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16. Abstract

Texas Department of Transportation (TxDOT) engineers are responsible for the design, evaluation, and implementation of video solutions across the entire state. These installations occur with vast differences in requirements, expectations, and constraints. Because the systems require extensive interoperability to other systems, agencies, and deployments, a systems engineering process (SEP) is employed to develop a consistent and structured approach to the development of concepts, needs, requirements, design, testing, and on-going operations. This report details the development of a guidebook and supplemental CD-ROM for TxDOT engineers to understand, assess, and deploy digital video solutions.

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DEVELOPMENT OF A VIDEO OVER IP GUIDEBOOK

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The researcher in charge of the project was Robert E. Brydia.

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TABLE OF CONTENTS

LIST OF FIGURES

Page

CHAPTER 1: INTRODUCTION

BACKGROUND

Video is a critical component of Traffic Management Centers (TMCs). Operators use video surveillance to monitor roadways, identify incidents, assist in operations, and support operational decisions. Within the Texas Department of Transportation (TxDOT), a wide range of solutions have been deployed, employing different technologies, standards, and capabilities.

Many existing installations are faced with increasing their deployment of surveillance video as a means of extending, improving, and updating their system. Likewise, emerging districts are developing and deploying video solutions to build out their systems. Additionally, the marketplace is rapidly transitioning to digital solutions and the convergence of communication networks to handle both data and video. These changes result in the need to develop and deploy video solutions that address several key concepts, including:

- integration with existing systems,
- provisioning for the future in terms of standards and interoperability,
- performing the functions required for traffic operations needs,
- providing sufficient quality for traffic operations needs, and
- cost-efficiency.

Key Concept: Integration

In many cases, video deployments are not new systems. They must join together with existing systems and resources. The integration must focus not only on physical location of devices and a communications pathway, but also providing for command and control functions in terms of software applications. If systems are not integrated, operators would be forced to use multiple systems of the same type of hardware (video) to accomplish their duties, which is inefficient and time-consuming.

Key Concept: The Future

The last several years have seen a transformation in the provision of video at all levels in the industry. In the consumer marketplace, digital video is now commonplace, from cell phones to camcorders. In the professional market, arenas like wedding and portrait photography are almost exclusively digital. In the security marketplace, digital solutions that record, archive, use motion-sensing alarms grids and more, are commonly deployed. Within the realm of transportation, the marketplace has rapidly evolved toward the digital transmission of video. In all of these areas, the key has been the use of new standards and technologies that extend the capabilities of the devices and the ability to integrate these devices into systems.

Key Concept: Functional Adequacy

One of the most important concepts in any solution is deploying a solution that meets the needs. The meaning of the word "needs" can be exceptionally broad, involving multiple agencies, multiple user groups, and multiple technical and performance requirements. Cataloging these needs and attempting to meet them in a systematic manner is a critical concept to embrace in the deployment of any video solution.

Key Concept: Video Quality

A key concept in the deployment of any video solution is quality. What some people find acceptable, others dismiss as inadequate for their needs. Video quality can be assessed either subjectively or objectively. A subjective evaluation deals with how video is perceived by an individual viewer. Running subjective quality tests is costly in terms of time and human resources. Objective testing uses mathematical models that seek to approximate the results of subjective tests, but instead are based on criteria that can be measured and evaluated by a computer program or piece of test equipment. Objective testing generally requires sophisticated and expensive test equipment.

Key Concept: Cost

No matter what technology, system, or deployment is under discussion, cost is always a concern. No agency typically has all of the funds necessary to deploy the ultimate solution that meets every need and wish on the list. Choices must be made, and cost is often one of the critical assessment points for those decisions. A dilemma often faced, however, is that cuts or decisions are made with respect to cost that eliminate fundamental functions. While the solution as deployed will be within budget, it will be handicapped from the start by not being functionally adequate.

OBJECTIVE OF THIS PROJECT

The overall objective of this research project was to develop an approach to deploying video solutions for the Texas Department of Transportation (TxDOT) that focuses on meeting the challenges expressed in the five key concepts in the previous section. As guided by the department, the approach focused on digital video deployments using the Internet Protocol (IP) for transmission of the video information.

PROJECT APPROACH

The research team developed a project approach based on systems engineering. While the basic concepts of systems engineering provide a starting point, the modifications made by the Federal Highway Administration (FHWA) to support Intelligent Transportation Systems (ITS) deployments provide an extensive base for the development of solutions specific to video deployments. Some modifications to the level of systems engineering developed for ITS have been employed for this project. This is in full accordance with the guiding principles of systems engineering as project, or scope level modifications to the process are recognized as being necessary by organizations that promote its use.

PROJECT WORKPLAN

To accomplish the stated objective, the researchers identified a five-task workplan that developed the knowledge for the guidebook as well as the document itself. The five tasks were:

1. Development of User Needs and Functional Requirements;
2. Evaluation of Technology Options;
3. Video Design/Architecture Options;
4. Guidebook Development; and
5. Preparation of Project Documentation.

PROJECT DELIVERABLES

The research team developed and delivered a guidebook focused on the deployment of IP-based video solutions. The entire process is guided by the principles of the system engineering process to analyze user needs, establish functional requirements, evaluate alternatives, and validate results. The guidebook is accompanied by a CD that visually illustrates some of the terminology and technology considerations associated with video solutions.

SUBSEQUENT CHAPTERS OF THIS REPORT

Subsequent chapters of this report briefly describe the content of the guidebook and the CD as well as providing visual examples from the deliverables. For full detail on all aspects of the approach of deploying video over IP solutions, the reader is referred to the guidebook itself.

CHAPTER 2: A SYSTEMS ENGINEERING APPROACH TO VIDEO DEPLOYMENTS

THE NEEDS OF COMPLEX PROJECTS

More so than ever, the types of projects undertaken by today's transportation engineers are highly complex and involve many different aspects. Often a project involves not only the physical aspects of building a facility, but also monitoring it, and using the data from the monitoring systems to analyze the situations, react to incidents, predict future conditions, send information and alerts to both drivers and agencies, and overall, manage the facility to obtain the best utilization of the capacity.

The need to accomplish so much, means that today, the planning for any facility encompasses far more than the physical design. As an example, consider a new roadway in an urban area. In addition to the physical design and construction, planning for the new facility could also include:

- the type, amount, and location of infrastructure for roadway monitoring systems,
- the type, amount, and location of infrastructure for disseminating information to travelers,
- the provision of the communications capability to carry the data,
- the expansion of analysis capability for roadway data,
- the integration into display systems inside a control center,
- the expansion of operational software inside a control center,
- the updating of response plans for incidents and roadway events,
- the expansion of web-based information (if present) for a new facility, and,
- the integration of a new facility into toll systems (if present).

As might be obvious after reading the above list, the requirements of how the facility will be used dictate that the actual planning must start long before the steps of earth-moving and placing pavement take place. Even after the facility is built, the process continues with the integration with other regional systems and the daily operations.

To address similar needs to take the big picture view in other fields of study, practitioners have turned to the Systems Engineering Process (SEP). The SEP focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with the design process and system validation to ensure that the functional requirements identified early in the process are met.

The systems engineering process was created by the Department of Defense (DOD) to quantify and verify that complex systems perform the required tasks and are implemented correctly. Later, other agencies, including FHWA adopted the use of SEP as a method to deploy solutions that better meet the stated needs. For ITS projects, FHWA has a rule that specifies that any project moving to design is required to follow a systems engineering process appropriate to the scope of the project.

WHAT IS SYSTEMS ENGINEERING?

In simple terms, systems engineering is a process for designing and managing complex projects. If a system is defined as "*a combination of interacting elements organized to achieve one or more stated purposes (1)*," then systems engineering can be defined as "*an interdisciplinary approach and means to enable the realization of successful systems (1).*"

Overall, the objective of the systems engineering process is to focus participants on identifying the needs and functionality early in the development cycle, creating designs that meet those requirements, supporting the design process with strong testing and validation procedures and maintaining the system throughout its life cycle. The International Council on Systems Engineering (INCOSE) states that when properly implemented, system engineering will:

- create a structured process for integrating and linking requirements, schedules, decision milestones, and verification;
- allow a project team to work to a single set of integrated requirements;
- move the integration aspect of the project to the requirements and design stage; and
- reduce unplanned and expensive fixes necessary to resolve omissions and oversights *(3)*.

WHY USE SYSTEMS ENGINEERING?

The use of systems engineering allows two major factors to not only be present, but work in concert, during the lifetime of the project. The first aspect is often referred to as a disciplined focus on the end product, which allows all technical aspects of the project to be designed to support the end product. The potential end products, or alternatives, are envisioned up front by analyzing stakeholder needs and converting their expectations into technical requirements. These technical requirements are then balanced with feasibility and economic considerations to develop the alternatives.

The second aspect is often referred to as a disciplined focus on the stakeholder's expectations, outside of the daily focus of the project needs. As has certainly been evident over time and past project experiences, technical or project can overshadow stakeholder expectations, resulting in project solutions that 'lost their way' and in the end did not meet the initial requirements. By designing to the end product and verifying that the solution meets stakeholder requirements, this focus can be maintained throughout the design process. In general, systems engineering results in solutions that:

- have improved stakeholder participation,
- are more adaptable systems,
- are more resilient systems,
- experience a reduction in the risk of schedule and cost overruns,
- incorporate more functionality in designs,
- experience fewer defects, and
- provide better documentation *(2)*.

THE SYSTEMS ENGINEERING PROCESS

Systems engineering is guided by several principles, including:

- *Start with your eye on the finish line* – Reach a consensus at the beginning of the process what will constitute success.

- *Stakeholder involvement is key* – While stakeholders may vary throughout the process, they hold key information to define the problem and the range of potential solutions as well as the criteria to determine the best solution.

- *Define the problem before implementing the solution* – Because there are often multiple ways to solve a problem, focusing on the problem first allows a more open process for defining all potential solutions.

- *Delay technology choices* – Specifying technology too early will lead to outdated results.

- *Divide and conquer* – Break down a big problem into several small ones.

- *Relate the items in one step of the process to another (traceability)* – Traceability connects the process together and allows designers to ensure that requirements are being met in implementation *(3)*.

As listed below, the systems engineering process contains several aspects or phases.

- *Plan or organize technical aspects* – Understand the general problem that needs to be solved, as well as the influencing factors and constrains. Understand the organization and schedule as well as the methodology to be employed in implementing the process.

- *Analyze the problem posed by the stakeholders* – Define the problem from the aspect of the system looking out towards its environment. How is the product affected by the environment and constraints? How will politics and policies affect any technical solutions?

- *Assess, develop, and select alternatives* – Development of alternatives allows the project team to respond to stakeholder direction without preconceived notions, to challenge requirements, to explore viable alternatives and to identify unbiased selection criteria.

- *Design the end product* – The concept of 'design follows requirements' applies here. Develop models and prototypes as necessary to reduce risks. Perform sensitivity analyses to establish design margins and evaluate each design alternative.

- *Verify solution meets stakeholder's needs* – Verification that the end product meets the design requirements and integrates with other end products. Resolve any implementation irregularities *(3)*.

While guided by the principles and phases listed above, the SEP is perhaps most commonly viewed in the "Vee" diagram. Figure 1 shows the generic systems engineering process. Examination of the diagram shows that the process starts on the left-hand side with the formulation of a management plan and the proceeds to a concept of operations, followed by the establishment of requirements. The process then moves into the design phases followed by implementation, which can cover coding and testing if there are hardware and software aspects to the project. Along the right-hand side of the diagram are the verification and validation aspects of the project, followed by long-term operations and maintenance.

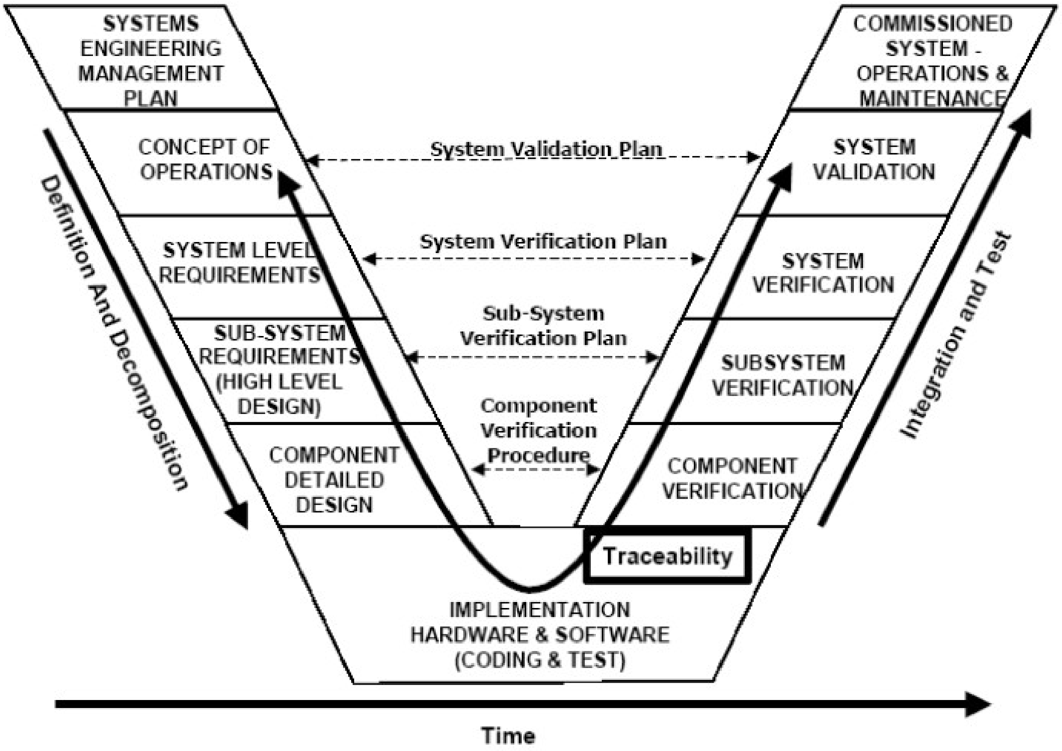


Figure 1. Systems Engineering Process [Source: 3].

Figure 2 shows the “Vee” diagram applied to a traditional Intelligent Transportation Systems (ITS) project. While the basic application is the same, note that “wings” have been added to each side of the diagram. Aside from looking a little more stylized, the starting point is now the regional architecture, which should govern the introduction and integration of any individual project into the overall systems deployed in a region, which typically involve multiple partners.

On the right side of the diagram, the ending point is now “changes and upgrades” and “retirement and replacement.” This speaks to the knowledge that no system lasts forever and the consideration of the life-cycle aspect of projects in the design phase may make subsequent maintenance and replacement an easier process.

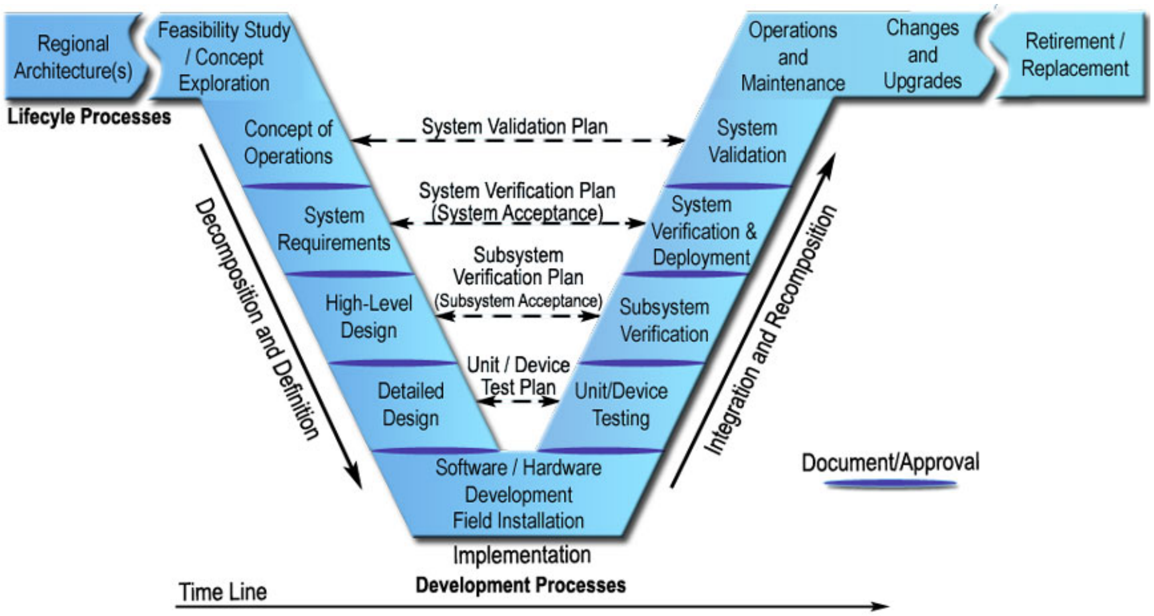


Figure 2. Systems Engineering Process for an ITS project.

SYSTEMS ENGINEERING FOR VIDEO OVER IP

Perhaps the most striking aspect of the diagrams presented in Figure 1 and Figure 2 is that while they address similar topics and show the same generic process, they are in fact different. This is actually one of the least understood aspects of systems engineering. SEP is as much a way of thinking and doing business as it is a process. In fact, it is not only acceptable, but encouraged to adapt the traditional “Vee” diagram to the particular project at hand. This streamlines the approach while keeping the important aspects in place.

Figure 3 shows the systems engineering process developed for this project to illustrate the approach to digital video projects. As an overview, the diagram is the same as the traditional ITS “Vee” diagram although some similar sections have been combined. On the right-hand side of the diagram, the testing and verification sections have been combined, as the guidebook presented one chapter on the overall testing methodology for video systems. Another chapter focused on system acceptance, which is closely related to testing. On the left-hand side of the diagram, the process reflects the development of a concept of operations which gets translated to functional requirements. A system design follows from the requirements.

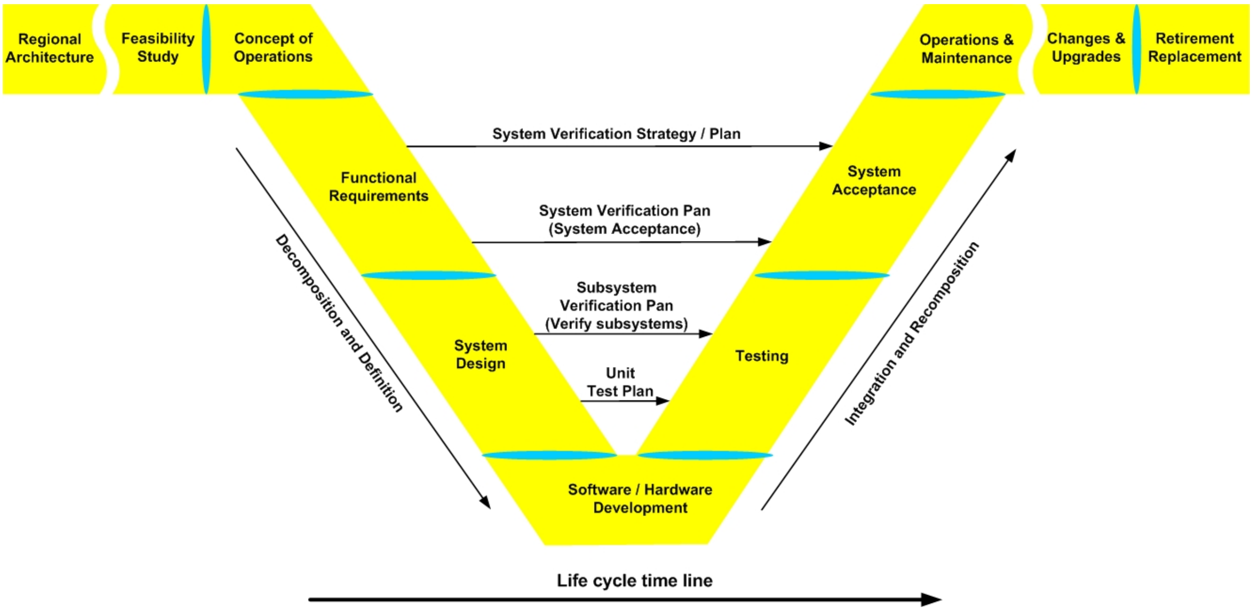


Figure 3. Systems Engineering Process for Video Projects.

The guidebook did not focus or discuss the software/hardware development phase identified in Figure 3 at the bottom of the "Vee" diagram. While included in the "Vee" for completeness, this type of information is typically very project specific and would be significantly more difficult to discuss without getting specific to an implementation. Additionally, it would also present the least value to the reader since much of the information would not be transferrable across projects.

Employing an SEP for video deployments, guided the principles discussed above, should address the five key concepts detailed earlier by:

- resulting in video solutions that can integrate with existing stakeholder systems,
- producing solutions that are standards and interoperable with other systems,
- fulfilling the specified functions of the stakeholders for traffic operations needs,
- providing quality video sufficient for the required stakeholder tasks, and
- producing cost efficient solutions that focus on needs, not technologies.

CHAPTER 3: GUIDEBOOK DEVELOPMENT

GUIDEBOOK CONTENT

Content for the guidebook came from numerous sources, including FHWA publications, technical documentation from various agencies, other Departments of Transportation (DOTs) and the research team's experience. The guidebook was organized into nine chapters as listed below:

- Chapter 1: Introduction;
- Chapter 2: A Brief Introduction to Systems Engineering;
- Chapter 3: Early Phases of the Systems Engineering Process;
- Chapter 4: The Functional Requirements Phase;
- Chapter 5: The System Design Phase;
- Chapter 6: The Testing and System Acceptance Phase;
- Chapter 7: The Concluding Phases of the Systems Engineering Process;
- Chapter 8: Procurement to Support Systems Engineering; and
- Chapter 9: Glossary.

A brief overview of the content in each chapter is described below. For full information, the reader is referred to the actual guidebook developed in the product.

Chapter 1

Chapter 1 serves as the introduction to the guidebook. It offers a concise description of the scope, describes the chapters in the guidebook, and states the audience for the guidebook.

Chapter 2

Chapter 2 introduces the concepts associated with systems engineering and leads the reader through the development of the SEP process and its application to video solutions. This material was also presented in Chapter 2 of this report.

Chapter 3

Chapter 3 covers the initial aspects of the SEP process including regional architectures, feasibility studies, and a concept of operations. The level of detail provided on these topics is meant to promote awareness and an understanding of the overall relation of each step in the SEP process. The level of detail is not intended to teach the guidebook reader the entire process of creating, as an example, a regional architecture.

Chapter 4

Chapter 4 focuses on defining the requirements of the project. A clear statement of requirements is one of the most important attributes in a successful project. However, this step is often seen as the most difficult. Many times, the initial list of requirements resembles more of the jumbled wish list, combined with project or technology preferences. It takes time and effort to develop a comprehensive set of good requirements.

The starting point for defining requirements is the stakeholder needs identified in the Concept of Operations. These needs should be reviewed, analyzed, and transformed into requirements that define *what* the system will do. At this point in the process, the emphasis should not be on *how* the system will do it.

Guidebook readers are led through the process of creating requirements that are Necessary, Clear, Complete, Correct, and Verifiable. The concept of traceability is introduced and demonstrated, as well as how it can be used to point out inconsistencies between needs and requirements statements.

Readers are then led through representative user needs and corresponding requirements in several critical project planning areas, including:

- systems users,
- camera control,
- distribution of video images,
- image quality,
- user interface,
- control room issues,
- communications infrastructure,

- security,
- system reliability and redundancy,
- system operating parameters,
- system administration,
- field equipment,
- standards/testing,
- system expansion, and
- system maintenance.

Chapter 5

The first part of Chapter 5 of the guidebook focuses on explaining what digital video is and what the characteristics of digital video are that can be altered, such as frame rate, resolution, color depth, and more. The middle portion of Chapter 5 focuses on conveying information on the vast range of media types or formats that are in use, with more than 20 detailed descriptions of common encoding schemes. The concluding part of Chapter 5 focuses on the different methods used to transmit digital video over an Internet Protocol (IP) network. Applicable technologies are discussed as well as presenting a brief capabilities listing. The chapter concludes with a bandwidth comparison table across the various technologies.

Chapter 6

Chapter 6 presents information to the guidebook reader on the testing and system acceptance activities that take place within the “Vee” diagram. A common assumption is that testing activities only take place on the “right” or “integration and recomposition” side of the diagram. However, testing activities actually take place on both sides of the “Vee” diagram. During the concept of operations phase, thought must be given to the development of a testing plan with roles and responsibilities considered. One should also keep in mind that, in some cases, testers are also users. During the systems requirements phase, each requirement needs to be analyzed as to whether it is testable. During the high-level and detailed design phases, the initial testing activity centers around traceability back to requirements. As the designs start to reach completion, the activity is a review to identify deficiencies before they become errors and omissions that present themselves in subsequent testing phases.

Chapter 7

Chapter 7 presents information pertaining to the concluding phases in the SEP. This includes Operations and Maintenance and Changes and Upgrades. Discussion is presented on activities within each phase and how it relates to the SEP.

Chapter 8

Chapter 8 address procurement as a statement of needs to be satisfied. The procurement specification should provide potential suppliers a clear, accurate, and full description of an organization's needs, which in turn, should allow a supplier to propose a solution to meet those needs. This section is included in this guidebook to provide some information on typical procurement options, including contract types and roles and responsibilities.

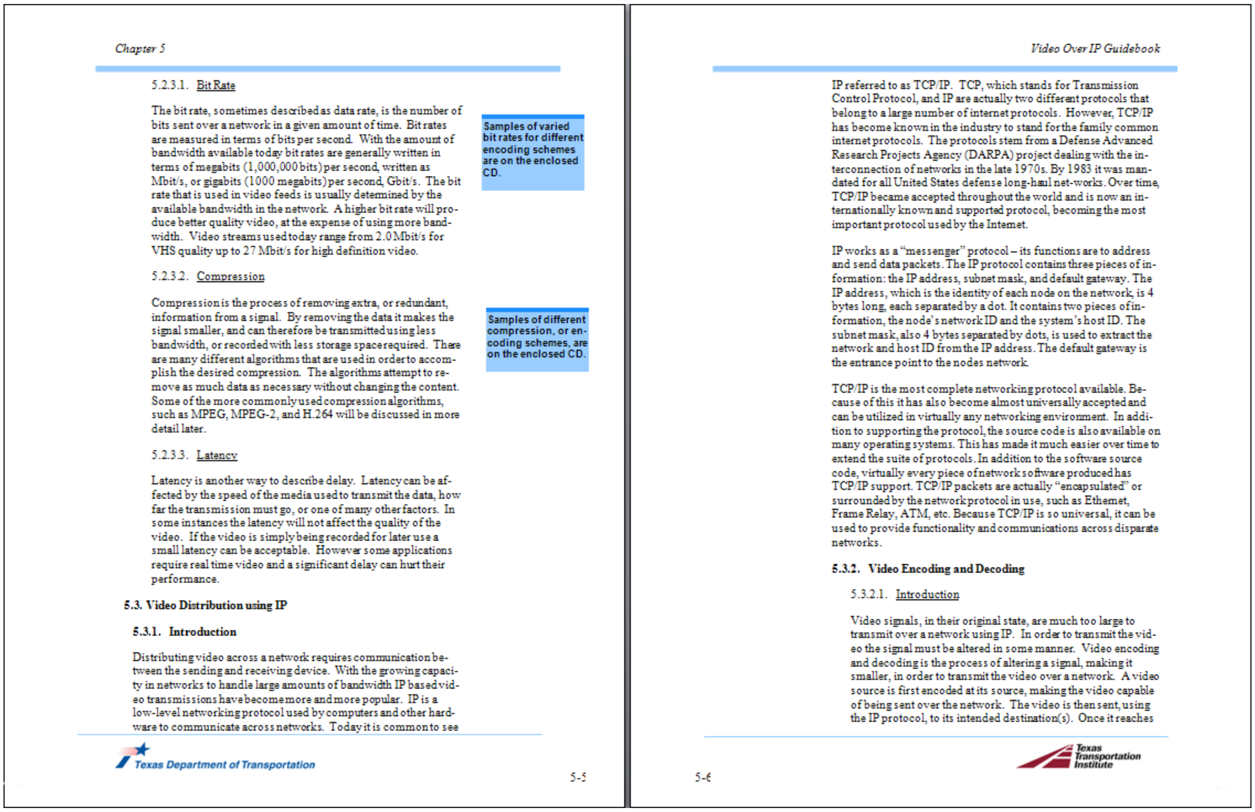
Chapter 9

Chapter 9 presents a glossary listing of the various terms identified throughout the guidebook.

GUIDEBOOK FORMAT

Figure 4 shows two sample pages from the guidebook. The notebook was designed with many features such as wide margins for taking notes, call-outs for critical information, and the use of color, where warranted, to provide additional clarity to the material.

It is anticipated that the guidebook will be a handy shelf reference for many aspects of understanding systems engineering and its application to digital video projects.



Chapter 5

5.2.3.1. Bit Rate

The bit rate, sometimes described as data rate, is the number of bits sent over a network in a given amount of time. Bit rates are measured in terms of bits per second. With the amount of bandwidth available today bit rates are generally written in terms of megabits (1,000,000 bits) per second, written as Mbit/s, or gigabits (1000 megabits) per second, Gbit/s. The bit rate that is used in video feeds is usually determined by the available bandwidth in the network. A higher bit rate will produce better quality video, at the expense of using more bandwidth. Video streams used today range from 2.0 Mbit/s for VHS quality up to 27 Mbit/s for high definition video.

Samples of varied bit rates for different encoding schemes are on the enclosed CD.

5.2.3.2. Compression

Compression is the process of removing extra, or redundant, information from a signal. By removing the data it makes the signal smaller, and can therefore be transmitted using less bandwidth, or recorded with less storage space required. There are many different algorithms that are used in order to accomplish the desired compression. The algorithms attempt to remove as much data as necessary without changing the content. Some of the more commonly used compression algorithms, such as MPEG, MPEG-2, and H.264 will be discussed in more detail later.

Samples of different compression, or encoding schemes, are on the enclosed CD.

5.2.3.3. Latency

Latency is another way to describe delay. Latency can be affected by the speed of the media used to transmit the data, how far the transmission must go, or one of many other factors. In some instances the latency will not affect the quality of the video. If the video is simply being recorded for later use a small latency can be acceptable. However some applications require real time video and a significant delay can hurt their performance.

5.3. Video Distribution using IP

5.3.1. Introduction

Distributing video across a network requires communication between the sending and receiving device. With the growing capacity in networks to handle large amounts of bandwidth IP based video transmissions have become more and more popular. IP is a low-level networking protocol used by computers and other hardware to communicate across networks. Today it is common to see

Texas Department of Transportation

5-5

Video Over IP Guidebook

IP referred to as TCP/IP. TCP, which stands for Transmission Control Protocol, and IP are actually two different protocols that belong to a large number of internet protocols. However, TCP/IP has become known in the industry to stand for the family common internet protocols. The protocols stem from a Defense Advanced Research Projects Agency (DARPA) project dealing with the interconnection of networks in the late 1970s. By 1983 it was mandated for all United States defense long-haul net-works. Over time, TCP/IP became accepted throughout the world and is now an internationally known and supported protocol, becoming the most important protocol used by the Internet.

IP works as a "messenger" protocol – its functions are to address and send data packets. The IP protocol contains three pieces of information: the IP address, subnet mask, and default gateway. The IP address, which is the identity of each node on the network, is 4 bytes long, each separated by a dot. It contains two pieces of information, the node's network ID and the system's host ID. The subnet mask, also 4 bytes separated by dots, is used to extract the network and host ID from the IP address. The default gateway is the entrance point to the nodes network.

TCP/IP is the most complete networking protocol available. Because of this it has also become almost universally accepted and can be utilized in virtually any networking environment. In addition to supporting the protocol, the source code is also available on many operating systems. This has made it much easier over time to extend the suite of protocols. In addition to the software source code, virtually every piece of network software produced has TCP/IP support. TCP/IP packets are actually "encapsulated" or surrounded by the network protocol in use, such as Ethernet, Frame Relay, ATM, etc. Because TCP/IP is so universal, it can be used to provide functionality and communications across disparate networks.

5.3.2. Video Encoding and Decoding

5.3.2.1. Introduction

Video signals, in their original state, are much too large to transmit over a network using IP. In order to transmit the video the signal must be altered in some manner. Video encoding and decoding is the process of altering a signal, making it smaller, in order to transmit the video over a network. A video source is first encoded at its source, making the video capable of being sent over the network. The video is then sent, using the IP protocol, to its intended destination(s). Once it reaches

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5-6

Figure 4. Sample Pages from Video Over IP Guidebook.

CHAPTER 4: SUPPLEMENTAL CD-ROM

OVERVIEW

Throughout the development of the guidebook, several topics were encountered that lent themselves more to a visual explanation than to written text. A typical example is frame rate. While descriptive text was written to convey what a video frame is and what frame rate is, for most people a more intuitive understanding comes from looking at these characteristics visually. For this reason, the supplemental CD-ROM was developed to convey this type of information.

The supplemental CD-ROM is a stand-alone component that requires no installation, supporting software, or particular technical expertise to operate. The interface to the CD-ROM is a simple menu interface constructed in standard HyperText Markup Language (HTML). This serves as an efficient mechanism for navigating the CD-ROM. Within each section on the CD-ROM, explanatory text, illustrations, and/or video clips are utilized to provide information. The information on the CD-ROM is cross-browser compatible. The CD-ROM is set to start automatically on computers where this option (AutoPlay) is set.

REPRESENTATIVE SCREENSHOTS

Shown below are several screenshots of various sections of the supplemental CD-ROM. Figure 5 is the screen that a user sees when the CD-ROM starts. Each of the graphic areas at the bottom of the screen are clickable to other sections of the formation. Figure 6 shows a screenshot of the “Vee” diagram where information on the systems engineering process is presented. Each block on the diagram is clickable and brings up a detail page of additional information, as shown in Figure 7.

Video over IP

Supplement to the Design Guidebook
TxDOT Project 0-5942

Texas Department of Transportation

Video is a critical component of Traffic Management Centers (TMCs). Operators use video surveillance to monitor roadways, identify incidents, assist in operations and support operational decisions. Within the Texas Department of Transportation (TxDOT), a wide range of solutions have been deployed, employing different technologies, standards, and capabilities. Many existing installations are faced with increasing their deployment of surveillance video as a means of extending, improving, and updating their system. Likewise, emerging districts are developing and deploying video solutions to build out their systems. Additionally, the marketplace is rapidly evolving with the push towards digital solutions and the convergence of networks to handle both data and video. Currently, no guidance exists as to how to design video solutions considering both the advantages of the newer market solutions and the constraints to implementation in a consistent and efficient manner.

Project Objective

The objective of this research project is to develop a guidebook on Internet Protocol (IP)-based video for TxDOT, guided by the principles of the system engineering. This CD accompanies the guidebook to visually illustrate some of the terminology and technology considerations associated with video solutions.

To accomplish this objective, the research team has identified five tasks that develop not only the knowledge for the guidebook but the document itself. The five tasks are:

1. Development of User Needs and Functional Requirements
2. Evaluation of Technology Options
3. Video Design / Architecture Options
4. Guidebook Development
5. Preparation of Project Documentation

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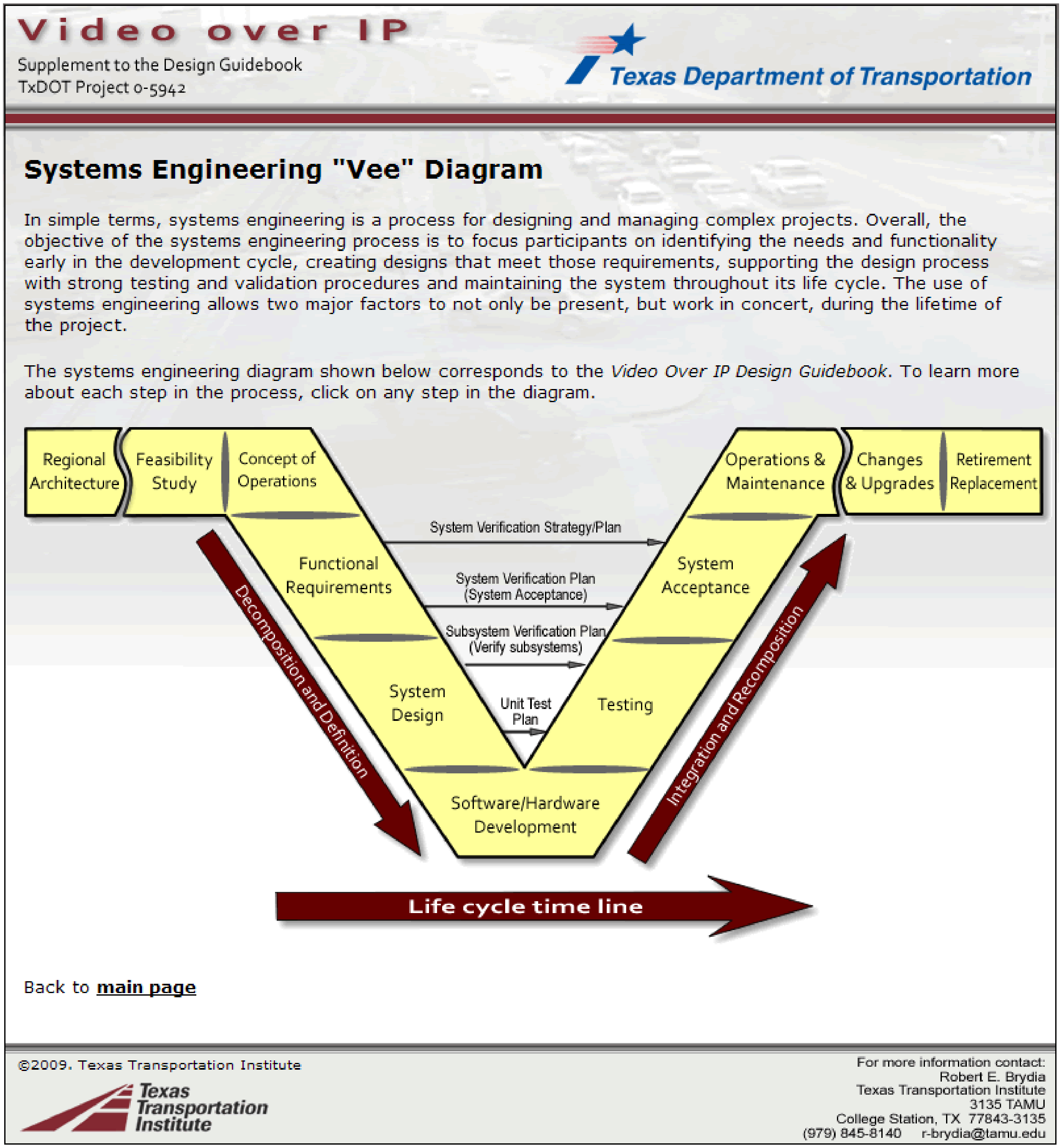
Figure 5. Screenshot of Introductory Page on Supplemental CD-ROM.



Systems Engineering "Vee" Diagram

In simple terms, systems engineering is a process for designing and managing complex projects. Overall, the objective of the systems engineering process is to focus participants on identifying the needs and functionality early in the development cycle, creating designs that meet those requirements, supporting the design process with strong testing and validation procedures and maintaining the system throughout its life cycle. The use of systems engineering allows two major factors to not only be present, but work in concert, during the lifetime of the project.

The systems engineering diagram shown below corresponds to the *Video Over IP Design Guidebook*. To learn more about each step in the process, click on any step in the diagram.

Back to **main page**

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Figure 6. Screenshot of Systems Engineering Process on Supplemental CD-ROM.

Functional Requirements

A clear statement of requirements is often the most important attribute in a successful project. However, this step is often seen as the most diffi-cult. Many times, the initial list of 'requirements' resembles more of the jumbled wish list, combined with project or technology preferences. It takes time and effort to develop a comprehensive set of good requirements.

The starting point for requirements should be the stakeholder needs identified in the Concept of Operations. These needs should be re-viewed, analyzed, and transformed into requirements that define what the system will do. At this point in the process, the emphasis should not be on how the system will do it.

When complete, the attributes of a good set of requirements include the following:

- Necessary – Each requirement should trace back to a specific stakeholder need or a parent requirement.
- Clear – Each requirement should be explicit in the needs listing, avoiding words and phrases that are subject to interpretation, such as "optimum" or "user-friendly".
- Complete – Every stakeholder or need should trace to at least one requirement.
- Correct – Requirements must accurately describe functionality and performance to be delivered without conflict to other requirements.
- Feasible –Requirement must be feasible, or able to be met by sys-tem developers. Avoid word like 'instantaneous' which specify an unreasonable requirement.
- Verifiable – Can meeting the requirement actually be demonstrated and confirmed? If so, then the requirement is verifiable.

Open the chapter on **Functional Requirements**

Back to **Systems Engineering diagram**

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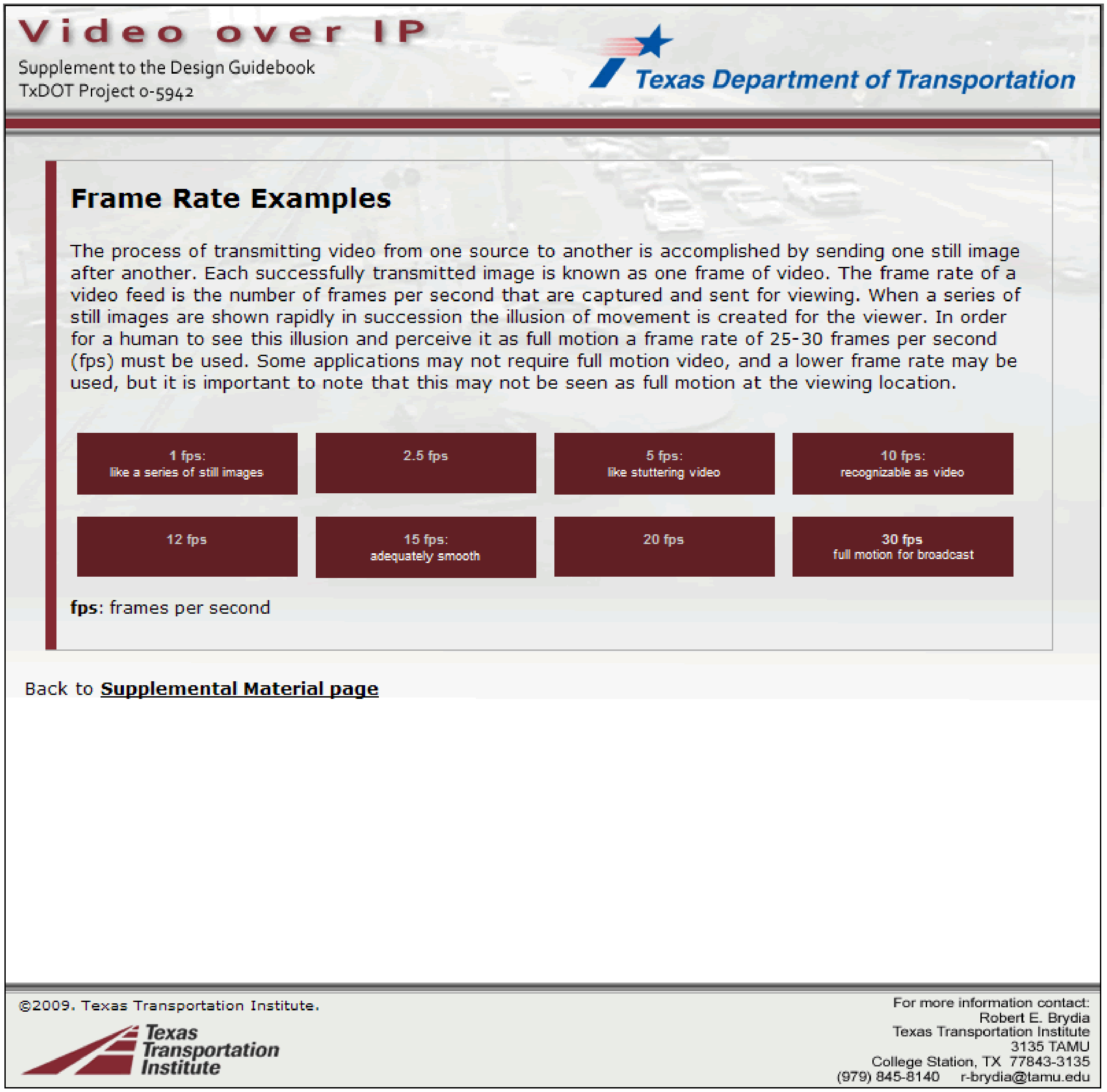
Figure 7. Screenshot of SEP Detail Information Supplemental CD-ROM.

A number of topics are addressed visually on the CD-ROM under the main menu tab "Supplemental Material." These topics include items such as:

- frame rate,
- codec bit rate,
- resolution,
- color depth,
- pixel count, and
- failure examples.

Figure 8 shows an example of the menu presented when a user is in the section pertaining to frame rates. A brief introductory text is presented along with clickable blocks to bring up each example diagram or video. Clicking on the menu items for 15 frames per second (fps) will take the user to the screen presented in Figure 9. Note that the visual presentation is highly effective, showing the industry standard 30 fps compared to the selected 15 fps in a diagonal cut across the same video. This is an exceptionally effective technique for presenting visual information.



Video over IP

Supplement to the Design Guidebook
TxDOT Project 0-5942

Texas Department of Transportation

Frame Rate Examples

The process of transmitting video from one source to another is accomplished by sending one still image after another. Each successfully transmitted image is known as one frame of video. The frame rate of a video feed is the number of frames per second that are captured and sent for viewing. When a series of still images are shown rapidly in succession the illusion of movement is created for the viewer. In order for a human to see this illusion and perceive it as full motion a frame rate of 25-30 frames per second (fps) must be used. Some applications may not require full motion video, and a lower frame rate may be used, but it is important to note that this may not be seen as full motion at the viewing location.

fps: frames per second

Back to **Supplemental Material page**

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Figure 8. Frame Rate Menu on Supplemental CD-ROM.

Video over IP

Supplement to the Design Guidebook
TxDOT Project 0-5942

Texas Department of Transportation

15 frames per second

Back to **Frame Rates page**

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Figure 9. Example Frame Rate Video Screen from Supplemental CD-ROM.

As shown in Figure 10, the CD-ROM also contains the Portable Document Format (PDF) versions of the guidebook chapters for easy reference as needed.

Video over IP

Supplement to the Design Guidebook

TxDOT Project 0-5942

Guidebook

Below are links to individual chapters (PDF format) from the design guidebook:

- Chapter 1: **Introduction**
- Chapter 2: **Systems Engineering Overview**
- Chapter 3: **Early Phases**
- Chapter 4: **Functional Requirements**
- Chapter 5: **System Design**
- Chapter 6: **Testing and System Acceptance**
- Chapter 7: **Concluding Phases**
- Chapter 8: **Procurement**
- Chapter 9: **Glossary**

Download the entire guidebook

Back to **main page**

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Figure 10. Guidebook Chapters on the Supplemental CD-ROM.

CHAPTER 5: NEXT STEPS

There are two recommended next steps arising from this project. The first is specific recommendations pertaining to implementing this project as a training course for the Department. The second is additional research that should be conducted to clarify video needs related to resolution and frame rate for typical traffic operations tasks.

IMPLEMENTATION

The material developed for this guidebook is a prime candidate for an implementation project. Implementation funds could be used to develop a 4- or 8-hour training course following the material in the guidebook. Significant class time would be spent on the discussion of user needs and their translation to requirements as well as the concept of traceability all the way to testing. While this information has never been compiled and presented to TxDOT employees before, the need for it is critically evident from the number of deployments on-going around the state.

An implementation course would first have to develop the instructor's version and the slides/materials necessary for classroom presentation. The guidebook developed for this project would serve as the participant's notebook.

The material should be broken into course modules, with learning objectives identified for each module. Consideration should be given to what, if any, in-class demonstrations could be made available to further showcase critical characteristics of digital video.

After pilot testing the materials and performing any refinements, the course could be taught at several locations across the state to reach a broad spectrum of TxDOT employees.

ADDITIONAL RESEARCH

The development of the video over IP guidebook presents significant information to advance the state-of-the-practice in TxDOT deployments. However, a critical component of developing video deployment solutions is still missing. That component is the recommendation for the question of what type of video solution is appropriate to what is needed.

As an example, many TMCs have been developed with full motion video capabilities. While this has often been considered the optimal solution, such systems are expensive to maintain and operate, from the perspective of both field equipment and the information technology infrastructure. Additionally, expansion of the system, particularly from remote sites, can be problematic to achieve the same degree of video capability with reasonable cost and communication options. Equipment interoperability is also still a significant issue. Are there levels of video less than full-motion that are suitable for various tasks, such as incident monitoring, snapshot distribution, video analytics, and more? Is full-motion, full-color video required for every task?

The use of video lower than full-motion, while attractive for initial deployments because of cost, needs to be carefully evaluated to ensure that both operators and travelers can still make accurate and objective decisions. A thorough investigation would not only look at the capabilities of various levels of video technology, but also the limitations. The research should answer questions such as:

- What is technologically possible with limited communications bandwidth?
- At what level of video do TMC operator functions become feasible?
- At what level of video are traveler demands satisfied?
- What are the recommended requirements for different groups and user needs?
- Can a single system/technology accommodate different user group needs?

Additionally, the research should assess not only video, but snapshot technologies, evaluate the impacts on mobile devices, and evaluate the impact on communications infrastructure, particularly in the forthcoming model of a statewide data center repository.

REFERENCES

1. "Systems Engineering for Intelligent Transportation Systems." FHWA-HOP-07-069. United States Department of Transportation. United States Federal Highway Administration. Washington, DC. January, 2007. Page 5.

2. "Systems Engineering." International Council on Systems Engineering. August 1997. http://www.incose.org/ProductsPubs/products/seprimer.aspx. Accessed multiple times, 2008.

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