Fundamentals of Video Over IP and Systems Engineering

Texas Department of Transportation
Providing safe, effective, and efficient movement of people and goods.

Texas Transportation Institute

Project: 5-5942-01
September 2011
Developer: Gary B. Thomas

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Introductions

- Participants
  - Name, location, job responsibilities
  - What do you hope to get from this course?
- Instructor
  - Gary Thomas, Texas Transportation Institute

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Announcements


Participant handbook


Restrooms/break area

Emergency exits


Turn off cell phones (or set to vibrate)


Active participation

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Purpose of This Course

1. To establish a fundamental level of knowledge in video concepts
2. To frame the discussion within the concept of systems engineering to provide a logical, consistent, and structured approach to video system development and deployment

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Course Learning Outcomes

1. Explain and apply the systems engineering process to a video over IP project
2. Discuss the various characteristics of video technologies

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Course Outline

- Overview of Systems Engineering
- Functional Requirements
- System Design
- Testing and Acceptance
- Concluding Phases
- Wrap-Up

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OVERVIEW OF SYSTEMS ENGINEERING

1. Define system engineering and describe how it can be applied to ITS projects
2. Describe the roles of an ITS architecture and a concept of operations within the systems engineering process

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OVERVIEW OF SYSTEMS ENGINEERING

What is systems engineering and why use it?

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Systems Engineering is…

…an interdisciplinary approach and means to enable the realization of successful systems.

9

In Other Words…

- Focus on identifying the user needs and functionality early in the process
- Creating designs that meet those requirements
- Supporting the design process with strong testing and validation procedures
- Maintaining the system throughout its life cycle

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Why Use Systems Engineering?

- Improved stakeholder participation
- More adaptable systems
- More resilient systems
- Less risk
- More functionality
- Fewer defects
- Better documentation

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Underlying Principles

- Start with your eye on the finish line
- Stakeholder involvement is key
- Define the problem before implementing the solution
- Delay technology choices
- Relate the items in one step of the process to another

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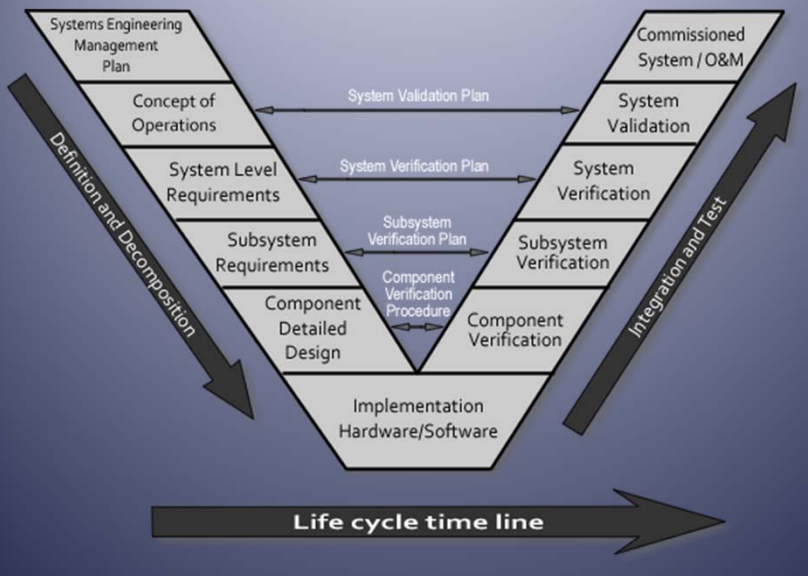
Traditional "V" Diagram



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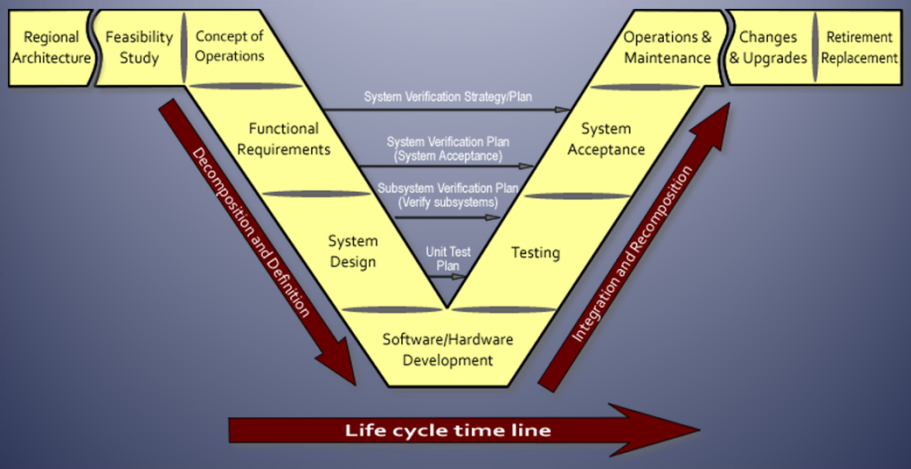
"V" Diagram Applied to Video Over IP Projects



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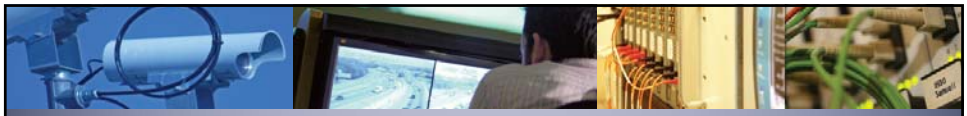

OVERVIEW OF SYSTEMS ENGINEERING

National and regional architectures

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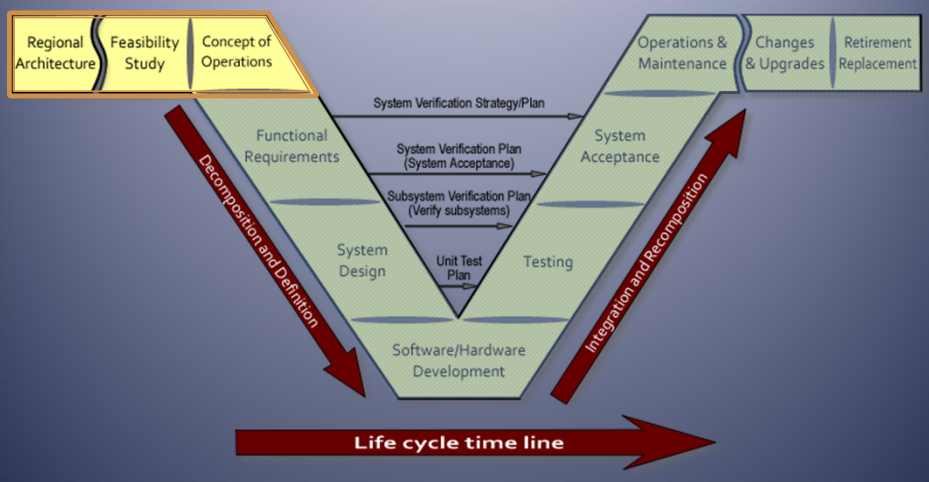

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What Is an ITS Architecture?

- Focuses on relationships between ITS components
- It is logically oriented not physically oriented
- It answers what and whom not how
- Written at a high level (not detailed)

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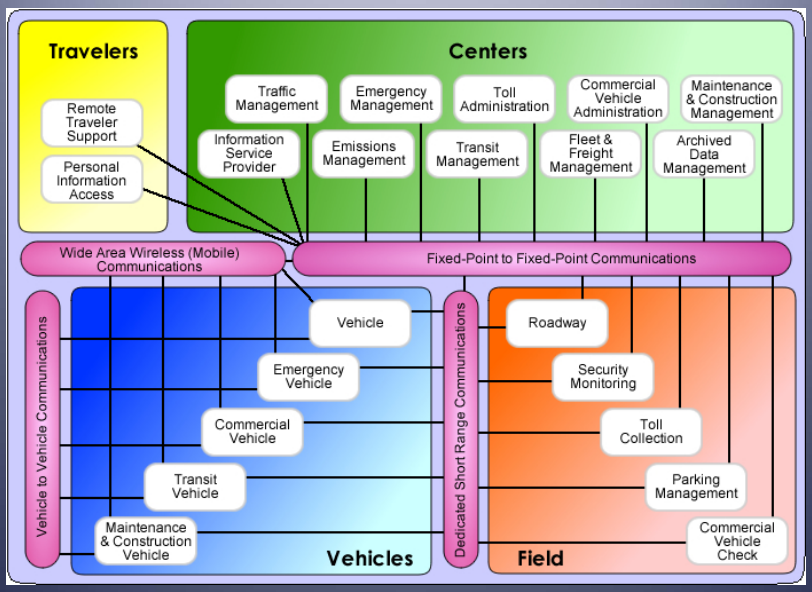
National ITS Architecture



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Regional Architectures

- 21 regional architectures have been developed for the State of Texas
  - http://www.consystec.com/
- Identify and bring together stakeholders
- Catalog existing resources
- Identify future needs

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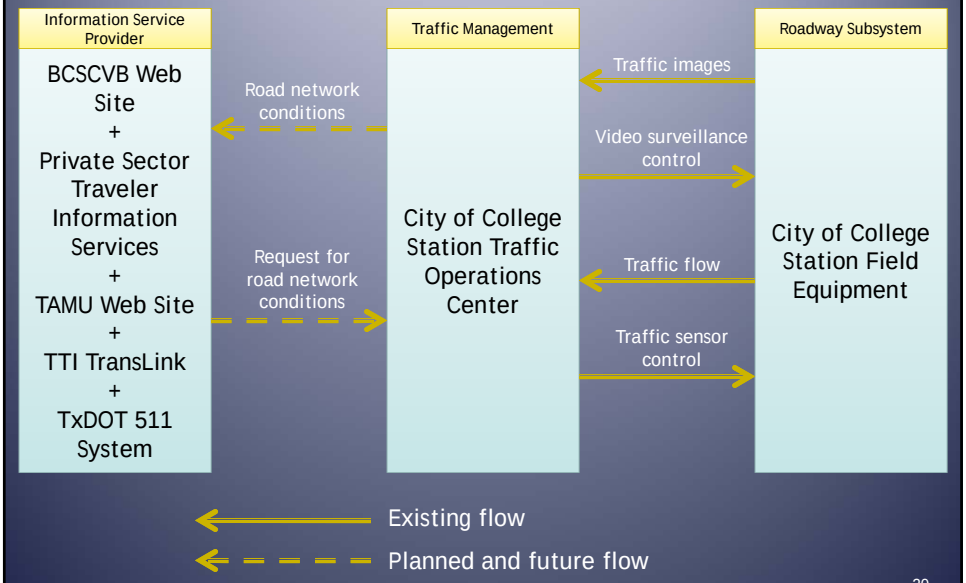
Example Regional Architecture



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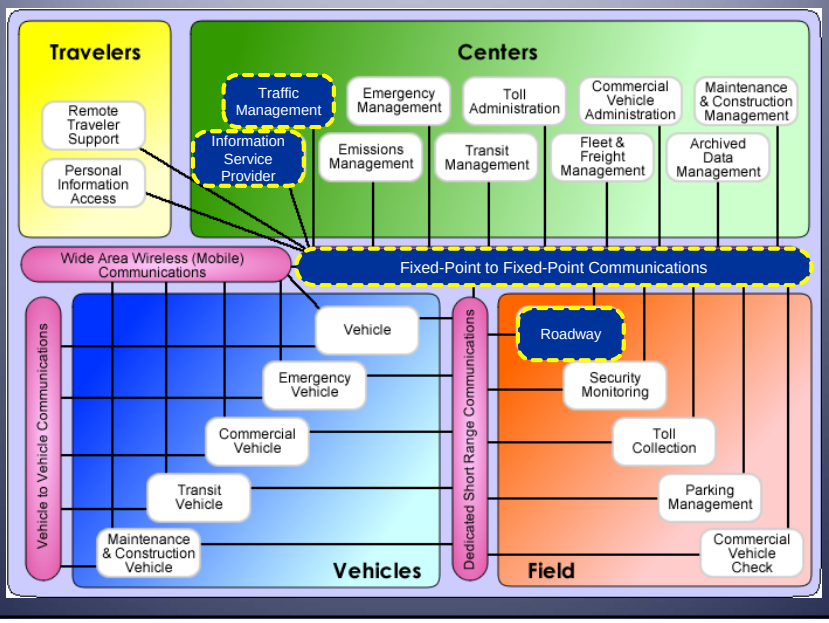
Relationship between National and Regional



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Feasibility Study

- Presents a business case for the project
- Economic considerations
- Political climate necessary
- Key risks
- Alternative concepts

Goal: To determine the project's technical, operational, economic, and political feasibility.

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Some Questions to Answer

- Are there several ways to address the needs?
- Are some needs or solutions unrealistic due to costs?
- Can the project be operated and maintained long term given budget constraints?
- What are the benefits and the costs?
- Which way delivers the best product for the price?
- What are the risks?
- Is there sufficient institutional interest and support to pursue and see the project through?

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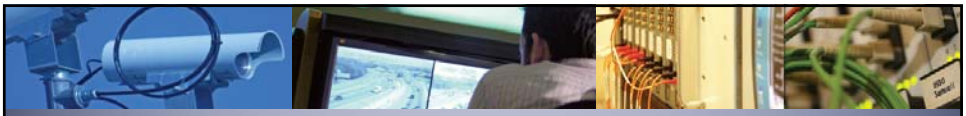

Overview of Systems Engineering

Concept of operations

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What Is a Concept of Operations?

- Communicates a clear conceptual framework
- Communicates an operational vision
  - Goals
  - Capabilities
  - Who is involved
  - Expectation of results
- Generic, non-technical terms
- Applicable to all stakeholders

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How Do I Write a Concept of Operations?

- Answer the following questions:
  - Who?
  - What?
  - Why?
  - Where?
  - When?
  - How?

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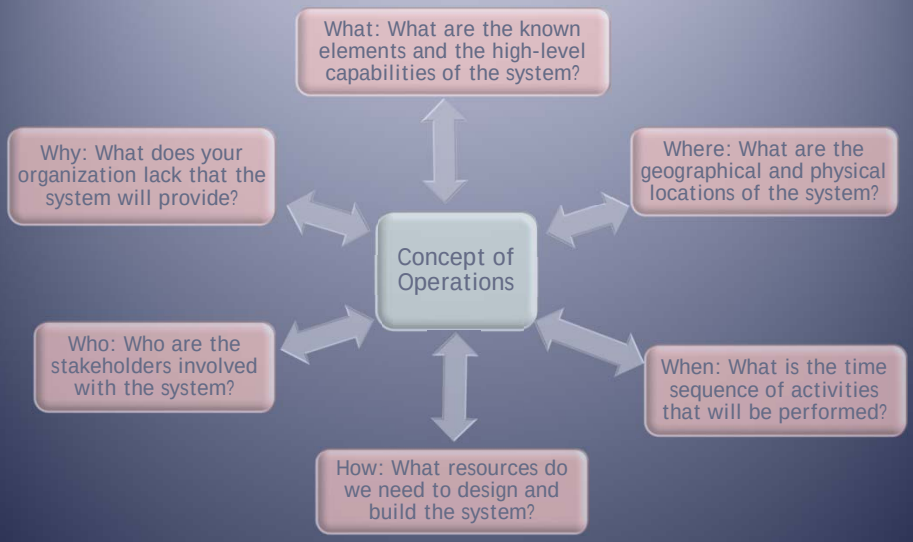
How Do I Write a Concept of Operations?



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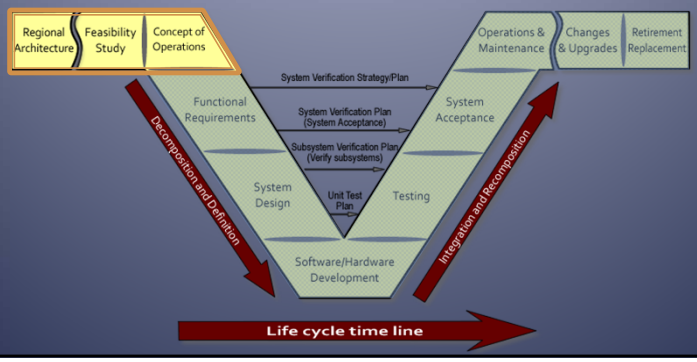
Why Develop a Concept of Operations?

- It's the cornerstone of everything that follows
- Enhance consensus
- Reduce risk
- Improve quality of operations across project life



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Concept of Operations

- A SCOPE communicates a description, a purpose, and an audience
- Resources are identified and documented in the REFERENCES section
- An OPERATIONAL DESCRIPTION can be either pictorial or textual
- Weaknesses in the current system can be identified in the OPERATIONAL NEEDS section

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Concept of Operations

- A SYSTEM OVERVIEW should summarize boundaries, users, interfaces, goals, objectives, and architecture
- The system environment is discussed in the OPERATIONAL AND SUPPORT ENVIRONMENT section
- A section on OPERATIONAL SCENARIOS describes how the system will be used under various conditions

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Quick Review

- What type of document would describe all of the potential exchanges of information in the transportation environment that would take place between agencies?
- What type of document would investigate multiple options for a perceived need?
- What type of document would present information particular to a selected project?

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Functional Requirements

1. Identify user groups
2. Develop a list of user needs
3. Develop a list of functional requirements

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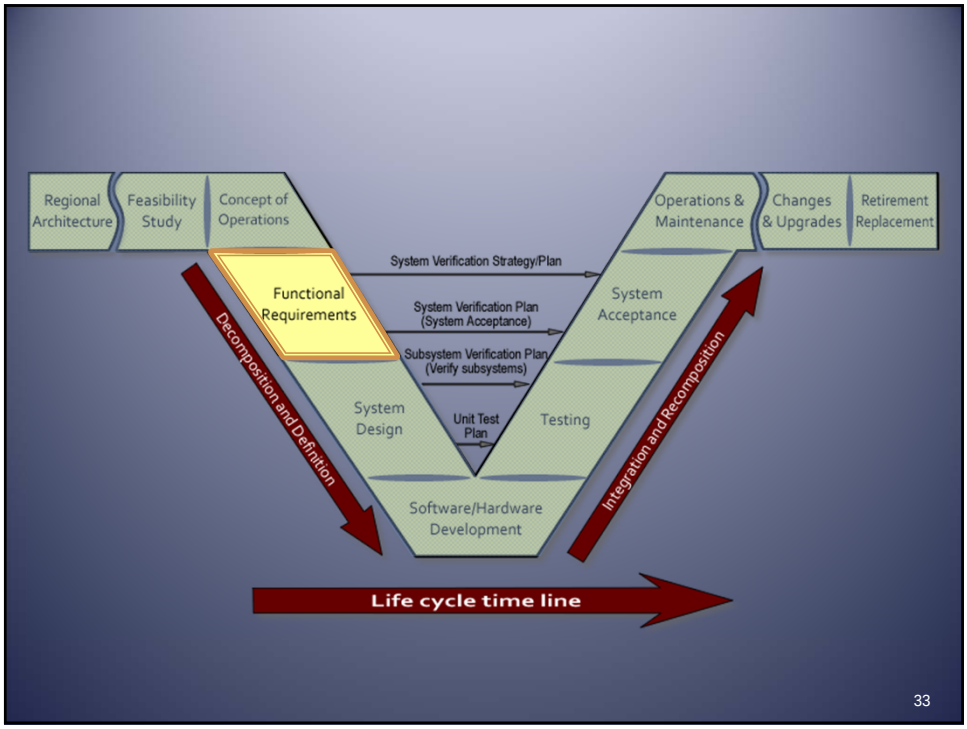

FUNCTIONAL REQUIREMENTS

Identifying user needs

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User Groups (Typically from ConOps)

- Not just operators
- Emergency medical services
- DPS
- Local engineers
- Transit management
- 911
- Media

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User Needs

- Precise and unambiguous

Defines what the system must do for a particular user

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One Technique: The 5 Whys

- Developed by Toyota in the 1970s
- A way of getting to the root of the cause
- Can be adapted to determine user needs

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User Need Example

- Operator: I need to see traffic at the intersection of Main St./1st Ave.
- Why? So we can modify signal timing quicker.
- Why? So we can adapt to traffic leaving the baseball stadium after the game.
- Why? The sudden influx of vehicles causes excessive delays if the normal timing is used.
- Why? Our system cannot automatically adjust for special events.
- Why? We have old software controlling the system that does not have that function.

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Possible User Needs

- System operators need software and hardware that can monitor traffic flows around the baseball stadium and automatically adjust signal timing without intervention.
- System operators need video cameras located at key intersections around the stadium to verify traffic conditions.

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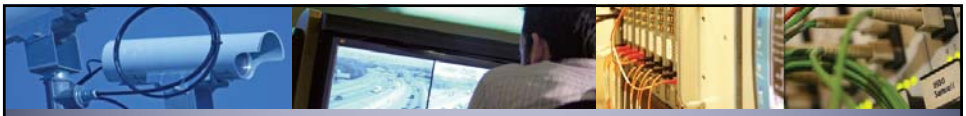

Functional Requirements

Attributes of a good functional requirement statement

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Functional Requirements

Defines *WHAT* the system will do not *HOW* the system will do it

Refresher: User needs define what the system must do for a particular user

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A Functional Requirement Should Be:

Necessary	• Trace to specific user need
Clear	• Avoid subjective terms
Complete	• Every user need should have at least one requirement
Correct	• Accurate • Not in conflict
Feasible	• Avoid unreasonable requirements
Verifiable	• Can meeting the requirement be demonstrated and confirmed

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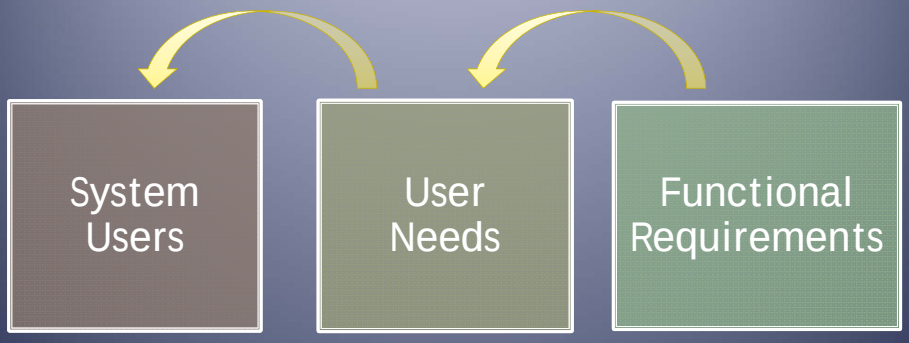
Traceability



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Identify the "Better" User Needs Statements

1. Media outlets need to be able to obtain user rights to view live video anywhere in the state without having to request special permission for each viewing instance
2. City engineer should be able to access archived video for traffic counting purposes
3. TMC operators need to see video to focus on details of incident and overall status of traffic nearby
4. 911 operators need access to the video system

Group Exercise – Part I

- Break into groups of 6-8
- Develop a list of users and user need statements for the scenario
- At least one statement for each user group
- Report Out

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Scenario

- Design a system for monitoring traffic on Interstate 35 between Austin and San Antonio to improve incident response times

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Group Exercise – Part II

- Develop a list of functional requirement statements for the scenario
- At least one statement for each user need
- Report Out

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Functional Requirement Areas for Video

- Systems User
- Camera Control
- Distribution of Camera Images
- Image Quality
- User Interface
- Control Room Issues
- Communications Infrastructure
- Security
- System Reliability and Redundancy
- System Operation Parameters
- System Administration
- Field Equipment
- Standards/Testing
- System Expansion
- System Maintenance
- System Users

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SYSTEM DESIGN

1. Explain IP and describe how it relates to video projects
2. Explain characteristics of video transmission and its impact on IP media

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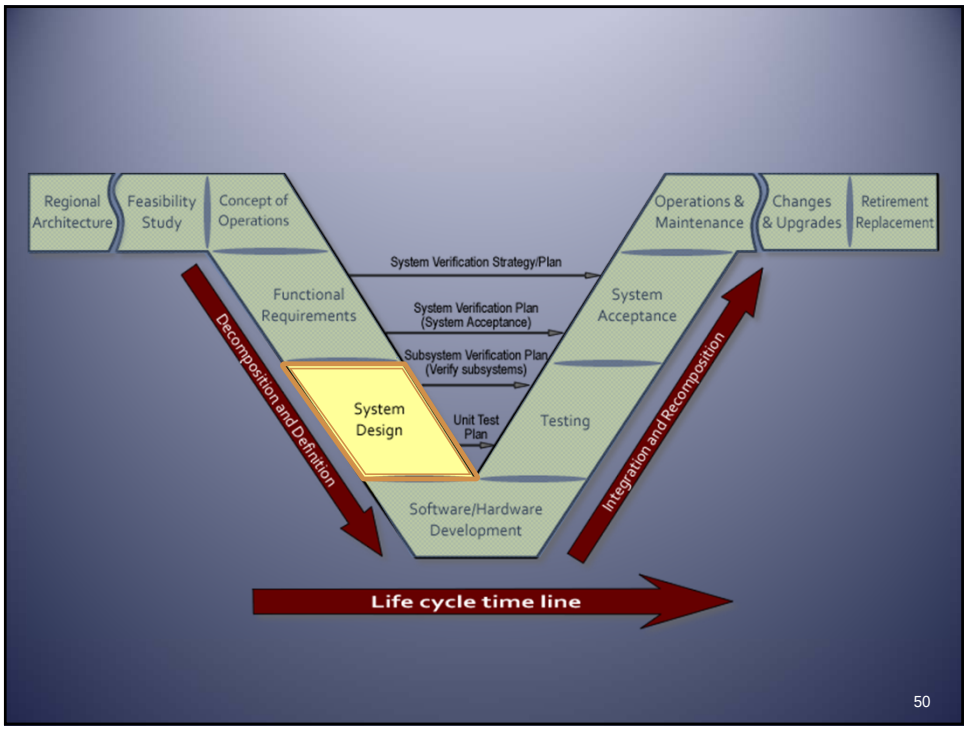

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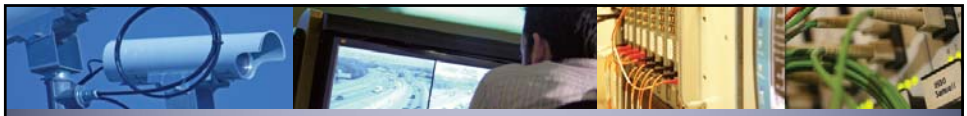

System Design

Video characteristics, formats, and compression schemes

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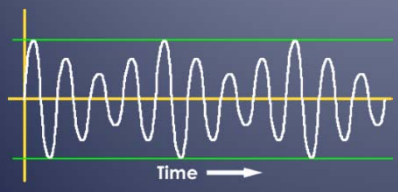
Analog and Digital

Analog

- Continuous electrical signal that varies in voltage
- Can degrade over time
- Can be stored in analog format only unless converted

Digital

- Not continuous but a series of sampled values
- Can be compressed
- Easily converted
- Easily stored



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Video – Frame Rate

- Number of frames per second that are captured and sent for viewing

53

Video – Frame Rate

- Number of frames per second that are captured and sent for viewing

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Video – Resolution and Aspect Ratio

- Resolution is a measure of horizontal and vertical lines of video such as VGA, SVGA, 480i, 720i/p, 1080i/p.
- Resolution has a sub-category called *aspect ratio*. The aspect ratio is the ratio of width to height of a video signal and is written as width:height.
- The two common aspect ratios used in video today are 4:3 and 16:9. 4:3 is called *standard screens* and 16:9 is called *wide screen.*
- HDTV is 720i, 720p, 1080i, 1080p.

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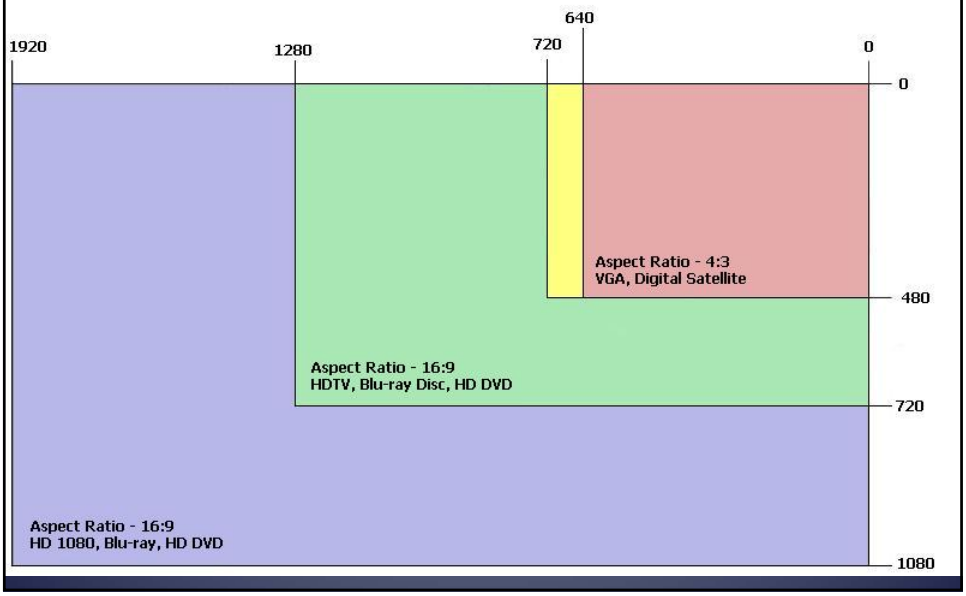
Video – Resolution and Aspect Ratio



Video – Luminance and Chrominance

- Luminance → Black & White
  - Dark and light values
- Chrominance → Color
  - Hue describes the actual color (e.g., red, yellow, green)
  - Saturation describes the intensity of the hues (dark green vs. light green)

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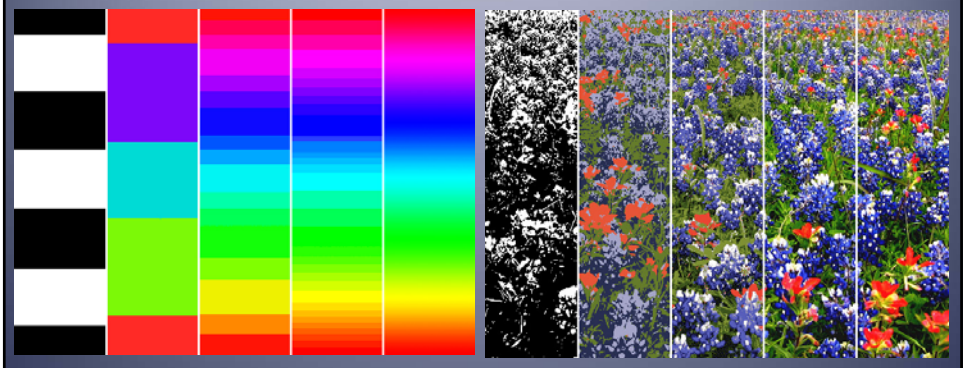
Video – Color Depth



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Video – Contrast Ratio

- Difference between the lightest and darkest values in an image

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Video – Signal to Noise Ratio

- Noise is unwanted information
- Humans can tolerate some noise; computers can not
- More a measure of the equipment than the signal itself

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Signal Characteristics – Bit Rate

- Number of bits transmitted (per second)
- Usually determined by available bandwidth

256Kb per second

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Signal Characteristics – Bit Rate

- Number of bits transmitted (per second)
- Usually determined by available bandwidth

3Mb per second

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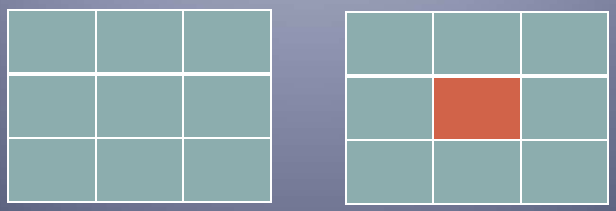
Signal Characteristics - Compression

Frame 1 Frame 2



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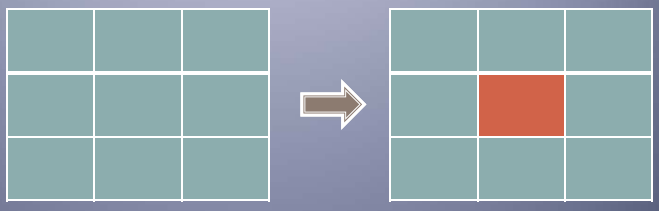
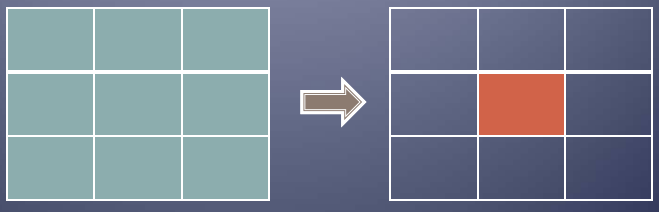
Signal Characteristics - Compression

Frame 1 Frame 2

Method 1



Method 2



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Signal Characteristics - Latency

- Latency is delay
- Affected by:
  - Media
  - Distance
- Some latency may be acceptable

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Sending Video

- Distributing video across a network requires communication between the sending and receiving device
- Video signals, in an uncompressed state, are much too large to transmit over a network
- Video encoding and decoding (compression) is the process of altering a signal and making it smaller, in order to transmit the video over a network, within acceptable bandwidth

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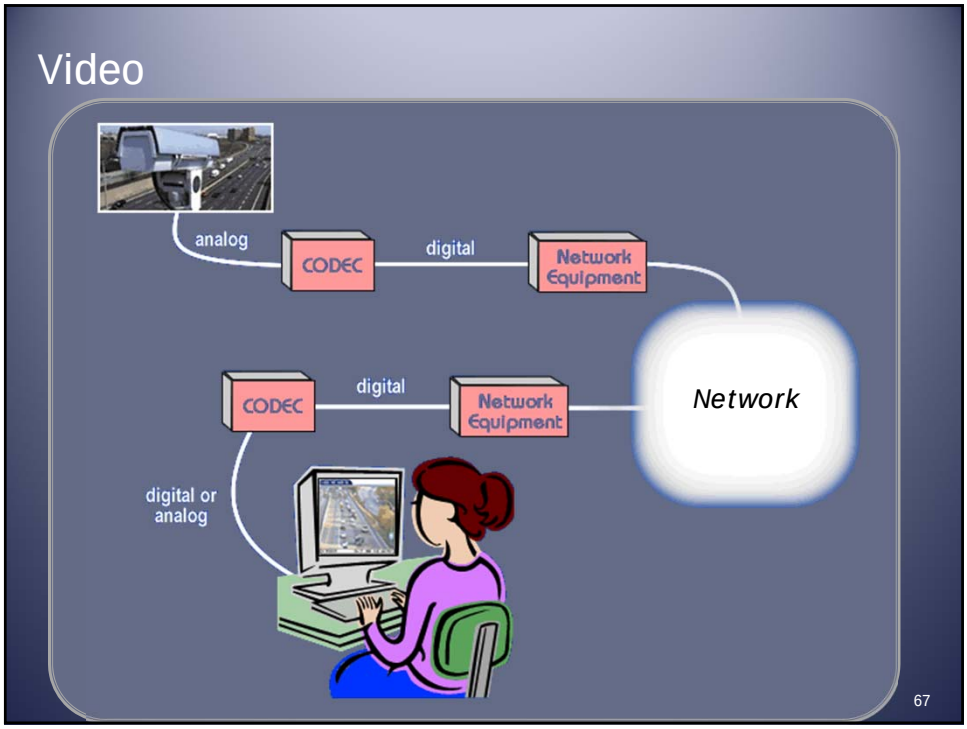
Video
analog
CODEC
digital
Network Equipment
CODEC
digital
Network Equipment
Network
digital or analog
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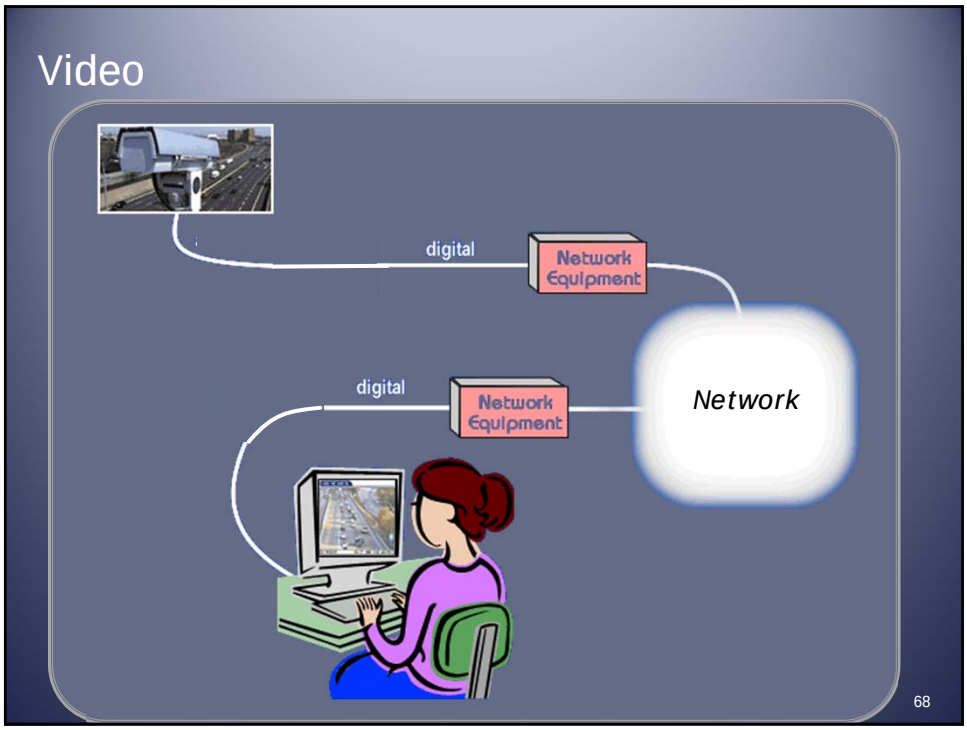
Video
digital
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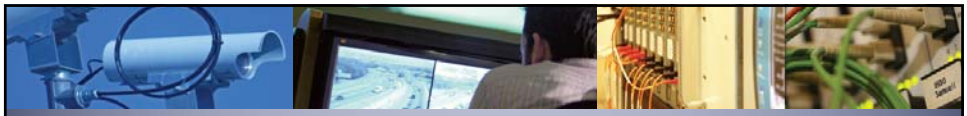

SYSTEM DESIGN

What is a protocol?

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Protocols: The Big Picture

- Takes usable information and:
  - Breaks it into discrete chunks
  - Surrounds each chunk with additional stuff
    - Where it came from, where it is going, order
  - Sends it down the line
- At the other end:
  - Reads the stuff
  - Assembles back into usable information

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5 Traits of Protocols

- Standard format for transmitting data between two devices
- Error checking
- Data compression
- Message has been sent
- Message has been received

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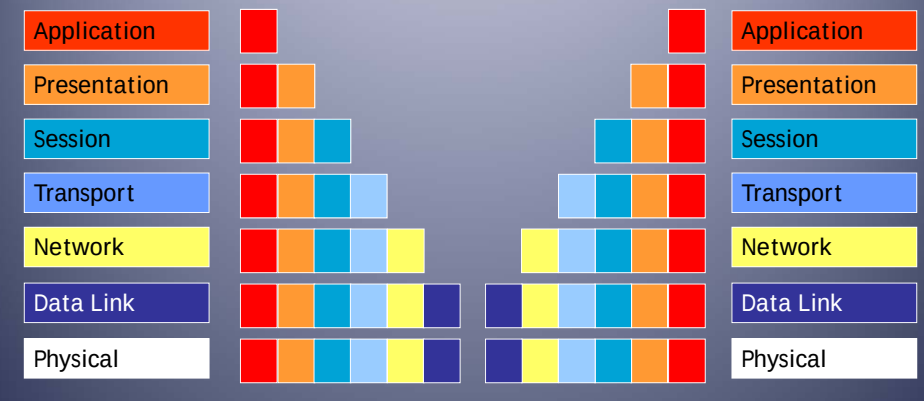
Protocol Stacking

OSI 7-Layer Model



Physical Data Transmission

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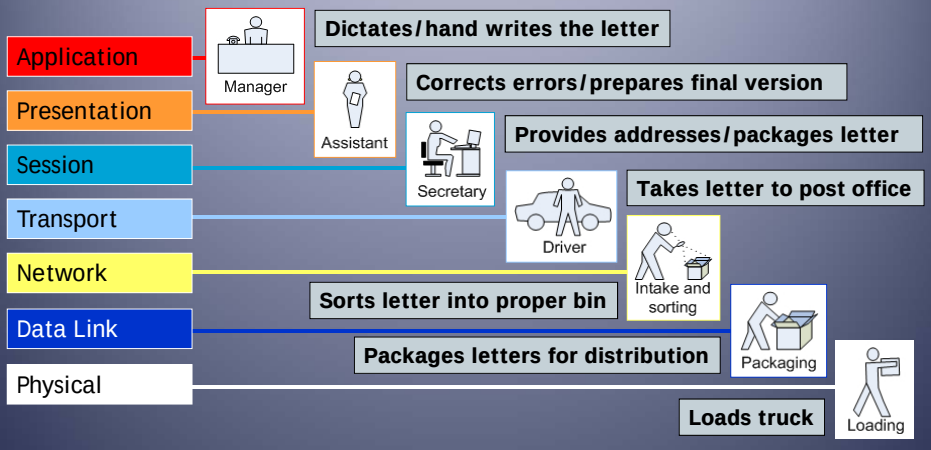
OSI Analogy



Adapted from: www.wikipedia.org

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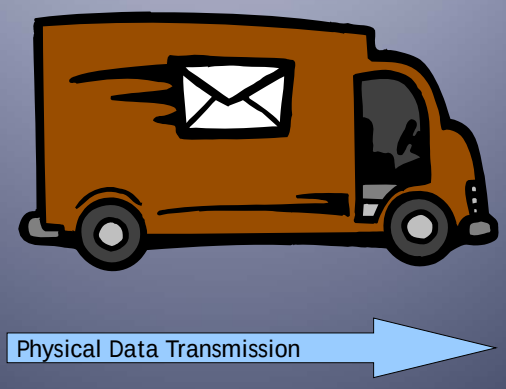
OSI Analogy



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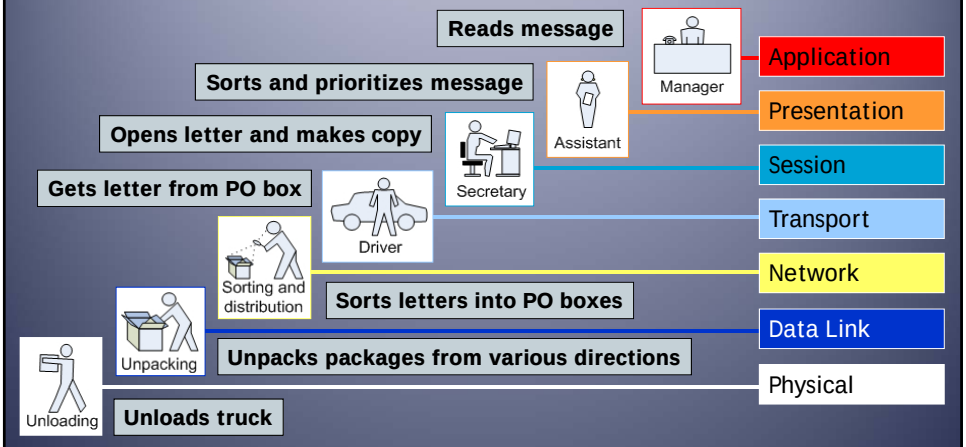
OSI Analogy



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Common Communication Protocols Used in ITS

- Serial
- Digital subscriber line (DSL)
- Frame relay
- Asynchronous transfer mode (ATM)
- Synchronous optical network (SONET)
- Transmission Control Protocol/Internet Protocol (TCP/IP)
- Ethernet

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TCP/IP

- Layered protocol
- TCP lives at Layer 4 (transport) of OSI Model
- IP lives at Layer 3 (network)
- Most universally accepted/used protocol
- Backbone of communication networks, such as the Internet
- Supported by virtually all other lower level protocols (protocol stacking)

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TCP – Transmission Control Protocol

- Sends data from one node on a network to another
- Establishes a connection to the other end
- Breaks information into packets
- Numbers and sends each packet
- Checks for delivery
- Processes packets in order (by number)
- Uses acknowledgments and resends to ensure proper delivery

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IP – Internet Protocol

- Considered a "connectionless" protocol
- Does not expect acknowledgments
- IP packet contains
  - Source address
  - Destination address
  - Protocol identifier
  - Checksum
  - Time To Live (TTL)

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Time To Live

- TTL is a mechanism for preventing packets of data from roaming around a network indefinitely.
- If they did, network bandwidth would eventually reach zero
- The TTL value of a packet is decreased each time it crosses a router (a.k.a. a "hop")
- When TTL = 0, the packet is discarded

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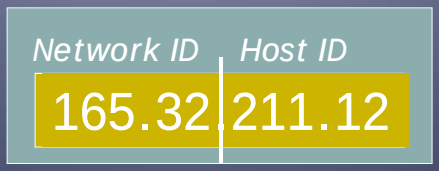
IP Addressing

- Two parts to an IP address
- Example:
  - Network ID = your street
  - Host ID = your house number
- Represented as dotted decimal notation
- Each group is called an octet



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Bits and Octets

Binary	Bit Value	Decimal
00000000	0	0
10000000	128	128
11000000	128 + 64	192
11100000	128 + 64 + 32	224
11110000	128 + 64 + 32 + 16	240
11111000	128 + 64 + 32 + 16 + 8	248
11111100	128 + 64 + 32 + 16 + 8 + 4	252
11111110	128 + 64 + 32 + 16 + 8 + 4 + 2	254
11111111	128 + 64 + 32 + 16 + 8 + 4 + 2 + 1	255

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Binary vs. Decimal

- Which is easier?

Binary	11000000 10101000 00000000 00000001
Decimal	192.168.0.1

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Fun with Numbers

Column 1	Column 2	Column 3	Column 4	Column 5
24	30	4	2	21
29	28	23	6	13
18	10	6	15	25
30	27	7	7	15
17	12	12	10	27
21	29	29	30	17
27	14	14	14	3
23	15	15	3	5
25	24	20	18	23
19	25	21	19	11
26	26	30	23	9
20	11	5	22	29
28	9	28	26	19
22	13	13	27	7
16	8	22	11	1

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IP Addressing

- Every device has a unique address
- Address are 32 bits in length
  - Example: 169.254.32.4
- Addresses are organized into “classes”
  - 1.x.x.x through 126.x.x.x = Class A
    - 126 networks with 16 million devices each
  - 128.0.x x through 191.255.x.x = Class B
    - 16,384 networks with 65,000 devices each
  - 224.0.0.X through 239.255.255.x = Class C
    - 2 million networks with 254 hosts each

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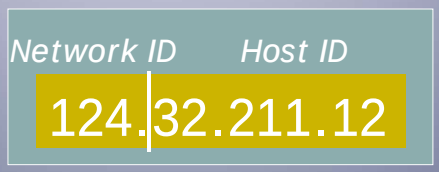
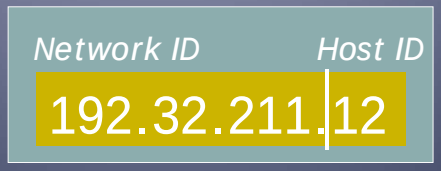
Addressing on Different Classes

- Class A



- Class B

- Class C



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Restricted Address Space

- 127.x.x.x – Network adapter diagnostics
- 127.0.0.1 – Local loop back
- Private networks
  - 10.x.x.x
  - 172.16.x.x - 172.31.x.x
  - 192.168.x.x
- 169.254.x.x – Automatic addressing

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Class D and Multicasting

- Class D (224.x.x.x through 239.x.x.x)
  - Reserved for multicasting
  - Overlaps with Class C addressing
  - Requires care in assigning multicast addresses
- Uses registration to send information to groups of devices
- Packets are replicated only when necessary (at divergent points on the network)

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IPv6 Addressing

- Next generation IP addressing
- Created to accommodate:
  - Increasing need
  - Dwindling supply
- 128 bit addresses (16 octets)
- 3.4×10^{38} unique addresses
- Need for change slowed by conservation of existing address space
- Significant marketplace resistance to implementation

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Private Address Space

- Does not communication directly to the Internet
- Conservation method for IPv4 addresses
- Works in conjunction with
  - NAT – Network Address Translation
  - DHCP – Dynamic Host Configuration Protocol

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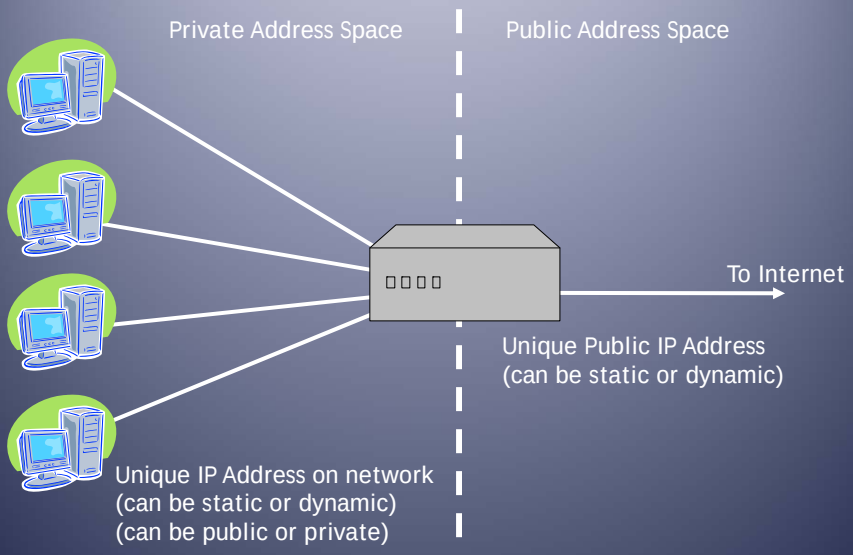
Private Address Space/NAT



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Compression/Encoding

- The process of reducing the size of digital files to take less storage space or less bandwidth for transmission
- Compression of digital files is done with codec (COding DECoding)
- Audio, video, and data content can all have different types of codec
- Common codecs include MPEG-2, Divx, JPEG, MJPEG, AVI, MPEG-4 Part 10, H.264, and PNG

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Decompression/Decoding

- Decoding is the process of converting a compressed signal back to its original size
- The encoder sets all the parameters for the video used. The decoder just decompresses what is sent
- Encoding and decoding the video introduces some level of loss to the signal quality, depending on the algorithm used

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Common Encoder/Decoders

- There are dozens of codecs – both proprietary and open standard
- Modern encoders are not simple compression only algorithms
- Modern encoders are multi-file type compressors, of video, audio, and data

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Video Format Types

- Multimedia format codecs apply to both physical hardware (camcorders, cameras, video tapes, and hard drives) and software
- Several common compression schemes are AVCHD, AVI, Blu-Ray, DVD, HDTV, H.264, MPEG-2, MPEG-4, MiniDV, RealPlayer, Windows Media, QuickTime
- The industry future of Video Over IP is MPEG-4 and H.264

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Transmission Output

- A unicast feed works as a one-to-one relationship between one source and one destination
- A multicast broadcast is a one-to-many relationship, where one source can be viewed at many different destinations

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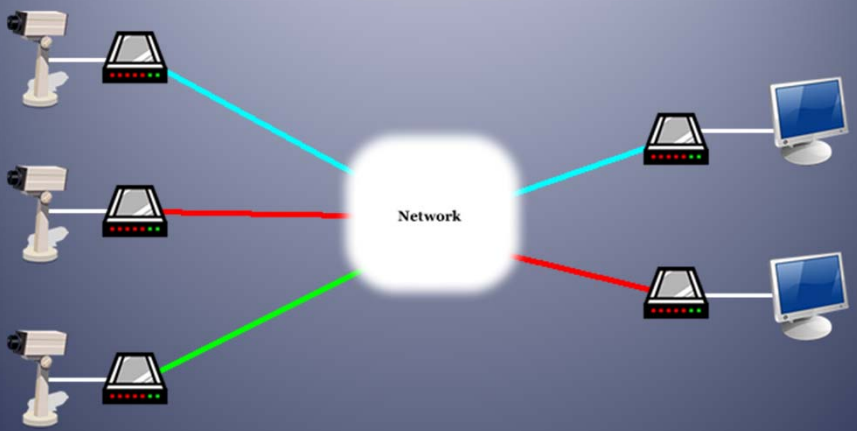
Unicasting



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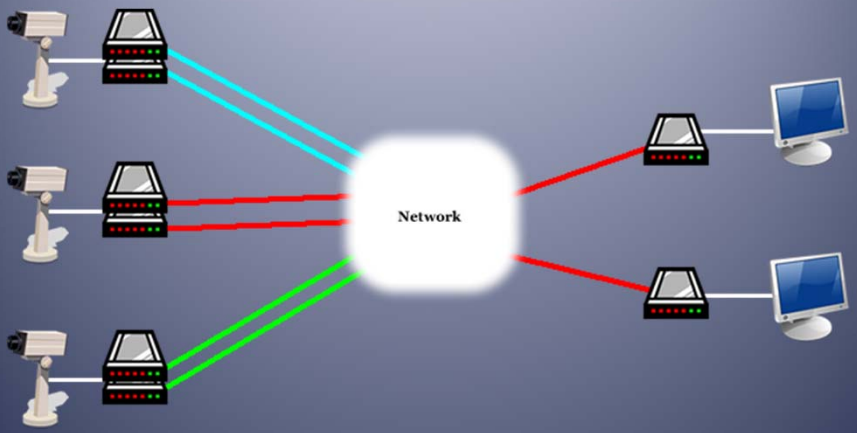
Unicasting



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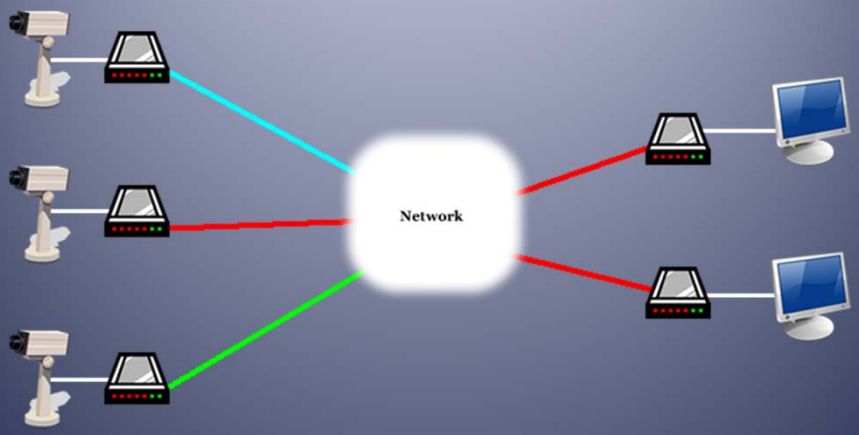
Multicasting



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Transmission Medium

- Video over IP means using IP over an underlying network protocol (e.g., Ethernet) to transmit information
- Ethernet has transmission protocol standards of 10Mbit, 100Mbit (fast Ethernet), 1000Mbit (GigE), and 10Gb (10 Gig Ethernet)
- The potential media for Ethernet includes twisted pair (CAT5e or 6), coaxial, cellular, fiber, radio, satellite, and wireless

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Transmission Media: Wired vs. Wireless

Wired media

- Coaxial cable
- Copper/Twisted Pair
- Fiber

Wireless media

- Radio
- Cellular
- Satellite
- Microwave
- Infrared
- Spread Spectrum
- 802.11x

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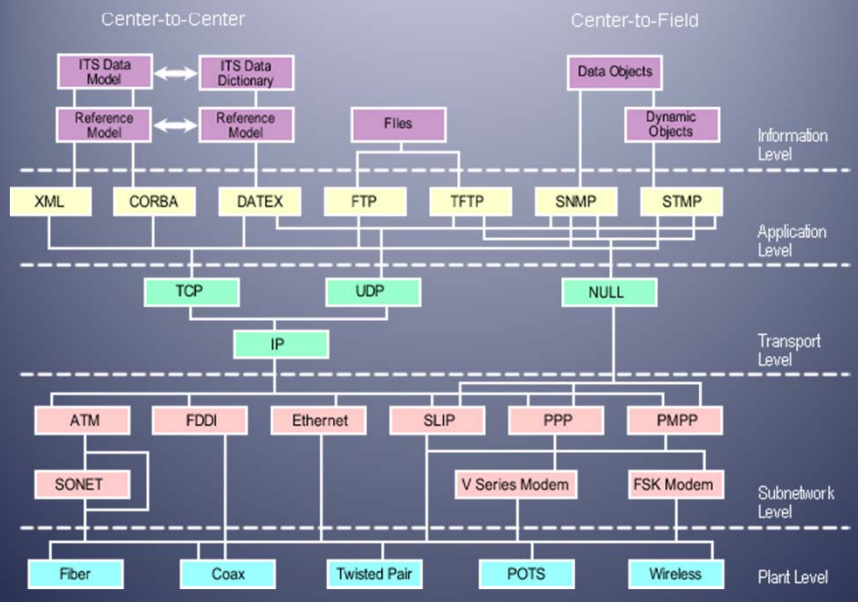
The Only Difference Is the Media



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The Future of Video Over IP

- Integration of analog to digital converters into IP-based cameras
- All digital systems replacing analog systems
- H.264 and MPEG-4 as the two dominant standards
- Increasing use of multicast transmission output
- Video being sent to more mobile devices not just desktop or fixed building systems

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TESTING AND ACCEPTANCE

1. Describe the key elements of developing a test plan addressing functional requirements and user needs

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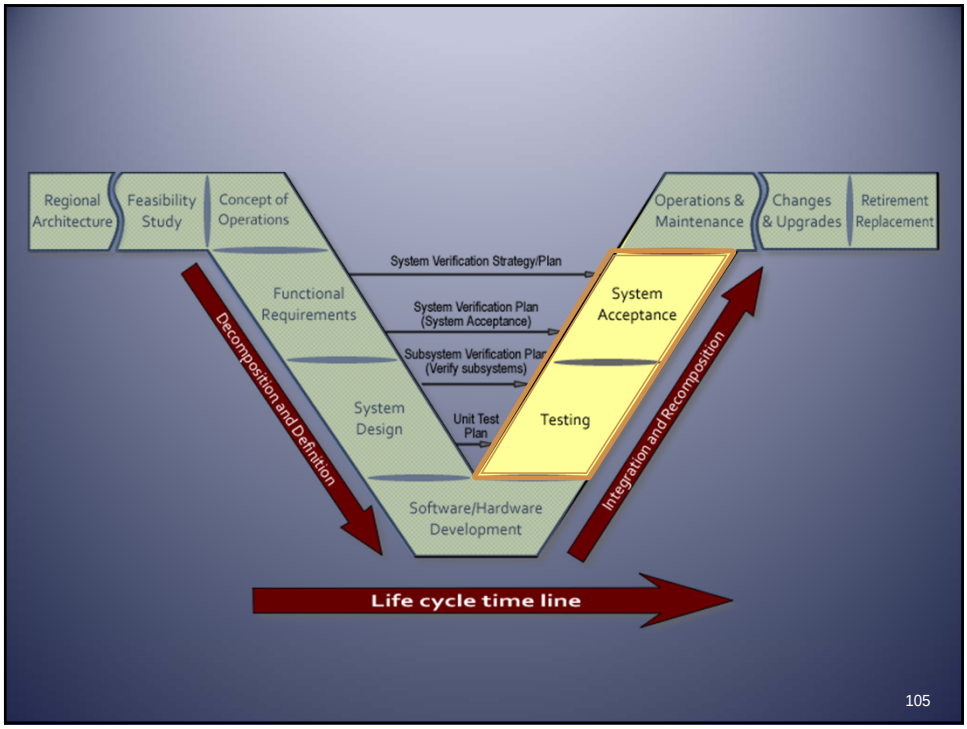

Test Planning

- Start early in the life cycle
- Good source:
  - IEEE Std 829: Standard for Software Test Documentation
- Developing a robust test procedure EARLY ON will likely save time and resources later on

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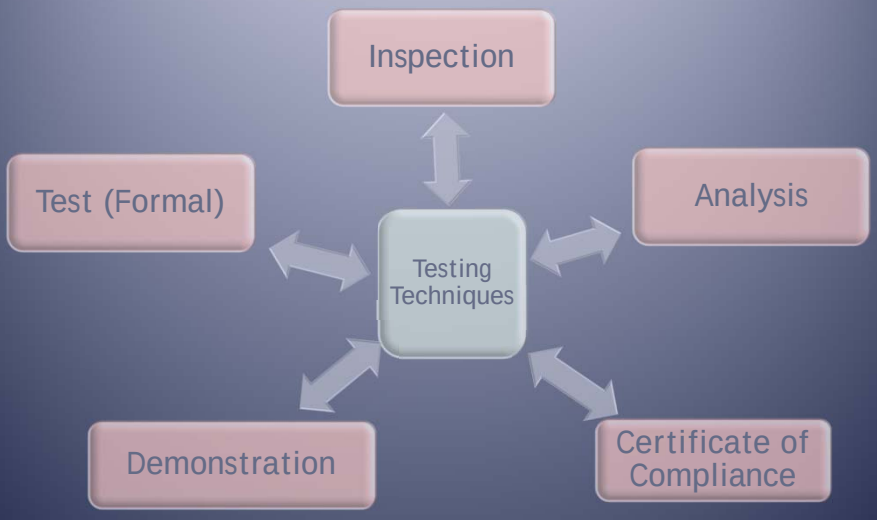
Testing Techniques



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Keys to Test Planning

- Scope
- Approach
- Resources
- Schedule of testing activities
- Stakeholders/involved parties
- Traceability

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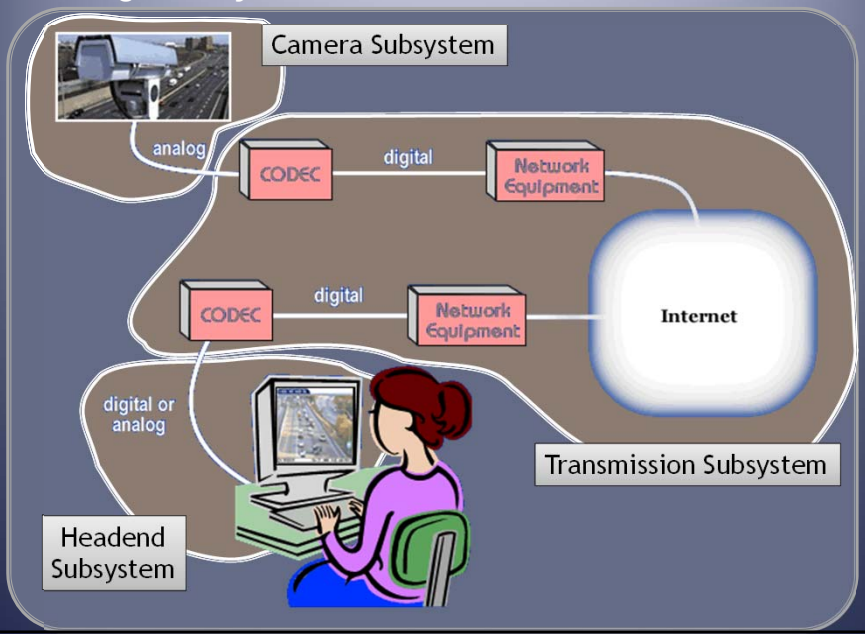
Testing Subsystems



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Group Discussion

- What parts of the camera subsystem should be tested?
  - Camera
  - Lens
  - Housing
  - Heater
  - Wiper
  - Pan/tilt/zoom unit
  - Mounting hardware
  - Interface cabinet

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Group Discussion

- What are some tests that may be performed on the camera?

- Sensitivity
- Maximum sensitivity
- Signal-to-noise ratio (random noise)
- Signal-to-noise ratio (fixed-pattern noise)
- Horizontal static resolution
- Aliasing
- Registration
- Geometry
- White shading or white level non-uniformity
- Black shading or black level non-uniformity
- Streaking
- Flare
- Transfer law or gamma correction
- Smearing
- Over-exposure headroom
- Blemishes
- Image format
- Colorimetric fidelity measurement

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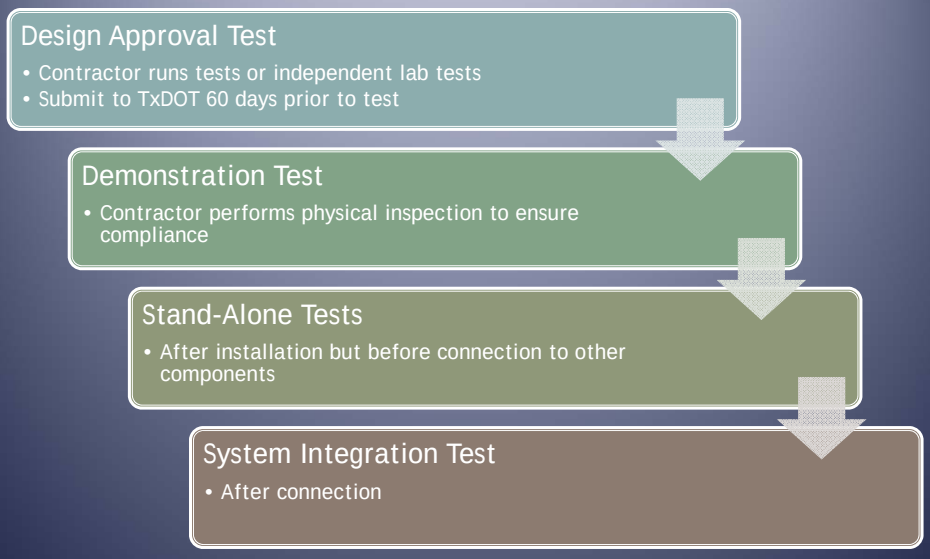
Testing Activities



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CONCLUDING PHASES

1. Describe the life cycle of a project after deployment

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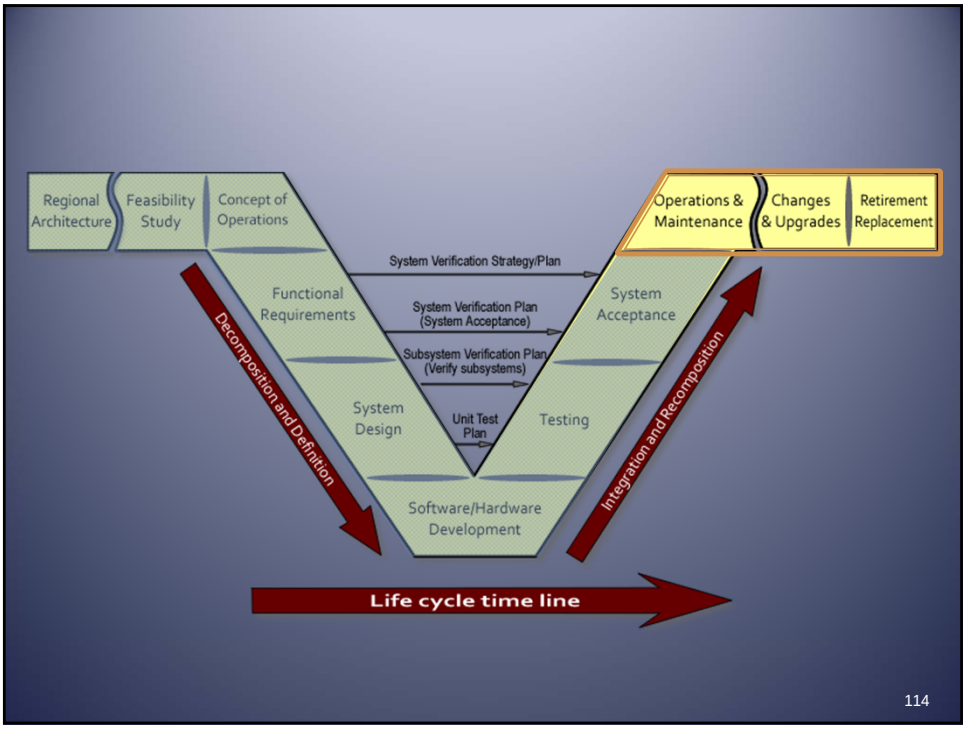

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System Operations: Keeping Your Project Viable

- Daily operations
- Monitoring the system
- Performance reporting
- Hiring and training staff
- Continued testing
- Fine-tuning of system installation

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System Maintenance

- Preventive
- Reactive
- Software

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The Future

- Obsolescence
- Expansion
- Procurement
  - Equipment
  - Services

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WRAP-UP

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