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CONNECTICUT ADVANCED TRAFFIC SIGNAL SYSTEMS OPERATION & MAINTENANCE GUIDELINES

FHWA

CONNECTICUT DEPARTMENT OF TRANSPORTATION

CAPITOL REGION COUNCIL OF GOVERNMENTS

Prepared as a collaborative effort between the Connecticut Department of Transportation (CTDOT) and the Capitol Region Council of Governments (CRCOG). The opinions, findings and conclusions expressed in this publication are those of CTDOT and CRCOG, and do not necessarily reflect the official views or policies of the U.S. Department of Transportation. The document is intended for use by any interested party in the State of Connecticut.

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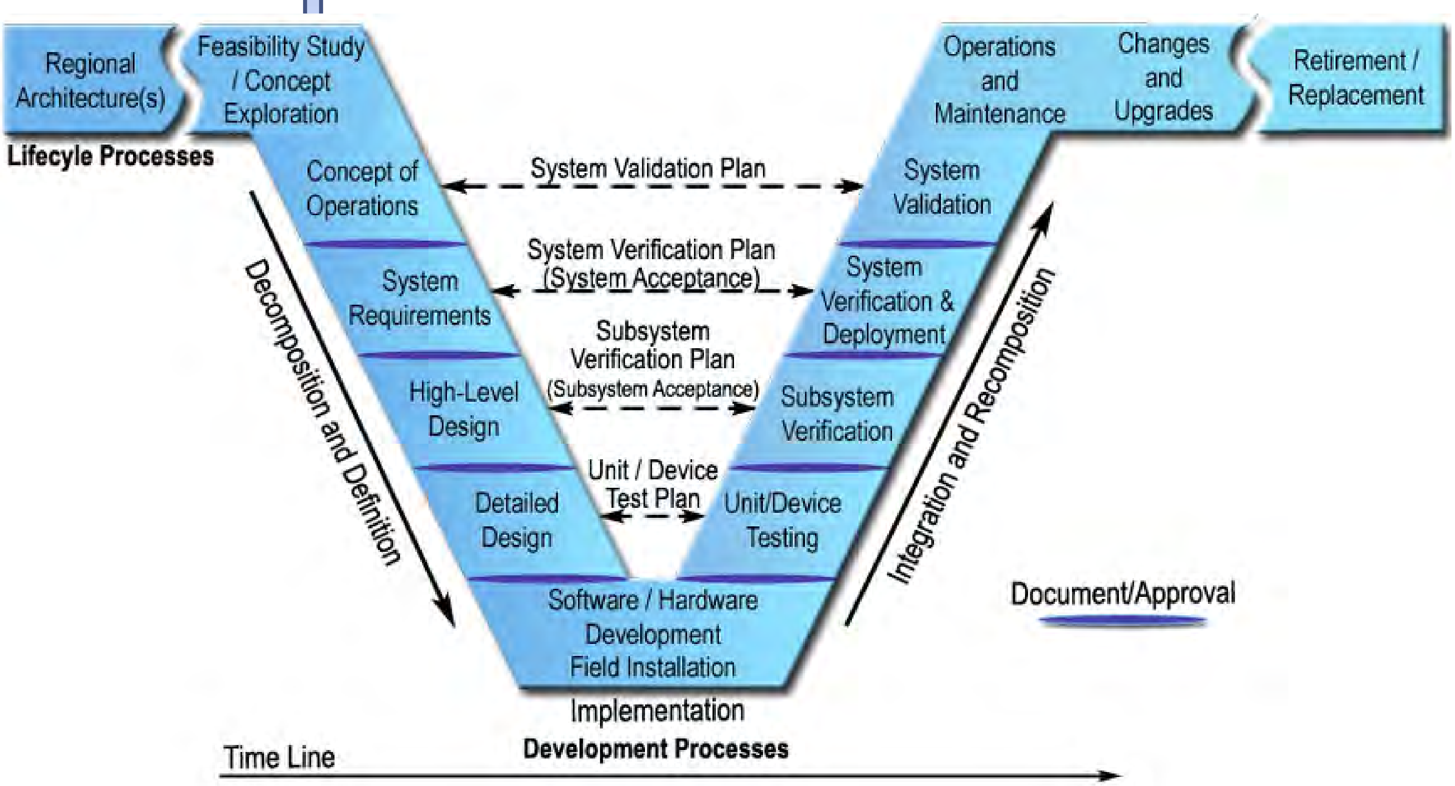
Executive Summary

In order for agencies to receive Federal funding for traffic signal projects, Title 23 of the Code of Federal Regulations requires that the Systems Engineering (SE) process be followed. Systems engineering is a process used to successfully construct, implement, and maintain a system. It is used to ensure that the right system is built, on time and within budget, while considering how it will be operated over its life cycle. In a nutshell, the SE process ensures that the user can figure out what they need, and get what they pay for. When using federal funds to deploy advanced signal systems in Connecticut, adherence to the SE process is only demonstrated through development and approval of the ConnDOT/FHWA SEAFORM.

The positive benefits of the systems engineering process make it a prudent undertaking in any advanced signals deployment, regardless of the source of funding for the project. Systems engineering is not only a valuable tool to ensure that the right system is implemented, but it also provides an opportunity to garner support from all stakeholders, and to examine how the implementation should interact with other systems and fit into any broader, regional plans.

The diagram below shows the "V" model, which shows different steps in the SE process. This handbook walks the user through each one of these steps, relates the steps to various sections of the SEAFORM, and guides the user to successful submission of the SEAFORM.



Systems Engineering V Diagram

This handbook discusses the systems engineering process within the specific context of advanced/computerized traffic signal systems. It is intended to be used by agencies responsible for advanced traffic signal systems, which includes the planning, design, construction, operations and maintenance of traffic signal systems. The following list discusses sections within the handbook, which correspond to steps within the "V" diagram.

- Regional ITS Architecture – The first step of an advanced signals project requires formation of a stakeholder group. The stakeholder group must identify the portion of the regional and statewide ITS architecture that is applicable to the traffic signal system project. The statewide ITS architecture for CT has already been completed and is located here http://www.consystec.com/ct/web/_regionhome.htm. The Hartford Area ITS architecture is located here http://www.consystec.com/hartford/web/_regionhome.htm. If the project does not conform to the architecture, the group must advise ConnDOT so that the architecture can be updated. The group must also assess its capabilities in order to determine if external consultant assistance will be needed.

- Feasibility Study/Concept Exploration –Next, the stakeholder group must identify the current problem and perform a needs assessment. By identifying needs, alternatives can be evaluated and the most viable alternative can be selected. For advanced signals systems, thorough needs *must* be established if federal funding will be used. Routine replacement or repair of existing systems does not constitute a need.

- Concept of Operations – Once an alternative is selected, a Concept of Operations (ConOps) must be created that documents answers to the following questions:
  - Who are the stakeholders?
  - What are the high-level capabilities of the system?
  - What are the geographic and physical extents of the system?
  - When and in what order do operations take place?
  - Why is the system proposed?
  - How will the system be procured?
  - How will the system be maintained and operated?

- System Requirements – Using the needs that were initially established by the stakeholders, requirements must be developed that will be used to verify that the traffic signal system is built correctly.

- System Design – Once the ConOps is created and system requirements are developed, preliminary design can occur. Once the preliminary design has been reviewed and approved, specifications can be made for individual components.

- Software/Hardware Development – Once design is complete, commercial off-the-shelf products can be procured and custom hardware/software can be developed, if needed. The components must then be tested to ensure they meet specifications.

- Integration and Verification – After the individual components are acquired, they can be integrated, step-by-step. After each integration step, the sub-system must be verified against system requirements to ensure the correct system is being developed. The sub-systems are integrated until the project is integrated into the existing traffic signal system.

- Initial Deployment – Once the system is fully integrated, the agency can obtain ownership, and after a startup period, can accept the system.

- System Validation – After the traffic signal project is accepted, it should be reviewed to determine if the completed system meets the original needs of the stakeholder group. Performance should routinely be measured throughout the life of the traffic signal system.

- Operations and Maintenance – The traffic signal project must be operated and maintained as part of the existing traffic signal operations and maintenance program. If changes or upgrades need to be made, the systems engineering process should be followed.

- Retirement/Replacement – Once the traffic signal system reaches the end of its useful life, it must be retired. Equipment must be properly disposed and lifecycle costs should be compared with what was projected at the start of the project.

The handbook summarizes the systems engineering process by including a reference checklist to be used to help tailor the SE process to individual traffic signal projects. The handbook concludes with a chapter of resources on systems engineering, traffic signal management, training and standards and regulations. Managerial staff should refer to the checklists as “quick reference guides” to systems engineering. If all aspects of the SE process are thoroughly considered, then completion of the SEAFORM becomes a simple documentation procedure. If used properly, this handbook will assist advanced computerized traffic signal system implementers to complete the SEAFORM and apply for any highway trust funding.

Introduction

The following document provides guidance on the planning, design, construction, operations, and maintenance of traffic signal systems. It is intended to be used by agencies that own and maintain traffic signal systems. In addition, the guide is intended to promote consistency with Connecticut Department of Transportation (CTDOT) signal requirements and Federal Highway Administration (FHWA) requirements for Systems Engineering (SE) processes and traffic signal operations. These requirements must be followed in order to receive Federal funding for a traffic signal project. Specifically, the following sections of Title 23 of the Code of Federal Regulations (CFR) must be followed to receive Federal aid for implementing transportation systems, including traffic signal systems:

- Part 655 (Traffic Operations), Subpart D (Traffic Surveillance and Control), Section 655.409 (Traffic Engineering Analysis)
- Part 655 (Traffic Operations), Subpart F (Traffic Control Devices on Federal-Aid and Other Streets and Highways), Section 655.607 (Funding)
- Part 940 (Intelligent Transportation System Architecture and Standards), Section 940.11 (Project Implementation).

Part 940 states that the need for all Intelligent Transportation System (ITS) projects, including traffic signals, which use Federal funding, must be based on a systems engineering analysis. SE is an interdisciplinary approach used to successfully construct, implement and maintain a system. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, designing and validating the system while considering the entire issue at hand and maintaining the system throughout its useful life. With respect to traffic signal systems, an important part of maintaining the system includes regular traffic signal retiming to maintain the safe and efficient transfer of right-of-way between complementary and competing traffic demands at intersections.

In short, systems engineering is used to ensure the right system is built, on time and within budget, while considering how the system will be operated over its life cycle.

SE analysis for ITS projects require:

1. Identification of portions of the Regional ITS Architecture being implemented
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
7. Procedures and resources necessary for operations and management of the system.

To ensure ITS projects in Connecticut are conforming to 23 CFR Part 940, CTDOT and FHWA created the *Systems Engineering Analysis Form (SEAFORM)*, which is located in Appendix A. The form contains prompts to verify that the project is being developed according to the systems engineering process. The form should be completed as early as possible in the project cycle and must be approved by FHWA in order for funding to be released for the project.

The V Diagram

Many agencies already perform some form of systems engineering process for projects, but it may not be formalized. In order to standardize SE for ITS projects, the “V” or “Vee” model is the recommended development model for ITS projects. The V model is shown in the illustration on the following page.

As shown in the V, the SE approach defines project requirements before technology choices are made and the system is implemented. On the left side of the V, the system is defined and broken into components that can be built or procured. The bottom of the V is the construction and procurement of components. The right side of the V integrates the components into sub-systems and then into the final system.

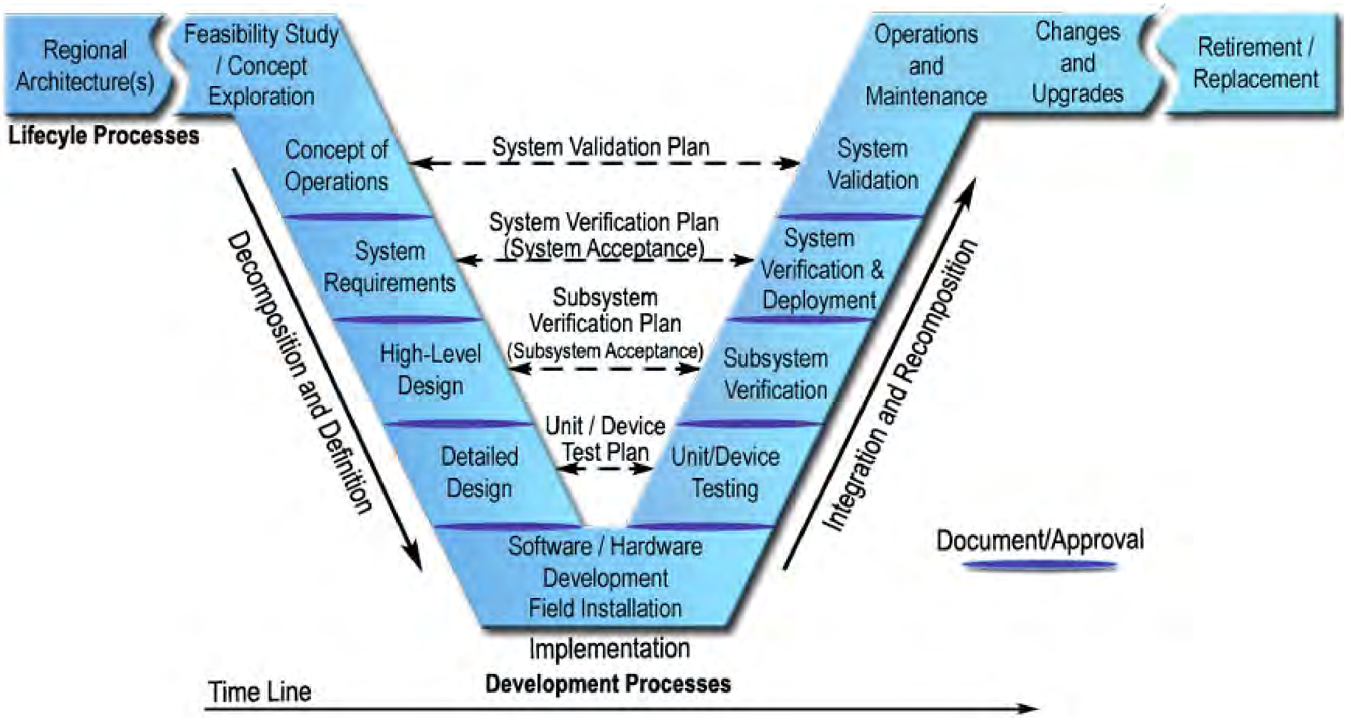
One noticeable aspect of the V model is that items on the left side are related to items on the right. Arrows illustrate the connections between the items, showing how system definition and requirements that are produced on the left hand side of the V are used to verify the actual system on the right. For example, the user needs and performance measures included in the Concept of Operations are the basis for the System Validation Plan used to validate the system at the end of the project deployment.

The connections provide continuity throughout the process and ensure the project is developed while focusing on completion from the beginning. Focusing on the completion of the project throughout the project development is a core SE principle.

Most steps in the V diagram require documentation and approval. The output of the previous step is reviewed and the project team determines whether the project can move on to the next step in the diagram. The project can only move forward if the criteria for that decision have been satisfied. It is good practice to have stakeholders sign signature pages for each approval step to ensure that the document was reviewed and approved by the stakeholders. Since the SE process requires thorough documentation, a library should be established to house all project documentation, including:

- Feasibility studies
- Concept of Operations document
- System Requirements document
- Design documentation (e.g., traffic signal construction plans)
- Software and hardware manuals
- Testing plan
- System verification plan
- System validation plan
- Performance measurement data (e.g., travel time data)
- Stakeholder approval for each step in the V diagram
- Updates to the system after it is deployed (e.g., if a traffic signal is retimed, signal timing sheets must be updated)
- Maintenance records
- Personnel certifications and training documents.

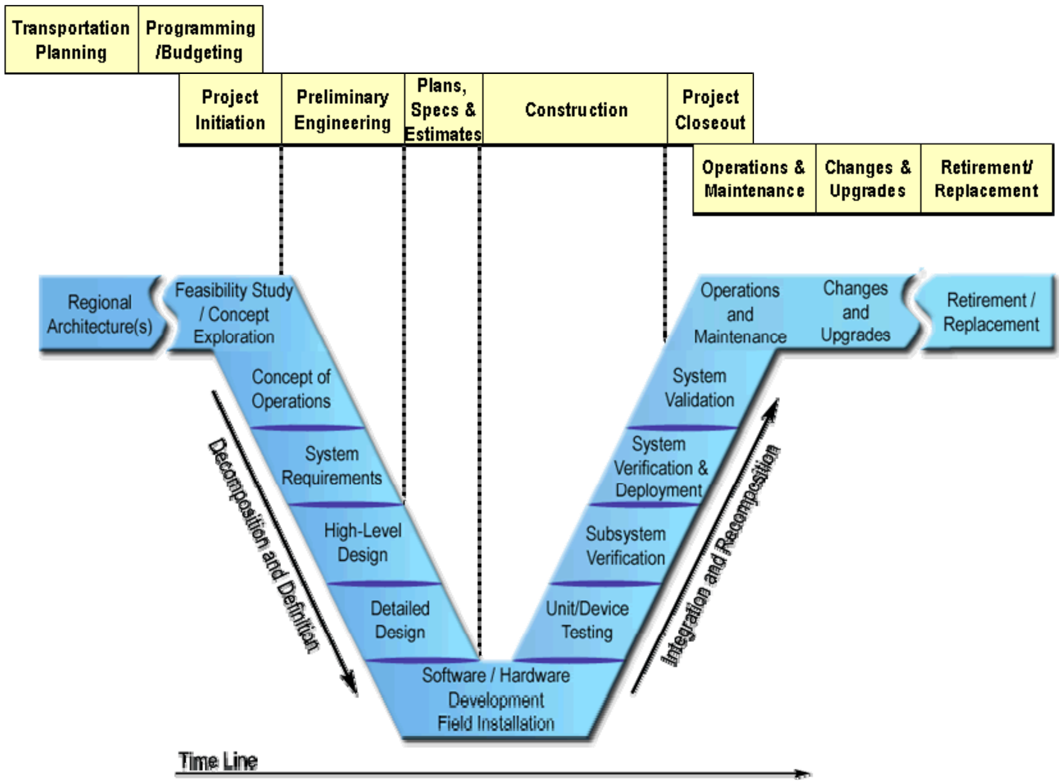
Systems Engineering V Diagram



While the V diagram and SE process may seem complicated and cumbersome, they are designed to ensure successful project developments. In addition, the SE process can be tailored to fit each project. The amount of systems engineering performed should be commensurate with the project scope and complexity. For example, the installation of a new, isolated traffic signal will require less systems engineering than the installation of an adaptive signal system along a corridor. Still, the SE process should be followed for both projects. Furthermore, the SE process should be "right sized" in terms of the documentation steps followed as well. For straightforward, non-complex projects, the SE process, which is comprised of discrete steps in the V diagram, can be combined into a single systems engineering report that addresses each of the steps. For complex projects such as full scale deployment of adaptive signals on an entire corridor, individual documents may be required for each of the steps in the V.

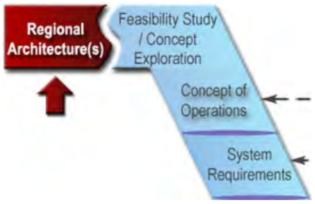
The following figure shows how the V diagram correlates with the traditional transportation project development process.

Relationship between Systems Engineering and Traditional Project Development Process



The table on the following page presents the layout of the rest of this guide.

Section	Description
Regional ITS Architecture	Each section discusses phases of the V diagram and includes considerations that must be made in order for a traffic signal project to follow the systems engineering process. In order to facilitate proper completion of the SEAFORM, each section in this guide that discusses the V diagram phases is related to the appropriate section of the SEAFORM.
Feasibility Study / Concept Exploration	
Concept of Operations	
System Requirements	
System Design	
Software / Hardware Development	
Integration and Verification	
Initial Deployment	
System Validation	
Operations and Maintenance	
Retirement / Replacement	
Traffic Signal Systems Engineering Checklist	This section provides a checklist to streamline the systems engineering process for traffic signal projects. If followed meticulously and properly completed, the checklist will guide practitioners to successful application for federal funding.
Resources	This section provides a list of local and national resources related to systems engineering, regulations and standards, traffic signals and training opportunities.
Appendix A: ITS Projects – Systems Engineering Analysis FORM (SEAFORM)	Appendix A includes a copy of the SEAFORM.
Appendix B: Traffic Signal Operations and Maintenance Program Considerations	Appendix B provides a list of items for agencies to consider for traffic signal operations and maintenance programs.



Regional ITS Architecture

Regional and statewide ITS architectures are the extension of the National Architecture developed from the requirements contained in 23 CFR 940. ITS architectures are meant to identify technological concepts for managing transportation systems, and describe the data flows between these technologies and their stakeholders. While the national ITS architecture does this on a broad, country-wide basis, the regional architectures extrapolate the national, and describe local and regional-specific technological concepts. Connecticut is covered by two architectures – a statewide architecture and an architecture specific to the Hartford Area. The statewide ITS architecture for CT is located here http://www.consystec.com/ct/web/_regionhome.htm. The Hartford Area ITS architecture is located here http://www.consystec.com/hartford/web/_regionhome.htm. In the event of a conflict or variation between architectures, ConnDOT and FHWA shall determine the best course of action. Refer to FHWA regulations for modifying the architecture.

The first step in the systems engineering process is to determine how the traffic signal project will fit within the context of the relevant statewide or regional ITS architecture. The ITS architecture provides a basis for planning and programming all ITS projects within the designated area. Specifically, the architecture:

- Provides a list of appropriate stakeholders
- Inventories ITS elements
- Shows how ITS elements are interconnected
- Defines what information is exchanged between the ITS elements.

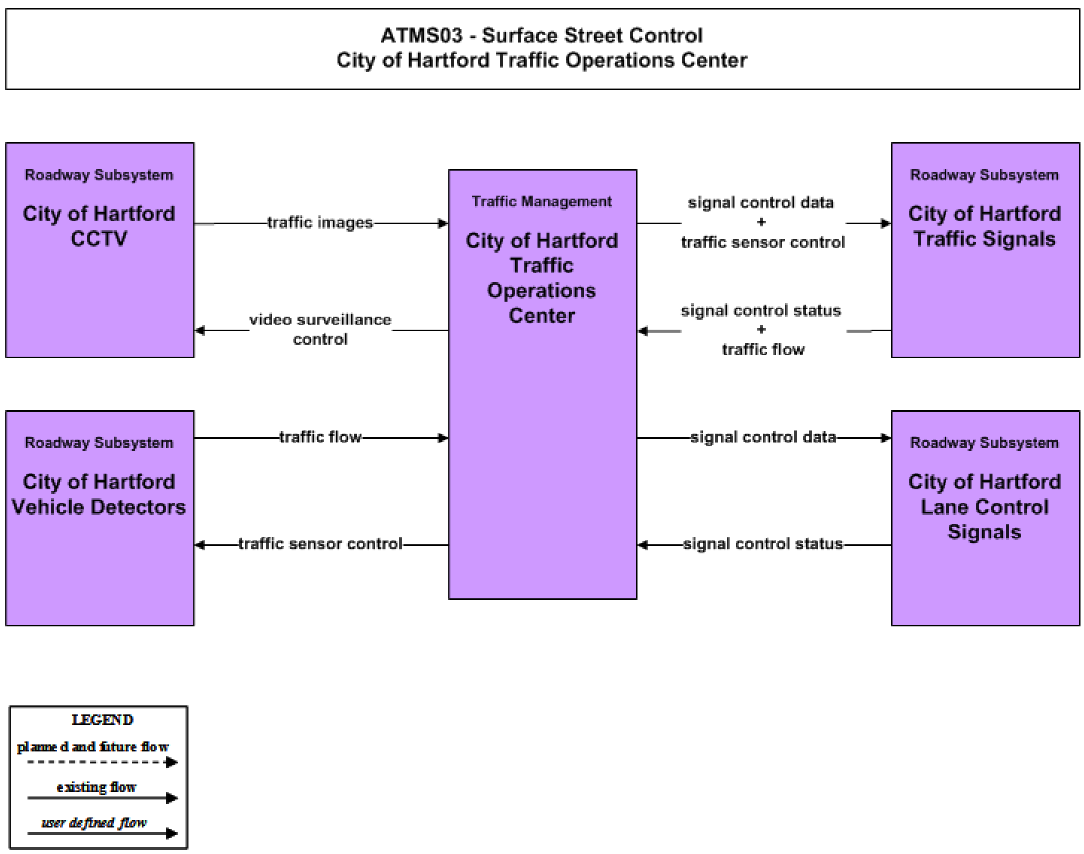
The example figure on the next page shows how different ITS elements are connected and what information is exchanged as part of surface street traffic control within Hartford.

Referring to the relevant ITS Architecture is the first step in the systems engineering process because it can be used as a tool to broadly define a traffic signal project. Using the architecture will promote consistency with other systems in the area and helps form the stakeholder group for the project. From the architecture, the stakeholders relevant to the project can be identified.

Identifying stakeholders is an important first step in developing a successful traffic signal project. Project stakeholders are those who will own, operate, maintain, use, interface with, benefit from or be affected by the system. Stakeholder involvement is critical throughout the development and life-cycle of the signal project. Without effective stakeholder involvement, the systems engineering and development team will not gain the insight needed to understand the key issues and needs of the system's owner and stakeholders. This increases the risk of not getting a valid set of requirements to build the system or to obtain buy-in on changes and upgrades. Possible stakeholders include:

- Regional councils of governments
- CTDOT
- Local law enforcement
- Transit agencies
- School districts
- Local fire departments
- Emergency medical services
- Other first response personnel
- Local business organizations
- Public officials
- General public
- Adjacent municipalities.

Example Surface Street Control Portion of the Hartford Area Regional ITS Architecture



Even if the regional architecture does not require a certain stakeholder for a traffic signal project, it can be beneficial to include optional stakeholders to collaborate on the project and create opportunities to cost-share.

At this point, project stakeholders should decide how to proceed throughout the rest of the V model phases, particularly with respect to deciding what steps can be performed in-house and what steps should be performed by consultants. For complex SE projects, it may be beneficial to contract a project manager with systems engineering experience who will oversee the entire process.

Any person who has a major role in one of the V model phases should be available throughout the duration of the project. In particular, component designers should be available for consultation during system integration and deployment. For example, a traffic engineer who develops the construction plans for an adaptive traffic signal system may need to be consulted during construction to clarify any questions the contractor may have.

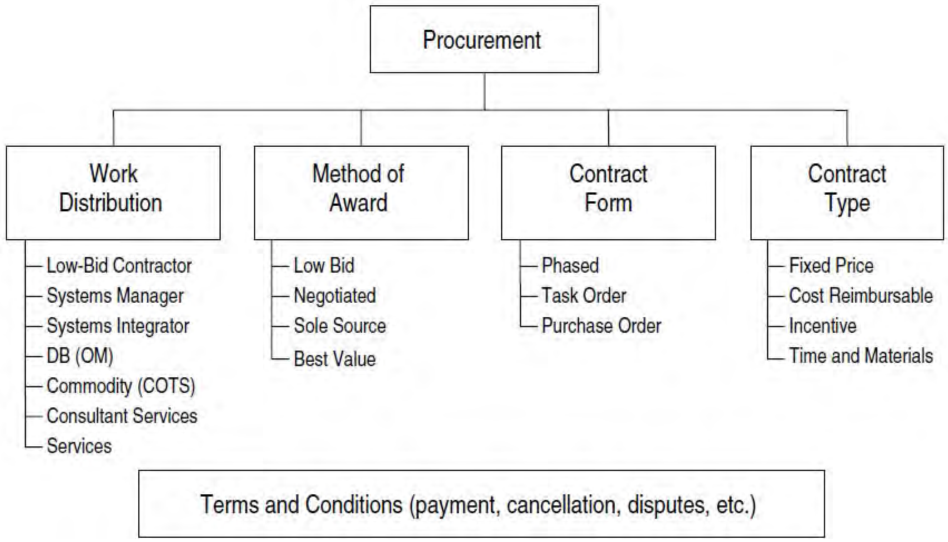
At the onset of a project it is commonly helpful to consider the options available to procure the system. Procurement can cover many aspects of an ITS implementation, from design to construction to inspection of the system.

Federal regulations state that construction contracts must be awarded based on the lowest responsive bidder, while non-construction contracts must be awarded through competitive procurement (not necessarily lowest bidder). Traffic signal projects are construction projects if there is a physical installation. If the project involves software development or integration of devices to a central center or communication system, then it is non-construction. So if a traffic signal support must be replaced because it was struck in a traffic accident, it would be a construction project. If software must be procured for closed loop central software, it is a non-construction project.

For non-construction projects, competitive procurement is satisfied as long as different options are evaluated with respect to how well each option satisfies the requirements (discussed later). This evaluation can include consideration of cost to determine best value for money. In many cases, it may be appropriate to procure through a “request for proposal” process.

NCHRP Report 560 – Guide to Contracting ITS Projects is a useful resource for procurement because it presents a decision model to help identify the most appropriate procurement options for traffic signal projects. It discusses the four aspects of the procurement process – work distribution, method of award, contract form and contract type. This guide will also be useful later in the SE process, when actual components must be purchased.

The Four Aspects of Procurement



This may be early in the project life cycle to think about procurement, but the systems engineering process defines the procurement approach, rather than permitting the procurement approach to define the systems engineering process.

Feasibility Study / Concept Exploration

Once the traffic signal project is broadly defined in relation to the regional ITS architecture, a feasibility study must be performed. During this stage, the stakeholders identify the problem and document their needs for the project, fundamentally different concepts are studied and the most viable alternative is selected.

In order to complete Section 2 of the SEAFORM, a needs assessment must be performed. The purpose of a needs assessment is to state the problem with the current situation and identify needs that the traffic signal project will address. In general, a need is a gap between a current condition and a desired condition. Needs must be well-defined and based on objectives, because the needs identified in this step will drive the requirements of the project. Identifying needs is a crucial step in the SE process, because if needs are not properly identified the SEAFORM will be rejected by FHWA.

Table 1.1 of *Traffic Signal Operations and Maintenance Staffing Guidelines* identifies some common objectives for traffic signal projects. Examples include:

- Reduce delay and fuel consumption for normal traffic patterns along an arterial.
- Provide transit priority along a corridor.
- Reduce rear-end crashes at an intersection.
- Serve as a diversion route during traffic incidents.

These objectives can be used to help define the needs of the traffic signal project. An example of a well-defined need is:

- Reduce delay, emissions and fuel consumption for normal traffic patterns by retiming the traffic signals and improving traffic signal operation through upgraded traffic signal equipment, such as detection.

Once the needs are identified, clarified, and documented, they can be validated by the group. If some stakeholders have conflicting needs, the needs must be prioritized. After the needs are agreed upon, the stakeholders should work together to identify constraints that will limit the acceptable alternatives. Identifying constraints can help simplify the selection of alternatives. Common constraints include limited financial resources, institutional constraints (e.g., agency-required standard specs) and legacy constraints (e.g., interoperability with older equipment).

Next, the stakeholder group should define criteria used as a basis to evaluate the alternatives. Evaluation criteria should, at a minimum, consider the following of each alternative:

- technical benefits
- initial costs
- operations and maintenance requirements and costs

- operational feasibility
- design life and
- economic impact.

In accordance with Section 4 of the SEAFORM, viable alternatives are studied and compared using the evaluation criteria. The "do nothing" alternative should always be examined to provided a baseline for comparison with the other alternatives. During this assessment, a preliminary risk analysis should also be performed to identify potential issues that may negatively affect the project.

Using the evaluation criteria, the stakeholders should select the most viable alternative to move into development. The most viable alternative is the alternative with the highest benefit compared to the estimated cost. This process selects the best business case for development and provides a basis for stakeholder buy-in. While a quantifiable cost benefit ratio is not always necessary, every project should, at a minimum, be justified by a qualitative analysis of the costs and benefits.

Once the preferred alternative is selected, the regional ITS architecture should be revisited to confirm how the project fits within the architecture. Once it is confirmed how the ITS architecture is related to the traffic signal project, Section 3 of the SEAFORM can be completed.

Just as the systems engineering process must be right-sized to fit the project, the level of effort behind a feasibility study should be commensurate with the complexity and size of the project. At a minimum, the final feasibility study document should include:

- A description of the problem or opportunity the project is intended to address. For traffic signal projects, this includes an inventory of existing conditions, including relevant photographs, current traffic volumes and projected traffic volumes, as needed.
- Stakeholder needs/project objectives
- Analyses of each alternative and the reasons for rejecting each alternative that was not selected
- A summary description of the selected alternative
- An analysis of how the project will be funded and life-cycle costs and benefits of the project compared to the "do nothing" alternative.

When exploring concepts for a new project, it is appropriate to identify sources of funding. There are several Federal-aid programs that can be used as funding sources for ITS projects, including traffic signal systems. *A Guide to Federal-Aid Programs and Projects* is a document produced by FHWA that provides basic information about the Federal-aid programs. Some programs that may be applicable to traffic signal projects include:

- 100% Federal Share For Safety ("G" Matching Ratio) – States may use up to 10% of their total Federal-aid apportionments at a 100% Federal share for certain safety activities.
- • Congestion Mitigation And Air Quality Improvement Program (CMAQ) – The CMAQ program supports transportation projects that improve air

quality and reduce traffic congestion. Generally, the Federal share for CMAQ projects is 80%; however, in Connecticut traffic signal projects are sometimes financed with 100% federal funds.

- Safe Routes To School (SRTS) – Infrastructure-related projects that substantially improve the ability of students to walk and bicycle to school could be eligible for 100% Federal share of funding. This includes pedestrian crossing improvements at signalized intersections.
- Surface Transportation Program (STP) - Urban – The STP-Urban program provides funds for projects not on the Interstate System or the National Highway System (NHS). The funds are intended to benefit minor arterial and collector roads in urban areas.
- Transportation, Community, and System Preservation (TCSP) Program – The TCSP program provides funds for planning, developing and implementing strategies to integrate transportation, community, and system preservation plans and practices.

Concept of Operations

The purpose of the Concept of Operations (ConOps) step is to clearly convey a high-level view of the system to be developed, so that it is easily understood by others. It is the initial definition of the system and sets the technical course for the project. A good Concept of Operations plan answers who, what, where, when, why, and how questions about the system from the viewpoint of each stakeholder.

- Who are the stakeholders involved with the project?
- What are the elements and high-level capabilities of the system?
- Where are the geographic and physical extents of the system?
- When, and in what order, do specific system operations take place?
- Why is the system being proposed? What is the existing problem or opportunity that will be addressed?
- How will the system be developed, operated and maintained?

The ConOps documents the way the envisioned system is to operate and how the envisioned system will meet the needs and expectations of the stakeholders. While expectations for the system will change over time, the performance measures outlined in the ConOps force early consideration and agreement of how system performance and project success will be measured. Again, Table 1.1 of *Traffic Signal Operations and Maintenance Staffing Guidelines* can be used to identify performance measures. Some examples include:

- Vehicle-hours of delay reduced
- Number of crashes reduced
- Number of public complaints reduced.

These performance measures provide a foundation for the System Validation Plan, a document used during the system validation step. Validation ensures that the right system was built.

For a simple traffic signal project, the ConOps document may only be a few pages long. In addition, each new project many not necessarily require a new ConOps. For example, if a ConOps has been written for an existing interconnected traffic signal system, and a project is adding a traffic signal to that system, the existing ConOps can be used in most cases. If a new Concept of Operations must be written, Section 8.4.5 of the *Systems Engineering Guidebook for ITS (Version 3.0)* provides an example template. In any case, a ConOps needs to be identified/created to complete Section 5 of the SEAFORM.

At this point in the process, the procurement method for the system should have been identified and documented within the ConOps.

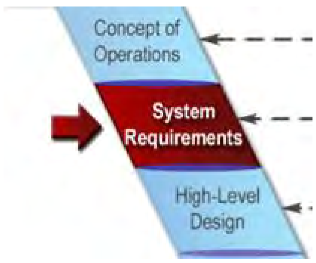
Example Concept of Operations Template

Section	Explanation
1 – Purpose of Document	This section is a brief statement of the purpose of the document. In one or two paragraphs, describe the contents, intention and audience.
2 – Scope of Project	This section gives an overview of the traffic signal project. It includes the purpose of the project and a high-level description of the system.
3 – Referenced Documents	This section is used to list any supporting documentation. It can include the feasibility study from the previous section and any transportation plans.
4 – Background	This section is a description of the current situation. It is intended to provide reasons and justification for the project.
5 – Concept for the Proposed System	This section begins with a list of the alternatives that were explored as part of the feasibility study. This leads into the justification for the selected approach and a high-level, conceptual, operational description.
6 – User-Oriented Operational Description	This section describes the stakeholders and identifies the users of the system. It covers when, and in what order, operations take place, personnel capabilities, organization structures, personnel and agency interactions and activities.
7 – Operational Needs	This section is a description of the vision, goals and objectives, and personnel needs that drive the system requirements. Specifically, this section describes what the system needs to do that it is not currently doing.
8 – System Overview	This section provides an overview of the system to be developed. This describes its scope, the users of the system, what it interfaces with, its states and modes, the planned capabilities, its goals and objectives, and the system architecture. It provides a structure for describing the operations, in terms of where the operations will be carried out, and what the lines of communication will be.
9 – Operational Environment	This section describes the physical operational environment in terms of facilities, equipment, computer hardware, software, personnel, operational procedures and support necessary to operate the finished system. For example, it will describe the personnel in terms of their expected experience, skills and training, typical work hours, and other activities that may be performed concurrently.
10 – Support Environment	This section describes the current and planned physical support environment. This includes facilities, utilities, equipment, computing hardware, software, personnel, operational procedures, maintenance, and disposal. This includes expected support from outside agencies.

Section	Explanation
11 – Operational Scenarios	This section describes different operation scenarios - a sequence of events, activities carried out by the user, the system, and the environment. It specifies what triggers the sequence, who or what performs each step, when communications occur and to whom or what, and what information is being communicated. Multiple operational scenarios must be described, and in each case the description must be from the perspective of the key stakeholder of the system. The scenarios need to cover normal conditions, stress conditions, failure events, and maintenance. This section stresses the importance of each stakeholder knowing what their expected roll will be.
12 – Summary of Impacts	This section provides an analysis of the proposed system and the impacts on each of the stakeholders. It also includes any constraints on system development and metrics for assessing system performance.

The following is a list of references and example ConOps that may be of use:

- The City of Scottsdale, Arizona, publishes a well-written, straightforward description of the City's traffic signal system, which describes elements of the system and how the system is operated. This is a basic ConOps that describes the overall traffic signal program for the City of Scottsdale. It is very good practice for all agencies that own and maintain traffic signals to have this sort of ConOps to establish a vision for their traffic signal program.
- USDOT has published a generic Concept of Operations for Integrated Corridor Management, which includes arterial signal systems.
- Virginia DOT Northern Region Operations Vehicle Detector Concept of Operations.
- Philadelphia Traffic Operations Center ConOps.
- *Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems* provides guidance for writing the required systems engineering documents for adaptive signal projects. Appendix B includes sample statements and prompts that can be used to assist in writing a ConOps for any traffic signal project.
- Georgia DOT Regional Traffic Operations Program Concept of Operations.
- Minneapolis Traffic Management Center Upgrade and ITS Enhancements ConOps.
- Minnesota DOT has a standard Concept of Operations for a standard traffic signal with optional features including railroad preemption, transit signal priority and traffic signal coordination.



System Requirements

The ConOps forms the basis for the System Requirements phase. During this phase, the stakeholder needs from the ConOps document are transformed into verifiable requirements.

System requirements define what the system must do, how well the system must perform its functions and under what conditions the system must operate. Note that this step does not dictate how the system will accomplish these requirements. Good system requirements should be necessary, testable, clear, concise, technology-independent, feasible and stand-alone.

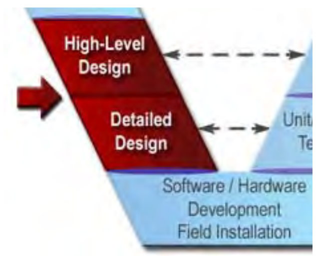
Each requirement should be traced back to an associated stakeholder need so that the system requirements can be used to create a verification plan. A verification plan is used to verify the system in a later phase. Verification ensures that the system was built correctly.

Section 8.4.6 of the *Systems Engineering Guidebook for ITS (Version 3.0)* provides an example template for a System Requirements document. The Systems Requirement document is used to complete Section 6 of the SEAFORM.

Example System Requirements Template

Section	Explanation
1 – Scope of System or Sub-system	This section provides an overview of the system.
2 – Reference	This section identifies all needed standards, policies, laws, concepts of operation, feasibility study documents and other reference material that supports the requirements. One requirement for all traffic signal projects is that design plans must be stamped by an engineer with a Professional Engineering license in Connecticut. Common standards for traffic signal projects include: • Manual on Uniform Traffic Control Devices • CTDOT Traffic Control Signal Design Manual • CTDOT Traffic Engineering Standard Drawings • CT DOT Functional Specifications for Traffic Control Equipment • National Transportation Communications for Intelligent Transportation System Protocol (NTCIP)
3 – Requirements	This section contains the requirements of the system: • Functional requirements – what the system must do • Performance requirements – how well the requirements should perform • Interface requirements – definition of the interfaces • Data requirements – data elements and definitions of the system • Non-functional requirements such as reliability, safety and environmental • Enabling requirements such as training • Constraints
4 – Verification Methods	This section must identify one way each requirement will be verified. Requirements can be verified in one of four ways: • Test – the requirement is verified using an external piece of test equipment (e.g., volt meter) • Demonstration – the system demonstrates the requirement • Inspection – the requirement is verified through visual inspection against a standard • Analysis – the requirement is verified through a logical conclusion or mathematical analysis of a result
5 – Supporting Documentation	This section is a catch-all for material that may add to the understanding of the requirements.
6 – Traceability Matrix	This section includes a table that traces each requirement back to user needs.

It should be noted that adhering to the National Transportation Communications for ITS Protocol (NTCIP) communications standards for traffic signal projects is a best practice. By ensuring the equipment follows NTCIP, components procured from different manufacturers are interchangeable and system owners do not have to depend on proprietary equipment. When the City of Baltimore upgraded their traffic management system, using NTCIP standards was key to the project's success, because it allowed for integration between the central software and traffic controllers with no major issues. More information regarding the SE process in the City of Baltimore's upgrade of their Integrated Traffic Management System can be found in Section 8.5.2 of the *Systems Engineering Guidebook for ITS (Version 3.0)*.



System Design

System Design is the first instance in the SE process where the focus is on the solution to the problems defined in the previous steps. In this step, a system design is created based on the system requirements identified in the previous step. The high-level design stage defines the framework of the system. Detailed design includes the specification of the software, hardware, and communications components, defining how each component will meet the system requirements.

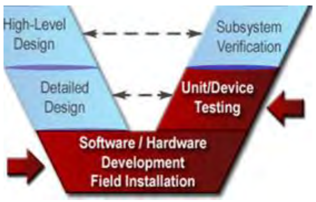
The high-level design step breaks the system into subsystems and defines the interfaces between the subsystems. In addition, the process identifies the required standards that the project must adhere to, including ITS standards to support subsystem interfaces. High-level design usually concludes with a preliminary design review.

During detailed design, the development team defines how the system will be built. Each subsystem is decomposed into components of hardware, software, database elements, firmware, and/or processes. The detailed design step also includes the definition of interfaces, which explain the communications to be used to link the various components.

For each component, specialists create documentation, or specifications, which will be used to build or procure the individual components. This documentation should also include testing procedures to demonstrate how the products will meet the detailed design specifications. At this point, commercial off-the-shelf (COTS) hardware and software products are specified, but they are not purchased until the review is completed and approved by stakeholders.

In practice, most hardware used in traffic signal projects is existing vendor offerings, so little hardware design is required. Development of custom software is more common, but most projects use preexisting vendor software that may be customized for the specific project.

Design documents created during this phase are used to complete Section 7 of the SEAFORM.



Software / Hardware Development and Testing

During the next two stages, hardware and software solutions are created/procured and tested for the components that are part of the system design.

The development stage involves hardware fabrication, software coding, database implementation, and the procurement and configuration of COTS products, as applicable. This stage is primarily the work of the development team, but the stakeholders can monitor this process with planned periodic reviews, e.g. technical review meetings.

How the system is procured is a focus of Section 8 of the SEAFORM. In practice, most of the hardware and software used for traffic signal projects are purchased off the shelf. If customization is not needed at this point, and it infrequently is, COTS hardware and software are acquired. The detailed specifications created as part of the Detailed Design are used to support the acquisition. Vendor demonstrations can help determine what products are available in the marketplace.

The need for custom software is established in the design phase, where the design is developed to meet the needs established by the stakeholders. *Generally, custom software is a highly complex and in-depth undertaking*. Never build a custom system if one can be purchased off the shelf. If no existing products meet a requirement, consider how necessary that requirement is. Only procure a custom system as a last resort.

If custom software must be written, it should be developed incrementally and released in stages. The initial releases should implement a few base features, and subsequent releases should add more features until all requirements are satisfied. CTDOT must be considered a primary stakeholder in the development of custom software, as the system must fit into the broader operational context of the region, and should be consulted throughout the concept exploration and design processes. CTDOT validation of the ConOps and requirements is required before the project can be let and procured.

FHWA has developed *The Road to Successful ITS Software Acquisition*, which provides best practices for managing software acquisitions for ITS projects. The guide is split into three parts:

- The Road to Successful ITS Software Acquisition – Executive Summary
- The Road to Successful ITS Software Acquisition – Volume I: Overview and Themes
- The Road to Successful ITS Software Acquisition – Volume II: Software Acquisition Process Reference Guide

The guide states that successful software acquisition is based on a few core themes, which are shown and explained in the following table.

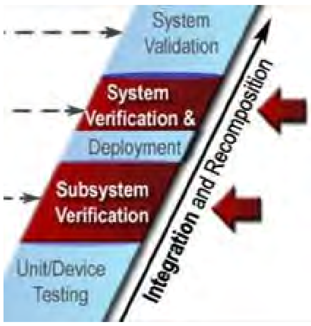
Themes for Successful Software Acquisition

Category	Theme	Explanation
People	Collaboration Team Building Open Communication Active Customer Involvement	For transportation agencies that don't build software with in-house staff (the usual case), the customer works together with a contractor to achieve common goals instead of having an adversarial relationship. They continually work at **open communications**, and **collaborate** on all activities, from requirements to risk management to system acceptance. This requires a greater customer role than many are used to; **active customer involvement** is essential. This in turn requires that project managers not go it alone. Instead, they practice **team building**, both within their agency and with the software contractor.
Management	Flexibility No Silver Bullets Up-Front Planning	**Flexibility** is needed in the contract to accommodate change and take advantage of the opportunities presented by application of the people themes. There must be the recognition that there are **no silver bullets**; no one acquisition practice or contracting mechanism is a panacea that can be relied upon to rescue a project. **Up-front planning** is needed early in the acquisition, even for activities such as system acceptance that do not take place until late in the acquisition process.
System	Never Build If You Can Buy Take Bite-Size Pieces	**Never build if you can buy** existing products. Purchasing pre-existing products alleviates many of the risks associated with building custom software. For most types of traffic signal systems, off-the-shelf products or components are available. Unique requirements can preclude their use, but any such requirements should be examined to determine whether they really are important or whether the system is over-specified. Ask yourself why your requirements are so much different from everyone else's. Many projects fail because they attempt to do too much at once. By **taking bite-size pieces**, an acquisition is more manageable. Contracting mechanisms must be chosen that allow for this instead of those that call for an all-at-once "big bang" approach.

Based on the synthesis of best practices, the guide has a checklist of considerations for software acquisition:

- ☐ Use existing products to the maximum extent possible.
- ☐ Document the software acquisition plan that addresses the entire project through operations and maintenance.
- ☐ Build a team and collaborate with them to acquire the system.
- ☐ Maintain on-going, open communications with the contractor and other members of your team.
- ☐ Prepare independent cost and schedule estimates.
- ☐ Document requirements and have them serve as the basis of other activities (test cases, budget and schedule, design, etc.).
- ☐ Trade off requirements to decrease cost and schedule. Keep all three in sync.
- ☐ Develop formal source selection criteria, which, for a software development process, include assessment of the bidders' software engineering process.
- ☐ Identify problems, record them, and track their status.
- ☐ Track expenditures and progress.
- ☐ Manage risks: identify and resolve them. Conduct risk management in conjunction with your contractor and other team members as an integral part of the acquisition process.
- ☐ Include system acceptance criteria in the contract.
- ☐ Develop an acceptance test plan and carry out acceptance testing in accordance with it. (Note: This plan could be developed by the contractor subject to your review and approval.)
- ☐ Have explicit contract language documenting licensing and ownership rights.
- ☐ Develop training materials and carry out a training program for use and operation of the system.
- ☐ Develop a support strategy for the system.
- ☐ Ensure software meets Federal requirements for architecture and standards consistency.

Once the components are acquired, bench testing can be performed to verify they meet their specifications. Custom software should be tested using an independent party who tests various scenarios, and testing must be repeated until all defects are fixed and resolved. It is also good practice to involve agency personnel in testing, so they can gain an understanding of equipment and/or software. Plans for testing components are used to complete Section 9 of the SEAFORM.



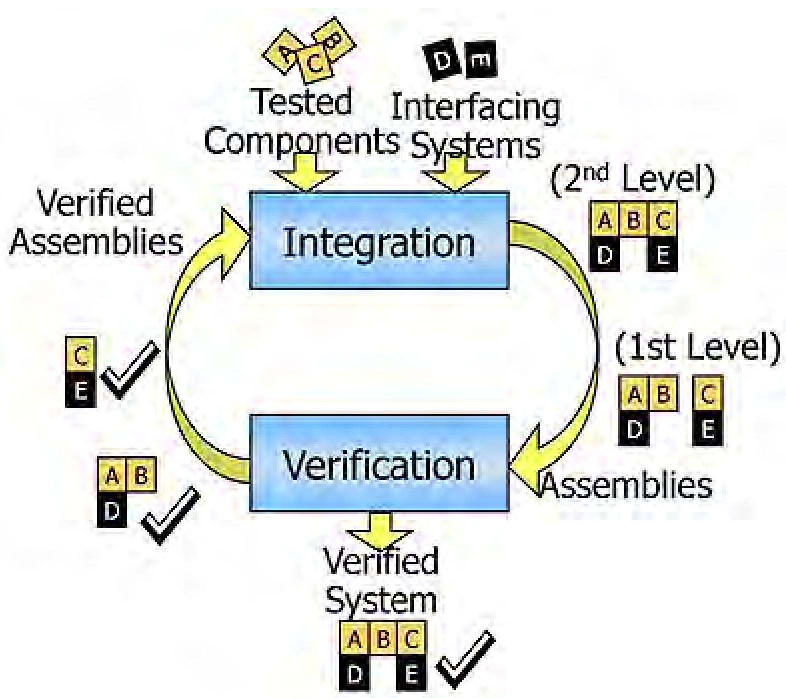
Integration and Verification

Once the hardware and software components are acquired and/or developed, they can be integrated into a higher-level system. For complex projects, a formal Integration Plan should be documented, as discussed in Section 9.1 of the SEAFORM. An Integration Plan should identify all participants, define what their roles and responsibilities are, establish the sequence and schedule for every integration step, and document how integration problems are recorded and resolved.

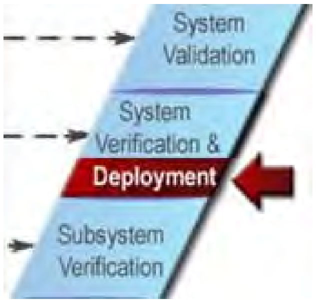
Once the first series of components are integrated into a higher-level system, the higher-level system can be verified against the system requirements using the verification plan that was developed as part of the system requirements phase.

Once the higher-level system is verified, more components can be integrated and verified. This is an iterative process that continues until the entire system is integrated into the existing external network and verified against all system requirements. The iterative process is portrayed in the figure shown below.

Iterative Integration and Verification Process



Verification should be thorough so defects are identified as early in the process as possible. It is easier to isolate and correct a defect at a component-level than it is during the entire system verification.



Initial Deployment

Once the compiled system is verified against all system requirements, the system can be deployed. During the initial deployment step, the final system is installed in the operational environment, and operation of the system is transferred from the project development team to the organization that will own and operate the system. Support equipment, documentation, operator training and other products that support the ongoing system operation and maintenance must also be transferred.

Many system issues surface when the system first begins operating in the real world environment, so it may be beneficial to obtain assistance from CTDOT and/or FHWA during this startup period. In addition, it is good practice to define a period during the initial deployment when the contractor assists in correcting any problems that are encountered. Include this integration period in any contract for computerized traffic signal systems, requiring that the contractor successfully address all issues prior to completing the project.

Once the initial deployment is complete, the system can be accepted as a final product. Ensure warranties and guarantees are specified for a period of time beyond the date of system acceptance.

System verification and acceptance are criteria for Section 10 of the SEAFORM.

System Validation

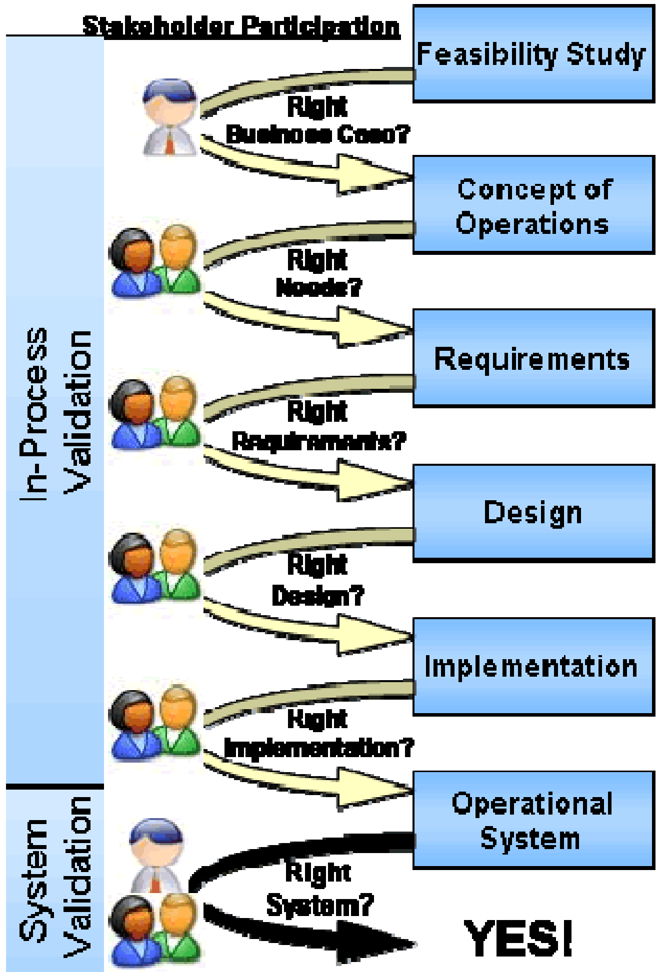
Once the system is accepted, it is the responsibility of the traffic signal project owner and stakeholders to conduct system validation. During this phase, the system's owner and stakeholders assess the system's performance against the intended needs, goals, and expectations documented in the Concept of Operations and the Validation Plan. System validation may also measure how satisfied the users are with the system. This can be assessed through surveys, interviews, reviews and direct observation.

It is important that this validation takes place as early as possible in order to assess its strengths, weaknesses, and new opportunities. As a result of validation, new needs and requirements may be identified. This evaluation sets the stage for the next evolution of the system. In addition, deficiencies of the project development should also be reviewed at this time. A "lessons learned" review can be very valuable for future projects.

Measurement of the system's performance should not stop after the system validation phase. Performance measurements should be collected throughout the life of the system to determine when the system becomes less effective.

While no traffic signals system is perfect, SE aims to maximize the chances of a successful system validation at the end of the project. This is achieved by validating individual components throughout the process, as shown in the following figure.

Validation Occurring Throughout the Systems Engineering Process



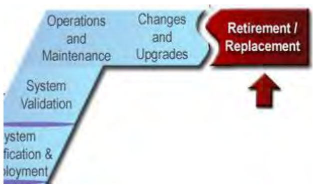
Operations and Maintenance

After the system is accepted by the owner, it moves into the Operations and Maintenance (O&M) phase. In this phase the traffic signal project will carry out the intended operations for which it was designed. This phase is the longest, extending through the life of the system and ends when the system is retired or replaced. It is important that there are adequate resources to carry out the needed operations and maintenance activities; otherwise, the life of the traffic signal project could be significantly shortened due to neglect.

The O&M plan for the deployed system is first identified in the ConOps. The plan identifies responsibilities and resources that are required to keep the traffic signal system performing optimally. Sufficient equipment, materials, supplies, and spares should be in place, inventoried, and working properly prior to transitioning to full operational status. Stakeholder roles and responsibilities throughout the lifecycle must be documented in the ConOps and adhered to by all project stakeholders for the project to be a success. Failure to outline the lifecycle responsibilities early in the SE process will result in a lack of ownership and a subsequent lack of operational sophistication of the system. In addition, it can lead to a much shorter lifecycle for the implementation, leading to wasted revenue and effort.

As the system is designed or changed, the O&M plan may need to be refined. The O&M plan for the completed project must fit within the context of the owner's existing traffic signal operations and maintenance program. Appendix B provides guidance on establishing a well-run O&M program, and the O&M plan is used to complete Section 11 of the SEAFORM.

If it is determined that the operating system must be changed or upgraded, the SE process should be used. Using the systems engineering process will help maintain system integrity. As the system is changed, relevant documents that are housed in the project library must be updated.



Retirement / Replacement

Eventually, every traffic signal system will be retired or replaced for one of the following reasons:

- The traffic signal may no longer be needed.
- It may not be cost effective to operate.
- It may no longer be maintainable due to obsolescence of key system elements.
- It might be an interim system that is being replaced by a more permanent system.

The retirement of the system should include a complete inventory of all software and hardware, final system and documentation configurations, and other information that captures the final operational status of the system. This should include identification of ownership so that owners can be given the option to keep their equipment and use it elsewhere. Disposal of the hardware and documentation should be planned, including any environmental concerns that may dictate disposal method. Retiring a system can also lead to a new project or system replacement, which would restart the systems engineering process.

The ConOps portion of the project should identify a reasonable anticipated lifespan of the system. This lifespan should be revisited upon retirement in order to compare the actual lifespan and final costs with the projections in the ConOps and from the manufacturer of the system.

Traffic Signal Systems Engineering Checklist

The following checklist can be used to ensure all aspects of the systems engineering process are considered while developing a traffic signal project.

Regional ITS Architecture

- ☐ Identify the portion of the regional ITS architecture that applies to the traffic signal project.
- ☐ Identify stakeholders.
- ☐ Assess capabilities of the stakeholder team and determine if external consultant assistance will be needed to complete some, or all, of the steps in the V diagram.

Feasibility Study / Concept Exploration

- ☐ Identify the current problem and existing situation.
- ☐ Document stakeholder needs.
- ☐ Prioritize conflicting stakeholder needs.
- ☐ Identify any constraints that will limit alternatives.
- ☐ Define evaluation criteria to evaluate alternatives.
- ☐ Conduct a preliminary risk assessment.
- ☐ Analyze each alternative with respect to the evaluation criteria.
- ☐ Select the most viable alternative.
- ☐ Consider the procurement options available to implement the system.
- ☐ Analyze the life-cycle costs associated with the selected alternative and determine how the project will be funded.
- ☐ Revisit the regional ITS architecture and revise the architecture, if needed.

Concept of Operations

Create a new ConOps document, or identify an existing one, that answers the following:

- ☐ Who are the stakeholders involved with the project?
- ☐ What are the elements and high-level capabilities of the system?

- Where are the geographic and physical extents of the system?
- When, and in what order, do specific system operations take place?
- Why is the system being proposed? What is the existing problem or opportunity that will be addressed?
- How will the system be procured?
- How will the system be developed, operated and maintained?

System Requirements

- Identify standards, policies, laws, ConOps, feasibility studies and other reference material that will support the requirements.

Identify and document requirements for the traffic signal project:

- Functional requirements – what the traffic signal project must do.
- Performance requirements – how well the requirements should perform.
- Interface requirements – definition of the interfaces.
- Data requirements – data elements and definitions of the system.
- Non-functional requirements such as reliability, safety and environmental.
- Enabling requirements such as training.
- Constraints.
- Identify one way each requirement will be verified. Methods for verification are testing, demonstration, inspection and analysis.
- Create a traceability matrix that matches each requirement back to the stakeholder needs.

System Design

- Perform high-level design, concluding with a preliminary design review.
- Perform detailed design, decomposing each subsystem into components of hardware, software, database elements, firmware and processes.
- Create/identify specifications for individual components.
- Develop test procedures for the components to meet the specifications.

Software / Hardware Development

- Procure commercial off-the-shelf products.
- Fabricate customized hardware, if needed.
- Develop customized software, if needed.
- Perform testing to verify components meet specifications.

Integration and Verification

- Identify participants in the integration process.
- Define the roles and responsibilities of the participants.
- Establish the sequence and schedule for each integration step.
- After each integration step, verify the newly completed system against the system requirements.
- Document integration problems and how they were resolved.
- Integrate the subsystems until the entire traffic signal project is integrated into the existing external network.
- Verify the entire traffic signal project against the system requirements.

Initial Deployment

- Deploy the traffic signal project in its operational environment.
- Obtain ownership of the system, including support equipment, documentation, operator training, and other supporting products.
- Consider startup assistance from CTDOT and FHWA.
- Ensure warranties and guarantees by the contractor are specified for a period of time beyond the date of system acceptance.
- Accept the system.

System Validation

- Assess the completed traffic signal project's performance against the intended needs, goals and expectations documented in the ConOps and Validation Plan.
- Identify any deficiencies of the project development to conduct a "lessons learned" review.

- Continue measuring the system's performance throughout the life of the system.

Operations and Maintenance

- Operate and maintain the traffic signal project as part of the existing traffic signal operations and maintenance program.

- If the operating traffic signal project must be changed or upgraded, follow the systems engineering process.

- As the system is changed, update relevant documents in the project library.

Retirement / Replacement

- Retire the system by inventorying all software and hardware, final system and documentation configurations, and other information.

- Plan for disposal of equipment, including any environmental concerns that may dictate disposal method.

- Compare the actual lifecycle costs and lifespan with what was required in the ConOps and projected by the vendor.

Best Practice Considerations for Software Acquisition
From The Road to Successful ITS Software Acquisition

- Use existing products to the maximum extent possible.
- Document the software acquisition plan that addresses the entire project through operations and maintenance.
- Build a team and collaborate with them to acquire the system.
- Maintain on-going, open communications with the contractor and other members of your team.
- Prepare independent cost and schedule estimates.
- Document requirements and have them serve as the basis of other activities (test cases, budget and schedule, design, etc.).
- Trade off requirements to decrease cost and schedule. Keep all three in sync.
- Develop formal source selection criteria, which, for a software development process, include assessment of the bidders' software engineering process.
- Identify problems, record them, and track their status.
- Track expenditures and progress.
- Manage risks: identify and resolve them. Conduct risk management in conjunction with your contractor and other team members as an integral part of the acquisition process.
- Include system acceptance criteria in the contract.
- Develop an acceptance test plan and carry out acceptance testing in accordance with it. (Note: This plan could be developed by the contractor subject to your review and approval.)
- Have explicit contract language documenting licensing and ownership rights.
- Develop training materials and carry out a training program for use and operation of the system.
- Develop a support strategy for the system.
- Ensure software meets Federal requirements for architecture and standards consistency.

Resources

Regulations and Standards

- Title 23 - Code of Federal Regulations
- Connecticut Stewardship Agreement
- FHWA Manual on Uniform Traffic Control Devices
- CTDOT Traffic Control Signal Design Manual
- CTDOT Traffic Engineering Standard Drawings
- CTDOT Functional Specifications for Traffic Control Equipment
- US DOT ITS Standards Program – List of Published Standards

Systems Engineering

- Systems Engineering for Intelligent Transportation Systems
- Systems Engineering Guidebook for ITS Version 3.0
- NCHRP Synthesis 307 – Systems Engineering Processes for Developing Traffic Signal Systems
- FHWA Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems
- Measures of Effectiveness and Validation Guidance for Adaptive Signal Control Technologies
- NCHRP Report 560 – Guide to Contracting ITS Projects
- The Road to Successful ITS Software Acquisition – Executive Summary
- The Road to Successful ITS Software Acquisition – Volume I: Overview and Themes
- The Road to Successful ITS Software Acquisition – Volume II: Software Acquisition Process Reference Guide

Traffic Signal Management

- Signal Timing on a Shoestring
- Traffic Signal Timing Manual
- Signal Timing Under Saturated Conditions
- Traffic Control Systems Handbook
- 2012 National Traffic Signal Report Card
- Traffic Signal Operations and Maintenance Staffing Guidelines
- Improving Traffic Signal Management and Operations: A Basic Service Model
- Institute of Transportation Engineers Traffic Signal Maintenance Handbook
- Telecommunications Handbook for Transportation Professionals: The Basics of Telecommunications
- Traffic Signal Audit Guide
- US DOT ITS Costs Database
- Traffic Detector Handbook

Training

- University of Connecticut Technology Transfer Center
- University of Idaho's MOST – A Hands on Approach to Traffic Signal Timing Education
- National Highway Institute courses on "Design and Traffic Operations" and "Intelligent Transportation Systems"
- Traffic Signal Systems Operations and Design
- The Consortium for ITS Training and Education (CITE)
- International Municipal Signal Association (IMSA)

Appendix A: ITS Projects – Systems Engineering Analysis FORM (SEAFORM)

The table below shows how sections of this handbook can be used to complete related sections of the SEAFORM.

Handbook Section	SEAFORM Section
Regional ITS Architecture	Section 3 – Regional Architecture Assessment and Concept Exploration
Feasibility Study/Concept Exploration	Section 2 – Needs Assessment Section 3 – Regional Architecture Assessment and Concept Exploration Section 4 – Alternative Analysis
Concept of Operations	Section 5 – Concept of Operations
System Requirements	Section 6 –Requirement Definitions (High-Level and Detailed)
System Design	Section 7 – Detailed Design
Software/Hardware Development	Section 8 - Implementation Section 9 – Integration and Test
Integration and Verification	Section 10 – System Verification and Acceptance
System Validation	Section 12 – Retirement / Replacement Schedule
Operations and Maintenance Appendix B	Section 11 – Operations and Maintenance Section 12 – Retirement / Replacement Schedule
Retirement/Replacement	Section 12 – Retirement / Replacement Schedule

Appendix B: Traffic Signal Operations and Maintenance Program Considerations

Operations and maintenance activities for traffic signal systems include:

- Routine/preventive maintenance – Periodic inspections and procedures to maintain the signal system.
- Emergency/response maintenance – Immediate repair of operational deficiencies or physical malfunctions that may occur.
- Operational maintenance – Activities, such as traffic signal retiming and equipment upgrades, which improve the operation of the traffic signal system.

The *2012 National Traffic Signal Report Card* states that an excellent traffic signal maintenance program includes the following key components:

- Timely response to critical malfunctions is a reliability objective.
- Maintenance resources and capabilities are considered in the design of traffic signal infrastructure and selection of control devices.
- Maintaining the reliability of field infrastructure in support of operations objectives is the core objective of the maintenance program.
- Contingency plans and maintenance strategies are developed and used to minimize disruptions to traffic signal operations in the context of resources and capability.
- Maintenance records, schematics, and documentation for all traffic signal control equipment are inventoried.
- A process is used to evaluate equipment reliability and schedule maintenance activity.
- Routine maintenance is performed.
- Maintenance activities are prioritized to ensure the integrity and readiness of critical infrastructure.
- Training resources are provided for traffic signal maintenance personnel.
- Maintenance personnel are supported, required and rewarded for attaining maintenance certifications from professional organizations.
- Critical components are continuously monitored for malfunctions and if a failure is detected, the notification system provides a report to maintenance personnel within a defined timeframe.
- Plans are developed to support traffic signal operations during power failures.
- Operational availability and functionality of a detection system at a 95% level.

The following pages outline steps in establishing a traffic signal maintenance and operation program.

Inventory existing signal assets

At a minimum, the number of signals that must be maintained should be listed or mapped. Ideally, signal information would be maintained in a traffic signal asset management system, which is a detailed inventory of all traffic signal components.

Determine maintenance duties

With consideration to available budget, staffing and equipment, determine if maintenance activities will be performed in-house and/or contracted externally. If maintenance tasks are performed in-house, prioritize activities to ensure the integrity and readiness of critical infrastructure.

Inventory maintenance equipment

Inventory equipment to be used for traffic signal maintenance tasks. Equipment can be owned, rented or required as part of maintenance contracting. Common maintenance equipment includes:

- Bucket trucks
- Testing equipment and tools
- Digital multimeter
- Controller and conflict monitor test equipment
- Detector sensor test equipment
- Small tools
- Vacuum cleaner
- Small generator for backup power for signals at major intersections during power outages
- Field laptop
- Traffic signal controller and detection software
- Small video monitor when using video detection systems
- Work zone traffic control devices (including work zone attire and equipment)

List agency staff and capabilities

Keep record of existing agency staff that maintains the traffic signal system. Agencies should have at least one professional engineer registered in Connecticut on staff or available to oversee maintenance and operations for every 75-100 traffic signals. Generally, an agency should have one qualified technician for every 30-40 signalized intersections. Additional technicians may be required if the agency has more than 150 traffic signals. Table 1.2 of *Traffic Signal Operations and Maintenance Staffing Guidelines* outlines requirements for traffic signal technicians.

Build and maintain a spare parts inventory

Build and maintain an inventory to ensure there is an adequate supply of spare parts that are available for repairs. Replacement parts include:

- Controllers
- CMU or MMU units
- LED modules
- Filters

- Cabinets
- Cabinet fans and bulbs
- Signal heads
- Mast arms and poles
- Pushbuttons
- Detectors
- Emergency vehicle preemption equipment
- Conduit
- Signal cables
- Detector cables
- Communication cables
- Signs

Budget

The agency should have a dedicated yearly budget for insurance, preventive maintenance, response maintenance, and operational upgrades such as retiming. For budgeting purposes, the US DOT ITS Costs Database includes example costs from implemented systems, as well as unit costs for ITS elements.

Explore opportunities for training

Explore cost effective training opportunities to learn how to properly maintain and operate the existing signal system and to stay informed about new technologies. The International Municipal Signal Association provides training and certification for traffic signal technicians. Additional training resources are listed in the "Resources" section of this handbook.

Review signal timings

Every 30 to 36 months, review traffic signal timings and update as necessary using a documented methodology. Collaborate with other local agencies to pool resources and cost-share retiming efforts, if retiming projects will be contracted externally. If signal timing will be performed in-house, consider changes in traffic demand, travel patterns and land use from when the timings were last updated and prioritize updates based on the agency's vision and mission for the traffic signal program. Appendix 1 of *Improving Traffic Signal Management and Operations: A Basic Service Model* and *Signal Timing on a Shoestring* both document methodologies for updating signal timings that are sensitive to available resources.

Review existing unsignalized intersections

Periodically review existing intersections to determine if geometric and/or signal system installations are required to relieve traffic congestion or improve safety.

Review existing signalized intersections

Periodically review the need to upgrade existing signalized intersections to enhance operations (e.g., adding a protected left turn phase to an approach, upgrading controllers, etc.).

Plan for response/emergency maintenance

Establish contingency plans to respond to possible emergency maintenance needs. These contingency plans must be identified in project ConOps. Example emergency scenarios are provided in the following table.

Response/Emergency Maintenance Considerations

Item	Repair Scenario
Signal Heads	• Restore unlit traffic signal (includes pedestrian signals) • Correct misaligned traffic signal (includes pedestrian signals) • Repair or replace mounting hardware • Repair or replace damaged signal head or parts thereof (e.g., visor, lens, backplates, and reflector) • Clean any obstructed indications including, but not limited to dirt or snow
Controller Assemblies	• Restore correct phasing and time setting in controller unit • Replace a malfunctioning controller unit • Replace a malfunctioning conflict monitor • Repair or replace malfunctioning flasher • Repair or replace malfunctioning load switch • Repair or replace malfunctioning time clock • Repair or replace malfunctioning relay
Traffic Signal Supports	• Repair or replace defective poles or other supporting hardware • Replace any damaged traffic signal supports • Address base plate cracks • Address pole cracks • Address cracks in any weld metal or base metal • Address anchor bolt connection failures, or other nut and bolt failures • Address gaps between base plate connection and foundation • Address foundation cracks • Restore required clearance between the roadway and bottom of signals and/or signs located over the roadway
Detection (Vehicular)	• Repair or replace malfunctioning detector amplifier • Repair or replace malfunctioning detector sensor • Repair or replace malfunctioning video detection equipment • Repair or replace malfunctioning preemption system equipment • Tune or adjust detection amplifier • Redirect or re-establish detection equipment
Detection (Pedestrian Push Button)	• Repair or replace malfunctioning push buttons • Repair or replace malfunctioning accessible pedestrian signal messages or indications • Remove obstructions preventing pedestrian push button accessibility, e.g., piles of snow

Item	Repair Scenario
Signs	• Correct misaligned signs • Repair or replace damaged or missing signs
Pavement Markings	• Restore pavement markings that are the responsibility of the permittee as indicated on the traffic signal permit (e.g. stop lines, crosswalks, legends, etc.)

Perform preventive maintenance

Perform routine preventive maintenance on each traffic signal to preserve equipment and extend the life of the assets. Sample preventive maintenance checklists are included in Appendix A of the *Traffic Signal Maintenance Handbook* and in the following table.

Sample Preventive Maintenance Checklist

Item	Maintenance Activity
Vehicular Signal Heads	☐ Clean and inspect all visors; replace those that are cracked or broken. Tighten all screws securing visors to the signal head. ☐ Clean and inspect all lenses; replace those that are damaged. ☐ Inspect traffic signal housing for cracks or damage. ☐ Check terminal block connections. ☐ Check gaskets and mounting hardware; retighten as necessary. ☐ Check head alignment relative to lanes they serve. ☐ Check safety chains. ☐ Re-lamp incandescent signals. ☐ Re-lamp all sealed beams for programmed signal heads. ☐ Clean reflectors on inside of signal housing (applies only to incandescent fixtures). ☐ Clear any obstructions (such as branches) that block visibility. ☐ Check underclearances for span wire mounted signals; adjust height as necessary. ☐ Check bushings on cable outlet and universal hangers; replace as necessary. ☐ Check for cracked and/or damaged mounting brackets. ☐ Clean back plates and check for cracks and/or missing screws. ☐ Replace burnt out LEDs.

Item	Maintenance Activity
Pedestrian Signal Heads	☐ Clean and inspect all visors. ☐ Clean and inspect all lenses. ☐ Inspect signal housing for cracks or damage. ☐ Check terminal block connections. ☐ Check gaskets and mounting hardware; retighten as necessary. ☐ Check head alignment relative to the crosswalks they serve. ☐ Re-lamp incandescent bulbs (if any) with correct wattage bulb. ☐ Clean reflectors on inside of signal housing (applies only to incandescent fixtures). ☐ Replace burnt out LEDs. ☐ Check the time provided for the pedestrian crossing. ☐ Check audio operation.
Pedestrian Pushbuttons	☐ Check housing for damage or signs or vandalism; replace as necessary. ☐ Check for tightness. ☐ Verify operation. ☐ Check accompanying sign; repair or replace as necessary. ☐ Check ADA accessibility.
Signal Poles and Mast Arms	☐ Check anchorage. ☐ Check tightness of mounting hardware. ☐ Check that each pole is electrically bonded. ☐ Re-tighten bolt covers. ☐ Check poles for plumbness; shim or adjust as necessary. ☐ Check mast arm alignment. ☐ Check pole and/or arms for warping or other damage; note deficiencies. ☐ Replace missing pole base access doors. ☐ Check paint condition and/or corrosion. ☐ Clear drainage holes in pole bases, if present. ☐ Check for missing pole caps and mast arm end caps; replace as required, ☐ Check condition of grout at pole bases, if applicable. ☐ Check condition of varmint screen at pole bases; if applicable.

Item	Maintenance Activity
Span Wire Signal Installations	☐ Check condition of strain vises, if applicable. ☐ Visually inspect each upper and lower tether span wire for damage or deterioration. ☐ Visually inspect each upper and lower tether span wire for excess sag; adjust as necessary. ☐ Inspect all connecting span wire hardware; tighten or replace as necessary. ☐ Inspect guy anchors for proper attachment and/or damage. ☐ Visually inspect pole condition for cracks; note any deficiencies.
Conduit System and Junction Boxes	☐ Check grounding bushings on rigid metallic conduit; replace as necessary. ☐ Inspect junction box covers for cracks or misalignment; replace as necessary. ☐ Check proper seating of junction and splice box covers. ☐ Check grounding; secure all straps and rod connections. ☐ Check above ground conduit for damage; replace damaged and/or missing conduit straps. ☐ Clear debris and/or overgrowth around junction box. ☐ Visually inspect junction box covers for cracks and/or other damage; replace-covers, as necessary. ☐ Clear lip of junction box cover to ensure proper seating of cover; tighten cover bolts if present. ☐ Check junction boxes for proper grade; note any deficiencies.
Traffic Signal Cable	☐ Check all splices in each traffic signal pole base; resplice as necessary using waterproof connectors or splice kits. ☐ Visually check the condition of the traffic signal cable for dry rot, nicks, cuts, or other damage to the outer jacket insulation; perform resistance and continuity tests, if required, ☐ Check all overhead cables arid connections. ☐ Check to ensure cable is not rubbing against cable outlet (free-swinging, end-mounted signals only).

Item	Maintenance Activity
Vehicle Detection – Loops	☐ Verify operation of areas of detection. ☐ Measure each loop for resistance, inductance, and loop quality. ☐ Visually inspect loop installation; reseal sawcut trench, if necessary. ☐ Check loop detector splices. ☐ Re-tune loop detector amplifiers at the cabinet. ☐ Check that all loop leads are properly tagged.
Vehicle Detection – Cameras	☐ Verify operation of areas of detection. ☐ Check video camera positioning. ☐ Check video camera mounting hardware. ☐ Inspect camera head for damage. ☐ Clean camera lens. ☐ Verify operation of video processor at cabinet. ☐ Update card firmware, if applicable. ☐ Verify camera cables are labeled for identification.
Overhead Street Name Signs	☐ Clean sign faces. ☐ Check mounting hardware; tighten as necessary.
Uninterruptible Power Source (Battery Back-Up)	☐ Verify automatic transfer switch operation. ☐ Verify incoming line voltage. ☐ Verify DC output to batteries. ☐ Verify AC output on inverter. ☐ Check electrical connections. ☐ Test system via simulated power outage at cabinet. ☐ Record events and run times either saved on UPS unit manually or uploaded to laptop.

Item	Maintenance Activity
Controller and Meter Cabinets	☐ Vacuum cabinet interior. ☐ Change cabinet filter. ☐ Check operation of fan and thermostat (thermostat set to operate at 85-90 degrees Fahrenheit). ☐ Check operation of cabinet light and switch; replace if necessary. ☐ Check and tighten all terminal connections. ☐ Verify operation of detector panel relays. Check for burned or pitted contacts. ☐ Check police functions. ☐ Lubricate hinges and locks. ☐ Check cabinet door gaskets. ☐ Check neutral and grounding bus. ☐ Check conditioning of incoming line voltage. ☐ Test circuit breakers. ☐ Check GFCI receptacle on power distribution panel; replace if necessary. ☐ Seal all conduit. ☐ Verify that all spare conductors are landed on spare terminal blocks or taped off. ☐ Verify all cables are tagged or otherwise identified. ☐ Seal around cabinet base with silicone caulking.

Item	Maintenance Activity
Controller Assembly	☐ Scan conflict monitor for logged events; note any entries. ☐ Perform conflict monitor test: place copy in cabinet. ☐ Run internal diagnostic routine on the controller. ☐ Verify input timing versus approved timing, including coordination and time-of-day parameters. ☐ Upload controller timing and parameters via laptop; place copy in cabinet. ☐ Check yellow change and all-red clearance intervals against current design standards for duration. ☐ Check pedestrian clearance times against current design standards for duration. ☐ Verify vehicle and pedestrian calls. ☐ Check preemption function for firehouses, if applicable. ☐ Check confirmation/telltale light for preemption, if applicable; relamp if needed. ☐ Check programming and operation of time clocks (school zone flashers only). ☐ Verify correct date, time and DST function for controller (intersections only). ☐ Verify communication with master controller, if applicable. ☐ Place cabinet wiring diagrams in cabinet, if missing. ☐ Place traffic signal permit in cabinet, if missing. ☐ Place user and/or programming manuals in cabinet, if missing.

Maintain documentation

Whenever signal timings are updated, equipment is upgraded, reviews are performed or maintenance is performed, properly document a record of work. Maintaining up-to-date traffic signal maintenance records can help provide efficient service, detect and correct recurring problems, develop future maintenance schedules and strategies and may protect against tort liability claims.

Coordinate

Traffic signal maintenance activities must be coordinated among municipal staff and/or with the contractor who conducts maintenance. Coordinating upgrades with other public works projects can reduce costs. At a minimum, coordination will reduce the risk of wasting maintenance funds. For example, if a municipality plans to upgrade traffic signal indications at an intersection, but a land developer plans to replace the traffic as part of a site plan, the municipality can avoid wasting funds by not upgrading the signal just before the land developer performs work.

In addition, collaborate with regional partners to address regional needs such as regional coordination for routine maintenance, planned and unplanned events, closures, and emergency preparedness.