Standards Gap Analysis for Cooperative Intelligent Transportation Systems (C-ITS)

Analysis Methodology

Document HTG7-2
Version: 2018-12

Standards Harmonisation Working Group
Harmonisation Task Group 7

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1. Introduction

1.1 Background

Advancements in transportation technologies are rapidly transforming the world's strategies for increasing safety; gaining operational, mobility, and cost efficiencies; opening access to underserved communities; and reducing environmental impacts from transportation. Using new forms of short-range communications, vehicles and devices are now capable of broadcasting or receiving data that allow them to sense the movements and status of other surrounding devices. These cooperative exchanges create a three hundred sixty degree awareness that, when further fused with other open data, can enable drivers and other users of the transportation system to receive alerts and warnings regarding the formation of threats and hazards. The alerts and warnings created through these communication technologies provide the opportunity to prevent some crashes, thereby reducing fatalities, injuries, and property damage. The cooperative exchange of data in this manner can also enhance the benefits of automation.

Access to new data sets can also transform network operations and minimize the capital investment costs of infrastructure owners and operators. Broadcast data sets from users within a highly mobile environment can complement or potentially supersede the need for significant roadside equipment on major roads. These new data can also form a more complete representation of conditions on the arterial network, including road weather impacts, effects of traffic signal timing, support for incident and emergency responders, or changes in traveller decisions, among other conditions.

Standards for interfaces in the public interest can play a key role in delivering these benefits to communities that implement cooperative-ITS technologies. Technical standards are developed to address coordination problems and overcome technical barriers that exist when different organizations need to work together while preserving their institutional and proprietary processes. The International Organization for Standards (ISO) defines a standard as, "… a document, established by a consensus of subject matter experts and approved by a recognized body that provides guidance on the design, use or performance of materials, products, processes, services, systems or persons." The end documents, which frequently represent the interests of the experts and parties that gather to develop them, are vetted by experts. Recognized benefits include improved safety, mobility, and sustainability for the travelling public and enhanced interoperability within an open market environment.[1]

[1] See definitions at: the European Committee for Standardization (CEN): https://www.cen.eu/work/ENdev/whatisEN/Pages/default.aspx; the International Organization for Standards (ISO): https://www.iso.org/sites/ConsumersStandards/1_standards.html; Wikipedia: https://en.wikipedia.org/wiki/Technical_standard; the National Institute of Standards and Technology (NIST): https://www.nist.gov/services-resources/standards-and-measurements.

1.2 History

In 2011, the United States (US) Department of Transportation (USDOT) and the European Commission (EC) approved a **Harmonisation Action Plan** to guide EC-US standards development via Harmonisation Task Groups (HTGs). The plan recognises that successful, interoperable, nationwide or regional, cooperative technology implementations are critically dependent upon consistent application of complete, technically sound standards and policies for critical functions, interfaces, and ***information flows***[2]. This worldwide need applies to the common services of a cooperative systems environment as well as to global markets for vehicles, devices, and applications. While the envisioned end state appears very similar in many parts of the world, past analyses have been regional and independent in nature and have proceeded with varying levels of coordination. The HTGs allow participating countries to collaborate on technical ITS issues that are of common interest and thus leverage critical expertise and resources while potentially realizing more compatible worldwide solutions.

Transport Certification Australia (TCA) joined the HTG initiatives in January 2014 by bringing security expertise and co-leadership to the sixth HTG (HTG6).[3]

1.3 HTG7

With the emergence in 2015 of plans in the US, Europe, and Australia to develop pilot ***Cooperative Intelligent Transportation Systems*** (***C-ITS***) [4] projects, a new HTG was established to identify how existing standards could support new C-ITS installations (i.e., “standards solutions for C-ITS”) and, in doing so, identify the issues in standards that could pose risks for deployers. This seventh HTG (HTG7) began in late 2015 as a joint effort between the EC, the USDOT, and TCA, with the Japan Ministry of Land, Infrastructure, Transport and Tourism (MLIT) joining in 2017.

Specifically, the objective of HTG7 was to identify standards that comprehensively support large-scale C-ITS deployments. HTG7 expects that fulfilling this objective will allow:

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[2] Terms that are in ***bold italics*** in this report are defined in a companion report, the **HARTS Reference Compendium (HTG7-5)**, which defines all of the terms used throughout this report set. Terms defined in the reference compendium are bold faced and italicised within each HARTS report upon their first use.

[3] Results of HTG6 are located here: https://ec.europa.eu/digital-single-market/news/harmonized-security-policies-cooperative-intelligent-transport-systems-create-international.

[4] C-ITS is a subset of ITS that requires the mutual, secure exchange of data between *independent* trusted entities (i.e., parties that have no contractual relationship). In other words, while traditional ITS typically deals with exchanges among system components owned and managed by a single or limited number of entities; these new ITS services expand this scope to include system components (e.g., vehicles) that may be owned and managed by any number of different entities. The scope of the HTG7 analysis included the C-ITS interfaces (i.e., exchanges between parties with no contractual relationship but with security and authentication as the basis for trust) as well as the more traditional “back-office” flows (between contracted parties) that enable the provision of the C-ITS services. This architecture presents a level of connectivity suggesting an “Internet of Things” for transportation.

1. **Governments, standards organisations, and other interested stakeholders** to track ***issues*** regarding those interfaces and information flows that are of significant public interest within the C-ITS ***architecture***, facilitating engagement with experts to address them;
2. **ITS deployment teams, device manufacturers, and application developers** to identify candidate standards-based ***solutions*** that are available to them for planning, understand the issues associated with those solutions, and mitigate the risks associated with those issues in their deployments. Future ITS deployment teams around the world will have a clearer understanding about which system functions and interfaces are critical for ***interoperability*** and where standards are defined (or not yet defined) to support interoperability.

1.4 Globally Harmonised Reference Architecture

To establish a foundation for analysing standards, the international HTG7 team first developed the **Harmonised Architecture Reference for Technical Standards (HARTS).** HARTS facilitates the understanding of the applicability of standards (ITS standards and other Information and Communications Technology (ICT) standards) for the successful implementation of ***C-ITS services***[5]. HARTS provided the framework for the HTG7 team to identify key interfaces that need to be standardised in the public interest and served as the basis for performing the ***gap*** and ***overlap*** analysis of C-ITS standards for those interfaces.

HARTS is an internationally harmonised reference architecture based on:

- **National ITS Architecture Framework (NIAF) from Australia**
- **EU's Framework Architecture (FRAME) from Europe**
- **Connected Vehicle Reference Implementation Architecture (CVRIA) from the US**
- **C-ITS architecture constructs from Japan**

The body of work produced by HTG7 includes key resources for industry, such as HARTS and the accompanying HTG7 reports. These tools not only provide a starting point for the ITS community to address the technical and interoperability challenges that face wide-scale ITS deployment; but also provide tactical guidance on standards, solutions, and risks for current or near-term project teams planning and implementing ITS systems. Although the reports are based on a globally harmonised ***reference architecture***, they formally recognise and accommodate regional and local approaches to ITS services, solutions, and standards.

1.5 Format of HTG7 Reports

The results summarized in this Executive Summary are presented in greater detail in the HTG7 series of reports:

- **Executive Overview (HTG7-1)** - A high-level summary of the approach, process and the key results of HTG7.

[5] For the purpose of this report, the term "C-ITS service" is intended to include all ITS services encompassed by the HARTS service packages; at the time of publication 34 are available on the HARTS website (http://htg7.org).

- **Analysis Methodology (HTG7-2, this document)** - Presents the HTG7 methodology used to develop HARTS, perform the gap analysis, and develop proposed resolutions.
- **Issues and Proposed Resolutions (HTG7-3)** - Summarises the issues identified through HTG7 analysis and proposes actions to resolve the issues. It introduces a series of more detailed reports, detailed below, each of which identifies the same set of proposed resolutions but adopts a presentation format and includes details relevant to a different perspective.
    - **Results: Solution Perspective for Deployers (HTG7-3-1-AU, HTG7-3-1-EU, HTG7-3-1-JP, HTG7-3-1-US)** - Addresses development or implementation teams in their planning and procurement processes. This detailed report lists each solution along with its associated issues and proposed resolutions and is divided into four regional sub-reports, one for each participating region. (The region is reflected by the appended 2-letter region code[6]).
    - **Results: Resolution Perspective for Standards Developers (HTG7-3-2)** - Presents each proposed resolution along with its associated issues and the data exchanges affected by these issues. This detailed report can assist standards development communities and governments in their planning and work processes.
    - **Results: Service Package Perspective (HTG7-3-3-AU, HTG7-3-3-EU, HTG7-3-3-JP, HTG7-3-3-US)** - Offers road operators the opportunity to evaluate the "readiness" of ***service packages***. This detailed report lists each service package, the data exchanges contained within the service package, and the issues associated with each solution for each data exchange. In this respect, this report helps deployers understand the levels of risk due to the standards gaps. The report is divided into 4 regional reports, one for each participating region. (The region is reflected by the appended the 2-letter region code[6]).
- **HARTS Website Overview (HTG7-4)** - Provides an overview of the HARTS public website, available at http://htg7.org. It describes each aspect of the website and provides instructions on how to submit comments about the information on the website.
- **HARTS Reference Compendium (HTG7-5)** - Provides reference material including:
    - A glossary of terms and associated definitions
    - Acronyms and associated meanings
    - Graphic symbols and associated meanings
    - Explanations of key terms and their inter-relationships

[6] As defined by ISO 3166-1:2013 *Codes for the representation of names of countries and their subdivisions – Part 1: Country codes*

1.6 Conventions

While the HTG7 Report set was developed using United Kingdom (UK) English, the HARTS (toolset and website) was developed using US English. Whenever an extract from HARTS is presented within the HTG7 Report set, it will retain its US English spelling.

As noted in footnote 2 on page 2, this report is supplemented by the HARTS Reference Compendium (HTG7-5), which defines all of the terms used throughout this report set. Terms defined in the reference compendium are bold faced and italicised within each HARTS report upon their first use.

1.7 Purpose of this Document

One of the major goals of HTG7 is to facilitate successful implementations of ITS through the assessment of the ability of standards to support the exchange of information between ITS components. To enable this assessment, a harmonised reference architecture, HARTS, and supporting tools were developed to support the analysis work. Subject matter experts were engaged to identify and define the standards-based solutions that either currently support or will in the near-term be able to support the data exchange needs of the ITS services as defined in the reference architecture. Given the multi-regional scope of HTG7's charter and the diversity of communication technologies, HTG7's analysis was designed to accommodate multiple solutions as options for each data exchange.

This document, **HTG7-2: Analysis and Methodology,** describes the development of the reference architecture and its supporting tools, and describes how those tools were used to perform the HTG7 analysis.

It should be noted that HARTS represents an analysis based on available ITS and ICT standards as they existed in 2017. It is inevitable that the effectiveness and relevance of this HTG7 analysis will diminish over time given:

- The dynamic nature of technology, and
- Considerations regarding:
    - The steady evolution of service packages based on deployment lessons learned;
    - Ongoing efforts in developing and maintaining ICT and ITS standards; and
    - The emergence of enabling technologies and vehicle automation services,

However, the HARTS database and website are designed to evolve; and in particular, are designed to evolve based on inputs from HARTS users as well as updates by experts and SDOs. It is the hope of the HTG7 project team that a periodic refresh of the analysis, using the toolset that was developed and using feedback from users, will result in an up-to-date reference tool that will offer future deployers ongoing, valuable insight.

2. Develop Analysis Framework

This section describes the analysis framework established by the HTG7 team. It will outline the overall approach adopted by the team, the structure and methodology of the analysis, and the supporting infrastructure and team organisation. Each major task identified in this section will be described in more detail in subsequent sections of the document.

2.1 Develop Overall Approach

The HTG7 project team held several face-to-face planning sessions to develop an overall approach, which included identifying the necessary support platforms and tools; constructing a preliminary methodology for performing the standards analysis; and determining the team organisational structure and project member roles and responsibilities.

The HTG7 project team developed their overall approach based on the following four tenets:

1. The interfaces to be analysed should be identified using a formal structure that reflects and harmonises the existing architectural approaches used within the participating regions.
2. The analysis should focus on those interfaces of significant public interest.
3. The analysis should consider previous analyses as well as inputs from industry experts.
4. The final results need to be presented in an intuitive format that allows the ITS community to interactively explore a harmonised architecture and determine which standards apply to each interface and the associated issues.

The HTG7 project team based their overall approach on the following three primary *inputs*:

1. Architecture frameworks, reference architectures, and ***ITS application*** concepts from all participating regions
2. An informal catalogue of known ITS standards and their abstracts
3. Several ITS standards gap analyses that had been previously prepared by other teams

The HTG7 project team tailored their overall approach based on the following organisational, logistical and practical *considerations*:

1. While the collective experience and skill sets of project team members provided significant expertise in ITS, IT, and data communications standards, there were subject areas in which external subject matter expertise[7] was recognised as helpful or necessary.
2. Engaging external subject matter expertise and conducting stakeholder outreach needed to be performed in a cost-effective and efficient manner at the points in time during the analytical work when needed.
3. The project's methodology and structure needed to be flexible enough to adapt to feedback received from stakeholders.

[7] Specific subject areas where expertise was required included regional architecture context, data distribution, secure communications, security operations, and detailed interpretations of clauses within standards, among others.

4. The multi-national nature of the project necessitated that team members were geographically dispersed across widely disparate time zones but needed to regularly collaborate.
5. The project output needed to balance between incorporating regional differences while striving for an open global marketplace, which results in C-ITS services being safe and interoperable across jurisdictional borders.
6. The project structure needed to be flexible enough to allow additional regions to join the project while the analysis was underway.

2.2 Structure the Analysis

After several planning workshops, the team adopted a three-phased approach described below and depicted in Figure 1.

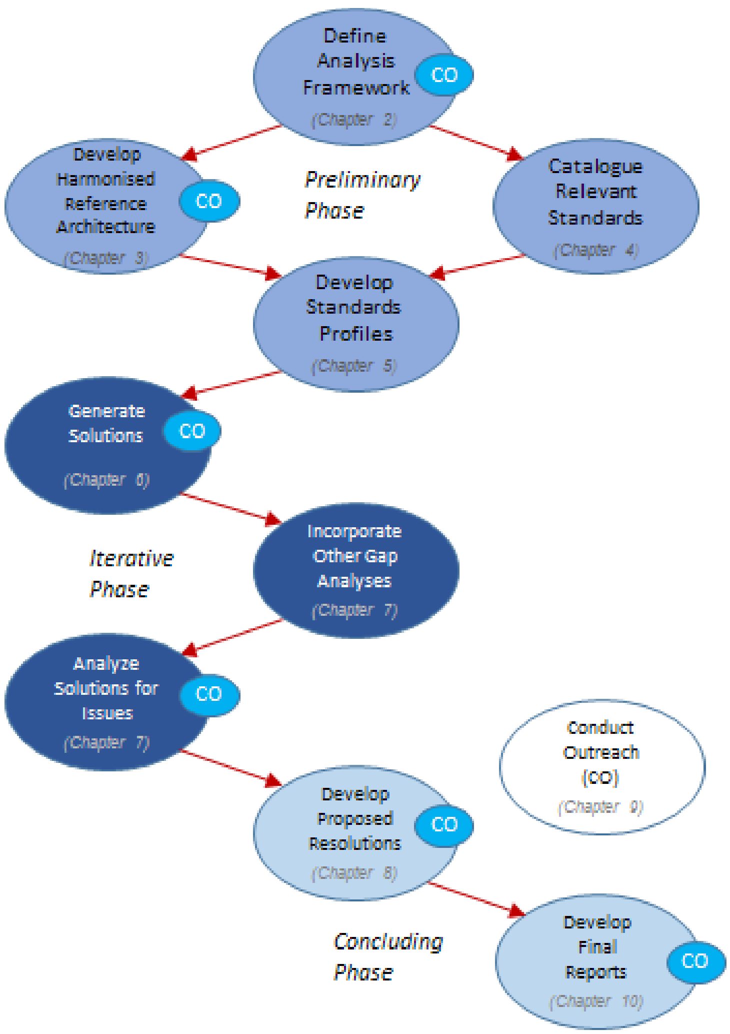

Figure 1: HTG7 Standards Analysis Process

The remainder of this report provides more details about each step of this process. Stakeholder outreach was conducted intermittently over much of the project's duration, and as depicted by the Conduct Outreach ("CO") bubbles in Figure 1, was an integral part of certain project activities. Formal outreach activities were planned after certain analysis milestones were reached which allowed the HTG7 project team to solicit feedback from experts and stakeholders. Typically, HTG7 outreach activities were scheduled at key stakeholder meetings or conferences, as described in Section 9.

2.2.1 Preliminary Phase

This initial phase focused on designing and constructing the foundation for the subsequent standards analysis. It consisted of the following tasks.

1. Define Analysis Framework
   The work to define an analysis framework consisted of establishing the overall approach, structure, and methodology of the analysis; identifying supporting platform, tools, and resources; and defining the team member roles and responsibilities.

2. Develop Harmonised Reference Architecture
   This work consisted of the synthesis of the four regional (AU, EU, JP, and US) reference architectures and components into HARTS, which provided a comprehensive harmonised reference architecture. The architecture was created in the HARTS database as described in Section 3. Various options were considered to meet the need for public access, and the team determined that a web portal would be the most appropriate mechanism, as described in Section 3.

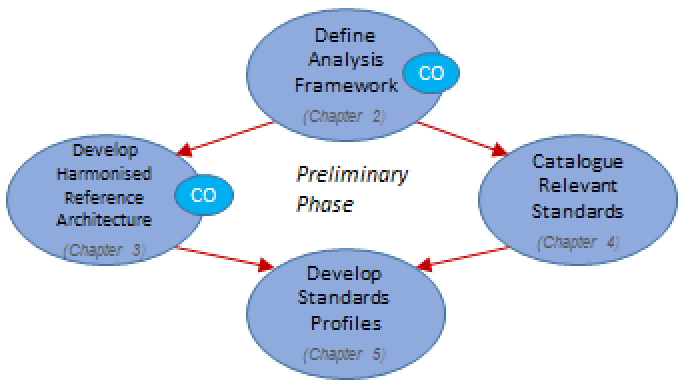

Figure 2: HTG7 Preliminary Phase

3. Catalogue Relevant Standards.
   A catalogue of relevant standards was entered into the analysis database. It was augmented as necessary during the subsequent analysis efforts. Each standard entry in the catalogue was tagged with metadata to facilitate the analysis as described in Section 4.

4. Develop Standards Profiles
   Standards ***profiles*** were developed by experts to provide reusable sets of standards that could be applied as applicable for each data exchange. Each profile was entered into the database and tagged with metadata to facilitate the subsequent analysis as described in Section 5.

2.2.2 Iterative Phase

The following tasks were performed iteratively over several stages of the project. This iterative approach was primarily adopted to allow the ***HARTS analysis team*** to validate and adjust their processes and content; and to allow reviewers and other stakeholders to examine preliminary results and website content. With the exception of step 7 below, the iterative phase was conducted on a regional basis, by the respective analysts, with frequent inter-regional collaboration and consultation.

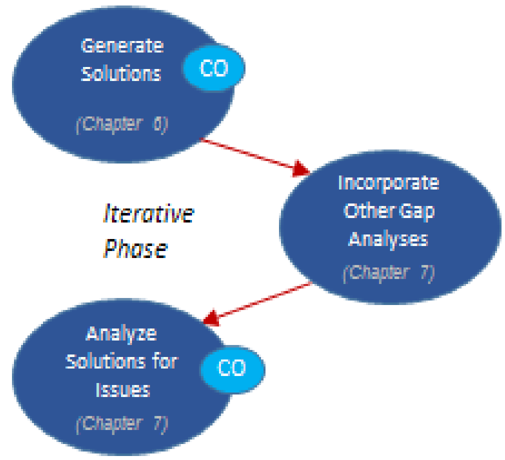

Figure 3: HTG7 Iterative Phase

5. Generate Solutions
   A rules-based database engine was used to match standards profiles to data exchanges to generate candidate solutions. The matching process was based on the metadata characteristics of the data exchange and the standards profile. All candidate solutions were subsequently reviewed and adjudicated by the HARTS analysis team with refinements made as needed. This is further detailed in Section 5.

6. Incorporate Other Gap Analyses
   Based on the results and insights provided by previous standards gap/overlap analyses, the HARTS analysts entered known issues (gaps and overlaps) into the HARTS database. Each issue entered was tagged with metadata characteristics to support analysis efforts as described in Section 6.

7. Analyse Solutions for Issues
   The analysis team methodically went through each data exchange within each service package and examined the identified standards-based solutions to identify issues. This was accomplished through use of direct knowledge about requirements of each service package, examination of the standards, and consultation with external subject matter experts. As above, each issue was appropriately tagged with metadata characteristics to support subsequent analysis, as described in Section 6. As the analysis progressed, and internal milestones were reached, a web-generation process ensured that the HARTS website was updated, as described in Section 3, iteratively to incorporate new content.

Each of the sequenced activities listed above, except for the sixth, "Incorporate Other Gap Analyses" activity, was iterated in the stages shown below. The entire list of service packages in HARTS was aligned to each stage based on the anticipated timeline for deployment. After this, and as described above, the iterative phase was conducted on a regional basis, by the corresponding analysts, with frequent inter-regional collaboration and consultation. This allowed each region to progress through the phases independently and at their own pace. Additionally, each region's analysts could focus on those phases most relevant to their region.

A. Stage A: Process & Platform Validation. A single service package, "Warnings about Upcoming Work Zones", was selected to serve as the prototype for the analysis approach.

This service package is a priority for deployments in multiple parts of the world[8] and has detailed descriptions about how it is expected to work. By choosing just one service package to start, the team was able to assess and adjust the analysis approach, toolset, and website to support an efficient and effective analysis.

B. Stage B: Early Deployment C-ITS Services. This stage addressed approximately 15 common service packages that were known to be part of active deployment projects around the world. The intent was to provide standards gap analysis information as soon as possible to assist the project teams of these on-going deployment projects as well as gain feedback and promote harmonisation across similar projects.

C. Stage C: Planned Deployment C-ITS Services. This stage continued the analysis to address another 19 service packages. When combined with the results from Stage B, approximately 35% of the service packages defined for C-ITS around the world are analysed through HTG7 efforts. This 35% of the service packages included all "Support", "Day 1", or "Day 1.5" service packages, many of which are being deployed as part of the European ***C-ROADS*** pilot deployments[9], the US Connected Vehicle Pilot deployments[10], the Australian Cooperative and Automated Vehicle Initiative (CAVI)[11] deployment, and the Japanese Electronic Toll Collection (ETC) 2.0[12] deployment.

D. Stage D: Future Deployment C-ITS Services. This stage addresses the remaining service packages. For the most part, these remaining service packages were less refined at the time of the analysis. Nonetheless, a preliminary analysis was performed for the remaining service packages. The preliminary results are not on the HARTS website but are available for potential comment, use, or tailoring by interested parties.[13]

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[8] This service package is being implemented in the C-ROADS projects across Europe (specifically: Finland, Norway, Sweden, Denmark, England, Netherlands, Belgium, Germany/Italy corridor, France, Spain, Portugal, Czech Republic, Austria, Slovenia, and Hungary), as part of the Connected and Automated Vehicle Initiative (CAVI) in Queensland, Australia, and in the United States (in the Wyoming Connected Vehicle (CV) Pilot and with a deployment in the State of Tennessee).

[9] C-Roads is a joint initiative of European Member States and road operators for testing and implementing C-ITS services. Please refer to the C-ROADS Pilots website.

[10] The USDOT is sponsoring a set of large-scale C-ITS pilot deployments across the United States. Please refer to the USDOT CV Pilots website.

[11] CAVI is a series of large-scale C-ITS pilot deployments underway in Queensland, Australia. Please refer to the CAVI website.

[12] ETC 2.0 is an electronic toll collection system that provides safe driving, congestion avoidance, disaster, and other information via C-ITS and is being deployed by East Nippon Expressway Company Limited, Central Nippon Expressway Company Limited, West Nippon Expressway Company Limited, Honshu-Shikoku Bridge Expressway Company Limited and other public corporations.

[13] Interested parties should contact htg7@dot.gov through their ISO-recognized national standards bodies.

2.2.3 Concluding Phase

After the analysts for each region completed their respective standards analysis and the results were synthesised into the HARTS database, the project entered its final phase which focused on recommending the way forward.

8. Develop Proposed Resolutions
   The analysis team evaluated the collective set of standards issues generated across all regions and developed a set of proposed resolutions for addressing them. As with the issues above, each proposed resolution was appropriately tagged with metadata characteristics to support analysis and reporting efforts as described in Section 7.

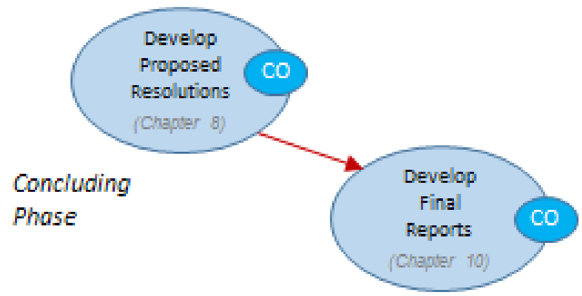

Figure 4: HTG7 Concluding Phase

9. Develop Final Reports
   The HTG7 team concluded with the development and publication of a set of final reports outlining the approach, methodology and results, as described in Section 9. A primary goal was identification of opportunities for multi-regional (harmonised) standards development activities. The proposed resolutions were categorised to reflect their expected urgency based on anticipated C-ITS deployment timelines.

2.3 Establish Internal and External Platforms

In parallel with developing the analysis methodology, the team developed the necessary internal and external platforms to support project activities. These included:

A. HARTS Analysis Toolset
   Given the anticipated size and intricacy of the planned reference architecture, the complexity of the associated analysis, and the geographically and temporally distributed workforce, the HTG project team recognised the need for a relational database and engine with sufficient processing power, storage capacity, and availability that could also provide a requisite set of analytics software tools. After discussion, the team settled on a cloud-based solution for the analysis toolset, developed in Microsoft Access on an access-controlled Microsoft Windows 10 virtual server hosted through Amazon Web Services, which would allow for easy access to our various team members located throughout the world.

B. HARTS External Portal
   The project team considered multiple options for supporting access for subject matter experts, and other stakeholders, and gravitated to a set of three websites. Each website had the same structure and format but was used for different purposes. All three websites were linked to the analysis toolset, and were dynamically populated with content; however, the graphics were developed separately and manually imported into the websites. The first (Development) was used internally to facilitate development of website content. The second (Staging) was also

used internally to adjust the graphics and validate the content, prior to public release. The third (Public) is intended for stakeholder access and is available at http://htg7.org/.

2.4 Workstreams

The project team was aligned into the following three workstreams.

1. Management with the primary responsibilities:
   - Oversight and guidance
   - Expert and stakeholder engagement
   - Commitment of resources, including meeting facilities and web conferencing capabilities
2. Architecture with the following primary responsibilities:
   - Development of the harmonised architecture and its subsequent entry into the HARTS database
   - Development and maintenance of the HARTS analysis toolset and its operating environment. In addition to the basic schema supporting the architecture and analysis, this included development of the user interface, rules engine and other processing algorithms.
   - Construction, management and support for the interactive websites, including graphics generation.
3. Analysis with the following primary responsibilities:
   - Development of the ***HARTS reference model***, including schema for the analysis portion of the HARTS database
   - Population of the HARTS database with the data required for the standards analysis
   - Definition of rules and exceptions required for the standards analysis
   - Conducting the standards analysis including the identification, assessment and characterisation of issues; and development and characterisation of proposed resolutions to address issues.
   - Development of queries and report scripts and overall analysis record keeping.

3. Develop Harmonised Reference Architecture

3.1 Overview

A formally-defined architecture provided the essential starting point for a communications-focused standards analysis. An architecture, by definition, provides a reference framework for the system it describes. The entirety of C-ITS is clearly a widely-scoped system of systems, with hundreds of interrelationships between disparate systems; the only reasonable way to conduct an analysis of these interrelationship was to bound the processing elements and delineate the exchange of information between elements as the basis for analysis. This concept of host processors exchanging information is consistent with the approaches taken by standards bodies throughout ITS, so it would be relatable to the objects being analysed, i.e., the standards. Harmonisation was necessary to capture and reflect regional perspectives and would possibly have the ancillary benefit of providing a sense of ownership among all parties.[14]

Additionally, using a harmonized architecture facilitates extensibility as C-ITS evolves, and expandability in the event that other regions wish to participate. Furthermore, the harmonised architecture allowed a single consistent gap analysis to reflect the needs of all participating regions. Any ensuing standards analyses, whether due to the extension of C-ITS, expansion of the architecture, or the evolution of standards, will be facilitated by simply extending this analysis.

3.2 Reference Architecture Sources

There are six major sources of ITS content included in the HTG7 harmonised reference architecture:

1) C-ITS-related aspects of FRAME; FRAME has one View, the functional[15], which is similar in form to the CVRIA's functional. [16]
2) C-ITS-related aspects of the Australian National ITS Architecture, which is based on FRAME but has some ancillary material related to communications.[17]
3) The CVRIA [18] , which includes four Views: Enterprise, Physical, Functional and Communications, specified in a form compatible with International Organisation for Standardisation (ISO) 42010: Systems and Software Definition: Architecture Description. During project execution, ARC-IT[19] was introduced in the US as the next-generation

[14] This could only be done effectively, in part, if there was a common terminology adapted by the project. The resultant terminology is found in the accompanying **HARTS Reference Compendium (HTG7-5)**.

[15] https://frame-online.eu/frame-architecture/faqs/what-is-a-functional-view

[16] Particular thanks is given to Richard Bossom for his help in assisting the HTG7 team in incorporating FRAME information into HARTS.

[17] https://austroads.com.au/network-operations/network-management/national-its-architecture

[18] https://local.iteris.com/cvria/

[19] http://arc-it.org

replacement for CVRIA. The project team decided not to wholly revise HARTS to reflect the differences between CVRIA and ARC-IT, as this would have introduced re-work and delays. Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) content was introduced on a case-by-case basis when such introduction would not adversely affect the HARTS analysis, would simplify the architecture and/or reflected a fundamental change in a support service.

4) Japanese V2I architecture.[20]
5) ISO 21217 and related standards information that are specific to C-ITS services. These standards are focused on functionality, though the linkage between physical and functional is often straightforward and the detail regarding communications technology is relatable to HARTS.[21]
6) ETSI Day 1 applications that are not already in CVRIA or FRAME[22]

The first four of these sources were used in defining the architecture views and developing the content for each view as described in Sections 3.3 and 3.4 below. [23] ISO 21217 heavily influenced the design of the Communications View as described in Section 3.3.3 and the ETSI Day 1 applications list heavily influenced the assignment of service packages to timeline categories as defined in Section 3.4.3.

3.3 Architectural Views

HARTS provides three distinct architecture views. Each view describes the same system from different perspectives (a.k.a., viewpoints) and thereby addresses different concerns. This is somewhat analogous to how engineering plans for a building might be presented in different views. For example, building plans might include structural views, electrical views, heating and ventilation views, etc. Each of the views describe the same building and changes to one view will often impact another view; nonetheless, each view is important to address a specific set of concerns. The three views of HARTS are described in the following subsections.

3.3.1 Functional Architectural View

The Functional (Architectural) View identifies logical processes that perform ITS functions, and the data that must be exchanged between those processes. The Functional View is the

[20] https://www.hido.or.jp/distributes/index.php

[21] https://www.iso.org/standard/61570.html

[22] https://www.etsi.org/deliver/etsi_ts/102600_102699/10263701/01.01.01_60/ts_10263701v010101p.pdf

[23] Each of the source architectures continue to evolve due to a variety of factors, including new services, new technologies, new and better understanding of stakeholder needs, etc. The content within the formal source architectures was supplemented with input from multiple leading experts to reflect the latest developments within each participating region. As a result, in some cases the content of HARTS reflect slightly updated views from the source architectures, but are generally not as advanced as formal updates that were released after HARTS (e.g., CVRIA was superseded by the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) mid-way through the HTG7 effort and FRAME is currently being updated with FRAME-NEXT). NIA/F has also started an update in late 2018.

foundational material that links user needs to ITS services. However, the Functional View is effectively one step removed from the Physical View that provides context for the implementation of ITS information exchanges that are the subject of HTG7. As a result, while Functional View content is inherent to HARTS, it is not explicitly expressed on the website or in these reports.

3.3.2 Physical Architectural View

The Physical (Architectural) View identifies the physical components (called ***physical objects***) and the information flows that must occur between these physical objects to implement ITS

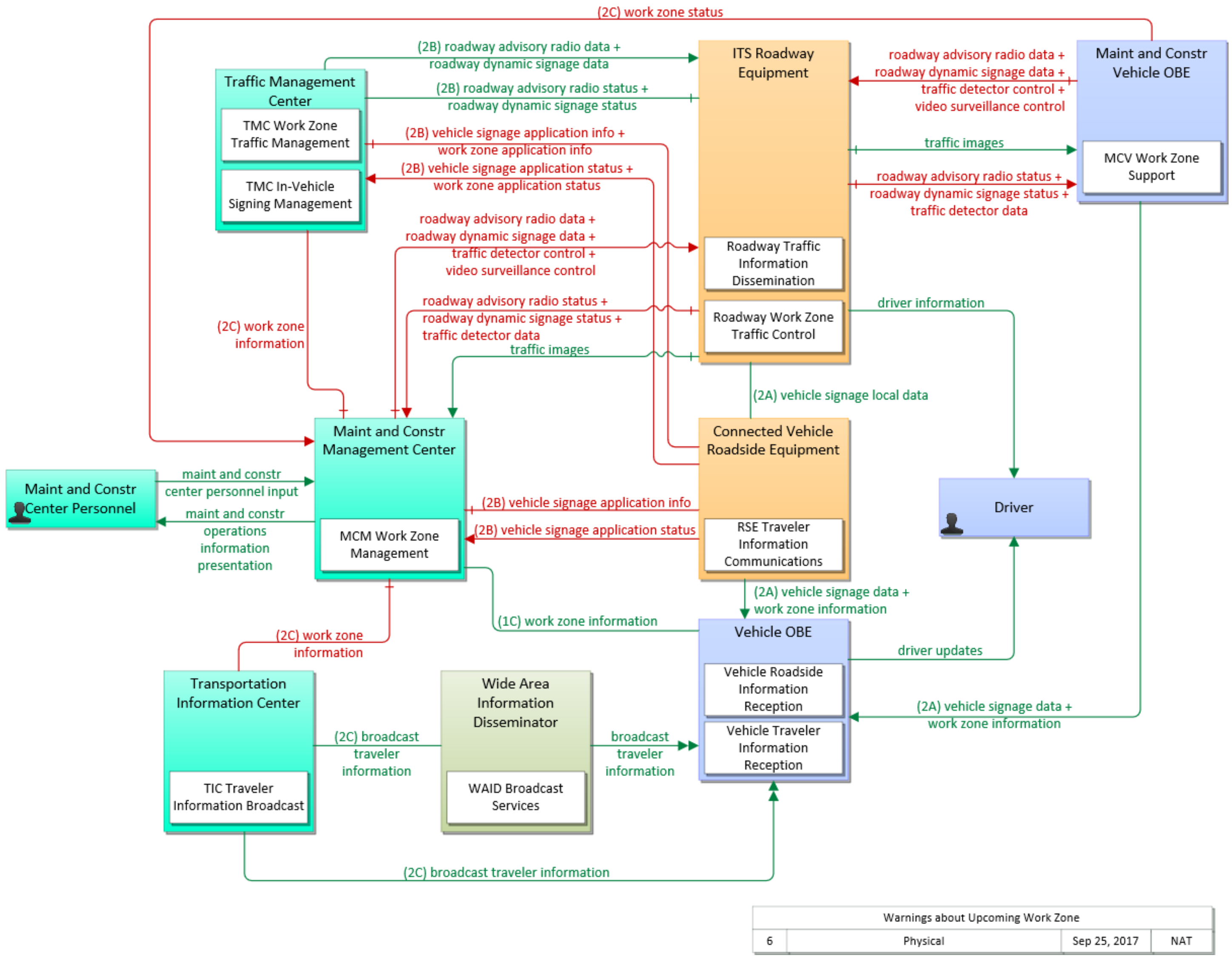

Figure 5: Service Package Diagram

services.[24] Each unique combination of a ***source*** physical object, an information flow, and a ***destination*** physical object constitutes a unique ***information triple*** (or just "triple"). The Communications View illustrates the alternative ***communication stacks*** (a.k.a., solution) that may be used to implement each triple.

The sheer complexity of ITS often makes it difficult to understand the proper context of any single information flow in isolation. To aid in the presentation of information, HARTS divides the scope of the architecture into more manageable service packages, which depict the physical objects and information flows used to deliver end-user functionality. Figure 5 (previous page) provides an example Physical View diagram for the “Warnings about Upcoming Work Zones” service package. This example is described in more detail in *HTG7-4 – HARTS Website Overview*.

3.3.3 **Communications (Architectural) View**

As part of the architecture, the Communications View identifies the reference protocol stacks (i.e., ***triple solutions***) needed to implement an information flow between a source and a destination (i.e., information triple) using industry standards. There is a distinct Communications View associated with each information triple (i.e., arrow on the ***service package diagram***). A specific triple may be included within multiple service packages, but it will only have a single Communications View. The Communications View defines the purpose of the triple and provides a listing of each triple solution defined that could potentially instantiate the triple. Each triple solution identifies known issues (e.g., gaps and overlaps) with the solution. As a corollary to the need for a harmonised reference architecture (see above), a harmonised reference model was needed to describe the communication stack for each triple solution in a consistent way. This is described in the subsections below.

3.3.3.1 Open Systems Interconnect (OSI) Reference Model

The HARTS reference model, like all of the other models mentioned below, is loosely based on the familiar Open Systems Interconnect Reference Model (OSI Model), as depicted in Figure 6. In fact, within our database system, each communication standard is assigned to one or more of the specific layers within the OSI Model. However, the HTG7 team also realises that most communication standards and implementations do not strictly conform to this reference model. There may be sub-layers that span issues between the OSI layers and in some cases, layers have interactions that are not strictly conformant with the model. For example, the upper three layers are often implemented in complex ways. Information may be encoded using one set of rules and then embedded into a packet that is encoded using another set of encoding rules (multiple times!).

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

Figure 6: OSI Model

[24] Internal data flows from the Functional View that are contained within a single physical component were not considered to be within the scope of HTG7.

Thus, rather than being a linear stack, the top three layers are often implemented in what some might describe as a ball of twine.

This also leads to confusion that the top "Application" Layer includes logic outside of communications (which it doesn't). What the model fails to show is that there is functionality above the Application Layer that is often called the "application" or "end application". This end application may or may not require access to communication functions. If it does, it should theoretically do so by accessing the Application Layer of the OSI Reference Model. However, the similarity in terms often causes confusion by those that are not experienced with this model.

Further, the reference model allows any standard at any layer to be paired with any standard at other layers; in practice, certain standards are nearly always deployed with certain pairings. For example, the Transmission Control Protocol (TCP) is seldom implemented over anything other than the Internet Protocol (IP). This is a good thing as it allows greater compatibility among off-the-shelf products than would otherwise exist while still allowing new market-driven pairings to emerge over time. This means that users can often logically group some of these layers together to reflect what is implemented rather than looking at each layer in isolation. Finally, while management and security issues can be addressed in the OSI Model, it does not distinctly depict how these issues are addressed via specific standards.

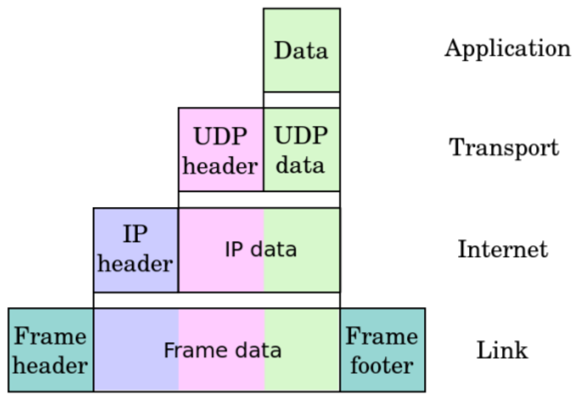

Figure 7: IETF Internet Protocol Suite (Wikipedia)

3.3.3.2 Other Reference Models

While the OSI Model is globally recognised by communication experts and a useful reference, the HTG7 group determined that it was not the best model for its purposes. The HTG7 Team noted that the Internet Engineering Task Force (IETF), Communications Access for Land Mobiles (CALM) Architecture and the National Transportation Communications for ITS Protocols (NTCIP) Framework simplify the base model in an analogous manner as shown in Figures 7, 8, and 9:

- The Physical and Data Link Layers are grouped together to describe how data is passed over a single communication link
- The Network and Transport Layers are grouped together to describe how data is passed through a network and provided to a destination process on the other side
- The top three layers (Session, Presentation, and Application) are grouped together to describe how information is packaged and encoded

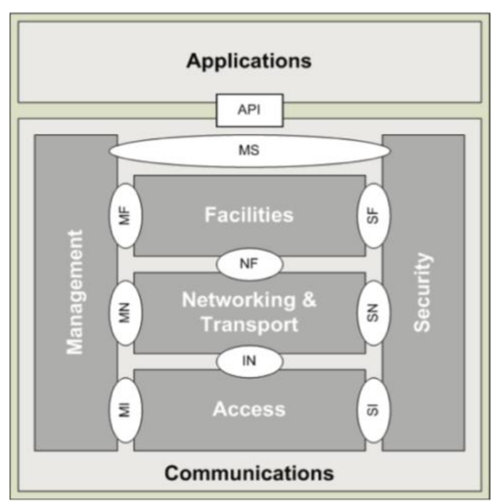

Figure 8: ITS Station architecture (ISO 21217)

- An additional layer is added above the model to describe the end application functionality

The CALM architecture defines two additional architectural entities that span all seven layers of the OSI model and respectively provide management and security services for any layer that needs them.

The HTG7 team concluded that its analysis needed a model that would group standards in an analogous way as the CALM architecture graphic. However, HARTS is intended to show all solutions, even those that do not fully conform to the more detailed requirements defined by the full CALM architecture.

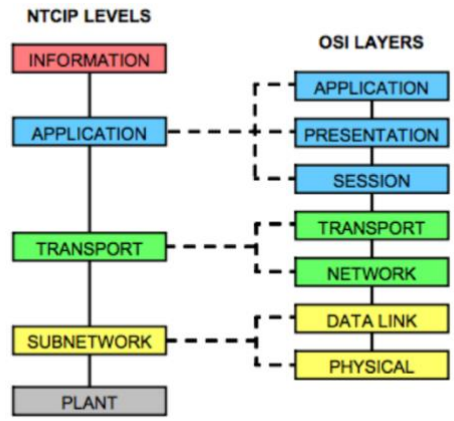

Figure 9: OSI to NTCIP Mapping (NTCIP 9001)

3.3.3.3 HARTS Reference Model

As such, in the HARTS reference model, shown in Figure 10 below:

- Layer names have been internationally harmonised for brevity and to make them more descriptive as follows:
  - The HARTS ***SubNet Layer*** maps to:
    - The Physical and Data Link Layers of the OSI Reference Model
    - The Link Layer of the IETF Internet Protocol Suite
    - The Access Layer of the CALM architecture
    - The Subnetwork Level of the NTCIP Model
  - The HARTS ***TransNet Layer*** maps to:
    - The Network and Transport Layers of the OSI Reference Model
    - The Internetworking Layer of the IETF Internet Protocol Suite
    - The Networking and Transport Layer of the CALM architecture
    - The Transport Layer of the NTCIP Model
  - The HARTS ***Facilities Layer*** maps to:
    - The upper three layers of the OSI reference model
    - The Application Layer of the IETF Internet Protocol Suite
    - The Facilities Layer of the CALM architecture but does not necessarily imply any additional functionality that may exist within a full ITS station
    - The Application Layer of the NTCIP Model
  - The HARTS ***ITS Information Layer*** maps to:
    - The Application that sits above the OSI Reference Model
    - The Application that sits above the IETF Internetwork Protocol Suite
    - The Application Layer of the CALM architecture
    - The Information Layer of the NTCIP Model
  - The HARTS ***Security Plane*** maps to:
    - The Security Architecture associated with the OSI Reference Model
    - The Security Architecture associated with the IETF Protocol Suite
    - The Security Entity of the CALM architecture
  - The HARTS ***Management Plane*** maps to:

- The Management Framework associated with the OSI Reference Model
- The Management Framework associated with the IETF Internetwork Protocol Suite
- The Management Entity of the CALM architecture

- The HARTS term ***Data Plane*** may be used to jointly refer to the SubNet, TransNet, and Facilities Layers as a whole
- The HARTS Facilities Layer includes the definition of encoding rules, dialogues, and message structures
- The HARTS ITS Information Layer includes the definition of data elements, performance criteria, and functionality
- The HARTS reference model does not define the existence of access points between layers; while these may exist, they are not required as that level of detail is beyond the scope of the HTG7 effort
- Standards are often only shown in the area of the HARTS reference model that is most descriptive of its role in the model. HTG7 realises that some standards could be placed in multiple locations, but the goal of our model is not to precisely display all the details of the solution, but rather to highlight the standards that are required. It is left to the implementer to investigate the full range of requirements within each standard. For example, Transport Layer Security (TLS) is only listed in the Security Plane, even though it could also be shown in the Data Plane.
- The general term “area” is used to identify any of the 6 identified portions of the HARTS reference model, which includes any of the three layers of the Data Plane, the Management Plane, the Security Plane, or the ITS Information Layer.

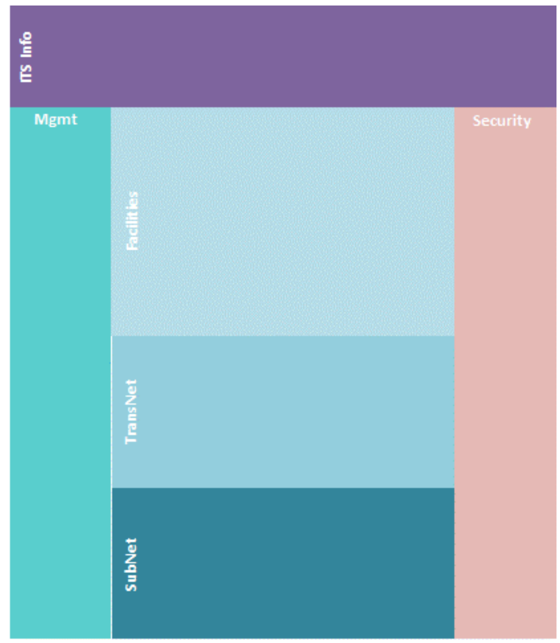

Figure 10: HARTS Reference Model

The complete HARTS reference model is shown in Figure 10, above.

The description of the HARTS reference model and the associated standards profiles (Section 5 below) are only provided so that the reader can understand the process used by HTG7 in its analysis. It is not intended that the definition of these profiles have any impact on the design of implementations.

3.4 Synthesising the Architecture

3.4.1 Combining the Functional Views

To combine the different source architectures, the HTG7 team adopted a systematic approach[25], which began with the identification of stakeholder concerns. The team concluded that the stakeholder concerns relevant to the HTG7 effort could be substantially addressed by three of the four architecture viewpoints already included within the CVRIA (Functional, Physical, and Communication). Further, previous efforts had already developed and proven a process by which Australia-specific and EU-specific applications, along with several Japanese-specific constructs could be imported into the CVRIA. This allowed the HTG7 team to expedite some of the cross-region import work necessary to produce the harmonized architecture.

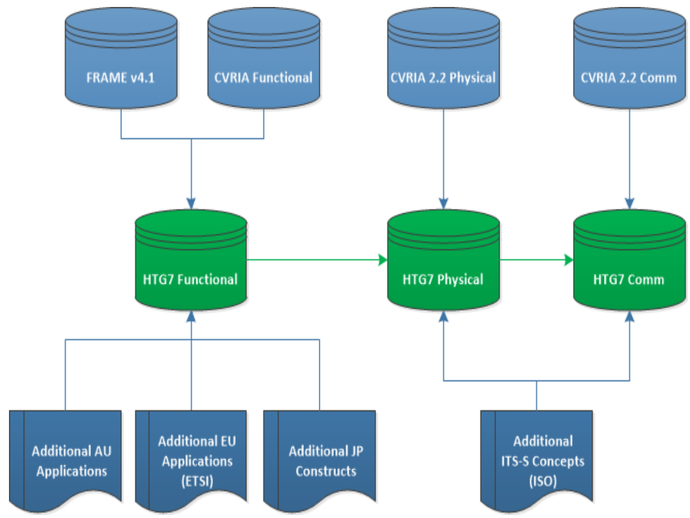

Figure 11: Architecture Harmonisation Process

As depicted in Figure 11, importing information from the other source architectures began by mapping content into the ***Functional View***. Since FRAME was developed by engineers that worked on the original Logical Architecture portion of the US ITS Reference Architecture, FRAME's functional schema mapped very closely to the CVRIA's Functional View schema. Further, portions of the Australian and Japanese content had already been incorporated into the CVRIA.

3.4.2 Physical and Communications Views

Once the HARTS Functional View was established, the architecture team worked on the ***Physical View*** then the Communications View content. The Physical view is key to contextualizing the Communications View. This process was considerably faster than the functional import, as CVRIA was the only base source that included both Physical View and Communications View content. Since there are correspondence rules dictating the relationship between functional artefacts and physical artefacts, this process went relatively quickly and without controversy.

There are several key distinguishing features that differentiate HARTS from CVRIA, FRAME, or NIAF:

[25] This approach follows the principles defined in ISO/IEC/IEEE 42010 *"Systems and software engineering — Architecture description"*.

- The focus in HARTS is on the data exchanges (also known as "triples"), and not the functionality of the endpoints, other than in their support for the information flow. Consequently, the Communications View for HARTS is vastly more sophisticated than any of the other architectures' analysis of communications flows. It is both more detailed and more flexible, while maintaining traceability and consistency.
- Each information flow in HARTS has been given additional characteristics necessary to ensure that proposed standards-based solutions are suitable during the subsequent analysis.
- HARTS only includes those external (non-ITS) components where they directly interface to ITS objects.
- HARTS does not include other views such as Enterprise or Information Views, as these views were not relevant to the communications-centric, standards-based analysis of HTG7, and because HARTS is not intended as a replacement for existing architectures.
- HARTS Physical View diagrams provide context for the Communications View. However, because HARTS is focused on precisely identifying issues in ITS standards, some of the information flows adopted from other architectures, were subsequently split into multiple flows appropriate to endpoint-specific solutions. For example, Figure 12 shows two flows from the CVRIA architecture that are exchanged between Traffic Management Centres and ITS Roadway Equipment; Figure 13 shows this same exchange on information using four flows to distinguish the different flows that will be used to communicate with each major type of field equipment (detectors, signal controllers, message signs, etc.)

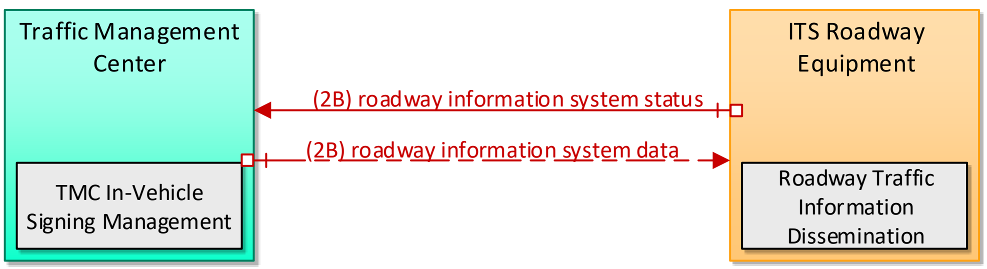

Figure 12 Sample CVRIA Generic Information Flows

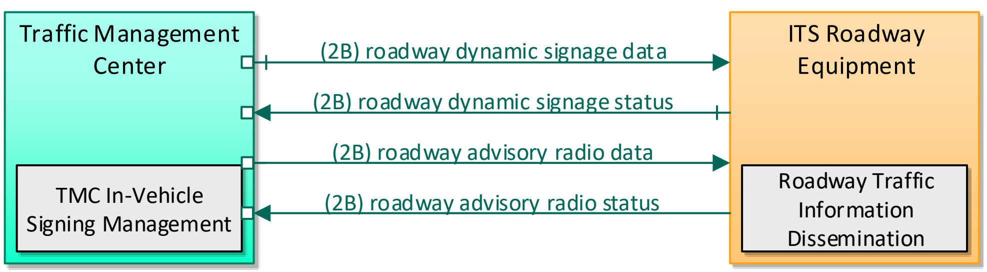

Figure 13 Corresponding HARTS Information Flows

3.4.3 Alignment to Deployment Timeline

The above harmonized architecture development process was followed to incorporate the ninety-six harmonised service packages into HARTS. Thirty-four of these service packages were identified by the participating regions as “Support”, “Day 1”, or “Day 1.5” service packages and were therefore fully analysed; the other sixty-two service packages received a preliminary analysis. The definition of these terms is as follows:

- **Support** - The eight Support service packages provide C-ITS services that enable other C-ITS services. For example, the Security and Credentials Management service package is only useful to the extent that it enables a secure environment for all other service packages to operate. Support service packages are the foundation of nearly every C-ITS service in HARTS and are anticipated to provide a critical trust and authentication service foundation for automated transportation technologies as well.
- **Day 1** - The fourteen Day 1 service packages (or significant portions of each) are included in current pilot deployments, early deployments, and/or are undergoing prototyping and testing efforts. There is an expectation that these will be the first set of C-ITS services to be widely deployed and put into operation.
- **Day 1.5** - Significant portions of the twelve Day 1.5 service packages are of general interest for near-term deployment but were not as mature as the Day 1 service packages when the HTG7 analysis began.
- **Other** - The remaining sixty-two service packages are of interest to the stakeholder community, but they are not expected to be needed in the near-term or are not sufficiently mature for near-term deployment.

3.4.4 Baseline Architecture

The resultant reference architecture provides a solid baseline into which other regional architectures can be imported. The relative ease with which this architecture was produced suggests that additional unique data exchanges or architectural components can be introduced based on regional architecture needs.

3.5 HARTS Website

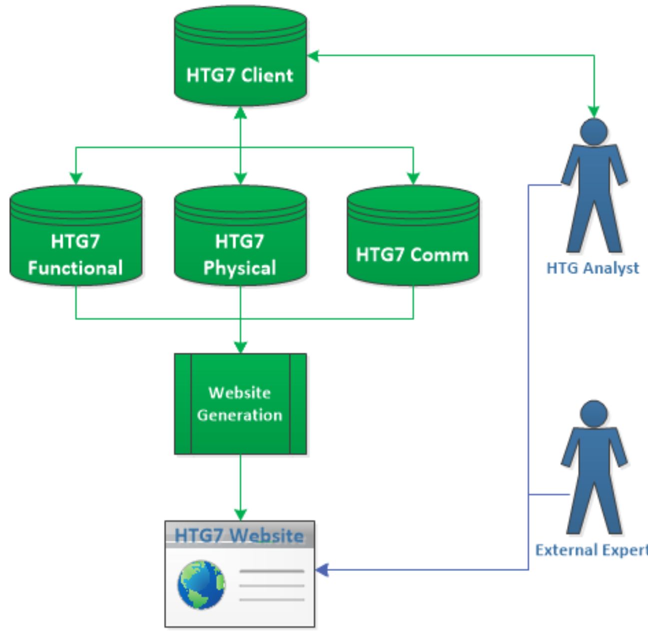

Figure 14: HARTS Website Generation

By using the CVRIA as the baseline structure for HARTS, the HTG7 team was able to benefit from a set of associated tools to assist in the development of the HARTS website. While these tools had to be modified to accommodate the enhancements made to the HARTS schema and to address some of the stakeholder concerns specific the HTG7, the synergy enabled the rapid development of a largely automated process to update the public website. Each time the website needed to be updated, a custom website generation tool was run, as depicted in Figure 14. This tool performs a series of queries against the HARTS database, and the results of those queries are fed into custom software, along with some manually created graphics, to generate the HTML and JavaScript that make up all of the different pages on the HARTS website. The resulting website allows users to view and identify the standards required to implement data exchanges that are in the public interest.

4. Catalogue Relevant Standards

At the same time the harmonised architecture was being constructed and entered into the HARTS database, the HARTS analysis team proceeded with the cataloguing of the standards into the database.

4.1 Determine Standards to Catalogue

The catalogue in the HARTS database was initially populated with readily obtained listings and abstracts of current standards available from ITS-related technical committees within standards development organisations (SDO). This initial list was supplemented with additional catalogue entries for current and emerging standards which were most likely to be needed to build the Communications Views for the service packages in HARTS (e.g., Internet Request for Comments (RFCs) and new standards that were not in our initial listing). As the analysis unfolded, additional standards and new SDOs were introduced when needed. While the focus was on those standards directly supporting the flow of information, certain technical reports and meta-standards were also included; mostly when they were included in the initial list of standards provided by ITS-related technical committees. When available, test standards were included as they are valuable to deployment efforts; but they may not be needed in all cases, and the lack of them was not considered a gating factor. While of lower priority, the lack of these standards for many of the mainstream standards should be addressed when feasible.

The HTG7 project team identified roughly 900 standards-related documents used within ITS from multiple SDOs, including:

- American Public Transportation Association (APTA)
- Association of Radio Industries and Businesses (ARIB)
- European Committee for Standardisation (CEN)
- European Telecommunications Standards Institute (ETSI)
- Highway Industry Development Organisation (HIDO) Standardisation Committee
- Internet Advisory Board (IAB)
- Institute of Electrical and Electronic Engineers (IEEE)
- Internet Engineering Task Force (IETF)
- Institute of Transportation Engineers (ITE)
- International Organisation for Standardisation (ISO)
- Japan Electronics and Information Technology Industries Association (JEITA)
- National Electrical Manufacturers Association (NEMA)
- National Marine Electronics Association (NMEA)
- National Radio Systems Committee (NRSC)
- National Transportation Communications for ITS Protocols (NTCIP)
- Organisation for the Advancement of Structured Information Standards (OASIS)
- Object Management Group (OMG)
- Society of Automotive Engineers (SAE)
- Urban Traffic Management and Control (UTMC)
- World Wide Web Consortium (W3C)

4.2 Characterise Standards with Metadata

Each standard catalogued in the HARTS database was characterised in numerous ways to assist the HTG7 team in referencing relevant standards in a timely manner. The characterisations included:

- The type of standard, which included
    - ~450 communication-related standards
    - ~50 security standards
    - ~100 testing standards
    - ~50 meta-standards
    - ~250 other standards and technical reports
- For communication standards, the OSI Reference Model layer(s) in which they reside, or to which they most closely relate
- The SDO that developed the standard
- The approval status of the standard
- A description of the standard

4.3 Create Standards Bundles

In some cases, a specific area of the HARTS reference model may be properly populated with multiple standards. For example, the Internet Protocol is defined by several specific IETF Requests for Comments (RFCs). Listing each of these standards may be more confusing to the reader than providing a simple group reference name. In this case, HARTS supports the construct of a standards ***bundle***. Bundles are groups of related standards that jointly fulfil a role of one Layer of the HARTS reference model and are given a collective name for easy reference. In addition to providing increased visual clarity and simplicity when presented on the HTG7 Website, these "building block" constructs saved needless re-keying, and increased flexibility and reuse capability.

A bundle may represent a real standard (i.e., a standardised document with a standard number that references other standards, such as NTCIP 2101) or may be an informal grouping to facilitate the HTG7 analysis effort (e.g., "Bundle: NTP" groups 4 distinct Request for Comments (RFC) under a single heading, even though there is no formal standard that defines this as a single group).

The standards referenced by a bundle can be defined as "required", "optional", or "alternative". If a contained standard is required, it must always be a part of the solution. If it is optional, it may or may not be supported.

If a standard is marked as an alternative, it means any given implementation of the solution will only use one of the alternatives listed for that particular information exchange. However, the device itself may support one or more alternatives. For example, ***WiFi®*** and Wired Ethernet are two alternatives for Internet communications, and one or both might be actively supported by any given physical object. Regardless, for each particular information exchange, only one alternative would be used. If a device supports both alternatives, then subsequent information exchanges could use either alternative, based on expediency. The concept of alternatives as used within the HARTS reference model greatly simplifies the presentation of real-world alternatives. Rather than presenting the user of HARTS with a nearly endless number of ***alternative triple solutions*** for a given information flow, it could present a relatively small number of complete triple solutions (often one per region) and then indicate the options available within each of the areas of the HARTS reference model. The inter-relationships among standards at various layers is another reason why the HARTS reference model was preferred for the purpose of our analysis over the more widely recognised OSI model.[26]

[26] HTG7 recognises the benefits of other reference models, especially for implementation modularity, but the HARTS Reference Model has proven to be a useful tool for our limited purposes which deals with these issues at a more abstract level.

5. Develop Standards Profiles

Once the standards[27] were catalogued, the HTG7 team constructed standards profiles using the HARTS reference model as a foundation. These profiles provided reusable modules for assignment to triple solutions for each of the many information triples in HARTS. This would both decrease the level of effort and significantly reduce the probability of errors in developing the Communications Views. Furthermore, they provided a more precise allocation of standards-related issues through an additional level of abstraction. In other words, an issue (i.e., a gap or overlap) could be assigned to a profile or a standard. Any triple solution using the profile or standard would then inherit the defined issue through the database logic. (Issues can also be assigned directly to a triple solution as described later.)

In certain cases, the combination of standards to meet needs were well defined, and specified in an industry standard or technical specification. In other cases, external Subject Matter Experts (SME) were consulted to help construct or complete the standards profile. For the most part though, the profiles were constructed by the HARTS analysis team by web-based searches and consultation with standards developers and other SMEs.

These standards profiles were then categorised based on the collective capabilities they provided (e.g. ***confidentiality***, ***availability***, ***latency***). This would be used to generate candidate solutions based on a match of profile characteristics to the characteristics required by each information flow (triple) in HARTS.

During preliminary analysis, the HTG7 team realised that the frequency of use for standards in the catalogue typically decreased at progressively higher layers of the HARTS reference model. This illustrated a strong delineation above and below the Facilities Layer. This indicated that there could be significant advantages in terms of both flexibility and efficiency necessary to streamline and expedite the analysis, if the layers of the HARTS reference model were allocated into two profile types, a HARTS ***communication profile*** and a HARTS ***data profile***, as shown in Figure 15, below. This would result in the need for a relatively small number of communication profiles, with many more data profiles, as data profiles tend to be unique to the needs of a given information flow or triple. Different metadata was tailored to characterise the instantiations of each profile type.

[27] The HTG7 effort was limited to a review of standards; it did not analyse the state of tools or institutional structures that may be required to realise the implementation of the identified standards. For example, the analysis did not consider whether certification authorities required by standards existed.

Once created, the various instantiations of these two different profile types, communication profile and a data profile, could be concatenated to generate candidate solutions. Understanding the communication profiles and data profiles are key to understanding how a rules-based analysis engine was used to generate our base set of solutions.

5.1 HTG7 Communication Profiles

The need and use for communication profiles stemmed from the realisation that most ITS data exchanges will likely rely on one of a relatively small set of lower layer protocol stacks. In fact, for most information flows, the likely set of lower layer standards can be determined by:

1. The type of communications link involved (e.g., centre-to-centre, centre-to-field, short-range wireless)
2. The region of the world in which the ITS Service would be deployed

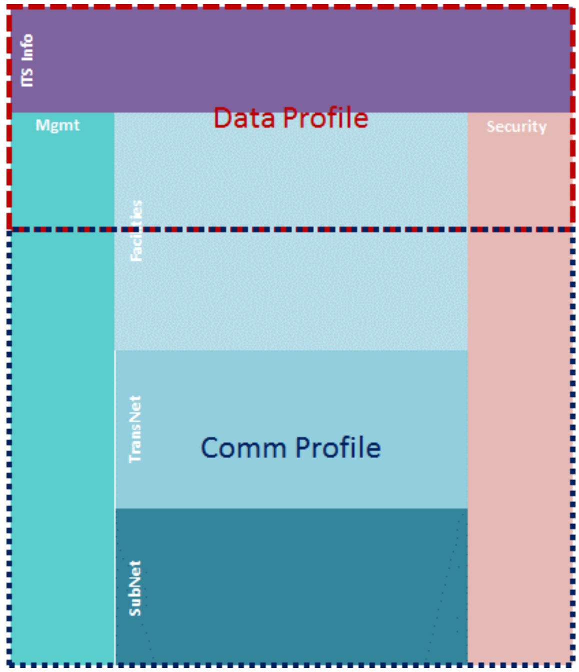

Figure 15: HARTS Reference Model Profiles

For example, short range wireless exchanges will use one of a small number of defined protocol stacks (e.g., ***Wireless Access in Vehicular Environments*** [WAVE], ***G5***, ***M5***, etc.); the selection of which will be determined largely based on deployment location.

As outlined in the previous section, rather than repeatedly defining each of the standards used in the lower layers for every information flow, the HTG7 Team defined a set of communication profiles that could be easily and repeatedly referenced. The communication profile still contains the full detail of the lower layers, but it provides a useful grouping to reduce the level of effort (and the chance of errors) in completing our analysis.

The communication profile includes a complete definition of the SubNet and TransNet Layers. It also includes any generic Facilities Layer standards. For example, this would include any generic ***information and communications technology*** (ICT) standards that might be used to package information, such as ***Simple Network Management Protocol*** (SNMP), ***File Transfer Protocol*** (FTP), ***Hypertext Transfer Protocol*** (HTTP), etc. The communication profile also includes any management and security standards that are used by these layers.

While the large majority of HARTS information triples fit into this paradigm, the ***HARTS Toolset*** still allows custom communication profiles to be defined and assigned to specific information flows, as needed. Therefore, the approach eased the development of solutions without inhibiting any of the flexibility of the system.

5.2 HTG7 Data Profiles

Analogous to the communication profile (above), the need for a data profile was based on the realisation that most of the information flows defined in the harmonised architecture are implemented with a specific set of standards independent of whichever lower layers protocols might be used to exchange the data. For example, the same set of data, encoding, and security standards might be used over different communication links (e.g., centre-to-vehicle and dedicated short range). In the case of centre-to-centre links, different regions of the world may use the same communication profiles while using different data profiles.

Furthermore, the same data profile may be used for multiple information flows or information flow triples, since many standards are broader in scope than a single flow. Therefore, grouping the standards into a single data profile is a useful way to define the combination of standards a single time while referring to it multiple times. Once again, this is primarily an HTG7 artifice used to reduce our workload in analysing the triples in Support, Day 1 and Day 1.5 service packages; it does not impose any restrictions or new requirements on deployments.

A data profile defines the necessary ITS information and the high-level rules for exchanging this information with its peer entity but does not define how the information is transported to the other entity. Much of this ITS information is defined as part of the ITS Information Layer (above the OSI Model), but may also include rules related to:

- Sequencing of messages
- Encoding
- Sessions
- Security (used by the ITS application)
- Management (of the ITS application)

As such, a data profile may include standards in the following areas of the HARTS reference model:

- ITS Information Layer
- Facilities Layer
- Management Plane
- Security Plane

Standards in the Facilities Layer, Security Plane, and Management Plane can be placed in either communication profiles or data profiles. The determination was at the discretion of the HTG7 analyst, but typically, generic ICT standards were assigned to a communication profile and ITS standards that define specific requirements to a particular information flow were assigned to a data profile.

6. Generate Solutions

Once the architecture, standards, and profiles were defined, most of the potential solutions could be generated automatically by the HARTS database engine through a set of relatively simple rules. However, these formulaic rules did not always produce the correct real-world result. Once the potential solutions were generated, they were manually reviewed by the HTG7 analysis team. For each region, the respective analysts meticulously reviewed each triple solution generated for each information triple relevant to the region, who refined the results by defining exceptions and in some cases overriding the generated solution. This process is described in more detail in Section 6.

6.1 Construct Rules and Exceptions

The HARTS analysis team developed a set of rules to assign communication and data profiles based on the characteristics of the information triples, as defined in HARTS. In other words, each rule would establish filter criteria; the database routine would then assign the associated profile only if all filters associated with the rule were passed. The assignment of communication profiles tended to be based largely on the type of communication link connecting the two physical objects while the assignment of data profiles tended to be based largely on the information being exchanged.

Exceptions were also defined and are very similar to rules, using the same structure and syntax, but usually define a more specific scope by adding additional filters. When an exception applies to a triple, it blocks the generation of any rule-based solution. Exceptions are typically only developed to adjust or augment the set of candidate solutions generated by the defined rules. This highlights the importance of correct metadata tagging for information triples.

6.1.1 Communication Profile Rules & Exceptions

The following table identifies the key characteristics that were or potentially could be used for assigning communication profiles based on the characteristics of each information flow.

Table 1: Communications Rules Characteristics

Characteristic	Description
Affinity Profile	In some cases, the analysts only wanted a communication profile rule to apply when a specific data profile was selected. This rule ensured that this affinity was realized in the resulting solution.
Availability	The minimum availability (any, low, moderate, high) required by an information triple for this rule to apply. For example, if an information triple requires moderate availability and the rule indicates a high availability, a candidate solution will be generated.

Characteristic	Description
Cardinality	The cardinality (e.g. broadcast, unicast) required by an information triple for this rule to apply. For example, if an information triple requires unicast, a candidate solution will only be generated if the rule also indicates unicast.
Communications Link Type	The type of communications link (e.g., centre-to-centre, short-range wireless, etc.) to which the rule applies
Confidentiality	The minimum confidentiality (any, low, high) required by an information triple for this rule to apply. (Confidentiality is typically implemented through encryption, which is most commonly accomplished using a digital certificate.)
Destination Class	The class of the destination physical object (e.g. vehicle, field, centre) to which the rule applies
Integrity	The minimum integrity (any, low, moderate, high) required by an information triple for this rule to apply. (Integrity is typically implemented through digital signatures, which is most commonly accomplished using a digital certificate.)
Latency	The maximum latency (ultra-low, low) allowable under typical operational conditions for this rule to apply. (This includes any latency internal to the responding physical object).
Region	The identifier for the region(s) to which the rule applies
Source Class	The class of the source physical object (e.g. vehicle, field, centre) to which the rule applies

The filters for exceptions are identical except that the source and destination filters are specific physical object types (e.g., “Traffic Management Centre”) rather than physical object classes (e.g., “Centre”).

For example, one standing rule is all information flows that are characterised as “Short Range Wireless”, “broadcast”, “Ultralow” latency, and applicable to the US region are assigned a “WAVE WSMP” communication profile. If instead, a given information flow needs an (Internet Protocol version 6 (IPv6) stack, the analysts could have either defined an exception to this rule (and applied the exception to any flow meeting a specified set of conditions), or manually overridden the automatically generated solution for the specific information flow.

The HARTS database tools also allowed the analysts to create multiple alternative triple solutions. For example, all information flows that were defined as “Short Range Wireless” with “Ultralow” latency and applicable to the EU region were assigned to both an “M5 FNTP” and a “G5 BTP” communication profile. For the moment, these are two alternative stacks and these rules ensured that both options were produced. Automatically assigning solutions in this way occasionally created inappropriate combinations. Analysts reviewed all generated solutions and either refined the rules for solution assignment, or overrode incorrectly generated solutions, depending on which approach was more efficient. Generally, this meant manually overriding solutions rather than creating more complex rules and exceptions

6.1.2 Data Profile Rules & Exceptions

The assignment of HARTS data profiles to information triple is primarily based on the name of the information flow and the region(s) where the information flow will be used, although other characteristics may be used as well. Many of the information flows contained in HARTS (especially within Day 1.5 and Other service packages) have not yet been standardised; in this case, the analysts assigned a default data profile, "(None-Data)", which had already been associated with the "Data profile not defined" gap. As with communication profiles, exceptions were defined for the data profile rules.

6.2 Generate Candidate Triple Solutions

As the analysis team created the requisite communication and data profiles, and the requisite rules and exceptions, an analyst could manually trigger the database engine to generate candidate triple solutions as follows.

- Existing triple solutions in the database are deleted except when tagged by the analysis team for retention.
- The HARTS database engine then assigns communication and data profiles based on the defined rules and exceptions to each information triple.
- The HARTS database engine then combines the two sets together, by region of the world, to produce a complete set of candidate triple solutions for each information triple defined in HARTS.

Assuming the rules and exceptions are both in place and defined correctly, the data and communication profiles for each region will be correctly matched, and each information triple will have one or more viable candidate triple solutions for each information triple.

The Management, Facilities, and Security planes of the HARTS reference model will combine standards from both the communication profile and the data profile. The ordering of standards displayed within each area of the HARTS reference model when displayed in Communications View diagrams is configurable as a part of the profile and/or bundle specification.

The result of this process is that the database engine can auto-generate an approximate 90% candidate triple solution set in a more orderly fashion that ensures better consistency of triple solutions than would likely be achieved if the analysts only considered each triple in isolation.

6.3 Validate Candidate Triple Solutions

The candidate triple solutions were subsequently validated through manual review to determine if they would be appropriate. This was done methodically for each Stage (e.g., A, B, etc.) of the project (as defined in Section 2.2.2), and shown in Figure 16:

- for each region
- for each service package applicable to the region
- for the information triples within that service package
- for the regional triple solutions for that information triple
- then finally for each area of the HARTS reference model for that triple solutions

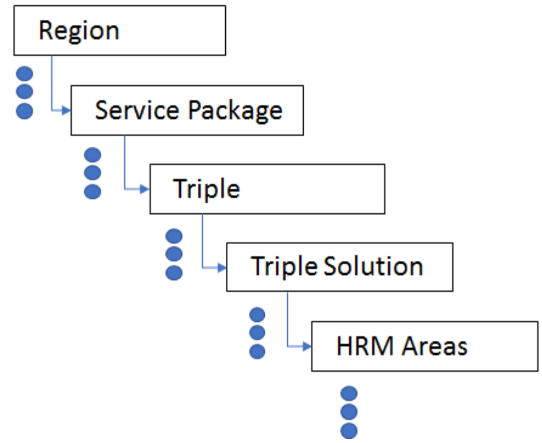

Figure 16: Triple Solution Validation Process

While the current version of HARTS includes a large number of triples (i.e., source, information flow, and destination); many of the defined triples were not analysed due to the following scope limitations:

1. Our efforts focused on the Support, Day 1, and Day 1.5 service packages.[28] Other (future) service packages are more likely to be revised as the services are better understood and supporting technologies change. While it was important to include these service packages in the reference architecture to ensure that the architectural structure will be able to support these services, it is less of a priority to perform a formal gap analysis on these interfaces as details may change over time and many of these triples do not have any existing standards (i.e., the gap would be "Data profile not defined").
2. HTG7 considered that it was not in the public interest to expend resources in attempting to standardise the human-machine interfaces. Competitive differentiation, rapidly changing technology, and end user preferences would make standardisation in this area difficult.
3. It is also not in the public interest to expend resources in attempting to define or even enumerate all the possible standards to boundary objects where outside groups are likely to define standards. For example, interfaces with social media, payment systems, and other Internet services are outside the scope of the HTG7 analysis.
4. Finally, HTG7 decided not to focus on identifying standards for the interaction between the Vehicle On-Board Equipment (OBE) and the In-vehicle network. While it is recognised that this interface will need to be defined, there is an ongoing debate as to whether this interface is an integral part of ITS or whether it is a boundary to an external system that is defined by other groups.

The end result is that the HTG7 analysis focused the full gap analysis on the triples that were determined to be within scope of the Support, Day 1 and Day 1.5 service packages.

[28] Appendix A provides a listing of Support, Day 1, and Day 1.5 service packages. Section 7.1 of the **HARTS Reference Compendium (HTG7-5)** provides a listing of all service packages included within HARTS analysis.

Once reviewed, the analysts applied a retention flag to a candidate triple solution to render it permanent; so that re-execution of the rules did not cause it to be deleted. In cases when the HARTS rules were not able to generate a specific triple solution that is or would be appropriate for a region, the analysts could manually create the missing triple solution and flag it for retention as well.

In the ideal scenario, the entire ITS community would use a single set of triple solutions for each defined information triple, and these solutions would meet all requirements placed on the triple. In practice, this seldom occurs.

As needed, refinements were made to the rules and exceptions so that subsequent re-execution of the solution generator produced a revised candidate triple solution set. This was significant, as the analysts could effect a change to one of the profile definitions, and the HARTS database engine would auto-correct the change in all associated triple solutions.

7. Analyse Solutions for Issues

As the triple solutions were being generated and validated, the HARTS analysis team also started the identification and database capture of issues within the associated standards. There are two broad categories of issues that are documented in HARTS: gaps and overlaps.

Gaps

If a solution did not meet all requirements of the information triple, it is said to have a "gap". For example, if a data profile that is assigned to an information triple fails to include all information required by that information flow, a gap was identified. Likewise, if a solution fails to provide the security required by the triple definition, a gap was identified.

Overlaps

In some cases, there may be multiple standards that provide different solutions to the same technical objective. When these solutions exist to accommodate different environments, they can be seen as deployment "*alternatives"*. For example, there are various communication technologies available for centre-to-field communications; if the system designer ensures that the central system and the field device both support the same technology, interoperability is achieved and the various alternatives allow for the best solution to be accommodated.

However, when the system is not centrally designed, either all implementation options must be supported (by at least one side of an exchange) or rules need to be established if full interoperability is to be achieved. For example, a vehicle that only supports a European Telecommunications Standards Institute (ETSI) G5 based solution won't be able to interoperate in an environment that only supports the ISO CALM M5 standards. Such undesirable duplications are termed "*overlaps".*

Where undesirable overlaps are identified, HARTS will, when feasible, identify industry's current practice for resolving the multiple designs to achieve interoperability (e.g., it will show that the Basic Safety Message [BSM] is used in America, while the Common Awareness Message [CAM] is used in Europe and Australia). The HARTS website includes this information to assist deployments in design.

7.1 Incorporate Previous Standards Analyses

HTG7 was not the first effort attempting to identify gaps and overlaps in ITS standards or to prioritise the standards related work that needs to be done. Accordingly, HTG7 incorporates and leverages the work done by others into a single, harmonised, on-line, up-to-date reference that is easy to navigate and which produces a comprehensive analysis. Further, HARTS is explicitly designed to gain industry feedback to ensure that it reflects industry consensus on the work that needs to be done.

The HTG7 Team considered the following sources in producing its first draft of the gap analysis within HARTS:

- "Cooperative Intelligent Transport Systems (C-ITS) Standards Assessment", **Austroads** Research Report AP-R474-15, January 2015

- "Standards and actions necessary to enable urban infrastructure coordination to support Urban-ITS", **CEN TC278 PT1701** Draft Interim Report January 2016, funded by The **European Commission** V10.05
- "Cooperative ITS – Gap/Overlap analysis from a road operator's point of view (Including contribution for outreach activity)", **ISO TC204 Internal Report**, August 2016
- "ITS Standards Support Task Two: Framework White Paper: Development of the Long-term Connected Vehicles Standards Framework", Society of Automotive Engineers (**SAE)**, November 2014
- "Interface Standardization Analysis", **USDOT ITS Joint Program Office (JPO)** – ITS Standards Program, March 23, 2015.
- ITS Standards Support for the Data Capture and Management Program Technical Report 2: Recommended Modifications and Additions to ITS Standards–Final Report, **USDOT Federal Highways Administration (FHWA)** Office of Operations, October 26, 2015

7.2 Issue Detection

As described in Section 6.1 above, many issues within the ITS standards have already been identified through previous gap analyses. The HARTS Analysis Team reviewed each of the identified analyses when reviewing the HARTS information flows and attempted to incorporate these previously identified issues – while also updating the information to reflect more recent standardisation activities as well as new issues that the industry has identified since these previous reports have been produced.

The HARTS analysis team members from each region evaluated each triple solution associated with their respective region. This was done methodically, as shown in the Figure 17:

- for each service package in the current stage
- for the information triples within that service package
- for the regional triple solutions for that information triple
- then finally for each area of the HARTS reference model for that triple solutions

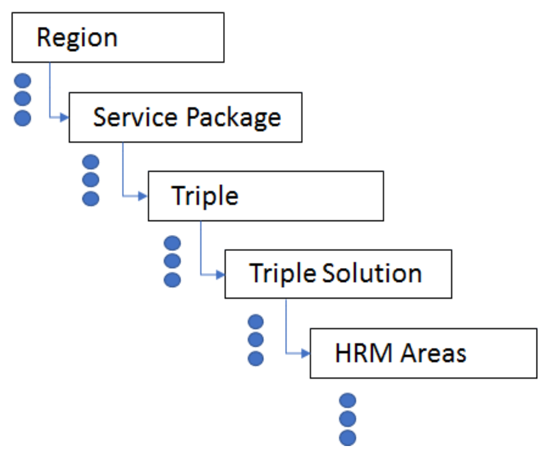

Figure 17: Issue Detection Process

As with the construction of the standards profiles, and solutions, external SMEs were engaged to help evaluate the effectiveness of the standards in each region. For the most part though, the profiles were constructed by the HARTS analysis team by examination of the standards, web-based searches and consultation with standards developers and other stakeholders.

Periodically and at the end of Stages B, C and D, (as defined in Section 2.2.2, the analysis team would review and level-set the collective issues, to ensure consistency and integrity. This was facilitated through custom database reports and queries, supplemented by ad-hoc queries.

7.3 Issue Characterisation

Each issue was assessed and characterised for the following characteristics described below.

Issue Severity

The HTG7 Team assigned each identified issue a specific severity level of: "low", "medium", "severe", or "ultra". These levels are described in the table below.

Table 2: Issue Severity Levels

Severity Level	Description
Low	The affected triple solution may be sufficient for wide-scale deployment, but known issues exist that deployments should consider
Medium	The affected triple solution may be sufficient for pilot deployments but fails to provide sufficient interoperability, management, and security to enable proper, full-scale deployment
High	The affected triple solution fails to provide even a base level of interoperability and security as recommended for pilot deployments
Ultra	Standardization efforts for major aspects of the triple solution have not even begun.

Issue Types

As the analysis progressed, the HARTS analysis team identified and recorded standards-related issues. Rather than creating an entirely new issue description each time an issue was discovered, the analysis process supported the assignment of generic "***issue types***" coupled with notes that customised the generic type to the specific assignment. The list of issue types grew as the analysis proceeded, but only contained forty-three issue types at the end of the process, listed below. Each issue type, broken down by severity is respectively shown in Tables 3, 4, 5, and 6 below.

Table 3: Low Severity Issue Types

Issue Name	Description
Accuracy of data	The standard is missing accuracy requirements for some of its data, which may cause anomalous behaviour.
Data may not be fully defined (low)	The information flow is not clear as to what precisely is needed; the standard may not fully support the needs of the information flow, depending on how it is interpreted.
Data not defined in standard format	The definition of data concepts should conform to ISO 14817-1 to promote reuse among ITS.
Guidance document under development	This recommended practice on how to use the related standards is still under development but is not seen as strictly necessary to begin deployment of ITS equipment.

Issue Name	Description
Inadequate guidance for complex data design	The standard provides a robust design, but there may be more than one way to convey the information contained in this information flow and the standard provides little or no guidance on how to use the defined structures.
Obsolete by events	This published standard sets up claims and assumes facts that conflict with the currently developed versions of the set of standards for C-ITS Release 2
Open source software	This is open-source software rather than a documented interface specification standardized through a formal and open process.
PICS available but no test case specifications	Conformance to the standard is formally defined using a protocol implementation conformance statement (PICS) proforma, but there are no standardized test case specifications (or mapping to standardized test procedures) for the standard.
Protocol features partly not applicable in the given context	A feature of the protocol is not fully applicable in the given context (e.g. GeoNetworking multi-hop forwarding in 5.9 GHz channels).
Superseded by newer version	The referenced standard is defined as a part of a regulatory solution, but it has been superseded by a newer version.
Test suite (conformance) not complete	The standard has a formalized protocol implementation conformance statement (PICS) proforma and a mapping of each requirement to a test case specification; however, the detailed test procedures for the test case specifications have not yet been standardized.
Ubiquitous broadcast technology	With the continual enhancement of broadcast technologies and a mixture of free and subscriber-based systems, it is difficult to identify any single technology that can be used to reliably reach the bulk of drivers in a timely manner.
Under revision	A standard is being revised due to technical problems.
Use case not considered in design (minor)	While the indicated standards nominally address the information flow, the design may not meet practical constraints because this particular use case was not the focus of the design effort.
Use TLS for SNMP Option	The standard allows for multiple security mechanisms. The only defined mechanism that meets the requirements for ITS is the one based on TLS.

Table 4: Medium Severity Issue Types

Issue Name	Description
Data not fully defined (medium)	Some of the data elements for this information flow are not fully defined.

Issue Name	Description
Dialogs are not fully defined (medium)	The specific dialogs for exchanging this data have not been fully defined.
Exception handling not defined	The dialogs do not define how to handle exceptions (e.g., error codes, permission denied, etc).
Functionality not fully defined	The functionality is not fully defined for this information flow.
Identifier registry does not exist	The standard defines a field which requires a globally unique identifier, but no registration authority exists to assign these values.
Inadequate data privacy	The standards do not adequately protect the privacy of data.
Missing a formal PICS	A design exists for the standard, but a formal protocol implementation conformance statement (PICS) proforma has not been provided. A PICS proforma unambiguously defines what requirements are mandatory, optional, and conditional and can be filled out by implementations/project specifications to identify what features are supported/required for a project.
Not a standard	The document may be publicly available but it is not currently available as a formal standard and details may change prior to adoption as a standard.
Not an open standard	The document may be publicly available but it is not a formal standard developed according to open standards development rules and details may change prior to adoption as open standard.
Overlap of standards	Multiple standards have been developed to address this information and it is unclear which standard should be used to address this specific information flow.
Performance not fully defined (medium)	The performance rules are not fully defined for this information flow.
Security inadequate	The solution does not provide adequate communications security for the information triple, which potentially jeopardizes ITS operations.
Still under development	A draft of the standard has been developed by the working group, but it was still under development at the time the HARTS analysis was performed.
Uncertainty about trust revocation mechanism	The mechanisms used to prevent bad actors from sending authorized messages is unproven.
Unvetted by community	The proposed solution uses a suite of standards that is accepted within some communities, but has not necessarily been accepted for use within the context of this information triple.

Issue Name	Description
Update data to SNMPv3	Data has been defined for SNMPv1, but needs to be updated to SNMPv3 format.
Use case not considered in design (medium)	While the indicated standards nominally address the information flow, the design may not meet practical constraints because this particular use case was not the focus of the design effort.

Table 5: High Severity Issue Types

Issue Name	Description
Communications profile not defined	The lower-layers of the OSI protocol stack have not been defined for this information flow.
Data not defined (high)	Some, or all, of the required data elements are not defined.
Data/ Communications profile pairing	There are ambiguities as to how to (or if one should) couple the upper-layer standards defined in this solution with the indicated lower-layer standards.
Dialogs not defined (high)	Some, or all, of the required dialogs are not defined for this information flow.
Draft not available (Critical)	The standards development organization has established a work item for the subject standard but a draft is not available for this critical feature to enable the interface. The draft may be missing due to the work item being new or simply a lack of activity on the work item.
Encoding rules not defined	The standards do not unambiguously define which set of encoding rules are to be used.
Out of date (high)	The standard includes normative references to other standards that have been subject to significant changes that could impact interoperability of systems and the industry has not specified if and how these updates should be implemented for deployments using this standard.
Performance not defined (high)	Some, or all, of the required performance rules are not defined for this information flow.
Security not provided	The solution does not provide any significant security and a communications link using this solution is easily hacked.
Use case not considered in design (critical)	While the indicated standards nominally address the needs of the information flow, the design details may not meet performance or other requirements because this particular use case was not the focus of the design effort.

Table 6: Ultra Severity Issue Types

Issue Name	Description
Data profile not defined	The performance, functionality, and the upper-layers of the OSI stack have not been defined for this information flow.

Issue Classes

The forty-three issue types described in the previous four tables were further categorised into thirteen issue classes to allow the analysts to more quickly locate the issues during the assignment process. Here are the list of issue types and classes.

Table 7: Issue Classes

Gap Class	Description
Communication Profile Gap	An uncategorized gap recorded in the Communications Profile
Data Profile Gap	An uncategorized gap recorded in the Data Profile
Facility Layer Gap	The dialogues are not fully defined for the associated messages
ITS Information Gap	These gaps all identify deficiencies in data dictionaries, application functionality, and/or performance requirements.
Management Plane Gap	The gap occurs in the Management Plane
Overlap	The associated standards have overlapping, non-interoperable content.
Performance / Applicability Gap	A gap related to reduced applicability within a given context, or to limited performance.
Registry Gap	A gap related to registry of information
Security Plane Gap	The solution does not provide adequate security for a Bounded Secured Managed Domain (BSMD).
Standardization Gap	A gap related to the standardization process
SubNet Layer Gap	The rules for the Physical and/or Data Link Layers are not fully defined
Testing Content Gap	These gaps all identify deficiencies in testing content included in individual standards.
TransNet Layer Gap	The rules for the Transport and/or Network layers are not fully defined

7.4 Issue Assignment

Within HARTS, each issue can be assigned to any of the following constructs, as appropriate:

- Standard: An issue was assigned to a standard only when the issue affected every triple solution that referenced the standard. The issue was associated with the area of the HARTS reference model to which the standard has been aligned.
- Profile: An issue was assigned to a profile only when the issue affected every triple solution that references the profile. When defining the issue, the analyst identified the area within the HARTS reference model where the issue exists.
- Solution: An issue was assigned to a solution only when the issue affected every triple solution based on the solution. When defining the issue, the analyst identified the area within the HARTS reference model where the issue exists.
- Triple Solution: An issue was assigned to a specific triple solution only when the issue was specific to that triple-solution, which very rarely occurred. When defining the issue, the user identified the area of the HARTS reference model where the issue exists.

While issues are associated at these levels within the HARTS database, it should be noted that this is only to ensure consistency in reporting the issue information. It should not be inferred that an issue associated with a standard must be resolved by an update to that standard; an issue reported at the standard level could be resolved by a separate standard or the emergence of solutions based on recent or emerging technologies and their associated standards. Proposed resolutions to resolve these issues will be described in Section 8 below.

The forty-three issue types were assigned to constructs at appropriate levels (e.g., standard, profile, solution, etc.) in the database. Each of these are called ***issue assignment***.

7.5 Issue Inheritance

Once the issue types are assigned to the appropriate database constructs, they propagate to all triple solutions that rely upon that database construct as shown in Figure 18. For example, if a standard has not yet been approved, it will be assigned an issue to that affect. That issue assignment then propagates to all information triples that rely upon that standard, resulting in multiple ***issue instances***.

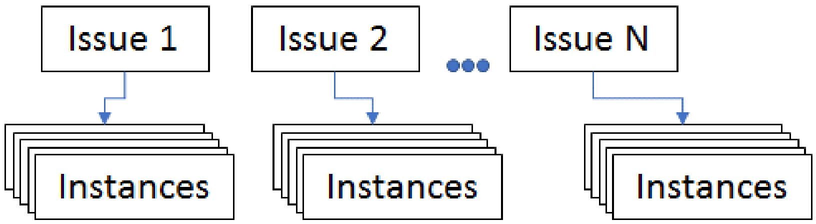

Figure 18: Issue Inheritance

When efforts begin to address these issues, they will need to consider whether their proposed solution will be viable in all cases; the database will assist in this analysis by providing a clear mapping of each issue instance that they will need to consider.

7.6 Issue Tasks

Although issues could be assigned to various constructs (e.g., standard, profile, solution, etc.) within the database, in some cases, an issue would apply to some, but not all triple solutions using that standard, as shown in Figure 19. As a result, the tasks required to address issues do not necessarily align exactly with the issue types, issue assignments, or issue instances. To capture a level of effort required to address all issue instances, the HTG7 team analysed the resulting issue instances to identify the unique ***issue tasks*** that would have to be performed to fully resolve all identified issue instances.

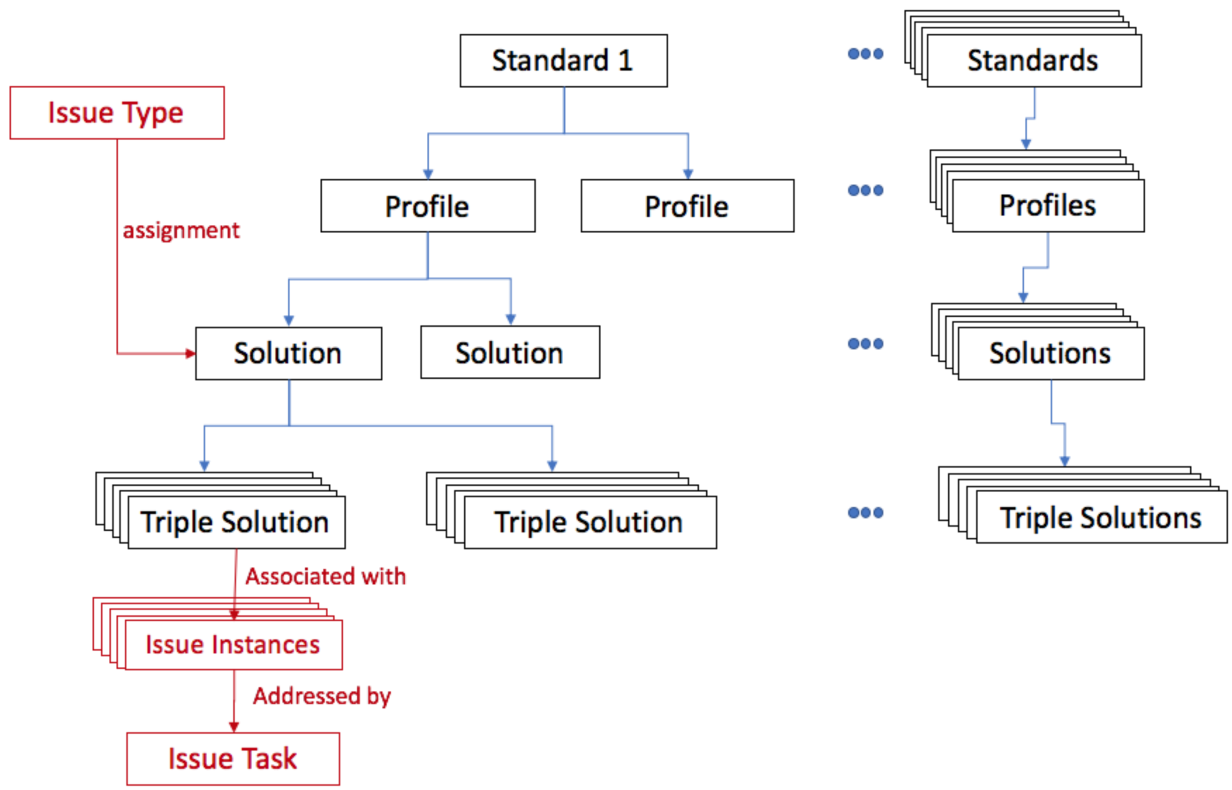

Figure 19: Issue Tasks vs. Issue Instances

7.7 Updating the Website

Once the HTG7 analysis team had completed its analysis of all triple solutions related to a service package, the service package diagram along with all of its triples and approved triple solutions would be made available for publication to the website. The publication process was designed to omit any triple solutions that were generated by the tool but not validated by the HARTS analysis team (e.g., perhaps because they manually created a custom solution overriding the generated solution). The generated site also provides details about each issue associated with the published triple solutions.

The generated website serves as a useful tool to:

- Facilitate public outreach and receive feedback from the community to ensure accuracy

- Provide the results of the analysis to deployers so that they are aware of the issues with various technologies
- Provide guidance to governments and standards development organisations in their management and development of ITS standards

8. Develop Proposed Resolutions

Both during and after the iterative analysis of solutions developed in the previous step, the HARTS analysis team developed a set of proposed resolutions based on the identified issues (i.e., gaps or overlaps) found during the analysis of the standards-based solutions. The relationships among issues and proposed resolutions are shown in Figure 20. In some cases, the mapping between issue instances and proposed resolutions might be fairly simple (e.g., Resolution 1). In other cases, a single proposed resolution (e.g., Resolution 2) might address issue instances from multiple issue assignments (e.g., a resolution might resolve multiple issues, but only the instances applied to a specific regional standard).

The proposed resolutions developed by the HARTS analysts were not intended to state or even suggest, technical solutions or approaches to resolving the associated issues. The focus of the project's proposed resolutions was on the identification, at a relatively elevated level, of the significant activities that will need to be undertaken to appropriately address one, or more, of the identified gaps and overlaps. As such, the project's proposed resolutions should assist standards development organisations in identifying needed work activities, during which potential technical solutions could be assessed and appropriate standards development actions taken.

Furthermore, by developing the report in this summary manner, standards development organisations and deployment teams can focus on the relatively low number of proposed resolutions rather than having to consider the large number of issue assignments, or worse, the very large number of issue instances.

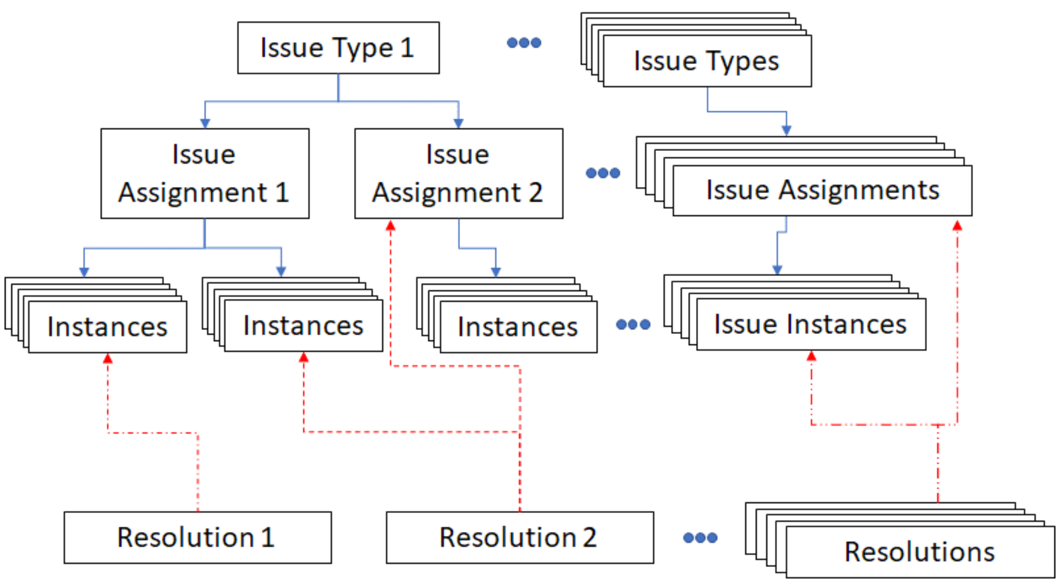

Figure 20: Issue Alignment

Each of the proposed resolutions is associated with the region(s) which were expected to be most interested in being involved in resolving the underpinning issues.

8.1 Issue Alignment

As with the development and assessment of standards-based solutions, the development of proposed resolutions and the alignment of identified issues to these proposals also followed the phased approach outlined in Section 2. In other words, the HTG7 analysts reviewed and assessed the issues from a service package perspective, looking at all triples/triple solutions for each respective service package included in the current phase. As they progressed through the list of service packages, the associated issues were aligned to an existing finding when applicable, or to a new finding when needed. Periodically, the HARTS analysts would review the collective alignments for consistency; and realign issues when warranted.

8.2 Prioritisation

Each finding was categorised into one of the following four tiers listed in the left-most column of Table 8. The tiers define an assessed urgency for each finding to be addressed—there is a corollary between the timeline for service package deployments and the prioritisation (i.e. urgency) of the finding. Other considerations that factored into the prioritisation include: 1) the criticality of the information triple in relation to the implementation of the service package; and 2) the correlation of a finding to a foundational or "support" need, such as lack of security. Typically, "foundational" or "support" proposed resolutions are marked as "urgent" since the result of completing those activities will significantly impact the approach taken to address other proposed resolutions.

Table 8: Proposed Resolutions Priorities

Urgency	Alignment Criteria		
	Service Package Category	**Gap Severity**	**Analyst Discrimination**
Urgent	• Support Service • Day 1 Service	• Ultra • Severe • Medium	• Proposed resolutions that address foundational issues. • Triples that are deemed core to the service package (subjective evaluation), as there are flows that are "nice to have" rather than "must have".
Near-Term	• Support Service • Day 1 Service	• Any	• Proposed resolutions that address one or more dependencies of other proposed resolutions.
Medium-Term	• Support Service • Day 1 Service • Day 1.5 Service	• Any	• None
Future	• All Others	• Any	• None

9. Stakeholder Outreach

Throughout the project duration, the HTG7 team conducted formal outreach with stakeholders to better meet the following objectives.

- Verify that the approach taken was on a trajectory that would achieve the project's goals
- Validate that the project would produce outputs that would be both relevant and useful.
- Socialise the HTG7 project, and its HARTS outputs, to expedite wide-spread ITS deployment
- Encourage review and feedback via the website (http://htg7.org/) by project stakeholders, and by the broader ITS community. The feedback received was, and will be, used to improve HARTS.
- Explore options for a long-term supported platform for HARTS, including both the websites and the supporting analysis database.

Table 9 identifies specific sessions held to discuss these issues with key stakeholders. In general, feedback received during these sessions was positive and indicated that there was a real need to ensure that the industry coordinated its efforts in addressing the remaining gaps while minimising regional differences. For the most part, the participants in the review seemed to be in agreement with the information presented, while providing specific feedback on specific issues. The types of feedback received included:

- Identifying resources that the HTG7 team could reference in developing their list of gaps and overlaps
- Refinement on how we presented information on the website for better understanding
- Identification of new service packages to address emerging needs
- Identification of issues that were not previously identified by the HARTS expert team
- Identification of efforts that were being initiated to address issues identified by HARTS

Table 9: Outreach Events

Period	HTG7 Topics	Events
Early 2016	Concept & Approach	• IEEE 1609 Working Group (WG), Annapolis, MD • IEEE 1609 WG, San Diego, CA • ISO TC204 Plenary, Concord • ITS Europe, Glasgow
Late 2016	Concept, Approach & Prototype Website	• IEEE 1609 WG, Rancho Santa Fe, CA • ISO TC204 Plenary, Auckland • ITS World Congress, Melbourne

Period	HTG7 Topics	Events
Early 2017	Progress & Public Website	• Connected Vehicle (CV) Security and Standards Workshop, Melbourne • IEEE 1609 WG, Milpitas, CA • ISO TC204 Plenary, Paris • SAE Dedicated Short Range Communications (DSRC) Technical Committee (TC), Milpitas, CA
Late 2017	Preliminary Results	• Australia ITS Summit, Brisbane • IEEE 1609 WG, Milpitas, CA • IEEE 1609 WG, San Diego • ISO TC204 Plenary, San Antonio • ITS World Congress, Montreal • SAE DSRC TC, San Diego

The feedback received from these sessions is reflected in the final results.

10. Final Reports

A set of final reports were developed to capture the methodology and results of the HTG7 project and culminating in a set of proposed resolutions. The website, available at http://htg7.org, provides an interactive mechanism to examine the details of the reference architecture and the results of the analysis. The website also contains copies of the written reports detailed below.

- **Executive Overview (HTG7-1)** - A high-level summary of the approach, process and the key results of HTG7.
- **Analysis Methodology (HTG7-2, this document)** - Presents the HTG7 methodology used to develop HARTS, perform the gap analysis, and develop proposed resolutions.
- **Issues and Proposed Resolutions (HTG7-3)** - Summarises the issues identified through HTG7 analysis and proposes actions to resolve the issues. It introduces a series of more detailed reports, detailed below, each of which identifies the same set of proposed resolutions but adopts a presentation format and includes details relevant to a different perspective.
    - **Results: Solution Perspective for Deployers (HTG7-3-1-AU, HTG7-3-1-EU, HTG7-3-1-JP, HTG7-3-1-US)** - Addresses development or implementation teams in their planning and procurement processes. This detailed report lists each solution along with its associated issues and proposed resolutions and is divided into four regional sub-reports, one for each participating region. (The region is reflected by the appended 2-letter region code[29]).
    - **Results: Resolution Perspective for Standards Developers (HTG7-3-2)** - Presents each proposed resolution along with its associated issues and the data exchanges affected by these issues. This detailed report can assist standards development communities and governments in their planning and work processes.
    - **Results: Service Package Perspective (HTG7-3-3-AU, HTG7-3-3-EU, HTG7-3-3-JP, HTG7-3-3-US)** - Offers road operators the opportunity to evaluate the "readiness" of ***service packages***. This detailed report lists each service package, the data exchanges contained within the service package, and the issues associated with each solution for each data exchange. In this respect, this report helps deployers understand the levels of risk due to the standards gaps. The report is divided into 4 regional reports, one for each participating region. (The region is reflected by the appended the 2-letter region code[6]).
- **HARTS Website Overview (HTG7-4)** - Provides an overview of the HARTS public website, available at http://htg7.org. It describes each aspect of the website and provides instructions on how to submit comments about the information on the website.
- **HARTS Reference Compendium (HTG7-5)** - Provides reference material including:

[29] As defined by ISO 3166-1:2013 *Codes for the representation of names of countries and their subdivisions – Part 1: Country codes*

- A glossary of terms and associated definitions
- Acronyms and associated meanings
- Graphic symbols and associated meanings
- Explanations of key terms and their inter-relationships

Appendix A
Support, Day 1, and Day 1.5 Applications

Service Package	Priority	Description
Advanced Traveler Information Systems	Day 1.5	The Advanced Traveler Information Systems applications provide for the collection, aggregation, and dissemination of a wide range of transportation information. The collection of information includes traffic, transit, road weather, workzone, and connected vehicle related data. All the sources of data are aggregated into data environments that can be used to drive data portals allowing dissemination of the entire spectrum of transportation information to travelers via mobile devices, in vehicle displays, web portals, 511 systems, and roadside signage.
Connected Vehicle System Monitoring and Management	Support	This service package provides monitoring, management and control services necessary to other applications and/or devices operating within the Connected Vehicle Environment. This service package maintains and monitors the performance and configuration of the connected vehicle system. This includes tracking and management of the infrastructure configuration as well as detection, isolation, and correction of infrastructure service problems. It also includes monitoring of performance of the infrastructure and mobile equipment, which includes RSEs, OBEs, the back office applications, as well as the communication links that connect the system.
Core Authorization	Support	Core Authorization is a connected vehicle support application that manages the authorization mechanisms to define roles, responsibilities and permissions for other connected vehicle applications . This allows system administrators to establish operational environments where different connected vehicle system users may have different capabilities. For instance, some Mobile elements may be authorized to request signal priority, or some Centers may be permitted to use the geographic broadcast service, while those without those permissions would not.
Curve Speed Warning	Day 1	The curve speed warning application allows connected vehicles to receive information that it is approaching a curve along with the recommended speed for the curve. This capability allows the vehicle to provide a warning to the driver regarding the curve and its recommended speed. In addition, the vehicle can perform additional

Service Package	Priority	Description
		warning actions if the actual speed through the curve exceeds the recommended speed.
Data Distribution	Support	Data Distribution is a support application that manages the distribution of data from data providers to data consumers and protects those data from unauthorized access. The application informs data providers of how to provide data, manages data subscriptions, and provides data forwarding capabilities. The application also maintains a directory of System Users that want data and supports multiple distribution mechanisms including publish-subscribe and directly from data provider to data consumer. The application allows data consumers to specify (and change the specification of) data they wish to receive.
Eco-Approach and Departure at Signalized Intersections	Day 1.5	The Eco-Approach and Departure at Signalized Intersections application uses wireless data communications sent from a roadside equipment (RSE) unit to connected vehicles to encourage "green" approaches to and departures from signalized intersections. The application, located in a vehicle, collects intersection geometry information and signal phase movement information using V2I communications and data from nearby vehicles using V2V communications. Upon receiving this information, the application performs calculations to provide speed advice to the driver of the vehicle allowing the driver to adapt the vehicle's speed to pass the next traffic signal on green or to decelerate to a stop in the most eco-friendly manner. The application also considers a vehicle's acceleration as it departs from a signalized intersection. Finally, the application may perform engine adjustments that provide increased fuel efficiency.
Electric Charging Stations Management	Day 1.5	The Electric Charging Station Management application provides an exchange of information between vehicle and charging station to manage the charging operation. The agency or company operating the charging station can use vehicle information such as the capability of the vehicle (e.g. operational status of the electrical system, how many amps can the vehicle handle, and % charge complete) to determine that the charge is being properly applied and determine an estimated time to complete charging.
Electronic Regulations	Support	This service package disseminates current local statutes, regulations, ordinances, and rules that have been adopted by local, state, and federal authorities that govern the safe, orderly operation of motor vehicles,

Service Package	Priority	Description
		bicycles, and pedestrians on public roads. The focus of this service package is electronic distribution to automated vehicles and their drivers so that automated vehicles can safely operate in compliance with the traffic or motor vehicle code for the current state and locality, though this information would also be useful to human drivers.
Emergency Vehicle Preemption	Day 1	The Emergency Vehicle Preemption (EVP) application is a very high level of priority for emergency first responder vehicles. Historically, priority for emergency vehicles has been provided by special traffic signal timing strategies called preemption. The goal of EVP is to facilitate safe and efficient movement through intersections. As such, clearing queues and holding conflicting phases can facilitate emergency vehicle movement. For congested conditions, it may take additional time to clear a standing queue, so the ability to provide information in a timely fashion is important. In addition, transitioning back to normal traffic signal operations after providing EVP is an important consideration since the control objectives are significantly different.
Freight Signal Priority	Day 1.5	The Freight Signal Priority application (FSP) provides traffic signal priority for freight and commercial vehicles traveling in a signalized network. The goal of the freight signal priority application is to reduce stops, delays, to increase travel time reliability for freight traffic, and to enhance safety at intersections.
In-Vehicle Signage	Day 1	The In-Vehicle Signage application augments regulatory, warning, and informational signs and signals by providing information directly to drivers through in-vehicle devices. The information provided would include static sign information (e.g., stop, curve warning, guide signs, service signs, and directional signs) and dynamic information (e.g., current signal states including highway intersection and highway-rail intersection status and local conditions warnings identified by local environmental sensors). This application also includes the capability for maintenance and construction and emergency vehicles to transmit sign information to vehicles in the vicinity so that in vehicle signing can be used without fixed infrastructure in work zones and around incidents.
Intelligent Traffic Signal System	Day 1	The Intelligent Traffic Signal System (ISIG) application uses both vehicle location and movement information from connected vehicles as well as infrastructure measurement of non-equipped vehicles to improve the

Service Package	Priority	Description
		operations of traffic signal control systems. The application utilizes the vehicle information to adjust signal timing for an intersection or group of intersections in order to improve traffic flow, including allowing platoon flow through the intersection. The application serves as an over-arching system optimization application, accommodating other mobility applications such as Transit Signal Priority, Freight Signal Priority, Emergency Vehicle Preemption, and Pedestrian Mobility to maximize overall arterial network performance. In addition, the application may consider additional inputs such as environmental situation information or the interface (i.e., traffic flow) between arterial signals and ramp meters.
Intersection Safety Warning and Collision Avoidance	Day 1	This service package enables a connected vehicle approaching an instrumented signalized intersection to receive information from the infrastructure regarding the signal timing and the geometry of the intersection. The vehicle uses its speed and acceleration profile, along with the signal timing and geometry information to determine if it appears likely that the vehicle will be able to pass safely through the intersection without violating the signal or colliding with other vehicles. If the vehicle determines that proceding through the intersection is unsafe, a warning is provided to the driver and/or collision avoidance actions are taken, depending on the automation level of the vehicle.
Location and Time	Support	Location and Time is a support application that shows the external systems and their interfaces to provide accurate location and time to connected vehicle devices and systems.
Map Management	Support	The Map Management application defines interfaces that can be used download or update all types of map data used to support connected vehicle applications. This map data will be accessed by centers, field, and vehicle physical objects. The application can be used to harness the Connected Vehicle Environment to provide rich source data that can be used to verify, refine, and enhance geographic map data.
Object Registration and Discovery	Support	The Object Registration and Discovery application provides registration and lookup services necessary to allow objects to locate other objects operating within the Connected Vehicle Environment. This is a support application that enables other connected vehicle applications.

Service Package	Priority	Description
Pedestrian in Signalized Crosswalk Warning	Day 1.5	The Pedestrian in Signalized Crosswalk Warning application provides to the connected vehicle information from the infrastructure that indicates the possible presence of pedestrians in a crosswalk at a signalized intersection. The infrastructure based indication could include the outputs of pedestrian sensors or simply an indication that the pedestrian call button has been activated. This application has been defined for transit vehicles, but can be applicable to any class of vehicle. The application could also provide warning information to the pedestrian regarding crossing status or potential vehicle infringement into the crosswalk.
Privacy Protection	Support	Privacy Protection is a connected vehicle support application that provides the privacy protection essential to the operation of other connected vehicle applications. Privacy Protection obscures the network identifiers of mobile devices in order to allow communications with credentials management and other centers.
Queue Warning	Day 1	The Queue Warning (Q-WARN) application utilizes connected vehicle technologies, including vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications, to enable vehicles within the queue event to automatically broadcast their queued status information (e.g., rapid deceleration, disabled status, lane location) to nearby upstream vehicles and to infrastructure-based central entities (such as the TMC). The infrastructure will broadcast queue warnings to vehicles in order to minimize or prevent rear-end or other secondary collisions. The Q-WARN application is not intended to operate as a crash avoidance system (e.g., like the forward collision warning [FCW] safety application). In contrast to such systems, Q-WARN will engage well in advance of any potential crash situation, providing messages and information to the driver in order to minimize the likelihood of his needing to take crash avoidance or mitigation actions later. The Q-WARN application performs two essential tasks: queue determination (detection and/or prediction) and queue information dissemination. In order to perform these tasks, Q-WARN solutions can be vehicle-based or infrastructure-based or utilize a combination of each.
Railroad Crossing Violation Warning	Day 1.5	The Railroad Crossing Violation Warning (RCVW) application will alert and/or warn drivers who are approaching an at-grade railroad crossing if they are on a crash-imminent trajectory to collide with a crossing or

Service Package	Priority	Description
		approaching train. This will be achieved through the integration of both vehicle-based and infrastructure-based technologies. The RSE sends to the vehicle detailed geometric information about the intersection, as well as information about whether a train is approaching or blocking the intersection. The geometric information could be obtained from an RSE at the intersection, or obtained from an RSE at some earlier point in the vehicles trip. The information about the approach or presence of a train would be obtained from the infrastructure via a connection between the rail infrastructure and the RSE. The information received from the RSE at the intersection could also be augmented with road surface information or other weather-related data. A more advanced version of the application could provide train arrival information or information about the amount of time the Highway Rail Intersection (HRI) will be blocked by the train.
Reduced Speed Zone Warning / Lane Closure	Day 1.5	The Reduced Speed Zone Warning / Lane Closure(RSZW/LC) application provides connected vehicles which are approaching a reduced speed zone with information on the zone's posted speed limit and/or if the configuration of the roadway is altered (e.g., lane closures, lane shifts). Reduced speed zones include (but are not be limited to) construction/work zones, school zones, pedestrian crossing areas, and incorporated zones (e.g., rural towns). The RSZW/LC application inside the connected vehicle uses the revised speed limit along with any applicable changed roadside configuration information to determine whether to provide an alert or warning to the driver. Additionally, to provide warnings to non-equipped vehicles, infrastructure equipment measures the speed of the approaching vehicles and if greater than the reduced speed zone posted speed limit will provide warning signage. The application will provide an alert to drivers in advance when aggressive braking is required to reduce to the posted speed limit.
Security and Credentials Management	Support	Security and Credentials Management (SCM) is a support application that is used to ensure the trusted communications between mobile devices and other mobile devices or roadside devices and protect data they handle from unauthorized access. The application grants trust credentials to qualified mobile devices and infrastructure devices in the Connected Vehicle Environment so that those devices may be considered trusted by other devices that receive trust credentials

Service Package	Priority	Description
		from the SCM application. The application allows credentials to be requested and revoked, as well as to secure the exchange of trust credentials between parties, so that no other party can intercept and use those credentials illegitimately. The application provides security to the transmissions between connected devices, ensuring authenticity and integrity of the transmissions. Additional security features include privacy protection, authorization and privilege class definition, as well as non-repudiation of origin.
Situational Awareness	Day 1	The Situational Awareness (SA) application determines if the road conditions measured by other vehicles represent a potential safety hazard for the vehicle containing the application. To enable this application other vehicles broadcast relevant road condition information, such as fog or icy roads. This application supports the capability for connected vehicles to share situational awareness information even in areas where no roadside communications infrastructure exists. This application can be useful to vehicles that are not fully equipped with sensors, or vehicles entering an area with hazardous conditions.
Smart Park and Ride System	Day 1.5	The Smart Park and Ride application provides real-time information on Park and Ride capacity and supports traveler's decision-making on where best to park and make use of transit alternatives. The application uses connected vehicles to monitor in real time the occupancy of parking spaces and provide the information to travelers via smartphones and to connected vehicles.
Special Vehicle Alert	Day 1	This service package alerts the driver about the location of and the movement of public safety vehicles responding to an incident, slow moving vehicles, oversized vehicles, and other special vehicles that may require special attention from the driver. These public safety, commercial, and maintenance vehicles share their current status and location with surrounding vehicles so that other drivers in the vicinity can avoid interfering with their actions and avoid collisions.
Speed Harmonization	Day 1	The Speed Harmonization application determines speed recommendations based on traffic conditions and weather information. The speed recommendations can be regulatory (e.g. variable speed limits) or advisory. The purpose of speed harmonization is to change traffic speed on links that approach areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that affect flow. Speed

Service Package	Priority	Description
		harmonization assists in maintaining flow, reducing unnecessary stops and starts, and maintaining consistent speeds. The application utilizes connected vehicle V2I communication to detect the precipitating roadway or congestion conditions that might necessitate speed harmonization, to generate the appropriate response plans and speed recommendation strategies for upstream traffic, and to broadcast such recommendations to the affected vehicles. The speed recommendations can be provided in-vehicle for connected vehicles, or through roadside signage for non-connected vehicles.
Spot Weather Impact Warning	Day 1	The Spot Weather Impact Warning (SWIW) application will alert drivers to unsafe conditions or road closure at specific points on the downstream roadway as a result of weather-related impacts, which include, but are not limited to high winds, flood conditions, ice, or fog. Application designed to use standalone weather systems to warn drivers about inclement weather conditions that may impact travel conditions. Real time weather information is collected via RWIS or via vehicle based probe data. The information is processed to determine the nature of the alert or warning to be delivered and then communicated to connected vehicles. If the warning includes road closure then diversion information can be provided. For non-equipped vehicles the alerts or warnings will be provided via roadway signage. In addition, the roadway equipment may calculate the appropriate speed for current weather conditions and provide this information to the connected vehicle or on roadway signage.
Stop Sign Gap Assist	Day 1.5	The Stop Sign Gap Assist (SSGA) safety application is intended to improve safety at non-signalized intersections where only the minor road has posted stop signs. This application includes both onboard (for connected vehicles) and roadside signage warning systems (for non-equipped vehicles). The application will help drivers on a minor road stopped at an intersection understand the state of activities associated with that intersection by providing a warning of unsafe gaps on the major road. The SSGA application collects all available sensor information (major road, minor road, and median sensors) data and computes the dynamic state of the intersection in order to issue appropriate warnings and alerts.

Service Package	Priority	Description
Stop Sign Violation Warning	Day 1.5	The Stop Sign Violation Warning (SSVW) safety application is intended to improve safety for at unsignalized intersections with posted stop signs by providing warnings to the driver approaching an unsignalized intersection. The application is designed to warn drivers that they may violate an upcoming stop sign based on their speeds and distance to the stop sign. In order for the application to operate the vehicle needs to have detailed geometric information about the intersection, which is used by the onboard portion of the application to determine if a stop sign violation is likely and to provide the driver a warning about the potential stop sign violation. The geometric information could be obtained from an RSE at the intersection, or obtained from an RSE at some earlier point in the vehicles trip. If the information is received from an RSE at the intersection then it could be augmented with road surface information or other weather-related data.
Transit Signal Priority	Day 1	The Transit Signal Priority application uses transit vehicle to infrastructure communications to allow a transit vehicle to request an priority at one or a series of intersection. The application includes feedback to the transit driver indicating whether the signal priority has been granted or not. This application can contribute to improved operating performance of the transit vehicles by reducing the time spent stopped at a red light.
Traveler Information-Smart Parking	Day 1.5	The Traveler Information -Smart Parking application provides users with real-time location, availability, type (e.g., street, garage, AFV only), and the price of parking. The parking information can be provided via DSRC or wide area communications. The application reduces time required for drivers to search for a parking space, which can have eco benefits such as reducing emissions. The application also supports dynamic pricing of parking based on factors such as demand, emissions, or vehicle type.
V2V Basic Safety	Day 1	This service package exchanges basic safety messages with surrounding vehicles to support safety warning and control automation features. These exchanges support safety services defined in various standards and technical reports: Emergency Electronic Brake Lights, Forward Crash Warning, Blind Spot Warning/Lane Change Warning, Intersection Movement Assist, Left Turn Assist, and Control Loss Warning. It also supports Do Not Pass Warning, Motorcycle Approaching

Service Package	Priority	Description
		indication, Tailgating Advisory, Stationary Vehicle, and Pre-Crash Actions.
Vehicle Data for Traffic Operations	Day 1	The Vehicle Data for Traffic Operations (VDTO) application uses probe data information obtained from vehicles in the network to support traffic operations, including incident detection and the implementation of localized operational strategies. The implantation of incident detection enables transportation agencies to determine the location of potential incidents so the agencies can respond more quickly to the incident and mitigate any negative impacts to the transportation network. Vehicle data that can be used to detect potential incidents include changes in vehicle speeds indicating the disruption of traffic flow, when a vehicle's safety systems have been activated or deployed, or sudden vehicle turns or deceleration at a specific location (indicating a potential obstacle in the roadway). Operational strategies might include altering signal timing based on traffic flows or using vehicle data collected on the freeway mainline to employ speed harmonization or to optimize ramp metering rates.
Warnings about Upcoming Work Zone	Day 1	The Warnings about Upcoming Work Zone (WUWZ) application provides information about the conditions that exist in a work zone to vehicles that are approaching the work zone. This application provides approaching vehicles with information about work zone activities that may result in unsafe conditions to the vehicle, such as obstructions in the vehicle's travel lane, lane closures, lane shifts, speed reductions or vehicles entering/exiting the work zone.