contribution of this testing effort:

- Two projects started at different time frames and at separate locations, involved different teams and expertise (software development vs ITS operational experience), and yet they came together at a testing process level to finish the task of developing a tool and then using it in a real-world operation environment respectively.
- Both the C2C RI tool and the TRANSCOM Middleware system projects have contributed greatly to FHWA's goal of fostering TMDD conformant in C2C

deployments. In addition, the collaborative and iterative process that was followed has significantly improved the tool and has somewhat simplified the testing environment and comfort level due to the development and successful testing of this free tool.

- The C2C RI tool has been made possible by FHWA policy and leadership. The successful coordination, develop and deployment of the C2C RI tool will allow for its future use as a resource that can be used at multiple real-world locations by operations staff to gain knowledge of what works and what doesn't and will also help eliminate or reduce the risk of failure in the development and deployment of non-conformant systems.
- TRANSCOM itself has achieved a significant level of success for its diverse, multi-modal membership by demonstrating that 100+ operations centers can seek and achieve an interoperability advantage, and by feeling secure and confident that ITS standards work and provide a real benefit at the operations level.
- FHWA has successfully coordinated a software development project and a deployment project to achieve a system engineering objective. They have developed a common testing tool to check for conformance to standards and system functionality. "Did they design the system right"? "Did they build right system?" Both questions are heading toward final fulfillment.
- The ITS industry in general, SDOs such as ITE, AASHTO and NEMA in particular, will benefit from the last step taken in the testing process. Their standards do promote interoperability and present an opportunity to improve their respective standards in the next update versions to eliminate conflicts among various layer standards.
- Finally, the preparation of the Testing Documentation based on IEEE 829-2008 standard is in full force and agencies across the United States will better understand how to prepare Test Plans for C2C system testing. This is a significant benefit, often not recognized by the practice.
- This Project has generated a body of readily usable documentation (Test Plan, Training Manual-Tool Software, testing reporting documentation) and understanding what test results mean; which can be directly used in ITS training modules in the hands-on format. The following section provides links and sources which can be used to gain access to these documents.

6. C2C References and Links

Each of the following will be presented later with details of content and where to find information.

- C2C RI v1.07 Software Download (FHWA-TransCore)
- C2C RI Training Manual-pdf (FHWA-TransCore)
- Middleware system NRTM (TRANSCOM)
- Test Plan – Conformance Test 1 (FHWA-Consensus Systems Technologies)
- Test Plan – Conformance Test 2 (FHWA-Consensus Systems Technologies)
- TMDD v3.03c standard Volumes I and II (SDOs-ITE)
- NTCIP 2306 XML v1.69 (NTCIP NEMA)
- IEEE 829 2008 standard (IEEE)
- Pre-test reports
- Test Plans (SA 1, SA 2)
- Test Results (SA 1, SA 2)
- Config. and Conformance reports
- NRTM 2016
- Training session-PPT
- Any other reports we published