

# **Task 4 Working Paper**

**to the**

**National Cooperative Highway Research Program  
(NCHRP)**

**on Project 03-77  
Guide to Contracting ITS**

LIMITED USE DOCUMENT

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**December 21, 2004**

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**AND *Kelcey***

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## **Task 4 Report**

### **The Impact of the Selected Procurement Approach to the Systems Engineering Process**

#### **BACKGROUND**

The successful procurement of Intelligent Transportation Systems (ITS) is a challenging task for state and local agencies. The procurement process must be flexible to accommodate the uncertainties of complex system acquisitions, while at the same time rigid 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 Transportation Research Board (TRB) through the National Cooperative Highway Research Program (NCHRP) has initiated the development of a Guide to Contracting ITS Projects (Project 3-77). This guide will highlight best practices and recommend contracting strategies and contract types, terms and conditions for the planning, design, implementation, integration, system acceptance, warranty, maintenance, and upgrade of ITS.

The activities outlined in the scope of work for this project are:

- Task 1 – Review of Transportation and Technology Literature
- Task 2 – Look at Other Industries
- Task 3 – Categorize ITS Projects
- Task 4 – Systems Engineering Process
- Task 5 – Recommend Contract Types
- Task 6 – Prepare a detailed Outline of the Guide
- Task 7 – Prepare the Guide
- Task 8 – Submit Final Report

The application of systems engineering principles to the acquisition of an intelligent transportation system will significantly increase the likelihood of a successful implementation. The contracting processes employed, to a large degree, determine the manner in which these principles are applied as well as the assignment of responsibilities for their application. These processes will all also influence the procuring agency's ability to ensure that contractors with appropriate systems engineering skills are employed to lead the project development. In many respects the contracting processes used can have as much of an impact on the project's success as the statement-of-work and system specifications.

When performing this work, it was concluded that some of the principles of project management, unique to ITS acquisitions should also be considered. For this reason, the

aspects of project management that are influenced by the procurement process have also been included in this report.

The purpose of this task 4 working paper is to provide a description of both the systems engineering and contracting concepts and an overview of relevant project management principles. This information is then followed by a description of the relationships and interactions among the three. It must be emphasized that this working paper focuses on fundamental relationships. It is not intended to address the actual contracting guidelines (i.e. what is the best contracting methodology for a particular system and agency), which are the subject of the activities of Task 5.

This working paper describes and analyzes alternative contracting procedures currently used by the ITS community. It does not suggest new (and untested) possibilities. A discussion of these alternatives is provided in subsequent tasks. However, the report is significant, in that it serves as a primer for the subjects of contracting and systems engineering, and because it suggests new ways of looking at the relationship between these disciplines.

## **OVERVIEW OF THE SYSTEMS ENGINEERING PROCESS**

This overview of the systems engineering process emphasizes its application to the acquisition (procurement, planning, design and implementation) of intelligent transportation systems. This discussion does not provide an extensive discourse on the subject systems engineering, but instead, describes process at a level of detail that will ensure an understanding of its relationship with procurement alternatives.

The principles of project management are also summarized here because of their impact on the manner in which systems engineering is conducted. Here again, the description of the project management process is intended to highlight the unique requirements of an ITS project, rather than to serve as a textbook on the extensive subject of project management.

## **ITS PROJECTS ARE UNIQUE**

When compared with traditional civil sector infrastructure projects such as highway or bridge construction, ITS projects have some unique aspects that must be considered, including:

- Real-time information technology (IT), which, during the acquisition process can present many challenges because of the difficulty of:
  - Developing accurate estimates of system development costs and schedules (One reference indicates that during the initial planning stages of an ITS project, cost and schedule estimates are accurate within +/- 400%)<sup>1</sup>

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<sup>1</sup> Kemerer, C.F., “Software Project Management Readings and Cases”, Pg. 63, Irwin/McGraw-Hill, New York, 1997

- Fully defining and specifying system characteristics
- Controlling changes in project (and system) scope. Changes in scope typically occur at an unacceptable rate of 1% to 2% per month.<sup>2</sup> Appropriate application of systems engineering practices have been found to reduce scope changes to less than 5% over the life of a typical project.<sup>3</sup>
- The management of information systems personnel can be difficult. Because of the creative nature of this profession, the implementation of formalized development processes and production of comprehensive documentation can be challenging. In addition, information systems staffs are often characterized by high turnover rates that threaten the continuity of long-term project developments.
- The need to include numerous stakeholders during the definition of system requirements, and during the system development. This results from the broad range of disciplines and organizations affected by most ITS developments. For example, a typical traffic management system may require the involvement of system operators, maintenance personnel, police, transportation engineers, planners and managers.
- Absence of starting and end points. This is the result of the introduction of relevant new technology at a pace that is shorter than the system development time. There is a continuing need to upgrade or replace computers, communications equipment and third party software.
- Interaction with many different types of equipment. Intelligent transportation systems are unusually complex (even when compared with more conventional information technology-based systems), in that they often control a variety of field devices, large screen displays, remote terminals, computer peripheral equipment, telecommunications equipment, etc. furnished by many different suppliers.

## Systems Engineering Basics

A system is a set of components (hardware, software, processes and people) that work together to achieve a common objective. Systems are made up of subsystems, which are groups of components within a system that work together to perform specific function. For example, if an automobile is considered a system, the springs and shock absorbers are considered to be the suspension subsystem. Similarly, in a transit management system, the radio, vehicle location equipment, data entry equipment, and driver displays are considered to be components of the vehicle subsystem of the overall transit management system.

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<sup>2</sup> McConnell, S.C., “Rapid Development: Taming Wild Software Projects”, 1996.

<sup>3</sup> Dennis A., et al, “Systems Analysis and Design: An Object-Oriented Approach with UML”, Pg. 83, John Wiley and Sons, Inc., 2002.

Systems engineering is a defined process that uses managerial and technical tools to analyze problems and provide structure to the overall process of planning, procuring, designing, implementing and testing a system. Systems engineering is the process by which we build quality into complex systems; it focuses on ensuring that requirements are defined early in the process and that the system satisfies these requirements. It also ensures that systems are not only robust but also incorporate the flexibility needed to satisfy needs that evolve during the system's life. Systems engineering supports the management of project activities, including monitoring and estimation of cost and schedule constraints, controlling project scope, managing risk and tracking development progress.

A system life cycle begins when the need for the system is conceived and ends when the system is discarded. The system life cycle is typically described in terms of the following stages:

- **Conception:** This stage begins when the need for a system is recognized. Two activities are required in this phase, 1) perform a needs analysis, and 2) develop a concept of operations. For example, if a transit information system is being developed, the concept of operations might indicate that “bus location information is needed to inform passengers of estimated times until the next arrival of a bus can be expected”. Thus the concept of operations is not describing the system requirements or its design. The concept of operations describes how the system is embedded in the business processes of its users.
- **Requirements:** This stage defines what the system must do. Using the example of the transit information system, one requirement might indicate that the “system shall provide bus arrival information at all bus stops”.
- **Design:** This stage defines how each requirement of the system is satisfied. Using the example of the transit information system, the design specification might indicate that: “variable message signs shall be installed at all bus stops”. This high level design specification will be supported by a series of more detailed, lower level specifications such as: “The variable message signs shall be capable of displaying four lines of text.”
- **Implementation:** This stage transforms the design into an actual system. This is the stage at which the variable message signs in the design example are installed.
- **Integration and testing:** The testing stage overlaps implementation. It begins with the testing of units of equipment (or software modules). Individual modules are integrated into subsystems, which are also tested. Finally, the subsystems are assembled into an overall system. The entire system is then tested by the developer and then at the customer's site using an acceptance test process. This is the stage at which the fact that the signs are capable of displaying four lines of text is confirmed.
- **Operation and maintenance:** This is the longest stage, during which, the system is operated and maintained during its useful life. The maintenance process

ensures that the system performs satisfactorily and includes system upgrades and expansion.

## THE “V” MODEL OF SYSTEMS ENGINEERING

The "V" diagram shown in figure 1 has been developed by the systems engineering profession to define the relationship among the phases of the system life cycle. As represented in the figure, the systems engineering process begins with the planning activities represented by the concept of operations in the upper left end of the “V”, and proceeds down the left side of the diagram and up its right side. The arrows in figure 1 show the time sequence of these activities.

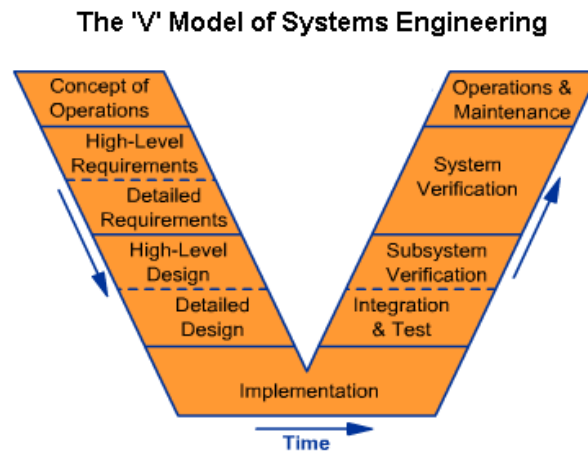


Fig. 1 “V” model or diagram of the system life cycle

The “V” shape is used to represent the systems engineering process to emphasize the relationship between the activities on the left and right branches of the “V”. The uppermost activities on each side of the “V” (concept of operations and Operations and Maintenance) define the system at its highest level. They must consider both the total system and its user interactions. The processes at lower levels of the “V” describe and work with the system with increasing detail, until one arrives at the bottom level (implementation) at which point the system is being considered at its most detailed level. At this level, the systems engineering process is involved with the definition, implementation and testing of individual lines of computer code, wires and components. The steps on the left side of the “V” (Concept of Operations to Implementation) are considered to represent the process of “decomposition”. The steps taken when proceeding up the right side of the “V” are known as “recomposition”. In other words, the left side of the “V” decomposes the system into its most basic elements, while the right side of the “V” reconstitutes these basic elements into a complete operational system. The steps that are horizontally aligned in the “V” (such as the requirements and system verification) are intended to represent the same levels of decomposition/recomposition. Because of these horizontal relationships, the tests (also known as verification) that must be conducted while the system is being “recomposed” are defined by their associated planning/requirements/design activities. If these earlier activities have been performed correctly, there is no need to define additional unit, subsystem, and system verification

tests. There may, however, be a need for additional details describing the manner in which this testing is to be performed. These relationships include:

- **Concept of operations vs. Operations and maintenance:** The concept of operations describes how the system will interact with the agency’s business practices once it has been fully developed and accepted. This relates directly to the operations and maintenance stage, at which point the system is being used operationally as an integral tool of the business practices. A knowledge and awareness of this relationship ensures that focus is placed on issues that will keep the system operating and effectively maintained once it’s built. This level is considered system validation since it confirms that the system that was developed to solve a specific set of operational needs, does in fact meet these needs. In other words, “Was the right system built?”
- **Requirements analysis vs. System verification:** The requirements analysis defines the functions the system must perform. It also defines the precision with which they must be performed as well as the system speed, capacity, etc. The overall system verification (acceptance testing) determines whether the system satisfies the system requirements. The latter involves the verification and validation of the system that can be phrased as a counterpoint to the question asked in the concept of operations. In other words this level of testing determines whether “the system was built right”.
- **High-level system design vs. Integration and testing:** High-level design breaks down the overall system into subsystems, each of which is assigned to a major functional area of the system. The subsystem verification integrates and tests the subsystems as units. So, there is a clear correlation between these two stages.
- **Detailed design:** This step relates to the definition of the complete system at the greatest level of detail. It also includes the specification of individual items (lines of code, software modules, hardware units) and their associated subsystems. Much of the work performed at this stage may be invisible to the agency, since it is performed at a level of detail required by the system implementers. The agency must only be concerned ensuring that the high level design and requirements meet its needs. It is the contractor’s responsibility to ensure that the detailed design reflects the high-level design specifications.
- **Implementation:** This stage transforms the design into a fully operational system.
- **Operations and Maintenance:** The final step of the “V” is the operations and maintenance, which occurs following the system implementation. It is essential that planning for operations and maintenance occur during the initial stages of the development process (concept of operations). One of the primary purposes of the concept of operations is the definition of responsibilities for operations and maintenance including identification of the possible need for outsourcing operations and maintenance services. The issues to be considered when planning for operations and maintenance include:

- The need for outsourcing – are the resources and skills required for operations and maintenance available from agency staff, or will it be necessary to outsource these services?
- What quality of O&M is required in terms of response times, system availability, hours of operation, etc?
- What are the requirements and availability of funding for O&M?
- Will maintenance requirements be specialized such that the installation contractor must play a role in providing these services?
- If a phased development is being pursued, will maintenance be considered an integral part of each development phase?
- What guarantees and warranties can be anticipated from the installation contractor and its suppliers? How will this affect the maintenance costs?
- Will intellectual property rights affect the ability to employ a third party for system maintenance, or will the system documentation be furnished in adequate detail to permit the acquisition of maintenance services from other than the system implementer.

The resolution of these issues is very important, since it will influence the budget and contracting requirements during the systems engineering process.

- **System upgrades:** As anyone who has ever owned a PC knows, there will be a continuing requirement for system upgrades throughout the life of the system. System upgrades are part of the operations and maintenance process. There will be a continuing need for upgrades as new releases of operating system and other third party software become available. There will also be a need for hardware upgrades due to aging of equipment, changes in technology and incompatibility of older equipment as other parts of the system are being replaced. The process of system upgrades is considered a part of the operations and maintenance process.

## SYSTEM DEVELOPMENT PROCESS MODELS

Systems engineering process models define alternative applications of the “V” diagram to the systems engineering process. A well-developed model also supports the project management process in that it defines the system acquisition steps, and helps convey to the team and others how a project will be managed. The process model also determines the procurement approach being used for the system acquisition. The process model must define the procurement approach rather than permitting the procurement approach to define the systems engineering process. In addition, the model helps communicate with others about the progress being made, it helps assess the risk of alternate paths, and it helps to take advantage of emerging opportunities. Alternative system development processes include:

- Waterfall Model
- Evolutionary Model
- Spiral Model

The selection of this process is a significant part of the project, as it determines the scheduling, contracting and many other project activities. No single model is applicable to all types of projects. The challenge is to select the most appropriate model for the implementation of a given intelligent transportation system.

**Waterfall Model:** Until recently, the waterfall model was one of the more commonly used models used for the system development process. As shown in figure 2, this model defines a linear process in which the steps of planning, designing and implementing (and their further subdivisions) are performed sequentially. This method of analysis was the dominant approach to system engineering during the 1980's, and is representative of the highway design and construction process. The waterfall model was designated the waterfall process because the series of steps shown in figure 2 are typically drawn in a descending pattern reminiscent of a waterfall. In actuality, the steps shown in figure 2 are no more than the representation of a single pass through the steps of the “V” diagram of figure 1.

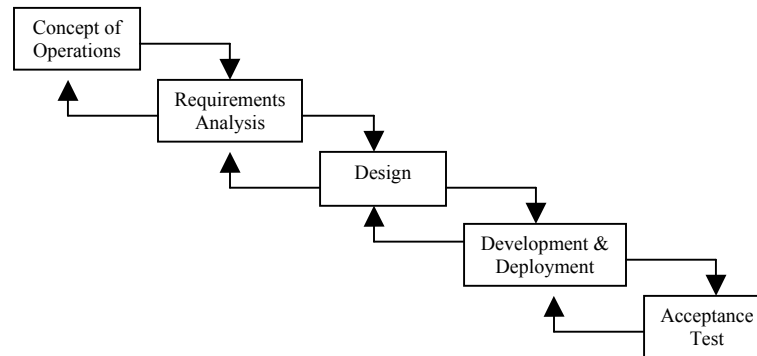


Fig. 2 Water Fall Model of Systems Life Cycle

The waterfall model defines the execution of the steps of the system development, and provides a limited capability to modify the previous step based on the activities of the current step. The arrows facing to the left in the diagram represent the fact that activities occurring during one step will cause the review and modification of a previous step. Suppose, for instance, that while acceptance tests are being conducted, it was concluded that an operator display was awkward to use. This recognition requires a system software modification. If the software modification is documented and managed correctly, it should be preceded by a modification to the system design. The system design, in turn requires a modification of the requirements. Thus, in effect, the developer is traveling up the waterfall (swimming upstream). Rarely are documentation changes correctly controlled to reflect changes made late in the system life cycle. Failure to make these changes frequently leads to maintenance problems during the operations and maintenance stage of the life cycle.

In spite of the possibility of managing changes by traveling up and down the waterfall, this model is, in actuality, representative of a straightforward linear process. Because of the difficulty of swimming upstream with the waterfall model, it is appropriate for

simple, well-defined systems, with functions and features that are proven and have been implemented elsewhere (such as Category 1 and 2 projects defined in Task 3) to minimize the number of times that the upstream direction must be traversed. If there is uncertainty regarding the final functional capabilities of the system (which is characteristic of systems that must satisfy the needs of multiple stakeholders), other process models should be used.

**Spiral Model:** The spiral model is intended for the acquisition of systems involving the development of new applications. For example, this model might have been used during the development of control centers for the automated highway system. It is characterized by a repetitive process of planning, requirements, design and prototyping. Prototypes are then evaluated to determine the degree to which they satisfy the initial vision and concepts of operation.

As shown in figure 3, the spiral model begins with the definition of a vision for the system. Once a vision has been defined, a risk analysis is generally performed that identifies some of the higher level risks associated with the implementation of the vision. A prototype is then used to support the development of a concept of operations, to provide an initial visual representation of the system operation that can be used to support the planning process. As with the waterfall model, the concept of operations is then used to define requirements, and produce a design. Additional prototyping is performed throughout the process utilizing the results of the requirements and design. Although not explicitly shown in the diagram, the requirements may also be supported by a prototype development, which may be used as a visual representation of the requirements. Risk analysis is performed frequently throughout the process.

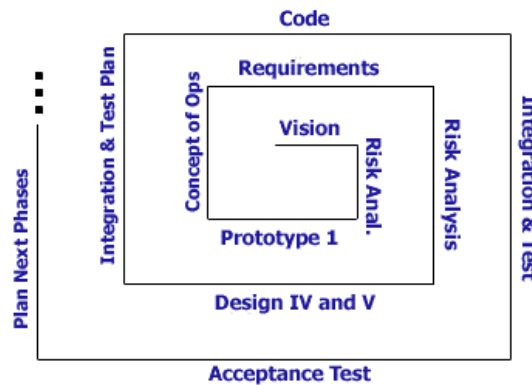


Fig. 3 Spiral Model of Systems Life Cycle

The spiral model is not a well-defined system engineering process. These steps may be performed in any order, depending on the application being examined. The spiral representation is used to define an expanding level of detail and understanding of the application as it is developed through the use of multiple prototypes and designs. The iterative nature of the spiral model permits the prototyping process to be repeated as

many times as necessary. When the designers (and customers) are confident that the prototypes meet their needs, final design and implementation is initiated.

The spiral model is applicable to the development of new systems and applications that are not well defined, and circumstances under which the agency wants to examine many alternative designs – which may include particular emphasis on input and output formats (such as Category 4 projects defined in Task 3). The use of the spiral model can be an expensive process and for this reason, it should be used only by organizations that are “breaking new ground”. For example, in the ITS community, this approach should be considered for some of the newer emergency preparedness applications being considered for the surface transportation system.

**Evolutionary Model:** The Evolutionary Model is a formalized description of a phased system development. As its name implies, the evolutionary model defines a sequence of stages such that the system evolves through a sequence of versions, such that each version is closer to its final vision.

The evolutionary model can be described graphically as a linear sequence of "Vs" connected end-to-end. The use of the “V” to describe an evolutionary phase is intended to indicate that all the activities included this diagram, up to and including operations and maintenance are executed for each development. See figure 4. This version of the evolutionary development may also be called sequential or iterative development. It begins with an initial vision, which defines the final goal of the system, as well as the functions to be included in each of the phases. It is recommended that the duration of these phases be from nine months to one year.

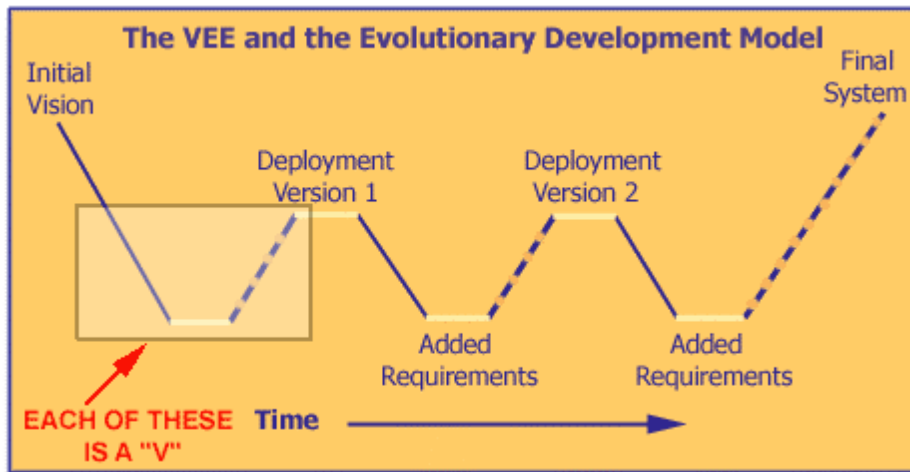


Fig. 4 Evolutionary Model of Systems Life Cycle

The evolutionary model recognizes the difficulty of fully and accurately defining the total set of requirements and specifications for software-based systems. It also recognizes the inaccuracies of estimating the cost and schedule of these systems, which as previously indicated can be subject to errors of +/-400%. Finally, it recognizes the possibility of project scope changes at a rate of 1% to 2% per month. By dividing the project into

smaller “bite-sized” pieces, the impact of these inaccuracies and scope changes are minimized. A one-year project phase is likely to experience manageable changes in scope of 12% to 24%. If the entire project were developed over a longer period (of say 5 years), it would experience scope changes in the range of 48% to 96%. Thus, a five-year project that has not been divided into shorter phases might never be completed, since at the end of the five-year period an entirely new set of project requirements will have been defined. This phenomenon has been experienced all too often in past ITS projects. With the evolutionary model, further control over scope changes can be exercised by deferring desired changes for later project phases. Finally, lessons learned during the development of one phase can be incorporated into subsequent phases.

It is not necessary to develop each phase in an entirely sequential manner. The planning and requirements steps of one phase can be initiated while final development and testing of its predecessor is underway. However, it is important not to begin the planning and design of the subsequent phase too early, since if this occurs, it will not be possible benefit from the lessons learned during earlier developments.

The evolutionary model is applicable to systems that require multi-year development, with functions that can be logically separated. For example a freeway management system might include the variable message sign control in one phase, detector data processing in a second phase and elaborate graphical displays of traffic and incident information in a third phase. It might also be possible to include limited field deployment of two or three variable message signs during the first phase, and further expansion of field equipment during subsequent phases.

Thus, the evolutionary model is very applicable to ITS systems, which can typically be functionally and geographically decomposed. It permits control over requirement changes, since new requirements can be delayed for subsequent iterations. It also allows the agency to familiarize itself with the system, because they can use the system that was developed during one “V” phase while a second iteration is underway. This model is a tested approach to the development of ITS systems, having been used on several successful system developments throughout the United States. It should be applied to systems that include any of the following characteristics (consistent with Category 2 and 3 as defined in Task 3):

- Moderately Complex to Complex
- System requirements not completely defined
- Involve the development of new software or new functions for existing software
- Need to account for technology evolution over the system life cycle
- The first system of its type developed by the procuring agency

## **CROSS-CUTTING SYSTEMS ENGINEERING ACTIVITIES**

A number of activities are conducted continuously during the system acquisition process. These activities are designated cross-cutting, in that they are performed during all of the

systems engineering steps of planning, requirements, design, implementation and testing. These four activities, which include configuration management, risk management, validation and verification, and metrics, serve as the supporting framework for the system development. They are summarized here. Many systems engineering references and courses exist that define these activities in greater detail.<sup>4</sup>

**Configuration Management:** Configuration management is a “process for establishing and maintaining consistency of a product’s performance, functional and physical attributes with its requirements, design, and operational information throughout its life. It is a process, which ensures that the system performs as intended and is documented to a level of detail sufficient to meet needs for operation, maintenance, repair and replacement.”<sup>5</sup> Implicit in this description is the fact that configuration management applies to the entire system life cycle beginning with its planning and continuing through operations and maintenance. Configuration management also ensures consistency between requirements, design and operation. During system implementation, every hardware unit and every software module must have a supporting set of specifications, and it must be possible to associate each specification with a requirement. Similarly, it must be possible to identify a set of specifications that define every hardware and software module being acquired or programmed. There must also be an acceptance test for each of the requirements. The relationship between requirements, specifications, hardware and software modules, and tests is maintained in a database known as a traceability matrix, which is used to define their associations. This often-overlooked aspect of system implementation is an essential element of the systems engineering process.

The Configuration Control Board (CCB) is another important element of configuration management. All of the key participants in the system development must be represented on the CCB. Typically, they include the agency’s project manager, the contractor’s project manager, systems engineering personnel, configuration management personnel, a manager with the authority to commit funding to the project, and other stakeholder representatives and specialists as required by the subjects being discussed. All changes to the system including new requirements, design changes, value engineering changes, bug fixes etc. must be approved by the CCB before they are implemented. Implementation can only be initiated following the incorporation of suitable changes in the requirements and other project documentation. Change requests submitted to the CCB must be based on a formal process that includes the justification for the change, its anticipated cost and schedule impacts. If practical, the CCB will often defer non-critical changes to subsequent project phases. The CCB’s role is to ensure that configuration management procedures are implemented and to control the rate of scope creep that the project experiences. It requires close interaction between the agency and the contractor for its successful implementation. Practice has shown that the CCB can significantly reduce the rate of scope creep experienced by a complex project.

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<sup>4</sup> Sage, A.P. and Armstrong, J.E., “Introduction to Systems Engineering”, Wiley and Sons, 2000.

<sup>5</sup> ANSI/EIA 649 1998, National Consensus for Configuration Management 8-55

**Risk Management:** Risk management is the process of identifying potential problems before they occur, planning for their occurrence and monitoring the system development so that early actions can be taken. A typical ITS project potentially experiences many risks from technology, people and management. Representative risks include inadequate products, insufficient funding, staff turnover, delayed deliveries, incorrect schedule and budget estimates, etc. Risk planning cannot be performed in a vacuum. It must be a collaborate process between the contractor and the agency. Each organization has concerns that must be addressed. A plan must be developed for every risk that is identified as important to the success of the project. The plan must include a definition of the risk, its potential impact on the project if it occurs, and the mediation measures that will be taken to alleviate its impact. The plan must also include the metrics (measures) that will be used for early identification of the risk's occurrence.

**Validation and Verification:** Validation and verification are processes for ensuring that the correct system was built (validation), and that the system was built correctly (verification). Validation occurs at the end of each evolutionary development phase, at which time the system is subjected to actual operational use by its operators and stakeholders. At this time, fundamental design shortcomings (e.g. the system does not adequately serve the organization's business processes) in the system concept may be identified and corrected during subsequent development phases.

Verification is the process of testing the system as it is being developed (unit and subsystem testing). It is also the process of formal acceptance testing of the fully assembled system. Acceptance testing is generally performed at the conclusion of each development phase. Acceptance tests are based on the system requirements using the information contained in the traceability matrix, and must be passed before the agency begins using the system under operational conditions. Acceptance tests must generally be passed prior to final reimbursement of the contractor for work performed on a given development phase.

**Metrics:** Metrics are measures used to judge the system development progress. Target objectives are generally defined prior to the beginning of development that can be used as the basis for comparison for concluding that development is proceeding in a satisfactory manner. Metrics may also be used as the basis for reimbursing the contractor for partially completed products. Typical metrics might include deliverables (documentation, completed subsystems, installed field equipment, etc.). They might also include comparison of schedule milestones with actual work accomplished. Other metrics include number of requirements defined, number of fully tested software modules, length of communications conduit installed or any other measurement that is an accurate representation of development status. Metrics are tools used to support both systems engineering and project management activities.

## **PROJECT MANAGEMENT CONSIDERATIONS**

It is also important to consider the general principles of project management that must be followed for a successful ITS project. In many respects, these principles are the basis for

the steps that have been defined for the systems engineering process, and for this reason, they should be explicitly addressed when selecting the appropriate contracting activity. These principles have evolved from the recognition of the unique characteristics of software-based systems, which include the difficult (if not impossible) task of preparing definitive software specifications, the need to control changes in project scope (scope creep), and the challenging task of developing reliable cost and schedule estimates for the system development. The following principles are key considerations that should be addressed within the project management process:

- **Collaboration** – Historically, the culture of transportation contracting has been based on the contractor’s desire to complete the specified work at the lowest cost, while the contracting agency’s responsibility is to monitor the contractor’s work to ensure that the work is satisfactorily performed. By its nature, this can be a contentious process. A software-based project requires a close working relationship between the agency and the contractor to define the agency’s needs and business processes, clarify uncertainties in the specifications, fully define all functions to be performed, modify the work as necessary to meet the needs of the users and stakeholders, etc. In other words, the agency must become a participant in the project rather than an overseer, and the contractor must help define needs rather than attempting to satisfy the requirements of a rigid specification. The need for collaboration exists throughout all project activities, but its presence is most visible in the area of risk management, configuration management, definition of metrics, and preparation of the concept of operations. Without collaboration, it is not possible to ensure the success of a complex system development. Collaboration between the contractor and the agency is an unusual relationship for the highway transportation industry, which is more accustomed to dealing with a low-bid contractor on an adversarial basis. It is difficult but essential to change these ingrained habits.
- **Off-the-shelf-solutions** – The functions performed by ITS systems, are rarely unique. In most cases, they are nearly identical to those of other systems that have been previously installed. For example, the typical freeway management performs a basic set of functions which might include:
  - Variable message sign control
  - Highway advisory radio control
  - Traffic data collection
  - Weather data collection
  - Entry and display of construction information
  - Ramp metering
  - Incident detection
  - Positioning of closed circuit television cameras
  - Display of video images
  - Graphical display of traffic information

- Logging
- Storage and display of route diversion plans
- Control of HOV lanes
- Control of reversible lanes
- Maintenance diagnostics

The relative low number of functions performed in a system of this type, and their commonality with the similar functions of other systems, suggests the use of software developed for previously installed system. This is known as commercial off-the-shelf (COTS) software. The use of COTS software offers a number of advantages over the development of unique software including the acquisition of a relatively mature (previously tested) package, the economic benefits of sharing the cost of upgrades with other agencies and the ability to acquire a package whose capabilities can be viewed prior to the initiation of system acquisition.

Because of differences in field equipment and other aspects of the system configuration, it is unlikely that the COTS software can be purchased as a “shrink-wrapped” product that can be installed without some modification to reflect the unique conditions of the environment in which it will be used. Whenever possible, functional requirements should be adjusted for compatibility with currently available COTS products, in order to minimize the amount of new software development that might be required.

If many new capabilities and interfaces are required, COTS software cannot necessarily be used. However, even under these conditions, it is desirable to maximize the amount of mature previously tested software and hardware used in the new system. Thus a version of COTS software can be acquired and used in its current form in the new system, or it can serve as the starting point for the system being developed.

If COTS software is a possibility, its use should be considered during the procurement phase of the system acquisition, since the contractor using the preferred COTS solutions should receive priority consideration as the system implementer. Some agencies base their contractor selection on the premise that the companies who do not offer any COTS solutions represent the best (unbiased) choice for system implementation. The selected contractor is then asked to select the most applicable COTS software and manage its installation. Agency’s using this approach have frequently encountered difficulties due to the problems of managing two or more organizations (including at least a system designer and a system implementer) with poorly defined responsibilities, who are competitors in the ITS marketplace.

COTS software should always be considered preferable to new software development because it can almost always be acquired at a lower cost, and its use

in other locations generally ensures a higher level of reliability than that which would be result from the development of a new software package.

- **Prequalification/certification** – Many projects require offerors (bidders or proposers) to demonstrate that they are qualified to perform work on a planned project before their proposals (or bids) are evaluated. Traditionally, this prequalification activity includes demonstrations of financial capacity to perform the work, or evidence that similar projects have been successfully completed and demonstration of their personnel or other resources availability for the project. In the past, this form of prequalification has proved to be of little value to the development of software-based systems because of the difficulty of defining “similar projects” and “successful completion”. As a result, the prequalification frequently leads to protests by firms that have failed to qualify for a project, sometimes with disastrous consequences. A solution to this problem is the use of a prequalification that demonstrates the knowledge and ability of potential bidders to implement the full systems engineering and development process. This demonstration of systems engineering and development capabilities can be established by requiring the contractor’s verification that its processes have been verified by an accredited organization. The appropriate certification for software development is known as the Capability Maturity Model (CMM)<sup>6</sup>. CMM defines five levels of proficiency. The chaotic processes of the past are defined as level 1. Levels 2 or 3 are generally adequate for ITS projects. A firm that has received this certification provides the agency with some degree of assurance that the firm has established systems engineering processes, and that these processes are applied to software-based projects. When requiring CMM certification it is important to ensure that the operational unit performing the work (division, project team, etc.) has been included in the certification prequalification. ITS projects involving the development and delivery of products (such as toll collection systems involving the production of large numbers of toll tags) might consider using the ISO 9001<sup>7</sup> certification in addition to CMM certification. ISO 9000 provides similar verification of the processes in use by potential offerors, but emphasizes equipment development, delivery and installation.
- **Organizational Considerations** – The two elements of an ITS project with the greatest development risk, and the most uncertain costs and schedules are the software and systems integration activities. Yet ironically, the work associated with these elements is usually significantly less than ½ of the total project cost. As a result, a second or third tier subcontractor may perform the most critical aspects of the work, while the prime contractor may be an electrical contractor. This organizational structure places the organization with which the most collaboration is required, at arms length from the agency. Whenever possible during an ITS procurement, organizational structures should be required that permit the agency and the software developer/systems integrator to collaborate on the work, and make necessary adjustments as the work progresses. This can be

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<sup>6</sup> For more information see: [www.sei.cmu.edu/cmm/cmm.html](http://www.sei.cmu.edu/cmm/cmm.html)

<sup>7</sup> For more information, see: <http://www.iso.org/iso/en/iso9000-14000/iso9000/iso9000index.html>

most readily accomplished if the systems integrator (who is likely to be the software provider) is the prime contractor.

These considerations should be kept in mind when reviewing the contracting alternatives described in the following section.

## OVERVIEW OF CONTRACTING

A framework has been developed to support the description and analysis of contracting alternatives analyzed during this research project. As indicated in figure 5, contracting activities have been defined in terms of four dimensions plus the terms and conditions, which are, in effect, a fifth contracting dimension. Terms and conditions are agency-specific and will not be included in this discussion. Each of the dimensions of figure 5 must be analyzed and selected when defining the contracting to be performed for an ITS acquisition. The options and considerations associated with these dimensions are discussed in this section.

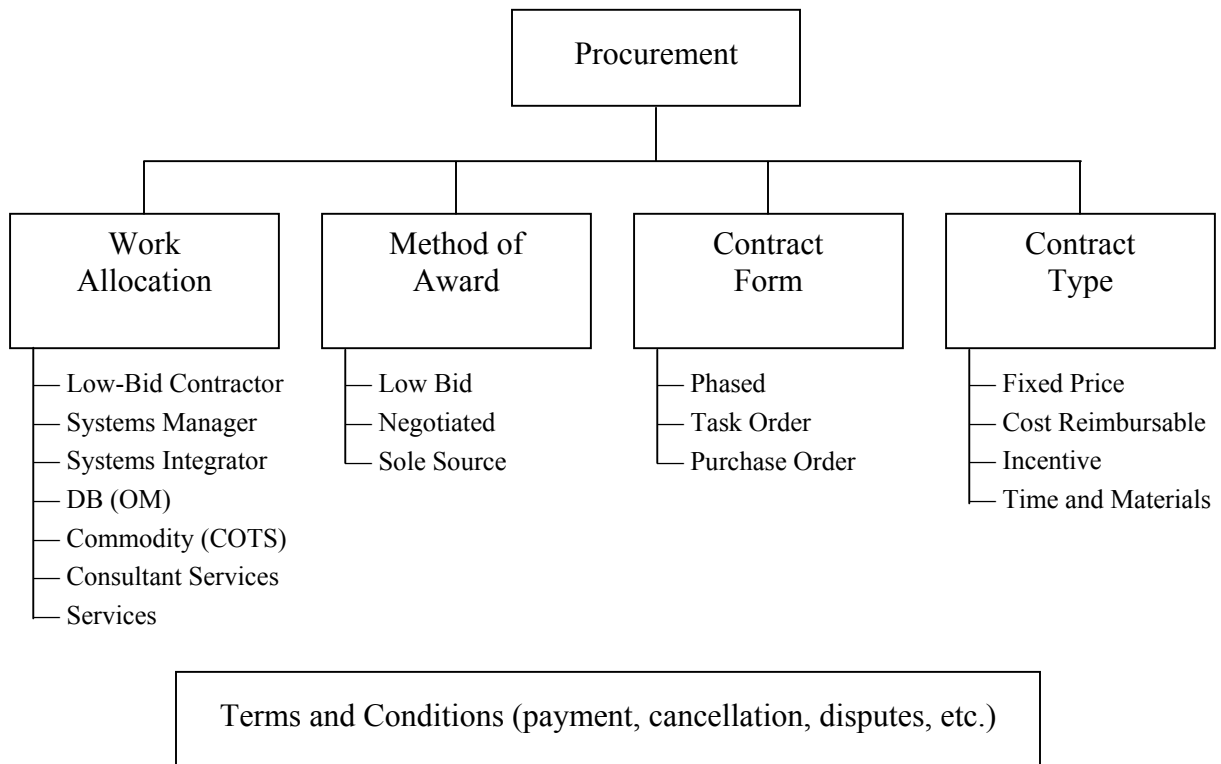


Fig. 5 Contracting Framework

Since contracting terminology is not always consistent, the terms used in the following discussion are defined here. To avoid the possibility of confusion, the following terminology will be used:

- Acquisition – A system acquisition is defined as the entire process of purchasing a system including planning, design, contracting, implementation, testing and acceptance.
- Burden – A percentage charge applied to the direct contract costs that cover the contractor’s cost of doing business. Typical burden items include overhead (rent, office supplies, business expenses, office equipment, legal expenses, etc.), fringes (employee benefits - including sick leave, vacation, health insurance, etc.), general and administrative costs (management costs).
- Commodity – A commodity is a product as distinguished from a service
- Consultant – A consultant is a contractor whose work is restricted to the provision of personal services. Consultants are not usually selected on a low-bid basis. They are generally restricted from providing hardware, construction services and electrical contracting services.
- Contract – A written agreement between two parties (in this case it is assumed that the parties will be the agency and an outside organization – usually a private sector firm) that is an agreement for doing or not doing something that is specified.
- Contracting – The selection of a firm to provide a set of services or products, as well as negotiating and executing a contract.
- Contractor – This term is used in two different ways. The general use of this term is that the contractor is an organization with which a contract has been signed. This general terminology can include a design contractor (consultant), software company, systems integrator, electrical contractor, construction contractor, etc. When the Consultant/Contractor form of work allocation is discussed, the term contractor is a reference to an organization that has been selected (usually on a low-bid basis) to implement a system specified by a consultant. To avoid confusion in the discussion of this form of work allocation, the organization selected in this manner will be referred to as a low-bid contractor.
- Direct Costs – Expenses directly attributable to work performed on a project, as opposed to indirect costs, which are unrelated to specific projects.
- Fee – Synonymous with Profit. The fee (or profit) is the payments received by the contractor in excess of contract costs and burdens that are value-added compensation for performing the work.
- Indirect Costs – Expenses of doing business that cannot be directly attributable to a specific project. Examples of indirect costs include office space, advertising, employee fringe benefits, etc.
- Invitation for bids (IFB) – A document released by a procuring agency requesting bids for services, equipment and/or commodities from potential contractors. A contract is awarded to the lowest responsive bidder.
- Negotiated Procurement – A process by which all procurement terms are discussed and may be reconsidered by the purchaser and the offeror. These terms

may include requirements, specifications, period of performance, location of work, scope of services, staffing requirements, etc. Negotiated procurements typically reflect a discussion of non-financial considerations prior to the discussion of the proposed contract cost although this “two step” evaluation is not always required.

- Procurement – Same as contracting
- Request for proposals (RFP) – A document released by a procuring agency asking for the submission of proposals for personal services from interested consultants.
- Statement of Work (SOW) – A section of a contract that defines the responsibilities and work to be performed by the contractor.

### **Work Allocation**

The work allocation category represents the project responsibilities defined by the agency for the contractor in the contract statement of work. These assignments are expressed in the systems engineering terminology – concept of operations, requirements, design, implementation and testing. They also include the crosscutting activities of configuration management, risk management, validation and verification, and metrics.

**Low-Bid Contractor:** This form of work allocation involves the selection of a contractor for system installation using the low-bid process. The contractor bids on a system design, typically prepared by a consultant. The consultant’s responsibilities are included in the “Services” category of work allocation. The consultant may provide a range of additional services including planning (concept of operations), requirements analysis, risk management and inspection. The low-bid contractor is responsible for furnishing a fully operational system including all hardware, software and construction services required to satisfy the consultant’s design as defined by the plans and specifications. If required to do so, the low-bid contractor also provides configuration management services. Both the low-bid contractor and the consultant participate in the system verification (acceptance testing). This work allocation typically requires the selection of a design consultant using a negotiated procurement (see definitions), and the selection of a contractor to provide the system using a low-bid procurement.

The allocation of responsibilities between a consultant working in the role of the agency’s representative, and a low-bid contractor is the same approach traditionally employed for new highway construction. For this reason, many agencies prefer to use the consultant as a designer and a low-bid contractor to furnish the system. The shortcoming of this approach is that it is difficult, if not impossible, to prepare a set of specifications for a software-based system that fully defines all features and functions to be provided. Low-bid contractors follow their interpretation of the specifications, which might differ from those of the agency. In addition, this approach is not compatible with systems with poorly defined characteristics, because of the likelihood of high levels of scope creep with their attendant change orders. Thus, consultant/low-bid contractor approach is best suited for procurement of very well defined systems that have been

installed elsewhere. It should be avoided for any system involving the development of new or modified software.

**Systems Manager:** The systems manager form of work allocation utilizes an organization known as the systems manager that has been selected using the negotiated method of award.

The scope of work defined by a systems manager contract may include all project activities associated with a system acquisition except for the provision of equipment<sup>8</sup>, electrical contracting and construction contracting. In other words, systems managers are operating under the constraints of consultant contracts, in that they can only participate in system implementation to the extent that personal services are being provided. Thus the systems manager may provide any combination of the following services:

- Planning and preparation of the concept of operations
- Definition of requirements
- System design including specification of construction services, electrical contracting services and equipment needed for the system implementation
- Software development
- System integration
- Testing at all levels including acceptance testing
- Inspection of construction and electrical contractor's work
- System operation and maintenance
- Risk management
- Configuration management including organization of the configuration control board
- Use of metrics to monitor project progress

The use of the systems manager simplifies the application of the systems engineering process. Thus it is critical that the systems manager be thoroughly versed in the principles and processes of systems engineering, software development and project management.

The agency is responsible for hiring low-bid contractors to provide equipment, construction and electrical contracting services. The agency's responsibility for the acquisition of this equipment and services, places it in an important role that can have a significant impact on the project's success or failure. These services must be acquired in

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<sup>8</sup> There are instances in which equipment can be furnished by the systems manager, subject to the interpretation of the agency's procurement organization. This is the case since the systems manager is only precluded from providing equipment and services that fall under the definition of construction. As a result, many agencies permit the systems manager to furnish control center equipment such as operator workstations, large screen displays and communications routers.

a timely manner, and must be responsive to the requirements of the specifications prepared by the systems manager.

Systems management contracting permits the use of the systems engineering and project management principles that have been discussed. It also permits the use of the evolutionary design process, since systems management contracts can be readily structured to accommodate the development of future system phases. Properly executed, the systems management enhances collaboration between the agency and the organization responsible for the system acquisition. It is significant that, in its role as a systems manager, the organization responsible for the highest risk aspects of the system development is the prime contractor.

**Systems Integrator:** The role of the systems integrator is similar to that of the systems manager, except that the integrator is not involved in the planning and design stages. The systems integrator provides all of the personal services associated with the systems implementation and relies on the agency to contract for construction, electrical contracting and equipment procurement. This form of work allocation offers the advantage that the systems integrator can be selected using a consultant selection. As the supplier of the software and systems integration services, the consultant becomes a prime contractor with which the agency has direct contact. But it has several disadvantages including the fact that a consultant is still required to perform the system planning and design leading to the problem of multiple points of responsibility as well as the need to coordinate and manage a large number of contractors.

**Design-Build (DB) Contracting:** DB contracting is based on an agreement “that provides for design and construction of improvements by a (single) contractor or private developer. The term encompasses design-build-maintain, design-build-operate-maintain, design-build operate, design-build-finance and other contracts that include services in addition to design and construction.”<sup>9</sup> According to the Federal rule<sup>6</sup>, when Federal funds are used in the project, design build contracting may only be used for ITS projects if “the estimated contract value exceeds \$5 million”. Design-build contracting is permitted for lower cost system developments with the prior approval of the Federal Highway Administration. The rule indicates that a two-step process may be utilized in which a short-list of no more than five offerors is selected based on qualifications, technical approach and past performance. In addition, it indicates that the final contractor selection must include the evaluation of price and the quality of the product or service being offered. Experience and past performance are optional considerations. Anecdotally, many professionals from both the public and private sectors have indicated that many design build awards tend to be made to the lowest bidder.

This form of contracting assigns total project responsibility to a single contractor, rather than splitting the responsibility between a design consultant and a low-bid contractor. The design-build contractor has all of the responsibilities of the systems manager, plus the ability to furnish equipment and electrical and construction contracting services.

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<sup>9</sup> Federal Register, Part II, Department of Transportation, Federal Highway Administration, 23 CFR Parts 627. et al. Design-Build Contracting; Final Rule, Tuesday, December 10, 2002.

Design-build contracts are typically preceded by the preparation of a partial design (sometimes designated a 30% design) prepared by a consultant. The design-build contractor is then responsible for completing the design as well as implementing the resulting system. This form of contracting is not allowed by some agencies.

Because they are based on a design planned and partially prepared by others, the design-build approach may experience the same problems as that of the consultant/contractor approach. In fact, the primary difference between the two is that the design-build contractor has the opportunity to influence the design (and subsequent specification) of the system being developed, and the flexibility to offer alternative approaches. However, when the design-build selection emphasizes low cost many of the barriers to collaboration and flexibility previously described for the consultant/low-bid contractor approach are created.

**Commodity (COTS):** Contracting for the acquisition of commodities is applicable to ITS contracting to the extent that an agency is procuring commercial-off-the-shelf (COTS) products. These may include field equipment such as variable message signs, traffic signal controllers, radios, or computers. From the perspective of the guidelines being produced in connection with this NCHRP project, consideration of commodity procurements is limited to COTS software and systems. As discussed earlier, the use of mature, tested software and systems is preferable to the acquisition of a new custom designed system. COTS procurements are quite different from consultant or low-bid contractor selections. The procurements are based on price and functionality of the COTS products. The management of a COTS procurement is also quite different from those discussed above. Acquisition focuses on delivery times, and verification of functions and features. The systems engineering process is not applicable to a commodity type application except to the extent that the process is used to define, validate and verify requirements.

The power of the COTS approach is well documented. As long ago as 1987, Frederick Brooks in his classic essay<sup>10</sup> stated “Any such product is cheaper to buy than to build afresh. Even at a cost of one hundred thousand dollars, a purchased piece of software is costing only about as much as one programmer year. And delivery is immediate at least for products that really exist, products whose developer can refer products to a happy user. Moreover, such products tend to be much better documented and somewhat better maintained than home-grown software.”

In cases where the COTS product is to be embedded into a system containing additional hardware and software, its installation may still require the use of a systems integrator or systems manager for its installation, adaptation and testing. An advanced traffic management system including the development of a control center with operator workstations and displays, but using COTS traffic management software, is one such example. This approach was used by the State of Utah when it adapted the Navigator

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<sup>10</sup> Brooks, Fredrick P., “No Silver Bullet” Essence and Accidents of Software Engineering”, from IEEE Computer; 20,4,10-19; April, 1987, and reprinted by Kemerer, Chris F., “Software Project Management Readings and Cases”, Irwin McGraw-Hill, New York, 1997, Pg 10.

traffic management software initially developed for the State of Georgia, for use in Salt Lake City. The Navigator software was implemented in Salt Lake City using a systems manager contract, in which the contractor was required to acquire and modify the Navigator software to meet the requirements of the new installation. Thus COTS software served as the basis for the implementation of a new system using a traditional form of system development.

However, a simple portable dynamic message sign system using COTS software along with portable signs provided by the same manufacturer would not require systems manager assistance. Because this report focuses on the development of complex systems, the commodity procurement is not considered in the comparison of procurement alternatives with the systems engineering process.

**Consultant Services:** Work provided by consultants is limited to provision of personal services. The use of consultants during the development of an ITS system has already been discussed in the context of the consultant/contractor, systems manager and design-build forms of work allocation. Some of the ways in which consultant contracts may be used include:

- System design and installation support – These services are typically provided for the purpose of developing a package of plans, specifications and estimates (PS&E) that serves as the basis for the selection of a low-bid and design-build contractors.
- Inspection - Inspection services might be provided in connection with construction activities and other contracting services provided by others.
- Design – Consultants might prepare designs for ancillary aspects of the ITS system including designs for installations of field equipment, control centers, roadway modifications, etc.
- Documentation and Training – Consultants other than the contractor responsible for the system acquisition might be employed to train agency personnel on the general principles of the technology with which they are working. Consultants might also be employed to develop documentation such as policy and procedures manuals for the use of ITS systems.

Thus consultant services are a key element of a system acquisition when low-bid and design-build contractors are used for the system implementation. Consultant services are used not only for initial design, but also to supplement the development activities during the system implementation.

**Outsource Contractor:** Outsourcing is the process by which organizations (public or private) use external providers to manage or maintain certain aspects of their business. Outsourcing is increasingly used by the public sector in response to citizen's demands for expanded services and due to the difficulty of competing with the private sector for highly skilled personnel. In some cases, outsourcing may result produce cost savings because of the outsource contractors' access to specialized resources including equipment, personnel and facilities. Contractors may also be able to deliver the needed

outsourcing support in a more flexible fashion by using streamlined contracting procedures, the absence of artificial constraints on personnel ceilings, and the ability to trade off capital expenditures with recurring maintenance and/or operating costs. As a result of these perceived benefits, government outsourcing is increasing at a rapid pace. For example, it is estimated that the overall Federal government's outsourcing will increase by approximately 16% between fiscal years 2001 and 2006, to a level of \$13.2 billion for IT outsourcing alone.<sup>11</sup> Total outsourcing expenditures including all types of support are significantly higher.

“But outsourcing also generates controversy. The results are mixed-some outsourcing initiatives fail to produce the expected results-and many agency managers see it as a means of government downsizing, an abdication of accountability or simply a risky financial maneuver.”<sup>12</sup> Difficulties encountered include lack of familiarity with the process, resistance from employee unions, changing political agendas, and uncertain support of budgetary requirements spanning multiple fiscal years. As a result, successes such as those experienced by Chicago's Public Housing Authority, the City of Phoenix's municipal services and the State of Pennsylvania's data processing functions, are offset by problems that have been experienced by the City of San Diego, and the State of Georgia.

Maintenance services are the most frequently used type of outsourcing in ITS. However, this form of contracting has also been used to provide system operations. The best known example of operations and maintenance outsourcing, is the INFORM system a regional traffic management system managed by the New York State DOT for the Long Island roadway system. INFORM operates 24 hours per day, seven days a week, and covers approximately 180 miles of roadway. This extensive system includes 113 variable message signs, 84 CCTV sites, 81 video detectors, 2,400 loop detectors, 75 ramp meters, 177 traffic signals, 2 highway advisory radio sites, 9 weather monitoring stations and 15 Help vehicles.<sup>13</sup> The system engineering, operations and maintenance is outsourced to consultants and contractors and administered by State personnel. New York State personnel have concluded that the annual cost of outsourced operations and maintenance are equal to 7 to 10% of the system's present worth. They have determined that the present worth values are \$1.0 million per freeway centerline mile and \$600,000 per arterial centerline mile. They emphasize the importance of continuous reevaluation of cost escalation due to system expansion and normal inflation, to ensure that operations and maintenance budgets keep pace with system requirements.

In some cases the agency will outsource its entire requirement for the implementation of a particular capability. This form of outsourcing is designated “Performance Based Services”. It is up to the contractor to furnish and install the system required to provide

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<sup>11</sup> “Government Outsourcing Grows Fastest of all Sectors”, Washington Technology, <http://www.washingtontechnology.com/>, Dec. 3, 2004.

<sup>12</sup> “Outsourcing in Government: The Path to Transformation”, Accenture, <http://www.accenture.com/xd/xd.asp?>, Posted June 2002.

<sup>13</sup> “DRAFT Case Study INFORM (10-29-04)”, TMC Business Planning and Plans Handbook, TMC Business Models, Federal Highway Administration, Washington, DC  
<http://tmcpsfs.ops.fhwa.dot.gov/cfprojects/>

that capability in the manner needed to meet the service requirements defined by the agency. In many cases, systems provided with this turnkey form of outsourcing remain the property of the contractor since the agency is providing financial support required to receive a certain level of services rather than paying for the acquisition of a system. Each of these types of outsourcing is summarized in this section.

**Maintenance Outsourcing:** System maintenance can be performed by the agency, it can be outsourced to a maintenance contractor, or a hybrid approach can be used, in which some system elements are maintained by the agency and others by a contractor. The hybrid approach is typically used by agencies experienced with the maintenance of field equipment (variable message signs, cameras, detectors, etc.), but with little capability in the maintenance of computer and telecommunications hardware and software. In these cases, field hardware is maintained by the agency and the central system is outsourced to a maintenance contractor. Central system maintenance is often (but not always) performed by the contractor that installed the system because of their familiarity with the details of complex software code and complex wiring. This approach is recommended for central system maintenance unless the contractor's work has been unsatisfactory, or sole source contracting to the system provider is precluded by state contracting policies. Whether outsourced or performed by the agency, maintenance activities should include many of the same systems engineering activities that are performed during the installation including:

- **Configuration Management, which** must be performed throughout the life of the system in order to facilitate maintenance activities and to track equipment performance. A good configuration management system will enable the evaluation of equipment reliability and the determination of the times at which equipment should be replaced because of increasing failure rates. Whether or not maintenance is outsourced, a Configuration Control Board (CCB) is required to control the introduction of new system features and to track maintenance activities that affect the overall system configuration.
- **Risk Management:** It is important to perform risk management planning and risk mitigation during the maintenance phase of the project. Since the maintenance phase of the project includes risks that are different from those that exist during the construction phase, the risk management process must be initiated from the beginning. Maintenance risks are associated with items such as catastrophic failures, availability of spares, contractor performance, and unanticipated equipment reliability problems.
- **Validation and Verification:** Validation and verification processes are relatively straightforward for the maintenance phase. Validation is typically an operational activity and is not performed by the maintenance contractor. Verification should be routinely performed by the maintenance contractor during repair and replacement activities. In the event that maintenance is outsourced, the agency should spot-check the contractor's verification activities to ensure that they are performed in accordance with the agency's requirements.

- **Metrics:** Maintenance metrics are different from those used during system installation. Metrics track both contractor performance and system performance. Typical metrics for the contractor include contractor’s response times, repair times, employee turnover rate, extent of failed components, etc. Typical system metrics include availability, mean times between failures, replacement equipment and component availability and cost, etc.

In the event that maintenance activities are outsourced, the requirement to perform these crosscutting activities must be included in the maintenance contract.

Operations Outsourcing: While operations are outsourced less frequently than maintenance, this form of outsourcing is not unheard of. Operations services for the INFORM system are outsourced to a private firm that furnishes a staff of approximately 26 full time equivalents (FTEs). Through contracting, the State places the complete staffing burden (recruiting, hiring, training and firing) on the private contractor.

Performance Based Services: Contracts for performance based services are initiated by agencies that do not want to be involved with the implementation of a complex system or service, but would prefer to contract on the basis of outcomes rather than specifying the manner in which a particular system or service is to be provided. In other words, the agency is contracting for an end result, rather than defining the system that is needed to produce the desired result.

This form of contracting is often used when there is an opportunity for the private sector to leverage the public sector funding by providing revenue generating, value-added services to travelers. Two examples of these types of services include traveler information systems and commercial vehicle systems. The advantages and disadvantages of performance based contracting are summarized in Table 1

Consideration	Advantages	Disadvantages
Contractor Selection	Simplified, in that it is based on offeror’s capabilities and financial proposal	Difficult to evaluate and compare alternate technical approaches
Ownership	System (if any) is owned and operated by the contractor. No need for agency to consider operations and maintenance.	In the event that the contractor is cancelled, the agency’s investment in system development is lost
Intellectual Property	No need to negotiate complex intellectual property rights agreements. Contractor owns intellectual property	Innovations suggested by agency typically become property of contractor unless otherwise specified

Requirements	Requirements defined in terms of outcomes, rather than outputs. Theoretically, outcome-based contracts ensure the achievement of the desired end product.	Difficult to define and measure outcomes. For example, the outcome for a traveler information system may be the percent of traffic that diverts during an incident due to the availability of traveler information. May be impossible to measure.
Priorities	Agency’s priorities are typically improved mobility and safety, or reduced transportation costs	Contractor’s priority is profitability Agency and contractor priorities may be different.
Successes	Private sector continues to pursue performance-based contracting opportunities	To-date, few successes to report. Most contracts of this nature have failed due to overly optimistic financial projections.

*Table 1. Assessment of Performance-Based Contracting*

From this table, it is evident that in some specialized situations, performance based contracting may be an attractive contracting approach. However, there are many potential pitfalls associated with defining and achieving desired levels of performance, with the result that this form of contracting should be used very selectively. In addition, it is essential that an exit strategy be developed for situations in which performance-based contracting is being considered. It is important to decide in advance whether (and how) the agency will continue to offer a particular service in the event that the relationship with the outsourcing contractor must be terminated.

**Services:** Contracts for other forms of services are frequently awarded during the life cycle of an ITS system. Technically, many of these other services may also be considered consulting services. The differentiation is made here to identify services that are outside the mainstream of system development. There are many forms of general services for which an agency may contract during an ITS life cycle. Representative services include:

- **Inspection:** Consultants may be employed to inspect the work of electrical and construction contractors. While field inspection is generally performed by agency staff, the requirements for inspection of ITS installations may be specialized and fall outside of the knowledge and capabilities of the traditional inspectors. For this reason, consultant assistance may be employed.
- **Independent Verification and Validation (IV&V):** These services are typically provided by an outside organization employed to examine the software, hardware and products being provided by the ITS contractor. IV&V services typically also assess the degree to which the contractor is adhering to the principles of systems engineering including such items as configuration management, quality assurance, testing, etc.

- **Data Collection and Entry:** Services are often required in connection with an ITS implementation for the collection and entry of data required to support the system operation. A wide variety of data may be required including:
  - Traffic count data to support the development of traffic signal timing plans
  - Traffic flow data required to verify the operational effectiveness of the system during acceptance testing.
  - As built data that describes the installation
  - Survey data required for placement of vehicle detectors and/or cameras
  - Geographic information to be used in the preparation of graphical user interfaces
- **Outreach:** A variety of outreach services may be employed for public relations and to inform other agencies of the system development that is underway.
- **Independent Service Providers (ISPs):** Contracts will be negotiated with a variety of service providers for Internet website hosting, telecommunications service, leased lines, etc.
- **Staff supplements:** Consultant services may be employed to supplement the existing agency staff. The consultant may provide employees that perform any of the functions associated with a system development including such items as contractor oversight, documentation reviews, testing and coordination.
- **Training:** Although the installation contractor is usually contractually responsible for providing training related to the operation and maintenance of the system being acquired, consultant services may be required to provide supplementary training of a more generalized nature. Consultant training may be provided to acquaint agency staff with the general principals of system management and traffic operations. It may also be provided to describe the general principles of system development including such items as configuration management, concepts of operations and risk management.

The dimensions of contracting discussed here are based on the considerations associated with the acquisition of a particular ITS system. However, these principles are also applicable to the acquisition of a broad range of services including consulting services (design, inspection, etc.), outsourcing, and other services. The process of contracting for services (as opposed to products or construction) is well defined. It is based on the use of a negotiated contract as the method of award. Any contract form (phased, task order or purchase order) may be used, and the contract type may be fixed price, cost reimbursable, incentive or time and materials. The criteria used for selection of contract form and contract type are the same as those that would be used for a system implementation.

## **METHOD OF AWARD**

The method of award category of contracting defines the criteria used and steps taken to select a contractor to perform the work. The method of award is determined by the form

of work allocation that has been selected. As indicated below, there are distinct differences between the various methods of award. These differences should be taken into account when selecting a form of work allocation.

**Low-bid:** Low-bid contracting commonly referred to as sealed bidding is a contracting method that employs competitive bids, public openings of bids and low price awards. This contracting method must describe the agency's requirements clearly, accurately and completely. Restrictive specifications or requirements that might unduly limit the number of bidders are not allowed. The Invitation for Bid (IFB) generally includes all documents whether attached or incorporated by reference furnished to prospective bidders for the purpose of preparing their bids. Bidders submit sealed bids to be opened publicly at a specific place and time and the bids are then evaluated without discussions with the bidders. Award of the contract is made to the responsive and responsible bidder, whose bid is most advantageous to the agency, considering only price and the price-related factors defined by the IFB.

**Negotiation:** Unlike formal advertising of a contract requirement which is precise, highly structured method of procurement with one definitive set of procedures, negotiation allows considerable flexibility, permitting the use of a number of different procedures in making awards. Negotiation differs considerably from low-bid procurement. First, proposals are not available for public inspection prior to award. In contrast, under low-bid procurement, public opening of bids is a major step in the selection of a contractor.

Second, the agency is not required to reject proposals that vary from the Request for Proposals (RFP) requirements but may consider such proposals. Thus, negotiation does not involve the concept of responsiveness developed in low-bids where the agency is prohibited from considering a bid that deviates from the IFB. This prohibition is not applicable to negotiation where the agency is permitted to conduct oral or written discussions with offerors whose proposals vary from the RFP.

Third, the negotiations permit discussions between the parties and modifications of proposals by offerors while low-bid does not. Finally, under negotiation, the procuring agency's source selection officials have a much greater discretion in selecting the successful offeror for award. They are not required to award to the low bidder but may "trade off" cost to the agency against other factors such as technical performance, management capability, and demonstration of technical capabilities using factors such as staff qualifications and certifications such as CMM in arriving at the source selection decision. Negotiation may be competitive or they may be held with a single organization identified as the conditionally selected offeror. Alternatively, some agencies choose to have very little contact with offerors prior to the final selection.

The negotiated selection is typically based on the evaluation of a technical approach, qualifications and experience as represented in a technical proposal and possible subsequent presentations to the agency. The Federal Acquisition Regulations (FAR) indicates that the negotiated procurement process should consist of a mix of technical,

qualifications and cost considerations defined in advance by a source selection authority (evaluation panel). The FAR indicate that: “The source selection authority’s (SSA) decision shall be based on a comparative assessment of proposals against all source selection criteria in the solicitation. While the SSA may use reports and analyses prepared by others, the source selection decision shall represent the SSA’s independent judgment. The source selection decision shall be documented, and the documentation shall include the rationale for any business judgments and tradeoffs made or relied on by the SSA, including benefits associated with additional costs. Although the rationale for the selection decision must be documented, that documentation need not quantify the tradeoffs that led to the decision.”<sup>14</sup>

It must be emphasized that the FAR applies to Federal procurements. State policies and procedures may be more restrictive. Many states require that the consultant selection process be based exclusively on merit as reflected by the offeror’s technical proposal and qualifications. Cost negotiations occur following the consultant selection and negotiation of technical terms.

**Best Value:** Best value selection is most often used for the selection of design-build contractors. The best value selection combines the features of the negotiated and low-bid procurements. During the first step in this process, offerors (contractors) submit their proposed designs for evaluation and negotiation with the procuring agency. Following these negotiations, and the development of an acceptable design, the contractor submits a bid for the design that has been approved. Selection may be made based on the proposal that offers the best value to the procuring agency. However, in many cases, the lowest bid is selected.

**Sole Source:** Sole source procurement is the direct selection of a contractor without competition. Although this form of contractor selection is discouraged and may be illegal, there are some cases for which it is appropriate including:

- The selection of a contractor that provides unique services or products that cannot be acquired elsewhere. One such example is the lease of telecommunications lines from the local telephone service provider.
- The acquisition of field equipment compatible with existing equipment. A common example would be a modest expansion of a system that currently consists of a homogenous set of existing equipment (controllers, dynamic message signs, weather stations, etc.) Maintaining a homogenous set of field equipment may offer the advantage of a simplified spares policy as well as lower cost maintenance and training.

Because sole-source contracting is associated with a unique set of circumstances, it does not receive further consideration in this report.

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<sup>14</sup> Federal Acquisition Regulation FAC 2001-2002 February 19, 2002, Paragraph 15.308.

## Contract Form

The contract form defines the manner in which work is authorized. Three contract forms are defined, phased contracts, task order (or indefinite quantity) contracts, and purchase orders.

**Phased Contracts:** Phased contracts are the conventional form of contracting that is in use for the majority of projects including ITS acquisitions. Phased contracts divide the work into predefined activities. The contractor is authorized to begin work on a particular contract phase through the issuance of a simple letter by the agency. For the purpose of this report, single-phase contracts are a specialized form of phased contracting.

Work may be divided into phases for a number of reasons including:

- Management simplicity – It is easier to supervise the contractor’s activities if the work is subdivided into smaller elements that can be more easily monitored.
- Funding – At time of contract signing, inadequate funding may be available for all contract phases. Authorization to begin work on a phase occurs only when adequate funding has been identified.
- Desire to assess contractor’s performance – Phased contracts provide the agency with logical decision points at which go/no-go decisions can be made to continue with the current contractor. If contractor performance is unacceptable, new phases can be awarded to another organization.

The distinguishing characteristic of phased contracts is the fact that work is well defined for all contract phases. As a result, this form of contracting is only applicable to the waterfall form of development. It cannot be readily used for the spiral or evolutionary development models.

**Task Order (Indefinite-Delivery) Contracts:** Indefinite-delivery contracts are used with contracts in which the required supplies and services are unknown at the time of contract execution. They provide a mechanism for the agency to place orders for these supplies and services during the life or term of the contract. In the case of ITS projects, the supplies and services requested are defined in terms of task orders that define the work to be performed by the contractor.

The three types of indefinite-delivery contracts are: Definite-quantity, Requirements, and Indefinite-quantity contracts. The appropriate type of indefinite-quantity contract may be used to acquire supplies and/or services when the exact times and/or exact quantities of future deliveries are not known at the time of contract award. These contracts are also known as delivery order contracts or task order contracts. Cost risk and administrative burden is shared between the procuring entity and contractor. These types of contracts \*further limit the procuring entity's obligation to only the minimum quantity specified in the contract and permit faster procurement of supplies and services as the contract requirements evolve.

Indefinite delivery contracts are ideally suited to both the evolutionary and spiral development processes, since they permit the issuance of task orders for additional planning, design and implementation services as various evolutionary phases evolve.

**Purchase Orders:** A purchase order is a form of sole-source contracting used for relatively small procurements. The cap on purchase order contract size varies among agencies, but is typically less than \$50,000. Purchase orders are a simple, rapidly executed form of contract that usually contains a standard set of terms and conditions (payment, insurance, cancellation clauses, etc.) and a relatively brief description of the work to be performed. Because this contract form is not applicable to the acquisition of large scale ITS systems, it is not discussed further in this report.

## **Contract Types**

Innovative contracting today is proving to be an acquisition methodology, which is saving more money and enhancing critical mission attainment. It requires structuring all aspects of an acquisition around the purpose of the work to be performed as opposed to how the work is to be performed or broad and imprecise statements of work. It often emphasizes quantifiable measurable performance requirements and quality standards in developing statements of work, determining contract types, incentives, selecting contractors and performing contract administration, including contract monitoring and oversight. Procuring entities are working to provide meaningful incentives for the contractor and the agency to encourage successful contract performance.

Numerous types of contracts are available for use with different types of projects and under various circumstances. Contract types may vary according to the degree and timing of responsibility assumed by the contractor for the costs of performance and the amount of time and nature of the profit incentive offered to the contractor for achieving or exceeding specific standards or goals. Contract types include a range of alternatives from firm fixed price, whereby the contractor assumes full responsibility for the performance costs and any profit or loss, cost plus fixed fee, whereby the contractor has minimal responsibility for the performance costs and the fee (profit) is fixed and time and materials, in which the agency assumes the financial risk for the successful project completion. Other contract types vary, but generally deal with incentives whereby the contractor's responsibility for performance costs and profit and/or fee incentives are dependent upon the uncertainties associated with the desired outcomes of the procurement.

Performance-based and design-build contracting methods continue to gain popularity in the ITS arena and prove to be both cost efficient and technically superior. These contract methods can combine performance specifications with incentives and penalties to achieve desired results based on the established goals and objectives of the procuring entity and at the same time, place more risk on the contractor. In these methods of contracting, the acquisition is structured around the purpose of the work to be performed as opposed to the manner in which the work is to be performed. The contractor is given freedom to

determine how to meet or exceed the procuring agency's performance objectives and quality levels are achieved and payment is only made for services that meet or exceed these levels.

**Fixed Price Contracts:** Fixed Price contracts place the risk and full responsibility for all costs and profit or loss on the contractor. After award, price under this type contract does not increase regardless of the costs incurred by the contractor during the performance of the contract. This type contract places the burden on the contractor to maintain control of costs and perform in the most effective and efficient manner. The agency on the other hand assumes the least risk and administrative burden. There are types of fixed price contracts that have an award fee or incentives where the award fee is based solely on factors other than a percentage of contract cost, however, the contract type remains firm fixed priced when used with these incentives.

Fixed Price contracts are best used for procuring commercial items and/or supplies or services when a definite functional or detailed specification can be fully defined. In addition, this type contract is preferred when the procuring entity can establish fair and reasonable prices, i.e. when there is adequate price competition, reasonable price comparisons in the marketplace, and available cost or pricing information. There are many variations of fixed price contracts that provide flexibility in the payment of both costs and fees (profits) to the contractor. Variations that are applicable to the development of intelligent transportation systems include:

- **Fixed Price Firm Target:** A fixed-price firm target contract specifies a target cost, a target profit, a price ceiling (but not a profit ceiling or floor), and a profit adjustment formula. This type contract is appropriate when the parties can negotiate at the outset a firm target cost, target profit adjustment formula that will provide reasonable incentives and a ceiling that provides for the contractor to assume an appropriate amount of the risk.
- **Fixed Price with Successive Targets:** This type of contract is a variation of the firm target alternative. It specifies an initial target cost, an initial target profit, an initial profit adjustment formula, a production point at which the firm target cost and profit will be negotiated and a ceiling price that is the maximum that may be paid to a contractor. This type contract is appropriate when cost or pricing is not sufficient to permit the negotiation of a realistic firm target cost and profit before award.
- **Fixed Price Award Fee:** This contract specifies a fixed-price including normal profit for a contractor's effort and provides for periodic evaluation of the contractor's performance against an award fee plan. This type of contract is used when the agency wishes to motivate a contractor and other incentives cannot be used because the contractor performance cannot be measured objectively. It differs from the first two forms of contracting in that the determination of the award fee is subjective, while the target fees are calculated on a formula basis.
- **Fixed price with Economic Price Adjustment:** Fixed-price with economic adjustment contract is a contract that provides for upward and downward revision

of the stated contract price upon the occurrence of specified contingencies. Economic price adjustments are of three general types and are based on established prices, actual costs of labor and materials, and cost indexes of labor and materials. This type contract is used when there is serious doubt concerning the stability of the market or labor conditions that exist during an extended period of contract performance.

**Cost Reimbursement Contracts:** Cost reimbursement contracts provide for payment of contractor costs, to the extent identified in the contract scope of work or specification. Cost reimbursement contracts establish an estimate of the total cost for the purpose of obligating not-to-exceed funds for the contractor (except at its own risk) without the approval of the procuring entity. Cost reimbursement contracts are used when the procuring entity is not clear as to total cost estimated to perform the work under consideration with complete accuracy. These type contracts place more of the cost risk and administrative burden on the procuring agency and less on the contractor. The contractor's risk is implicit in the fact that a fixed fee will be paid independent of the actual cost of performing the work. Thus, while the contractor is guaranteed a profit (as opposed to fixed price contracts where the contractor can lose money), the profit measured as a percent of total cost can vary considerably.

Cost reimbursement contracts are applicable to ITS developments where the end product cannot be fully defined. This is generally the case for projects involving the development of new or modified software. It is also used for research and development or preliminary exploration or study where the level of effort required is unknown. Forms of Cost Reimbursement contracts include:

- **Cost plus Fixed Fee (CPFF):** This is the most common form of cost reimbursement contracting. The contractor is reimbursed for all costs associated with performing the work plus an audited burden. In addition, the contractor receives a fee negotiated based on the actual cost of performing the work. The fee payment is fixed and does not vary whether the actual cost of the work is higher or lower than the original estimate.
- **Cost plus Incentive Fee (CPIF):** Cost-plus-incentive-fee contract is a cost-reimbursement contract that provides for the initially negotiated fee to be adjusted later by a formula based on the relationship of total allowable costs to total target costs. This contract specifies a target cost, a target fee, minimum and maximum fees, and a fee adjustment formula. This type contract is used for services or development and test programs when a cost-reimbursement is necessary and a target cost and fee adjustment formula can be negotiated that are likely to motivate the contractor to manage the effort effectively.
- **Cost plus Award Fee (CPAF):** Cost-plus-award-fee contract is a cost-reimbursement contract that provides for a fee consisting of a base amount fixed at the inception of the contract and an award amount that the contractor may earn in whole or in part during contract performance. This type contract is used when the work to be performed is such that it is neither feasible nor effective to devise

objective incentive targets on costs, technical performance or the performance schedule.

The Federal Acquisition Regulation (FAR) defines cost reimbursable contracts in the following manner: “Cost -reimbursement types of contracts provide for payment of allowable incurred costs, to the extent prescribed in the contract. These contracts establish an estimate of total cost for the purpose of obligating funds and establishing a ceiling that the contractor may not exceed (except at its own risk) without the approval of the contracting officer.”<sup>15</sup> In the event that the costs exceed the estimate, the FAR indicates “However, in the event the work cannot be completed within the estimated cost, the Government may require more effort without increase in fee, provided the Federal Government increases the estimated cost.”<sup>16</sup> In other words, if the cost exceeds the initial estimate, the Federal Government is obligated to pay the cost in order to receive the finished product, but is not obligated to pay any additional fee.

This differs from the policy of many states, which apply a contract ceiling (maximum dollar expenditure for cost and fee) to cost reimbursement contracts while requiring the contractor to furnish a completed product. This restriction, effectively converts the contract into a fixed price contract with the additional burden (to the contractor) of supplying the agency with extensive financial backup information to support its invoices. Incentive contract ceilings requiring completion of work should be avoided and fixed price contracts used in their place, since these types of “hybrid” CPFF contracts capture the worst features of incentive and fixed price contracts. This approach should only be used if the agency is willing to accept a partially completed project when the contractor’s expenditures have reached their ceiling amounts.

**Time and Materials Contracts:** Time and materials contracts allow for procuring supplies or services on the basis of direct labor hours at agreed to fully burden fixed hourly rates and materials at cost, including material handling fees as a part of material costs. Time and material contracts are generally used when it is difficult to accurately estimate the extent and duration of the work to be performed by the contractor. This type contract provides no positive profit incentive to the contractor for cost control or efficiency and places the majority of risk on the procuring entity requiring extreme care to ensure the proper level of contract monitoring and oversight is obtained.

**Incentive Contracts:** Incentive contracts establish reasonable and attainable targets that are clearly defined and communicated to the contractor and include proper incentive arrangements designed to motivate contractor efforts that might not otherwise be emphasized and discourage contractor inefficiency and waste. When predetermined formula-type incentives on technical performance or delivery are included, increases in profit or fee are provided only for the achievement that surpasses the targets, and decreases are provided to the extent that such targets are not met. The incentive increases

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<sup>15</sup> “Federal Acquisition Regulation”, Paragraph 16.301-1, General Services Administration, Washington, DC, September 2001.

<sup>16</sup> “Federal Acquisition Regulation”, Paragraph 16.306 (d)(1), General Services Administration, Washington, DC, September 2001.

or decreases are applied to performance targets rather than minimum performance requirements.

When considering the possible use of incentives, it is important not to be misled by the positive results produced by incentives that have been used to encourage early completion of civil construction contracts. The same degree of schedule compression cannot be achieved with software-based projects. As a result, incentives can have only a modest impact on overall cost and schedule. This fact is well documented by the software industry. For example, one source indicates that “you can compress software development schedules 25% of nominal, but no more.”<sup>17</sup> Theoretically, schedule compression on labor-intensive software and systems integration projects can be achieved by merely adding additional staff to the project. However, this technique has the unfortunate impact of increasing the schedule, due to the need for increased coordination and other forms of interaction among the programming team. The need for communication among members of the programming team grows at a faster rate than the size of the team. In addition, new members of the team must be mentored by existing team members, with the result that the productivity of the most important team members is further reduced. The only proven technique for schedule compression is reduced functionality. This can only be accomplished with collaboration and contracting flexibility; two features that are difficult to implement when fixed price contracting is used.

Incentives are effectively built into the fixed price and cost reimbursement contracts described above. In the case of these contracts, the possible variations in fee are essentially intended to offer incentives to contractors to meet or exceed the contract requirements. Since it is to the procuring entities advantage for the contractor to assume substantial cost responsibility and an appropriate share of the cost risk, fixed-price incentive contracts are preferred when costs and performance requirements are reasonably certain.

Delivery incentives should be considered when the delivery schedule is critical. Incentives defined at the time of contract signing permit the contractor to develop a project management plan that will ensure that the schedule is met. Explicit incentives may be defined separately from the contract terms for contractor reimbursement. These incentives and disincentives include award of early completion bonuses and late delivery penalties.

Late delivery penalties may be defined in terms of liquidated damages, which are a penalty that is assessed for late delivery of a system, when the actual damage to the agency due to the delay is difficult to ascertain. However, when considering the use of liquidated damages as a disincentive for late delivery, it is important to recognize that:

- Courts generally do not enforce liquidated damages that are intended to serve as a penalty or are far in excess of the amount of damages the parties may reasonably

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<sup>17</sup> Royce, Walker, “Software Project management – A Unified Framework”, Addison-Wesley, Reading, Massachusetts, 1998, pg. 18

forecast. For this reason, the agency must be prepared to justify the value of the damages it intends to assess.

- On negotiated contracts, contractors will often request the use of symmetrical contract provisions. In other words, contracts with provision for a certain level of liquidated damages (say a penalty of \$500 for each day the contract is late), be offset with an equal bonus (say a payment to the contractor of \$500 for each day the contract is early).

When appropriately applied, this combination of incentives and disincentives can be a powerful motivator to contractors providing the work does not include a significant percentage of new software development, and a high level of uncertainty regarding the system requirements.

**Performance-Based Contracting:** Performance based contracting is a form of contractor incentive or disincentive, in that payments made based on the outcomes resulting from the system installation. Contracting today and in the foreseeable future will place special emphasis on what the agency wants performed by the contractor, (outcomes), versus the manner in which the work should be performed. In other words, more general work scopes, and more specifics on final system performance defined in measurable terms. Performance standards (i.e., quality, quantity, timeliness) will then be assigned to tasks, and an associated quality assurance (QA) plan that describes how the agency will measure contractor performance against the standards will be developed. Positive and negative incentives based on the QA plan measurements can then be used to adjust contractor's payments, in order to ensure a high level of performance. However, performance-based contracting must be used carefully, because of the difficulty of providing definitive goals that will not lead to subsequent disputes with the contractor. One unsuccessful example that illustrates the potential pitfalls of performance-based contracting occurred when a state agency contracted for the installation of an adaptive traffic signal system. The contractor agreed to a performance-based contract in which the fee would be based on the percent reduction in delay that resulted from the operation of the new system. However, a significant increase in traffic demand occurred during the system installation period that negated any potential benefits that might have been produced by the system. The contractor claimed that it was eligible for the entire incentive payment and was able to produce simulation results in support of this claim. The state claimed that the traffic demand was due, in part to the late delivery of the system, which was caused by the contractor.

The importance of selecting the proper type and method of contracting for ITS procurements cannot be over stated. The primary concern for using innovative contracting approaches is the reduction in time and resources from project planning through construction and final acceptance and completion. By using the most effective type contract that focuses on innovation, the procuring entity will provide real benefits in terms of cost, time and quality.

## RELATIONSHIP BETWEEN CONTRACTING AND SYSTEMS ENGINEERING

Each of the four dimensions of procurement, to a greater or lesser extent, has an impact on the manner in which systems engineering process can be applied. The challenge is to select a procurement approach that:

- Compatible with the agency’s capabilities (including experience) and personnel resources needed for project management and support.
- Appropriate for the project characteristics including the project’s complexity and uniqueness
- Supports the systems engineering process, and the principals of high technology project management.

Many of these issues will be considered during Task 5 of this project. The purpose of this task 4 report is limited to consideration of the relationships between procurement and systems engineering. These relationships will be discussed in terms of the four dimensions of procurement and the system engineering process (including the steps of the “V” diagram, the alternative processes and the cross-cutting activities), along with the principles of project management.

The details of the relationships between the work allocation and the systems management/project management process and principles are presented in the appendix and summarized here.

### Work Allocation

Work allocation has one of the most significant impacts on the relationship between systems engineering and procurement. For example, constraints on contractor participation in the process prevent active participation of low-bid contractors in the early stages of system planning and design that are essential elements of the process. These restrictions are portrayed in the summary of responsibilities and relationships presented in Tables 2 and 3 below. Commodity procurements and services contracts are not included in this comparison since they are not directly related to the system acquisition. Tables 2 and 3 present a simplified view of the process, but only to define the fundamental relationships between the procurement and systems engineering processes.

In this table, the reference to an optional activity (“O”) means that the agency can optionally select the assignment for a given responsibility. It is not intended to indicate that execution of the activity is optional. For example, either the agency or the consultant might perform the inspection activity. It is up to the agency to determine who will be assigned the responsibility for performing this work. The steps for which an N is entered, indicates that the work is performed by an organization other than the one for whom the data is entered. For example, the N for the systems integrator in the Requirements row, is provided as an indication that the systems integrator will not be defining requirements, but either the agency or its consultant will be performing the work

System Engineering and Project Management Processes	Consult./Contractor		Systems Integrator	Systems Manager	Design-Build	Outsource Contractor
	Consult.	Low-Bid Contractor				
Planning (concept of operations)	PO	N	N	PO	N	N
Requirements	P	N	N	P	Partial <sup>18</sup>	N
Design	P	N	N	P	Partial <sup>19</sup>	P
Implementation	N	P	P	P	P	P
Testing	S	P	P	P	P	P
Risk Management	PO	N	N	P	P	P
Configuration Management	N	P	P	P	P	P
Tracking Metrics	SO	N	N	P	P	P

Table 2. Relationship Between the Systems Engineering Process and Contract Work Allocation

Key:

P = Primary (lead) responsibility

S = Supporting responsibility

PO = Primary responsibility an option – either could serve in the lead role

SO = Support optional

N = Not a participant

Table 2 implicitly illustrates the relative strengths and weaknesses of the various forms of work allocation. For complex systems it is desirable for the implementer to participate in the early stages of planning and requirements definition to ensure that the organization responsible for developing the software and acquiring (or specifying the hardware) has a complete understanding of the agency’s desires and needs. Only the systems manager form of work allocation addresses this need.

Well-defined systems do not necessarily require the implementer’s early participation in the process. However, even for these types of systems it is desirable for the implementer to have as much of the systems engineering responsibility as possible during the implementation stage of the contract. Either the systems manager or design-build forms of work allocation include this level of participation.

<sup>18</sup> High-level requirements are developed by the procuring agency, typically with consultant support.

<sup>19</sup> Typically a 30% design is developed by the procuring agency with consultant support and used as the basis for the design-build contractor selection and contract.

Project Management Principles	Consult./Contractor		Systems Integrator	Systems Manager	Design-Build	Outsource Contractor
	Consult.	Low-Bid Contractor				
Collaboration	H	L	M	H	M	M
Off-the-Shelf Solutions	N/A	Possible	Possible	Possible	Possible	Likely
Prequal.- Certification	H	L	H	H	L	H
Organization	N/A	L	H	H	M	M

*Table 3. Relationship Between the Project Management Principles and Contract Work Allocation*

The high (H), medium (M) and low (L) ratings in this table refer to the degree to which the project management principles can be followed with the selected form of contracting.

The ratings in this table were assigned on the following basis:

- Collaboration is the degree to which the contractor and agency can work together to arrive at an acceptable system implementation. The low-bid contractor’s relationship with the agency is frequently confrontational, and the relatively low profit margins and fixed price nature of the work precludes positive collaboration for this contracting work allocation. In all other cases, relatively high levels of collaboration are possible, except that in the systems integrator’s case, collaboration during the planning and design stages of the contract have not been possible, and for this reason a medium rating was applied.
- In all cases, it is possible to specify off-the-shelf solutions for the system implementation, so this is not a consideration in the identification of a preferred contracting technique.
- Prequalification/certification can be readily implemented and used during the selection process for negotiated procurements. Although prequalification is frequently used as part of the low-bid contracting, it is not as effective because of the more restrictive definition and evaluation of the contractor’s capabilities. For this reason, work allocations involving low-bid were assigned a low rating.
- The organizational category in this table is a rating of the ease with which the software developer/systems integrator can interact directly with agency personnel. The evaluation of this category is based on the likelihood that the organization responsible for these aspects of the system implementation is likely to serve as a prime contractor or subcontractor. Historically, low-bid procurements are led by electrical contractors, and for this reason, an “L” rating has been given. An “M” rating is given to the design-build alternative because historically, large contractors performing this work have done so with a focus on the “big ticket items” of construction and field equipment. As a result, the software and system integration aspects of the contract (whether performed by the prime contractor or a subcontractor) tend to receive less attention during the performance of the work.

This table also demonstrates the fact that the systems management work allocation is most applicable to the principles of ITS project management. Here again, the systems integrator, design-build and outsourcing methods are also acceptable.

### **Method of Award**

The relationship between the method of award and the systems engineering and project management processes is based on the capabilities and flexibility of the award alternatives. The low bid alternative requires that a contract award be made exclusively on the basis of price to prequalified bidders with responsive bids. This “black and white” selection approach prevents agencies from selecting contractors with the best certifications and systems engineering qualifications. But more significant the low bid alternative prevents application of the principles of collaboration and evolutionary system development. As a result, the low-bid alternative is only applicable to systems that can be fully specified, will not experience scope creep, and for which the waterfall development process is appropriate. This is not a surprising conclusion, since the work allocation alternatives are directly related to the method of award. As the name implies, the low-bid contractor is based on a low-bid selection process. The design-build alternative utilizes the best value method of procurement, while all of the other alternatives are based on the use of negotiated contracts.

### **Contract Form**

Here again, there is a strong relationship between the contract form and the work allocation. It is possible to use the phased contracting approach with the consultant/low-bid contractor and design-build alternatives. However, the task order and other versions of indefinite quantity contracting can only be used with the systems manager and systems integrator alternatives.

As previously indicated, task order contracts are most appropriate for application of the evolutionary development model. Thus, the use of this model, is restricted to the systems manager and systems integrator form of contracting.

### **Contract Type**

The contract type is the basis for allocating financial risk, and influencing contract performance. It is an explicit technique for defining agency priorities, influencing contractor behavior and managing uncertainties. For this reason, contract type can be a valuable project management tool. The value of this tool for project management is directly related to the range of alternatives that can be applied. The range is defined in Table 4 for each type of work allocation. The work allocation for which a given contract type may be used is indicated by an X. Blank cells in the table indicate that a relationship between the two cannot be established.

Contract Type	Consult./Contractor		Systems Integrator	Systems Manager	Design-Build	Outsource Contractor
	Consult.	Low-Bid Contractor				
Fixed Price	X	X	X	X	X	X
Cost Reimburse.	X		X	X		
Incentive	X	X	X	X	X	X
Time and Materials	X		X	X		

Table 4. Relationship Between the Contract Type and Contract Work Allocation

## SUMMARY AND CONCLUSIONS

This report has summarized three complex subjects; systems engineering, project management and procurement. It has then defined the relationship between the three by indicating the impact of procurement approaches on the application of the systems engineering and project management process. The discussion highlighted the following principles and relationships:

- Implementation of ITS projects is quite different from the implementation of civil works. It is necessary to select a systems engineering process, a step that will influence the selection of contracting alternatives.
- The systems engineering development model selected for ITS projects is directly related to the system’s complexity.
- Off-the-shelf solutions should be used whenever possible.
- The need for collaboration influences the contracting methodology selected.
- Contracting approaches that work well for civil engineering projects are not equally applicable to ITS.
- The interrelationships among the four dimensions of the contracting must be thoroughly understood. These relationships are summarized in the matrix of Table 4.
- Incentives should be used cautiously, but can be useful in the management of ITS acquisitions.

Contract Form => Type =>		Phased				Task Order			
		Fixed Price	Cost Reimb	Incentive	T&M	Fixed Price	Cost Reimb	Incentive	T&M
Work Allocation	Method of Award								
Low-bid Contractor	Low-Bid	X		X					
	Negotiated								
Systems Manager	Low-Bid								
	Negotiated	X	X	X	X	X	X	X	X
Systems Integrator	Low-Bid								
	Negotiated	X	X	X	X	X	X	X	X
Design-Build	Low-Bid	X		X					
	Negotiated								
	Best Value	X		X					
Outsource Contractor	Low-Bid	X		X					
	Negotiated								
	Best Value	X		X					

Table 5. Interrelationship of Procurement Model Components

The four components of the contracting framework are influenced by the work allocation, which in part, is determined by the systems engineering model, the system and agency characteristics. These relationships are summarized in Table 6.

Work Allocation	Key Considerations		General Comments
	Systems Engineering	Project Management	
Consultant/Low-Bid Contractor	<ul style="list-style-type: none"> <li>Only applicable to waterfall model</li> </ul>	<ul style="list-style-type: none"> <li>Eliminates possibility of collaboration and risk management</li> </ul>	<ul style="list-style-type: none"> <li>Use should be restricted to well-defined systems</li> </ul>
Systems Manager	<ul style="list-style-type: none"> <li>Used with any systems engineering model.</li> <li>Single contractor responsible for planning, design, implementation, and testing</li> </ul>	<ul style="list-style-type: none"> <li>Permits use of collaboration and risk management</li> <li>Increased flexibility for use of contract form</li> <li>Permits qualification-based selection</li> </ul>	<ul style="list-style-type: none"> <li>Additional contracting burden placed on agency</li> </ul>
Systems Integrator	<ul style="list-style-type: none"> <li>Used with any systems engineering model.</li> </ul>	<ul style="list-style-type: none"> <li>Permits use of collaboration and risk management</li> <li>Increased flexibility for use of contract form</li> <li>Permits qualification-based selection</li> </ul>	<ul style="list-style-type: none"> <li>Additional contracting burden placed on agency</li> <li>Requires additional consulting assistance</li> </ul>

Work Allocation	Key Considerations		General Comments
	Systems Engineering	Project Management	
Design-Build	<ul style="list-style-type: none"> <li>• Most applicable to the waterfall model.</li> <li>• Possible to include other models, but their application would be the responsibility of the contractor.</li> </ul>	<ul style="list-style-type: none"> <li>• Only moderate collaboration and risk management possible.</li> </ul>	<ul style="list-style-type: none"> <li>• Most applicable to systems with time constraints and requirement for continuity between the design and implementation</li> </ul>
Commodity (COTS)	For large systems, may be combined with one of the work allocation processes above (for example, the COTS product is acquired in the same manner as any other system component.)		
Outsource Contractor	<ul style="list-style-type: none"> <li>• Most applicable to the waterfall model.</li> </ul>	<ul style="list-style-type: none"> <li>• Only moderate levels of collaboration possible</li> </ul>	<ul style="list-style-type: none"> <li>• Difficult to define and measure outcomes</li> </ul>
Services	N/A	N/A	N/A

*Table 6. Summary of Considerations in the Selection of Work Allocation*

The considerations discussed here will be used in the development of the procurement guidelines to be prepared during Task 5.