SAE J2735 Standard: Applying the Systems Engineering Process

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Roy Sumner (FreeAhead Inc.), Bruce Eisenhart and John Baker (Consensus Systems Technologies Corporation)	

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The GTM for USDOT was Steve Sill and Emiliano Lopez.

16. Abstract

This project consisted of the development of a revision of the SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary, published 2009-11-19. This revision will be submitted, at the end of this project to the Society of Automotive Engineers (SAE) as a comment.

The environment within which this standard applies is referred to here as Connected Vehicles or CV (formerly VII), defined as vehicles that support wireless communications between vehicles and wireless communications between vehicles and infrastructure.

The purpose of this document is to describe the process used to develop the J2735 SE candidate document and to provide recommendations as to how the process may be improved. One goal of this document is to provide sufficient details to enable personnel who did not participate in the development of the J2735 SE to understand the process used in its development.

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Table of Contents

I. Introduction

1.1 Purpose of this Document

The purpose of this document is to describe the process used to develop the J2735 SE candidate document and to provide recommendations as to how the process may be improved. One goal of this document is to provide sufficient details to enable personnel who did not participate in the development of the J2735 SE Candidate Standard to understand the process used in its development.

In this document the use of the term "J2735" refers to the SAE standard J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary published 2006-12 and revised 2009-11. Various SAE Committees have continued to develop this standard since its publication. The term "J2735 SE" refers to the subject of this project: a candidate revision to this standard developed using the systems engineering process.

Project Objectives and Scope

This project consists of the development of a revision of the SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary, published 2009-11-19. This revision will be submitted at the end of the project to the Society of Automotive Engineers (SAE) as a comment.

The environment within which this standard applies is referred to here as Connected Vehicles or CV (formerly VII), defined as vehicles that support wireless communications between vehicles and wireless communications between vehicles and infrastructure.

The developers of the J2735 SE Candidate Standard applied the systems engineering process in order to define a set of user needs and requirements that address the scope of the standard. The effort then identified the design data concepts needed to fully address those requirements. The intent was not to create a new set of design concepts, but to use as many design concepts from the existing standard as possible to satisfy the defined requirements.

The objectives for this update were as follows:

- Create a complete and correct standard, which includes creating a set of verifiable requirements.
- Incorporate lessons learned from the Proof of Concept (POC) test bed in Michigan, which performed testing of aspects of J2735.
- Ensure that the developed candidate standard addresses needs relating to transit vehicles, commercial vehicles, and freight.
- Ensure that the candidate standard reflects comments provided by a broad range of CV developers.

Although the J2735 is labeled as the DSRC data dictionary, its current development has endeavored to keep the standard independent of the DSRC and IEEE 1609 processes. This

project continued that approach in order to ensure that the standard can be more broadly applied to alternative communications media.

The general scope of the J2735 SE Candidate Standard is to define data concepts (dialogs, messages, data frames, and data elements) required for CV communications between equipped vehicles or between an equipped vehicle and infrastructure. The exact scope of the effort was defined during the user needs portion of the project and is described in Section 3 of the J2735 SE document.

Document Overview

This document is divided into seven (7) main sections.

- **Section 1: Introduction.** This section provides introductory and background information about this document, its purpose, and why it is needed.
- **Section 2: Management and Process.** This section describes the systems engineering process used to manage the development of the J2735 SE Standard, including lessons learned while managing the project.
- **Section 3: User Needs and Concept of Operations.** This section describes the approach used to develop the Concept of Operations for the J2735 SE Standard, including the User Needs.
- **Section 4: Requirements.** This section describes the approach used to develop the system requirements for the J2735 SE Candidate Standard
- **Section 5: Design.** This section describes the approach used to develop the design for the J2735 SE Candidate Standard.
- **Section 6: Development of the Draft Standard.** This section describes the approach used to develop the Draft J2735 Standard.
- **Section 7: Recommendations.** This section provides recommendations for future ITS standards development using the systems engineering process.

II. Management and Process

2.1 Approach

Two documents were created to define the process and guide the management of the J2735 revision. A Systems Engineering Management Plan (SEMP) outlines the Systems Engineering Process (SEP) used in the J2735 revision. The Project Management Plan (PMP) outlines the project scope, objectives, tasks, schedule, deliverables, and management.

Systems Engineering Management Plan

The SEMP is the top-level plan for organizing and managing all engineering activities required for the project. The SEMP defines how the systems engineering portion of the work item will be organized, structured, and performed and how the total engineering process will be controlled to provide a product that fulfills customer requirements. The outline included in the *IEEE Std 1220-2005, IEEE Standard for Application and Management of the Systems Engineering Process, Annex B, The Systems Engineering Management Plan*, was used as a guide for the development of the SEMP for this project. The format and content of the SEMP were tailored to fit this proposed standards update project.

The SEMP was used in technical management of this project, describing the process and steps performed and the roles and responsibilities of the participants. The SEMP describes how each systems engineering subtask of the PMP was to be performed and completed and defines the controls applied to ensure that each subtask was completed correctly and on-schedule. The PMP focused on management processes, whereas the SEMP concentrated on applying the systems engineering structure.

Controls used for this work item included a risk management plan, a verification and validation plan, and a configuration management plan. The client, USDOT, and the consultant team used the SEMP as a reference throughout the project to confirm that project development tasks and controls were properly executed during the performance of each subtask.

Project Management Plan

While the SEMP outlines the systems engineering processes used to develop the revision of the J2735 Standard, the PMP spells out the management process.

The PMP outlines the tasks associated with this project, as well as the structure and roles and responsibilities of the project team. In addition, the PMP defines the relationship between the project team and USDOT in developing the J2735 SE Candidate Standard, as well as the relationship between the project team and other stakeholders (e.g., SAE, the developing standards organization for J2735).

The PMP includes a register of stakeholders from which subject matter experts were drawn to support the development process. The PMP additionally describes a Quality Management Plan through which the project team ensures the quality of deliverables. Finally, the PMP provides a detailed project schedule for the effort.

2.2 Steps Taken

The PMP and SEMP were the first deliverables developed for the project. A draft of each was submitted two weeks after project inception. Incorporation of comments into final documentation and acceptance of the documents by USDOT were prerequisites for beginning work on the remaining tasks. Portions of the PMP/SEMP, including the detailed project schedule and the risk management plan, were updated several times during the project as the schedule changed or the original set of risks required amendment or supplementation. These updates were described in a monthly Progress Report provided to the customer.

From a project management viewpoint, two other activities are worthy of note.

First, in order to keep the SAE involved in and informed about this project, as well as to provide the J2735 SE team with the latest thinking concerning the standard, a project team member attended most of the SAE DSRC technical and subcommittee meetings.

Second, the project team used a Wiki site to share data, reports, and project documents. This site was divided into two areas. One section contained draft and final files accessible to the development team, USDOT, and other approved users. A second area, reserved for the J2735 SE development team only, served as a repository for in-progress documents and references.

2.3 Lessons Learned

The systems engineering process was used to both manage and perform this project. That process focuses on planning the activities of a project before project initiation, monitoring those activities and the associated risks throughout the project, and defining user needs and requirements prior to performing design. The process seeks to control cost, adhere to schedule, and provide a high quality product that meets stakeholder expectations.

On this particular project, the primary challenges related to schedule and to meeting stakeholder expectations. Although the original schedule for development of the J2735 SE Candidate Standard was 260 working days, by the time the draft document was delivered to SAE, the actual schedule had stretched to approximately 400 days. The original schedule was aggressive regarding the amount of time planned for concept of operations and requirements development, and it was in the execution of these two tasks that schedule slippage occurred.

This slippage occurred due to the nature of the development effort. The current J2735 Standard includes a set of design concepts, but it does not define user needs or requirements. The exact scope of the standard (defined by the set of user needs covered by the standard) was intentionally left vague. The initial task of this project was to more precisely define the scope of the standard, as well as expand the scope to cover additional commercial vehicle operations and transit needs. The effort required to engage and obtain information from stakeholders proved to be considerably more difficult than expected and took considerably longer than expected. USDOT program areas (such as CVO and transit) have multiple points of contact and typically did not respond quickly to requests for meetings or information.

This stakeholder input issue was initially defined as a risk area. Thus, a lesson learned is that when input from multiple USDOT program areas is needed, additional time must be allocated for obtaining such information. This challenge, which continued well after the development of the initial set of user needs, will be discussed further in the Concept of Operations section.

Another cause of schedule slippage was the need to develop additional draft versions of deliverables. The original schedule laid out for each deliverable a draft, followed two weeks later by a walkthrough, followed by a final version several weeks after that. In fact, in the case of several deliverables, two or three drafts were developed before comments, which were provided primarily by the USDOT review team, could be resolved. Two of the additional drafts were necessary in part because of a document quality problem, which in turn was exacerbated by team members using different versions of Microsoft Word, thus allowing spelling and grammar errors to slip through the review cycles. When the team is creating a document that is several hundred pages long (as here), the use of several different versions of Word can create substantially more work and allow errors to slip through the reviewing net. A lesson learned is that every team member should use the same version of Word.

One additional lesson learned related to the coordination between the project team and the SAE J2735 standards development group, which continued development of J2735 during the period of this project. Having a team member attend the ongoing meetings allowed the project team to remain informed about changes being planned by the standards group. However, the project was not set up to have SAE committee members provide review at each step in the SE process. The earlier documentation was all posted on the SAE web site and members of the Technical committee were informed when documents were posted. In addition, reports on the status of the J2735 project were provided at the monthly meetings. Some SAE members did review the earlier

documents (user needs and concept of operations), but in general only a few comments were provided. It should be noted that the members of the various DSRC related committees and subcommittees are not paid staff of SAE but are generally employed by others; much of the work they do for standard development is voluntary. The documents produced were generally quite extensive, so their reluctance to engage in substantive review could be understandable. This effect was also noted during the various walkthroughs, when it was often difficult to obtain reviewers who could spare the time needed. At the design stage of the project several members of the Technical Committee were engaged as Subject Matter Experts (SMEs) to provide a more thorough review of the their specific technical areas. This proved very useful in obtaining comments, which were addressed by the project team. However, the comments received were from individuals, not the SAE Technical Committee, and the team learned towards the end of the project that the SAE Technical Committee had not bought into the approach and the overall output. The lesson learned is that additional interaction with the committee would have been a good in order to improve the chances of them buying into the product.

III. User Needs and Concept of Operations

3.1 Approach

The purpose of Task 2, Develop Concept of Operations for J2735 SE Candidate Standard, was to develop a Concept of Operations (ConOps). A ConOps should clearly convey a high-level view of the system that each stakeholder can understand. In the context of the development process for the J2735 SE Candidate Standard, this portion of the development effort identified the user needs that must be addressed by the standard.

The current SAE J2735 Standard does not contain a set of user needs or a ConOps. The SAE J2735 Standard does contain two sections, Section 4.1, Introduction to DSRC Goals and Objectives (Informative), and Section 4.2, DSRC Overview, which provide an introduction on what general user needs the standard addresses. Details of the user needs are not discussed in the current J2735, however.

The plan for this task was to create a ConOps document that included a set of user needs that addressed the operational needs of the CV environment, which supports information exchanges between one vehicle and another vehicle, or between a vehicle and a roadside device.

In developing the ConOps document, the contractor team considered *IEEE Std 1362-1998, IEEE Guide for Information Technology – System – Definition – Concept of Operations (ConOps) Document* for guidance. The outline for a ConOps document is defined in IEEE Std 1362-1998 is shown in Figure 1.

IEEE Std 1362-1998 Outline

1. Scope
2. Referenced Documents
3. Current System or Situation
4. Justification for and Nature of Changes
5. Concepts for the Proposed System
6. Operational Scenarios
7. Summary of Impacts
8. Analysis of the Proposed System
9. Notes

Figure 1: IEEE Std 1362-1998 Concept of Operations Outline

In addition the USDOT directed that the process should follow NTCIP 8002 Annex B1.

3.2 Steps Taken

The initial identification of user needs was came from a literature review of the existing SAE J2735 Standard, the outputs of the Core System effort, and other relevant ongoing research-related projects and programs, including other programs similar in concept to CV outside of the United States. The SAE J2735 committees and subcommittees also were informally surveyed to determine other relevant documentation that contained user needs.

Approximately 80 documents were gathered from these sources and each was reviewed in detail for its relevance to the project. Of these documents, 45 were found to be directly relevant and were annotated and compiled into a report that summarized the content and their relevance to this project.

To gather information from sources outside the project, a number of stakeholders were interviewed. The stakeholders' areas of interest included the following:

- International Standards Harmonization US/EU
- Clarus/Weather
- AERIS and Environment
- Connected Vehicle Program
- SAE J2735 Standard Working Group
- SAE J2945 Performance Requirements
- Government (USDOT, State and local transportation agencies, Transit, CVO)
- Industry CV/Transit Manufacturers, Telecoms, and SDOs

A list of 51 representative and interested persons was compiled first. Approximately 37 of these were interviewed. Their responses were compiled into a summary report. This report was used as the basis for the identification of user needs that are now summarized together with their rationale in section 2.5.2 of the Candidate Standard.

A questionnaire, which was submitted to USDOT for approval, formed the basis for the interviews. The results of the interviews were entered into an Access database to assist in the determination of the key user needs.

The project team delivered a report to USDOT that summarized the results of the literature review and interviews. Based on the literature review and the interviews, an initial set of user needs was developed and documented. This set of user needs helped in defining the scope of the standard by specifying what areas or applications would be addressed by the identified user needs.

The following criteria were used as the basis for documenting well-written needs:

1. **Uniquely Identifiable.** Each need must be uniquely identified (i.e., each need shall be assigned a unique number and title).
2. **Major Desired Capability.** Each need must express a major desired capability of the system, regardless of whether the capability exists in the current system or situation.
3. **Solution Free.** Each need must be solution free, thus giving designers the flexibility and latitude required to produce the best feasible solution.
4. **Capture Rationale.** Each need must capture the rationale or intent as to why the capability is needed in the system.

A User Needs Analysis Workshop was held to review and refine this initial set of user needs. The focus of the workshop was to clarify the scope of the standard (through review of the draft user needs), verify that the user needs are accurately documented, and identify any additional user needs (and associated requirements/design inputs) of the participants.

Following the workshop, the full set of user needs (the initial set developed prior to the workshop plus revisions from the workshop) was used to develop a draft ConOps document. The outline for the ConOps document was based on the IEEE document mentioned above and was provided to the client as a part of the User Needs Analysis Workshop Workbook deliverable.

After the draft ConOps document was delivered to the customer, a technical review, in the form of a walkthrough, was conducted in order to verify that the contents of the ConOps document, including the user needs, were accurately documented. The technical review included a workbook to guide the discussions and review. Following the walkthrough, a ConOps Walkthrough Workbook Comment Resolution Report, which identified all the comments received at the walkthrough with the comment resolution identified, was delivered to the customer.

3.3 Lessons Learned

Literature Review

The literature review produced information that was used throughout the project. The documentation was most useful, however, during the earlier parts of the project as the ConOps was developed. Previous work in the CV area was very extensive; although this information was summarized, there was insufficient time for all members of the team to look at all of the resources. A recommendation would be to scope the literature review effort based upon an initial list of documents, allowing scope to increase in the case that an extensive review is anticipated.

Stakeholder Interviews

A questionnaire for stakeholders used the following questions:

1. *What is your experience with the areas of CV identified in the table?*
2. *For what areas from the table would you like to provide input regarding User Needs?*
3. *Are there any additional CV areas not listed in the table that you would like to provide an input regarding User Needs?*
4. *What are your operations relative to this area and what information type do you need to support your operations?*
5. *What specific Operational Needs do you, the organization you represent, or the area of CV that your expertise covers, have that are relevant to the V2V interface that will be defined in the data dictionary?*
6. *What specific Operational Needs do you, the organization you represent, or the area of CV that your expertise covers, have that are relevant to the V2I interface that will be defined in the data dictionary?*
7. *Are there any performance related needs relative to the operational needs defined above (e.g., do any operational needs place specific performance constraints on the interfaces?)*
8. *Is there any additional information you would like to provide that you believe would be of value to this effort?*

Although the questionnaire attempted to elicit descriptions of user needs, the responses tended to be couched in terms of applications and data requirements. A great deal of effort was devoted to the development of the questionnaire (including multiple iterations), but even so the interviewers often had to stray from the specific questions in the questionnaire. It was often necessary during the interviews to ask the respondents to define their desires in broader terms in order to develop the needs to conform to the well-written criteria.

A lesson learned is not to put too much effort into fine tuning interview questions intended for such a broad range of users, as their experience and outlook will largely drive the directions of the interview. The current J2735 is potentially supportive of dozens of applications, but until this effort there had never been defined a specific set of user needs and this led to a wide range of expectations. The interviewers received requests that covered a range of near- to longer-term applications or needs. This resulted in an extensive list of possible user needs supporting many DOT program areas and made the process of winnowing the list a long and complex task. Developing the list of user needs and then prioritizing them was the key output of the ConOps task. As the task progressed it became apparent that some needs were near-term and some much longer term. It would have been useful to assign an implementation timeframe or importance criteria to the user needs earlier in the process in order to speed the development of the final set of user needs.

One issue that arose during the development of the user needs was the definition of a user. This issue was extensively discussed but never really put to rest as each new reviewer had an opinion. The term user could mean many things, including the following:

- A person who uses the system – such as to receive traffic data.
- A device that responds to a message – such as an on-board unit (OBU) or a signal controller sending data to an application.
- A vehicle that responds to a message by taking some action – such as tensioning seat belts.
- A communications device - such as a phone that receives a message from a signal controller to assist pedestrians.

After significant discussion, the definition was crafted to include a vehicle and various groups of stakeholders, as described in section 2.2 of the Candidate Standard. The lesson here is that it is advisable to get early consensus on what may seem basic definitions. More time is spent in discussion later in the job if definitions are not finalized earlier. In addition, it may be beneficial to provide interviewees with some short basic material that defines the terms to be used and expectations for the project at this stage of the system engineering process.

IV. Requirements

4.1 Approach

Defined as Task 3, Develop Draft Software Requirements Specification, this portion of the development process identified the system requirements that fully satisfied the user needs addressed by the J2735 SE Candidate Standard.

The current SAE J2735 Standard does not contain a systems requirements section. The approach for this task was to create a Software Requirement Specification (SRS) document. Functional, performance, and security (specific to J2735 communications) requirements were considered for inclusion in the SRS document.

In developing the SRS document, the *IEEE Std 830-1998, IEEE Recommended Practice for Software Requirements Specification*, was used as guidance. The outline for an SRS document proposed in IEEE Std 830-1998 is shown in Figure 2. In addition the USDOT directed that the process should follow NTCIP 8002 Annex B1.

IEEE Std 830-1998 Outline

1. Introduction
2. Overall Description
3. Specific Requirements

Figure 2: IEEE Std 830-1998 Software Requirements Specifications Outline

The SRS document for the J2735 SE Candidate Standard contains subsections in compliance with the above outline.

4.2 Steps Taken

The consultant team parsed each user need identified in the ConOps. Requirements were then developed and derived from each user need. Some requirements may satisfy more than one user need, but the full set of requirements satisfies all the user needs identified in the ConOps. Each developed requirement is uniquely numbered to support traceability throughout the project.

The team used the following criteria when documenting and writing requirements:

1. Is it a well-formed requirement? Some of the attributes of well-formed requirements are:
    a. Necessary – Is the requirement an essential part of the system?
    b. Clear – Can the requirement be interpreted one and only one way?
    c. Complete – Can the requirement stand on its own without further clarification?
    d. Consistent – Does the requirement contradict or duplicate another requirement?
    e. Achievable – Is the requirement technically feasible at a reasonable cost and in a reasonable time?
    f. Verifiable – Can one unambiguously determine if the requirement has been met?
    g. Concise – Is the requirement described succinctly and without superfluous text?
    h. Technology-independent – Is the requirement statement technology independent?
2. Is the requirement mapped to one or more user needs? This will also answer the question of whether the requirement is in fact needed.
3. Does the requirement satisfy the intent and all key parts of the need?

The well-formed requirements generally take the form: [Actor] [Action] [Target] [Constraint] [Localization]. The localization and constraint portions are important, but not all requirements have both. The constraint identifies how to measure success or failure of the requirement. The localization identifies the circumstances under which the requirement applies. For example: The System [Actor] shall generate [Action] event reports [Target] containing the following information [Constraint] on a scheduled interval [Localization].

A requirements analysis was then performed. The purpose of the requirements analysis was to accomplish the following:

- Decompose the requirements to a level of detail sufficient for mapping to the system design.
- Verify that the full and refined set of the requirements completely defines all system functions that are needed to satisfy the user needs.

Upon deriving the first set of (higher level) requirements from the user needs identified in the ConOps, each requirement was analyzed, decomposed, and refined into more detailed requirements. Some detailed requirements were allocated to specific components (e.g., a transit vehicle, signal controller) or a state (e.g., parked vehicle, a roadside device in a failure mode). Newly derived requirements emerged from this process, which continued until all requirements were defined and analyzed in enough detail that a design could be defined.

In addition, a set of performance requirements was added. The current SAE J2735 Standard does not have a set of performance requirements, which define the minimum criteria for an acceptable quality of data, and when and how often information should be exchanged.

A draft SRS document containing the full set of requirements was delivered to the client on October 7, 2011. Rather than a separate requirements document, this deliverable was a combination of final Concept of Operations and draft requirements. The full set of requirements also was entered into a requirements traceability tool in order to perform requirements traceability. A Protocol Requirements List (PRL) was developed that mapped the user needs to the requirements. This PRL was used to define the traceability from user needs to requirement.

A technical review in the form of a walkthrough was conducted to verify the following:

- Each user need in the ConOps document can be satisfied by a set of requirements in the SRS document;
- The requirements in the SRS document are accurate and correct; and
- The list of requirements in the SRS document is complete.

After completion of the technical review, the project team collected and logged comments and provided a Comment Resolution Report that indicated how each comment received at the walkthrough (or outside the walkthrough) was addressed. Finally the SRS document was updated and delivered.

4.3 Lessons Learned

To be well formed the requirements need to meet the criteria defined above. Reviewing all requirements initially defined against the list of well-formed attributes is an essential and important aspect of requirements development. Through several draft sets of requirements, numerous additions, deletions, and changes were made to the requirements to align them with the attributes. Because of the nature of this effort in developing a version of an existing standard that went through the systems engineering process, one aspect of the effort was review of the existing data concepts and identification of potential requirements that would map to each. The testable attribute was a key criterion in deciding whether to include a number of requirements that would have been needed to address some of the data elements that were part of SAE J2735 v2. The existing standard had not been subject to an analysis; some of the data elements, particularly those defining data confidence, were not sufficiently defined to be testable. The lesson is to compare each requirement to the entire list of criteria to identify requirements that may need to be removed.

One aspect of the requirements output that caused continuing confusion was use of the term Protocol Requirements List, or PRL. When the PRL was mentioned it was inevitably followed by an explanation of what it contained. The PRL is a Needs to Requirements Traceability Matrix (NRTM), which is the name given to it in the Traffic Management Data Dictionary Standard. The term PRL, which comes from the NTCIP program, was originally defined to support device interface standards. The customer requested its use in this standard so that the DOT developed Test Plan Generator (TPG) could be used with this effort. (The TPG requires a standard to conform precisely to NTCIP 8002 Annex B1 in order to operate properly). It would be helpful to allow the use of the term NRTM to reduce confusion among stakeholders.

Development of this candidate standard involved a unique dynamic between the stakeholders, in that some provided input that they thought would relate to applications that they considered desirable, while other stakeholders would be responsible for the actual development of the applications. For example, various safety groups wanted to provide warnings to drivers using systems within cars. This was considered a basic user need. Automakers, however, may not want such warnings, as they affect automobile design decisions. Their position is that these types of actions are the responsibility of the automaker and not other stakeholders or the interface standard, because automakers need the ability to develop their own systems in a competitive environment. However, the need for interoperability across systems demands that the interface be precisely defined, which is the role of the standard. The standard does not say anything about the applications which use the data on the interface or how they will be developed for any particular vehicle. Many ITS standards are developed to define interfaces that will be deployed by the public sector (e.g. most of the NTCIP standards). J2735 SE defines interfaces that are primarily private sector to private sector or private sector to public sector. The data on these interfaces move to and from vehicles owned by the general public. The lesson here is when standards development affects private sector products, the development effort needs to be especially sensitive to the inputs from these private sector developers.

V. Design

5.1 Approach

Task 4, Develop Draft System Design Description, identified the design that fulfills the requirements to be addressed by the J2735 SE Candidate Standard. In the context of J2735 SE Candidate Standard development, design is the definition of dialogs, messages, data frames, and data elements, together known as data concepts.

The approach for this task was to create a Software Design Description (SDD) document. The purpose of the SDD document is to document the full set of data concepts for the J2735 SE Candidate Standard.

The SDD document was created to be consistent with NTCIP 8002 Annex B1, using the design sections from ITE/AASHTO Traffic Management Data Dictionary (TMDD) v3.0 Volume II as a model.

5.2 Steps Taken

The general approach to the design development for the J2735 SE Candidate Standard was to create a set of data concepts that completely fulfill the requirements. The process for defining data concepts begins with identifying what information exchanges are required to fulfill each requirement.

The current SAE J2735 Standard already has a defined set of messages (Section 5), data frames (Section 6), and data elements (Section 7). These data concepts defined in the SAE J2735 Standard were used as the source of the baseline for the J2735 SE Candidate Standard data concepts. Note that the SAE J2735 Standard has no dialogs defined. Where possible, existing messages, data frames, and data elements were re-used. As necessary, the existing data concepts were updated, or new messages, data frames, and data elements were created. One other important difference between the design content created and the existing SAE J2735 Standard design content was that the J2735 SE Candidate Standard data concepts were formatted using ISO 14817, which defines a standardized structure and format for data concepts.

The current J2735 standard describes the design in both ASN.1 and XML formats. Due to the nature of connected vehicle information exchanges, it was decided in conjunction with the USDOT early in the program to develop the design only in ASN.1, as the XML process adds too much overhead to make it a viable coding process for wireless based communications.

Each data concept was uniquely numbered to support traceability throughout the project. Each data concept was reviewed for the following:

1. Is it a well-formed data concept? Some of the attributes of a well-formed data concept are as follows:
    a. Necessary
    b. Clear (unambiguous)
    c. Complete (fulfills the requirement)

d. Consistent (does not conflict with other data concepts).

2. Is each requirement mapped to one and only one dialog and its associated messages, data frames, and data elements?
3. Is each data concept mapped to a requirement? The answer to this question will determine whether the data concept is in fact needed.
4. Does the data concept fulfill the intent and all key items of the requirement?

The consultant team began creating the design document by identifying the pieces of data that need to be exchanged to fulfill a requirement, the sequence of actions that must occur to exchange this information, and any preconditions for this sequence of actions to occur. A set of data concepts was specified or created to fulfill each requirement. Each set of data concepts minimally includes one dialog, one message, and associated data elements. (Note that many of the messages in J2735 are broadcast messages.) Each dialog may fulfill more than one requirement.

Once the dialogs were created, the consultant team created a detailed design document that includes complete descriptions of all data concepts, including the design content, constraints on formats, timing, and any other relevant factors needed by the implementation.

A draft SDD document containing the full set of data concepts and their description was developed and delivered. The draft document was created by adding the design section to the final ConOps and Requirements document. The full set of data concepts also was entered into a requirements traceability tool in order to perform requirements traceability as discussed in Section 4.3.2. A Requirements Traceability Matrix (RTM) was developed to maintain traceability and logical consistency with the identified requirements.

A technical review, in the form of a walkthrough, was conducted via web conference, to verify the following:

- Each requirement in the SRS document is fulfilled by a set of data concepts;
- The data concepts in the SDD document are accurate and correct; and
- The list of data concepts in the SDD document is complete.

After completion of the technical review, comments were collected, logged and the SDD document was updated.

5.3 Lessons Learned

Each version of the developing document was subject to a walkthrough process that involved SMEs chosen either for their expertise in one technical area or their broad knowledge of the background and concepts in the current version of J2735. Obtaining volunteers for the ConOps walkthrough posed no challenges, but recruitment process was not successful for the Requirements walkthrough. Due to the size and complexity of the design, it was decided that the project could not rely on purely volunteer reviewers, so an honorarium was offered to compensate the SMEs for their efforts. Some refused the payment, stating that reviewing potential changes to the standard could be considered part of their work, while others were appreciative of receiving the compensation. All SMEs provided valuable input. The lesson: if the size of the standard that is the subject of the walkthrough is large, it is worthwhile to offer payment to SMEs in order to generate the detailed review necessary to create a quality product.

A second lesson learned is that creating data concepts that are ISO 14817 compliant is a difficult process. There is only one ITS standard that has done this (TMDD), and there were still several

issues to be resolved in order to create a usable set of data concepts that adhere to ISO 14817. Consequently, the design effort took longer and was more difficult than anticipated.

Some of the issues that arose during the design definition might have been more quickly addressed if the team had included staff with software engineering skills. Since the project did not include any software development this was not originally considered when developing the staffing plans, but the detailed ASN.1 data definitions will ultimately be used by software developers and having additional expertise to consider issues that these developers might have with the data definitions would have been helpful.

VI. Development of the Draft Standard

6.1 Approach

Task 5, Development of the Draft J2735 SE Candidate Standard, was facilitated by the prior task's approach of adding each new section to a single document (rather than creating separate requirements and design documents). With a single document in place, the primary remaining effort was to decide whether to include all of the appendices that have been created over the years in support of the current J2735 standard.

The document produced was intended to be a comment to SAE, and thus it was not a standard, nor was it a draft standard. The document produced was titled *J2735 System Engineering Version, Candidate Draft Standard, for consideration by SAE*.

6.2 Steps Taken

The development of the full Candidate Draft Standard primarily required the incorporation of a set of Annexes, taken from the current standard and modified, that provided additional information about aspects of deploying the standard. Due to comments being provided late in the development process, however, additional changes to the standard were first incorporated in this step. These included adding a new set of data concepts relating to weather to satisfy requests made by the AERIS program. A section on external data entries (5.5) was also added, including ITIS codes, NTCIP data, and IEEE components.

Annexes from the current J2735 were added. In addition, the message priority tables were added. The performance requirements were all added as Annex G. It is the intent of SAE to add all performance requirements to J2945; however, since it is not yet published and the performance requirements were needed to complete the document, these were added in one annex such they can be readily removed to another document when this is available.

6.3 Lessons Learned

Due to the size and complexity of the output, the use of different tools to check various aspects of the J2735 SE was helpful. While using the traceability matrices to walk through the standard was helpful, other tools were used to check the design content. These included syntax checkers and a data model developed to verify the consistency of the design content.

Probably the most significant lesson learned in this portion of the effort was the need to better coordinate with USDOT program areas earlier in the project. A set of changes generated by the AERIS program was delivered very late in the process, requiring additional data concepts to be added. What the contractor team did not do was poll the key program areas in the USDOT affected by this standard and get positive responses from them regarding concurrence with the standard. In short, the team fell into the trap of assuming no response was a positive response.

VII. Recommendations

Several aspects of the J2735 SE development project were unique:

- The project consisted of updating an existing standard, but the development process was not performed by the standards body (SAE), but independently.
- The potential scope of the standard cut across several sectors of the USDOT including FHWA, FTA, FMCSA, and many program areas within these sectors). In addition it encompassed large private sector organizations such as the automobile manufacturers
- Creating data concepts that are ISO 14817 compliant is a difficult process.

It is due to these unique aspects that the project encountered challenges with defining and managing scope and schedule. The scope was informed by requests from a wide range of stakeholders seeking to add their needs to the standard, resulting in one that became considerably larger than the original standard. The project schedule challenges arose in equal parts due to the continued debate over the scope of the standard (which lasted until the early stages of the design task) and due to the difficulty of creating error free requirements and trace matrices (tracing tools did not provide 100% accuracy for traceability checks and logic and traceability methods were not developed sufficient to address this quality control issue).

Probably the most significant recommendation arising from this effort relates to participation by the USDOT program areas. Deciding early in the process which areas are relevant to the standards effort and then actively seeking comments and concurrence at each stage would substantially improve efficiency.

In order to be more complete and correct in producing quality documents, tools and methods need to be developed that will make traceability checks and logic checks more effective.

Appendix A: Acronyms

Acronym	Description
AERIS	Applications for the Environment: Real-Time Information Synthesis
AIAA	American Institute of Aeronautics and Astronautics
ANSI	American National Standards Institute
ASN.1	Abstract Syntax Notation One
ConOps	Concept of Operations
CV	Connected Vehicles
CVO	Commercial Vehicle Operations
DSRC	Dedicated Short Range Communications
EU	European Union
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Organization for Standardization
NRTM	Needs to Requirements Traceability Matrix
OBU	On-Board Unit
PMP	Project Management Plan
PRL	Protocol Requirements List
POC	Proof of Concept
RTM	Requirements Traceability Matrix
SAE	Society of Automotive Engineers
SDD	Software Design Description
SDO	Standards Development Organization
SEMP	System Engineering Management Plan
SE	Systems Engineering
SEP	Systems Engineering Process
SME	Subject Matter Expert
SRS	Software Requirement Specification
US	United States
USDOT	United States Department of Transportation
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VII	Vehicle Infrastructure Integration
XML	Extensible Markup Language

U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

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