FINAL REPORT

To: The Tennessee Department of Transportation
Research Development and Technology Program

Update of the TDOT Traffic Design Manual

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16. Abstract

The Tennessee Department of Transportation (TDOT) Traffic Design Manual provides information on Traffic Signal Design, Signing and Pavement Markings, Roadway Lighting and Intelligent Transportation Systems. While the chapters on Signing and Pavement Markings, as well as the chapter on Roadway Lighting, have been recently revised, the Traffic Signal Design chapters did not specifically reflect the standards of the 2009 Manual on Uniform Traffic Control Devices (MUTCD) and current signal timing guidelines. The subject manual also lacked the provision of relevant information regarding Traffic Signal Inspection Guidelines and Traffic Signal Maintenance Guidelines. Furthermore, the chapter on Intelligent Transportation Systems (ITS) has been partially revised, but still lacks additional information on Systems Engineering Analysis, Project Stage Diagram and Device Procurement.

Since TDOT does not maintain traffic signals, it is very important for TDOT to make current and detailed documentation available to agency designers, consultants and city/county administrators to provide better operations and maintenance of traffic signal control devices. The manual update, provided to the Traffic Operations Division at TDOT, consists of a comprehensive review of available standards and guidelines related to the design, operation and maintenance of traffic signals. In addition to that, the proposed revision of the ITS chapter provides agencies with relevant and consistent information on policies, guidelines and standard procedures related to Intelligent Transportation Systems, Systems Engineering Analysis templates, Project Stage Diagrams and Device Procurement. The project also updated TDOT 730 Traffic Signals Specifications.

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Executive Summary

The Tennessee Department of Transportation (TDOT) Traffic Design Manual provides information on Traffic Signal Design, Signing and Pavement Markings, Roadway Lighting and Intelligent Transportation Systems. While the chapters on Signing and Pavement Markings, as well as the chapter on Roadway Lighting, have been recently revised, the Traffic Signal Design chapters did not specifically reflect the standards of the 2009 Manual on Uniform Traffic Control Devices (MUTCD) and current signal timing guidelines. The subject manual also lacked the provision of relevant information regarding Traffic Signal Inspection Guidelines and Traffic Signal Maintenance Guidelines. Furthermore, the chapter on Intelligent Transportation Systems (ITS) has been partially revised, but still lacks additional information on Systems Engineering Analysis, Project Stage Diagram and Device Procurement.

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1. INTRODUCTION

The Update of the TDOT Traffic Design Manual project was focused on reviewing all information regarding Traffic Signals Standards and Specifications, as well as developing new Traffic Signals Guidelines to be used by practitioners across the State. The project is also aimed at updating, to federal standards, the ITS information available in the subject manual including the creation of additional documentation for dissemination. The tasks from the project are outlined as follows:

Task 1 – Update of Chapter 1 – Introduction
Task 2 – Update of Chapter 2 – Project Development
Task 3 – Update of Chapter 3 – Need for Traffic Signals
Task 4 – Update of Chapter 4 – Traffic Signal Design
Task 5 – Update of Chapter 5 – Other Types of Traffic Signals
Task 6 – Update of Chapter 8 – Intelligent Transportation Systems
Task 7 – Development of Inspection Guidelines
Task 8 – Development of Maintenance Guidelines
Task 9 – Development of Flashing Yellow Arrow for Permissive Left Turns Guidelines
Task 10 – Update of TDOT 730 Traffic Signals Specifications
Task 11 – Update of the Glossary
Task 12 – Update of the Table of Contents

2. LITERATURE REVIEW

In researching available documentation on ITS and Flashing Yellow Arrow for Permissive Left Turn movements and its application to the subject project, the following documents were researched most greatly:

- FHWA Traffic Signal Timing Manual;
- FHWA Addressing ITS Architecture Requirements in the TMA Certification Review;
- FHWA ITS Executive Summary;
- FHWA Logical Architecture Vol 1, 2 and 3
- FHWA Physical Architecture
- FHWA Service Packages
- FHWA Theory of Operations
- FHWA Rule / FTA Policy
- FHWA Regional ITS Architecture Guidance
- FHWA Systems Engineering for ITS
- FHWA Systems Engineering Guide Book California
- Minnesota ITS Project Management Design Manual
- Flashing Yellow Arrow Left-turn signal – Oregon, Michigan, Minnesota, Iowa, Missouri, Nevada, Indiana, Texas, etc

In addition to the listed research, documentation regarding proposed modifications to the TN Traffic Design Manual submitted from the Federal Highway Administration (FHWA) Division office. Regarding ITS language, the Tennessee (TN) division office of FHWA was essential in providing additional information regarding the following topics:

- ITS Project Development;
- Systems Engineering;
- Procurement Options for ITS projects;
- Eligibility for purchase of ITS spare parts;
- “Sole-source” approvals for ITS project items

The documentation was analyzed and, ultimately, implemented to the master copy of the document for TDOT.

3. SUMMARY OF TASK COMPLETION

This section outlines the timeline through which each of the tasks were completed over the life of the project, how TDOT and FHWA employees were involved in the process, and outlines what documentation was edited, updated, or created through this project.

Updating Chapter 8: Intelligent Transportation Systems

In the first few months of the project, a meeting with TDOT staff determined some prioritized tasks to the project, particularly updating Chapter 8 of the ITS manual (Task 6) and generating the Flashing Yellow Arrow (FYA) for Permissive Left Turn guidelines (Task 9). (FYA is discussed in the next section.) Work then started on research of available documentation. The research of available documentation regarding ITS, Systems Engineering and the Flashing Yellow Arrow for Permissive Left Turn movements were the focus first. Relevant information was selected from several sources mentioned in the Literature Review section and was implemented in a master document of the Traffic Design Manual ultimately provided to TDOT (citations are provided in this document and can be requested from TDOT’s Traffic Operations Division).

In June 2014, FHWA presented a pilot course on ITS related to Systems Engineering Analysis and Adaptive Traffic Signal Control, providing additional information that was incorporated into Chapter 8. Through August 2014, three teleconferences were held, which included TDOT and FHWA staff. The meetings were focused on editing of the language, ITS compliance diagram formatting and sequence of chapters regarding the ITS material being worked on.

Due to the depth of the content, one of the outcomes for Chapter 8 was a *standalone document* serving as guidance on ITS in Tennessee (Appendix 1). Due to the amount of information available on ITS, Chapter 8 could be extracted and separated from the TDOT Traffic Design Manual to serve as a guidebook on the subject and emulating the practice in other states in the country. This possibility was further discussed with TDOT staff.

The update of Chapter 8 was completed in the 4th quarter of the project, and a draft document was made available to TDOT staff for review. Feedback was collected from end users including consultants and government agencies. Agreement on the use of the checklists on the Systems Engineering Analysis was provided by the end of the year.

As of November 2015, there was still a need for feedback from end users (consultants, government agencies, etc) for the completion of Task 6. The presentation on completed work at TDOT headquarters on November 23rd offered an opportunity to reiterate this need.

Flashing Yellow Arrow Guidelines

As previously mentioned, the Flashing Yellow Arrow (FYA) Guidelines were a priority task from TDOT. Due to an e-mail exchange with FHWA and several researchers around the country regarding a new research proposal focusing on the FYA for Permissive Left Turn movements, the research focused on best practices around the country and refining the operation of FYA. For example, the use or not of an all-red clearance, the timing of intervals and other issues related to the sequence of lights during FYA.

Current available information on FYA for Permissive Left Turn movements was provided to TDOT staff, and the request for additional information was received from different practitioners around the country and from FHWA for analysis and incorporation into the TDOT Traffic Design Manual language. Regarding the guidelines on FYA for Permissive Left Turn movements, available information was provided to TDOT staff and some questions regarding cabinet wiring were addressed in the 3rd quarter of the project.

Additional clarification on red clearance timing for the FYA was requested from FHWA and practitioners around the country and is not yet available for incorporation in the Traffic Design Manual.

Also, a TDOT staff person requested input on an issue related to Right Turn on Red (RTOR) for a steady red arrow signal indication that prompted further input from FHWA. Information on the Tennessee Code Annotated related to the issue was provided, and the topic was also addressed on the update of the TDOT Traffic Design Manual.

In early 2015, TDOT's feedback was received on the Flashing Yellow Arrow material and recommendations were incorporated accordingly through the middle of the year. The Flashing Yellow Arrow Guidelines website incorporating brochures, press releases and videos was made available to TDOT for revision during this period. The English and Spanish brochures can be found in Appendix 2.

Lastly, a draft copy of the FHWA Signal Timing Manual 2 was made available to the research team, contributing valuable information, especially on strategies to be used on oversaturated traffic conditions. This carried great potential to be incorporated into the TDOT Traffic Design Manual (See Chapter 7.5 of the final manual).

Updating the Rest of the TN Traffic Design Manual

The Microsoft WORD version of the TN Traffic Design Manual was provided to the research team. There are several documents and some chapter updates as well as figures that will need to be organized to create a master document where all the proposed modifications can be presented.

Tasks 1, 2, 3, 4, and 5 began in early 2015. Chapter 3 material was sent for TDOT's revision. Necessary feedback was provided from a group meeting in February. Work on Tasks 4 and 5 then commenced. The original Chapter 4 and 5 diagrams were not provided and were redone for the update. During this same period, the ITS Project Development Guidelines (Chapter 8, discussed in the previous section) continued to be reviewed by TDOT and a meeting was scheduled in March to discuss pending issues. A comprehensive revision of Chapters 4 and 5 continued to be performed, focusing on current deficiencies of the material presented on the manual (e.g.: yellow and red clearance recommendations, advance detection recommendations, etc.). Ultimately, fifty figures and twenty-one tables were redone for the update during this period, addressing previous deficiencies in the Design Manual.

During the latter part of 2015, a comprehensive revision of Chapters 1 thru 5 was performed, focusing on reorganizing the manual in a more user friendly and logical order, providing accurate and current information and referencing literature throughout the text. Work on Tasks 1 thru 5 continued, as well as on Task 12, and a final draft was sent to TDOT for revision. Material was submitted for TDOT revision and a presentation of the findings was held in September at the 2015 TDOT Traffic Engineering Conference and Workshop.

Near the end of 2015, chapters 1 thru 5 continued to be reviewed by TDOT and adjustments to the text were incorporated on Tasks 1 thru 5, as well as on Task 12. FHWA and TDOT reviewed the document in early 2016 to provide needed feedback. Modifications were requested by May of 2016.

Work on Task 7 and Task 8 started in late 2015, regarding the development of Inspection and Maintenance guidelines. Selection of relevant information from the IMSA Manual, Signal Timing Manual and additional FHWA documents was performed. A set of descriptive pictures continued to be assembled and will be used to enhance understanding of inspection and maintenance guidelines. A set of descriptive pictures was assembled for these sections, as well, to be used to enhance understanding of inspection and maintenance guidelines. Task 11 to update the glossary was also completed during this time.

Additional work on Task 7 continued into 2016, regarding the development of Traffic Signal Inspection guidelines. A copy of a worksheet used by the City of Memphis was requested and enhanced with pictures and inspection procedures. Task 7's TDOT Traffic Signal Inspection Guidelines was submitted to TDOT for analysis in mid-2016.

730 Traffic Signal Specifications Updates

The official 730 Traffic Signal Specifications were requested to be done next by TDOT in summer 2016, and information used regarding the 730 Traffic Signal Specifications was found online. The specifications were the last item completed for TDOT.

Work continued on Task 10 into 2017, regarding the 730 Traffic Signal Specifications. Work was being coordinated with TDOT staff on the update of the 730 Specifications. Sections on Signal Heads, Controllers, Miscellaneous Traffic Signals, Detectors, and Coordination were developed. This final task was completed by May. The updated specifications can be found in Appendix 3.

4. DELIVERABLES AND REPORT PREPARATION

The ITS Project Development Guidelines (Appendix 1) was developed and the Flashing Yellow Arrow Guidelines (Appendix 2) website incorporating brochures, press releases and videos were made available to TDOT in December 2014. The 730 Traffic Signal Specifications (Appendix 3) were completed and provided to TDOT in June of 2017. The TDOT Traffic Design Manual updates were completed and approved by relevant stakeholders by December 2016. The Design Manual is separate from this final report and can be provided upon request to the Traffic Operations Division at TDOT. All updates are described in the Summary of Task Completion above.

5. CONCLUSION

This final report details the timeline, literature review, updates, and documents developed as a result of this research project. These guidelines were developed as part of a team effort between the University of Tennessee Knoxville, the Tennessee Department of Transportation, and the Federal Highways Administration. Recommendations and relevant information can be found in the documents created and updated. These documents are provided in the Appendices as noted in the Table of Contents, with exception of the TDOT Traffic Design Manual, which is available through the Traffic Operations Division.

6. APPENDICES

Appendix 1

ITS Guidelines:
Previously Chapter 8 of Traffic Design Manual

Tennessee Department of Transportation Intelligent Transportation Systems Project Development Guidelines

CONTENTS

1 *Introduction*

This Chapter of the Tennessee Department of Transportation Traffic Design Manual addresses definitions, policies, guidelines, procedures and provides relevant information related to the deployment of Intelligent Transportation Systems (ITS) in the State of Tennessee.

1.1 Definition of ITS

According to the 23 Code of Federal Regulations (CFR) 940 [(1)] *Intelligent Transportation System (ITS)* means electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system.

2 *ITS Federal Rule/Policy – 23 CFR Part 940*

On January 8, 2001 the Final Rule on ITS Architecture and Standards Conformity and the Final Policy on Architecture and Standards Conformity were enacted by the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) respectively. The Final Rule/Final Policy ensures that Intelligent Transportation Systems (ITS) projects carried out using funds from the Highway Trust Fund including the Mass Transit Account conform to the National ITS Architecture and applicable ITS standards. Conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a Regional ITS Architecture, and the subsequent adherence of all ITS projects to that Regional ITS Architecture. In addition, the Final Rule states that all ITS projects that use Highway Trust Fund funds shall be developed using a systems engineering analysis.

2.1 Definition of National ITS Architecture

National ITS Architecture [(2)] (also "National Architecture") means a common framework for ITS interoperability. The National ITS Architecture comprises the logical architecture and physical architecture which satisfy a defined set of user services. The National ITS Architecture is maintained by the United States Department of Transportation (DOT).

[(1)] *The 23 Code of Federal Regulations is available at http://www.gpo.gov/fdsys/pkg/CFR-2008-title23-vol1/pdf/CFR-2008-title23-vol1-part940.pdf*

[(2)] *The National ITS Architecture is available at http://www.its.dot.gov/arch/*

2.2 Definition of Regional ITS Architecture

Regional ITS Architecture means a regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects. Region is the geographical area that identifies the boundaries of the Regional ITS Architecture and is defined by and based on the needs of the participating agencies and other stakeholders. In metropolitan areas, a region should be no less than the boundaries of the metropolitan planning area. Development of the Regional ITS Architecture should be consistent with the transportation planning process for Statewide and Metropolitan Transportation Planning.

2.3 Definition of Project Level ITS Architecture

Project Level ITS Architecture is a framework that identifies the institutional agreement and technical integration necessary to interface a major ITS project with other ITS projects and systems.

2.4 Definition of ITS Project

ITS project means any project that in whole or in part funds the acquisition of technologies or systems of technologies that provide or significantly contribute to the provision of one or more ITS user services as defined in the National ITS Architecture. In Tennessee ITS projects are classified as Low-Risk or High-Risk. (Section 3.4).

2.5 Definition of Systems Engineering

Systems engineering is a structured process for arriving at a final design of a system. The final design is selected from a number of alternatives that would accomplish the same objectives and considers the total life-cycle of the project including not only the technical merits of potential solutions but also the costs and relative value of alternatives.

The Systems Engineering Analysis is discussed in Section 5.

3 ITS Project Development

3.1 Overview

The determination of the ITS project development process to be used is dependent on the ITS project risk characteristics. An ITS project can follow the Traditional Road Building Process or the Systems Engineering Process, depending on its complexity.

Refer to Section 4 for ITS Compliance Guidelines.

3.2 Traditional Road Building Process

The Traditional Road Building Process project development as shown in Figure 1 has been used for many years. Over the years, requirements have become well defined, designs are well documented and proven, product performance is solid, and the technology is also proven. As with roadway elements (pavement, drainage), ITS field elements (signals, DMS, CCTV, RWIS) are designed and constructed with Standard Plans, Standard Specifications, and Standard Special Provisions that are well documented. Risk of failure is low for these ITS projects, except when changing to new technology. **Low-Risk** ITS projects will follow the Traditional Road Building process but will still require 23 CFR 940 compliance documentation. Refer to Section 4 for ITS Compliance Guidelines.

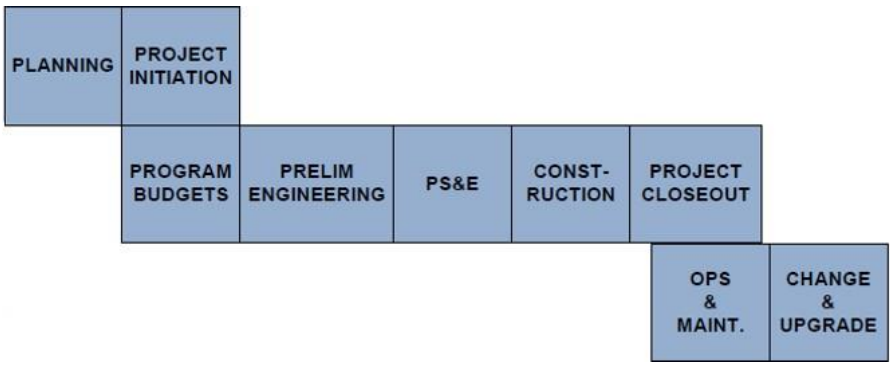


Figure 1 – Traditional Road Building Process

3.3 Systems Engineering Process

More complex ITS projects lead to higher risk of failure (termination, time delays or cost increases). The Traditional Road Building process does not work for complex ITS projects. Additional elements are needed in the process of development to mitigate the higher risks as shown in Figure 2. These additional elements can be thought of as extensions to the Traditional Road Building process and a Systems Engineering Analysis is necessary (see Section 5). For **High-Risk** ITS projects, a Systems Engineering process will be necessary for compliance documentation.

Figure 2 – Systems Engineering Process

Therefore, one of the first steps in the ITS project development is to classify the project according to its risk: Low-Risk or High-Risk.

3.4 ITS Project Classification Guidelines

There are two main categories of ITS projects in Tennessee: **Low-Risk** and **High Risk.** The decisive factor in the risk determination is the scale and complexity of the project. The nature of the engineering development for ITS projects implies a greater risk and uncertainties to successful completion. Project risk may be defined in terms of schedule, cost, quality, and requirements. These risks can increase or decrease significantly based on several identified factors associated with ITS projects.

The factors are:

- Number of jurisdictions and modes;
- Extent of software creation;
- Extent of proven hardware and communications technology used;
- Number and complexity of new interfaces to other systems;
- Level of detail in requirements and documentation;
- Level of detail in operating procedures and documentation;
- Service life of technology applied to equipment and software.

Generic criteria for the determination of risk are shown in the list below.

- Technology: functions are not fully identified, user interface not right, unrealistic technical requirements, component shortcomings;
- People: personnel shortfalls;
- Physical Environment: external dependencies, device placement;
- Political Environment: adding requirements that are not tied to a need, do you have a champion;
- Contract Issues: unrealistic schedules and budgets, requirements change;

Additional discussion on Risk Factors is shown in Table 1.

3.4.1 Projects Not Requiring Systems Engineering Analysis (Non-ITS)

Some projects do not require a Systems Engineering Analysis (SEA). For these, all activities of the traditional roadway project development life-cycle process will be followed. Only general ITS project documentation is necessary. (See Section 4 for required documentation). No further ITS-specific action is necessary.

Projects that do not require a Systems Engineering Analysis are usually projects that do not add new functionality to the system.

The following are examples of projects that do not require a Systems Engineering Analysis:

- Upgrades to an existing traffic signal – This may include, for example, adding or revising left turn phasing or other phasing, adding pedestrian-crossing displays;
- Installing an "isolated" traffic signal – This is a signal not connected to any type of external signal-control system, nor likely to be in the future because of its isolation;
- Traffic signal timing projects – This includes all studies whose purpose is to change the coordination parameters for controlling a group of signals – but with no installation of new hardware or software;
- Studies, Plans, Analyses – This includes ITS Master Plans, Deployment Plans, Technology Studies, etc. whose product is only a document, with no new hardware of software installed.
- Routine Operations including the operation and maintenance of any ITS elements or systems – with no new hardware or software installed.

3.4.2 Low Risk ITS Projects

Low-Risk ITS projects are often referred to as ITS infrastructure expansion projects. Standard Plans, Standard Specification, and Standard Special Provisions are usually well documented.

Low Risk ITS projects will have ***all*** of the following characteristics:

- Single jurisdiction
- No software creation – commercial-off-the-shelf (COTS) or proven software;
- Proven COTS hardware & communications technology;
- No new interfaces;
- System requirements fully documented;
- Operating procedures fully documented;
- Project life-cycle not shortened by technology service life.
- Agency has previous experience

The following are examples of Low Risk ITS projects:

- Expanding a pre-existing system/network by adding field ITS elements (e.g.: DMS, CCTV, RWIS) with no other changes to the system and how it is used;
- Expanding existing communications systems – this consists of extending existing fiber-optic or wireless communications systems, using the same technology and specifications as the preexisting system;
- Expanding a Traffic Signal System by adding additional intersection(s), with no changes needed to the central system;
- Installing an existing parking management system at 2 additional garages – with no changes
- Leasing turnkey services only (e.g., website-based information service) – with no hardware or software purchases.

3.4.3 High Risk ITS Projects

ITS projects are often referred to as ITS System Development projects. A High Risk ITS project is an ITS project that implements part of a regional ITS initiative that is multijurisdictional, multi-modal, or otherwise affects regional integration of ITS. An ITS project is considered High Risk when it involves new technology and custom software development.

High Risk ITS projects have *one* (or more) of the following characteristics:

- Multi-Jurisdictional or Multi-modal;
- Custom software is required;
- Hardware and Communications are "cutting-edge" or not in common use; (new hardware integration)
- New interfaces to other systems are required;
- System requirements not detailed or not fully documented;
- Operating procedures not detailed or not fully documented;
- Technology service life shortens project life-cycle;

- New technology applications.

The following are examples of High Risk ITS projects:

- Implementation of Traffic Signal Systems with:
  - Adaptive Signal Control Technology (ASCT);
  - Traffic Responsive Plan Selection (TRPS);
  - Bus Traffic Signal Priority (TSP);
  - Centrally controlled management;
- Traveler Information System that collects data from multiple agencies or modes;
- Electronic Fare-Payment System;
- Regional Transit Systems;
- ITS project that involves multiple-jurisdictions or multi-modal system implementation;
- New Traffic management centers; and
- New active traffic management systems.

3.5 ITS Project Attributes and Risk Factors

	Low-Risk Project Attributes	High-Risk Project Attributes	Risk Factors
1	Single jurisdiction and single transportation mode (highway, transit or rail)	Multi-Jurisdictional or Multimodal	With multiple agencies, departments, and disciplines, disagreements can arise about roles, responsibilities, cost sharing, data sharing, schedules, changing priorities, etc. Detailed written agreements are crucial!
2	No software creation; uses commercial-off-the-shelf (COTS) or proven software	Custom software development is required	Custom software requires additional development, testing, training, documentation, maintenance, and product update procedures - all unique to one installation. This is very expensive, so hidden short-cuts are often taken to keep costs low. Additionally, integration with existing software can be challenging, especially because documentation is often not complete and out-of-date.
3	Proven COTS hardware and communications technology	Hardware or communications technology are “cutting edge” or not in common use.	New technologies are not “proven” until they have been installed and operated in a substantial number of different environments. New environments often uncover unforeseen problems. New technologies or new businesses can sometimes fail completely. Multiple proven technologies combined in the same project would be high risk if there are new interfaces between them.
4	No new interfaces	New interfaces to other systems are required.	New interfaces require that documentation for the “other” system be **complete and up-to-date.** If not (and often they are not), building a new interface can become difficult or impossible. Duplication of existing interfaces reduces the risk. “Open Standard” interfaces are usually well-documented and low risk.

5	System requirements fully detailed in writing	System Requirements not detailed or not fully documented	System Requirements are critical for the procurement process. They must describe in detail all of the functions the system must perform, performance expected, plus the operating environment. Good requirements can be a dozen or more pages for a small system,and hundreds of pages for a large system. When existing systems are upgraded with new capabilities, requirements must be revised and rewritten.
6	Operating procedures fully detailed in writing	Operating procedures not detailed or not fully documented	Standard Operating Procedures are required for training, operations, and maintenance. For existing systems, they are often out-of-date.
7	None of the technologies used are near end of service life	Some technologies included are near end of service life	Computer technology changes rapidly (e.g. PC's and cell phones become obsolete in 2-4 years). Local area networks using internet standards have had a long life, but in contrast some mobile phones that use proprietary communications became obsolete quickly. Similarly, the useful life of ITS technology (hardware, software, and communications) is short. Whether your project is a new system or expanding an existing one, look carefully at **all** the technology elements to assess remaining cost- effective service life.

Table 1 - ITS Project Attributes and Risk Factors

4 ITS Compliance Guidelines

4.1 Overview

The application and oversight process for ITS projects is summarized in Figure 3. There are four participants involved in the process, each with distinct roles:

- **Planning agencies,** who will program the funds in the TIP and maintain the regional ITS architecture;

- **Local agencies,** who will carry out the projects. This includes their consultants, who may provide assistance with project management, and/or provide systems engineering technical assistance.

- **Tennessee Department of Transportation (TDOT)**, who will be the contracting agency for federal funding.

- **TN FHWA Division Office**, who will obligate federal funding and oversee some aspects of High-Risk projects.

4.2 *Steps to ITS Compliance*

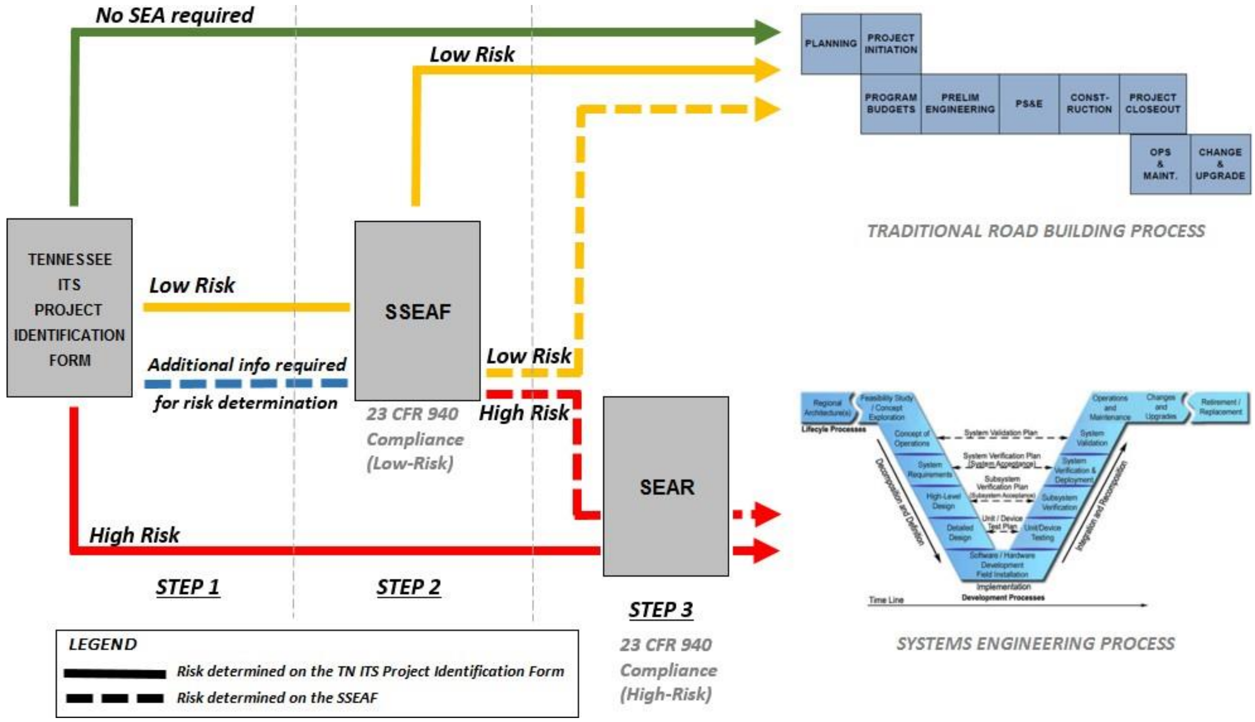


Figure 3 – Steps to ITS Compliance

Step 1 is initiated by the local agency in coordination with the planning agency. In Tennessee, Planning Organizations, comprised of various urban local officials, have a structure to identify and prioritize proposed transportation improvements. As projects are submitted for inclusion in the TIP each project should be evaluated by the submitting agency to determine if the project includes any ITS elements. If the project contains any ITS elements, then the project needs to be reviewed by the Planning Organization to determine if the ITS elements in the project are in conformance with the Regional ITS Architecture (see Sections 7.2 and 7.3). TIPs, once adopted, are forwarded to TDOT for inclusion, by reference into the STIP. ITS projects must be included in the TIP/STIP to receive Federal funds.

➡ For **all** projects related to ITS, (including non-ITS traffic operations improvements described in 3.4.1), TDOT requires the project information, risk assessment questionnaire and proposed funding identification as preliminary documentation. The information shall be documented in the **Tennessee ITS Project Identification Form**, available at (*to be filled* in) and shall be submitted electronically to TDOT Traffic Operations Division Office (ITS e-mail).

It is the responsibility of TDOT to validate if a project is an ITS project, and if so, to verify the need and extent of the Systems Engineering Analysis required and to notify, in writing, the Planning Organization and the project sponsor of the determination and of any additional required documentation. In areas not served by a Planning Organization, the TDOT Traffic Operations Division Office representative will perform the ITS project identifying function and notify the project sponsor of the determination in writing.

If the ITS project does not require a Systems Engineering Analysis, then the remainder of the process is exactly the same as for a traditional road building project (see Section 3.2). No further ITS-specific action is necessary.

If TDOT needs additional information to determine the appropriate Risk Factor for the project or if TDOT determines an ITS project to be Low-Risk**,** then the guidelines on **Step 2** are applicable.

If TDOT determines an ITS project to be High-Risk, then the guidelines on **Step 3** are applicable.

Step 2 occurs when TDOT determines that an ITS project is **Low-Risk** or when additional information is necessary to determine the appropriate Risk Factor for the project.

➡ The local agency is required to fill out the **Simplified Systems Engineering Analysis Form (SSEAF)** available at (*to be filled* in) and submit it electronically to TDOT Traffic Operations Division Office (ITS e-mail).

The SSEAF provides responses to the seven requirements for systems engineering analysis (see Section 5.3) within 23 CFR 940 and has the following objectives:

- to document 23 CFR 940 compliance if the ITS project was determined as **Low-Risk** on Step 1; or
- to provide additional information to assist TDOT in determining if the project is **Low-Risk** or **High-Risk**.

It is the responsibility of TDOT to verify the Risk Factor (Low-Risk or High-Risk) and to notify, in writing, the Planning Organization and the project sponsor of the determination and of any additional required documentation.

If the ITS project is **Low-Risk**, no additional documentation is necessary, the remainder of the process (after FHWA approval, if necessary) is exactly the same as for a traditional road building project (see Section 3.2).

If the ITS project is **High-Risk,** additional documentation is necessary, proceed to Step 3.

Step 3 – for **High-Risk** ITS projects, a detailed Systems Engineering will be necessary to document 23 CFR 940 compliance.

➡ The local agency is required to fill out the **Systems Engineering Analysis Report (SEAR)** available at (*to be filled in*) and submit it electronically to TDOT Traffic Operations Division Office (ITS e-mail).

TDOT reserves the right to ask for additional documentation regarding ITS projects and regarding ITS Compliance anytime during the process.

4.3 Summary of TDOT Required ITS Documentation

1 - Tennessee ITS Project Identification Form – link – to be submitted (ITS e-mail).

2 – Simplified **Systems Engineering Analysis Form (SSEAF**) – link – to be submitted if an ITS Project is determined to be Low Risk or if additional information is required to determine the ITS project risk level. (ITS e-mail).

3 – **Systems Engineering Analysis Report (SEAR**) – link – to be submitted if an ITS Project is determined to be High Risk. (ITS e-mail).

5 Systems Engineering Analysis (SEA)

5.1 Overview

By definition, Systems Engineering is a structured process for arriving at a final design of a system. The final design is selected from a number of alternatives that would accomplish the same objectives and considers the total life-cycle of the project including not only the technical merits of potential solutions but also the costs and relative value of alternatives. There are two main processes that support Systems Engineering Analysis: technical processes and project management processes. Technical processes are depicted in the "V" systems engineering model (see Section 5.3) and are performed to develop an ITS project that meets the user's needs. Project management processes (or cross-cutting activities) are activities that support the steps of the technical processes and are used to plan, monitor, and control the ITS project so that it is completed on time and on budget.

Systems Engineering focuses on defining stakeholder's needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. The Systems

Engineering Analysis provides an opportunity to identify and correct defects as early as possible in the process. Other benefits include:

Improve the quality of Intelligent Transportation Systems

Systems engineering thinking promotes increased up-front planning and system definition prior to technology identification and implementation. Documenting stakeholder needs, expectations, the way the system is to operate (Concept of Operations), and the system requirements (what the system is to do) prior to implementation leads to improved system quality.

Reduce the risk of cost and schedule overruns

Systems engineering promotes stakeholder involvement throughout project development and improves project control with clearly defined decision points (Control Gates). With the up-front planning described above, the risk of costly rework and schedule slips during later stages of implementation are greatly reduced.

Gain wide stakeholder participation

Participation of stakeholders is essential for successful system developments. Using a common and standard development process enables stakeholders to understand and actively participate in the development. Plus, it reduces the learning curve when new stakeholders get involved in a project. A common process ensures a wider set of resources (staff, expertise) that agencies can draw upon within the project life cycle.

Maintain, operate, and evolve the Intelligent Transportation System

Project developments that use a systems engineering approach will improve the documentation of the system (requirements, design, verification, development, and support documentation). Having such documentation will improve the long-term operations & maintenance, of the system. Good documentation will make it easier to upgrade and expand the system.

Maintain consistency with the regional and state ITS architectures

Once a regional ITS architecture is developed and projects are defined, a common and clear roadmap for ITS project development is laid out. A systems engineering approach enables consistency with the regional ITS architecture to be verified and maintained.

Provide flexibility in procurement options for the agencies

Intelligent Transportation Systems that are well documented have greater flexibility for procurement options. Proprietary developments are minimized, proprietary sub-systems are identified, and the use of industry standard interfaces are promoted. This enables alternate system integrators and consultants to support the agencies in upgrades and system expansion. In other words, it minimizes the agencies' need to be "locked into" a specific vendor or system integrator.

Keep current with the rapid evolution of technology

One of the challenges for agencies is staying current with the rapid changes in technology. Intelligent Transportation Systems are long term investments for agencies. So it is important to avoid technology obsolescence. In other words, when field devices fail, the agency should be able to replace them without a major development effort and without maintaining large inventories of obsolete technology. Systems engineering promotes system modularity and the use of standard interfaces where possible. When a technology changes or is unavailable, the functionality can be replaced with minimal impact to other parts of the system (goal of plug and play).

5.2 *The Need for a SEA*

According to the Project Implementation section of 23 CFR 940 all ITS projects funded with highway trust funds shall be based on a systems engineering analysis. In Tennessee, it is recommended that all ITS projects, regardless of funding source, use a systems engineering process.

23 CFR 940 also states that the analysis should be on a scale commensurate with the project scope. Therefore, tailoring the Systems Engineering Analysis for ITS projects is particularly important because so many ITS projects are smaller, less complex, less risky projects. Nevertheless, even for small projects, you still should have documented requirements, design, and verification procedures. Tailoring isn't an invitation to skip steps. Tailoring allows you to adjust the amount of formal documentation and reviews and to focus the process on those steps that are most critical to your project's success. In order to decide on the process that is appropriate for your project, you should perform a risk assessment to understand the complexities involved and how many unknowns there are. Some ITS projects are much larger and more complex than others, which makes them a greater risk and thus candidates for more rigorous processes. See Section 3.4.

5.3 *The Systems Engineering "V" Diagram*

According to the Project Implementation section of 23 CFR 940, the systems Engineering Analysis shall include, at a minimum:

1 - Identification of portions of the regional ITS architecture being implemented (or if a regional ITS architecture does not exist, the applicable portions of the National ITS Architecture);

2 - Identification of participating agencies roles and responsibilities; 3 -

Requirements definitions;

4 - Analysis of alternative system configurations and technology options to meet requirements;

5 - Procurement options;

6 - Identification of applicable ITS standards and testing procedures; and

7 - Procedures and resources necessary for operations and management/maintenance of the system.

It is important to realize that the Systems Engineering approach is actually broader than these seven specific requirements identified in the Rule/Policy. If you implement a good systems engineering process, you will meet or exceed the specific systems engineering analysis requirements identified in the Rule/Policy. Figure 4 shows the steps of the Systems Engineering Analysis.

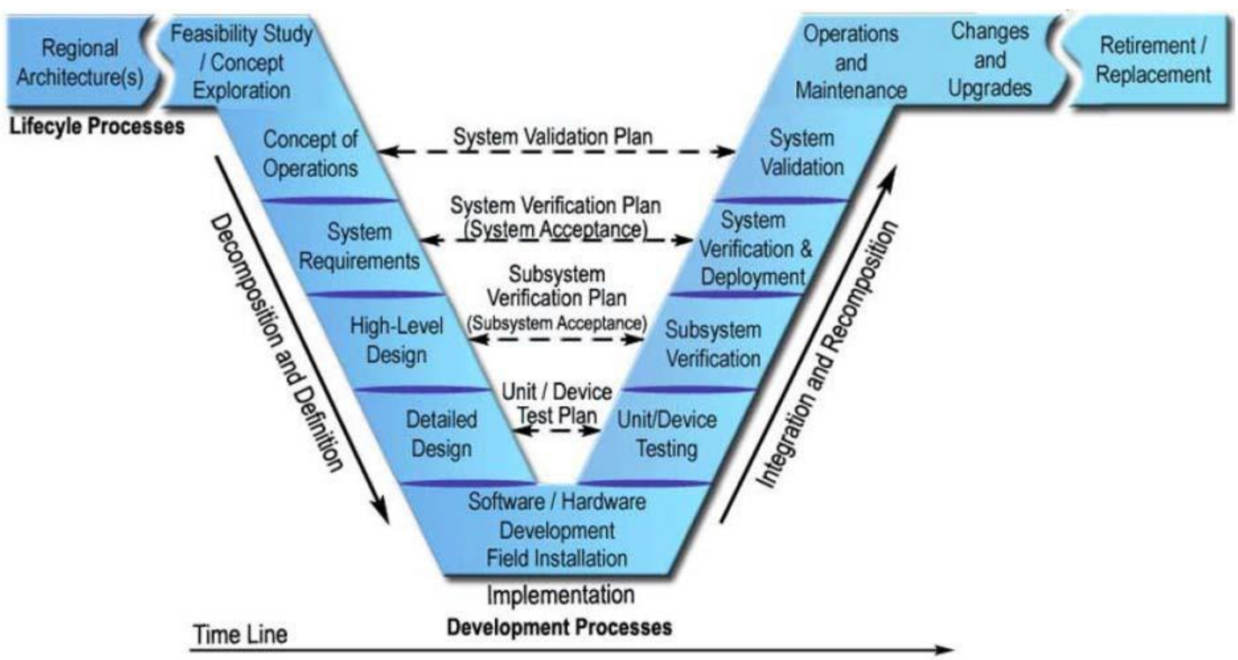


Figure 4 – "V" Diagram - Systems Engineering Analysis

5.4 *Cross-Cutting Activities*

Cross-cutting activities are instrumental activities that are ongoing throughout the systems engineering analysis. Project management, configuration management or change control, traceability and risk management are some of the cross-cutting activities that support the technical processes of systems engineering as demonstrated on Figure 5.

Figure 5 – Cross-cutting activities

5.5 *Key Observations for the "V" Development Model*

The left side of the "V" is the definition and decomposition of the system into components that can be built or procured. The bottom of the "V" is the construction, fabrication, and procurement of the component items. The right side of the "V" integrates the components into sub-systems then into the final system. Each level of integration is verified against the left side of the "V" through the Verification Plans.

Decision gates provide the system's owner with formal decision points for proceeding to the next step of the process. A decision gate is an interface from one phase of the project to the next. There is an interface between each phase from the left side to the right side.

There is a relationship of the activities performed on the left side of the "V" to the products being produced, integrated, and verified on the right side of the "V" (model versus reality).

The most important view of the system for the system's owner and stakeholders is at the Concept of Operations level. Below that level is the area of most interest to the development team. It is the area for which they are responsible (system's owner responsibility versus the development team responsibility).

Importance of stakeholder involvement is shown on both sides of the "V". It is shown on the left side by defining the system and on the right side by the verification of the system.

The arrow in the "V" diagram shows the time sequence of these activities.

5.6 *Basic Systems Engineering Principles*

The Systems Engineer should have the following mindset when developing a system:

1. View the system from the stakeholder point of view (walk in the shoes of the system's owner and stakeholders). Key processes include needs assessment, elicitation, Concept of Operations, and stakeholder involvement.

2. Start at the finish line to define the output of the system and the way the system is going to operate. Key processes include Concept of Operations and Validation Plan.

3. Address risks as early as possible when the cost impacts are lowest. Key processes include risk management, requirements, and stakeholder involvement (spend more time on the left side of the "V").

4. Push technology choices to the last possible moment. Define *what* is to be done before defining *how* it is to be done (form follows function).

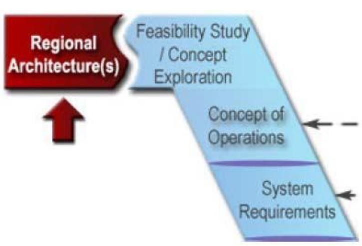
5. Focus on interfaces of the system during the definition of the system. Defining clear and standard interfaces and managing them through the development will ease the integration of the individual elements of the system.

6. Understand the organization of the system's owner, stakeholders, and development team.

5.7 *ITS Technical Process Guidelines*

The following briefly describe each step of the "V" diagram including objectives, necessary input, key activities performed, output results and review information. This guidance is not all encompassing as ITS projects can vary significantly in scope, but should provide adequate information to address a majority of situations.

5.7.1 *Regional Architecture(s)*



The regional ITS architecture is the first step in the "V" because the best opportunity for its use is at the beginning of the development process. The architecture is most valuable as a scoping tool that allows a project to be broadly defined and shown in a regional context. Initial use of the regional ITS architecture requires a few basic activities: locating the right architecture(s), identifying the portion of the architecture(s) that applies to your project, and notifying the architecture(s) maintainer of any required regional architecture changes. The Turbo Architecture software tool can be used to accurately define an ITS project architecture and to generate diagrams and reports that fully document the portion of the regional ITS architecture that will be implemented by the project. This step satisfies 23 CFR 940.11 Requirement 1 and partially satisfies Requirement 6.

Objectives

- Define the project scope while considering the regional vision and opportunities for integration.
- Improve consistency between ITS projects and identify more efficient incremental implementation strategies.
- Improve continuity between planning and project.

Input

- Relevant regional ITS architecture(s)
- Regional/national resources supporting architecture use
- Other planning/programming products relevant to the project

Key activities

- Identify regional ITS architecture(s) that are relevant to the project
- Identify the portion of the regional ITS architecture that applies
- Identify applicable ITS standards
- Verify project consistency with the regional ITS architecture and identify any necessary changes to the regional ITS architecture

Output

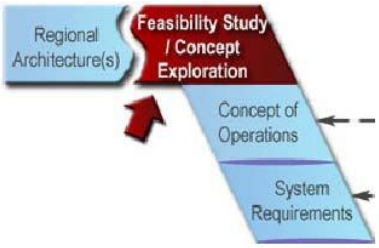
- List of project stakeholders and roles and responsibilities
- List of inventory elements included in or affected by the project
- List of requirements the proposed system(s) must meet
- List of interfaces and the information to be exchanged or shared by the system(s)
- Regional ITS architecture feedback as necessary

Review

Proceed only if you have:

- Demonstrated consistency with the regional ITS architecture and identified needed changes to the regional ITS architecture, if applicable
- Extracted the relevant portion of the regional ITS architecture that can be used in subsequent steps
- Reached consensus on the project/system scope

5.7.2 *Feasibility Study / Concept Exploration*



The proposed ITS project is assessed to determine whether it is technically, economically, and operationally viable. Major concept alternatives are considered, and the most viable option is selected and justified. While the concept exploration should be at a fairly high level at this early stage, enough technical detail must be included to show that the proposed concept is workable and realistic. The feasibility study provides a basis for understanding and agreement among project decision makers – project management, executive management, and any external agencies that must support the project, such as a regional planning commission.

Objectives

- Identify superior, cost-effective concept, and document alternative concepts with rationale for selection
- Verify project feasibility and identify preliminary risks
- Garner management buy-in and necessary approvals for the project

Input

- Project goals and objectives
- Project purpose and need
- Project scope/subset of the regional ITS architecture

Key activities

- Define evaluation criteria
- Perform initial risk analysis
- Identify alternative concepts
- Evaluate alternatives
- Document results

Output

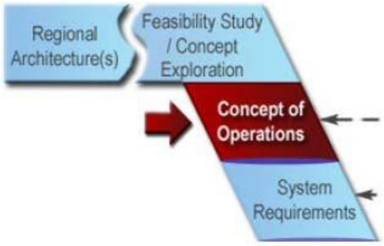
- Feasibility study that identifies alternative concepts and makes the business case for the project and the selected concept

Review

Proceed only if you have:

- Received approval on the feasibility study from project management, executive management, and controlling authorities, as required
- Reached consensus on the selected alternative

5.7.3 *Concept of Operations*



The Concept of Operations (ConOps) is a foundation document that frames the overall system and sets the technical course for the project. Its purpose is to clearly convey a high-level view of the system to be developed that each stakeholder can understand. The Concept of Operations provides a bridge between the needs that motivated the project to begin with and the specific technical requirements. A good ConOps answers who, what, where, when, why, and how questions about the project from the viewpoint of each stakeholder.

- Who – Who are the stakeholders involved with the system?
- What – What are the elements and the high-level capabilities of the system?
- Where – What is the geographic and physical extent of the system?
- When – What is the sequence of activities that will be performed?
- Why – What is the problem or opportunity addressed by the system?
- How – How will the system be developed, operated, and maintained? This step satisfies 23 CFR 940.11 Requirement 2 and Requirement 7.

Objectives

- High-level identification of user needs and system capabilities in terms that all project stakeholders can understand
- Stakeholder agreement on interrelationships and roles and responsibilities for the system
- Shared understanding by system owners, operators, maintainers, and developers on the who, what, why, where, and how of the system
- Agreement on key performance measures and a basic plan for how the system will be validated at the end of project development

Input

- Stakeholder lists, roles and responsibilities, and other components from the regional ITS architecture
- Recommended concept and feasibility study from the previous step
- Broad stakeholder input and review

Key activities

- Identify the stakeholders associated with the system/project
- Define the core group responsible for creating the Concept of Operations
- Develop an initial Concept of Operations, review with broader group of stakeholders, and iterate
- Define stakeholder needs

- Create a preliminary System Validation Plan

Output

- Concept of Operations describing the who, what, why, where, and how of the project/system, including stakeholder needs and constraints
- Preliminary System Validation Plan defining the approach that will be used to validate the project delivery

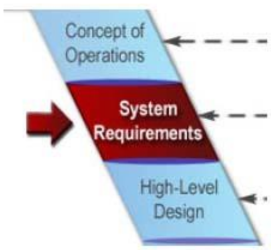
Review

Proceed only if you have:

- Received approval on the Concept of Operations from each stakeholder organization
- Received approval on the preliminary System Validation Plan from each stakeholder organization

A template is available at:
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_5.cfm

5.7.4 *Systems Requirements*



The stakeholder needs identified in the Concept of Operations are reviewed, analyzed, and transformed into verifiable requirements that define *what* the system will do but not *how* the system will do it. One of the most important attributes of a successful project is a clear statement of requirements that meet the stakeholders' needs. System requirements are also essential for the development of contract specifications language. There is no need to develop a set of new requirements specification from scratch for every project. Projects that enhance or extend an existing system should start with the existing system requirements. Each of the requirements listed in this document must be linked to a corresponding need described in the Concept of Operations. If you define a requirement that cannot be traced to a statement of need defined in the Concept of Operations, then either the Concept of Operations document must be revised (so its readers will clearly understand why the requirement exists), or the requirement should be deleted. This step satisfies 23 CFR 940.11 Requirement 3.

Objectives

- Develop a validated set of system requirements that meet the stakeholders' needs

Input

- Concept of Operations (stakeholder needs)
- Functional requirements, interfaces, and applicable ITS standards from the regional ITS architecture
- Applicable statutes, regulations, and policies
- Constraints (required legacy system interfaces, hardware/software platform, etc.)

Key activities

- Elicit (evoke) requirements from stakeholders
- Analyze requirements
- Document requirements
- Validate requirements
- Manage requirements
- Create a System Verification Plan
- Create a System Acceptance Plan

Output

- System Requirements document
- System Verification Plan
- Traceability Matrix (see Section 5.8.3)
- System Acceptance Plan

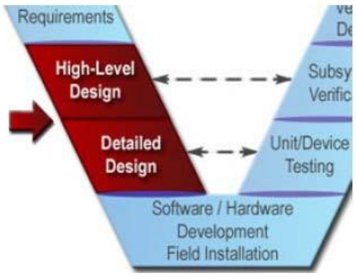
Review

Proceed only if you have:

- Received approval on the System Requirements document from each stakeholder organization, including those that will deploy, test, install, operate, and maintain the new system
- Received approval on the System Verification Plan from the project sponsor, the test team, and other stakeholder organizations
- Received approval on the System Acceptance Plan from the project sponsor, the Operations & Maintenance (O&M) team, and other stakeholder organizations

A template is available at:
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_6.cfm

5.7.5 *Systems Design*



A system design is created based on the system requirements including a high-level design that defines the overall framework for the system. Subsystems of the system are identified and decomposed further into components.

Requirements are allocated to the system components, and interfaces are specified in detail. Detailed specifications are created for the hardware and software components to be developed, and final product selections are made for off-the-shelf components. In the systems engineering approach, we define the problem before we define the solution. The previous steps in the "V" have all focused primarily on defining the problem to be solved. The system design step is the first step where we focus on the solution. This is an important transitional step that links the system requirements that were defined in the previous step with system implementation that will be performed in the next step. This step satisfies 23 CFR 940.11 Requirement 4 and Requirement 5.

Objectives

- Produce a high-level design that meets the system requirements and defines key interfaces, and that facilitates development, integration, and future maintenance and upgrades
- Develop detailed design specifications that support hardware and software development and procurement of off-the-shelf equipment

Input

- Concept of Operations
- System Requirements document
- Off-the-shelf products
- Existing system design documentation
- ITS standards
- Other industry standards

Key activities

- Evaluate off-the-shelf components and procurement options
- Develop and evaluate alternative high-level designs
- Analyze and allocate requirements
- Document interfaces and identify standards
- Create Integration Plan, Subsystem Verification Plans, and Subsystem
- Acceptance Plans
- Develop detailed component-level design specifications

Output

- Off-the-shelf evaluation and alternatives summary reports
- High-level (architectural) design
- Detailed design specifications for hardware/software
- Integration Plans, Subsystem Verification Plans, Subsystem Acceptance Plans, and Unit/Device Test Plans

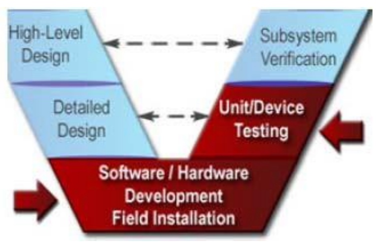
Review

Proceed only if you have:

- Approved high-level design for the project
- Defined all system interfaces
- Traced the system design specifications to the requirements
- Approved detailed specifications for all hardware/software components

A template is available at: http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_7.cfm

5.7.6 *Software/Hardware Development and Testing*



Hardware and software solutions are created for the components identified in the system design. Part of the solution may require custom hardware and/or software development, and part may be implemented with off-the- shelf items, modified as needed to meet the design specifications. The components are tested and delivered ready for integration and installation. Although hardware and software development may be the first task that comes to mind when thinking about an ITS project, the systems engineering approach focuses on the preceding requirements and design steps and on the integration, verification, and validation steps to follow. This is where the investment in a clear set of requirements and a good system design should begin to pay dividends. The systems engineering process now provides technical oversight as an implementation team of specialists fabricates the hardware and writes the software.

This is a highly iterative process, particularly for software, where key features may be incrementally implemented, tested, and incorporated into the baseline over time.

Progress is monitored through a planned series of walkthroughs, inspections, and reviews. Although the systems engineering approach does not specify the mechanics of hardware and software development (this is left to the implementation team), the development effort is obviously critical to project success. This is the time to build quality into the hardware/software and to minimize defects. This step partially satisfies 23 CFR 940.11 Requirement 6.

Objectives

- Develop and/or purchase hardware and software components that meet the design specifications and requirements with minimum defects
- Identify any exceptions to the requirements or design specifications that are required

Input

- System and subsystem requirements
- System design
- Off-the-shelf products
- Industry standards
- Unit/Device Test Plans

Key activities

- Plan software/hardware development
- Establish development environment
- Procure off-the-shelf products
- Develop software and hardware
- Perform unit/device testing

Output

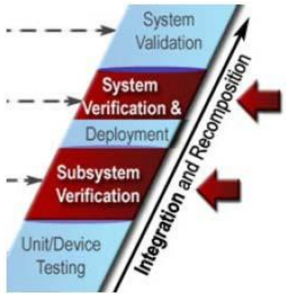
- Software/hardware development plans
- Hardware and software components, tested and ready for integration
- Supporting documentation (e.g., training materials, user manuals, maintenance manuals, installation and test utilities)

Review

Proceed only if you have:

- Conducted technical reviews of the hardware/software
- Performed configuration/quality checks on the hardware and software
- Received all supporting documentation
- Verified that unit/device testing has been successfully completed

5.7.7 *Integration and Verification*



The software and hardware components are individually verified and then integrated to produce higher-level assemblies or subsystems. These assemblies are also individually verified before being integrated with others to produce yet larger assemblies, until the complete system has been integrated and verified. In this step, we assemble the system components into a working system and verify that it fulfills all of its requirements.

Assembling a puzzle is a nice, simple analogy for this step, but the challenge in an ITS project "puzzle" is that you may find that not all of the pieces are available at the same time, some won't fit together particularly well at first, and there will be pressure to change some of the pieces after you have already assembled them. The systems engineering approach provides a systematic process for integration and verification that addresses the challenges and complexity of assembling an ITS system. Integration and verification are iterative processes in which the software and hardware components that make up the system are progressively combined into subsystems and verified against the requirements. This process continues until the entire system is integrated and verified against all of its requirements. This is the opposite of the decomposition that was performed during the Requirements and Design steps, which is reflected in the symmetry between the left and right sides of the "V". Components that are identified and defined on the left side of the "V" are integrated and verified on the right. In systems engineering, we draw a distinction between verification and validation. *Verification* confirms that a product meets its specified requirements. *Validation* confirms that the product fulfills its intended use. In other words, verification ensures that you "built the product right", whereas validation ensures that you "built the right product". This is an important distinction because there are lots of examples of well-engineered products that met all of their requirements but ultimately failed to serve their intended purpose. This step partially satisfies 23 CFR 940.11 Requirement 6.

Objectives

- Integrate and verify the system in accordance with the high-level design, requirements, and verification plans and procedures
- Confirm that all interfaces have been correctly implemented
- Confirm that all requirements and constraints have been satisfied

Input

- System Requirements document
- High-level design specifications
- Detailed design specifications

- Hardware and software components
- Integration plan
- System and Subsystem Verification Plans
- Subsystem Acceptance Plans

Key activities

- Add detail to integration and verification plans
- Establish integration and verification environment
- Perform integration
- Perform verification

Output

- Integration plan (updated)
- Verification plan (updated)
- Testing plan
- Integration test and analysis results
- Verification results, including corrective actions taken

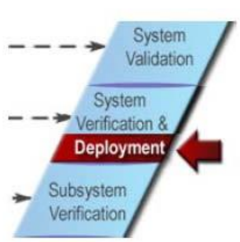
Review

Proceed only if you have:

- Documented evidence that the components, subsystems, and system meet the allocated requirements
- Documented evidence that the external and internal interfaces are working and consistent with the interface specifications

A template is available at: http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_8.cfm

5.7.8 *Initial Deployment*



The system is installed in the operational environment and transferred from the project development team to the organization that will own and operate it. The transfer also includes support equipment, documentation, operator training, and other enabling products that support ongoing system operation and maintenance.

Acceptance tests are conducted to confirm that the system performs as intended in the operational environment. A transition period and warranty ease the transition to full system operation.

Objectives

- Uneventful transition to the new system

Input

- Integrated and verified system, ready for installation
- System Acceptance Plan

Key activities

- Plan for system installation and transition
- Deliver the system
- Prepare the facility
- Install the system
- Perform acceptance tests
- Transition to operation

Output

- Hardware and software inventory
- Final documentation and training materials
- Delivery and installation plan, including shipping notices
- Transition Plan with checklists
- Test issues and resolutions
- Operations and maintenance plan and procedures

Review

Proceed only if you have:

- Formally accepted the system
- Documented acceptance test results, anomalies, and recommendations

5.7.9 *System Validation*

After the ITS system has passed system verification and is installed in the operational environment, the system owner/operator, whether the state DOT, a regional agency, or another entity, runs its own set of tests to make sure that the deployed system meets the original needs identified in the Concept of Operations. Validation is the responsibility of the agency, and cannot be delegated to the system supplier or vendor.

Objectives

- Confirm that the installed system meets the user's needs and is effective in meeting its intended purpose

Input

- Concept of Operations
- Verified, installed, and operational system
- System Validation Plan

Key activities

- Update Validation Plan as necessary and develop procedures
- Validate system
- Document validation results, including any recommendations or corrective actions

Output

- System Validation Plan (update) and procedures
- Validation results

Review

Proceed only if you have:

- Validated that the system is effectively meeting its intended purpose
- Documented issues/shortcomings
- Established ongoing mechanisms for monitoring performance and collecting recommendations for improvement
- Made modifications to the Concept of Operations to reflect how the system is actually being used

A template is available at: http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_11.cfm

5.7.10 *Operations and Maintenance*

Once the customer has accepted the ITS system, the system operates in its typical steady state. System maintenance is routinely performed and performance measures are monitored. As issues, suggested improvements, and technology upgrades are identified, they are documented, considered for addition to the system baseline, and incorporated as funds become available. An abbreviated version of the systems engineering process is used to evaluate and implement each change. This occurs for each change or upgrade until the ITS system reaches the end of its operational life.

Objectives

- Use and maintain the system over the course of its operational life

Input

- System requirements (operations/maintenance requirements)
- Operations and Maintenance Plan and procedures
- Training materials
- Performance data
- Evolving stakeholder needs

Key activities

- Conduct Operations and Maintenance Plan reviews
- Establish and maintain all operations and maintenance procedures
- Provide user support
- Collect system operational data
- Change or upgrade the system
- Maintain configuration control of the system
- Provide maintenance activity support

Output

- System performance reports
- Operations logs
- Maintenance records
- Updated operations and maintenance procedures
- Identified defects and recommended enhancements
- Record of changes and upgrades
- Budget projections and requests

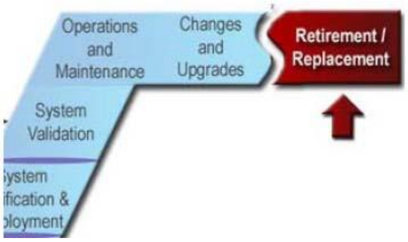
Review

Proceed only if you have:

- Demonstrated that the system has reached the end of its useful life

A template is available at: http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_12.cfm

5.7.11 *Retirement/Replacement*



Operation of the ITS system is periodically assessed to determine its efficiency. If the cost to operate and maintain the system exceeds the cost to develop a new ITS system, the existing system becomes a candidate for replacement. A system retirement plan will be generated to retire the existing system gracefully.

Objectives

- Remove the system from operation, gracefully terminating or transitioning its service
- Dispose of the retired system properly

Input

- System requirements (retirement/disposal requirements)
- Service life of the system and components
- System performance measures and maintenance records

Key activities

- Plan system retirement
- Deactivate system
- Remove system
- Dispose of system

Output

- System retirement plan
- Archival documentation

Review

Proceed only if you have:

- Planned the system retirement
- Documented lessons learned
- Disposed of the retired system properly

5.8 ***ITS Project Management Process Guidelines***

In addition to the technical process steps identified in the "V" diagram, there are several project management and control activities that are essential in order for an ITS project to be successful. These are also known as cross-cutting activities. Any ITS project can benefit from these project management processes, but larger, more complex ITS projects will benefit the most. Project management, configuration management or change control, traceability and risk management are key cross-cutting activities that support the technical processes of systems engineering.

5.8.1 *Project Management*

Project Management [3] encompasses project planning and project monitoring and control.

Project planning lays out the activities, resources, budget, and timeline for the project. This effort, which begins early in the project life cycle (usually before the Concept of Operations), results in the creation of two major plans, the Project Plan (PP) and the Systems Engineering Management Plan (SEMP). Both of these documents should be written in such a way that a newcomer to the project team can understand the type and scope of the project, the responsibilities of the major players, the staffing, the schedule and budget, and the processes that will govern the project. The Project Plan (PP) documents how the project will be managed and controlled from a programmatic standpoint. It identifies the detailed work plans for both administrative and technical tasks.

For each project task, the PP documents what is to be done, by whom, with what funds, when, how (processes to be used), and dependencies. The Systems Engineering Management Plan (SEMP) is the top-level plan for managing the systems engineering effort to produce a final operational system from initial requirements.

Just as the PP defines how the overall project will be executed, the SEMP defines how the engineering portion of the project will be executed and controlled. It describes how the efforts of system designers, test engineers, and other engineering and technical disciplines will be integrated, monitored, and controlled during the complete life cycle. For a small project, the SEMP might be included as part of the PP document, but for any project of greater size or complexity a separate document is recommended.

Project monitoring and control relies on project tracking and project reviews to follow project progress against its plan. Performance measures and metrics are recommended for project tracking. Project reviews are a primary method of communicating progress, monitoring risk, and transferring products and knowledge between project team members. The reviews often occur at the completion of a "V" process step and

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[3] *For more information on Project Management, the reader is encouraged to access the FHWA/Caltrans Systems Engineering Guidebook for ITS website at:* *http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section3/3_9_3.cfm*

represent *decision points* that must be passed successfully before moving to the next step in the process.

5.8.2 *Configuration Management or Change Control*

Change during the ITS project life-cycle is inevitable. Even small changes, if not controlled, can have major effects on the project. Therefore, once the items that will be tracked (software, hardware, documentation, etc) have been identified, any changes to them must be handled in a controlled fashion. Basically, the change control process [(4)] steps are:

- Submit change request
- Assess impact and prepare recommendation
- Submit report to Configuration Control Board (CCB)
- CCB deliberates and decides
- Document approved changes
- Update traceability matrices

It is important to document changes made during project development, how those changes were accommodated and how change orders will be processed and managed during construction, including necessary approvals.

5.8.3 *Traceability*

As you move from one step to the next in the systems engineering process, it is important to be able to relate the items in one step with those in another. The relationship between items is called *traceability* [(5)]. For example, you use traceability to relate a requirement to the subsystem that will implement the requirement. Traceability connects many items together. The requirement will be related to a user need as well as to a test that will be used to verify the requirement. Traceability is a powerful concept that allows you to be certain that the system that is implemented at the end of the project is directly connected with the user needs that were identified at the beginning.

The traceability matrix may be included in the contract documents for use during construction.

[(4)] *For more information on Change Control, the reader is encouraged to access the FHWA/Caltrans Systems Engineering Guidebook for ITS website at:*
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section3/3_9_6.cfm

[(5)] *For more information on Traceability, the reader is encouraged to access the FHWA/Caltrans Systems Engineering Guidebook for ITS website at:*
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section3/3_9_11.cfm

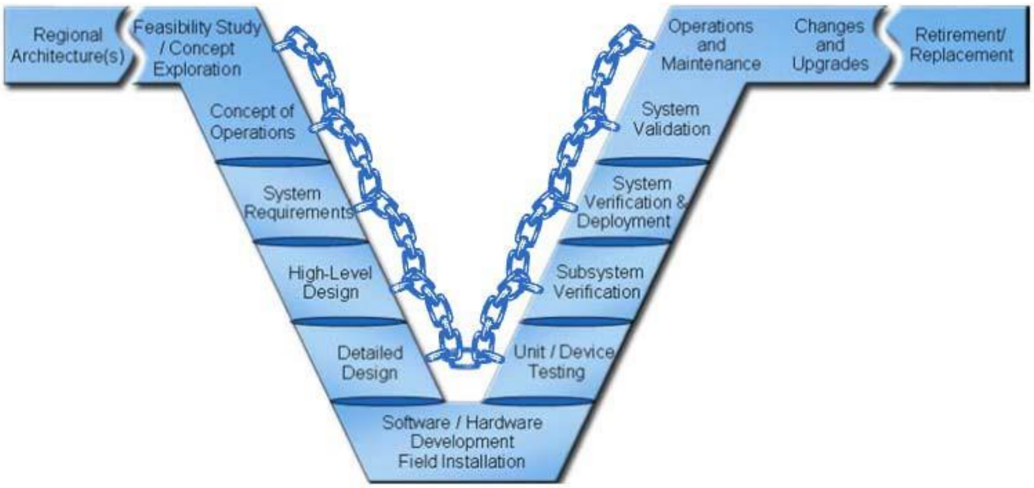

Figure 6 - Traceability

5.8.4 *Risk Management*

Risk management [(6)] is the identification and control of risks during all phases of the project life-cycle. The goal of risk management is to identify potential problems before they occur, plan for their occurrence, and monitor the system development so that early action can be taken if the risk occurs.

Risk management is composed of the following general steps:

- Risk identification
- Risk analysis and prioritization
- Risk mitigation
- Risk monitoring

5.9 *SEA and Adaptive Signal Control Technology (ASCT)*

A Systems Engineering Analysis (SEA) support the process of exploring the need for Adaptive Signal Control Technology (ASCT) and helps articulate a set of requirements that enable agencies to specify, select, implement and test adaptive signal control technology. In the past, a significant number of adaptive systems have been deactivated well before the end of their useful life due either to a lack of adequate resources or agency capability to support system operation and maintenance, or in some cases a failure to properly align agency and system operations objectives.

[(6)] *For more information on Risk Management, the reader is encouraged to access the FHWA/Caltrans Systems Engineering Guidebook for ITS website at:* *http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section3/3_9_4.cfm*

The risks associated with ASCT implementation are significant. Therefore, the SEA process will help an agency confirm that its expectations are realistic and achievable before committing to a system.

The SEA documentation for ASCT will provide a structure within which an agency can examine its current operation (or the operation the agency expect to have within the near future), assess whether or not adaptive control is likely to address the agency issues, and then decide what type of adaptive control will be right.

For guidance on the Systems Engineering Analysis (SEA) documentation for Adaptive Signal Control Technology (ASCT), TDOT recommends the guidelines provided by the Federal Highway Administration on FHWA-HOP-11-027 *Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems* [7], in addition to the guidelines in this chapter.

6 *Procurement Guidelines*

6.1 *Overview*

An analysis of procurement options is a requirement of the Systems Engineering Analysis identified on the Project Implementation section of 23 CFR 940. The successful procurement of ITS projects is a challenging task.

The challenges are especially paramount when procuring ITS projects that involve advanced technologies which require specialized skills and knowledge. Although there are similarities, there are also key differences between the traditional process and the systems engineering approach that should be considered when planning your next ITS project. For example, in the traditional transportation project development process, there is clear contractual separation between the consultant that prepares the PS&E and the contractor that builds the project. This is a risky approach for many ITS projects, in which it is important to have more continuity across the project development life cycle so that the contractor who ultimately implements the ITS system clearly understands the underlying user needs and requirements and has the latitude to implement the most cost-effective solution. For example, the contractor that implements custom software for an ITS project should also participate in the detailed software design. You would not want to impose a contractual barrier between the software designer and the software implementer.

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[7] *The Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems is available at http://www.ops.fhwa.dot.gov/publications/fhwahop11027/mse_asct.pdf*

ITS projects vary in scope and typically require collaboration and iteration between the design and implementation phases. Therefore, different procurement approaches are warranted for ITS system acquisitions. The procurement process for an ITS project must be flexible to accommodate the uncertainties of complex system acquisitions, but, at the same time, structured enough to ensure that the responsibilities of the participants are fully defined and their interests protected. This process should also ensure that the most qualified organizations are selected for the system implementation. The project development process is strongly influenced by the selected procurement strategy because it will determine who (agency, consultant, or contractor) takes the lead for each process step. It is important to tailor the procurement strategy based on the scope of ITS project and not to assume that it always has to be done the same way.
The definitions of “construction”, ”engineering and design services,” and “non-engineering/non-architectural” form the framework for grouping ITS project requirements in terms of products, systems, and services.

This guidance is not all encompassing as ITS projects can vary significantly in scope, but should provide adequate information to address a majority of situations. It is recommended that State and local agencies consult with the FHWA Division Office when attempting to choose appropriate contracting techniques for their planned ITS projects.

6.2 *Scope of ITS Projects and Contracting Requirements*

23 USC 101 (G) [(8)] defines “*Construction*” in terms of “*improvements that directly facilitate and control traffic flow*”.

For example, contractor installation of field devices and hardware typically meets the definition of construction. Rehabilitation of an existing physical ITS infrastructure is also generally considered a construction contract. If an ITS project meets the definition of construction, then the contract should be bid competitively with award to the lowest responsive bidder meeting the specified conditions of responsibility. In this case, the procurement procedures in 23 CFR 635 [(9)] (competitive sealed bidding) will apply.

[(8)] *23 USC 101 (G) is available at http://www.gpo.gov/fdsys/pkg/USCODE-2011-title23/pdf/USCODE- 2011-title23-chap1-sec101.pdf*

[(9)] *23 CFR 635 is available at http://www.gpo.gov/fdsys/pkg/CFR-1999-title23-vol1/pdf/CFR-1999-title23- vol1-part635.pdf*

23 USC 112(b)(2)(A) [(10)] and 23 CFR 172[(11)] require the procedures of the Brooks Act (40 USC § 1101-1104) [(12)] to be used for each contract for program management, construction management, feasibility studies, preliminary engineering, design, engineering, surveying, mapping or architectural related services with respect to a construction project performed by or supervised by the State with Federal-aid funds. These services are typically defined as "*Engineering and design related services"* and perform an identifiable task (*see TDOT Standard Procurement of Engineering and Technical Services (13) for additional information*). The Brooks Act requires agencies to promote open competition by advertising, ranking, selecting, and negotiating contracts based on demonstrated competence and qualifications for the type of engineering and design related services being procured, and at a fair and reasonable price (qualification- based selection).

If an ITS project does not meet the legal definition of "*Construction*" and is not categorized as an "*Engineering and design related services*", then it may be considered to be "*Non-engineering/non-architectural*", commonly known as a "*Service contract*" and may be procured using the State of Tennessee's own procurement procedures [(14)] in accordance with 49 CFR 18 [(15)]. Examples may include research and planning projects including ITS field operational tests and ITS early deployment planning studies.

Oftentimes ITS projects do not fit neatly into one category – construction, engineering/architectural, or service contract. High-risk ITS projects will usually need some sort of engineering/architectural procurement due to the expected degree of hardware or software customization, integration and testing. However, there may still

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[(10)] *23 USC 112(b)(2)(A) is available at http://www.gpo.gov/fdsys/pkg/USCODE-2011-title23/pdf/USCODE-2011-title23-chap1-sec112.pdf*

[(11)] *23 CFR 172 is available at http://www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=23:1.0.1.2.3*

[(12)] 40 USC § 1101-1104 *is available at http://www.gpo.gov/fdsys/granule/USCODE-2011-title40/USCODE-2011-title40-subtitleI-chap11-sec1101/content-detail.html*

[(13)] *TDOT Standard Procurement of Engineering and Technical Services is available at* http://www.tdot.state.tn.us/Chief_Engineer/assistant_engineer_design/design/consultant_information/Poli cy301-01.pdf

[(14)] *The Procurement Procedures Manual of the Tennessee Central Procurement Office is available at http://tn.gov/generalserv/cpo/documents/ProcurementManual-PCApproved05-15-14.pdf*

[(15)] *49 CFR 18 is available at http://www.ecfr.gov/cgi-bin/text idx?c=ecfr;sid=b4638f907e1b978ef4494bdc12956079;rgn=div5;view=text;node=49%3A1.0.1.1.12;idno=49;cc=ecfr* be a significant amount of roadway construction that's either independent of the ITS portion (such as concurrent road widening that's part of the same project scope) or required for the ITS installation (such as trenching and installing conduit for a communications system). There may also be portions more suited towards a service contract, such as purchase of data or website-hosting services. With such "hybrid" projects that have multiple types of work, there should be at least one contract per type of work.

For questions regarding classification of projects by the types listed above, and for questions regarding the State of Tennessee's procedures for "service contracts," please contact the TDOT Traffic Operations Division.

6.3 *Sole Source Procurement*

23 USC 112(a) [(16)] requires procurement of ITS systems and components to be competitive. The specification of a particular product may restrict competition as the pool of available products is reduced to the product selected. In some cases, however, the need for a particular product outweighs the need to procure products competitively. Therefore, 23 CFR 635.411 [(17)] allows the acquisition of proprietary materials with federal funds under Certification, Public Interest Finding or Experimental Products.

Additional information is available at TDOT Guidelines for Submittal of Proprietary Products Certifications, Public Interest Findings and Experimental Products [(18)].

6.3.1 *Certification*

A written and signed statement of an appropriate contracting agency official is required, certifying that a particular patented or proprietary product is either:

- Necessary for *synchronization* with existing facilities; or
- A unique product for which there is no equally suitable alternative.

For *synchronization* it is understood that the product matches specific current or desired characteristics of a project. Synchronization may be based on:

- Function (the proprietary product is necessary for the satisfactory operation of the existing facility),

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[(16)] *23 USC 112(a) is available at [http://www.gpo.gov/fdsys/pkg/USCODE-2011-title23/pdf/USCODE- 2011-title23-chap1-sec112.pdf](http://www.gpo.gov/fdsys/pkg/USCODE-2011-title23/pdf/USCODE-2011-title23-chap1-sec112.pdf)*

[(17)] 23 CFR 635.411 *is available at [http://www.gpo.gov/fdsys/pkg/CFR-2011-title23-vol1/pdf/CFR-2011- title23-vol1-sec635-411.pdf](http://www.gpo.gov/fdsys/pkg/CFR-2011-title23-vol1/pdf/CFR-2011-title23-vol1-sec635-411.pdf)*

[(18)] *TDOT Guidelines for Submittal of Proprietary Products Certifications, Public Interest Findings and Experimental Products is available at http://www.tdot.state.tn.us/materials/reseval/products.htm*

- Aesthetics (the proprietary product is necessary to match the visual appearance of existing facilities),
- Logistics (the proprietary product is interchangeable with products in an agency's maintenance inventory),
- Or any combination thereof.

In addition, it may be advisable to evaluate the following factors as they relate to synchronization:

- Lifecycle (the relative age of existing systems that will be expanded and the remaining projected life of the proposed proprietary element in relation to the remaining life of the existing elements);
- Size/extent of products and systems to be synchronized to/with, and the relative cost of the proprietary elements compared with replacing the elements requiring synchronization.

"*Engineering and design related services" cannot be selected by* Certification.

6.3.2 Public Interest Finding (PIF)

An approval by the FHWA Division Administrator is required, based on a request from a contracting agency that it is in the public interest to allow the contracting agency to require the use of a specific material or product even though other equally acceptable materials or products are available.

6.3.3 Experimental Products

If a contracting agency requests to use a proprietary product for research or for a distinctive type of construction on a relatively short section of road for experimental purposes, it must, submit an experimental product work plan [(19)] for review and approval. The work plan should provide for the evaluation of the proprietary product, and where appropriate, a comparison with current technology.

6.4 Contracting Techniques

The selection of appropriate contracting options for designing and constructing an ITS project depends on many variables. These variables include:

- Type and complexity of the required products, systems, and services;
- Interdependence of project components and subsystems;
- Inclusion of ITS systems components with roadway construction projects;

[(19)] *Additional information regarding Experimental Products is available at http://www.fhwa.dot.gov/programadmin/contracts/expermnt.cfm*

- Use of varied and rapidly changing advanced technologies;
- Need to prequalify consultants and/or contractors;
- Constrained deployment schedule;
- Magnitude of construction impacts on road users;
- Risk management factors associated with capital investments in transportation systems.

The following identifies some of the contracting techniques that have been used for ITS projects and highlights a few of the considerations for their use in your next project.

6.4.1 *Design-Bid-Build*

The design-bid-build technique has historically been used by transportation agencies for designing and constructing construction projects. It is an effective procurement vehicle only for ITS projects that meet the definition of "*Construction*" (see Section 6.2)

Design-bid-build is a project delivery system in which a transportation agency utilizes the services of an engineering consulting firm (or in-house staff) to design a project (design step), invites contractors to submit bids (bid step), and subsequently constructs the project using the services of a contractor (build step). The technique utilizes two independent but sequential contracts - engineering and design services and construction. These projects typically incorporate physical installations of field hardware, devices, cables, foundations, pull boxes, conduit system, poles, or other definable physical components such as traffic management buildings. However, the design-bid- build technique may not be best suited for ITS projects that contain rapidly-changing technologies, unknown factors and specifications, software, computer hardware, communications, and system integration.

6.4.2 *Design-Build*

The design-build technique [20] is a project delivery system in which a single entity provides design services and constructs the project - all under one contract. Design- build may be effectively leveraged to overcome some of the challenges of the traditional contracting techniques when designing and constructing technologically complex ITS projects.

The design-build contracting technique is best suited for:

- Projects that can best be defined by functional or performance based specifications;

[20] Guidelines for design-build contracts in Tennessee are available at http://www.tdot.state.tn.us/construction/Design_Build.htm

- Projects that have the propensity to benefit significantly from innovative design and construction solutions;
- Projects containing complex systems and subsystems that require major integration efforts and involve many unknown and indefinable factors and rapidly changing advanced technologies.

Here are some important considerations when using the design-build technique:

- Requirements/high-level design prepared prior to selection;
- All requirements must be identified and must be strong;
- Places burden of verification and validation on agency;
- Significant quality control required.

6.4.3 *System Manager and System Integrator*

The systems manager technique is a project delivery strategy in which all project design and interface functions are performed by a consultant under engineering and design services contracts, and all construction activities are performed by various contractors under different construction contracts.

The responsibilities of a systems manager overlap both design and construction phases of the project and typically includes development of project sequencing and coordination of the various subsystems, design, preparation of PS&Es, inspection, testing, and integration of the various subsystems into a total operating system. The agency maintains direct management, administration, and control authority over the contractors.

The system integrator technique is similar to the system manager technique except that the integrator is not involved in the planning and design stages.

FHWA has allowed the State DOTs to evaluate non-traditional contracting techniques under a program titled "Special Experimental Project No. 14 - Innovative Contracting”

(21). SEP-14 is a functional experimental program that may be used to evaluate promising non-traditional contracting techniques.

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(21) Special Experimental Projects No.14 – Alternative Contracting is available at http://www.fhwa.dot.gov/programadmin/contracts/sep_a.cfm

6.5 *Use of System Requirements on the Procurement Process*

Regardless of the procurement approach selected, systems engineering support is always useful for an ITS project, most importantly its System Requirements. Here are some considerations regarding the use of requirements on the procurement process:

- Good requirements reduce the most risk when developed and used right from the start;
- Good requirements allow agencies to control the procurementprocess leading to successful project implementation;
- Requirements should be used on the selection of technology;
- Make technology decisions as late as possible in the process;
- The burden of clarity is on the agency writing the documentation;
- Avoid ambiguity on requirements;
- It is good practice to ask vendors to document how their system/product will satisfy the requirements.

6.5.1 *Request for Information (RFI) – (Optional)*

Once your requirements have been drafted, there may be some that you are not sure can be met by any, or a sufficient number, of the available systems. This is a point at which you need to consider whether it will be appropriate to purchase a commercially available system (with or without some customization) or develop a unique system.

When this occurs, it is appropriate, and perhaps desirable, to release to vendors a formal request for information (RFI) focused on the specific requirements about which you are uncertain. Response to an RFI should not be a condition of future participation by a vendor in the procurement process. Use of the RFI will allow you to decide whether or not your requirements can be satisfied by a commercially available system. If not, you can then decide whether to modify your requirements or develop a much more detailed set of requirements and a specification that would be appropriate for development of a unique system.

6.5.2 *Industry Review of Requirements– (Optional)*

More comprehensive feedback from vendors can be obtained by distributing a draft version of your requirements to vendors. This is appropriate when you have developed requirements that will involve some customization or may include assumptions about appropriate technology. Provided you have included a Concept of Operations and clear statements of need, this provides the opportunity for vendors to contribute in two effective ways.

Vendors will recognize requirements that assume a design that is different from theirs and this gives them the opportunity to redefine the requirement in a manner that does not preclude their system simply because of the wording or structure of the requirement. Vendors will also recognize high cost customization or new development that would be necessary to satisfy a requirement, and this also gives them the opportunity to suggest alternatives that would substantially reduce the procurement cost or streamline the development.

Responses from vendors should be treated as confidential and not shared with other vendors. If a vendor expects a response to be shared, he is less likely to offer advice that he considers proprietary and part of his competitive advantage.

6.5.3 Request for Qualification (RFQ) – (Optional)

A request for qualifications (RFQ) is appropriate when there are mandatory requirements placed on the capabilities and experience of the vendor. This is a means of reducing the agency's risk. It provides the opportunity to assess a vendor's financial stability, their track record in providing support and training, and proof that an advertised system is fully operational and successful. It should NOT be used simply to reduce the workload of the agency in evaluating responses to an RFP by limiting the number of vendors permitted to respond to a detailed specification or RFP. It should be used after requirements have been prepared and the agency is certain that vendors who show satisfactory qualifications will be able to also satisfy the technical requirements.

6.5.4 Request for Proposals (RFP)

A request for proposal (RFP) is the key vehicle for assessing the extent to which an ITS system will satisfy the agency's requirements. For Federal-aid (Highway Trust Fund/FHWA) projects, RFPs are the common contracting mechanism for fulfilling the Brooks Act requirements for engineering or architectural related services. Response proposals are used to determine the most qualified firm that will fulfill the system requirements. As illustrated in Figure 7, the requirements are referenced at every step in the process to help guide the selection.

While it may contain mandatory, desirable and optional requirements, the vendor should be required to explain how their system fulfills each requirement, and not simply be permitted to provide a Yes/No or Pass/Fail response. There are often different ways in which different systems may claim to satisfy a requirement, and not all methods will be equally suitable (or acceptable to an agency) in all situations. Each answer should be evaluated to determine firstly whether or not the answer is accurate, secondly the extent to which it satisfies the requirement, and thirdly as to whether the method of satisfaction is acceptable to the agency.

In addition, the method by which a vendor satisfies a requirement may have other implications, such as the effect on work practices, staff efficiency or requiring additional equipment or software to be efficiently implemented. The method used to compare responses to an RFP should include a means of accommodating the assessment of compliance.

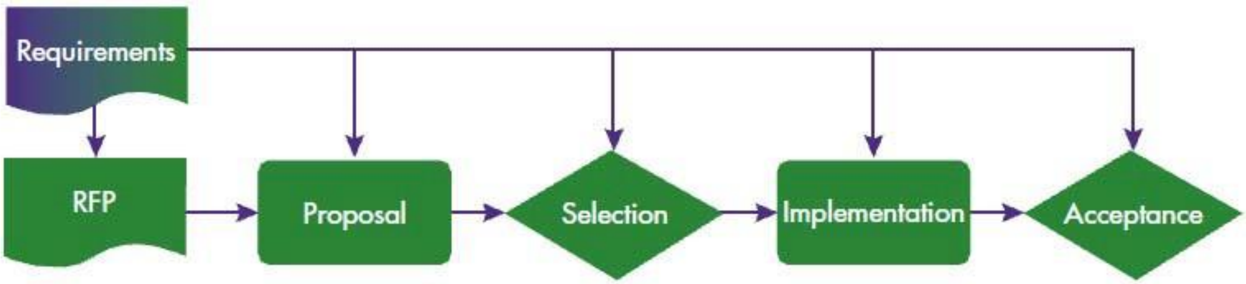

Figure 7 - Engineering/architectural services contracting approach supported by Systems Engineering Analysis

7 ITS Architecture

7.1 Overview

An Intelligent Transportation System (ITS) Architecture is a high level plan for how ITS can be used to address transportation needs in a State or Region. In Tennessee, a Statewide and eleven Regional ITS Architectures have been developed and are currently in use (See Sections 7.2 and 7.3).

According to 23 CFR 940, the Regional ITS Architecture [(22)] shall include, at a minimum:

- A description of the region;
- Identification of participating agencies and other stakeholders;
- An operational concept that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the systems included in the regional ITS architecture;
- Any agreements (existing or new) required for operations, including at a minimum those affecting ITS project interoperability, utilization of ITS related standards, and the operation of the projects identified in the regional ITS architecture;
- System functional requirements;
- Interface requirements and information exchanges with planned and existing systems and subsystems (for example, subsystems and architecture flows as defined in the National ITS Architecture);

[(22)] *Additional information on Regional ITS Architecture is available at http://ops.fhwa.dot.gov/publications/regitsarchguide/*

- Identification of ITS standards supporting regional and national interoperability; and
- The sequence of projects required for implementation.

7.2 *Tennessee Statewide ITS Architecture*

The development of the Tennessee Statewide ITS Architecture was led by the Tennessee Department of Transportation (TDOT) and involved representatives from each of the four TDOT Regions as well as from planning, design, incident management, wireless communications, and public transportation at the statewide level. The Tennessee Division of the Federal Highway Administration, the Tennessee Highway Patrol, the Tennessee Emergency Management Agency, and numerous other agencies were also active in the process.

The geographic scope of the Tennessee Statewide ITS Architecture [(23)] covers all rural areas of the state that are outside the eleven Metropolitan Planning Organization (MPO) areas that were designated as needing regional ITS architectures.

7.3 *Tennessee Regional ITS Architecture*

Tennessee has eleven Regional ITS Architectures [(24)] currently developed: Bristol, Chattanooga, Clarksville, Cleveland, Jackson, Johnson City, Kingsport, Knoxville, Lakeway, Memphis and Nashville.

7.4 *Tennessee Turbo Architecture Databases*

The Turbo Architecture™ tool [(25)] is a high-level, interactive software program that assists transportation planners and system integrators, both in the public and private sectors in the development and maintenance of regional architectures using the National ITS Architecture as a reference. Turbo Architecture allows a user to generate a variety of architecture reports, diagrams, and tables used to supplement the Systems Engineering Analysis documentation necessary for ITS Compliance (See Section 4).

[(23)] *The current Tennessee Statewide ITS Architecture documentation is available at http://www.tdot.state.tn.us/trafficoperations/its/statewide.htm*

[(24)] *The Tennessee Regional ITS Architecture documentation is available at http://www.tdot.state.tn.us/trafficoperations/its/regions.htm*

[(25)] *Current information on the Turbo Architecture™ tool is available at http://www.iteris.com/itsarch/html/turbo/turbomain.htm*

Figure 8 shows a Turbo Architecture™ output of the Tennessee Statewide ITS Architecture Disaster Traveler Information – Tennessee 511 Service Package [26].

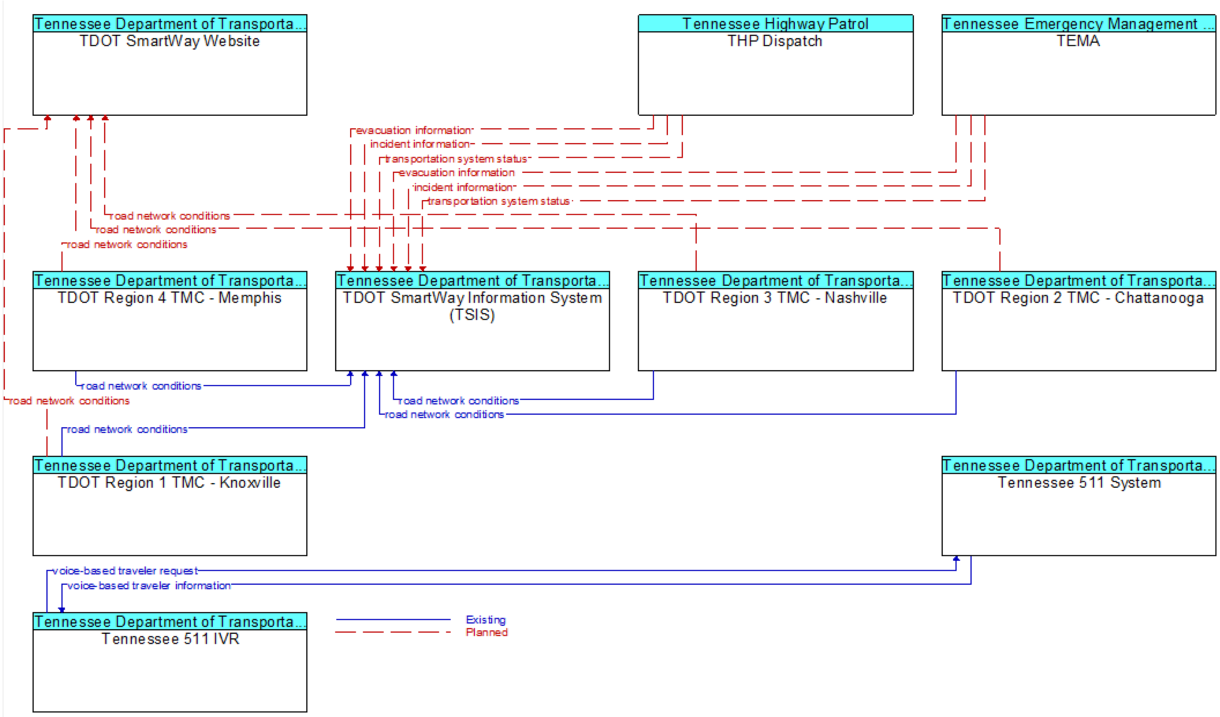

Figure 8 - Turbo Architecture™ output

7.5 *ITS Architecture Update Guidelines*

According to 23 CFR 940, agencies and other stakeholders participating in the development of an ITS architecture shall develop and implement procedures and responsibilities for maintaining it, as needs evolve within the region. The 23 CFR 940, also mentions that the final design of all ITS projects shall accommodate the interface requirements and information exchanges as specified in the Regional or Statewide ITS Architecture. If the final design of the ITS project is inconsistent with the Regional or Statewide ITS Architecture, then the discrepancies shall be reconciled and the ITS Architecture or the project shall be modified as appropriate by the local or state agency.

Therefore, there are several factors or events that influence the need and decision to update an ITS architecture. The following should be considered:

- Changes in ITS priorities or objectives;
- New stakeholders;

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[26] *The Tennessee Statewide and Regional ITS Architectures Turbo Architecture databases are available at http://www.kimleyhorn.com/projects/tennesseeITSarchitecture/statewide.html*

- Updates to the National ITS Architecture;
- Changes in Federal Policy or Legislation;
- Changes in State Policies or Legislation; and
- ITS Deployment and Integration.

As each ITS project is implemented, the regional ITS architecture will need to be updated to account for any expansion in ITS scope, and to allow for the evolution and incorporation of new ideas. When actually defined or implemented, a project may add, subtract or modify elements, interfaces, or information flows from the regional ITS architecture. Because the regional ITS architecture is meant to describe the current (as well as future) regional implementation of ITS, it must be updated to correctly reflect how the developed projects integrate into the region. Update requests will be submitted by the local agency project manager.

The Tennessee Statewide and Regional ITS Architectures as well as the ITS deployment recommendations reflect the needs and priorities of stakeholders at the time it was developed. In order for the ITS architecture to remain a valuable ITS planning and project programming tool for TDOT, it is important that both the architecture and deployment plan be periodically reviewed and updated to reflect changes in priorities, policies or needs in Tennessee.

The procedures for maintaining the Statewide and the Regional ITS Architectures have been determined in the documentation mentioned in Sections 7.2 and 7.3. TDOT Traffic Operations Division Office has been designated as the entity responsible for updating and maintaining the Statewide ITS Architecture. The responsibility to lead the maintenance process in the Regional ITS Architectures is delegated to each individual Planning Organization. Major updates to the Regional ITS Architectures shall be approved by TDOT Traffic Operations Division Office and the FHWA Division Office.

It is recommended that full updates of the Regional ITS Architecture and Deployment Plan occur in the year preceding the Long Range Transportation Plan (LRTP) update so that stakeholders will be able to determine, document and submit for consideration the ITS needs and projects that are most important to the Region. Minor changes to the Regional ITS Architecture should occur as needed between full updates of the plan, particularly if a project is being deployed and requires a change to the Regional ITS Architecture in order to establish conformity.

7.6 *Using the Regional ITS Architecture*

The Regional ITS Architecture is a tool that can be used to support planning processes, programming and budgeting activities and project implementation activities. Planning processes are used to identify projects whose implementation will respond to regional needs. These projects are placed in programming documents such as the Transportation Improvement Program (TIP) in order to secure funding. Once funded, the projects are implemented. Use of the Regional ITS Architecture throughout the project lifecycle (Figure 9) improves continuity between the transportation planning process and the projects that are ultimately implemented.

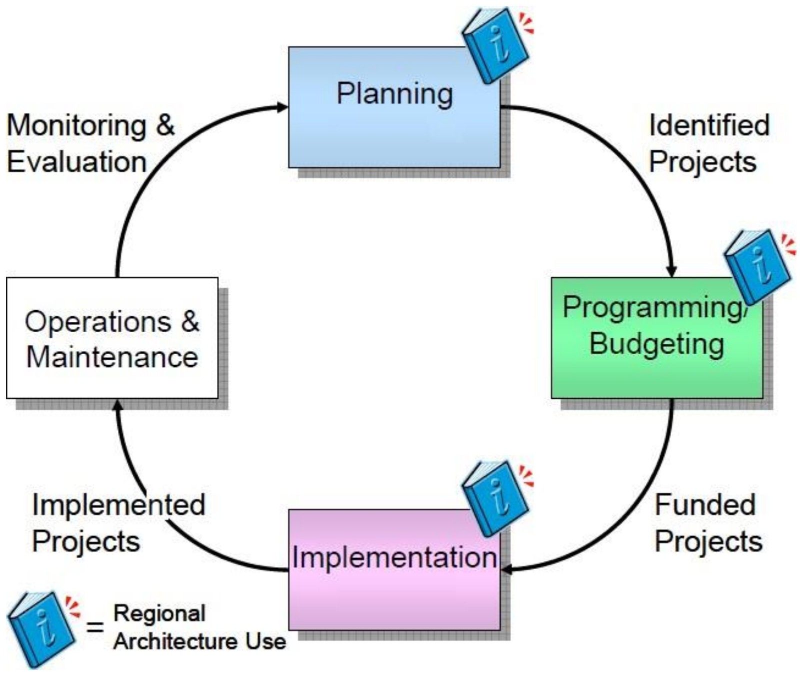

Figure 9 – Regional ITS Architecture and project lifecycle

7.6.1 Planning

The goal of the planning process is to make quality, informed decisions pertaining to the investment of public funds for regional transportation systems and services. Using the regional ITS architecture to support these planning activities is an important step in the mainstreaming of ITS into the traditional decision-making of planners and other transportation professionals.

The long range plan is the expression of a state or metropolitan area's long range approach to constructing, operating, and maintaining the multimodal transportation system. It is the policy forum for balancing transportation investments among modes, geographic areas, and institutions. A Regional ITS Architecture is related to both the statewide transportation plan, the metropolitan transportation plan, and agency long range plans.

The Regional ITS Architecture can provide decision-making tools to evaluate and prioritize the various strategies for transportation improvement. This can be accomplished by analyzing performance measures data providing the planning organization the ability to measure non-recurring congestion, travel times and travel time reliability, and other aspects of system performance and service reliability across all modes.

Regional ITS Architecture outputs, specifically the project sequencing output may also be useful to planning staff as an aid to evaluation and prioritization of strategies. The architecture provides a short-term and long-term, multimodal view of the ITS systems in the region, what is very important for planning. It provides the details of the transportation services and functions that can be provided by the stakeholders via ITS projects. The regional ITS architecture also illustrates the interfaces necessary between transportation systems to meet the transportation needs of the region. It facilitates development and integration of ITS projects by housing applicable national ITS Standards and/or the local agency own ITS Standards. Finally it translates these details to the definition of a set of projects to be implemented.

A regional ITS architecture serves as a visible demonstration of the institutional dependencies that exist in a region, how agencies can benefit from each other's activities and presents a significant opportunity to support the needs for effective planning for operations [27].

Several other planning activities can also be supported by outputs of the Regional ITS Architecture, like Congestion Management Process, Safety Planning and Freight Planning.

7.6.2 *Programming and Budgeting*

Using a Regional ITS Architecture to define an ITS project links the objectives and needs of the region identified in the architecture with the ITS deployed in the field. In a region, ITS projects are deployed by many organizations including State DOTs, transit agencies and many local agencies and authorities. If projects of the various organizations are defined from the same reference point, the Regional ITS Architecture, then coordination begins in the initial planning and funding phase. ITS projects in a region may be funded by a variety of sources. ITS projects that are funded with federal funds are programmed by Metropolitan Planning Organizations (MPOs) and State DOTs with input from transportation agencies in the region.

7.6.3 *Project Implementation*

Once an ITS project has been funded and implementation begins, there is a natural tendency to focus on the programmatic and technical details of the project to be implemented and lose sight of the broader regional context for the project. Using the

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[27] *Applying a Regional ITS Architecture to Support Planning for Operations is available at* *http://www.ops.fhwa.dot.gov/publications/fhwahop12001/fhwahop12001.pdf*

regional ITS Architecture as a basis for project implementation provides this regional context. It provides each project sponsor the opportunity to view their project in the context of surrounding systems. It prompts the sponsor to think about how their project fits within the overall transportation vision for the region. It identifies the integration opportunities that should be considered and provides a head start for the systems engineering analysis that is required for ITS projects.

8 ITS References

The following ITS references are useful resources supplementing this TDOT ITS Project Development Guidelines:

Regional ITS Architecture Guidance – Developing, Using and Maintaining an ITS Architecture for Your Region - http://www.ops.fhwa.dot.gov/publications/regitsarchguide/raguide.pdf

Systems Engineering for Intelligent Transportation Systems – An Introduction to Transportation Professionals - http://ops.fhwa.dot.gov/publications/seitsguide/seguide.pdf

Systems Engineering Guidebook for Intelligent Transportation Systems - https://www.fhwa.dot.gov/cadiv/segb/files/segbversion3.pdf

FHWA California Division website on ITS (Process, Deliverables, Checklists, Examples, etc) - https://www.fhwa.dot.gov/cadiv/segb/views/index.cfm

The Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems - *http://www.ops.fhwa.dot.gov/publications/fhwahop11027/mse_asct.pdf*

NCHRP 560 Guide to Contracting ITS Projects - http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_560.pdf

The Road to Successful ITS Software Acquisition - http://www.fhwa.dot.gov/publications/research/operations/its/98036/rdsuccessvol2.pdf

Using Systems Engineering and Regional ITS Architecture for ITS Projects - http://www.virginiadot.org/travel/resources/userguideReprint4-7.pdf

Applying a Regional ITS Architecture to Support Planning for Operations - *http://www.ops.fhwa.dot.gov/publications/fhwahop12001/fhwahop12001.pdf*

Tennessee ITS Project Identification Form

INSTRUCTIONS: Refer to Section 4.2 of the TDOT ITS Project Development Guidelines. Attach or make available any documents referenced in this form when submitting.

SECTION 1 – PROJECT INFORMATION

Agency:____

Agency Information (Address, phone number, e-mail, etc):

____

Project Name and Location:

____

☐ New Project
☐ Modification Project ☐ Expansion Project

Nature of Work:

☐ Planning
☐ Design Software / Integration
☐ Operations
☐ Evaluation
☐ Scoping
☐ Construction
☐ Maintenance (Equipment Replacement)
☐ Other: ___________________________

Please provide the following background information. In most cases, 1-3 sentences will be sufficient for each item.

Brief Description of ITS project objectives – (What is the purpose of the project? What needs are being addressed?):

____

____

Project Summary – (What solutions will address the needs? What major elements will be installed? What major function(s) will be performed?)

____

____

Work to Date: (Any preliminary planning, investigation of options, associated internal or external systems examined?)

____

SECTION 2 – RISK ASSESSMENT

(For each question, answer Yes, No, Not Sure or N/A for not applicable):

1 – Will the project depend on **only your agency** to implement and operate?

____

2 - Will the project use only software proven elsewhere, with **no** new software writing?

____

3 - Will the project use only hardware and communications **proven** elsewhere?

____

4 - Will the project use only **existing interfaces** (no new interfaces to other systems)?

___________ (If YES include reference)

5 - Will the project use only **existing system requirements** that are well documented?

___________ (If YES include reference)

6 - Will the project use only **existing operating procedures** that are well documented?

___________ (If YES include reference)

7 - Will the project use only technologies with service life **longer** than 2-4 years?

____

SECTION 3 – FUNDING

Identify all that apply: ☐ Local Agency ☐ State ☐ Federal Funds

TIP/STIP Identification and Description:

____

Project Termini:____

Agency Representative	Signature	Date

FOR TDOT USE ONLY:

☐ No additional documentation required ☐ Inconclusive risk level determination (SSEAF is required) ☐ Low Risk (SSEAF is required) ☐ High Risk (SEAR is required)

TDOT Representative	Signature	Date

7. SIMPLIFIED SYSTEMS ENGINEERING ANALYSIS FORM (SSEAF)

Refer to Section 4.2 of the TDOT ITS Project Development Guidelines. Attach or make available any documents referenced in this form when submitting.

23 CFR 940 COMPLIANCE INFORMATION

Please answer each question briefly (often one paragraph is enough). If the question cannot be fully answered *now*, but will be answered during the project implementation, please indicate the step at which it will be answered.

1 - Identification of portions of the Regional ITS Architecture (RA) being implemented:

Instructions: Contact your MPO to get this information from your Regional ITS Architecture ("RA"). In the RA, the project might be identified specifically by name and agency, or by a more generic description (e.g. "Arterial Traffic Management"). If listed in the RA, document which inventory elements, market packages, subsystems, and/or information flows are being completed in this project. If there is ***no*** *information in your RA, arrange with your MPO to provide them this information when your project is designed; they will use it in the next update of the RA.*

2 - Identification of participating agencies roles and responsibilities:

Instructions: Can you identify all stakeholders that must participate in the implementation phase of this project? What are their roles/responsibilities? Have they committed to the responsibilities? Some of this information might appear in your RA (e.g., "Operational Concepts" or other sections). If this will be defined in later phase of the project (e.g., Concept of Operations), the RA may be a good source to start definition.

3 - Requirements definitions:

Instructions: Can you identify all stakeholders that must participate in operations, management and maintenance of the system throughout its life cycle? What are the roles, responsibilities, and resources required from each stakeholder? Examples include: money, special equipment, staff time, special expertise, provision of data, and many more. You should consider hardware, software, and communications issues.

4 - Analysis of alternative system configurations and technology options to meet requirements:

Instructions: Have you considered alternative designs yet? This could include system configurations, different organizational roles; alternative hardware, software, or communications technology; If you can not yet make a choice of available alternatives, this analysis will occur in later phase of the project (High- Level Design).

5 - Procurement options:

Instructions: Have you considered different procurement options for each of the project phases (design, implementation, operation, and management)? Procurement options must consider the level of staff technical expertise, existing agency procurement practices, who will be the project manager, and whether you need a systems engineer and/or system integrator. Refer to Section 8.6 of the TDOT Traffic Design Manual for guidance.

6 - Identification of applicable ITS standards and testing procedures:

Instructions: Do you know yet if any ITS Communications Standards are applicable to this project? If they are applicable, will you use them? If your RA identifies specific Architecture Flows, you can ask your MPO to produce a "Standards Report" for those Flows; it will identify ITS Standards to consider.

7 - Procedures and resources necessary for operations and management of the system: *Instructions: Can you identify all stakeholders that must participate in operations, management and maintenance of the system throughout its life cycle? What are the roles, responsibilities, and resources required from each stakeholder? Examples include: money, special equipment, staff time, special expertise, provision of data, and many more. You should consider hardware, software, and communications issues.*

Agency Representative	Signature	Date

FOR TDOT USE ONLY:

☐ Low Risk ☐ High Risk – Systems Engineering Analysis (SEAR) is required

TDOT Representative	Signature	Date

8. SYSTEMS ENGINEERING ANALYSIS REPORT (SEAR)

Refer to Section 4 and 5 of the TDOT ITS Project Development Guidelines. Please provide the following information on your report:

- Agency (Address, phone number, e-mail, etc);
- Project Name and Location;
- Date.

At a minimum, the SEAR shall present the following information with appropriate level of documentation:

- Identification of portions of the Regional ITS Architecture (RA) being implemented or applicable portions of the National ITS Architecture;
- Identification of participating agencies roles and responsibilities;
- Concept of Operations;
- System Requirements;
- System Design;
- Analysis of alternative system configurations and technology options to meet requirements and rationale for technology selection;
- Analysis of procurement options including rationale for selected option;
- Identification of applicable ITS standards;
- System Integration Plan;
- System Verification Plan including the testing Plan;
- System Validation Plan;
- Procedures and resources necessary for operations and management of the system;
- Project Plan and Systems Engineering Management Plan (SEMP) (if applicable)
- Traceability matrix;
- Change Management Control;
- Documentation to revise applicable ITS Regional Architecture.

  - Suggested Turbo Reports to attach with this documentation:
  - Stakeholder Report
  - Inventory Report
  - Project Architecture Report – Interconnect and flow diagrams
  - Region to Project Comparison (tabular form)
  - Market Packages Report – Roles and Responsibilities Report
  - Functional Requirements Report
  - Standards Report
  - List of Agreements

Appendix 2

Flashing Yellow Arrow (FYA)
Press Release
Brochure (English)
Brochure (Spanish)

TDOT Traffic Operations Division Office

FLASHING YELLOW ARROW
for
Permissive Left Turns

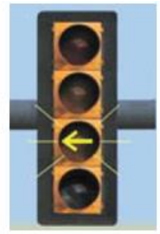
PRESS RELEASE

The following is suggested language on the implementation of the Flashing Yellow Arrow for Permissive Left Turns.

The city of _____________ is installing a Flashing Yellow Arrow Left Turn Signal at the intersection of _____ and ______.

On this new signal configuration, the "green ball" indication will be replaced by a Flashing Yellow Arrow for drivers who want to turn left.

TRADITIONAL DISPLAY



NEW DISPLAY

When approaching a Flashing Yellow Arrow Left Turn Signal, drivers should yield to any oncoming traffic, carefully determine if there is an adequate gap in traffic and ensure there are no pedestrians or bicyclists crossing before turning left.
The new signals offer a safer, more efficient way to handle traffic turning left at busy intersections. The signals are being introduced nationwide as a result of a national study, conducted for the Federal Highway Administration, that showed they help prevent crashes, move more traffic through intersections and provide additional traffic management flexibility.

The Flashing Yellow Arrow Left Turn Signals are placed over left-turn lanes at intersections. Typically, there are four sections on this traffic signal head:

- *SOLID RED ARROW - Drivers intending to turn left must stop and wait. Do not enter an intersection to turn left when a solid red arrow is being displayed.*

- *SOLID YELLOW ARROW -The left-turn signal is about to change to red. Prepare to stop or to complete the left turn if legally within the intersection and there is no conflicting traffic present.*

- ***FLASHING YELLOW ARROW** - Drivers are allowed to turn left after yielding to all oncoming traffic and to any bicyclists and pedestrians in the crosswalk. Drivers must wait for a safe gap in oncoming traffic before turning.*

- *SOLID GREEN ARROW - Left turners have the right of way. Proceed.*

For more information about how the new signals work, go to TDOT's website at (fill in).

The Tennessee Department of Transportation

is recommending the use of the

Flashing Yellow Arrow for permissive

left turn indication to provide a safer,

more efficient left turn for motorists.

WHAT ARE THE BENEFITS OF THE FLASHING YELLOW ARROW?

SAFETY
Provides a distinct indication to permissive left turn movements, minimizing confusion with the green ball interpretation.

FLEXIBLE SIGNAL TIMING
Provides more options to handle all types of traffic volumes by adjusting the mode of operation in diffferent times of the day.

SHORTER WAIT TIMES
Due to its operational characteristics, the use of the flashing yellow arrow may reduce driver delay.

ENVIRONMENTALLY FRIENDLY
Provides improved traffic flow resulting in reduction of fuel consumption and vehicle emissions.

For more information, including a link to download this brochure and
a demo of how the Flashing Yellow Arrow for permissive left-turns work, go to TDOT's web site:

TDOT TRAFFIC OPERATION DIVISION OFFICE

MISSION STATEMENT

To maximize the capacity of the existing infrastructure in Tennessee with the use of technological innovations, standardized traffic management procedures and practices, and by forming strong strategic partnerships with local and state agencies.

VISION

To lead TDOT to the forefront of Transportation Management & Operations practices nationally.

STATE OF TN

FLASHING YELLOW ARROW

A SAFER, MORE EFFICIENT LEFT-TURN SIGNAL

HOW DOES THE FLASHING YELLOW ARROW WORK?

SOLID RED ARROW

Drivers intending to turn left must stop and wait.
Do not enter an intersection to turn left when a solid red arrow is being displayed.

SOLID YELLOW ARROW

The left-turn signal is about to change to red. Prepare to stop or to complete the left turn if legally within the intersection and there is no conflicting traffic present.

FLASHING YELLOW ARROW

Drivers are allowed to turn left after yielding to all oncoming traffic and to any bicyclists and pedestrians in the crosswalk. Drivers must wait for a safe gap in oncoming traffic before turning. Oncoming traffic has a green light.

SOLID GREEN ARROW

Left turners have the right of way. Proceed.
Oncoming traffic has a red light.

The flashing yellow arrow for permissive left turn indication can replace the circular green indication at selected signalized intersections.

(See website for more details)

WHAT SHOULD A MOTORIST DO WHEN APPROACHING THE FLASHING YELLOW ARROW LEFT TURN SIGNAL?

Drivers should YIELD to any oncoming traffic and carefully determine if there is an adequate gap in the oncoming traffic and ensure there are no pedestrians or bicyclists crossing before turning left.

At the end of the flashing period, the flashing yellow arrow transitions to the solid yellow left turn arrow and then drivers should prepare to stop or complete the left turn if there is no conflicting traffic.

DRIVERS MUST ALWAYS REMEMBER:

A FLASHING YELLOW ARROW

MEANS

El Departamento de Transportación de Tennesse está recomendando la utilización del **Flecha Amarilla Intermitente como indicación de viraje permitido a la izquierda para proveer mayor seguridad y eficiencia a los conductores.**

¿CUÁLES SON LOS BENEFICIOS DE LA FLECHA AMARILLA INTERMITENTE?

SEGURIDAD

Provee una indicación distintiva para movimientos de viraje a la izquierda permitidos, lo cual minimiza la confusión al interpretar la señal de luz verde.

ADMINISTRACIÓN DE LA SEÑAL

Provee más opciones para manejar todo tipo de volúmenes de tráfico mediante el ajuste del modo de operación en diferentes horas del día.

MENORES TIEMPOS DE ESPERA

Debido a sus características operacionales, la utilización de la Flecha Amarilla Intermitente puede reducir el tiempo de demora al conductor.

AMBIENTALMENTE AMIGABLE

Provee mejoría al flujo de tráfico que resulta en una reducción al consumo de combustible y a las emisiones de los vehículos de motor.

Para mayor información, incluyendo un enlace para descargar este folleto y una demostración **de cómo funciona la Flecha Amarilla Intermitente para el viraje permitido a la izquierda, visite a la página web de TDOT (Departamento de Transportación de Tennessee):**

TDOT DIVISIÓN DE OPERACIÓN DEL TRÁFICO

MISIÓN

Maximizar la capacidad de la infraestructura existente en Tennessee con la utilización de innovaciones tecnológicas, prácticas y procedimientos estandarizados para el manejo de tráfico y la creación de alianzas solidas con agencias locales y estales.

VISIÓN

Para llevar al TDOT a la vanguardia en las prácticas de Operaciones y Manejo de Transporte a nivel nacional.

ESTADO DE TENESSEE

FLECHA AMARILLA INTERMITENTE

UNA SEÑAL DE VIRAJE A IZQUIERDA MÁS EFICIENTE Y MÁS SEGURA.

¿CÓMO FUNCIONA LA FLECHA AMARILLA INTERMITENTE?

FLECHA ROJA SÓLIDA

Los conductores que tengan la intención de virar a la izquierda deberá detenerse y esperar. No entrar en una intersección para virar a la izquierda cuando se está mostrando una flecha roja sólida.

FLECHA AMARILLA SÓLIDA

La señal de viraje a la izquierda está próxima a cambiar a rojo. Prepárese a detenerse para completar el viraje a la izquierda si está legalmente dentro de la intersección y no hay conflicto con el tráfico presente.

FLECHA AMARILLA INTERMITENTE

Los conductores se les permiten virar a la izquierda después de ceder a todo el tráfico que se aproxima a la intersección incluyendo, peatones y ciclistas en el cruce peatonal. Los conductores deberán esperar a que haya una brecha segura en el tráfico en la dirección contraria antes de efectuar el viraje.

FLECHA VERDE SÓLIDA

Los conductores que desean virar a la izquierda tienen el derecho de vía. Proceda. El tráfico de la dirección contraria tiene la luz roja.

La flecha amarilla intermitente para indicar un viraje permitido la izquierda puede reemplazar la indicación verde circular en las intersecciones señalizadas seleccionadas.

(Véase el sitio web para más detalles).

¿QUÉ DEBE HACER UN CONDUCTOR CUANDO SE APROXIMA A LA SEÑAL CON LA FLECHA AMARILLA INTERMITENTE DE VIRAJE A LA IZQUIERDA?

Los conductores deben ceder a cualquier tráfico que se aproxima y determinar cuidadosamente si hay un espacio adecuado en el tráfico en sentido contrario y asegurar que no hay peatones o ciclistas cruzando antes de virar a la izquierda.

Al final del período intermitente, la flecha amarilla intermitente cambia gradualmente a una flecha amarilla sólida a la izquierda y luego los conductores deberán prepararse para detenerse o completar el viraje a la izquierda siempre y cuando no haya conflicto con el tránsito.

LOS CONDUCTORES DEBERÁN

RECORDAR SIEMPRE:

UNA FLECHA

AMARILLA INTERMITENTE

SIGNIFICA VIRAR CON

Appendix 3

Section 730 Traffic Signal Specifications

SECTION 730 – TRAFFIC SIGNALS

DESCRIPTION

730.01 Description of Work

This work consists of furnishing and installing all necessary materials and equipment to complete in-place traffic signal systems, modify existing systems, or both, all as shown on the Plans or the Standard or Special Details, and as specified in these Specifications. Unless otherwise shown on the Plans or specified in the Special Provisions, all materials shall be new.

Where existing systems are to be modified, incorporate the existing material into the revised system, salvage it, or abandon it as specified or as directed by the Engineer.

Furnish and install all incidental parts that are not shown on the Plans or specified herein, but that are necessary to complete the traffic signal or other electrical systems, or that are required for modifying existing systems, as though such parts were shown on the Plans or specified herein. Include the costs of such incidentals in bid price for other items. All systems shall be complete and in operation to the Engineer's satisfaction at the time of completion of the work.

GENERAL REQUIREMENTS

730.02 Regulations and Code

Ensure that all equipment provided conforms to NEMA Standards Publication, Traffic Control Systems, latest revision, or the Radio Manufacturers Association, whichever is applicable. In addition to the requirements of these Specifications, the Plans, and the Special Provisions, all material and work shall conform to the requirements of the NEC; the Standards of ASTM, ANSI, ITE, and IMSA; the MUTCD; and other applicable local ordinances.

Wherever reference is made to the NEC, or the Standards mentioned above, consider the reference to mean the code or standard that is in effect on the date of advertising the bids or authorization for force account.

730.03 Submittal Data Requirements

Within 30 days after the issuance of the work order, submit to the Engineer, the Division of Materials and Tests, and the local entity (city or county engineer), one collated set of the manufacturer's descriptive literature and technical data that fully describes the types of signal equipment proposed for use. In the descriptive literature, identify the manufacturer and models and include sufficient information for the Engineer to determine if the equipment or material meets the requirements of the Plans and these Specifications. Include with these sets of submittal data a list of the materials submitted along with descriptive material for, but not limited to, the following items:

1. Controller
2. Cabinet and Exhaust Fan
3. Detectors
4. Signal Heads including Lamp Information and Mounting Hardware
5. Loop Wire and Loop Sealant
6. Shielded Detector Cable
7. Signal Cable
8. Cable for Span Wire, Guys, and similar features
9. Pull Boxes
10. Conduit
11. Coordination Equipment

Also include in the submittal sets detailed scale drawings of all non-standard or special equipment and of all proposed deviations from the Plans. Upon request, submit for approval sample articles of materials proposed for use. The Department will not be liable for any materials purchased, labor performed, or delay to the Work prior to such approval.

In addition to the above, submit to the Engineer a notarized letter certifying that all traffic signal materials listed in the submittal conform to the Plans and Specifications along with a copy of a statement from the maintaining agency that the system is acceptable to the agency. Any material substitutions requested by the maintaining agency shall meet minimum Department standards and shall be approved by the Department in writing prior to purchase or installation. The Department will not be liable for any materials purchased, labor performed, or delay to the Work regarding such approval.

Submit six prints of "Design" or "Shop" drawings, indicating the proposed dimensions and material specification for each of the supports and mast arms involved, to the Division of Structures for approval purposes within 30 days after the work order is issued. The Department will review these drawings at the earliest possible date and will return two prints marked "Approved for Fabrication," or "Returned for Revisions as Noted." Respond by taking appropriate action to ensure the earliest possible correction of these items so as not to delay the installation.

730.04 Mill Test Reports and Certification

Provide Mill Test Reports (MTR) or Certifications of Conformance to the Specifications for Materials and Design for all materials incorporated into the Work. Supply the following prior to acceptance of the structures:

1. MTRs for MAJOR structural items only, as identified in Table 730.04-1, shall include both physical and chemical descriptions of the material as supplied to the fabricator. When physical properties are altered during the fabrication, supplement the MTR covering chemical composition with certified test reports indicating the physical properties of this material after fabrication.

2. Certifications of Conformance to the Specifications for all remaining material not covered by MTR as identified in Table 730.04-1.

3. Certification that all welding was performed by operators qualified as follows: Steel welders to AWS and aluminum welders to ASME.

4. Certification of Conformance to the Specification for the Design of all components not completely dimensioned and detailed on the Standard Drawing.

Table 730.04-1: Required Mill Test Reports and Certifications

Component Materials	MTR	Certification
Tubes for arms and poles	X	
Base Castings	X	
Anchor Bolts	X	
Pole tops, misc. fittings, and hardware		X
Fabricated or cast-type arm connections		X
Galvanizing		X

730.05 Working Drawings

Provide within the controller cabinet and to the local maintaining agency an electrical schematic diagram of the cabinet and system wiring. Submit manufacturer's instructions for installation, maintenance, and operation of all equipment to the local maintaining agency and also place a copy within the controller cabinet. Place all such materials inside a plastic envelope mounted in the cabinet.

730.06 Guarantee

Guarantee the Traffic Signal System(s) installed under these Specifications, including all equipment, parts, and appurtenances in connection therewith, to the City or County and State against defective workmanship and materials for a period of not less than 1 year following the date the signal system is installed and made operational, except in no case shall this guarantee expire prior to 3 months after the final acceptance of the Project. Upon completion of the Project, turn over to the government agency responsible for maintaining the signal installation all warranties or guarantees on equipment and materials that are offered by the manufacturers as normal trade practice and that have not expired.

730.07 Training

Provide to the maintaining agency and/or the Department a training session on the controller and associated cabinet equipment to be supplied on the Project. The training session shall last for a minimum 4 hours unless the maintaining agency and/or the Department determines a lesser time is adequate. Train the user in the complete operation and programming features of all controllers. Provide this training prior to the acceptance of the Project at a facility agreed upon by the maintaining agency.

After the required training, the contractor shall certify to the Engineer that training has been completed.

This training requirement shall not apply if a training program meeting these criteria has been provided to the maintaining agency by this vendor and/or manufacturer on the equipment being bid within 18 months prior to the date of the invitation to bid. This requirement shall apply if the bidder is proposing new, upgraded, or modified equipment not covered in the previous training program.

MATERIALS AND INSTALLATION

730.08 Excavating and Backfilling

Perform excavation needed to install conduit, foundations, and other equipment, so as to cause the least possible damage to the streets, sidewalks, and other improvements. Excavate trenches no wider than necessary to properly install the electrical equipment and foundations. Do not begin excavating until immediately before installing conduit and other equipment. Place the material from the excavation where it will cause the least disruption and obstruction to vehicular and pedestrian traffic and the least interference with the surface drainage.

Backfill the excavations and compact to at least the density of the surrounding material. Remove all surplus excavation material and dispose of outside the highway right-of-way, in accordance with **203.07**, or as directed by the Engineer.

After backfilling, keep excavations well-filled, and maintain in a smooth and well-drained condition until permanent repairs can be made.

At the end of each day's work, and at all other times when construction operations are suspended, remove all equipment and other obstructions from that portion of the roadway used by public traffic, and park a minimum of 30 feet from the edge of pavement unless otherwise protected by guardrail, bridge rail, or barriers installed for other purposes.

Perform excavation in the street or highway so as to restrict no more than one traffic lane in either direction at any time. Do not obstruct traffic during hours of peak flow unless otherwise approved by the Engineer. Incorporate construction signing in accordance with the MUTCD.

730.09 Removing and Replacing Improvements

Replace or reconstruct, with the same kind of materials as found on the Work, improvements, such as sidewalks, curbs, gutters, Portland cement concrete and asphalt concrete pavement, bituminous surfacing, base material, and all other improvements removed, broken, or damaged by the Contractor.

Before removing the sidewalk and pavement material, use an abrasive type saw to cut, to a minimum depth of 2 inches, the outline of all areas to be removed in Portland cement concrete sidewalks and in all pavements. Use any method satisfactory to the Engineer to cut the remainder of the required depth. Make cuts neat and true with no shatter outside the removal area.

Whenever a part of a square or slab of existing concrete sidewalk or driveway is broken or damaged, remove the entire square or slab and reconstruct the concrete as specified above.

Perform all work in accordance with these Specifications, or the applicable local ordinance, whichever is of a higher standard. Consider this removal and replacement work to be incidental to other items.

730.10 Foundations

Construct foundations for posts, standards, and cabinets of Class A Portland cement concrete.

Pour foundations for posts, standards, and pedestals after the post, standard, pedestal, or anchor bolts or reinforcing steel is in proper position. Form the exposed portions to present a neat appearance. Rest the bottom of concrete foundations on firm undisturbed ground.

Construct forms to be true to line and grade. Finish tops of footings for posts and standards, except special foundations, to curb or sidewalk grade or as ordered by the Engineer. Use rigid forms, securely braced in place. Place conduit ends and anchor bolts by means of a template until the concrete sets. Moisten both the forms and the ground that will be in contact with the concrete before placing concrete. Do not remove forms until the concrete has cured for at least 12 hours and hardened sufficiently to allow form removal without causing damage to the concrete.

Apply an ordinary surface finish to exposed surfaces of concrete. Wherever the edge of a concrete foundation or sidewalk section is within 18 inches of any existing concrete improvement, extend the sidewalk section to meet the existing improvement.

Where obstructions prevent the construction of planned foundations, construct a foundation satisfactory to the Engineer.

730.11 Anchor Rods

Furnish, with anchor-base type rods, anchor bolts meeting the requirements of ASTM F1554, grade as required by design. Fit each anchor bolt with two heavy hex nuts. Hot-dip galvanize all nuts and not less than 10 inches of the threaded ends of anchor bolts according to ASTM A153. The anchor bolts shall be capable of resisting at yield strength stress the bending moment of the shaft at its yield strength stress.

Set standards, posts, and pedestals plumb by adjusting the nuts before the foundation is finished to final grade. Do not use shims or similar devices for plumbing or raking. After plumbing or raking has been completed, cut off anchor bolts 1/4 inch above the top nut, and paint the exposed surface with rust protective paint.

Furnish all anchor bolts and nuts required for relocating existing standards and posts.

730.12 Pull Boxes

Construct and install pull boxes as shown on the Plans and the Standard Drawings or as directed by the Engineer. Additional pull boxes may be required where conduit runs are more than 150 feet long as directed by the Engineer. Install pull boxes wherever practicable out of the line of traffic. Set covers level with the pavement, or with the curb or sidewalk grade, or with the surrounding ground as required.

Place electrical conductors within pull boxes so as to be clear of the metal frame and cover.

Rest the bottom of the pull box firmly on a bed of crushed stone with a minimum depth of 12 inches below the bottom and extending 6 inches beyond the outside edge of the pull box, unless otherwise directed by the Engineer.

A. Concrete Pull Boxes

Construct concrete pull boxes of a mixture of one part cement, two parts sand, and four parts gravel or 1-inch crushed stone with reinforcement placed as shown on the Standard Drawings. Reinforcement shall consist of welded wire reinforcement, 4 x 4 inches - No. 4/4 at 85 pounds per 100 square feet, meeting the requirements of **907.03**. Pull boxes may be poured in place or precast. The color of the pull box concrete material shall match the surrounding concrete color.

Install a cast iron frame and cover of the dimensions shown on the Drawings in each pull box. Provide castings of Class 30, meeting the requirements of **908.07**. The covers shall have a roughened top surface of 1/8 inch in relief. Provide notches for removing the cover. Inscribe the words "TRAFFIC SIGNALS" on top of the covers with letters 1-1/2 inches high and 1/8 inch in relief as shown on the Drawings.

The frame shall have a minimum weight of 42 pounds. The cover shall be of the "Extra Heavy" type with a minimum weight of 54 pounds.

B. Reinforced Plastic or Epoxy Mortar Pull Boxes

Ensure that pull boxes composed of reinforced plastic or epoxy mortar are designed and tested to temperatures of -50 °F and meet the requirements of the following: ASTM D543, ASTM D570, ASTM D790, and ASTM D635, and are based on a 30,000-pound single axle load over a 10 x 20 inch area. The top of the pull box shall consist of a concrete frame (ring) and cover. The color of the pull box concrete material shall match the surrounding concrete color. Inscribe the words "TRAFFIC SIGNALS" on top of the covers.

730.13 Transformer Base

Fabricate the transformer base from steel plate and sheet, and design it to harmonize with the shaft. Provide each transformer base with:

1. One 7-1/2 x 9-inch minimum handhole, with a cover secured with stainless steel fastening screws;

2. Four galvanized steel bearing plates to fasten the base to the anchor bolts;

3. Four galvanized steel bolts, nuts, and washers to fasten base and standard; and

4. One 1/2-inch, 13 UNC grounding nut welded to the inside of the base opposite the handhole opening.

Ensure that the strength of the transformer base is comparable with that of the shaft.

When a transformer base is required, no handhole will be required in the shaft.

730.14 Conduit

Furnish and install plastic and steel conduit in accordance with these Specifications and close conformity with the lines shown on the Plans or as established by the Engineer.

Threads shall be clean cut, straight, and true and of sufficient length to allow proper coupling. Do not use long running threads on any part of the Work. Protect threads in transit and during installation and provide conduit with proper supports and protection during construction to prevent damage. Properly thread, ream, and cap all ends of pipe installed for future connections to prevent water and foreign matter from entering the conduit system. Provide threaded ends with approved conduit bushings.

Signal conduit shall be a minimum 2 inches in diameter, and detector conduit a minimum 1 inch in diameter, unless otherwise specified or directed by the Engineer. Conduit for service connections shall be 1 inch in diameter. Do not use conduits smaller than 1 inch in diameter unless otherwise specified, except grounding conductors at service points shall be enclosed in 3/4-inch diameter conduit. The Contractor may, at no additional cost to the Department, use larger size conduit, in which case it shall be for the entire length of the run with no reducing couplings allowed.

A. Materials

Provide conduits and fittings as follows:

1. Steel Conduit

a. Rigid conduit and fittings shall be heavy-wall, hot dipped galvanized steel conforming to Federal Specification WW-C-581-d(3) and ANSI C80.1. It shall be galvanized inside and out and shall meet the requirements of ASTM A53. Each length shall bear the label of Underwriters Laboratories, Inc.

b. Flexible conduit shall be galvanized flexible steel meeting Federal Specification WW-C-581-d(3), ANSI C80.1 and UL Standard 6 with a minimum 40-mil thickness of polyvinyl chloride (PVC) coating conforming to ASTM D746.

2. Plastic Conduit. For plastic conduit, provide high impact PVC, Schedule 40.

3. High-Density Polyethylene (HDPE). Materials used for the manufacture of HDPE conduit and fittings shall be per ASTM F2160 and consist of a Standard Dimension Ratio (SDR) 9-11. No other substitutions shall be allowed unless directed by the Engineer. HDPE conduit can be used with preassembled cable and rope-in-conduit.

B. Installation

All bends shall be in strict compliance with the NEC.

Lay conduits to a minimum depth of 6 inches below subgrade but not less than 24 inches below pavement grade except when approved by the Engineer; conduit may be laid at a depth of not less than 24 inches below top of curb when placed in back of the curb. Place conduit runs for detectors parallel to existing or proposed curbs and not more than 18 inches behind the curb face unless other specified. Place steel conduit or Schedule 80 PVC conduit under existing pavements by approved jacking or drilling methods. Do not disturb pavements without the Engineer's approval. Where trenching is allowed in a traffic bearing area, use PVC conduit (Schedule 40) encased in concrete.

Conduits shall be continuous and extend from end point (i.e. pull box, foundation signal pole, pedestal pole, etc.) to another end point, or as directed by the Engineer. Conduit splicing shall not be permitted between end points.

After completing the installation of the conduit, test all conduits installed under the Contract with a mandrel having a diameter 1/4-inch smaller than the conduit and a length of 2 inches. Repair, to the Engineer's satisfaction, all conduits that will not allow passage of the mandrel; if repairs cannot be accomplished, remove and replace the conduit at no additional cost to the Department. After the mandrel test, scour all conduits with a stiff wire brush slightly larger in diameter than the conduit. Clear all conduits in the Engineer's presence.

Extend conduits terminating in anchor base standards and pedestals approximately 2 inches above the foundation and slope them toward the hand-hole opening. Conduits shall enter concrete pull boxes from the bottom and shall terminate not less than 2 inches nor more than 4 inches above the bottom of the box and near the box walls to leave the major portion of the box clear.

Clean existing underground conduit to be incorporated into a new system by blowing with compressed air, or by other means approved by the Engineer.

730.15 Conductors

Furnish and install conductors in accordance with these Specifications and close conformity as shown on the Plans, or as directed by the Engineer.

Traffic Control Conductors shall be rated at 600 volts. Run all conductors, except loop conductors and cables run along messengers, in conduit, except where run inside poles. Where signal conductors are run in lighting standards containing high voltage street lighting conductors, encase the signal conductors in flexible or rigid metal conduit. Where telephone circuits are introduced into controller foundations, encase the telephone conductors in flexible metal conduit and in conformance with the NEC.

Conductors for traffic loops shall be continuous AWG No. 14 XLP stranded wire to the detector terminals or spliced with shielded detector cable within a pull box, conduit, or pole base.

Detector cable shall be two conductor twisted pair shielded AWG No. 14 stranded meeting IMSA Specification No. 50-2.

730.16 Cable

All signal cable shall conform to applicable IMSA Specification No. 19-1 or 20-1. Use stranded cable color coded AWG No. 14 for all signal and accessory circuits. Retain the same color identification for the entire length of a circuit run.

730.17 Wiring

1. Terminate all wiring to screw terminals using lugs.

2. Make all splices with solderless connectors and insulate splices with weatherproof tape applied to a thickness equal to the original insulation.

3. Attach cables to messenger with non-corrosive lashing rods or stainless-steel wire lashings.

4. All wiring within enclosed cabinets shall be neatly formed and harnessed and shall have sufficient length for access and servicing.

730.18 Service Connection

Coordinate service connection details and metering with the local utility as directed by the Engineer and in conformance with the City and County requirements. Obtain the necessary service for each installation.

730.19 Sealant

Provide sealant material selected from the Qualified Products List maintained by the Department’s Material and Test Division for sealing saw-cuts. The sealant material shall resist the upward movement of loop and lead-in and shall exhibit stable dielectric characteristics, including a low permittivity and high dielectric strength. It shall bond to the roadway paving material, preventing entry of moisture, and shall remain flexible without melting through the anticipated temperature and weather conditions.

730.20 Strand Cable

Span cable for suspending signal heads between pole supports shall be 7-strand, Class A, copper-covered steel wire strand or greater, meeting the requirements of ASTM A460, with a minimum breaking strength as noted on the Plans. An acceptable alternate is 7-strand steel wire with a Class A zinc coating meeting the requirements of ASTM A475, with a minimum breaking strength as shown on the Plans.

Strand cable for messenger wire (other than span wire as specified above) and pole guy cable use shall be of the diameter(s) shown on the Plans and shall meet the requirements of ASTM A475 for zinc-coated steel wire strand, 7-strand Siemens-Martin Grade with a Class A zinc coating or greater.

A Figure 8 cable combining the messenger cable and conductor cable in an insulated jacket is an acceptable alternate to conductor cable lashed to a messenger cable.

730.21 Bonding and Grounding

Make metallic cable sheaths, conduit, transformer bases, anchor bolts, and metal poles and pedestals mechanically and electrically secure to form a continuous system, and ensure they are effectively grounded. Bonding and grounding jumpers shall be copper wire or copper strap of not less than the same cross-sectional area as No. 6 AWG.

Furnish and install a ground electrode at each service point. Ground electrodes shall be one-piece lengths of copper weld ground rod not less than 8 feet in length and 1/2 inch in diameter, installed in accordance with the NEC. Ground the conduit and neutral as required under the NEC, except that grounding conductors shall be No. 6 AWG or approved equal, as a minimum. Enclose exposed ground conductors in 1/2-inch diameter conduit, and bond to the electrode with a copper weld ground clamp.

730.22 Field Test

Prior to completing the work, conduct the following tests on all traffic signal and lighting circuits in the Engineer's presence:

1. Test for ground in circuit.

2. Conduct a megger test on each circuit between the circuit and ground. The insulation resistance shall be not less than the values specified in Section 119 of the NEC.

3. Conduct a functional test to demonstrate that each part of the system functions as specified or intended herein.

4. Test all detector loops and leads before and after they are sealed in the pavement to ensure there are no shorts to ground in the system and to ensure that the loop plus lead-in inductance is within the operating range of the detector.

Replace or repair, in a manner approved by the Engineer, all faults in material or in the installation revealed by these tests. Repeat the applicable testing until no fault appears.

730.23 Inspection

After completion of the installation and before final acceptance of the Project, conduct a full operational check of the system under actual traffic conditions in the presence of the Engineer. The operational check shall cover a minimum time period of 30 calendar days. During this period, perform all necessary adjustments and replace all malfunctioning parts of the equipment required to place the system in an acceptable operational condition at no additional cost to the Department. Perform all work and furnish all materials required under these Specifications subject to the direct supervision, inspection, and approval of the Engineer. Provide the Engineer and authorized representatives free access to the work, and to all plants, yards, shops, mills, and factories where, or in which, articles or materials to be used or furnished in connection with such work are being prepared, fabricated, or manufactured. Provide full and sufficient information to determine that the performance of the work, the character of materials, and the quality of workmanship and materials meets the intent of these Specifications.

Only perform work in the presence of the Engineer or the Inspector appointed by the Engineer, unless permission to do otherwise has first been obtained. The Engineer may reject any work that is performed or constructed in the absence of the Engineer or Inspector, without such permission having been granted, either expressly or by implication.

The inspection of the work shall not relieve the Contractor of its obligation to properly fulfill the Contract as specified. If the Engineer finds a part of the work, or the materials used in the work, to be defective or unsuitable at any time prior to final acceptance, repair or replace such defective or unsuitable work or material.

Request the presence of an Engineer or Inspector in connection with the work under these Specifications at least 24 hours before such services will be required.

SIGNAL HEADS

730.24 Signal Heads

Signal heads shall meet the latest requirements published in the Equipment and Materials Standards of the Institute of Transportation Engineers (ITE) for Adjustable Face Vehicle Traffic Control Signal Heads" and the National Electrical Code. The arrangement of traffic signal heads shall be mounted as shown on the Plans or as specified by the Engineer and be in accordance with the latest versions of the MUTCD and the TDOT Traffic Design Manual.

All circular indications shall use 12-inch lenses unless otherwise shown on the Plans. All arrow indications shall use 12-inch lenses. All new vehicle signal heads installed at any one intersection shall be of the same style and from the same manufacturer. All exposed metal signal housings, doors, visors, backplates and framework parts shall be painted with a powder coated finish and be in accordance to the MUTCD specifications. Suspensions for span wire mounting of multi-faced signal heads and signal head clusters (such as a 5-section signal head) shall include an approved swivel type balance adjuster for proper vertical alignment.

Signal head housings shall be cast aluminum and all associated parts/hardware shall be of non-corrosive material. In addition to these requirements, comply with the following:

A. Optical Units

Traffic signal indications shall be LED type and meet the Institute for Transportation Engineers (ITE) latest LED specifications. All LED indications shall have a five-year warranty.

B. Signal Head Mounting and Mounting Brackets

Furnish signal heads that either have integral serrations or are equipped with positive lock rings and fittings designed to prevent heads from turning due to external forces. Lock ring and connecting fittings shall have serrated contacts. Provide signals with water-tight fittings.

Support bracket-mounted signal heads, as shown on the Plans, by mounting brackets consisting of assemblies of 1-1/2-inch standard pipe size. Ensure that all members are either plumb or level, symmetrically arranged, and securely assembled. Conceal all conductors within poles and mounting assembly. Secure each slip fitter to the pole.

C. Directional Louvers

Where shown on the Plans, furnish and install louvers in the hoods of the signal head sections designated.

Directional louvers shall have a snug fit in the signal hoods. Construct the outside cylinder and vanes from a non-ferrous metal or galvanized sheet steel. Louvers shall be painted with a powder coated finish.

D. Back Plates

Where shown on the Plans, furnish and attach back plates to the signal heads. All back plates shall be louvered and constructed of 3,003, half-hard, 0.051-inch minimum thickness aluminum sheet. Other materials such as plastic or fiberglass may be used where approved. In fabricating back plates, bend back the inside vertical edges, adjacent to the signal head, to form mounting brackets for attaching to the signal. Form back plates in two or more sections and bolt together, thus allowing for installation after signal heads are in place. Back plates shall have a dull black appearance in the front and back.

E. Wiring

Signal head leads shall be No. 18 AWG stranded with 221 °F thermoplastic insulation. Wire a separate white (common) lead to each socket shell; and wire a colored lead, corresponding to the color code shown on the Plans, to each socket terminal. Provide leads of sufficient length to allow connection to the terminal block specified. Provide each complete signal head with a minimum 4-point terminal block, properly mounted in a signal section. Stud type terminal blocks shall have not less than 1/4-inch edge clearance to any portion of the stud. Exterior wiring shall have a 360-degree drip loop in advance of entering the head.

F. Pedestrian Signals

Pedestrian signal heads shall meet the latest requirements published in the Equipment and Materials Standards of the Institute of Transportation Engineers (ITE) for Adjustable Face Pedestrian Signal Heads", the National Electrical Code and be compatible with NEMA standards. The arrangement of pedestrian signal heads shall be mounted as shown on the Plans or as specified by the Engineer and be in accordance with the latest versions of the MUTCD and the TDOT Traffic Design Manual. The pedestrian indications shall be LED symbols and in conformance with the Institute for Transportation Engineers (ITE) latest LED specifications. All LED indications shall have a five-year warranty.

In addition, where pedestrian signal heads are provided, they shall:

1. include a pedestrian change interval countdown display where the calculated pedestrian change interval is more than 7 seconds;
2. include Accessible Pedestrian Signals and pedestrian pushbuttons complying with MUTCD Accessible Pedestrian Signals section;
3. incorporate a locator tone meeting the requirements of the MUTCD Accessible Pedestrian Signals;
4. include a pedestrian pushbutton with tactile vibrating arrow button and audible sound.

The pedestrian countdown display shall conform to the latest FCC regulation on Emission of Electronic Noise.

The manufacturer must supply certification, which includes a copy of the test report by an independent technical laboratory as to the compliance with ITE specifications (where it applies). The report shall also indicate that the tests were performed only after the modules received a thirty (30) minute operational warm-up period immediately preceding the tests.

The housing door, door latch, and hinges shall be of aluminum, or polycarbonate or approved equal. Hinge pins shall be stainless steel. Provide the door with a neoprene gasket capable of making a weather resistant, dust-proof seal when closed.

All pedestrian signal heads, mountings, outside of hoods, and pedestrian push button housings shall have a powder coated finish (if aluminum) or colored resin (if polycarbonate) in accordance to MUTCD specifications.

G. Signal Head Installation

Install signal heads and pedestrian signal heads with the faces completely covered until the entire installation is ready for operation.

CONTROLLERS – GENERAL

730.25 Controllers

Controller equipment shall be permanently marked with the manufacturer's name or trademark, part number, and serial number.
Controllers must meet the following applicable industry standards and amendments:
NEMA TS2 Controller .... NEMA TS-2-2016
ATC Controller .... AASHTO/ITE/NEMA ATC 5.2b
All NEMA TS2 and ATC controllers must provide functionality that meets or exceeds operational characteristics, including NTCIP support, as described in NEMA TS-2-2016.
NEMA TS2 Type 2 controllers shall be used when downward compatibility to existing TS1 cabinets is desired.
Except for replacing controllers in existing systems, all new installations must include controllers that capture high resolution event-based data elements to provide the automated traffic signal performance measures.

The manufacturer must supply certification of the conformance to the above requirements at the time of the bid.
In addition to the above requirements, the controller shall:

5. have all timing values entered via a front panel mounted keyboard. This keyboard shall be an integral part of the controller unit;
6. have an English language menu for programming or reading all controller features;
7. continue to operate the intersection as values are inspected or altered;

8. include the ability to upload and/or download the controller software operating system and user programmed database to or from external media (data key, USB, SD card, etc.).
9. support Flashing Yellow Arrow for Permissive Left-turn Movements applications.

Surge Protection Devices The cabinet shall have Surge Protective Devices (SPDs) for the main AC power input, all signal head field wiring terminals, interconnect cable terminals and loop lead-in cable terminals which are located in the cabinet. Furnish SPDs to provide effective defense against high transient voltages caused by lightning discharges or other sources. SPDs must be unobstructed and accessible from the front side of any panel used in the cabinet. The SPD for the main AC power input of the cabinet must be connected on the load side of the cabinet circuit breaker. SPDs must meet the following minimum requirements:

1. AC power SPD:

   a. Must be UL 1449 4th Edition Listed
   b. Parallel connected device
   c. UL Nominal Surge Rating (In): 20kA
   d. UL Short Circuit Current Rating (SCCR): 150kA minimum
   e. Surge current rating: 50kA per phase minimum
   f. Visual status indication
   g. Remote signalization contacts for monitoring purposes
   h. 10-year manufacturer's warranty minimum

2. DC power SPD:

   a. Must be UL 1449 4th Edition recognized
   b. Parallel connected device
   c. UL Nominal Surge Rating (In): 10kA minimum
   d. Must provide protection between all +/-/Gnd connections
   e. Surge current rating: 20kA per phase minimum

f. Visual status indication
g. Remote signalization contacts for monitoring purposes
h. 10-year manufacturer's warranty minimum

3. Data and communication SPD:

   a. Must be UL 497B listed
   b. 10-year manufacturer's warranty minimum

4. Signal and interconnect cable field wiring terminal SPD:

   a. Clamp the surge voltage to a level no greater than twice the peak operating voltage of the circuit being protected
   b. Withstand a surge current of 1000A with an 8 by 20 µs waveform six times (at 1 second intervals between surges) without damage to the suppressor
   c. 10-year manufacturer's warranty minimum

5. Loop lead-in cable field wiring terminal SPD:

   a. Protect the detector unit loop inputs against differential (between the loop lead) surges, and against common mode (between loop leads and ground) surges
   b. Clamp the surge voltage to 25 V or less when subjected to repetitive 300A surges
   c. Withstand repetitive 400A surges with an 8 by 20 µs waveform without damage
   d. 10-year manufacturer's warranty minimum

All SPDs must be installed according to the SPD manufacturer's instructions and not affect the operation of equipment. SPD leads must be kept as short and straight as possible.

CABINETS – GENERAL

730.26 Cabinets

Cabinets must be permanently marked with a label including the manufacturer's name or trademark, model/part number, and the year and month of manufacture. The label should be placed on the inside of the main door using a water-resistant method. The label must be visible after installation.
<u>Cabinets shall be provided as a complete unit and have all terminals and facilities necessary for traffic signal control as shown on the plans and shall meet at a minimum, the following requirement:</u>
<u>NEMA TS2 Controller Cabinet .... NEMA TS 2 2016</u>
The manufacturer must supply certification of the conformance to the above requirements at the time of the bid.
Cabinets shall also be in accordance with the latest version of the TDOT Traffic Design Manual.
<u>Two paper copies of the cabinet wiring diagram shall be provided with each cabinet. The nomenclature of signal heads, vehicular movements and pedestrian movements on the wiring diagram must be in accordance with the signal operating plan. Documentation must include a list identifying the termination points of cables used for vehicular and pedestrian signal heads, detector loop lead-ins, and pedestrian pushbutton wires. A heavy duty, resealable plastic bag must be mounted on the backside of main cabinet door for storing cabinet documentation.</u>

House the controller in a rigid, weatherproof cabinet, constructed, finished, and equipped as follows, and as shown on the Standard Details:

1. **Material.** Provide weather-tight cabinets fabricated from aluminum sheet or cast aluminum alloy with a minimum 0.125-inch thickness. All welds on fabricated cabinets shall be internal and continuous; spot

welding is not acceptable. Painting of cabinets is only required if the final finish presents an unsightly appearance.

2. **Doors.** Type III, IV, and V cabinets shall have a hinged front opening door that shall include substantially the full area of the front of the cabinet. Equip the door with a positive hold fast device to secure the door in at least two open positions: one position at approximately 90 degrees and the other at 120 degrees or more. The holdfast device shall be easily secured and released without the use of tools. Equip doors for Type II, III, IV, and V cabinets with a switch compartment, and provide the manual switches, specified in **730.26..6.k**, with a hinged front opening auxiliary door. Each door shall have a gasket to provide a weatherproof seal when closed.

   Provide the main door with a No. 2 pin-tumbler cylinder lock, and the auxiliary door with a standard police sub-treasury lock. Provide four keys for each lock.

   Provide a switch which is to be tied to the cabinet light so that cabinet light will be on when the door is open and off when the door is closed.

3. **Cabinet Mounting.** Mount cabinets as shown on the Plans or Standard Details.

4. **Ventilation.** Unless otherwise specified, provide ventilation as follows:

   a. On all cabinets housing controllers, mount a screened, rain-tight vent, 1-1/2 inches in diameter or larger, on the cabinet top.

   b. Provide screened or filtered inlet ventilation openings, equal to or greater in area than top vents, located in the bottom or lower back side of Type I and II cabinets or around the lower 8 inches portion of Type III cabinets.

   c. Construct the vents so as to project within the cabinet no more than necessary to provide for lock nuts and gaskets to retain the vent.

   d. Locate vents so as to not interfere with the mounting of controller equipment.

5. **Cabinets with Exhaust Fans.** Exhaust fans shall consist of an electric fan with ball or roller bearings and a capacity of at least 100 cubic feet per minute. Mount the fan in a rain-tight housing attached to the top of the controller cabinet.

   The fan shall be controlled by a thermostat having a temperature differential between turn-on and turn-off of 15 °F (-0, +5 °F), adjustable for turn-on through a minimum calibrated range of from 100 °F to 150 °F.

   Whenever a fan is to be installed, provide the air inlet filter and filter holder shown in the Standard Details, or approved equal. Internally seal other air inlets. Provide exhaust fans in all cabinets that house controllers, with the exception of flasher controllers.

6. **Auxiliary Equipment.** With the exception of cabinets used in special applications (Type I and II), provide all cabinets with the following:

   a. Substantial shelves or brackets to support controller and auxiliary equipment.

   b. Panel for terminals arranged for adequate electrical clearance. Panels should be located in the cabinet as described below:

- Detectors	Lower left wall
- AC power	Lower right wall

- Auxiliary/police switches	Door
- Load switch bay	Back wall

c. The cabinet shall include an LED light and GFI duplex receptacle which can be used when the main circuit breaker is off.

d. Control panel assembly consisting of:

1. Power supply connections made to a 30-ampere circuit breaker mounted on the cabinet separate from the signal terminal panel. The circuit breaker shall be a magnetic trip type, having an interrupting capacity of at least 2,000 amperes at 125 volts AC. The circuit shall trip between 101% and 125% of rated load, with an inverse time delay characteristic provided. Instantaneous tripping shall occur at ten times the nominal rating. All controllers shall be internally fused.

2. Service line surge protection.

3. Electrical service termination point sized to accept No. 4 AWG copper wire.

4. Ground fault receptacle.

5. Porcelain lamp receptacle to accept a standard traffic signal lamp (if necessary).

6. Circuit breakers in accordance to the National Electric Code for:
   (a) Main power input to provide all power associated with normal operation.
   (b) Flasher power input to provide all power associated with flash operation.
   (c) Service power to provide power for the lamp and duplex receptacle and cabinet light.

7. Copper ground bus (minimum of 12 positions).

e. Flasher mechanism independent of controller. The cabinet shall be wired for and include a NEMA flasher mounted on the back panel. All cabinets shall have a two-circuit flasher. The flasher shall have output indicators mounted on the front of the flasher case and shall be rated at a minimum of 15 amperes.

f. General purpose relays, where required to perform specified functions. All relays external to the controller or appurtenances shall meet NEMA standards. In addition:
- Flash transfer relays shall be of heavy-duty type and have a minimum contact rating of 10 amperes. Contacts shall be of silver material to reduce contact pitting.
- Unless otherwise specified, each cabinet shall include six (6) flash transfer relays.
- Flash transfer relays shall support Flashing Yellow Arrow for Permissive Left-turn Movements applications.

g. Type II, III, IV, and V cabinets, when specified as housing for traffic actuated controllers, with two or more insulated terminal blocks mounted within the housing, one or more for terminating each field wire.

h. A minimum of 12 available bare ground positions tied to AC Common Return.

i. Earth (driven) ground tie point to terminate a single No. 4 AWG copper ground.

j. A tie point to tie all ground systems within the cabinet to a single reference point. All grounds (AC - return, Chassis, and Logic Ground) must be referenced to a single ground point at the electric service.

k. A panel (police subpanel) shall contain the following:

1. A main power switch, which shall be wired to remove all cabinet power when in the Off position

2. An Automatic Flash switch, which shall be wired as follows:

(a) The Flash position shall cause the cabinet to provide Flash Operation. The controller shall continue to operate and Stop Time shall be applied to the controller.
(b) Auto/Manual switch to activate Manual Control Enable.
(c) Manual control pushbutton switch with self-coiling cord. Cord shall attach to a 2-position terminal strip via fork type connector

(d) Upon return from Flashing to Automatic, the controller shall initialize in the Start-Up Display condition as programmed in the controller, typically major road phases.

3. A panel mounted inside the main door shall contain the following switches:

(a) A technician Stop-Time switch to apply Stop Time to each controller ring.

(b) An Interval Advance switch enabled only by the Stop Time switch, to be momentary pushbutton switch to apply Interval advance to the timer.

(c) A Signal On-Off switch, which shall remove the AC power applied to the signal heads for normal operation while the controller continues to operate.

(d) Individual phase vehicle and pedestrian detector test switches to be miniature toggle of the On-Off Momentary type to place:
i. No Call - Call provided by detectors
ii. Locked detector call
iii. Momentary detector call

Insulate or shield switch terminals on back of main cabinet door so that no live parts are exposed.

Leads from the terminal block to the auxiliary door switches shall be no less than No. 18 AWG stranded, with TW plasticized polyvinyl chloride or nylon insulation enclosed in an insulating loom and shall be of sufficient length to allow full opening of the main cabinet door.

l. The cabinet shall be wired with the appropriate number of load switches to accommodate vehicular and pedestrian phasing according to plans. At a minimum, cabinets shall include 16 load switch bases. The load switch wiring shall support Flashing Yellow Arrow for Permissive Left-turn Movement applications.

m. All cabinet wiring shall be neatly routed and labeled, laced and permanently secured. All cable shall be secured to the panel, where practical. There shall be no holes drilled through the cabinet walls to mount panels or secure cables.

n. All terminals in the cabinet shall be of the barrier type. The following field connector terminals shall be provided:

- Four (4) signal output positions per load switch bay (R-Y-G-FL).
- Ten (10) positions per phase for vehicle loop detector harness.

- One position per phase for pedestrian detector inputs.

o. Cabinets shall have SDLC communication between the controller, MMU, Detector Rack, Radar Detector (if applicable) and Video Detection (if applicable).
p. Cabinets should have an electrical outlet (Non GFI) that has 120 VAC from the OUTPUT side of the Main Power Surge unit.
q. Cabinets shall support Flashing Yellow Arrow for Permissive Left-turn Movements applications.
r. All cabinets shall be supplied with a Malfunction Management Unit (MMU) and shall meet at a minimum, the following requirement:

NEMA TS2 Malfunction Management Unit .... NEMA TS 2 2016

The manufacturer must supply certification of the conformance to the above requirements at the time of the bid.

According to NEMA TS2 the MMU shall be able to detect the presence of voltage on conflicting on conflicting field connection terminals, the absence of proper voltages on all the signal field connection terminals of a channel, and shall be capable of monitoring for the presence of satisfactory operating voltages within the Controller Unit (CU) and the MMU itself. The MMU shall be able to operate as a Type 16 with sixteen channels or as a Type 12 with twelve channels (compatible with NEMA TS1 cabinets.

The MMU should have an Ethernet port.

730.27 Auxiliary Equipment for Traffic Signal Controllers

Furnish and install the following auxiliary equipment in each cabinet for traffic actuated controllers.

A. Load Switches

Provide each cabinet complete, with the necessary number of NEMA load switches and Flash Transfer relays necessary to affect the specified signal sequence and phasing. Load switches shall:

1. Meet NEMA standards.

2. Have front-face mounted LED indicators to indicate the “On” condition of both the Input and Output circuits.

3. Use replaceable “cube” type circuitry or encapsulated discrete component construction. No unencapsulated discrete component construction are acceptable.

B. Time Clock Switches

Where shown on the Plans, provide time clock switches of solid-state circuitry, continuous duty, with a 7-day cycle clock operating from the 120-volt AC service line. Provide switching for a minimum of one independent output and ensure the time of day selection is adjustable to within 1 minute of the desired time. Provide a battery backup system that can maintain time keeping and memory a minimum of 24 hours after power interruption. Furnish an omitting device as an integral part of the time switch to allow the switching operation to be skipped for any preselected day or days of the week. The time clock shall automatically compensate for daylight savings time changes. When the time clock is supplied as an internal component of the controller, supply the clock feature to provide for the selection of Maximum Green II on time of day, day of week, week of year basis. Time clocks shall meet NEMA environmental specifications.

When required in the traffic signal plans, the auxiliary equipment listed below shall meet the following requirements:

A. Uninterruptable Power Supply (UPS) – An UPS shall power the traffic signal cabinet in the event of a power failure for a minimum of 3 hours.

UPS assemblies should include off-the-shelf deep cycle AGM batteries.

Loss of utility power, transfer from utility power to battery power, and transfer back to utility power must not interfere with normal operation of connected equipment. In the event of UPS failure or battery depletion, connected equipment must be energized automatically upon restoration of utility power.

Removal and replacement of the UPS must not disrupt the operation of the equipment being protected.

All harnesses necessary to connect and operate the system must be included. All connectors must be keyed to prevent improper connection.

UPS assemblies shall be installed in accordance with the manufacturer's recommendations.

An UPS operation and maintenance manual shall be provided in the cabinet where the UPS is installed with cabinet wiring schematics, electrical interconnection drawings, parts layout and parts lists.

The UPS shall include a manufacturer's warranty covering defects for a minimum of three years (5 years for the external batteries) from the date of final equipment acceptance. The warranty must include provisions for providing a replacement UPS within 10 calendar days of notification for any UPS found to be defective during the warranty period at no cost to the maintaining agency.

B. Communications - Wireless - consist of installing a Wireless Network Communications Link with all necessary hardware in accordance with the plans and standard drawings to provide a data link between field devices (i.e. Traffic Signal Controllers).

Each link shall consist of Master ODU (Outdoor Unit, Antenna) connected to a data switch within one of the signal cabinets and a Slave ODU connected to a data switch within the other signal cabinet. Each ODU is aligned to face the opposing ODU. The cable length between the ODU and its associated data switch may not exceed 300 feet.

The Wireless Network Communications Link components at each of the linked traffic signal cabinets shall include an ODU, an LPU (Lightning Protection Unit), power supply mounting hardware, and CAT 5e cabling. The ODU is pole mounted per manufacturer's specifications. The LPU and power supply are mounted within the traffic signal cabinet. CAT 5e cable is installed between the ODU and LPU.

For the applicable frequency spectrum of the radios being deployed, perform a spectrum analysis to ensure no competing equipment in the area. Ensure the radio path site survey test is performed using the supplied brand of radio equipment to be deployed. Typically, if the ODUs can be mounted with clear line of sight between them, this is enough to ensure proper operation. If this is not possible, it may be determined that a repeater station is necessary to complete the intended link. Provide the test results to the ENGINEER for review and approval. Submit copies of the test results and colored copies of the frequency spectrum scan along with an electronic copy of this information. The ENGINEER will approve final locations of the ODUs and any necessary repeater stations.

Install each ODU in such a manner that avoids conflicts with other utilities (separation distances in accordance with the guidelines of the NESC) and as specified in the ODU manufacturer's recommendations. Secure the ODU mounting hardware to the pole and route the CAT 5E cable such that no strain is placed on the RJ-45 connectors. Align each antenna/radio to be perpendicular to the ground (using bubble level) and to face the opposing radio.

C. Fiber optic cables - Multi-mode type fiber optic cable shall be 50 µm core diameter, with at least 12 fibers per cable unless otherwise specified in the plans. Single-mode type cable shall be between 8-9 µm core diameter, with at least 12 fibers per cable unless otherwise specified. A fiber optic drop cable shall be a minimum of 6 fibers (each type) and be spliced into the trunk line in a splice enclosure either aerially or in a pull box. Contractor shall provide 50ft of slack either lashed to a span aerially or coiled in a pull box for underground installations. Termination panels shall be provided with sufficient size to provide for a neat installation, and enough panel space to accommodate the specified number of fibers for termination. ST connectors shall be used unless otherwise specified. Contractor shall provide any necessary jumpers for installed equipment.

MISCELLANEOUS TRAFFIC SIGNALS

730.28A Flashing School Signals

When shown on the Plans, provide flashing school signals that conform to the following:

1. The signal shall produce two alternate flashing lights within the marginal limits of a school speed limit sign. Details of the sign construction shall be as shown on the Plans. Sign colors shall conform to the MUTCD and be constructed of materials complying with these specifications.

2. The two lenses shall be yellow in color and a minimum of 8 inches in diameter. Mount the lenses in the sign using a molded endless rubber gasket with the sign being mounted to the signal case. The reflector for the round lens shall be glass and firmly mounted between the lens assembly and the case so as to produce a weather-proof and water-tight optical unit.

3. Provide a two-circuit type flasher unit to provide alternating equal on-off operation. The flashing mechanism shall produce between 50 and 60 flashes per minute through two 120-volt, 60-cycle AC, 15-ampere circuits. The flasher shall be of solid-state construction.

4. Wire the unit for external circuits.

5. The signal shall be actuated by time switch meeting **730.27**. Locate the timing device in a remote mounted control cabinet.

6. Where an illuminated speed limit indication is shown on the Plans, the numeral message shall be illuminated in Portland Orange in a rectangular lens and illuminated only during the period when the signal produces two alternately flashing amber lights.

In addition, the Time Clock Unit/Switch used for Flashing School Signals shall be a programmable module that allows a user to define the time and day that the school speed zone flasher assembly will initiate and terminate flashing operation. The module shall be installed within the pole-mounted signal cabinet provided as part of project. The time clock shall be compatible with the cabinet's wiring relays and termination panels and the battery power supply system. The time clock switch provided shall also have the following features/capabilities outlined below:

1. Daylight Savings Time shall be a user-programmable setting, in addition to having automated compensation per TDOT specifications.

2. The unit shall provide a minimum 12-character, multi-line alpha-numeric LCD back-lit display capable of displaying all programming parameters.

3. The unit shall be capable of being programmed manually (using an integral keyboard pad) or programmed externally using an optional software program via a laptop computer and cable connection (compatible software program is a separate and distinct item from the time switch unit, and if required, will be separately specified and noted in list of estimated project quantities).

4. Unit shall provide automatic Leap Year compensation.

5. The time clock switch shall be capable of up to minimum 24-hours of capacitive back-up operation, 48 hours desirable, in the event of power interruption.

6. Unit shall be compatible with the supplied solar powered power system / battery unit

7. Time clock switch shall be capable of being programmed for one (1) Normal / Main program, and an additional minimum of 12 Exception periods /programs allowing holiday, vacation and custom skip plans. The exception programs will allow for the Normal / Main program to be skipped or allow for flasher operation on alternative schedules (i.e. early release days, summer school, etc.).

8. Unit shall conform to TDOT standard specification subsection 730.27 – Auxiliary Equipment for Traffic Actuated Controller – Time Clock Switches except as superseded herein.

9. Unit shall have non-volatile program memory to allow retention during power loss.

730.28B-Solar Power Flashers. When required, the solar power flasher equipment listed below shall meet the following requirements:

1. Solar panel and mounting equipment shall be installed on cantilever pole shaft as illustrated on layout detail sheet and as directed by manufacturer instructions.

2. Solar power unit assembly shall include all required mounting equipment, wiring/cables, battery supply, battery charging unit and other ancillary equipment necessary to operate the solar panel and properly charge the battery. The photovoltaic array shall include mounting bracket assembly to permit adjustment of the array to optimal sun exposure. The photovoltaic module shall be mounted and aligned per manufacturer recommendations to maximize solar exposure.

3. Battery unit shall meet manufacturer specifications required to operate and power L.E.D. signal displays and continuous time clock switch operation. Battery shall be compatible with cabinet equipment, including the time clock switch and the flasher signal displays. Battery unit shall meet minimum environmental and performance specifications required for system operation as recommended by solar panel and time clock switch manufacturers.

4. Solar panel and battery supply shall be of a size and power rating necessary to provide required power to time switch clock and flasher signal displays. The contractor shall obtain the power load requirements from the solar power equipment manufacturer and provide as required. On a typical school day, it should be expected that the flasher system will operate up to four (4) hours per day with the time clock continuously operating to maintain its clock timer. Contractor shall provide a solar system sizing report from the manufacturer indicating the power supply requirements of the proposed system required to meet the expected power demand.

5. The photovoltaic modules shall be warranted for a minimum of five (5) years from date of installation.

6. The battery system shall be a gelled-electrolyte type battery with capacity to provide a minimum of five (5) days continuous operation of the flasher assembly without charging. Batteries shall be field replaceable. Batteries shall have prorated warranty of a minimum of five (5) years from date of installation.

730.28C Portable Traffic Signals

Portable Traffic Signals (PTS) consists of furnishing, installing and configuring a complete PTS system that may be used in construction zones or in other temporary signal locations. The work will be at various sites throughout the state of Tennessee and will consist of providing all labor, materials, equipment and incidentals necessary to make functional the PTS in accordance with these specifications.

The PTS shall be trailer or cart mounted units that provide for easy transportation and quick setup and deployment.

There shall be 2-unit options and each unit shall be self-contained.

1. Type 1 units are typically used for long term projects (i.e. projects 5 days or longer in duration) and shall include 2 signal heads per trailer with an upper signal head mounted on an overhead mast arm that can be extended over the travel lane, and a lower signal head mounted on the vertical upright of the trailer.

2. Type 2 units are typically used for short term projects (i.e. projects 4 days or shorter in duration) and shall include 1 signal head that is mounted on the vertical upright of the trailer or cart. Cart-mounted units shall be successfully crash tested to NCHRP 350 TL-3, or equivalent MASH standards. If the project duration is extended beyond 4 days, then Type 1 units should be substituted in lieu of the Type 2 units for all PTS within the signal system.

The PTS shall be MUTCD Compliant and utilize standard ITE signal heads and adhere to the ITE Specifications and Standards for Vehicle Traffic Control Signal Heads, Light Emitting Diode (LED) Circular Signal Supplement. The unit shall be solar powered and communicate via a wireless or hardwire connection. The unit shall include all the major components listed below or be able to perform the functions of these components. The major components of the unit shall include but are not limited to the trailer or cart, telescoping mast arm (on Type 1 units only), signal head(s) and back plates, traffic signal controller with operating software, solar charging system with batteries, input and output devices, flasher units, conflict monitor, relays, communications system and other equipment required for the safe operation and installation of the unit.

The PTS signal heads and all applicable components of the PTS shall meet the physical display and operational requirements of conventional traffic signals as specific in the MUTCD.

1. For Type 1 units, each unit shall contain 2 signal heads with an upper signal head mounted on an overhead mast arm that can be extended over the travel lane with a minimum clearance of 17 feet measured from the bottom of the signal head unit to the road surface. The lower signal head shall be mounted to the vertical upright of the trailer at a minimum height of 8 feet from the bottom of the signal head unit to the road surface. The signal heads shall also include black back plates that can be easily removed. The signal heads shall have the ability to be rotated 180 degrees to face in the opposite direction and shall have the ability to rotate and lock in approximately 10-degree increments to position the signal head for the optimum visibility to motorists.

2. For Type 2 units, the signal head of the unit shall be mounted to the vertical upright at a minimum height of 8 feet from the bottom of the signal head unit to the road surface. The signal head shall also include black back plate that can be easily removed. The PTS shall be easily rotated to position the signal head for optimum visibility to motorists.

The PTS shall include a solid-state controller with operating temperature range of -40ºF to +180ºF and compliance with NEMA TS-5 Performance Standard. The controller or programming module shall have an easy to read front panel indicator display. The display shall be backlit and have the capability to facilitate programming and display the currently operating program for each vehicular approach. The controller shall be capable of operating the PTS system in a fixed time, traffic actuated, or manual control mode. Each PTS in a connected system shall have the capability to serve as either the master or slave signal. Each PTS shall include a Conflict Monitor Unit (CMU), or Malfunction Management System (MMS) to ensure phase conflicts do not exist during operation.

1. A minimum of 5 automatic time-of-day timing plans within a 24-hour period should be available in fixed time mode. The operating system should have the ability to control a minimum of 4 traffic phases with programmable cycle time adjustments and user adjustable red, amber, minimum green and maximum green times. The operating system shall also have the capability of facilitating standby modes of red, red flash and yellow flash.

2. The system shall also have the ability to operate in vehicle actuation mode when vehicle detection detectors are used. The operating system shall have the capability to allow the PTS to be connected to and controlled by a standard NEMA controller.

3. The system shall have the capability to be configured and controlled remotely using a handheld wireless remote control with the capability of being operated at a distance up to ¼ mile from the master.

4. The system shall have the capability of remote monitoring for reporting, at a minimum, signal location and status, battery voltage and system defaults. The remote monitoring shall have capability to alert designated individuals if a fault condition occurs.

5. The operating system shall include password protection to prevent unauthorized programming.

The PTS shall communicate with all other PTS within the signal system via license-free wireless 900 MHZ radio link communications. The radio units shall maintain communications at a minimum distance of 1 mile. The radio system shall conform to the applicable Federal Communications Commission (FCC) requirements, including FCC 90.17, and all applicable state and local requirements. The PTS shall be in direct communication at all times either by wireless or hardwire connection to provide for the required conflict monitor.

The system shall also have the ability to operate in vehicle actuation mode when vehicle detection detectors are used. For Type 1 units, the PTS detector shall be a high-definition, multi-beam, microwave radar stop bar detector for each vehicular approach. The Type 1 radar detector shall have a minimum range of 140 feet and shall be mounted at a minimum height of 17 feet measured from the top of the road surface. For Type 2 units, the PTS detector shall be a radar detector for each vehicular approach. The Type 2 radar detector shall have a minimum range of 140 feet and shall be mounted and have complete radar detection functionality at a minimum height of 8 feet measured from the top of the road surface.

The PTS shall be equipped with a solar power array, charging unit and battery system. For Type 1 units, the number and size of batteries shall be sufficient to operate the signal for a minimum of 21 days at 70 degrees without additional charging or assist from the solar array. An on-board battery charger shall be compatible with both the solar array and with a 120V AC power source. The solar panel array shall provide for a minimum of 440 watts of solar collection capability. For Type 2 units, the PTS shall have batteries sufficient to operate the signal for a minimum of 5 days at 70 degrees without additional charging or assist from a solar array. All instrumentation for the electrical system and battery compartment shall be mounted in a lockable weatherproof enclosure. Solar panels shall be secured to the mounting brackets for theft prevention. All wiring for the unit shall be protected against weather and damage.

The trailer or cart, and all mounted components, shall conform to the wind loading requirements (90 mph minimum) as described in the AASHTO Standard Specifications for Highway Signs, Luminaries and Traffic Signals. The wind load calculations shall be completed by an independent third-party contractor and stamped by a U.S. Registered Professional Engineer. The trailer or cart shall be made of structural steel and shall include 4 leveling/stabilizer jacks capable of lifting the trailer or cart a minimum of 6 inches. The trailer or cart shall be equipped with a hydraulic or electric lift system sufficient for 1 person to be able to raise and lower the vertical upright and/or horizontal mast arm to and from the operating position. For Type 1 or 2 units, the trailer or cart shall be equipped to provide legal and safe transport on the public highway system at speeds up to 55 mph. All exterior metal surfaces, except signal heads and back plates, shall be powder-coat painted highway safety orange.

The PTS work shall meet the following general contractor requirements:

1. The Contractor shall be responsible for locating the PTS in the appropriate location based on MUTCD and ITE standards for visibility to motorists and for safe operation.

2. The Contractor shall be responsible for providing all hardware, software, communications equipment and licenses to operate a complete PTS system.

3. The Contractor shall be responsible that all PTS equipment is installed according to the manufacturer's recommendations including wireless or hardwire connections.

4. The Contractor shall be responsible for transport, setup, configuration, operation and monitoring of the PTS throughout the entire project. The Engineer shall approve all timing and settings that are used for operation of the signal.

5. As directed by the Engineer, it may be necessary to relocate the PTS during the project. The cost of the relocation shall be included in the PTS price bid.

DETECTORS

730.29 Detectors

Provide detectors, of the type shown on the Plans, to actuate signal phases of traffic actuated controllers. Provide ample lightning protection to provide effective defense against high transient voltages caused by lightning discharges or from other sources. The lightning protection unit must withstand repeated 400-ampere surges on a 9 x 20 microsecond waveform. Also, the unit must be a two-stage device capable of clamping a minimum of one hundred 300-ampere surges to 25 volts within 40 nanoseconds for surge applied across the two detector leads.

A. Inductive Loop Detection System

Inductive loop detector units (loop amplifiers) shall meet at a minimum, the following requirement:

NEMA TS2 Inductive Loop Detector Units .... NEMA TS 2 2016

Loop amplifiers may be single or multi-channel and shall be of the totally self-contained type.

All loop amplifiers shall be of the type to provide both "Extended" and "Delayed" outputs.

The loop detector amplifier shall be fully automatic, requiring no adjustments to effect operational ability other than setting of the operating frequency and sensitivity. The amplifier shall:

1. Sense any legal motor vehicle traveling at speeds up to 65 miles per hour.

2. Have both a “Pulse” and “Presence” Output:
   a. Pulse output shall generate an output of 125 ±25 millisecond output for each vehicle entry.
   b. Presence output shall provide a continuous output for up to 60 minutes as long as a vehicle is within the detection zone.

3. Provide at least four user selectable sensitivity ranges.

4. Be supplied with at least three frequency ranges for crosstalk minimization.

5. Have a front-face mounted indicator to indicate active output of the internal relay. This indicator shall indicate the presence of:
   a. Normal Output
   b. Delayed Output
   c. Extended Output

6. Have a front-panel mounted “Reset” switch that when pressed shall cause the unit to completely re-tune itself.

7. Have Delayed or Extended timing features with the following ranges:
   a. Delayed output of 0 to 30 seconds in 1-second increments.
   b. Extended output of 0 to 10 seconds in 1/4-second increments.

8. Have internal diagnostics to determine the operational ability of the loop. These diagnostics shall determine if a loop is opened or shorted and shall provide a visible indication of such condition. Additionally, if such a condition occurs, the amplifier unit shall default to a “constant” output.

9. Provide output by a mechanical relay, which shall be “off” to provide an output.

10. Have all delay functions wired to the associated plan phase green to inhibit that function during controller phase green.

11. Be able to operate with loop lead-in lengths of at least 2,000 feet.

Comply with the details of the detector loop installation as shown on the Plans or Standard Drawings.

B. Video Detection System (VDS)– when specified in the plans, the equipment shall consist of all items necessary to provide a complete functional video detection system that process images and provide detection outputs to the traffic signal controller.

VDS shall be capable of NEMA TS2 operation.

VDS shall be waterproof and weather resistant.
VDS shall provide user-defined detection zone programming via a graphical user interface (GUI) and any necessary equipment for future programming. The configuration database shall have the ability to be stored on a removable data storage external to the video card,
VDS shall display programmable detection zones and detection activations overlaid on live video inputs. It shall detect vehicles in real time as they travel across each detection zone.
VDS shall have a minimum of 24 programmable detection zones per camera.
VDS shall be capable of:

1. shadow rejection without special hardware;
2. non-impaired operation under light intensity changes;
3. maintained operation during various weather conditions (e.g. rain, fog, snow)
4. anti-vibration, 5% rejection based on image change;
5. ability to select direction of flow parameters;
6. ability to properly detect directionally;
7. ability to configure presence, pulse, extend and delay outputs;
8. ability to set up a minimum of six detection zones per camera view to count the number of vehicles detected and store the information for retrieval;
9. variable focus providing a minimum of 4 to at least 40-degree horizontal field of view;
10. store detection zones in non-volatile memory;

VDS shall have no splices between the processors and the cameras.
VDS shall provide LED indicators to show active detection.
VDS camera shall have an internal heater to assure proper operation of the equipment during low temperatures.
VDS shall have surge ratings as set forth in NEMA specifications.
VDS shall have a two-year warranty and updates of all software shall be available without charge during the warranty period.

C. Radar Vehicle Detection System (RVDS) – when specified in the plans, the equipment shall consist of all items necessary to provide a complete functional RVDS that process high-definition, multi-beam radar electromagnetic waves and provide detection outputs to the traffic signal controller.

RVDS shall be capable of NEMA TS2 operation.
An RVDS shall consist of the following components: Radar sensor (1), detector rack interface module (1) power and surge protection panel or module (1) (cabinet interface devices that combine one or more of the above components shall be acceptable as well), and all associated equipment required to setup and operate in a field environment including software, serial and ethernet communication ports, cabling, electrical connectors and mounting hardware.

The RVDS shall be able to operate in all types of weather conditions including rain, snow, sleet, ice, fog and windblown dust.
Lightning and surge protection will be provided for power connections and communications links to the radar RVDS.
The RVDS shall provide a “fail safe” operation that triggers when communication between the radar vehicle sensor and the interface module is broken. Contact closure from the interface module will occur on all programmed detector channels associated with the affected radar sensor when the failsafe is triggered and will remain in this state until communication is re-established between the interface module and the radar vehicle sensor.
The RVDS shall comply with all applicable Federal Communications Commission (FCC) requirements. The manufacturer will provide documentation of compliance with FCC specifications.
The RVDS shall maintain frequency stability without the use of manual tuning elements by the user.
The RVDS as a minimum must provide a minimum of 4 separate RF channels selectable by the user to avoid interference with other devices working on the same frequency.
The communication port(s) shall support a communication speed that will not introduce excessive latency between when a vehicle is detected and the contact closure in the traffic signal cabinet.
RVDS interface modules that utilize the detector rack must operate at 12V or 24V DC. Shelf mounted interface modules must operate within a range of 89V to 135V AC, 60 Hz single phase. Power to the RVDS radar sensor must be from the transient protected side of the AC power distribution system in the traffic control cabinet in which the RVDS is installed.
RVDS documentation shall include a comprehensive user guide as well as quick reference guide(s).
<u>RVDS shall have the ability to configure presence, pulse, extend and delay outputs.</u>

D. <u>Wireless Magnetometer Detection System (WMDS)</u> - when specified in the plans, the equipment shall consist of all items necessary to provide a complete functional wireless magnetometer detection system that process changes to earth magnetic field and provide detection outputs to the traffic signal controller.

<u>WMDS shall be capable of NEMA TS2 operation.</u>
The WMDS shall consist of the following components: In-pavement sensors, all wireless communication equipment needed to establish communication links to the controller cabinet, interface modules compatible with NEMA TS-2 V2.06b cabinet detector rack, surge protection for the WMDS and system software for set-up and monitoring of the WMDS.
The WMDS must be capable of detecting a variety of vehicle types including motorcycles, automobiles and large trucks. The system must allow the user to select sensitivity levels that adjust the amount of hysteresis to the magnetic field needed to achieve contact closure to the assigned detector channel. Magnetometer sensitivity level adjustments must allow for different levels of vehicle detection.
<u>WMDS shall have the ability to configure presence, pulse, extend and delay outputs.</u>
WMDS equipment failure such as: the sensor, communications link, access point radio, repeater radio (if used) or interface module, shall result in constant vehicle call “fault state” on the affected detector channel to the traffic controller.
WMDS detection accuracy must be comparable to properly operating inductive loops.
The WMDS shall provide real-time vehicle detection (within 150 milliseconds (ms) of vehicle arrival). Once detection is achieved by the sensor, the traffic controller must receive contact closure to the assigned detector channel within the 150 ms time frame.
The WMDS in-pavement sensor must operate on batteries without the need for underground power or communication cable connections to the unit.
The average operating life span of the sensor under battery power must be a minimum of 10 years.
The interface module must provide 2 or 4 detector channels. Sensors must be assignable to the available detector channels on the interface module using software provided with the WMDS.
The front face of the module shall identify detector channel 1 and detector channel 2. Each must use an LED to indicate contact closure on the channel. When vehicle detection is achieved, the LED will be on and contact closure applied to the detector channel. During periods of no vehicle detection the LEDs will be in an off state and no contact closure will be applied to the detector channel.
The interface module will use an LED indication to indicate a “fault state” with the WMDS. When the fault state is active contact closure will be applied to the appropriate detector channel.

E. Pedestrian Push Buttons

Where shown on the Plans, furnish and install pedestrian push buttons of substantial tamper-proof construction. They shall consist of a direct push type button and single momentary contact switch in a cast metal housing. Operating voltage for pedestrian push buttons shall not exceed 24 volts.

Provide a weatherproof assembly, constructed to prevent electrical shocks under any weather condition.

Where a pedestrian push button is attached to a pole, the housing shall be shaped to fit the curvature of the standard or post to which it is attached to provide a rigid installation.

Unless otherwise specified, install the push button and sign on the crosswalk side of the pole.

Pedestrian push buttons shall have a transient protection that meets NEMA specifications.

730.30 (Reserved)

730.31 (Reserved)

TRAFFIC SIGNAL SUPPORTS

730.32 Cantilever Signal Supports

This Subsection applies to the manufacture of steel poles and mast arms for the support of traffic signals. The height of poles, shaft dimensions and wall thickness shall meet the design requirements and mounting height of traffic signals as set forth in these Specifications and shown on the Plans. The Plans indicate bracket arm lengths.

Furnish poles consisting of a straight or uniformly tapered shaft, cylindrical or octagonal in cross-section, having a base welded to the lower end and complete with anchor bolts. All castings shall be clean and smooth with all details well defined and true to pattern. Steel castings shall conform to ASTM A27, Grade 65-35. Gray iron castings shall conform to ASTM A126, Class A.

All mast arms shall be compatible with the poles in material, strength, shape, and size.

A. Anchor Base

Secure an anchor base of one-piece cast steel or steel plate of adequate strength, shape, and size to the lower end of the shaft. Place the base so as to telescope the shaft, and weld at the top and bottom faces with continuous fillet welds so that the welded connection develops the full strength of the adjacent shaft section to resist bending action. Provide each base with a minimum of four holes to receive the anchor bolts. Provide cast steel bases with removable cast iron covers for anchor bolts and tapped holes for attaching covers with hex head cap screws.

Provide a welded frame handhole, 5 x 8 inches minimum and located with a clear distance above the base of no less than the pole diameter, “D”. Weld a 1/2-inch 13 UNC grounding nut to the inside of the pole at a point readily accessible for wiring.

B. Shaft

Fabricate shafts from the best, hot-rolled basic open-hearth steel. The shaft shall have only one longitudinal electrically welded joint and may have electrically welded intermediate transverse full penetration circumferential joints, at intervals of not less than 10 feet. The shaft shall be longitudinally cold-rolled to flatten the weld and increase the physical characteristics so that the metal will have a minimum yield strength of 48,000 pounds per square inch. Where transverse full penetration circumferential welds are used, the shaft fabricator shall furnish to the Engineer certification that: (1) all such welds have been radiographed and ultrasonically tested by an independent testing laboratory using a qualified Nondestructive Testing (NDT) technician and (2) the NDT equipment has been calibrated annually.

Fit the shaft with a removable pole cap, a J-hook wire support welded inside near the top, and a flange plate assembly to match that welded to the butt end of the mast arm.

C. Mast Arms

Provide mast arms fabricated and certified in the same manner as the upright shafts and that have the same physical characteristics.

The mast arms shall meet the design requirements necessary to support rigidly mounted traffic signals as shown on the Plans. All arms shall include a removable cap at the tip, grommeted wire outlets, and signal hanger assemblies of the type and number shown on the Plans, and a flange plate welded to the butt end to provide a rigid connection to the mast. The assembly shall be constructed so that all wiring can be concealed internally.

Connect mast arms to the upright pole at a height necessary to provide a minimum clearance of 16 feet 6 inches and a maximum clearance of 19 feet under the traffic signal heads. Install separate signal heads to provide the same clearance.

D. Finish

Galvanize steel poles, mast arms, and hardware in accordance with ASTM A123.

Galvanize all steel and cast iron components, hardware, and threaded fasteners, except anchor bolts, after fabrication in accordance with ASTM A123, or A153 or A385, as applicable.

730.33 Steel Strain Poles

Provide steel strain poles consisting of a uniformly tapered or equivalent upright shaft fitted with a removable pole top, J-hook wire support and 45-degree wire inlet near the top, a span wire clamp, a 5 x 8 inch handhole with reinforced frame and cover, bent anchor bolts, and all other accessories needed to make a complete installation. The pole and all its component parts shall be designed to support tethered traffic signals of the type and number shown on the Plans, suspended from a span wire assembly. Fabricate and certify the poles as specified for the upright shafts in **730.32**.

Determine the shaft length required to meet field conditions and vertical clearances of signal heads over the roadway. The signal head clearance shall be a minimum of 16 feet 6 inches and a maximum of 19 feet. Fasten the span wire no closer than 1 foot 6 inches from the top of the pole.

Unless otherwise specified, provide all strain pole traffic signal supports with a one-piece anchor type base, fabricated from drop forged or cast steel of sufficient cross-section to fully develop the ultimate strength of the poles. Fasten the base to the pole with a welded connection that develops the full strength of the pole. Provide the base with a minimum of four holes of sufficient size to accommodate the proper size anchor bolts that are capable of resisting at yield strength stress, the bending moment of the shaft at its yield strength stress. Provide removable cast iron covers for the anchor bolts.

The shaft shall be fabricated from material providing a minimum yield strength of 48,000 pounds per square inch after fabrication.

Galvanize the steel poles and hardware in accordance with ASTM A123.

Galvanize all steel and cast iron components, hardware, and threaded fasteners, except anchor bolts, after fabrication in accordance with ASTM A123, or A153 or A385, as applicable.

730.34 Pedestal Support Signal Poles

Provide pedestal poles consisting of one upright pole with suitable base and other accessories or hardware as required to make a complete installation.

All poles shall be made of one continuous piece from top of base connection for the entire height of the pole. The cross-section shall be either cylindrical or octagonal and may or may not be uniformly tapered from butt to tip.

The cross-section at the tip shall have a 4-1/2 inch outside diameter.

A. Type "A" Pedestal (Aluminum)

Pedestals shall be of uniform octagonal or cylindrical cross-section of the tubular tapered type fabricated of one full length sheet.

Bases shall be octagonal or square in shape, of the ornamental type fabricated of cast material. Provide a handhole in each base.

Caps shall be of the nipple or tenon type mounting fabricated of cast material.

Furnish bases with four steel anchor bolts of sufficient size and length to securely anchor the base to the concrete footing. Weld the shaft to the cast metal base. Refer to the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (current edition).

Type A pedestal shaft shall be fabricated from aluminum tubing 6063-T4 heat treated to T-6 temper after fabrication, and meeting ASTM B221.

Type A anchor base shall be made of sand-cast aluminum alloy 356-T6 meeting ASTM B26 - SF 70A-T5 specifications.

B. Type "B" Pedestal (Steel)

Pedestals shall be fabricated from a 4-1/2 inch (outside diameter) seamless steel pipe.

Bases shall be octagonal in shape of the ornamental type fabricated of cast or malleable iron and shall have minimum height of 12 inches. The top opening of the base shall be threaded to receive the shaft. Provide a handhole in each base.

Furnish bases with four steel anchor bolts of sufficient length to securely anchor the base to the concrete footing.

730.35 Wooden Pole Signal Supports

A. General

Provide wooden poles of the class and length shown on the Plans and that meet **917.11**. Set poles to the depth shown on the Plans and fit them with all the necessary hardware to make the installation complete.

The signal head clearance shall be 16 feet 6 inches minimum and 19 feet maximum. Fasten the span wire at least 2 feet below the top of the pole.

B. Guying Components

Guy clamps shall be steel, 3-bolt type, 6 inches in length, and of the proper strand size to fit the wire used. The clamp bolts shall have upset shoulders fitting into the clamp plate. Substitution of the cable grip is subject to the Engineer’s approval.

Attach guy wire to the pole with a 5/8-inch diameter x 12-inch length single strand angle-type eye bolt with 2 x 2 inch square cut washers, lock washer, and square nut.

Instead of the eye bolt specified above, an angle single strand eye of drop forged steel may be used, fastened on threaded end of span wire eye bolt.

Sidewalk guy fittings shall consist of 2-inch inside diameter standard galvanized steel pipe of required length with malleable iron pole plate and guy clamp. Fasten the pole plate to the pole with a 3/8-inch thru bolt and 1/2-inch lag screws.

All guying components and hardware shall be galvanized in accordance with ASTM A123 or A153.

Anchors for guys shall be of the pressed steel four-way expanding fluke type or of the steel or malleable iron sliding plate type. The minimum unexpanded diameter shall be 8 inches, and the minimum expanded area shall be 110 square feet. Coat anchors with a black asphaltic paint.

Guy anchor rods shall be drop-forged steel, 3/4-inch diameter and 7-foot minimum length, threaded, of the single thimble eye type, with a square anchor bolt nut.

730.36 Pole Location

Install all signal support poles at the locations shown on the Plans or where directed by the Engineer.

COMPENSATION

730.37 Method of Measurement

Measurement for traffic signals will be on a per item basis for each item to be furnished and installed, as specified herein and shown on the Plans.

With regard to items for signal head assemblies, each item to be furnished, installed, or both furnished and installed shall be distinguished with a code number as follows:

1. The first digit is the number of faces per assembly.
2. The second digit will indicate the number of 12-inch lenses per assembly (including arrow lenses).
3. The third digit is the quantity of 8-inch lenses per assembly.
4. The letter "A" indicates an arrow lens and the digit following the "A" indicates the number of 12-inch arrow lenses per assembly.
5. The letter "H" or "V" indicates the arrangement of arrow signal lenses to be horizontal or vertical with respect to solid ball indications.
   EXAMPLE:
   1 5 0 A 2 H
   Digits indicate the following:
   1 = one face
   5 = five 12-inch lenses
   0 = zero 8-inch lenses
   A2 = two 12-inch arrow lenses
   H = Arrow lenses placed horizontally with respect to circular indications

A. Removal of Signal Equipment

The Department will measure items of equipment or material designated or required for removal on a per each intersection basis. Removal and salvage of all signal heads, poles, control equipment, cabinets, span wire, cable, and similar features to be performed at an intersection shall be included as a unit cost per each intersection. This includes the cost of stockpiling salvable equipment for pick-up by the appropriate agency, as noted in the Plans.

Signal Head Assembly (includes Pedestrian Signal Heads)

The Department will measure signal heads of the type shown on the Plans by the individual assembly complete in place, per each. This item shall include the signal heads, terminals, lamps, attachment hardware, cable connection, and testing.

Pull Box

The Department will measure each pull box of the type required as one complete unit, installed, per each. This item includes the pull box, excavation, backfilling, crushed stone base, and other incidental items as called for in the Plans or Standard Drawings.

Electrical Service Connection

The Department will measure Electrical Service Connections on a per each signal installation basis. This item includes the electrical service supplied to the weatherhead by the local utility, all necessary materials and labor for connection of the electrical service from the controller to the weatherhead, the wiring of the controller and detectors, and all incidentals necessary to render a complete and operable system.

Signal Cable

The Department will measure the length of Signal Cable of each size (number of conductors) installed in linear feet to the nearest foot from point to point along the routing for each cable.

The Department will make horizontal measurements by center to center measurement from:

1. Pole to pole
2. Pole to signal head (when terminating in a signal head)
3. Pull box to pull box
4. Pull box to pole
5. Pull box to pole-mounted or base-mounted controller

For cable inside mast arms, the Department will measure from center of vertical support to signal head where cable terminates.

The Department will make vertical measurement by one of the following:

1. For cable inside poles or conduit risers, the distance from ground level to the point of attachment of the span wire.

2. For cable inside mast arm supports, the distance from ground level to the mast arm connection.

3. For cable to pole-mounted controller,
   a. From ground level to bottom of controller.
   b. From bottom of controller to point of attachment of span wire.
4. For cable to pole-mounted signal head or pushbutton,
   a. From ground level to bottom of signal head or pushbutton
   b. From bottom of signal head or pushbutton to point of attachment of span wire.

The Department will make no additional allowance for slack length, length inside equipment or supports (except as noted), length for the required 360-degree drip loop, and similar instances requiring additional length of cable.

Span Wire

The Department will measure Span Wire Assembly, Tether Wire Assembly, and Messenger Cable by type in linear feet to the nearest foot. The measurement will be made from center to center of poles. These items include attachment hardware, strain insulators, and other hardware shown in the Plans as part of the assembly. The Department will make no additional allowance for slack length and other instances requiring additional length of wire.

Steel Conduit Riser Assembly

The Department will measure conduit riser assemblies per each for each size conduit riser installed on the outside of a pole, as shown on the Plans. This item includes conduit, weatherhead, condulet, fittings, nuts, washers, banding, clamps, grounding, and other items necessary for installation.

Conduit

The Department will measure conduit in linear feet to the nearest foot for each size and type of conduit installed.

The Department will measure underground conduit along the conduit by one of the following:

1. From the face of curb to the center of a pull box, pole or controller foundation,

2. From center to center of pull boxes,

3. From center to center of a pull box and a pole or controller foundation, or

4. From center to center of pole foundations or pole foundation and controller foundation.

The Department will add:

1. 1 foot to the above measurements for each entry to a pull box or pole foundation and each exit of a pull box or pole foundation.

2. 3 feet to the measurement for each capped extra entry (conduit stub) or exit to a pull box or pole foundation installed, as shown on the Plans.

3. 3 feet to the measurement for each connection between underground conduit and above ground riser.

4. 3 feet to the measurement for each entry or exit to a foundation for a base-mounted controller.

This item includes trenching, backfilling, sealing, capping, fittings, bushings, banding, grounding, and other accessories and hardware required for installation of the conduit system.

Vehicle Loop Detector (Amplifier)

The Department will measure vehicle detector loop amplifier per each unit, including the cable and associated hardware necessary to electrically connect the amplifier to the controller and loop lead in.

The Department will measure two and four channel card rack type amplifiers per each unit, including the cable, card rack(s), and associated hardware necessary to electrically connect the amplifiers to the controller and loop lead-ins.

Shielded Detector Cable

The Department will measure the two-conductor shielded detector cable installed between the controller cabinet and the loop detector wires in linear feet to the nearest foot.

The Department will make horizontal measurements (overhead and underground) by one of the following:

1. From center to center of pull boxes,
2. From center to center of pull box and pole,
3. From center to center of poles, or
4. From center to center of pull box or pole and controller foundation.

The Department will make vertical measurements by one of the following:

1. From ground level to the point of attachment of span wire, inside pole or conduit riser,
2. From the bottom of controller cabinet to the point of attachment of span wire, or
3. From ground level to the bottom of controller.

The Department will make no additional allowance for slack length, length inside equipment or supports (except as noted), splices, and similar instances requiring additional length of cable.

Saw Slot

The Department will measure the length of saw slot for installation of detection loop and lead wiring in linear feet to the nearest foot. Measurement for detection loops in the traffic lanes will be made based on the loop size shown on the Plans (the nominal length plus the nominal width) times 2. The Department will make no additional allowance for saw overruns to obtain full depth of saw slot or diagonal cuts to prevent sharp bends in the loop wire. The Department will measure saw slot for detection loop leads from the conduit entry at the face of curb or edge of pavement and along the route of the lead-in to the detection loop.

This item includes backing rods, or polyethylene foam sealant, loop sealant, and all other incidentals necessary to render a complete and operable system.

Loop Wire

The Department will measure the length of loop wire for installation of detection loops and lead-ins in linear feet to the nearest foot. Measurement will be made from the pull box or pole to the detection loop, around the loop the required number of turns and back to the pull box, pole, or point of splice. The Department will make no additional allowance for slack length, length inside equipment or supports, splices, and similar instances requiring additional length of wire.

This item includes electrical connections, testing, and all other incidentals necessary to render a complete and operable system.

Controller

The Department will measure controllers as one complete unit, installed, per each. This item includes all auxiliary equipment shown the Plans to provide signalization control as shown on the Plans, and all hardware, including the cabinet (and cabinet foundation, if base-mounted), necessary for installation.

Wood Pole

The Department will measure Wood Poles, of the type and size shown on the Plans, per each, installed.

Guying Device

The Department will measure Guying Devices, of the type shown on the Plans, per each, installed. This item includes the guy wire, anchor, clamps, and all other components shown on the Plans necessary for installation.

Steel Strain Pole

The Department will measure Steel Strain Poles of the type and size shown on the Plans, per each, installed. This item includes the pole, foundation, anchor bolts, grounding, and all other hardware shown on the Plans necessary for a complete installation.

Cantilever Signal Support

The Department will measure Cantilever Signal Supports, of the type and size shown on the Plans, per each, installed. This item includes the vertical pole shaft, mast arm, foundation, anchor bolts, grounding, and all other hardware shown on the Plans necessary for a complete installation.

Service Cable

The Department will measure two conductor power service cable, of the type and size shown on the Plans, in linear feet to the nearest foot, installed. Horizontal runs will be measured center to center of poles. Vertical runs will be measured from the ground to the weatherhead inside a pole or conduit riser, or from the ground to the bottom of the controller, or from the bottom of the controller to the weatherhead. This item includes all necessary attachment hardware. The Department will make no additional allowance for slack length or other instances requiring additional length of cable.

Pedestrian Pushbutton with Sign

The Department will measure Pedestrian Pushbutton with Sign as one complete unit, in place, per each. This item includes the pushbutton, sign, mounting hardware, wiring of pushbutton, testing, and all other incidentals necessary for a complete installation.

Pedestrian Signal Display with Pushbutton and Sign

The Department will measure Pedestrian Signal Display with Pushbutton and Sign as one complete unit, in place, per each. This item includes the signal heads, terminals, lamps, cable connections, pushbutton, sign, all attachment hardware, testing, and other incidentals necessary for a complete installation.

Portable Traffic Signal

The Department will measure Portable Traffic Signal, of the type shown on the Plans or as directed by the Engineer, per each, installed. This item includes the all of the software and hardware necessary for a complete installation.

730.38 Basis of Payment

The Department will pay for accepted quantities, complete in place, at the contract prices as follows:

Item	*Pay Unit*
Traffic Signal	Lump Sum
Removal of Signal Equipment	Each
Signal Head Assembly (Description)	Each
Install Pull Box (Description)	Each

Electrical Service Connection	Each
Signal Cable – (Description)	Linear Feet
Span Wire Assembly (___ pounds min. break strength)	Linear Feet
Tether Wire Assembly – __" Diameter	Linear Feet
Messenger Cable – __" Diameter	Linear Feet
Riser Assembly (Description)	Each
Conduit __" Diameter (Type)	Linear Feet
Vehicle Detector (Description)	Each
Shielded Detector Cable	Linear Feet
Saw Slot	Linear Feet
Loop Wire	Linear Feet
Controller (Description)	Each
Wood Pole (Description)	Each
Guying Device (Description)	Each
Steel Strain Pole (Description)	Each
Cantilever Signal Support (Description)	Each
Service Cable	Linear Feet
Pedestrian Pushbutton with Sign	Each
Pedestrian Signal Display with Pushbutton and Sign	Each
Portable Traffic Signal (Type)	Each

The unit price to be paid includes the cost of furnishing and installing, complete in place, each of the various types of equipment required by the Summary of Quantities shown on the Plans. Total payment is full compensation for all materials, labor, equipment, and incidentals necessary to produce a completely operative and finished installation of a traffic signal or traffic signal system as shown on the Plans and as specified herein, including restoration of pavements, sidewalks, and appurtenances damaged or destroyed during construction and tests. All additional materials and labor not specifically shown or called for, which are necessary to complete the traffic signal installation or traffic signal system described, will be considered incidental to the system and no additional allowance will be made.