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# Development of a Systems Engineering Education Module for Undergraduates

TTI/ITS RCE-00/01

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**DEVELOPMENT OF A SYSTEMS ENGINEERING EDUCATION  
MODULE FOR UNDERGRADUATES**

by

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Research Report 00/01  
Research Project: Professional Capacity Building

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## SUMMARY

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Professional capacity building (PCB) throughout the transportation profession is critical to the success of Intelligent Transportation Systems (ITS) nationwide. The current and future success of ITS depends on developing a larger cadre of transportation professionals capable of designing, planning, managing, operating, and maintaining the ITS program. Furthermore, overall awareness of ITS by the general public is necessary to ensure political, community, and financial support of future ITS efforts. PCB has been used to identify this movement to educate and prepare existing and future transportation professionals and the general public with respect to ITS. It is the goal of this movement to ensure that the next generation of transportation professionals emerging from undergraduate and graduate programs in our universities has the tools it needs to work with the transportation infrastructure of the 21st century.

The purpose of this study was to develop a systems engineering educational module that could easily fit within any existing transportation undergraduate course or appropriate technical course in other engineering disciplines. The study was conducted by the Center for Professional Development (CPD), Texas Transportation Institute (TTI) staff and involved the following major tasks: review of an earlier case study analysis of specific job roles and tasks of staff from the various agencies that work at Houston TranStar; the development of draft education materials (visual aids, lecture notes, exercises) as appropriate to address educational needs related to these roles as they relate to systems engineering; a presentation of the draft module to the agencies for review and comment; and the development of a final module for distribution.

The case study analysis of specific job roles and tasks of staff from the various agencies that work at Houston TranStar was conducted in 1998 under a separate project. It revealed some hiring preferences and knowledge requirements regarding staff who work at TranStar. In short, all of the agencies that operate within TranStar hire individuals with (1) an undergraduate degree in engineering with an emphasis in transportation, (2) an undergraduate degree in engineering with no knowledge of transportation, or (3) a non-engineering undergraduate degree. With respect to skill levels expected by these agencies and the tasks that these staff perform that are enhanced by ITS knowledge, expectations varied but most agencies expected

or desired basic traffic engineering knowledge, a brief background knowledge of ITS, and a general understanding of systems engineering concepts for most positions. Other skills noted as desirable in staff include verbal communication, interagency cooperation, communication technology (fiber, etc.), Internet site development and design, contracting and procurement, time management, and general computer skills. The desirability of these skills indicates that the transportation professional of today and the future needs a variety of skills that may not be generally obtained in all traditional transportation engineering curricula. Thus, these findings support the development of the Systems Engineering Module and provide argument for the development of future modules aimed at enhancing the knowledge, skills, and abilities (KSAs) in similar areas. Similar knowledge and hiring preferences reported by traffic management center (TMC) staff from Arizona and Georgia confirmed the general assumption that most TMCs have similar needs with respect to staff roles and KSAs.

The project team determined that the educational module would have three objectives. These objectives are to:

- (1) provide a definition of systems engineering;
- (2) discuss its importance with respect to ITS; and
- (3) provide basic exercises that introduce the concept of systems engineering and begin to develop skills in that arena.

The success of incorporating new educational materials into a course relies heavily on the functionality and appropriateness of the material itself. Faculty must be willing to use the material. In a recent survey of faculty at universities in Arkansas, Louisiana, New Mexico, Oklahoma, and Texas, respondents identified the three most preferred material formats: presentation slides, lecture notes, and video clips. Since videos have a production cost that is considerably high, the project team determined that a video was out of the scope of this project. Thus, they selected visual aids and lecture notes as primary delivery mechanisms to be supplemented with exercises for students.

Presentation slides are an easy way to deliver a significant quantity of information in a visually attractive and comprehensive manner. Based on the widespread use of the presentation software Microsoft® PowerPoint®, the project team determined that this software would be the

platform for the visual aid development. The visual aids developed for this module were created from a variety of sources including textbooks, reports, workshops, transportation course materials, Internet sites, and other sources containing related information that was pertinent to the objectives of the module. Visual aids were developed, modified, and updated to target an undergraduate engineering audience.

Lecture notes are a natural complement to presentation slides when developing an educational module. Faculty members can refer to the notes when presenting the material, and they provide more detailed information than is feasible to present on a slide. The lecture notes for the module were developed from the same sources noted previously, designed to target an undergraduate engineering audience, and compiled directly on the PowerPoint® notes pages.

The results presented in this report address an educational need of the transportation profession. While the focus was on the staff needs within Houston TranStar, the systems engineering objectives the module addresses are needed across the country. The educational module can easily be incorporated into any undergraduate engineering program, transportation or otherwise, to increase awareness and understanding of systems engineering and to encourage students to pursue transportation as a career. Furthermore, the material can be used in non-engineering arenas to increase awareness of transportation as a viable career choice for the wide variety of individuals with technical backgrounds necessary to operate and maintain the complex technologies being used in our cities to make transportation more safe and efficient. Thus, this module works to meet the goals and objectives of the national PCB program, especially as they relate to educating the future professionals that will design, build, operate, manage, and maintain the transportation system.



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# 1. INTRODUCTION

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While Intelligent Transportation Systems (ITS) deployment has been widespread throughout the United States since the passing of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, its current and future success depends on developing a larger cadre of transportation professionals capable of designing, planning, managing, operating, and maintaining the ITS program. Furthermore, overall awareness of ITS by the general public is necessary to ensure political, community, and financial support of future ITS efforts. This movement to educate and prepare existing and future transportation professionals and the general public with respect to ITS has been labeled professional capacity building (PCB). It is the goal of this movement to ensure that the next generation of transportation professionals emerging from undergraduate and graduate programs in our universities has the tools it needs to work with the transportation infrastructure of the 21<sup>st</sup> century.

## 1.1 BACKGROUND

Currently, many university programs across the country have nominal expertise in transportation and ITS-related topics. In these programs, course material is often limited or non-existent. Furthermore, faculty members who are already overburdened do not have the time to develop additional materials for use in their classes. Thus, an opportunity exists to take advantage of expertise available at some universities for the benefit of the entire transportation education program as it pertains to ITS.

As stated above, PCB throughout the transportation profession is critical to the success of ITS nationwide. The three ITS Research Centers of Excellence (RCE) and the ITS Institute at the University of Minnesota committed a portion of their FY 98 financial resources to support ITS PCB activities. This study was sponsored by the Texas A&M ITS RCE, and its objective was to develop a systems engineering education module to address an ITS education need for one or more of the RCE local sponsoring agencies. While the immediate focus was regional, the resulting module can be incorporated into virtually any undergraduate engineering program,

transportation or otherwise, to increase ITS awareness and to encourage students to pursue transportation and ITS as a career.

## **1.2 PURPOSE**

The purpose of this study was to develop a systems engineering educational module that could easily fit within any existing transportation undergraduate course or appropriate technical courses in other engineering disciplines. The study was conducted by the Center for Professional Development, Texas Transportation Institute staff and involved the following major tasks: a review of a previous case study analysis of specific job roles and tasks of staff from the various agencies that work at Houston TranStar; the development of draft education materials (visual aids, lecture notes, exercises) as appropriate to address education needs related to these roles; a presentation of the draft module to the agencies for review and comment; and the development of a final module for distribution.

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## 2. CASE STUDY REVIEW

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Each state in the United States has a transportation infrastructure that is constantly expanding and improving to meet the needs of the motoring public. Thus, future transportation professionals must have the knowledge, skills, and abilities to perform their roles in maintaining that infrastructure in the 21st century. The paradigm shift occurring within the profession is moving emphasis from construction to operations. In response to this shift, state and local agencies in over 50 cities across the nation are building and operating transportation management centers (TMCs). The purpose of these centers is to coordinate the use of advanced technologies to work to maximize the efficiency of the existing roadway and provide the best level of service possible to the transportation system user while improving safety.

Houston TranStar is the transportation management center in Houston, Texas. Four agencies - Texas Department of Transportation (TxDOT), the Metropolitan Transit Authority of Harris County (METRO), the City of Houston, and Harris County - work in tandem under one management structure to operate a variety of traffic-related management programs to assist the motoring public. These agencies share the expense and responsibility of operating TranStar while other agencies in the region assist in operations to ensure interagency coordination and to minimize administrative boundaries. The various ITS-related transportation management programs coordinated from TranStar include the following:

- traffic signalization systems;
- freeway management systems;
- transit management systems;
- incident management systems;
- electronic toll collection systems;
- electronic transit fare payment systems;
- smart railroad grade crossing systems;
- coordinated emergency and disaster services; and
- real-time traveler information systems.

As with similar TMCs across the country, TranStar hires numerous individuals that perform the roles necessary to maintain the variety of systems operational within TranStar. However, these individuals may or may not have a background in transportation, ITS, or systems engineering upon hiring. While some may not necessarily need that information to perform their jobs, they could definitely benefit from such background knowledge, especially with respect to how systems engineering is integrated with transportation. Thus, the first step in developing the systems engineering education module was to review a previous case study analysis that addressed specific knowledge requirements with respect to systems engineering and ITS.

A case study analysis conducted in 1998 by the Center for Professional Development indicated that many entry-level employees at TMCs have little or no knowledge of systems engineering and its relationship to ITS prior to hiring (*1*). The case study analysis consisted of conducting personal interviews of selected individuals within TranStar who are responsible for hiring and managing personnel in the various agencies. Since each agency has specific roles and responsibilities under the TranStar management structure and as identified by its overall mission, an individual from each sponsor agency was interviewed. The study surveyed staff from two other TMCs in other states to determine if the needs within TranStar are similar to those in other regions of the country.

All of the agencies that operate within TranStar hire individuals with either an undergraduate degree in engineering with an emphasis in transportation or a non-engineering undergraduate degree. The City of Houston also hires individuals with an undergraduate degree in engineering with no knowledge of transportation. The following sections outline the positions for which entry-level staff are hired, the knowledge desired of these staff, skill levels expected by these agencies, and the tasks that these staff perform that are enhanced by systems engineering knowledge.

## **2.1 ENGINEERING DEGREE WITH TRANSPORTATION KNOWLEDGE**

Graduates with engineering degrees and some knowledge of transportation are hired into various entry-level positions within each agency. These positions range from operators, engineering assistants, and signal engineers to project managers and supervisors of control room operations. All of these positions require brief background knowledge of ITS. Specific

required knowledge includes but is not limited to signal operations and timing, signal systems, system engineering, system integration, electronics in ITS, and general traffic engineering concepts. Note that many of these topics overlap with traditional transportation-related knowledge. Within their roles, these individuals perform various tasks that require systems engineering and transportation-related knowledge. These tasks include signal investigations and troubleshooting, monitoring of existing systems, operations and maintenance of the Automatic Vehicle Identification (AVI) system, evaluation and monitoring of project progress, and project management. Depending on the depth of their transportation background, these individuals might be a potential audience for the systems engineering education module.

## **2.2 ENGINEERING DEGREE WITH NO TRANSPORTATION KNOWLEDGE**

Graduates with engineering degrees and no knowledge of transportation are hired primarily within TranStar by the City of Houston. As with individuals with a transportation background, these individuals - who might have a civil, mechanical, or electrical engineering degree - are hired as signal engineers. It is desired that they have a brief background knowledge regarding transportation, ITS, and systems engineering. However, such knowledge is not required for employment. Tasks these individuals might perform that would be enhanced by ITS and systems engineering knowledge include signal investigations and signal problem troubleshooting such as operational issues, re-phasing, sequencing, and signal timing. Thus, these individuals are a potential audience for the systems engineering education module as they generally have little to no transportation background, especially with respect to how systems engineering is applied to the transportation industry.

## **2.3 NON-ENGINEERING DEGREE**

Graduates with non-engineering degrees and no transportation background are hired into various entry-level positions within each agency. The entry-level positions they fill range from police officers, electrical estimators, and ITS operators to engineering technicians and maintenance and inspection technicians. Most, but not all, of the agencies desire brief background knowledge of transportation for individuals in these positions. Tasks these individuals perform within their jobs that would be enhanced by ITS and systems engineering knowledge include but are not limited to system engineering, dispatch and emergency radio

operations, data analysis and reduction, high-occupancy vehicle (HOV) operations, lane control signal operations, dynamic message sign (DMS) operations, signal maintenance, and traffic signal design. As with the previous staff categories, these individuals are a target audience for the systems engineering education module.

## **2.4 OTHER FINDINGS**

During discussions, agency staff representatives revealed other KSAs as desirable in entry-level hires. These skills include but are not limited to the following:

- interpersonal and verbal communication;
- interagency cooperation;
- communication technology (fiber, etc.);
- Internet site development and design;
- contracting and procurement;
- time management; and
- general computer skills.

This list combined with the other general skills outlined in the previous sections indicates that the transportation professional of today and the future needs a variety of skills that are not generally obtained in the traditional transportation engineering curriculum. Thus, these findings support the development of the systems engineering education module and provide argument for the development of future modules aimed at enhancing the KSAs in these areas. Furthermore, TMC staff from Arizona and Georgia reported similar knowledge and hiring preferences, confirming the general assumption that most TMCs have similar needs with respect to staff roles and KSAs.

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### **3. MODULE DEVELOPMENT**

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A key to developing educational materials for widespread dissemination is to provide relevant and useful information in a medium that is easy to use and pervasive throughout the profession. The intent is for faculty to incorporate new material into existing course outlines with a minimum of effort on the part of the instructor. Thus, the second task in developing an educational module for systems engineering was to create a draft module, including all its components, for review and revision by professionals who hire individuals that can benefit from the included knowledge.

The project team determined that the educational module would have four objectives. These objectives are to:

- (1) provide a definition of systems engineering;
- (2) describe the systems engineering process;
- (3) discuss the importance of systems engineering with respect to transportation and ITS; and
- (4) illustrate the concept of systems engineering in the context of transportation.

The following sections outline the process undertaken to accomplish the task of developing this draft module, review of the draft material, and development of a final module for dissemination.

#### **3.1 DRAFT MODULE DEVELOPMENT**

The success of incorporating new educational materials into a course relies heavily on the functionality and appropriateness of the material itself. Faculty must be willing to use the material. In a recent survey of faculty at universities in Arkansas, Louisiana, New Mexico, Oklahoma, and Texas, respondents identified their preferences in resource material for use in the classroom. The three most preferred material formats, in order of preference, were presentation slides, lecture notes, and video clips (2). Since the cost of video production is considerably high, the project team determined that a video was out of the scope of this project. Thus, they selected visual aids and lecture notes as primary delivery mechanisms to be

supplemented with exercises for students. The following sections provide a description of the material developed for each component of the module.

### **3.1.1 Visual Aids**

Presentation slides are an easy way to deliver a significant quantity of information in a visually attractive and comprehensive manner. Based on the widespread use of the presentation software Microsoft® PowerPoint®, the project team determined that this software would be the platform for the visual aid development. Once developed, the slides can be provided to faculty in electronic or hard-copy format and can be printed or used in various formats for presentation (i.e., electronic, slide, or transparency). Furthermore, lecture notes can be included in the slide files to minimize the number of files that must be used. Moreover, PowerPoint® files can be converted to HTML files for use on the Internet, increasing the flexibility of the module in its use and application. The project team created the visual aids developed for this module from a variety of sources, including textbooks, reports, workshops, transportation course materials, Internet sites, and other sources containing related information that was pertinent to the objectives of the module. Visual aids were developed, modified, and updated to target an undergraduate engineering audience. The result was 49 PowerPoint® slides that address the objectives of the module as an overview. Appendix A shows the slides prepared for this module.

### **3.1.2 Lecture Notes**

Lecture notes are a natural complement to presentation slides when developing an educational module. Faculty members can refer to the notes when presenting the material, and they provide more detailed information than feasible to present on a slide. Furthermore, faculty can make additions and changes to the notes as needed. As with presentation slides, the target team determined that Microsoft® PowerPoint® was appropriate software for lecture note development, since notes can be easily included in slide files and printed for faculty use. Once developed, the notes can be provided in electronic format for HTML conversion or in hard-copy format for direct distribution to students. The lecture notes for the module were developed from the same sources noted previously as those used in development for the presentation slides. The notes were designed to target an undergraduate engineering audience and were compiled

directly on the PowerPoint® notes pages, resulting in lecture notes for the 49 presentation slides. Appendix B contains the lecture notes for the slides.

### **3.1.3 Module Exercises**

Systems engineering is a concept that applies itself well to the transportation profession, particularly within the ITS arena. Thus, the study team decided that a module exercise designed to expose students to systems engineering within the scope of transportation would support the objectives of the module. The exercise provides students with the opportunity to learn more about the systems engineering process with respect to the design and operation of TMCs. A copy of the systems engineering exercise is located in Appendix C.

## **3.2 DRAFT MODULE REVIEW**

Task three of this project was to present the draft education module to staff at TranStar to provide the opportunity for them to review and critique the module, identifying areas of improvement as appropriate. The presentation slides and lecture notes were printed in the PowerPoint® notes format and sent to the key staff in each organization at TranStar that participated in the previous case study analysis. They were asked to review the material and provide a critique of it, identifying any areas needing improvement based on the educational objectives of the module. Reviewers were given one month in which to look at the material, and comments were welcome in all formats: e-mail, fax, surface mail, or telephone. No comments were received from the reviewers, which led the project team to assume that they desired no changes in the either presentation slides or lecture notes.

## **3.3 FINAL MODULE DEVELOPMENT**

Since no comments were received from the module reviewers, no major alterations to the educational module were necessary. Minor changes to the format of the presentation slides and lecture notes were made to streamline the module.



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## 4. FINDINGS AND RECOMMENDATIONS

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The purpose of this study was to develop a systems engineering educational module that could easily fit within any existing transportation undergraduate course or appropriate technical courses in other engineering disciplines. A previous case study analysis of specific job roles and tasks of staff from the various agencies that work at Houston TranStar revealed some hiring preferences and knowledge requirements regarding staff that work at TranStar. In short, all of the agencies that operate within TranStar hire individuals with (1) an undergraduate degree in engineering with an emphasis in transportation, (2) an undergraduate degree in engineering with no knowledge of transportation, or (3) a non-engineering undergraduate degree.

Expectations of entry-level staff varied according to skill levels expected by agencies and the tasks the staff perform. However, most agencies expected or desired basic traffic engineering knowledge, a brief background knowledge of ITS, and a general understanding of systems engineering concepts for most positions. Other skills noted as desirable in staff include verbal communication, interagency cooperation, communication technology (fiber, etc.), Internet site development and design, contracting and procurement, time management, and general computer skills. The desirability of these skills indicates that the transportation professional of today and the future needs a variety of skills that may not be generally obtained in all traditional transportation engineering curricula. Thus, these findings support the development of a systems engineering education module and provide argument for the development of future modules aimed at enhancing the KSAs in similar areas. Similar knowledge and hiring preferences reported by TMC staff from Arizona and Georgia confirmed the general assumption that most TMCs have similar needs with respect to staff roles and KSAs.

The results presented in this report address an educational need of the transportation profession. While the focus was on the staff needs within Houston TranStar, the systems engineering objectives the module addresses are needed across the country. The educational module can easily be incorporated into any undergraduate engineering program, transportation or otherwise, to increase awareness and understanding of systems engineering and to encourage students to pursue transportation as a career. Furthermore, the material can be used in non-engineering arenas to increase awareness of transportation as a viable career choice for the wide

variety of individuals with technical backgrounds necessary to operate and maintain the complex technologies being used in our cities to make transportation more safe and efficient. Thus, this module works to meet the goals and objectives of the national PCB program, especially as they relate to educating the future professionals that will design, build, operate, manage, and maintain the transportation system.

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## REFERENCES

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1. Kuhn, B.T. *Development of an Intelligent Transportation Systems Education Module for Undergraduates*. Report No. TTI/ITS RCE-98/02, Texas Transportation Institute, College Station, Texas, 1998.
2. Kuhn, B.T. *Assessment of a Regional Transportation Education Alliance to Improve Mobility*. Report No. SWUTC/98/167103-1, Texas Transportation Institute, College Station, Texas, 1998.
3. "Training Course on Freeway Traffic Operations." Report No. FHWA-HI-97-009, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1997.
4. Athey, T.H. "Systematic Systems Approach." Prentice-Hall, Inc, Englewood Cliffs, New Jersey, 1982.
5. ReVelle, C.S., E.E. Whitlatch, and J.R. Wright. *Civil and Environmental Systems Engineering*. Prentice Hall, Upper Saddle River, New Jersey, 1997.
6. International Council on Systems Engineering. "What is Systems Engineering?" URL: <http://www.incose.org/whatis.html>, INCOSE, 1999.
7. McClinton, David F. "Systems Engineering: A Tutorial." Unpublished report, 1999.
8. McClinton, David F. "The Unwritten Laws of Systems Engineering." Presented at the Fourth Annual International Symposium of the National Council on Systems Engineering, 1994.
9. INCOSE: SE Practice Working Group – Subgroup on Pragmatic Principles. "An Identification of Pragmatic Principles – Final Report." INCOSE WMA Chapter, URL: <http://www.incose.org/workgrps/practice/pragprin.html>, 1999.



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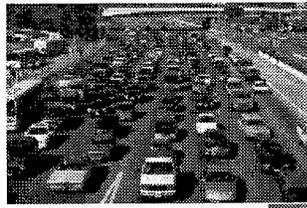
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**APPENDIX A: MODULE PRESENTATION SLIDES**

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# SYSTEMS ENGINEERING AND TRANSPORTATION

Center for Professional Capacity Development

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*Slide 1: Title*

## What is a system?

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**. . . any set of components that  
could be seen as working  
together to achieve a common  
goal or objective. (2)**

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*Slide 2: What is a System?*

# What is a transportation system?

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## An Example:



## Freeway System

- physical features
- operational controls
- all components work together to achieve a common objective

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*Slide 3: What is a Transportation System?*

## Elements of a System (2)

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- **Primary Components**
  - physical objects, concepts, processes, feelings, beliefs, etc.
- **System Boundary**
  - encompasses components that can be directly influenced or controlled
- **Environment**
  - factors that have influence but cannot be controlled

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*Slide 4: System Elements*

## Systems Engineering Defined (2)

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... an *integrated* and *interdisciplinary* approach to the synthesis (i.e., the combination of parts, elements, etc. to form a working or coherent whole) of an *entire system* to perform various tasks in the most efficient manner.

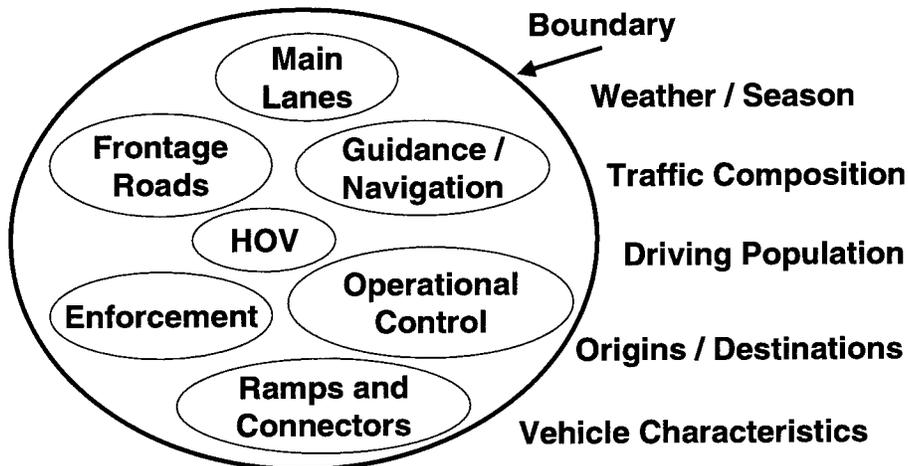
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Slide 5: Freeway System Elements

### Freeway System Elements

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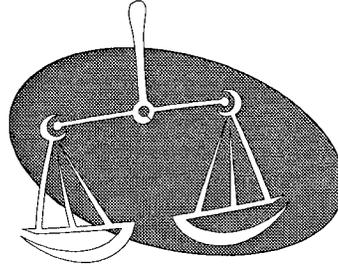
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Slide 6: Systems Engineering Defined

## 3 Laws of Systems Engineering (6)

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- 1 Everything interacts with everything else.
- 2 Everything goes somewhere.
- 3 There is no such thing as a free lunch.



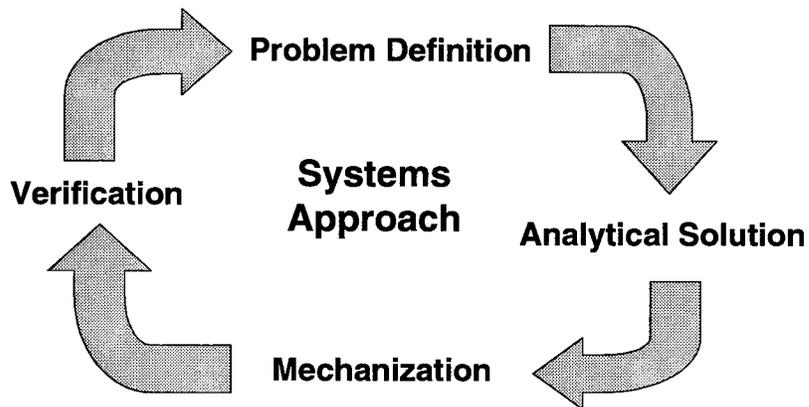
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*Slide 7: Three Laws of Systems Engineering*

## Systems Engineering Process

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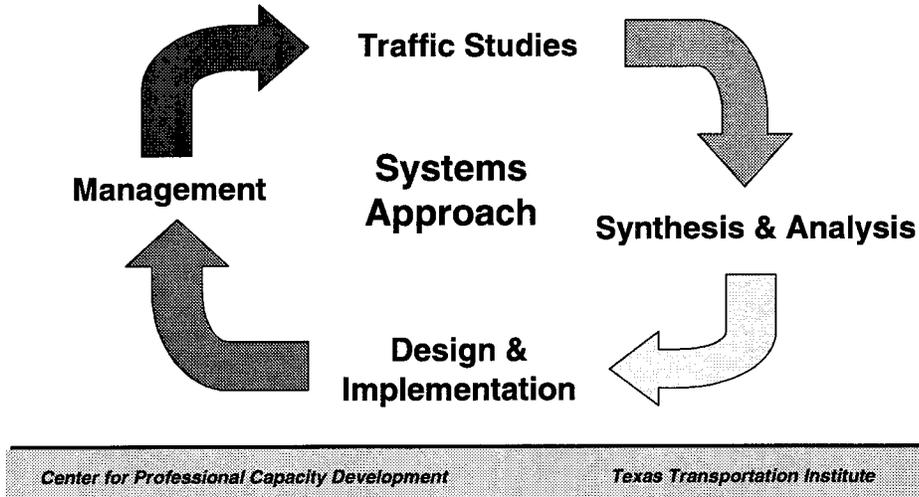
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*Slide 8: Systems Engineering Process*

# Systems Engineering Process - A Transportation Perspective

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*Slide 9: Systems Engineering Process – A Transportation Perspective*

# Symptoms of Poor Systems Engineering (5)

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- Behind schedule
- Over budget
- Confusion over requirements and mission
- Not achieving technical requirements
- Frayed nerves

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*Slide 10: Symptoms of Poor Systems Engineering*

# Systems Engineering Philosophy

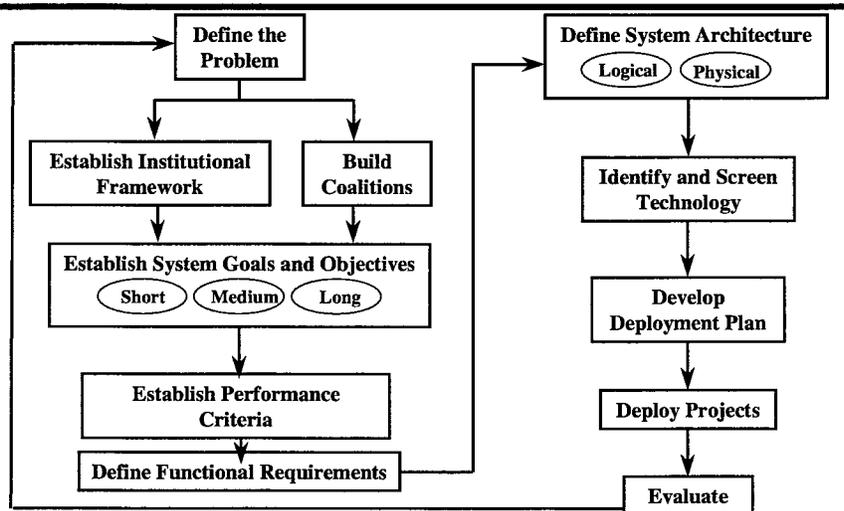
- Focus on identifying requirements
- Not technology driven
- Includes:
  - System analysis
  - Decision making

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Slide 11: Systems Engineering Philosophy

# Systems Engineering Approach

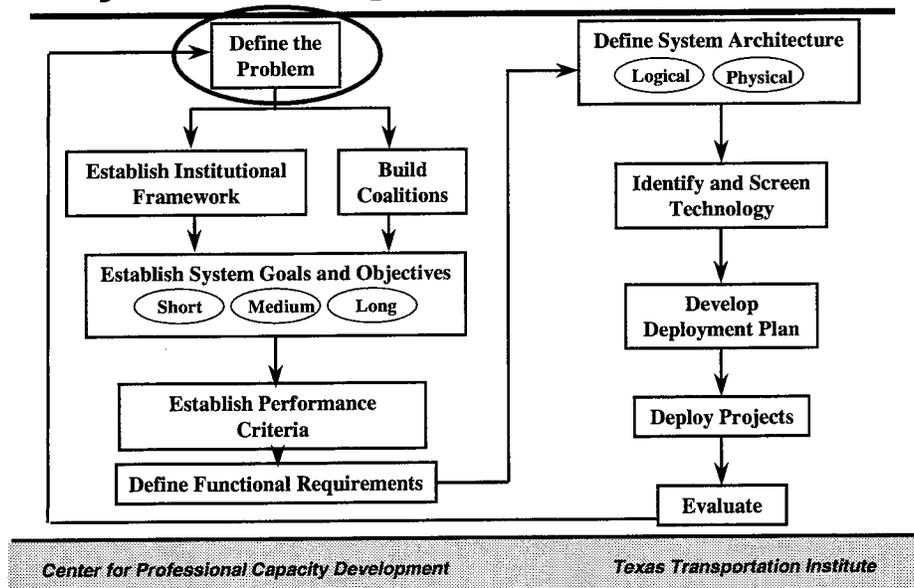


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Slide 12: Systems Engineering Approach

# Systems Engineering Approach



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Slide 13: Systems Engineering Approach - Define the Problem

## Define the Problem

- Vary in breadth from operational to institutional
- Methods of identifying problems:
  - Traditional operational studies
  - Regional transportation and land-use studies
  - Air quality assessments
- Coordination with other agencies critical

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Slide 14: Define the Problem

# Inventory of System

- PHYSICAL*
- Roadway network
  - Existing surveillance and control systems
  - Existing information dissemination systems

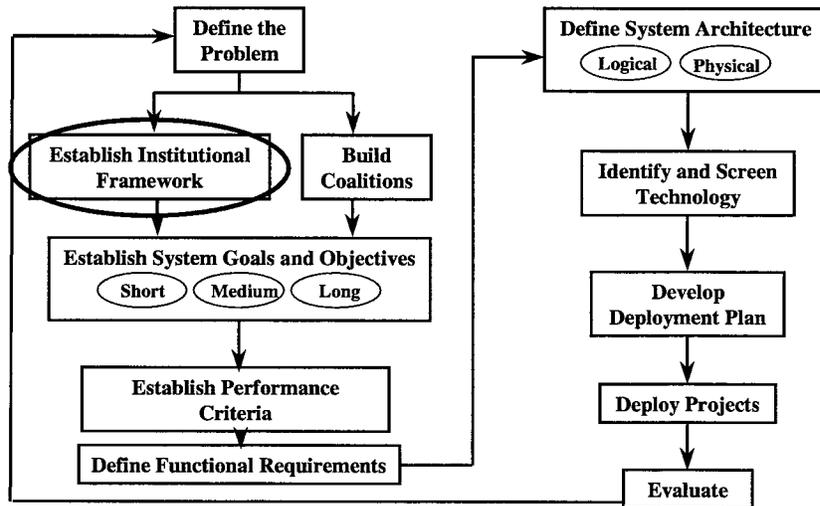
- ORGANIZATIONAL*
- Operating agencies
  - Funding sources
  - Political and agency jurisdictions

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Slide 15: Inventory of System

# Systems Engineering Approach



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Slide 16: Systems Engineering Approach - Establish Institutional Frameworks

## **Establish Institutional Framework**

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- **Critical step in process**
- **Needed at three levels**
  - Interagency
  - Intra-agency
  - Other stakeholders
- **Input identifying problems and developing goals**



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*Slide 17: Establish Institutional Framework*

## **Interagency**

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- **MPOs**
- **Highway/public works**
- **Transit**
- **Law enforcement**
- **Emergency services**
- **Turnpike/toll road authorities**
- **Port authorities**
- **State and federal emergency management agencies**

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*Slide 18: Interagency*

## Intra-agency

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- **Planning**
- **Administrative**
- **Construction**
- **Design**
- **Operations**
- **Maintenance**

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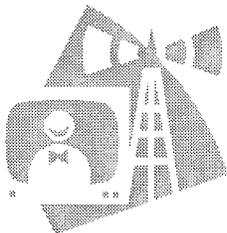
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*Slide 19: Intra-agency*

## Other Stakeholders

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- **Major traffic generators**
- **Utility companies**
- **Politicians**



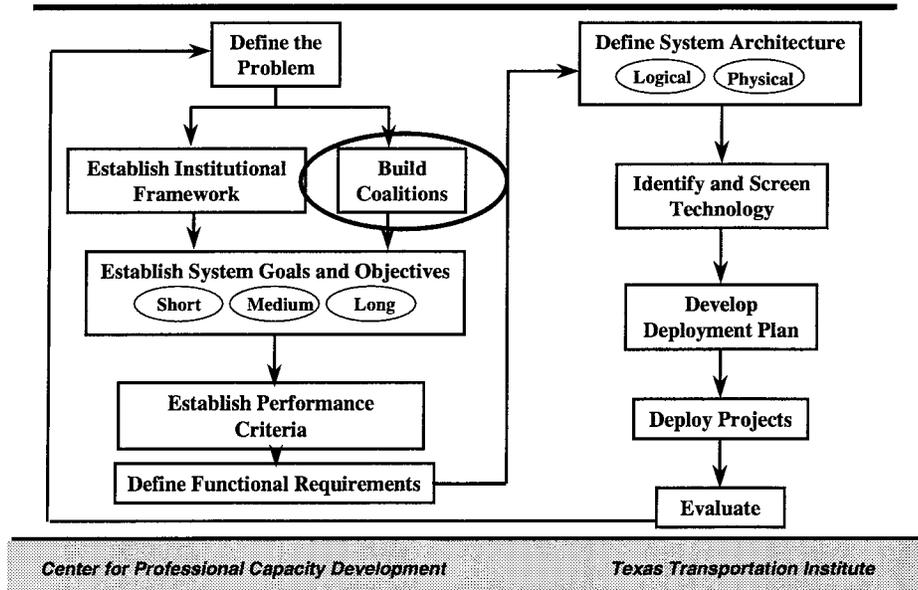
- **Media**
- **Private transportation providers**

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*Slide 20: Other Stakeholders*

# Systems Engineering Approach



Slide 21: Systems Engineering Approach - Build Coalitions

## Building Coalitions

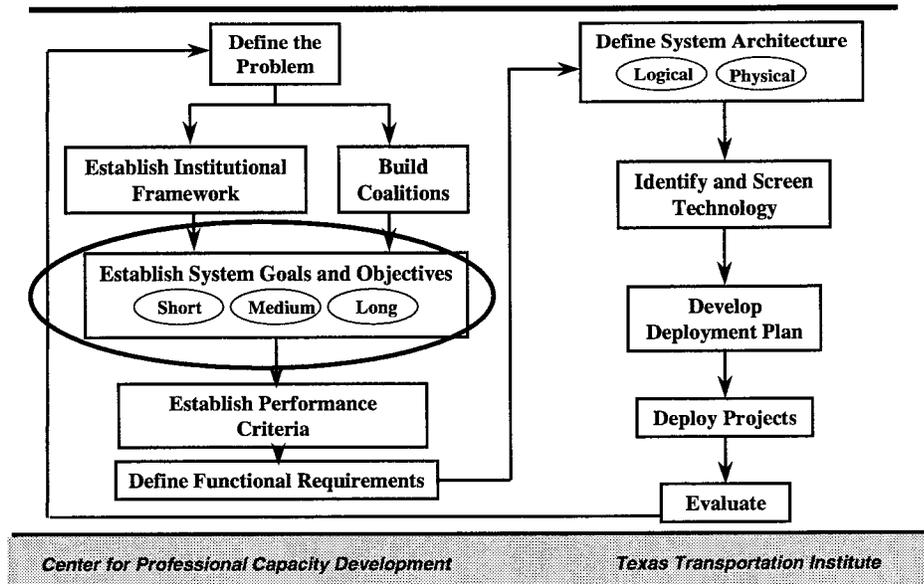
- **Identify “champions”**
  - “Top-down” or “bottom-up” support
- **Find individuals critical to success**
  - Key individuals with knowledge and authority
  - Present throughout entire process
- **Use existing institutional frameworks**

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Slide 22: Building Coalitions

# Systems Engineering Approach



Slide 23: Systems Engineering Approach - Establish System Goals and Objectives

## Establish Goals and Objectives

- Describe what system is to accomplish
- Directly related to specific problems
- Goals => long-range and broad
- Objectives => measurable and specific



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Slide 24: Establish System Goals and Objectives

# Example of Goals and Objectives

## IDENTIFIED PROBLEM

- Incidents => primary source of congestion

## SYSTEM GOAL

- Reduce impacts of incidents

## SYSTEM OBJECTIVES

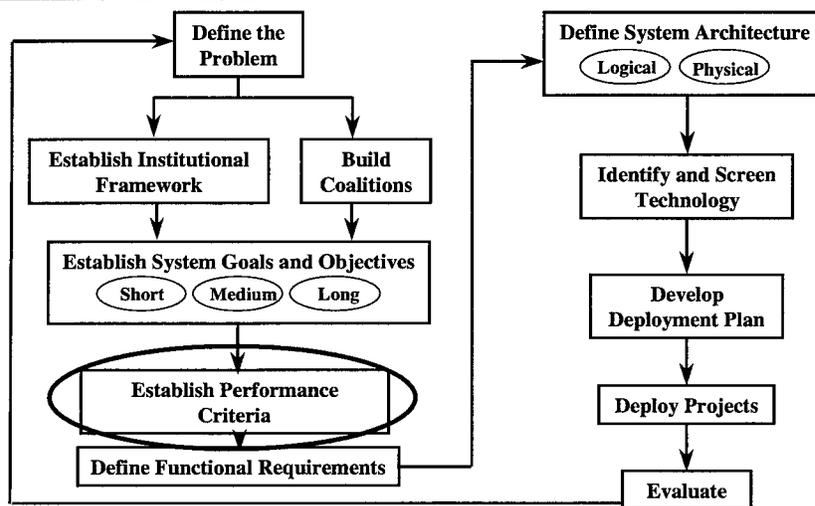
- Detect all incidents within 2 minutes
- Reduce clearance time by 5 minutes

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Slide 25: Example of System Goals and Objectives

# Systems Engineering Approach



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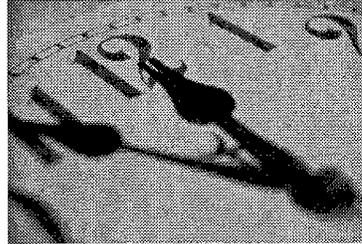
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Slide 26: Systems Engineering Approach - Establish Performance Criteria

## Establish Performance Criteria

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- Judging performance of system
- System achieving design objectives
- Measures of performance
  - Qualitative
  - Quantitative



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*Slide 27: Establish Performance Criteria*

## Example of Performance Criteria - Incident Management

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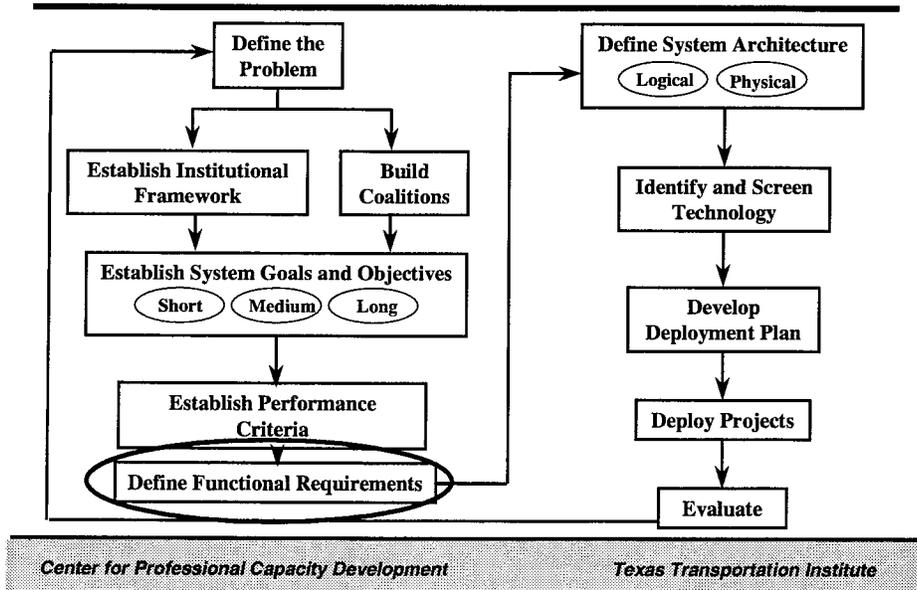
- **Objective: Detect all incidents within 2 minutes**
  - Average detection time
  - % of incidents detected in 2 minutes
- **Objective: Provide first response within 15 minutes**
  - Average response time
  - % of incidents responded to in 15 minutes
- **Objective: Reduce clearance time by 5 minutes**
  - Average clearance time **before** system implemented
  - Average clearance time **after** system implemented
  - % of incidents where clearance time reduced by 5 minutes

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*Slide 28: Example of Performance Criteria / Incident Management*

# Systems Engineering Approach



Slide 29: Systems Engineering Approach - Define Functional Requirements

## Define Functional Requirements

- Features needed by system to accomplish objectives
- Independent of technology or architecture
- Describes what system does, not how!

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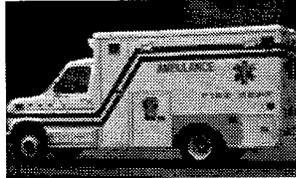
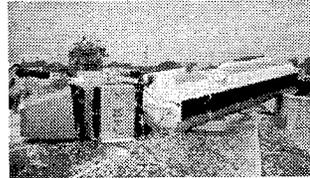
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Slide 30: Define Functional Requirements

## Example of Functional Requirements

- **Identify incidents**

- Identify location
- Identify impacts
- Identify characteristics



- **Formulate response actions**

- Identify appropriate emergency response
- Select information to disseminate
- Identify appropriate traffic control

- **Initiate and monitor response**

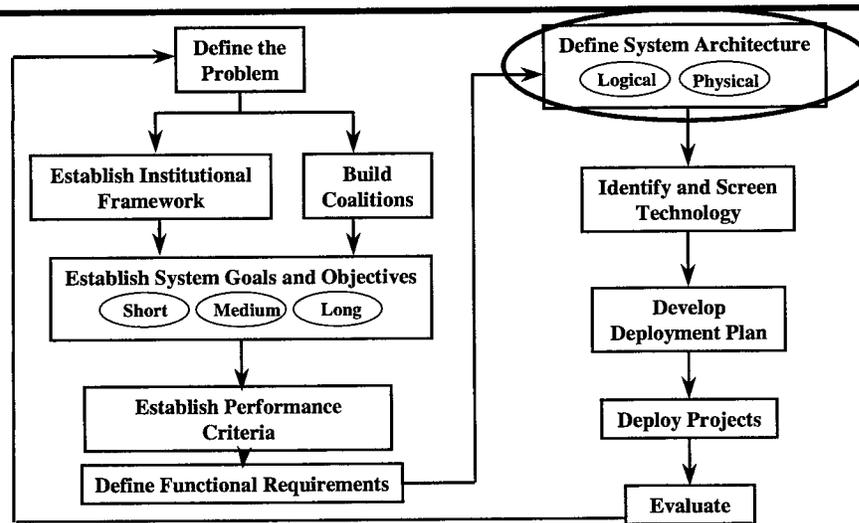
- Provide response procedures

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Slide 31: Example of Functional Requirements

## Systems Engineering Approach



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Slide 32: Systems Engineering Approach - Define System Architecture

## Define System Architecture

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- **Framework for achieving system objectives**
- **Example:**
  - **Function:**
    - » Incident detection
  - **Architecture:**
    - » Surveillance system
    - » Detection algorithm
    - » Communication system

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*Slide 33: Define System Architecture*

## Benefits from *Planning* System Architecture

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- **Minimizes redundant systems**
- **Promotes efficient use of equipment, staff, and resources**
- **Permits easy expansion and modernization**
- **Facilitates information sharing**

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*Slide 34: Benefits from Planning System Architecture*

## **System Architecture Levels**

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- **Functional Requirements => what system is supposed to do**
- **Logical architecture => what information flows between components**
- **Physical architecture => where function occurs and who is responsible for performing it**

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*Slide 35: System Architecture Levels*

## **“Open” System Architecture**

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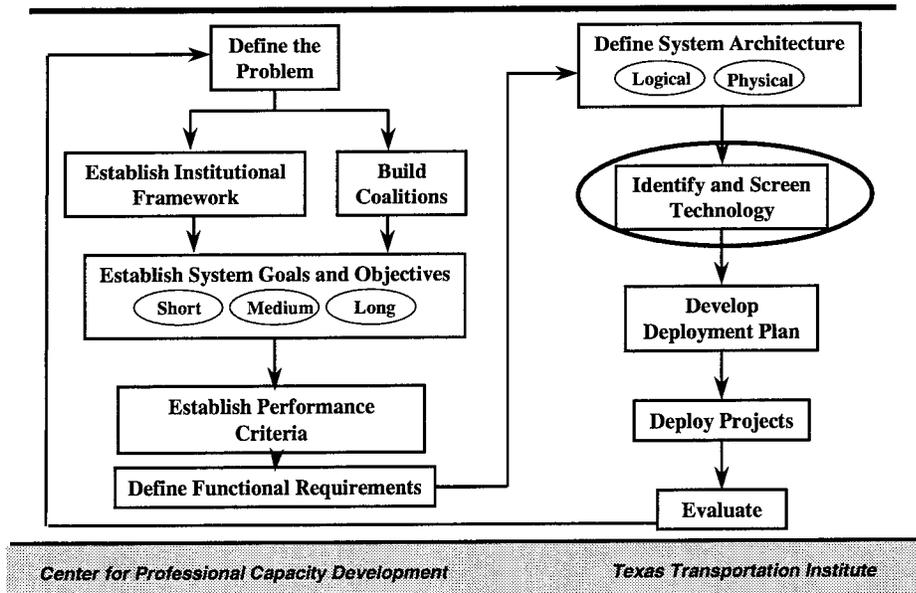
- **Designed with standard data interfaces**
- **Not vendor specific**
- **Benefits:**
  - Keeps system from being obsolete
  - More compatible with ITS technologies

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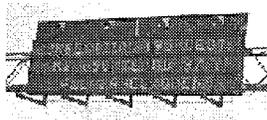
*Slide 36: “Open” System Architecture*

# Systems Engineering Approach

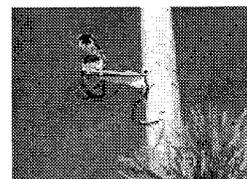


*Slide 37: Systems Engineering Approach - Identify and Screen Technology*

## Identify and Screen Technologies



- Meets performance and reliability standard defined by architecture
- Sources of information:
  - Evaluation studies and reports
  - Site visits



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*Slide 38: Identify and Screen Technology*

# Evaluating Technologies

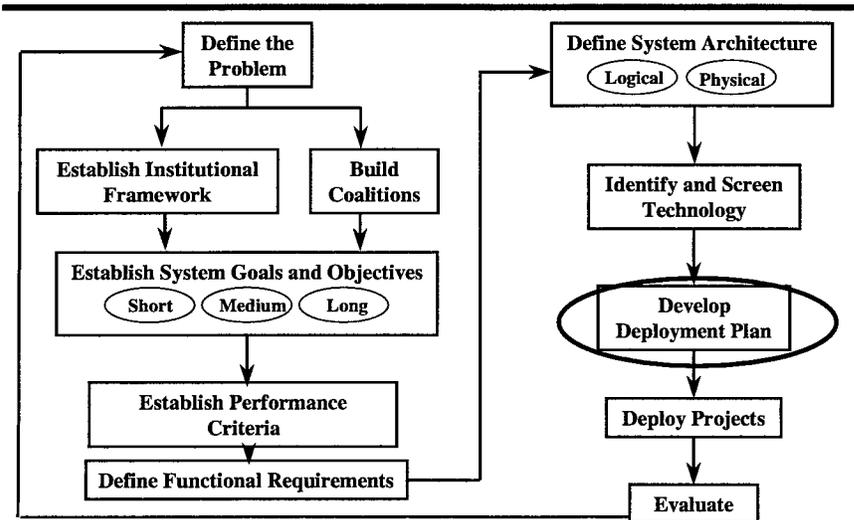
- Interaction with system
- Impacts on physical configuration of system
- Expandability and flexibility
- Life-cycle costs:
  - Procurement, installation, and construction
  - Operating and maintenance
  - Replacement and expansion costs
- Operations and maintenance

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Slide 39: Evaluating Technologies

# Systems Engineering Approach



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Slide 40: Systems Engineering Approach - Develop Deployment Plan

## **Develop Deployment Plan (3)**

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- **Outlines how system is implemented**
- **Elements:**
  - Problems and opportunities to be addressed
  - Institutional arrangements
  - Goals and objectives
  - Functional requirements and architecture
  - Technology options
- **Includes implementation plan**

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*Slide 41: Develop Deployment Plan*

## **Typical Elements of Implementation Plan**

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- **Goals and objectives**
- **Laws, ordinances, etc.**
- **Start-up procedures**
- **Adding functions**
- **Organizational and reporting structure**
- **Agency responsibilities**
- **Operating procedures**
- **Communications protocols / procedures**
- **Staffing requirements**
- **Hours of operation**
- **Training**
- **Maintenance**
- **Budget**

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*Slide 42: Typical Elements of Implementation Plan*

# Procurement Approaches

- Sole-source
- Engineering / contractor
- Two-step
- System management
- Design / build

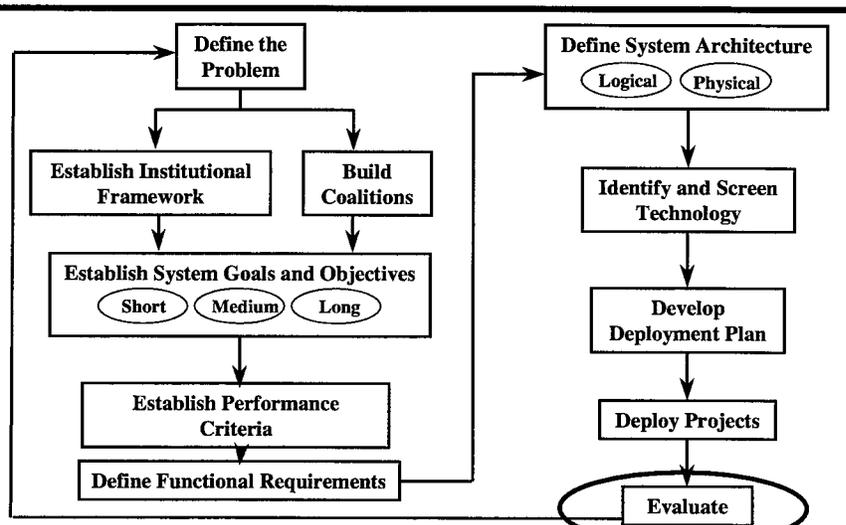


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Slide 43: Procurement Approaches

# Systems Engineering Approach



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Slide 44: Systems Engineering Approach - Evaluation

## Evaluation

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- Ongoing process
- Occurs at all stages
- How well system is achieving design objectives
- Identify improvements
- Lessons learned



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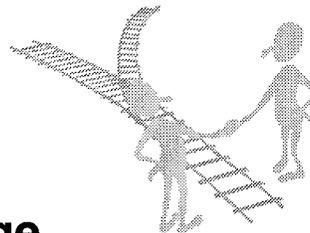
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*Slide 45: Evaluation*

## Pragmatic Principles (7)

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- Know the problem, the customer, and the consumer
- Use effectiveness criteria
- Establish and manage requirements



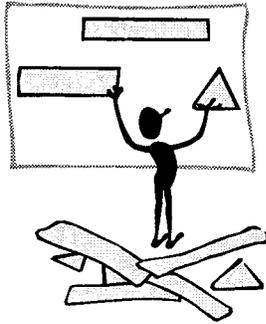
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*Slide 46: Pragmatic Principles (1 of 3)*

## Pragmatic Principles (7)

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- Identify and assess alternatives
- Verify and validate requirements and solution performance
- Maintain integrity

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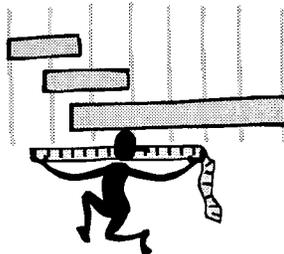
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*Slide 47: Pragmatic Principles (2 of 3)*

## Pragmatic Principles (7)

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- Use articulated and documented process
- Manage against a plan



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*Slide 48: Pragmatic Principles (3 of 3)*

# Module Summary

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- **Systematic approach**
- **Process**
  - Systems analysis
  - Decision-making
- **Steps**
  - Define problem, goals, and objectives

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*Slide 49: Module Summary*



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**APPENDIX B: MODULE PRESENTATION SLIDE NOTES**

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# Systems Engineering & Transportation Education Module

## Slide Notes

### *Slide 1: Title*

The surface transportation system is made up of various components that must function together as a single system. This module addresses how different subsystems or components work together to form a system and how to utilize a systems engineering approach to develop, operate, and maintain the freeway component of the transportation system. This process can be applied to any other component of the transportation system – not just freeways.

### *Slide 2: What is a System?*

A system is defined as any set of components that *could be* seen as working together to achieve a common goal or objective. (2)

### *Slide 3: What is a Transportation System?*

Example: A freeway can be thought of as a transportation system in and of itself.  
Physical features (main lanes, ramps, connectors, high occupancy vehicle lanes, etc.)  
Operational controls (speed limits, regulatory restrictions, management controls, etc.)  
All components must work together to achieve the common objective of the freeway: the safe and efficient movement of people and goods.

### *Slide 4: System Elements*

Each system is comprised of primary elements or *components*, which are not limited to physical objects. Concepts, processes, feelings, and beliefs represent some system components.

Those components that can be directly influenced or controlled in the system are contained in the *system boundaries*.

The *environment* includes all factors that have influence on the effectiveness of a system, but are not controllable. (2)

### *Slide 5: Freeway System Elements*

#### *Physical Components*

- freeway main lanes,
- ramps and connectors,
- frontage roads,
- high occupancy vehicle lanes,
- operational controls, and
- navigation/guidance displays.

### *Non-Physical*

- The process of clearing an incident from the freeway main lanes can be considered a component of a freeway incident management system.

### *Boundary*

- Only those elements that can be directly influenced by the traffic engineer are inside the boundary.

### *Environment*

- In the freeway system, components such as weather, driving population, vehicle characteristics, traffic composition, drivers' origins and destinations, etc. are all part of the environment since they cannot normally be controlled or influenced by the traffic engineer.

## ***Slide 6: Systems Engineering Defined***

Transportation officials may use system or systems engineering to describe an integrated and interdisciplinary approach to the synthesis of an entire system to perform various tasks in the most efficient manner – the result being a successful system. (2)

It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- operations,
- performance,
- test,
- manufacturing,
- cost and schedule,
- training and support, and
- disposal.

In short – systems engineering describes an approach that views an entire system of components as an entity rather than simply as an assembly of individual parts. It integrates many disciplines and specialty groups into a team effort.

## ***Slide 7: Three Laws of Systems Engineering***

There are three unspoken laws of systems engineering that come to mind for the various activities within the systems engineering process. They are as follows:

### *Everything interacts with everything else.*

- Anything done to the system creates impacts that ripple throughout the system and can never be ignored.

### *Everything goes somewhere.*

- When working with a system, one deals with multiple interfaces. These interfaces have to be consistent and account for all things generated. You must account for everything at the interface and follow where it goes. If it leaves someplace, then it must arrive someplace else.

*There is no such thing as a free lunch.*

- Never become so enamored with a design decision that you forget the negative aspects of that decision. Everything comes at a price. (6)

***Slide 8: Systems Engineering Process***

The system engineering approach is an iterative process, whereby system concepts and objectives are established, potential solutions are developed and evaluated, new solutions are identified, and system objectives are redefined.

Through each iteration, the level of detail in the design and analysis of the system is increased. This iterative process continues throughout the entire life cycle of the system (planning, design, construction, and operations) with most of the iterations occurring during the planning and design phase of the system.

***Slide 9: Systems Engineering Process – A Transportation Perspective.***

***Slide 10: Symptoms of Poor Systems Engineering***

Several conditions or situations can indicate poor systems engineering. These symptoms include:

- behind schedule,
- over budget,
- confusion over customer requirements,
- confusion over customer mission,
- not achieving technical requirements,
- not achieving customer expectations,
- point design without consideration of options,
- conflict between systems and design engineering,
- failure to document decisions in engineering memos,
- floating baseline,
- no rigid formal change control, and
- frayed nerves. (5)

***Slide 11: Systems Engineering Philosophy***

- Focus on identifying requirements
- Not technology driven
- Includes:
  - system analysis, and
  - decision making.

### ***Slide 12: Systems Engineering Approach***

This is a system engineering approach for designing and implementing a freeway management system – an example that will be used throughout the remainder of the module. Note that the system engineering approach is an iterative process that lasts throughout the life of the system. After first identifying specific problems, a system is developed to address these problems. Continuous evaluation of the performance of the system allows new problems and opportunities to be defined. By using this process, continuous improvement to the system can be identified and implemented.

### ***Slide 13: Systems Engineering Approach - Define the Problem***

#### ***Slide 14: Define the Problem***

Problems can vary from being operational in nature (e.g., congested areas or times of days, high accident frequencies, poor air quality or non-attainment with air quality standards) to institutional (e.g., better coordination between and within agencies, underutilization of transit facilities, etc.).

Several methods are available to help with defining problems that can be addressed by a freeway management system. Traditional operational studies such as traffic flow and capacity analyses, travel time and delay studies, and accident studies are often used to identify operational problems that can be addressed by a freeway management system. Other sources of information include:

- regional transportation and land use planning studies,
- site impact analyses, and
- air quality assessments.

It is important not to overlook the importance of coordinating with other transportation-related agencies to identify problems to be addressed by a freeway management system. Input from commercial industries can also be valuable in identifying specific areas of concerns or needs from the freeway system. Finally, and perhaps most importantly, input from local politicians could also provide insight into the public's perception of problems with the freeway system.

#### ***Slide 15: Inventory of System***

Another critical element in defining the problems that exist with the freeway system is to obtain an accurate and complete inventory of the existing transportation system. This inventory should include both physical and organizational components. Examples of physical components that should be identified in the inventory include:

- roadway network,
- existing surveillance and control components, and
- existing information dissemination components.

Examples of the operational components that might influence the design of a freeway management system and, thus, must be identified in an inventory include:

- operating agencies,
- funding sources, and
- political and agency jurisdictions.

***Slide 16: Systems Engineering Approach - Establish Institutional Framework***

***Slide 17: Establish Institutional Framework***

Institutional frameworks and coalitions can dramatically affect the design of the system. These need to be established at the beginning of the planning and design process. Coalitions and institutional frameworks are needed at three levels: between agencies (interagency), within agencies (intra-agency), and with other stakeholders affected by traffic operations.

Traffic congestion is not restricted by jurisdictional boundaries. Therefore, there is a strong need to develop good working relationships and build coalitions between agencies responsible for managing traffic in an area.

***Slide 18: Interagency***

Examples of the types of agencies where strong coalitions would help in the implementation of a freeway management system include:

- metropolitan planning organizations (MPOs),
- highway and public works agencies,
- transit agencies,
- law enforcement,
- emergency services (fire, ambulance),
- turnpike / toll road authorities,
- port authorities, and
- state and federal emergency management authorities.

***Slide 19: Intra-agency***

Cooperation and coalitions within an agency are also essential in establishing an effective freeway management system. Often, this type of cooperation is the hardest to obtain. Some sections within an agency may view a freeway management system as usurping some of their responsibilities and power. Therefore, it is essential that all elements within an agency be committed to constructing, operating, and maintaining the system.

Examples include:

- planning,
- administrative,

- construction,
- design,
- operations, and
- maintenance.

***Slide 20: Other Stakeholders***

There may be other groups in the community that may be important allies when implementing a freeway management system. Perhaps the biggest of these is the general public. Without the support of the general public, it will be extremely difficult to implement a freeway management system. Extensive public relations and media campaigns may be required to show the public how a freeway management system will have a direct benefit to them. Strong public support makes it easier to secure funding and political support. Without public support, transportation planners find it will be extremely difficult to generate interest and support for freeway management.

Other stakeholders that may be useful in implementing a freeway management system include:

- major traffic generators,
- utility companies,
- politicians,
- the media,
- private transportation providers.

***Slide 21: Systems Engineering Approach - Build Coalitions***

***Slide 22: Building Coalitions***

Establishing institutional frameworks and coalitions can be difficult at times. The first step in building effective coalitions is to identify “champions” in those agencies responsible for transportation in a community (e.g., state highway agencies, MPOs, transit authorities, etc.). Champions are individuals who you expect to be strong proponents of the project. They are likely to be top administrative officials in these organizations.

It is also important to identify those individuals that will be crucial for the success of the system (e.g., the public, politicians, major employers, etc.). The support of one or more local politicians can be highly effective in securing funding for the system.

Take advantage of institutional frameworks that already exist. Many locales have institutional frameworks to address freeway management concerns. For example, many locations use Traffic Management Teams and Incident Management Teams to address problems on freeways. Often these teams are a coalition between state and local transportation agencies and law enforcement personnel. These coalitions can be expanded to encompass additional functions of a freeway management system.

***Slide 23: Systems Engineering Approach - Establish System Goals and Objectives***

### ***Slide 24: Establish System Goals and Objectives***

Once coalitions have been formed, agencies should work together to define the goals and objectives of the system. The system goals and objectives should describe what it is the system is supposed to accomplish. The goals and objectives should be related directly to the specific problems to be addressed by the system.

Generally, system goals define the long-range desires of the system. System goals also tend to be broad in terms of their scope. System objectives, on the other hand, define the level of performance that is expected to be obtained in the future. As such, system objectives are measurable. Often, more than one system objective is required to fulfill a system goal. Likewise, more than one system goal may be required to address an identified problem in a system.

### ***Slide 25: Example of System Goals and Objectives***

The following list provides an example of a system goal and objectives developed to address the problems of incidents in a system. Note that while the defined problem and system goals are broad in nature, the objectives of the system are specific and measurable. Also note that more than one objective is required to fulfill the goal of the system.

#### ***Identified Problem***

- Incidents are the primary source of congestion on freeway.

#### ***System Goal***

- Reduce the impacts of incidents.

#### ***System Objectives***

- Detect all major incidents within 2 minutes of occurrence.
- Reduce the time to clear an incident from the freeway by 5 minutes.

It is also important to note that system objectives are defined in terms of what services and functions a system is to provide—not in terms of technology. Notice in the example that no mention is made of the type of technology that will be employed to achieve a two-minute detection time. Focusing on what the system is to achieve instead of on how it is to achieve it gives the designers flexibility in the way that components can be combined to build a system to achieve a desired outcome.

### ***Slide 26: Systems Engineering Approach - Establish Performance Criteria***

### ***Slide 27: Establish Performance Criteria***

After establishing the system goals, the next step in the system engineering approach is to establish the criteria for judging the performance of the system. The performance criteria are used to determine whether the objectives of system are being achieved. The criterion includes

both qualitative and quantitative measures of performance for the system. It also forms the basis for evaluating the design and operations of the system.

***Slide 28: Example of Performance Criteria / Incident Management***

The following list illustrates some potential criteria for evaluating the performance of a system to reduce the impacts of an incident. Note that the criteria used to measure the performance of the system directly correspond, and are added to, the goal and objectives of the system.

***Identified Problem***

- Incidents are the primary source of congestion on freeway.

***System Goal***

- Reduce the impacts of incidents.

***System Objectives***

- Detect all major incidents within 2 minutes of occurrence.
- Provide first response to an incident within 15 minutes of verification.
- Reduce the time to clear an incident from the freeway by 5 minutes.

***Performance Criteria***

- Detect all major incidents within 2 minutes of occurrence:
  - *average detection time and*
  - *percent of incidents detected within 2 minutes of occurrence.*
- Provide first response to an incident within 15 minutes of verification:
  - *average response time and*
  - *percent of incidents responded to within 15 minutes of verification.*
- Reduce the time to clear an incident from the freeway by 5 minutes:
  - *average clearance time before system was initiated,*
  - *average clearance time after system was initiated, and*
  - *percent of incidents where clearance time was reduced by 5 minutes.*

***Slide 29: Systems Engineering Approach - Define Functional Requirements***

***Slide 30: Define Functional Requirements***

The next step in the systems engineering approach is to define all of the features or activities (commonly called functions) of the system that are necessary to achieve the identified objectives. The system functions need to be described, at least initially, independent of the technology or architecture to be employed in the system. In other words, this step focuses on describing *what* it is the system will be designed to do not *how* the system will be doing it.

***Slide 31: Example of Functional Requirements***

The functional requirements needed to achieve a system objective can often be outlined in hierarchical order. Note that each of the functional requirements defines an action or activity that is to be performed by the system and is independent of technology.

- I. Incident Management
  - a. Identify incidents
    - 1. Identify location of incident
    - 2. Identify impacts of incident
    - 3. Identify characteristics of incident
  - b. Formulate response actions
    - 1. Identify necessary emergency vehicle response
    - 2. Select incident information for dissemination to travelers
    - 3. Identify traffic control strategies
  - c. Initiate and monitor response
    - 1. Provide response procedures to agencies
      - a. Implement emergency vehicle response
      - b. Provide incident information to travelers
      - c. Implement traffic control strategies
    - 2. Monitor response
      - a. Arrival of emergency vehicles
      - b. Implementation of traffic control
      - c. Clearance of incidents
      - d. Clearance of congestion

***Slide 32: Systems Engineering Approach - Define System Architecture***

***Slide 33: Define System Architecture***

After defining *what* the system is supposed to accomplish, the next step in the system approach is to define the system architecture. System architecture is a framework within which the system carries out the functions required to support the desired objectives. It describes the system elements and their relationships to one another.

***Slide 34: Benefits from Planning System Architecture***

The system architecture of many freeway management systems in operation today evolved as new functions were added to the system. However, there are real benefits to be achieved in planning the system architecture in advance, even if the system will not be fully implemented at one time. Planning the system architecture minimizes the number of redundant functions and efforts performed by the system. Planning the system architecture also promotes the efficient use of equipment, staff, and resources. A well-planned system architecture permits easy expansion and modernization of the system in the future. How the system architecture is defined also facilitates the sharing of information between jurisdictions and leads to cost savings throughout the design, implementation, and operation of the system.

***Slide 35: System Architecture Levels***

The system architecture consists of three elements: the functional requirements, the logical architecture, and the physical architecture. As discussed above, the functional requirements

define what the system is supposed to do. The logical architecture identifies what information flows between the functions. The physical architecture identifies where functions occur and who is responsible for performing the function. The physical architecture permits like functions to be grouped into subsystems or system components.

***Slide 36: “Open” System Architecture***

It is extremely important when defining the system architecture that it remain as open as possible. An “open” architecture is a system that has been designed with standard data interfaces so that equipment from multiple vendors can be used throughout the system. In addition, an open architecture helps to keep the system from becoming obsolete because new functions and technologies can be easily added as they become available. Furthermore, an open architecture will make system components being developed today compatible with the national ITS architecture as it emerges.

***Slide 37: Systems Engineering Approach - Identify and Screen Technology***

***Slide 38: Identify and Screen Technology***

The next step in the process is to identify alternative technologies whose performance and reliability meet the defined functional requirements. This can be accomplished by conducting a state-of-the-art review of the available technologies, including review of:

- evaluation studies,
- reports,
- literature and demonstrations from manufacturers, and
- site visits.

***Slide 39: Evaluating Technologies***

Evaluators need to consider the interaction between alternative technologies and other elements within the system should be considered when evaluating different technologies. How the components work together and what functions they perform can greatly influence how different technologies perform in a system. The impacts of different technologies on the physical configuration of the system and on the performance of other technologies and components in the system should also be considered. The expandability and flexibility of the technologies should also be considered.

Cost is another factor that should be considered when identifying and screening different technologies. The engineer should consider the life-cycle costs of each of the alternative technologies. Life-cycle costs include:

- procurement, installation, and construction costs;
- the costs associated with operating and maintaining each technology;
- replacement costs during the system’s life cycle; and
- the costs associated with expanding the system.

Operations and maintenance are other important factors that must be considered when evaluating different technologies for use in a freeway management system. Often, each technology requires unique operating and maintenance activities. The resource requirements in terms of the number and qualifications of the personnel, the equipment and facility needs, and the operating and maintenance costs should be factored into the evaluation.

The process of identifying and screening different technologies for inclusion in a system is often iterative. There are multiple ways that different technologies can be combined to achieve an objective. Because how different technologies interact with one another can affect system performance, each combination must be evaluated in an iterative fashion.

***Slide 40: Systems Engineering Approach - Develop Deployment Plan***

***Slide 41: Develop Deployment Plan***

After the technologies that will be used in the system have been selected, the next step in the process is to develop a plan for deploying the system. The deployment plan documents the results of the previous steps and identifies how the system will be implemented in the field. Most deployment plans document: (3)

- the transportation system problems and opportunities to be addressed by the system,
- the institutional arrangements (i.e., who, what, when, where, why, and how) needed to make the system work,
- the goals and objectives of the system,
- the functional requirements and architecture of the entire system., and
- the technology options to be used in the system.

The deployment plan should also assess the phasing, procurement, and funding options available for implementing the system.

***Slide 42: Typical Elements of Implementation Plan***

The deployment plan should also include an implementation plan. The purpose of an implementation plan is to ensure that the system is designed, built, operated, and maintained so that it accomplishes its purpose in the most efficient manner possible, considering performance, cost, and schedule. An implementation plan is required when either a new traffic control system or an expansion of an existing system uses federal funds, and is also recommended for those systems that do not use federal funds. This illustrates a list the elements of a typical implementation plan.

***Slide 43: Procurement Approaches***

There are a number of approaches that are commonly used by agencies to deploy individual projects or system components. The more common types of procurement approaches include:

- sole-source,
- engineer/contractor,
- two-step approach,
- system management, and
- design-build.

With a sole-source project, a contract is awarded to a named supplier without any competition for the project, typically involving a standard off-the-shelf product that can be made by only one manufacturer.

With an engineer/contractor approach, a single contract is awarded to the lowest responsive bidder to a specific request by the highway agency. The contractor is then responsible for providing a complete and fully operational system.

With a two-step procurement approach, a formal technical prequalification process is added to the engineer/contractor approach. This helps ensure that the contract team has the appropriate skills and expertise in implementing the desired type of system.

With the system management approach, a system manager is hired to perform the system design, software development, and system integration activities. Separate contracts are then prepared and awarded for implementing the various components as dictated by the design.

In a design-build approach, a single entity is responsible for all of the work associated with deploying a system. Upon completion of the project, the designer-builder turns over the system to the agency for operations and maintenance. Agency supervision is required to ensure that the contractor provides a satisfactory quality of product.

#### ***Slide 44: Systems Engineering Approach - Evaluation***

#### ***Slide 45: Evaluation***

Evaluation is an ongoing process that occurs at all stages of system development and continues for the entire life of the system. Through the evaluation process, the system designers and operators are able to determine how well individual projects meet the previously established system objectives. The evaluation process also allows engineers to identify possible enhancements to the system. These enhancements can be to correct operational or design problems, expand the system either functionally or geographically, or include additional components into a regional architecture.

One of the most critical parts of the evaluation process is to document the lessons learned during the development and operations of the system. These lessons learned provide critical information to others who may be considering implementing a similar type of system. The lessons learned should not focus solely on the problems that were encountered during the development or operations of the system, but also describe the positive elements of a particular system architecture or technology.

***Slide 46: Pragmatic Principles (1 of 3)***

There are a series of pragmatic principles that underlie the practice of systems engineering. They are good pieces of advice, system engineering adages to be taken into account when planning the engineering of a system. They are not an outline of a complete systems engineering process. In fact, not all the principles apply to all situations.

- Know the problem, the customer, and the consumer.
- Use effectiveness criteria based on needs to make system decisions.
- Establish and manage requirements. (Z)

***Slide 47: Pragmatic Principles (2 of 3)***

- Identify and assess alternatives so as to converge on a solution.
- Verify and validate requirements and solution performance.
- Maintain the integrity of the system. (Z)

***Slide 48: Pragmatic Principles (3 of 3)***

- Use an articulated and documented process.
- Manage against a plan. (Z)

***Slide 49: Module Summary***

*Systematic Approach  
Process*

- systems analysis and
- decision-making

*Steps*

- define problem, goals, and objectives.

## Module References

1. "Training Course on Freeway Traffic Operations." Report No. FHWA-HI-97-009, Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1997.
2. Athey, T.H. "Systematic Systems Approach." Prentice-Hall, Inc, Englewood Cliffs, New Jersey, 1982.
3. ReVelle, C.S., E.E. Whitlatch, and J.R. Wright. *Civil and Environmental Systems Engineering*. Prentice Hall, Upper Saddle River, New Jersey, 1997.
4. International Council on Systems Engineering. "What is Systems Engineering?" URL: <http://www.incose.org/whatis.html>, INCOSE, 1999.
5. McClinton, David F. "Systems Engineering: A Tutorial." Unpublished report, 1999.
6. McClinton, David F. "The Unwritten Laws of Systems Engineering." Presented at the Fourth Annual International Symposium of the National Council on Systems Engineering, 1994.
7. INCOSE: SE Practice Working Group – Subgroup on Pragmatic Principles. "An Identification of Pragmatic Principles – Final Report." INCOSE WMA Chapter, URL: <http://www.incose.org/workgrps/practice/pragprin.html>, 1999.

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**APPENDIX C: MODULE EXERCISE**

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## **SYSTEMS ENGINEERING AND TRANSPORTATION EDUCATION MODULE EXERCISE**

Your community is going to design and build a transportation management center (TMC) to manage the transportation system from a centralized location. Step through the entire systems engineering process and map the way in which your community would proceed. Document everything and prepare a report that outlines the entire exercise.

If your community already has a transportation management center, then step through the systems engineering process to determine how the TMC operations could be improved, changed, or enhanced.

**SOLUTION:** This solution will vary depending on the community in which you live. Use the slides as a model to discuss the various steps of the process.

