UTC**M**

"Improving the Quality of Life by Enhancing Mobility"

University Transportation Center for Mobility

Development of a Special Topics Course on Intelligent Transportation Systems for the Zachry Department of Civil Engineering of Texas A&M University

Final Report

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16. Abstract

With Intelligent Transportation Systems (ITS), engineers and system integrators blend emerging detection/surveillance, communications, and computer technologies with transportation management and control concepts to improve the safety and mobility of the surface transportation system. Individuals responsible for developing, deploying, and managing ITS projects need a solid foundation not only in transportation engineering concepts and principles but also systems engineering, communications, and technology. This project developed a special topics course on the planning, design, and implementation of ITS projects for transportation management. This course is a graduate-level survey course in which students are provided with the basic knowledge and concepts needed to plan, design, and implement an ITS project that can be deployed in the field. Course topics include:

- an overview of ITS technologies and applications for advanced transportation management,
- the application of system engineering concepts in the planning and design of advanced ITS projects,
- techniques and strategies for managing and deploying ITS projects,
- design and application of advanced telecommunication techniques for ITS deployments, and
- techniques and tools for evaluating ITS project and technologies.

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Development of a Special Topics Course on Intelligent Transportation Systems for the Zachry Department of Civil Engineering of Texas A&M University

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Disclaimer

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Acknowledgements

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Development of a Special Topics Course on Intelligent Transportation Systems for the Zachry Department of Civil Engineering of Texas A&M University

Purpose

With Intelligent Transportation Systems (ITS), engineers and system integrators blend emerging detection/surveillance, communications, and computer technologies, and transportation management and control concepts to improve the safety and mobility of the surface transportation system. Individuals responsible for developing, deploying, and managing ITS projects need a solid foundation not only in transportation engineering concepts and principles, but also systems engineering, communications, and technology. The purpose of this project was to develop and teach, at least once, a special topics course on the planning, design, and implementation of ITS projects for transportation management. This course was envisioned to be a graduate-level survey course in which students would be provided with the basic knowledge and concepts needed to plan, design, and implement an ITS project that could be deployed in the field. The topics covered in the proposed course include the following:

- an overview of ITS technologies and applications for advanced transportation management,
- the application of system engineering concepts in the planning and design of advanced ITS projects,
- techniques and strategies for managing and deploying ITS projects,
- designs and application of advanced telecommunication techniques for ITS deployments, and
- techniques and tools for evaluating ITS project and technologies.

Learning Objectives

The learning objectives used in the development of this project were as follows.

At the conclusion of this course the student should be able to do the following:

- Highlight and discuss the fundamental characteristics of ITS and its importance as a traffic management tool in addressing today's mobility and safety problems.
- Apply basic system engineering principles and concepts to develop an understanding of operations and system and functional requirements for an ITS implementation.
- Using the results of the system engineering process, conduct a high-level alternatives analysis of different communication systems and alternatives.

- Demonstrate a basic understanding of the traffic detection and surveillance technologies.
- Demonstrate a basic understanding of the principles, procedures, and tools for evaluating ITS projects.

Target Audience

The course was developed as a graduate-level course intended for students who are pursuing an advanced degree in civil engineering with a concentration in transportation engineering. The following prerequisites are needed by students to successfully complete this course:

- a bachelor's degree in civil engineering or equivalent area of study,
- a fundamental understanding of traffic flow concepts and objectives, and
- a fundamental knowledge of traffic control concepts and systems.

The course was designed to accommodate 10-15 students per class and laboratory period.

Course Structure

The course was structured as a 3-credit hour course, with 2 hours devoted to instructor-led lecture and a 3-hour laboratory period per week. The laboratory periods were intended to provide the student with opportunities to apply concepts and materials presented in the lectures to real-world problems in the hopes of further strengthening the learning objectives in the students. The laboratories themselves consisted of both problem-solving exercises as well as field visits to local testbeds where students could see a real ITS project in operation.

Course Outline

The basic outline developed for the course is as follows:

Week 1
Basic Introduction – What is ITS? History of ITS, current Federal Highway Administration (FHWA) initiatives, applications overview (Lab: Tour of TransLink center)

Week 2
National ITS Architecture, logical architecture, physical architecture, market packages, equipment packages, local and regional architectures (Lab: Turbo Architecture)

Week 3
Systems Engineering – Introduction to systems engineering concepts, concept exploration and benefits assessment (feasibility study), development and use of concepts of operations, Unified Modeling Language (UML) use case diagrams (Lab: Development of concept of operations)

Week 4

Systems Engineering (cont.) – Functional and system requirements, project level architecture (physical and logical), UML activity diagrams (Lab: Preparation of functional requirements)

Week 5

Systems Engineering (cont.) – Deployment/integration plan, planning of operations and maintenance, 1st partial exam

Week 6

Deployment of ITS Project – Procurement of ITS systems and technologies, managing ITS contracts, system testing and verification (Lab: Development of system testing and verification plan)

Week 7

Traffic Sensors and Detection Technologies – Embedded traffic sensors, non-intrusive detection systems, evaluation of sensor technologies (Lab: Site visit to local sensor testbed and field deployments)

Week 8

Traffic Sensors and Detection Technologies (cont.) – Embedded traffic sensors, non-intrusive detection systems, evaluation of sensor technologies (Lab: Conduct alternatives analysis for detection strategies)

Week 9

Communications – Basic concepts and terminology, wireline communications technologies, wireless communications technologies, standards and protocols (Lab: Design of communications plan)

Week 10

Communications (cont.) – Basic concepts and terminology, wireline communications technologies, wireless communications technologies, NTCIP standards, 2nd partial exam

Week 11

Evaluation Strategies and Tools – Evaluation concepts, use of sketch-planning, mesoscopic, and microscopic simulation models in evaluating ITS systems (Lab: IDAS/Dynasmart application/demonstration)

Week 12

Evaluation Strategies and Tools – Microscopic simulation concepts, microscopic simulation models (Lab: Corsim/VISSIM application/demonstration)

Week 13
Presentation of semester project (Lab: Conduct site visit to Houston TranStar)

Week 14
Summary and final review of course material, final exam

Lecture Materials

A series of lecture materials were developed to provide students with the basic knowledge they needed to achieve the learning objectives. The lecture materials were grouped into five modules:

- Module 1: Overview of Intelligent Transportation Systems
- Module 2: Systems and Systems Engineering
- Module 3: Traffic Sensing Technologies
- Module 4: Communications Systems for ITS Applications
- Module 5: Evaluating ITS Projects

A copy of the lecture materials are contained in the appendices to this report.

Laboratory Exercises

Laboratory exercises were designed to provide students with opportunities to solidify and apply the concepts, principles, and tools discussed in lectures to real-world situations. Ideally, students would be provided a scenario/problem to address during the first week of the course. Students would then use the same scenario throughout the semester and work on different aspects of planning and designing an ITS project to address the scenario. For the first class session, the plan was to use the scenario for developing a system to detect wrong-way vehicles and disseminate this information to travelers on a stretch of semi-rural roadway in College Station. Students would then be asked to develop concepts of operations, prepare functional requirements, develop test plans, etc., for ITS solutions that they developed for this scenario. At the end of the course, students would present their system designs to their classmates and the instructor for review, comment, and evaluation. Students would need to be able to respond to comments and questions and defend their design and selected approach.

A list of the planned laboratory exercises is shown below:

- Tour TransLink® Research Center laboratory
- Use Turbo Architecture to develop high-level architecture
- Develop concept of operation document
- Prepare functional requirements
- Develop system testing and verification plan
- Conduct site visit to local sensor testbed and field deployments

- Conduct alternatives analysis for detection strategies
- Design communications plan
- Conduct IDAS evaluation of proposed system
- Apply/demonstrate Corsim/VISSIM
- Conduct site visit to Houston TranStar (optional)

Evaluation Materials

The suggested grading policy for the course is as follows:

Homework/Lab Assignments	10%
Exam #1	20%
Exam #2	20%
Semester Project	20%
Final Exam	25%
Class Participation	5%

Passing grades for graduate students are A, B, C and S.

As discussed above, 20 percent of the student's final grade was to come from a semester project. The class would be divided into groups, depending on the number of students in the class. Each group would prepare an ITS application using the concepts and techniques discussed in class. The other members of the student's group would be asked to assess the relative contribution of the student to the group effort. An individual's grade would then be adjusted based upon the amount of contribution the individual made to the group effort. For example, if a group scored a 90 on its project and the members of the group felt that a particular student's contributed only at 75 percent to the total group effort, then that student would receive a grade of 75 percent of the total project score, for an individual score of 67.5. Therefore, it would be important for the student to participate fully in all of the group's activities. Specific information and instructions regarding this project would be provided when the project was assigned.

Refinement of Materials

The scope of work for this project included developing the course material and teaching the course at least once before refining the material; however, teaching did not occur during the timeframe of the project. The course was offered twice – in the Fall 2008 and Spring 2009 semesters – but failed to receive the minimum number of registration to make the course viable according to University policies. Therefore, the prepared lecture and laboratory materials are presented here prior to refinement based on instructor and student feedback.

Appendix A: Lecture Slides for Module 1. Overview of Intelligent Transportation Systems

Overview of Intelligent Transportation Systems

Module 1

What is ITS?

- Use of a broad range of wireless and wireline communications-based information and electronics technologies that, when integrated into the transportation system's infrastructure, and in vehicles themselves, relieve congestion, improve safety and enhance American productivity.

Intelligent Infrastructure

- Arterial Management
- Freeway Management
- Transit Management
- Incident Management
- Emergency Management
- Electronic Payment
- Traveler Information

- Crash Prevention and Safety
- Roadway Operations and Maintenance
- Road Weather Management
- Commercial Vehicle Operations
- Intermodal Freight

Freeway Management

Sensor and Surveillance Systems

Freeway Management Center

Managed Lane Systems

Ramp Control Systems

Information Dissemination Systems

Transit Management Systems

- Advanced Communication Systems (ACS)
- Automatic Vehicle Location System (AVL)
- In-Vehicle Diagnostic System (IVD)
- Transit Operations Software (TOS)
- Computer-Aided Dispatch Systems
- Automatic Passenger Counters (APC)

Electronic Toll Collection

Intelligent Vehicles

- Collision Avoidance Systems
- Collision Notification Systems
- Driver Assistance System

Example of Intelligent Vehicle Systems

Adaptive Headlights

Rear Collision Warning

Information Displays

Forward Collision Warning

Lane Departure

Obstacle Detection

Brief History of ITS

- *Intermodal Surface Transportation Efficiency Act* of 1991 (ISTEA)
  - Formally Federal program
  - Facilitate deployment of technology to enhance efficiency, safety, and convenience to improve access, save lives and time, and increase productivity
- Safe, Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA-LU)
  - Ended ITS Deployment Program in 2005
  - Continued ITS research funding through 2009
  - Authorized ITS eligibility for regular Federal-aid highway funds

Overview of Intelligent Transportation Systems

NATIONAL ITS ARCHITECTURE

What is an "Architecture"?

- Framework within which a system can be built
- Defines
  - Functions
  - Physical entities or subsystems
  - Information and data flows
- Describes
  - "<u>What</u> a system must do"
  - NOT how it will be done → independent of technology

What is the "National ITS Architecture"?

- Common framework within which a system can be built
- Defines
  - Functions
  - Physical entities or subsystems
  - Information and data flows
- Describes
  - "<u>What</u> a system must do"
  - NOT how it will be done → independent of technology

National ITS Architecture: Key Concepts

- User Services and User Service Requirements
- Logical Architecture
- Physical Architecture
- Equipment Packages
- Market Packages
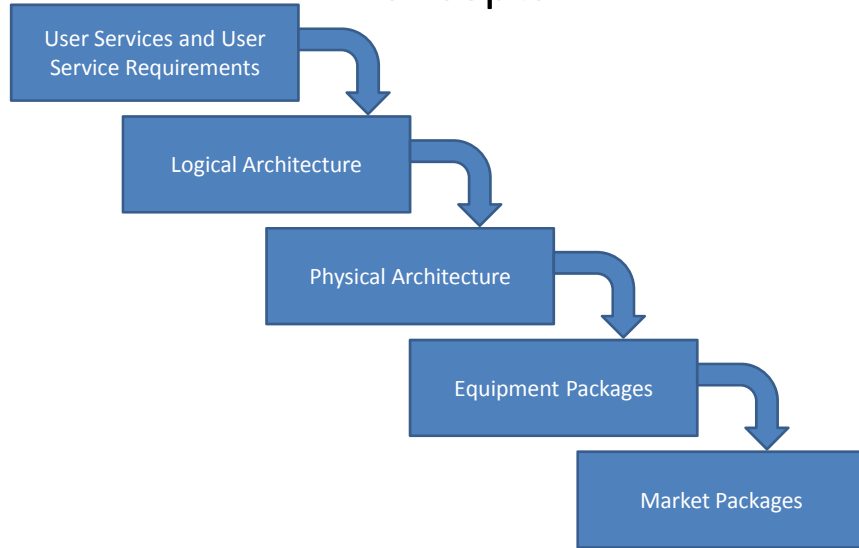
User Services and User Service Requirements

- 33 user services grouped into 8 user service bundles
  - Travel and Traffic Management
  - Public Transportation Management
  - Electronic Payment
  - Commercial Vehicle Operations
  - Emergency Management
  - Advanced Vehicle Safety Systems
  - Information Management
  - Maintenance and Construction Management

User Services Bundles/User Services

Travel and Traffic Management
- Pre-Trip Travel Information
- En-route Driver Information
- Route Guidance
- Ride Matching and Reservation
- Traveler Services Information
- Traffic Control
- Incident Management
- Travel Demand Management
- Emissions Testing and Mitigation
- Highway Rail Intersection

Public Transportation Management
- Public Transportation Management
- En-route Transit Information
- Personalized Public Transit
- Public Travel Security

User Services Bundles/User Services

Electronic Payment
- Electronic Payment Services

Commercial Vehicle Operations
- Commercial Vehicle Electronic Clearance
- Automated Roadside Safety Inspection
- On-board Safety and Security Monitoring
- Commercial Vehicle Administrative Processes
- Hazardous Materials Security and Incident Response
- Freight Mobility

User Services Bundles/User Services

Emergency Management

- Emergency Notification and Personal Security
- Emergency Vehicle Management
- Disaster Response and Evacuation

Advanced Vehicle Safety Systems

- Longitudinal Collision Avoidance
- Lateral Collision Avoidance
- Intersection Collision Avoidance
- Vision Enhancement for Crash Avoidance
- Safety Readiness
- Pre-cash Restraint Deployment
- Automated Vehicle Operations

User Services Bundles/User Services

Information Management

- Archived Data

Maintenance and Construction Management

- Maintenance and Construction Operations

User Service Requirements

- A specific <u>functional requirement</u> statement of what must be done to support an ITS user service.
- Example: Traffic Control
  - ITS shall include a Traffic Control (TC) function. Traffic Control provides the capability to efficiently manage the movement of traffic on streets and highways. Four functions are provided, which are (1) Traffic Flow Optimization, (2) Traffic Surveillance, (3) Control, and (4) Information. This will also include control of network signal systems with eventual integration of freeway control.

Logical Architecture
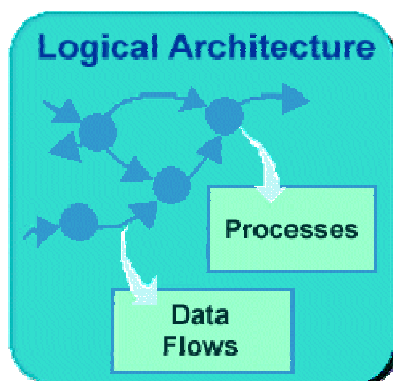
- Processes – functions or activities performed
- Data Flows – pipelines along which information of known composition is passed

Data Flow Diagram
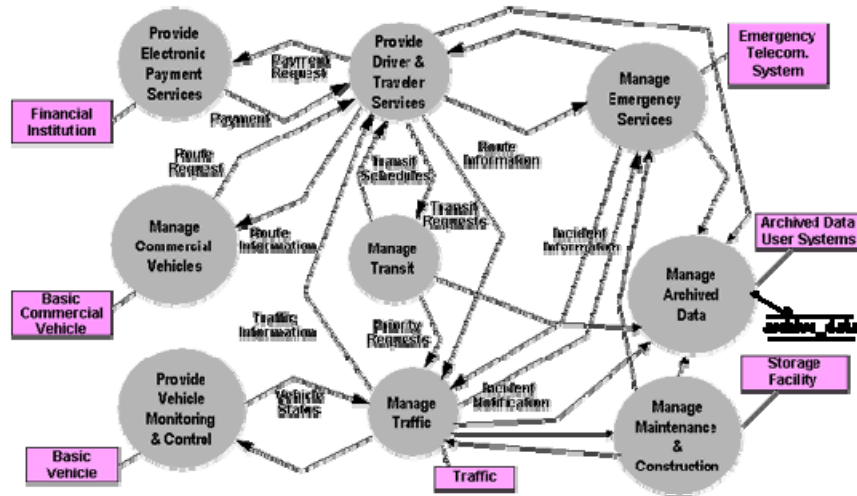
Physical View of National ITS Architecture

Systems and Subsystems

Centers	• Archived Data Management Subsystem (ADMS) • Commercial Vehicle Administration (CVAS) • Emergency Management (EM) • Emissions Management (EMMS) • Fleet and Freight Management (FMS) • Information Service Provider (ISP) • Maintenance and Construction Management (MCMS) • Toll Administration (TAS) • Traffic Management (TMS) • Transit Management (TRMS)
Field	• Commercial Vehicle Check (CVCS) • Parking Management (PMS) • Roadway Subsystem (RS) • Security Monitoring Subsystem (SMS) • Toll Collection (TCS)
Travelers	• Personal Information Access (PIAS) • Remote Traveler Support (RTS)
Vehicles	• Commercial Vehicle Subsystem (CVS) • Emergency Vehicle Subsystem (EVS) • Maintenance and Construction Vehicle (MCVS) • Transit Vehicle Subsystem (TRVS) • Vehicle (VS)

Terminators

- Define the boundaries of an architecture
- Represent the people, systems, and general environment that interface with ITS
- Example: Basic Commercial Vehicle Terminator
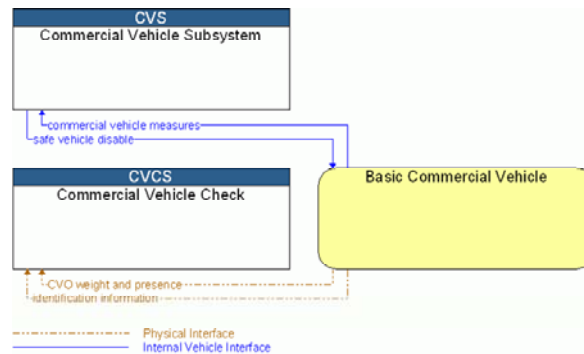
Physical Architecture
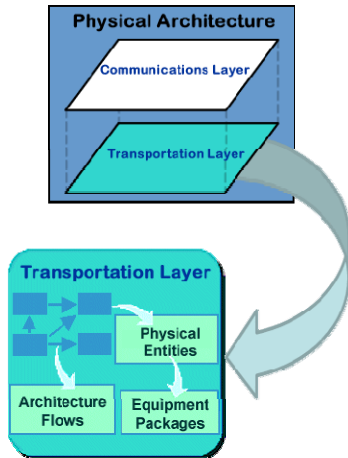
- Communications Layer
- Transportation Layer
  - Physical Entities – persons, places, and things
  - Architecture Flows – information that is exchanged between subsystems and terminators
  - Equipment Packages – grouping of similar processes of a particular subsystem into "implementable" packages
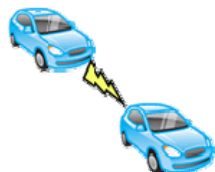
Communications Layer

Fixed Point to Fixed Point
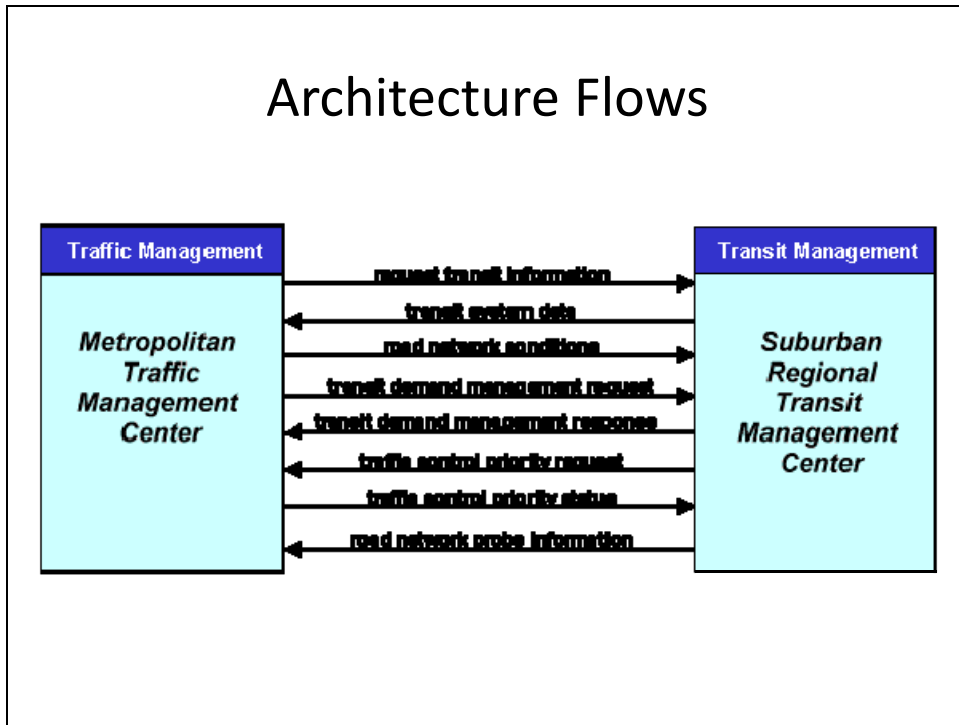
Fixed Point to Vehicle

Vehicle to Vehicle

Wide Area Network (Mobile)

Architecture Flows

Traffic Management

Metropolitan Traffic Management Center

Transit Management

Suburban Regional Transit Management Center

request transit information

transit system data

road network conditions

transit demand management request

transit demand management response

traffic control priority request

traffic control priority status

road network probe information

TMC Traffic Management Decision Support (Equipment Packages*)

[Functionality] [Inputs/Outputs]

This equipment package recommends courses of action to the traffic operator based on current and forecast road and traffic conditions. Traffic incidents, special events, maintenance activities and other events or conditions that impact capacity or demand are monitored. Historical data and models are used to compare the impact of potential courses of action and make recommendations to the operator. Decisions are supported through presentation of filtered and fused network-wide road and traffic conditions that identify network imbalances and recommended courses of action. The recommended actions may include predefined incident response plans, signal timing plan changes, DMS/HAR messages, and freeway control strategies including ramp metering, interchange control, and lane controls. Multimodal strategies may also be recommended that include suggested transit strategies and suggested route and mode choices for travelers. Once a course of action is selected, other equipment packages implement these actions within the traffic management center and coordinate the response with other centers in the region.

Included In:

Traffic Management

Market Packages:
- ATMS09-Traffic Decision Support and Demand Management

Functionality:

Functional Requirements*:
1. The center shall provide center personnel with an integrated regional view of current and forecast road and traffic conditions including traffic incidents, special events, maintenance activities and other events or conditions that impact capacity or demand.
2. The center shall identify network imbalances and potential courses of action.
3. The center shall compare the impact of potential courses of action and make recommendations to the operator.
4. The recommended actions shall include predefined incident response plans, signal timing plan changes, DMS/HAR messages, and freeway control strategies including ramp metering, interchange control, and lane controls.
5. The recommended actions shall include multimodal strategies that include suggested transit strategies and suggested route and mode choices for travelers.
6. The center shall provide an interface to center personnel to input control parameters for the decision support process and receive recommended actions and supporting information presentation.

Pspecs:
- 1.3.4.2-Provide Traffic Operations Personnel Incident Data Interface
- 1.3.5-Manage Incident Response Planning

Inputs/Outputs (Included Architecture Flows)

| Source	Architecture Flow	Destination
Traffic Management	traffic operator data	Traffic Operations Personnel
Traffic Operations Personnel	traffic operator inputs	Traffic Management

Standards - This icon indicates that the associated architecture flow either has been or will be addressed by ITS Standards. Select the architecture flow for more information on relevant standards activities.

Market Packages

- A collection of one or more **equipment packages** within the **subsystems** that are required to deliver a particular transportation service and the **architecture flows** that connect them. These three things identify the **physical architecture** that is required to implement the particular transportation service.

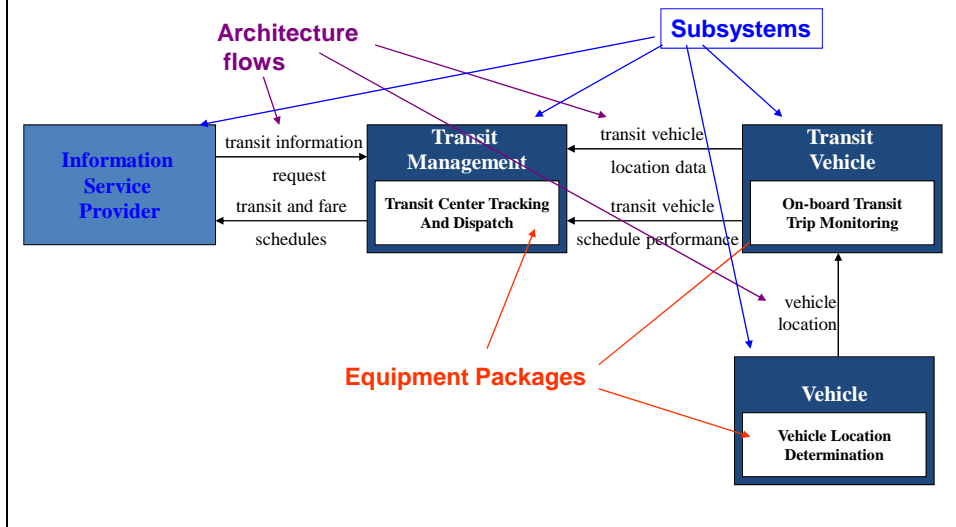ATMS09 – Traffic Decision Support and Demand Management
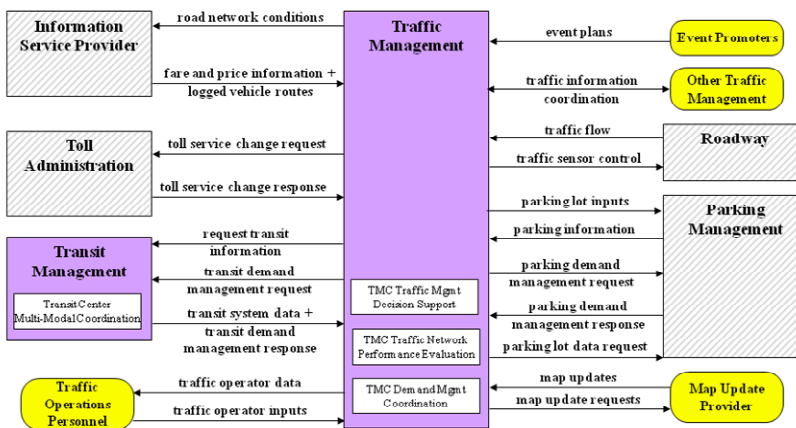
Institutional Layer

- Includes the policies, funding incentives, working assignments and jurisdictional structure that support the technical layers of the architecture
- Basis for understanding who the stakeholders are and what role they play

What is a "Stakeholder"?

STAKEHOLDER	EXAMPLES
Public Agencies	State /City Department of Transportation (DOT) Public Transportation Agencies Metropolitan Planning Organization (MPO) Emergency Services
Private Organizations	Private information service providers Manufacturers Special interest groups
Travelers	Commuter Transit riders Commercial vehicle operators (CVO)

Example of a Market Package: Transit Vehicle Tracking

Architecture flows

Subsystems

Information Service Provider

transit information request

transit and fare schedules

Transit Management

Transit Center Tracking And Dispatch

transit vehicle location data

transit vehicle schedule performance

Transit Vehicle

On-board Transit Trip Monitoring

vehicle location

Equipment Packages

Vehicle

Vehicle Location Determination

ITS Standards

- Define how ITS systems products and components can interconnect, exchange information and interact to deliver services
- Cover the communications layers – how data is communicated between systems
- Interoperability: ability of systems to…
  - Provide information and services to other systems
  - Use exchange information and services to operate together effectively

Standard Development Organizations (SDO) Home Page	Applicable Interfaces in the National ITS Architecture	ITS Standards Specific Sites
AASHTO, ITE, NEMA	Traffic Management Center to other Centers	National Transportation Communications for ITS Protocol(NTCIP)
	Traffic Management Center to Field Devices	
AASHTO, ITE	Traffic Management Center to other Centers	Traffic Management Data Dictionary (TMDD) and Message Sets
ANSI	Commercial Vehicle Operations (CVO)-related system interfaces	Commercial Vehicle Information Systems and Networks (CVISN)
ASTM	Archived Data Management Center Interfaces	Archived Data
ASTM, IEEE, SAE	Vehicle to Vehicle; Field to Vehicle	Dedicated Short Range Communications (DSRC)
IEEE	Emergency Management Center to other Centers	Incident Management
APTA	Transit Center to other Centers and Transit Vehicles	Transit Communications Interface Profiles (TCIP)
SAE	Traveler Information (Information Service Provider interfaces)	Advanced Traveler Information Systems (ATIS)
	Location Referencing	

National Transportation Communications for ITS Protocol (NTCIP)

- family of standards that provides both the rules for communicating (called protocols) and the vocabulary (called objects)
- set of standards for the transportation industry
- reduce the need for reliance on specific equipment vendors and customized one-of-a-kind software
  - Data Dictionary Standards
  - Message Set Standards
  - Protocol Standards

Laboratory Exercise

- Exploring the National ITS Architectures (http://www.iteris.com/itsarch/index.htm)

Overview of ITS

CURRENT FEDERAL INITIATIVES

Cooperative Intersection Collision Avoidance Systems

- Use both vehicle-based and infrastructure-based technologies to help drivers approaching an intersection understand the state of activities within that intersection

Electronic Freight Management

- Improve speed, accuracy, and information transfer when freight is transferred from one mode of transportation to another

Emergency Transportation Operations

- Improve the management of all forms of transportation emergencies through the application of ITS technologies by:
    - Providing effective traveler information during major disasters
    - Planning and managing major incidents involving evacuation
    - Getting ITS into operation quickly during a disaster
    - Using ITS to monitor travel conditions on alternate and evacuation routes

Integrated Corridor Management Systems

- Uses ITS technologies to efficiently and proactively manage the movement of people and goods in major transportation corridors in large cities.

Integrated Vehicle-Based Safety Systems

- Combines existing safety and collision avoidance systems into an integrated system that can warn drivers of imminent crashes
  - Rear-end Collision Avoidance
  - Road Departure Collision Avoidance
  - Lane Change/Merge Collision Avoidance

Mobility Services for All Americans (MSAA)

- Improve transportation services and simplify access to employment, healthcare, education, and other community activities by means of the advanced technologies of ITS

CLARUS: National Surface Transportation Weather Observing and Forecasting System

- Mitigate the effects of adverse weather on all surface transportation users and operators by providing timely and accurate weather, pavement, and water level information.

Next Generation 9-1-1 (NG911)

- Enable the transmission of voice, data, or video from different types of communication devices to the Public Safety Answering Points (PSAPs) and onto emergency responder networks

IntelliDrive^{SM}

- Formerly Vehicle Infrastructure Integration (VII)
- Deploy advanced vehicle-vehicle and vehicle-infrastructure communications that could keep vehicles from leaving the road and enhance their safe movement through intersections

IntelliDrive^{SM} Levels
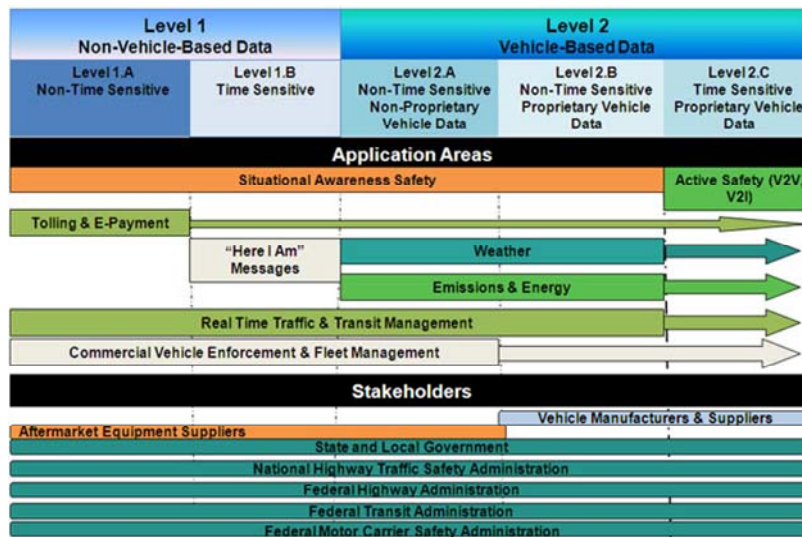
Why is ITS Important to You?

- As Designers / Builders / Operators/ Maintainers
  - Continued emphasis at federal level
  - Better operating system delay need for expensive construction
  - Offer potential to improve safety
- As User
  - Improved decision-making at travel
  - Seamless transportation system

Questions/Comments/Discussion
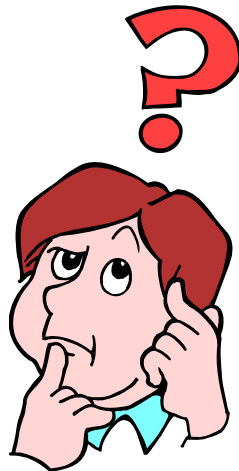
Appendix B: Lecture Slides for Module 2. Systems and Systems Engineering

Systems and Systems Engineering

Module 2

Reference Documents

- *Systems Engineering for Intelligent Transportation Systems*. USDOT, FHWA, January 2007.
- *Developing and Using a Concept of Operations in Transportation Management Systems*, August 2005.

  (http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/conops_tms_handbook.pdf)

- *Developing Functional Requirements for ITS Projects*, April 2002.
  (http://www.itsdocs.fhwa.dot.gov//JPODOCS/REPTS_TE/13621.html)

- M. Fowler and K. Scott *UML Distilled* 2nd Edition. Addison-Wesley, 2000.

What is a "System"

- International Council on Systems Engineering (INCOSE) defines a system as:

  A combinations of interacting elements organized to achieve one or more stated purposes

Examples of Systems in Transportation

- Using Bryan/College Station, can we list examples of transportation systems?

Definition of Systems Engineering

- INCOSE defines systems engineering as:

  Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. 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.

  Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structural development process that proceeds from concept to production to operations. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Why Do We Need Systems Engineering?

- 23 CFR 940.11 Project Implementation
  - All ITS projects funded with highway trust funds shall be based on a system engineering analysis.
  - The analysis should be on a scale commensurate with the project scope.
  - The systems engineering analysis shall include, at a minimum:
    - Identification of portions of the regional ITS architecture being implemented (or if a regional architecture does not exist, the applicable portions of the National ITS Architecture);
    - Identification of participating agencies roles and responsibilities;
    - Requirements definitions;
    - Analysis of alternative system configurations and technology options to meet requirements;
    - Procurement options;
    - Identification of applicable ITS standards and testing procedures; and
    - Procedures and resources necessary for operations and maintenance.

  http://www.ops.fhwa.dot.gov/its_arch_imp/policy.htm

Cone of Uncertainty
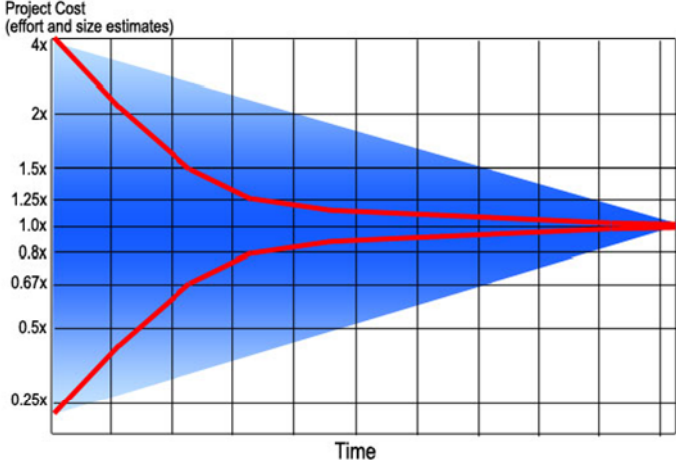
Project Costs
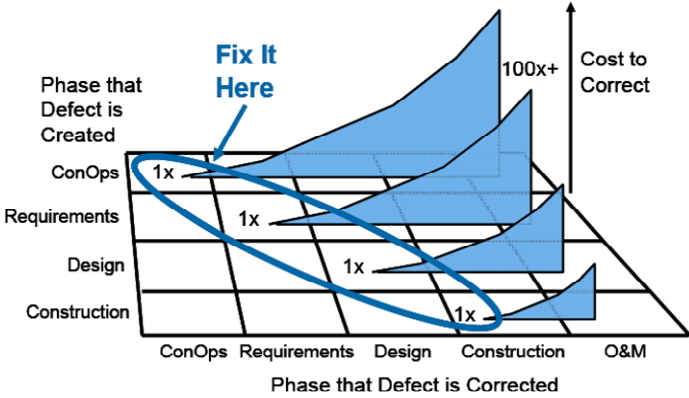
Figure 5: Late Changes Drive Project Costs
(Adapted from Steve McConnell, *Code Complete*)

System Engineering Principles

- Begin with the end in mind
- Stakeholder involvement is critical
- Define the problem before implementing the solution
- Delay technology choices
- Maintain traceability
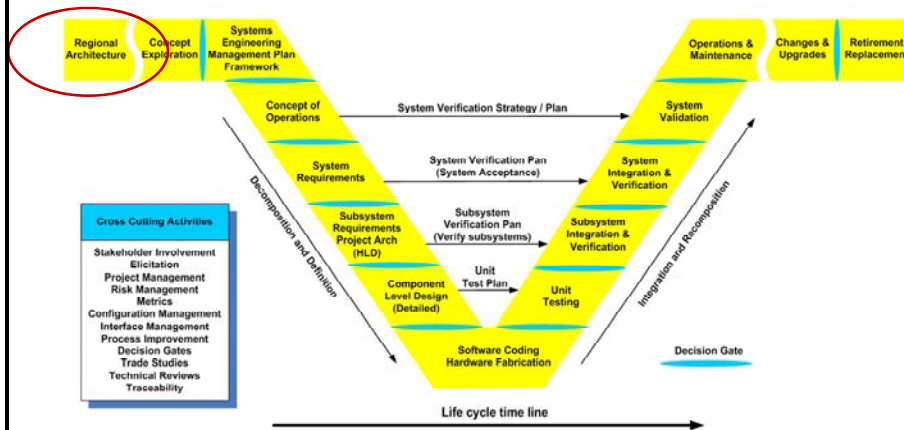
Systems Engineering "V" Diagram
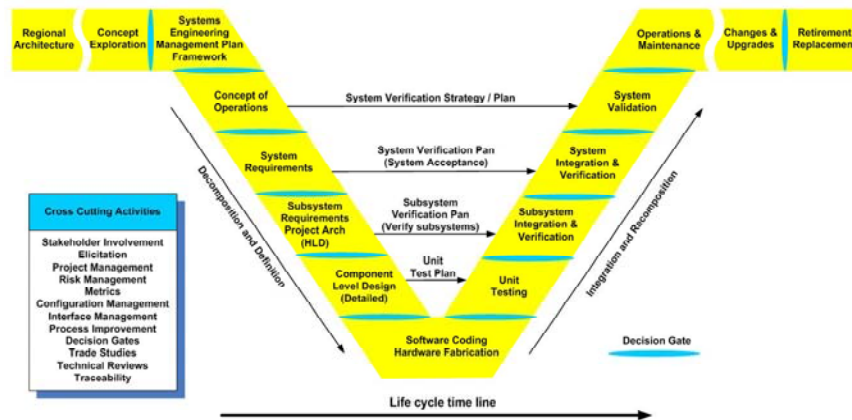
Technical Documentation in the "V"
System Engineering Process

- See Handout #1: Technical Documentation in the "V" System Engineering Process

---

System Engineering Process
Regional Architecture

Regional ITS Architecture

- Framework for institutional agreement and technical integration
- Starting point for defining basic scope of project
- Elements
  - Identification of stakeholders
  - Inventory of assets
  - Existing and future "market packages"
  - Identification of functions
  - Identification of system "interfaces"
  - Listing of appropriate standards

Example of Regional Architecture

- Brazos Valley Regional ITS Architecture
(link address: http://www.consystec.com/texas/web/brazos/brazosintro.htm)
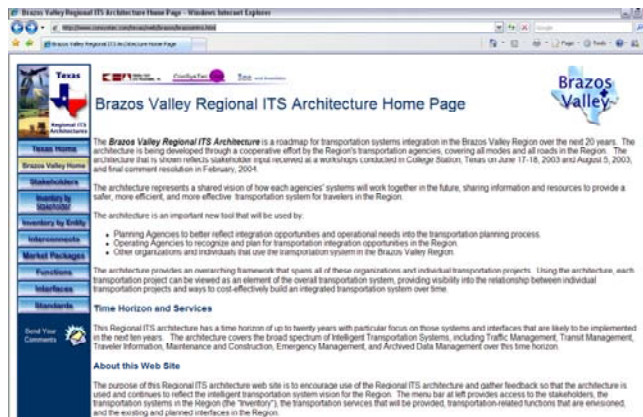
Regional ITS Architecture: Key Activities

- Identify regional ITS architecture(s) that are relevant to the project
- Identify the portion of the regional ITS architecture that applies
- Verify consistency with the regional ITS architecture and identify any necessary changes to it

Laboratory Exercise:

- Demo Turbo Architecture
- Develop Sample Architecture for Bryan/ College Station Regional Transportation Operations

System Engineering Process: Concept Exploration/Feasibility Study
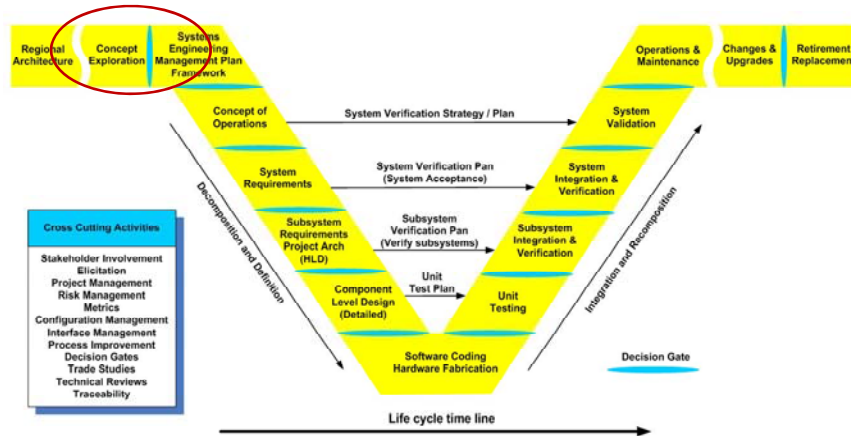
Feasibility Study/Concept Evaluation

- Purpose: to determine whether project is viable
  - Technically
  - Economically
  - Operationally
- Consider multiple alternative concepts
- Alternatives considered at a high level, but with enough technical detail to ensure concept is implementable
- Establishes business case for investing in a project

Concept Exploration Process

State the Problem

Generate Ideas

Candidate Solutions

Select Practical Solutions ← Specify Constraints & Criteria

Evaluate Candidates

Optimum Solution
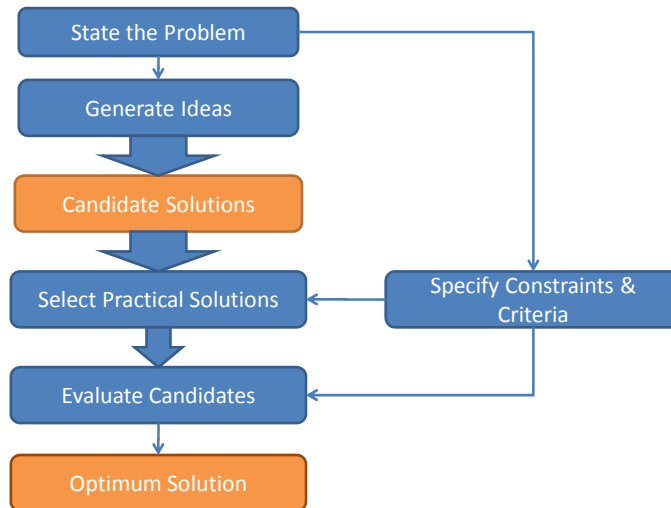
Concept Exploration: Key Activities

- Define evaluation criteria
- Identify alternative concepts
- Evaluate alternatives
  - ITS Cost database
  - ITS Benefits database
  - ITS Deployment Analysis System (IDAS)
  - SCRITS (SCReening for ITS)
- Document Results

Content of Feasibility Study Report

- Description of problem or opportunity
- Project objectives and evaluation criteria used
- Economic and risk assessment for each alternative and reasons for rejecting alternatives
- Summary description of selected alternative, including major system features and resources
- Economic analysis of funding sources, and life-cycle costs and benefits

System Engineering Process: Concept of Operations
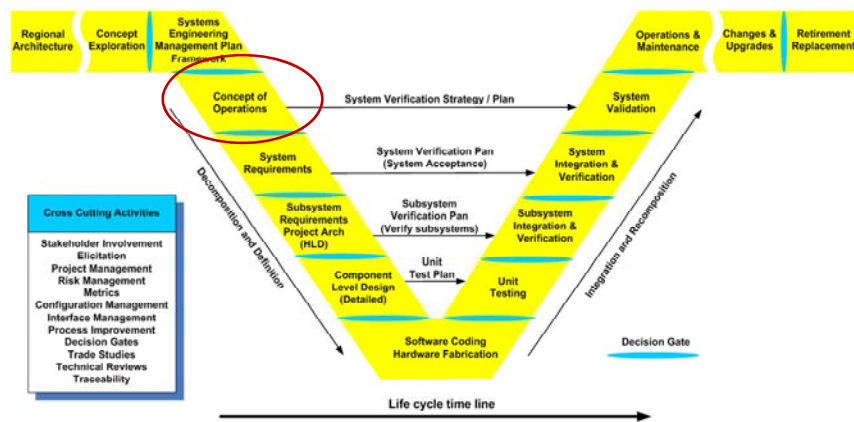
Concept of Operations (ConOps)

- High-level identification of user needs and system capabilities
- Stakeholder agreement on roles and responsibilities
- Shared understanding by system owners, operators, maintainers, and developers on the WHO, WHAT, WHY, WHERE, and HOW of the system
- Key performance measures and basic implementation and validated plan

Concept of Operations
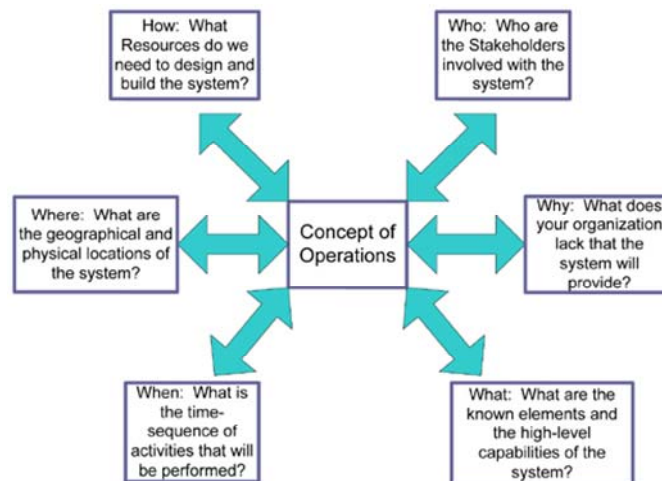
Primary Questions to be Addressed in ConOps

- Who – Who are the stakeholders involved with the systems?
- What – What are the elements and the high-level capabilities of the systems?
- Where – What is the geographic and physical extent of the system?
- When – What is the sequence of activities that will be performed?
- Why – What is the problem or opportunity addressed by the system?
- How – How will the system be developed, operated, and maintained?

ConOps: Key Activities

- Identify the stakeholders associated with system/project
- Define core group responsible for creating ConOps
- Develop an initial ConOps, review with broader group of stakeholders, and iterate
- Define stakeholder needs
- Create a System Validation Plan – approach to be used to validate the project delivery

Industry Standards for ConOps

- **ANSI/AIAA-G-043 Outline**
  - Scope
  - Referenced Documents
  - User-Oriented Operational Description
  - Operational Needs
  - System Overview
  - Operational Environment
  - Support Environment
  - Operational Scenarios

- **IEEE 1362 Outline**
  - Scope
  - Referenced Documents
  - The Current System or Situation
  - Justification for and Nature of Changes
  - Concepts of the Proposed System
  - Operational Scenarios
  - Summary of Impacts
  - Analysis of the Proposed System

Elements of a ConOps
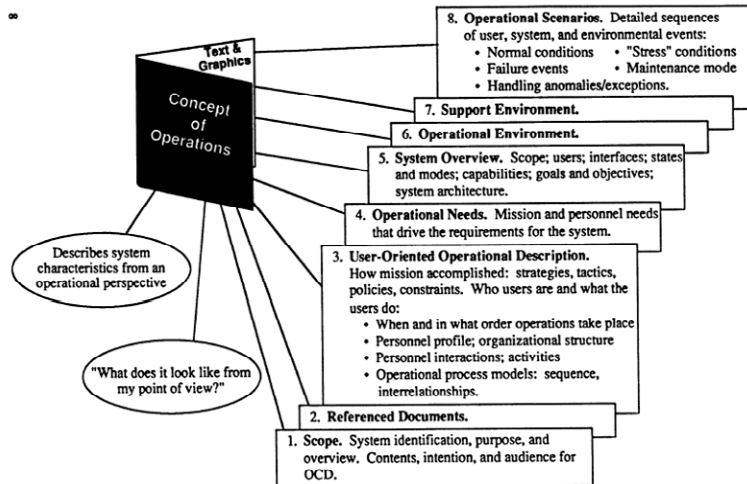
Example: Roles and Responsibilities

Position	TMC Manager	TMC Operator	Maintenance Dispatch	TMS Engineer	IT	HQ Engineer	District Deputy of Operations	Program Manager	Director
L = Lead **S = Support**									
Contacting Executives	L	S					L	S	S
After incident briefing and analysis	L	S	S	S		S	S		
Signal timing adjustments				L					
Field data detection				L					
Weather monitoring		L	S						
Road condition monitoring and communication	S	L	S						
Special event traffic monitoring	S	L	S						
Workzone lane closure logging	S	L	S						
Monitor workzone duration and congestion	S	S	S						
Incident response management	L	L	S						
News monitoring	S	L							

Example: System Overview
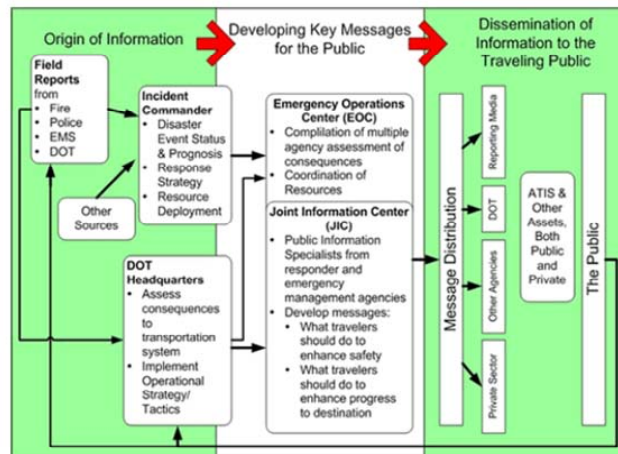
Figure 14: Example of System Overview Graphic   (from *Communicating with the Public Using ATIS During Disasters Concept of Operations*)

Example: Operational Scenario Description

Marcel, a StarTran bus operator, usually begins his work shift with administrative activities. After receiving supervisory direction, he boards the bus and prepares the AVL system. He begins by logging into the system.

The system then prompts Marcel for the route to be followed. He enters the planned route number, and the AVL system retrieves the appropriate route and schedule information from the AVL system server. The bus' AVL system then asks Marcel to verify the appropriate route and schedule information were properly retrieved.

Once he provides verification, the bus' head sign is automatically updated to reflect the appropriate route information. The fare payment schedule is automatically adjusted to reflect the verified route, modified as necessary by the system clock to reflect any applicable time-differential rates.

The system then loads the appropriate bus stop announcements for the chosen route. These prerecorded announcements are consistent regardless whether Marcel or another bus operator is driving the route, and have been verified as ADA compliant. These announcements are then broadcast at the appropriate bus stop throughout the route.

Lab Activity

- Development of Concept of Operations for Regional Incident Management Responses for Bryan/College Station Mobility Initiative

System Engineering Process:
System Requirements
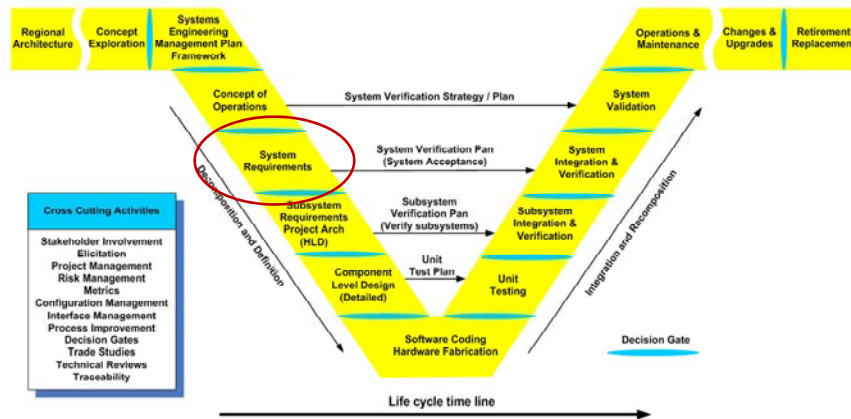
System Requirements

- One of the most important (and often most difficult) steps in the process
- EIA-632 defines requirement as "something that governs what, how well, and under what conditions a product will achieve a given purpose"
- Functional requirements specify **WHAT, NOT HOW** system will accomplish its functions

Requirement Process
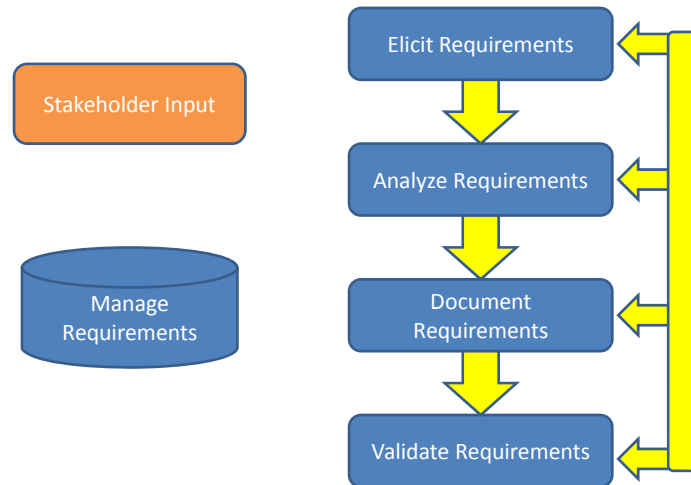
Elicit Requirements

- Elicit – draw forth or evoke a response
- Critical to not only involve right organization, but right **person** within organization
- Techniques
  - Interviews
  - Scenarios
  - Prototypes
  - Facilitated meetings
  - Surveys
  - Observations

The "Five Whys" Technique

Stakeholder

- I need irrigation channels on my keyboard.
- I occasionally spill coffee on my keyboard.
- I need to have three or four manuals open to operate the system and the coffee just gets knocked over.

System Engineer

- Why?
- Why?
- Why do you need to have three or four manuals open?

Food for Thought

- Look beyond operational requirements and cover complete life cycle
  - System development
  - Deployment
  - Training
  - Transition
  - Operations and maintenance
  - Upgrades
  - Retirement
  - Security and safety

Writing System/Functional Requirements

- Verb / Noun Description
- User Requirement → "monitor road weather conditions"
- Functional/Operational Requirements
  - Shall detect ice
  - Shall monitor wind speed
  - Shall monitor pavement temperature
- Performance Requirements → define the different kinds of ice conditions and range of wind speeds

Analyzing Requirements

Parent Requirement	Child Requirement	Grandchild Requirement
•The system shall read tag data	•The system shall read tag ID •The system shall read tag data	•The tag ID shall be checked for validity •The tag ID shall be sent to other processes to debit user account

Increasing Detail and Specificity →
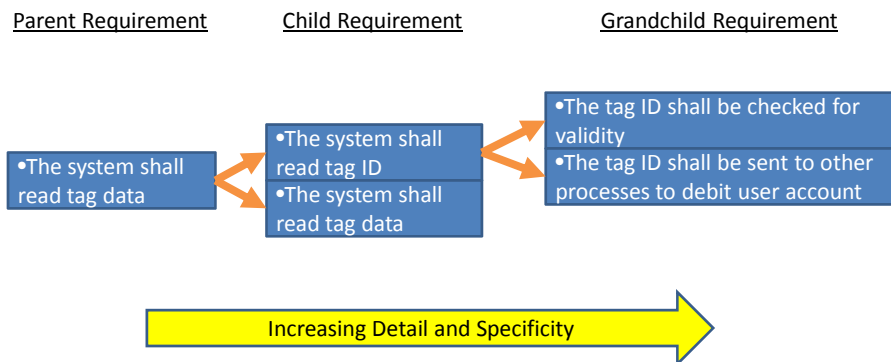
Documenting Requirements

- Attributes of requirements
  - Requirement number
  - Source
  - Author
  - Creation date
  - Change history
  - Verification method
  - Priority
  - Status

Traceability Matrix

- Example of Traceability Matrix

Qualities of a Good Requirement

- **Necessary** – Does it relates to stakeholder need
- **Clear** – Is it ambiguous ? Are there any other interpretations?
- **Complete** – If you implement all requirements, will need be met?
- **Correct** – If a child requirement is in conflict with parent, then either parent or child is incorrect
- **Feasible** – Can it be implemented? -- reality check
- **Verifiable** – Does requirement have a verification method? Is the requirement really stated in a way that is verifiable?

Output of System Requirements

- System boundary with interfacing systems clearly identified.
- General system description, including capabilities, modes, and users, as applicable
- External interface requirements for interfacing systems and people
- Functional requirements and associated performance requirements
- Environmental requirements
- Life-cycle process requirements
- Reliability and availability
- Expandability
- Staffing, human factors, safety and security requirements
- Physical constraints

Example: Oregon Department of Transportation (ODOT) TripCheck User Requirements (Excerpt)

REQ ID	ODOT PRIORITY	REQUIREMENT	AUDIENCE SEGMENTS					
			C	ICT	TT	ADA	CT	ALL
RR001	2	The system should allow the user to enter a multi-point route using a combination of the criteria specified in MP004c-f and h.	X	X	X	X		
RR0011	1	The system shall allow the user to select destination points by clicking on the map.	X	X	X	X		
		The system shall allow the user to specify the following when determining road routes (note: this functionality is for trip planning.):						
RR002a	2	- starting date AND/OR ending date if only one date is specified, the system calculates the other.			X	X		
RR002b	2	- starting time/ending time if only one time is specified, the system calculates the other.			X	X		
RR002c	2	- month of travel (instead of start/end)			X	X		
RR002d	4	- quickest route (by time)						X
RR002e	1	- shortest route (by miles)	X	X	X	X		
RR002f	2	- most scenic route (based on scenic byways within a user-specified mile radius of the direct (shortest) route			X	X		
RR002g	3	- routes most recommended by others			X	X		

Example: Maryland's Coordinated Highway Action Response Team (CHART) System Requirements (Excerpt)

3.1.3 Equipment Inventory

The equipment inventory is a list of SHA equipment used in connection with CHART response to incidents. The system provides functions to maintain the inventory, equipment status, and to generate alerts for delinquent equipment.

3.1.3.1 The system shall provide the capability to maintain the equipment inventory.

3.1.3.1.1 The system shall support the addition of new equipment entries to the inventory.

3.1.3.1.2 The system shall support the modification of existing equipment inventory entries.

3.1.3.1.3 The system shall support the deletion of equipment inventory entries.

3.1.3.1.4 The system shall support the allocation of equipment to events.

3.1.4 Report Generation

This section lists requirements for the generation of reports from the CHART system and archive data.

3.1.4.1 The system shall provide the capability to generate reports from online and archived data.

3.1.4.2 The system shall support the generation of operational reports.

3.1.4.2.1 The system shall support the generation of a Center Situation report.

3.1.4.2.2 The system shall support the generation of a Disable Vehicle event report.

3.1.4.2.3 The system shall support the generation of an Incident event report.

3.1.4.2.4 The system shall support the generation of traffic volume reports.

Further Example:
http://www.chart.state.md.us/downloads/readingroom/chart_ii_documents/CHART_R3B3_Detailed_Design.pdf

Laboratory Exercise

- Develop system requirements for traffic signal controller

System Engineering Process:
System Design
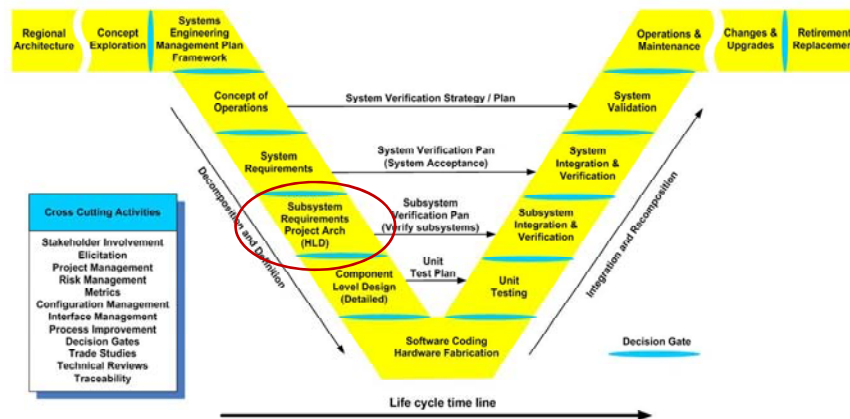
System Design

- High-level design
  - Also referred to as *architectural design*
  - Defines overall "structure" of design
  - IEEE 610 – "the process of defining the collection of hardware and software components and their interfaces to establish the framework for the development of a computer system."

System Design

- Detailed Design
  - Complete specification of the software, hardware, and communications components
    - Software specifications – enough detail to allow developers to write code for individual modules
    - Hardware specifications – enough detail to allow hardware to be fabricated or purchased.

High-Level Design – Key Activities

- Evaluate "off-the-shelf" components
  - Conventional wisdom – avoid "custom solutions" when possible
  - Advantage:
    - permits interoperability and interconnection
    - "bugs" generally worked out
  - Disadvantage: technology changes rapidly
  - Use recognized standards

High-Level Design: Key Activities

- Develop and evaluate high-level design alternatives
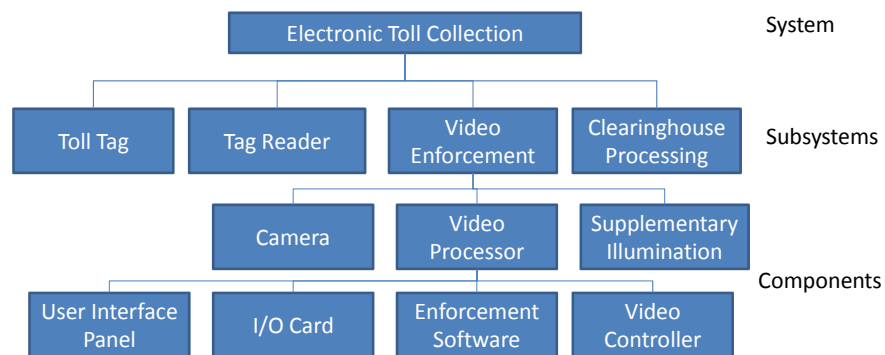
Selection Criteria for Comparing High-level Design Alternatives

- Consistency with existing physical and institutional boundaries
- Ease of development, integration, and upgrading
- Management visibility and oversight requirements

- Remember: KISS principle (Keep It Simple, Stupid)

System Engineering Process: Detailed Design

Detailed Design
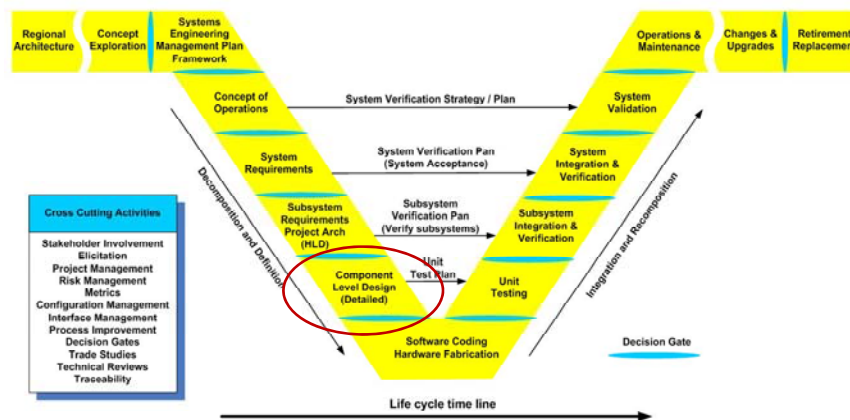
```
        ┌─────────────────────┐
        │  High-Level Design  │
        └─────────────────────┘
                  │
                  ▼
              ╱───────╲            No
             ╱ Off-the-╲ ──────────────────┐
             ╲  Shelf? ╱                    │
              ╲───────╱                     ▼
                  │              ┌──────────────────────┐
                Yes              │   Prototype User     │
                  │              │     Interface        │
                  ▼              └──────────────────────┘
        ┌──────────────────┐                │
        │ Select Off-the-  │                ▼
        │  Shelf Products  │     ┌──────────────────────┐
        └──────────────────┘     │  Develop Detailed    │
                  │              │      HW/SW           │
                  │              │   Specifications     │
                  │              └──────────────────────┘
                  │                         │
                  ▼                         ▼
        ┌────────────────────────────────────────────┐
        │              Implementation                │
        └────────────────────────────────────────────┘
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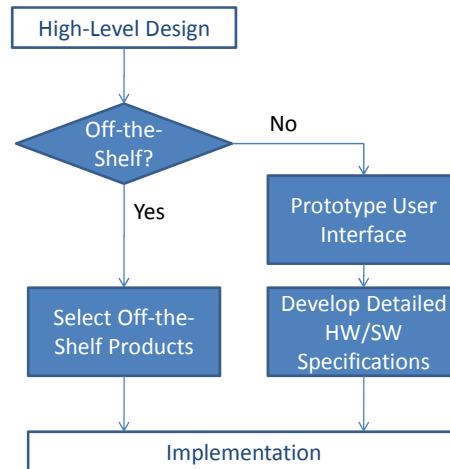
Prototyping

- Quick, easy-to-build approximation of system
- Can be used for any part of system, but most often used with user interface design
- Helps user and developer "visualize" how system would work without detecting significant resources
- Expect multiple iterations

System Engineering Process: Implementation
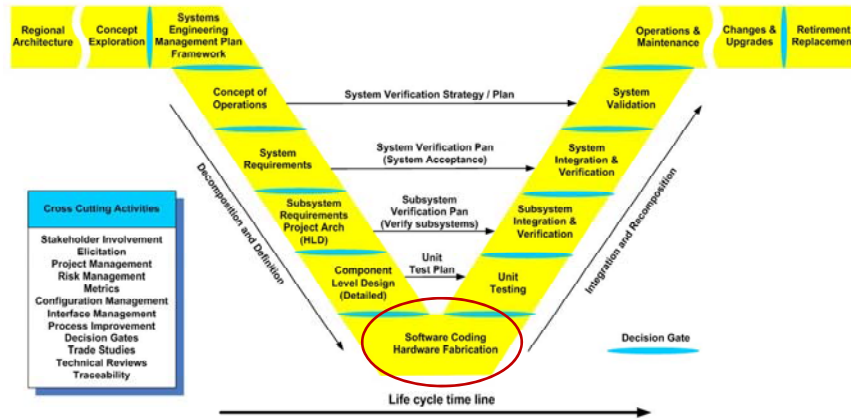
What is UML?

- UML = Unified Modeling Language
- Communicates
  - Requirements
  - Architecture
  - Implementation
  - Deployment
  - States
- System described in terms of object
  - The actions that objects take
  - The relationships between objectives
  - The deployment of objects
  - The way the states of objects change in response to external events

What is an Object?

- Objects are "Things"
- Example
  - Students in the classroom
  - Instructor
  - Computer
  - Powerpoint presentation

Use Case Scenarios

- Scenarios → sequence of steps describing an interaction between a user and system
- Example: Web-based on-line store

"The customer browses the catalog and adds desired items to the shopping basket. When the customer wishes to pay, the customer describes the shipping and credit card information and confirms the sale. The system checks the authorization on the credit card and confirms the sale both immediately and with a follow-up email. "

- Source: M. Fowler and K. Scott *UML Distilled* 2nd Edition

Use Case Scenario (continued)

- Use Case →set of scenarios tied together by a common user goal
- Example: Buy a Product
    1. Customer browses through catalog and selects items to buy
    2. Customer goes to check out
    3. Customer fills in shipping information (address; next-day or 3-day delivery)
    4. System presents full pricing information, including shipping
    5. Customer fills in credit card information
    6. System authorizes purchase
    7. System confirms sale immediately
    8. System sends confirming email to customer

    Alternative: *Authorization Failure*
    At step 6, system fails to authorize credit purchase
    Allow customer to re-enter credit card information and re-try

    Alternative: *Regular Customer*
    3a. System displays current shipping information, pricing information and last four digits of credit card information
    3b. Customer may accept or override these defaults
    Return to primary scenario at Step 6.

Source: M. Fowler and K. Scott *UML Distilled* 2nd Edition

Use Case Diagrams

- Depicts
    - Actions by people and systems outside your system
    - What your system does in response to actions
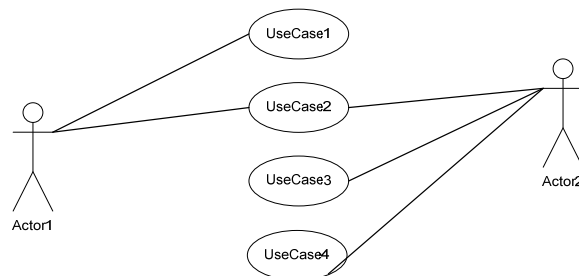
Example: Buy a Product
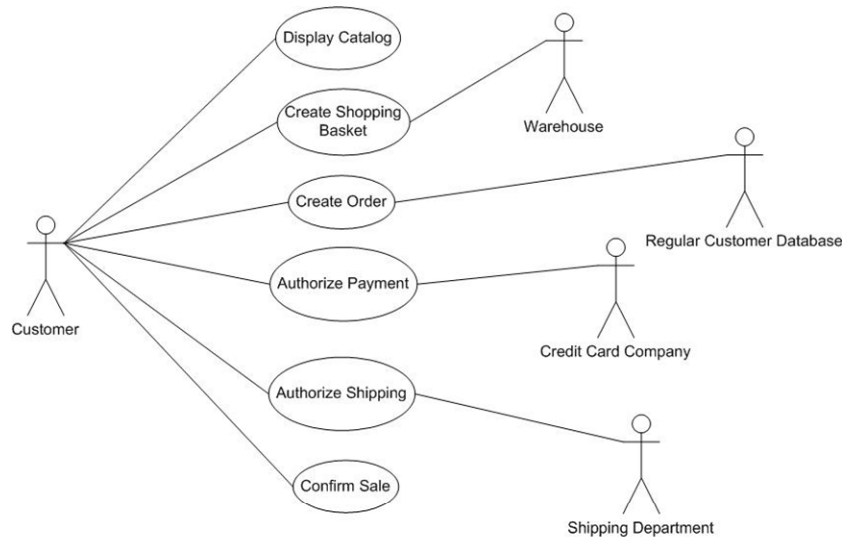
Sequence Diagram

- Depicts detailed behavior over time within one path or scenario of a single functional requirement
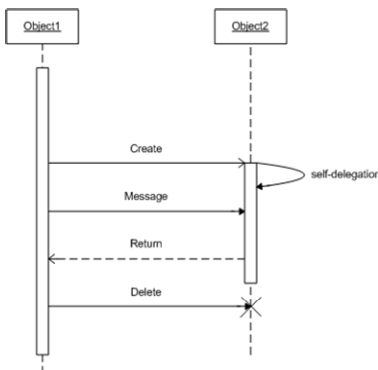
Example of Sequence Diagram
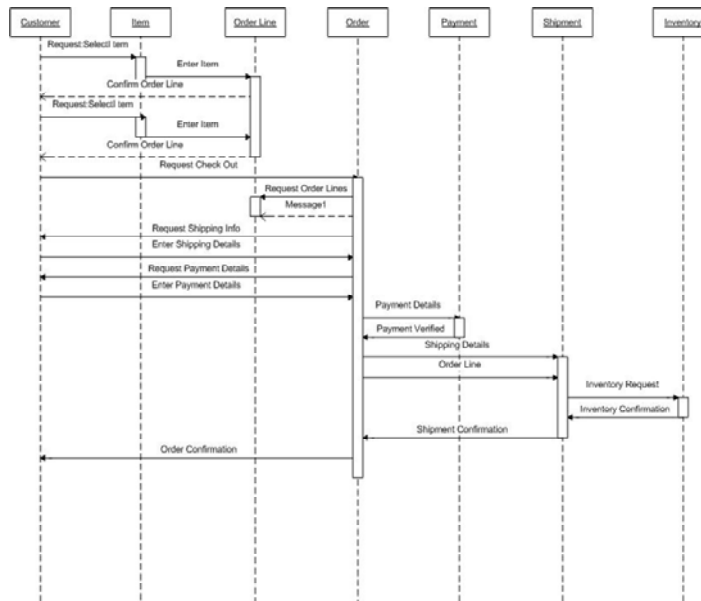
Class Diagrams

- Classes of objects and interfaces within the design of system as well as relationship between them
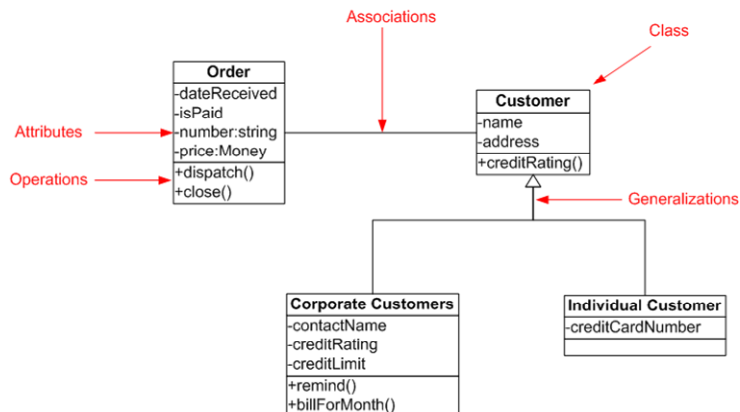
State Diagram

- Depicts how the state of system change in response to internal and external events
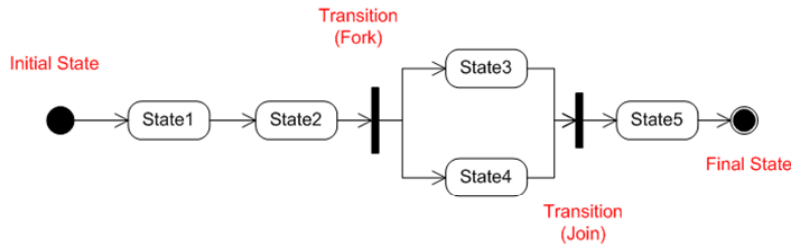
Activity Diagrams

- Similar in concept to state diagram, but show sequence of activities which cause a change in state of system
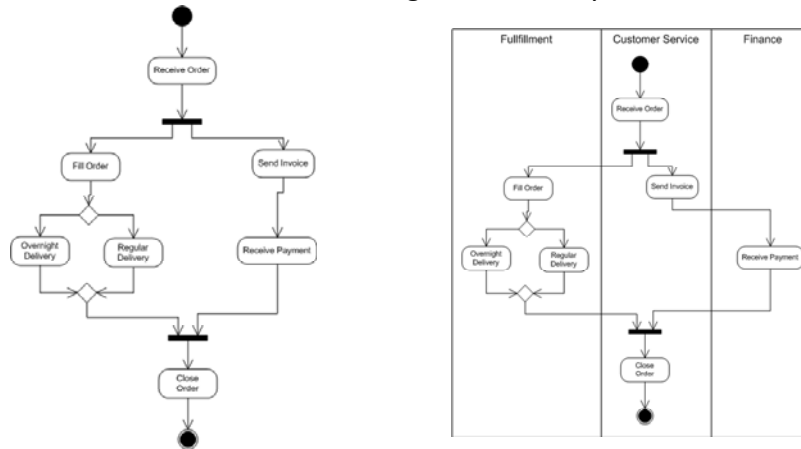
Laboratory Exercise

- Develop Use Case Diagrams and Activity for Bryan/College Station Mobility Initiative – Regional Signal Control

System Engineering Process: Integration and Validation
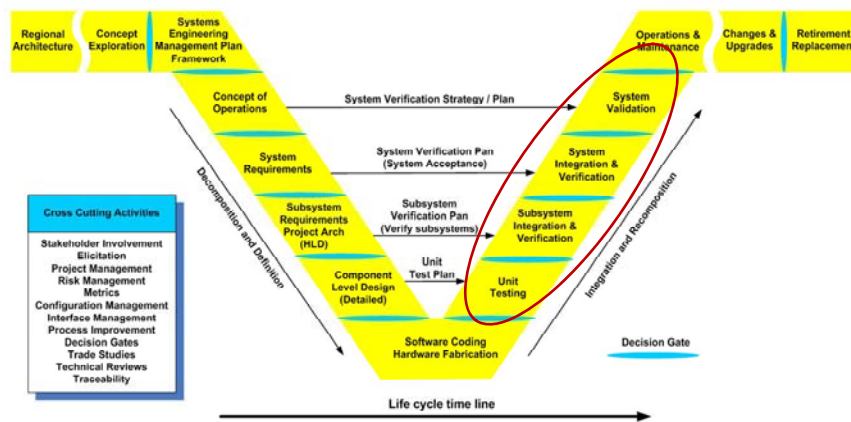
Validation vs. Verification

- Verification
  - Does the product meet its requirements?
  - Built the product correctly
- Validation
  - Does the product fulfill its intended use?
  - Built the right product

Types of Test Plans

- Component Testing
- Integration Testing
- System Testing

Example: Functional Test Plan

STEP	INPUT	SCRIPT	EXPECTED RESULT
1	None	Test winter travel links	
1.a		Select Chain Laws	Opens: Pages/RCMap.asp?curRegion=ChainLaws
1.b		Select Traction Tires	Opens: Pages/RCMap.asp?curRegion=TractionTires
1.c		Select Minimum Chain Requirements	Opens: Pages/RCMap.asp?curRegion=MinChainReqs
2	None	Test related links	Each link opens a browser window with an external URL

Example: CHART R3B2 Integration Test Plan/Procedures

3.1 Pending Traffic Events

3.1.1 Create Pending Incident Event

3.1.1.1 Purpose
The purpose of this test is to create a Pending Incident Event.

3.1.1.2 Set-up / Preconditions
A user should be logged in. User should have permissions to manage traffic events.

3.1.1.3 Requirements Tested
4.1.3.3, 4.2.1.7

3.1.1.4 Test Procedure

Date/Time of Test: _____

Tester(s): _____

Step #	Procedure	Expected Results	Pass / Fail/Comments
1	Log in, and click on the Traffic Events, open View Pending Events. Add New Pending Traffic Event	New Pending Traffic Event popup is displayed in the working window.	
2	Create a pending incident event with all data elements (incident info, participant, roadway conditions, lane, RPI)	New pending event shall be in the list of pending events	

Example: System Verification Testing Procedures

3.1.3 Verify MdTA Camera Function with SHA Monitor
A privileged individual will verify MdTA Camera Function with SHA Monitor

3.1.3.1 Environment
This test case is applicable to all Configurations. Refer to Section 2.0 of the Test Plan - Volume 1 for a description of the configurations.

3.1.3.2 Data
Refer to the Test Cases listed below for the applicable test data.

3.1.3.3 Test Procedure

Test Step #	Input Action	Expected Result	Requirement #
	Verify MdTA Camera Function with SHA Monitor		3.3 3.3.1 3.3.6
1	The operator selects camera FMT Cam1 (SVFT). If not in online mode, place on online.		
2	The operator selects "display"	The local monitor names are listed with empty check boxes	
3	The operator checks the box for "NODE1 MON1 (n1)".		
4	The operator pushes "OK"	FMT Cam1 (SVFT)is displayed on monitor NODE1 MON1.	
5	The operator selects the link for FMT Cam 1.		
6	The operator selects the link for "Request Control" on the left	The camera control window appears	
7	The operator hits the "up" arrow to move the camera up	The camera moves up, pointing to the ceiling	
8	The operator hits the "left" arrow to move the camera to the left	The camera moves to the left	
9	The operator selects the "close" button to end the camera control session	The camera control window goes away	

Example Test Form

Appendix A – Test Data Sheet Templates

System/Factory and Operational/Acceptance test Results for R3B2 will be recorded on Test Data Sheets as shown below.

TEST DATA SHEET

Software Version Number: R3B2   Date:

Configuration Number: 1   Test Area: Area to be Tested

Test Case 1 – Name of Test Case

Objective:

[Insert the objective of the Test Case]

Test Step #		S	SA	U	COMMENT	PR NUMBERS
1						
2						
3						
4						
5						
6						
7						
S						

(Legend: S = Successful; SA = Successful with Anomaly; U = Unsuccessful)

PASS _____ FAIL _____   _____ _____
                              (Signature)   (Date)

Systems and Systems Engineering

CONTRACTING

Deploying ITS Projects
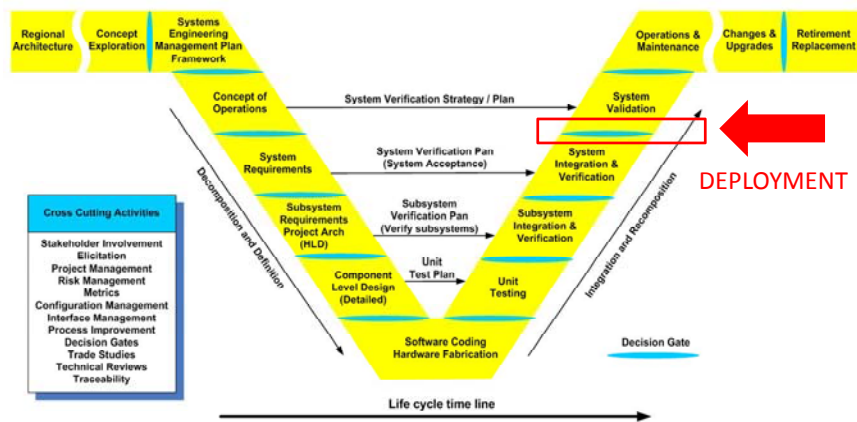
References/Sources of Information

- *Guide to Contracting ITS Services.* NCHRP Report 560.

ITS Acquisition Decision Model

- Step 1. Make Initial Decisions
- Step 2. Determine Work Distribution
- Step 3. Define Project Category
- Step 4. Determine Agency Capability Level
- Step 5. Select Applicable System Engineering Process and Candidate Procurement Package
- Step 6. Apply Differentiators
- Step 7. Assess Package and Make Final Selection
- Step 8. Define Contract Scope, Terms, and Conditions.
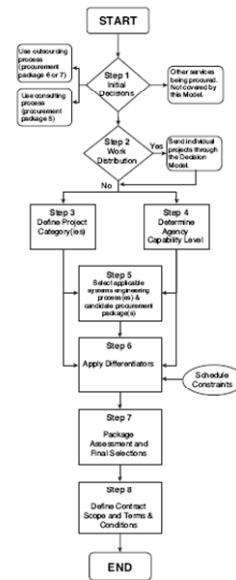
COTS versus Custom System Development

- COTS= Commercial "Off-the-Shelf"
- Advantages
  - "Bugs" and "Kinks" already worked out
  - Capitalize on lessons learned by others
  - Generally less expensive
  - Something tangible to "see and touch"
  - Most agency procurement processes designed to support
- Disadvantages
  - May not be "latest" and "greatest"
  - May not support specialized or all needed functionality
  - "Logged in" to a technology (creating a legacy system)
  - May still need integration contract

Outsourcing

- **Outsourcing** – process of contracting with either private or public sector vendors and service suppliers to obtain services that have traditionally been, or would otherwise be, performed by staff. Responsibility to public for the quality, reliability, and cost-effectiveness of the services still remains with the public agency
- **Commercialization** – a subset of outsourcing activities, in which the transfer of service provision is made from the public agency to a private for-profit organization whose activities are nevertheless still controlled and regulated by the public agency in an ongoing relationship
- **Privatization** – a public policy designed to transfer activities from the public to the private sector
- **Public-Private Partnerships** – expression used to describe certain forms of privatizing actions or relationships involving public agencies and private interests.

Source: NCHRP Synthesis 246

The Procurement Process

Procurement

Work Distribution	Method of Award	Contract Form	Contract Type
Low-Bid Contractor	Low Bid	Phased	Fixed Price
Systems Manager	Negotiated	Task Order	Cost Reimbursable
Systems Integrator	Sole Source	Purchase Order	Time and Materials
DB (OM)	Best Value		Incentives
Commodity (COTS)			
Consultant Services			
Services			

Terms and Conditions (payment, cancellations, disputes, etc.)

Source: NCHRP Report 560

Work Distribution

- Low-bid contractor
- Systems manager
- Systems integrator
- Design-build (operate and maintain) (DB[OM])
- Commodity
- Consultant Services
- Services

Methods of Award

- **Low Bid** – contracting method that employs competitive bids, public openings of bids, and contractor selection based on the lowest price offered.
- **Negotiated –** commonly used for projects oriented toward obtaining services or where design/contract requirements not well defined.   Uses a number of different procedures in making awards. Commonly used to select individuals or consultants as opposed to equipment. Evaluation of technical approach, qualifications, and experiences.
- **Sole-Source** – selection of a contractor without competition. Commonly used with matching legacy equipment or systems.
- **Best Value** – beginning to be used more frequently with ITS. Selection made based on weighted combination of evaluation criteria. Criteria may include technical approach, qualifications, experience, and price.   Frequently a combination of negotiated and low bid.

Contract Form

- **Phased contracts** – divide the work into sets of predefined activities (or phases) with specified deliverables
- **Task order (or indefinite delivery) contracts –** used with contracts in which required supplies and services are unknown ("umbrella" contracts)
- **Purchase orders** – form of a sole-source contract usually containing standard set of terms and conditions and a relatively brief description of work

Contract Types

- **Firm, fixed price**– Contract sets price of services/equipment. Contractor assumes full responsibility of the costs and any profit or loss at a fixed price
- **Cost reimbursable** – Contractor paid (reimbursed) for actual costs of performing the work. Contractor will charge a fixed fee that defines profit for project.
- **Time and materials** – Contractor paid for actual costs of performing the work and a percentage fee is added to all payments.
- I**ncentive/disincentive** – Contractor responsible for performance costs. Profit and/or fee incentive /penalties is dependent upon the uncertainties associated with the desired outcomes of the procurement. Incentives/penalties can be added to the three other contract types.

Handouts

- Procurement Packages
- Common Contact Terms and Conditions Definitions

Factors Affecting the Procurement Process

- An understanding of the project specifics
- An understanding of the risks associated with different procurement types and packages
- An awareness of federal, state, and local procurement regulations, policies, and guidelines
- Familiarity and experience with project management principles of high-technology projects

Federal Acquisition Regulations

- All Executive Branch agencies are required to follow Federal Acquisition Regulations
- The Federal Acquisition System will—
    1) Satisfy the customer in terms of cost, quality, and timeliness of the delivered product or service by, for example—
        i. Maximizing the use of commercial products and services;
        ii. Using contractors who have a track record of successful past performance or who demonstrate a current superior ability to perform; and
        iii. Promoting competition;
    2) Minimize administrative operating costs;
    3) Conduct business with integrity, fairness, and openness; and
    4) Fulfill public policy objectives.
- http://www.arnet.gov/far/

State and Local Procurement Practices and Policies

- General Procurement and Contracting requirements
  - Texas DOT: http://www.txdot.gov/business/
- Disadvantaged Business Enterprises (DBE)
  - created to provide a level playing field for small minority- and women-owned companies
- Historically Underutilized Businesses (HUB)
  - created to promote full and equal procurement opportunities for small minority- and women-owned businesses
- Small Business Enterprises
  - offers small businesses another avenue of maximizing their opportunities of doing business with TxDOT.
  - applies only to highway construction and maintenance projects that are funded entirely by state and/or local funds.

Elements of Contract

- Parties to the contract
- Scope of the contract
- Compensation and method of payment
- Extras
- Assignment of claims
- Agency-furnished property
- Order of precedence
- Commercial Warranty
- Patent rights
- Multi-year contracts contingent upon appropriations
- Termination of default
- Termination of convenience
- Execution and commencement of work
- Delays and extensions of time
- Modifications
- Multiple contract awards
- Liquidated damages
- Variations in estimated quantities
- Suspension of work
- Incorporation by reference
- Specifications
- Delivery and acceptance
- Intellectual property
- Contractor's invoices
- Conflicting terms

Systems and System Engineering

MANAGING ITS PROJECTS

Project Management Plan

- Generally required for projects using Federal funds
- Lays out activities, resources, budget and timeline – what is to be done, by whom, with what funds, and by when
- Standard project management tools
  - PERT Chart
  - Gantt Chart

Project Monitoring and Control

✓ Are the project's goals and objectives clear? Do they need to be further defined before project planning takes place?
✓ Are the task descriptions, as well as the identification of inputs and outputs prepared for the project activities?
✓ Are the task descriptions, as well as the estimates for cost and time [needed for the budget and the schedule], being prepared by people familiar with the underlying processes?
✓ Are the task descriptions, budget, and schedule accepted by the performing organizations?
✓ Do the financial tracking processes provide accurate and timely information on team expenditures?
✓ Are regular, periodic [usually weekly] meetings being held with each active task team?
✓ Do these meetings review progress on the activity by looking at the preparation of products [outputs], expenditures, and progress relative to the schedule?
✓ When an activity encounters a problem, are intervening actions done in a timely and effective manner?

Example: Project Tracking Performance Measures

Performance Measures		
Technical		Programmatic
Development Progress	System Performance	
# of requirements defined	Transit vehicle maintenance database usage	# of tasks performed
# of requirements predicted		# of planned tasks scheduled
	# disk space allocated	
# of SW modules completed		Cost as of today
total # of planned installations	# of times traffic signal equipment reports faults	Budget as of today
	Total # traffic signal equipment faults	
# of field sites installed		
Total # of planned installations	Failure rate of DMS equipment	
	Predicted failure rate	
# of acceptance tests passed		
Total # of acceptance tests		

Risk Management

- RM is identification and <u>control</u> of risks during ALL phases of the project life cycle.
- Goal of RM
  - Identify problems BEFORE they occur
  - Plan for their occurrence
  - Monitor system development so that early action can be taken
- Expression of Risk
  - "If <situation> then <consequence>."

Areas of Risk in ITS Project

- Technical
  - Technologies not widely deployed
  - Project team unfamiliar with technology
  - Requirements not well defined
  - Development and test facilities inadequate
  - Technical documentation not reviewed or adequate
- Institutional
  - Formal agreements between agencies (MOUs, IACs, etc.)
  - Regulations or agency hurdles
- Schedule
  - Too aggressive
  - Impacts of slippages on final deliverable
  - Schedule dependences (what is in critical path?)

Areas of Risk in ITS Project (cont.)

- Funding
  - Total or partial funding
  - Long-term operational and maintenance support
- Personnel
  - What happens if there is loss of key agency or contractor personnel?
  - Adequate experience
- Environmental
  - Effects of adverse weather on deployment schedule
  - Environmental restrictions (height, sight obstruction, colors, etc.)
- Commercial
  - Adequate time/vendors of equipment

Configuration Management

- "A management process for establishing and maintaining consistency of a product's performance, functional, and physical attributes with its requirements, design, and operational information throughout its life." (ANSI/EIA 649-1998)

Configuration Management Activities

- Configuration management planning – what needs to be controlled, how changes are controlled, how to track changes, and how to verify CM process is working
- Configuration identification – identifying the functional and physical characteristics of a configuration item
- Configuration change management – control changes to those characteristics
- Configuration status accounting – Keep track of status of changes (proposed, approved, or implemented)
- Configuration auditing – verifying the CM procedures are being followed

Configuration Management References

- TMC Pooled-Fund Study *Configuration Management for Transportation Management Systems*
  (http://ops.fhwa.dot.gov/freewaymgmt/publications/cm/handbook/index.htm)
- *A Guide to Configuration Management for Intelligent Transportation Systems*
  (http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13622.html)

Appendix C: Lecture Slides for Module 3. Traffic Sensing Technologies

Traffic Sensing Technologies

Module 3

References

- L. Klien, M. Mills, and D. Gibson. *Traffic Detector Handbook: Third Edition – Volume I.* Report No. FHWA-HRT-06-108. U.S. Department of Transportation, Federal Highway Administration, October 2006.

- *R. Gordon, and W. Tighe. Traffic Control Systems Handbook*. Report No. FHWA-HOP-06-006. U.S. Department of Transportation, Federal Highway Administration, October 2005.

Definition

- National Electronic Manufacturers Association's (NEMA) definition of a vehicle detection system: *" … a system for indicating the presence or passage of vehicle."*
- More types of sensors
  - Environmental sensing stations
  - Automatic vehicle identification system
  - Tracking systems
  - Positioning systems
  - Air quality
  - Passenger counting systems
  - Vehicle intrusion systems

Types of Detection Systems

- Intrusive
  - Embedded in the pavement
  - Embedded in subgrade
  - Temporarily /permanently affixed
- Non-Intrusive
  - Above the roadway itself
  - Along the roadway
- Vehicle-based

Inductive Loop Detector

- Still workhorse of transportation detection
- Senses presence of conductive metal object by inducing current in the object, which reduces loop inductance
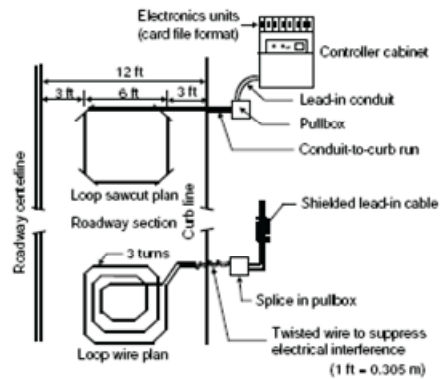
Example of Inductive Loop Detectors

TxDOT Loop Saw Cut Detail

LOOP SAW CUT CROSS-SECTION

* SAWCUTS IN BRIDGE DECKS ARE TYPICALLY 1" DEPTH MAXIMUM
SAWCUTS IN BRIDGE DECKS AND ACROSS EXPANSION JOINTS
SHALL BE AS APPROVED BY ENGINEER

Typical Loop Lead-In Configurations
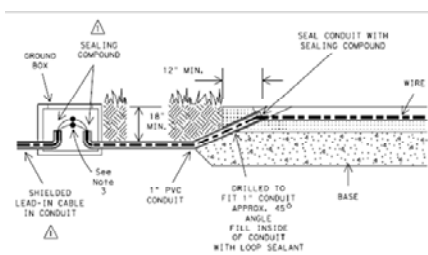
Without Curbing   **With Curbing**
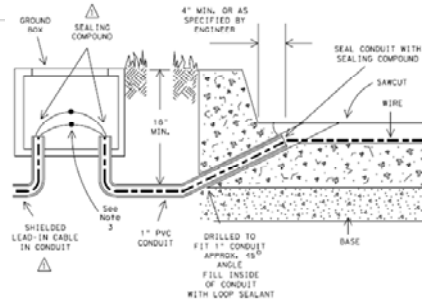
Magnetic Sensors

- Detect the presence of a ferrous metal object through perturbations (magnetic anomaly) they cause in Earth's magnetic field
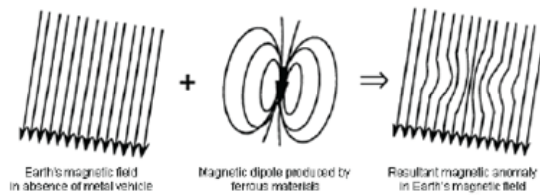
(a) Magnetic anomaly induced in the Earth's magnetic field by a magnetic dipole.
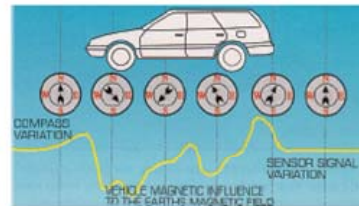
(b) Perturbation of Earth's magnetic field by a ferrous metal vehicle (Source: Nu-Metrics, Vanderbilt, PA).

Video Image Processor

- Also called….
- VIVDS (Video image vehicle detection system)
- VDS (Video Detection Systems)

Freeway Application of VIVDS
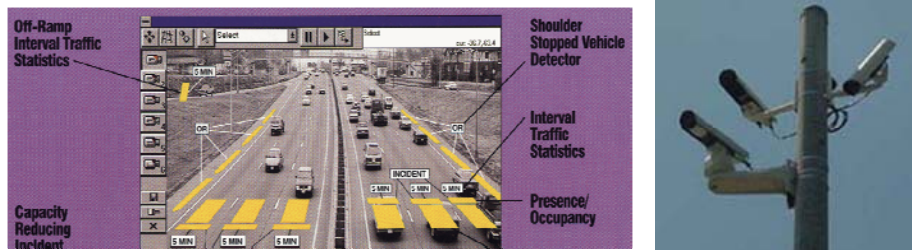
Intersection Application of VIVDS
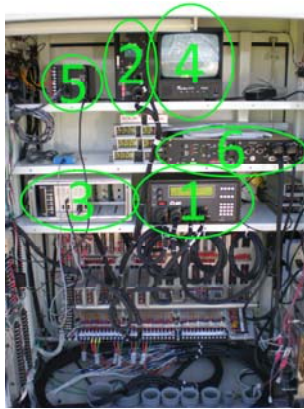
Microwave Radar Sensors
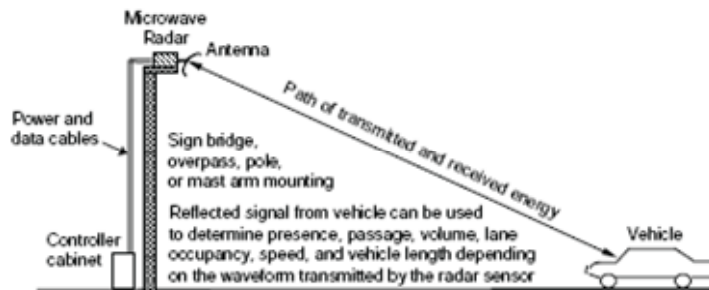
Infrared Sensors

- Active: Transmits infrared energy from detector and detects the waves that are reflected back.
- Passive: Doesn't transmit energy; detects energy from vehicles, roadway, and other objects, as well as energy from sun reflected by vehicles
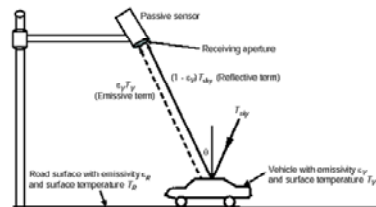
Acoustic

- Measure vehicle passage, presence, and speed by passively detecting acoustic energy or audible sounds produced by vehicular traffic.
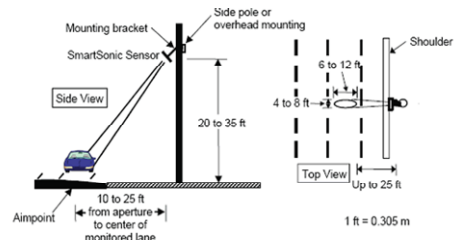
RFID / Electronic Toll Collection

- RFID = Radio-Frequency Identification

RFID Applications

License Plate Recognition
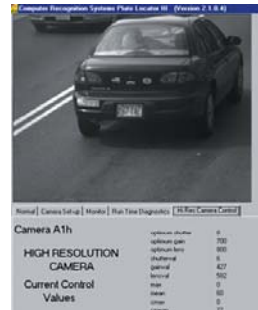
Overheight Detection Systems
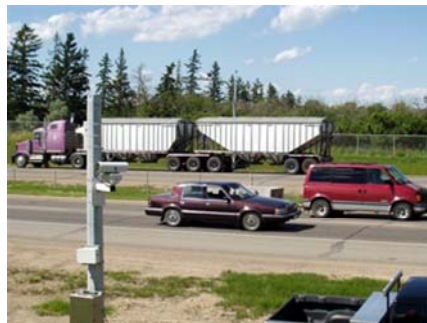
Weigh-In-Motion
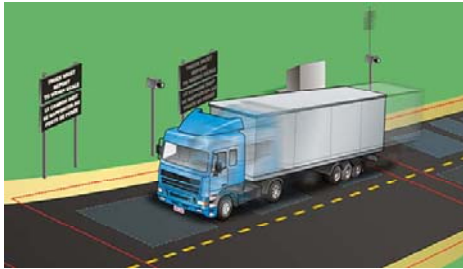
Road Weather Information

Automated Enforcement

Automated Speed Enforcement

Red-Light Running

Positioning Systems

Traffic Sensing Technologies

VIDEO SURVEILLANCE

Closed Circuit Television (CCTV)

- Use of video cameras to transmit a signal to a specific place on a limited set of monitors
- Differs from broadcast television in that signal NOT openly transmitted (although it can employ point-to-point wireless links)

Video Transmission
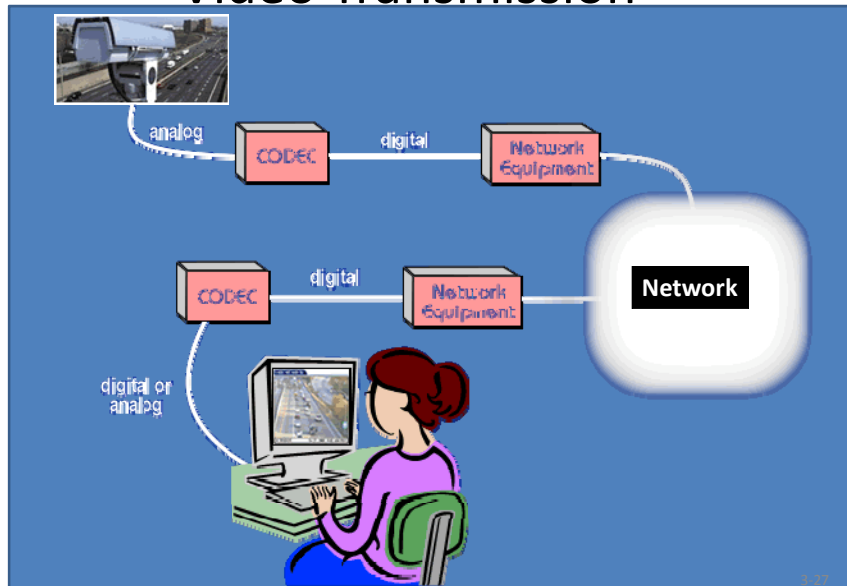
Uses of CCTV

- Monitoring traffic movements
  - Freeway mainlanes, HOV, entrance and exit ramps
  - Intersection operations
- Real-time command and control decisions support for operators
  - When to implement new control
  - Monitor effects of control change
  - Verify message display on DMS

Components of CCTV Systems

CAMERA

Pan-Tilt-Zoom Unit

Examples of Camera

Source: http://www.cohu-cameras.com

REV. 02/19/07
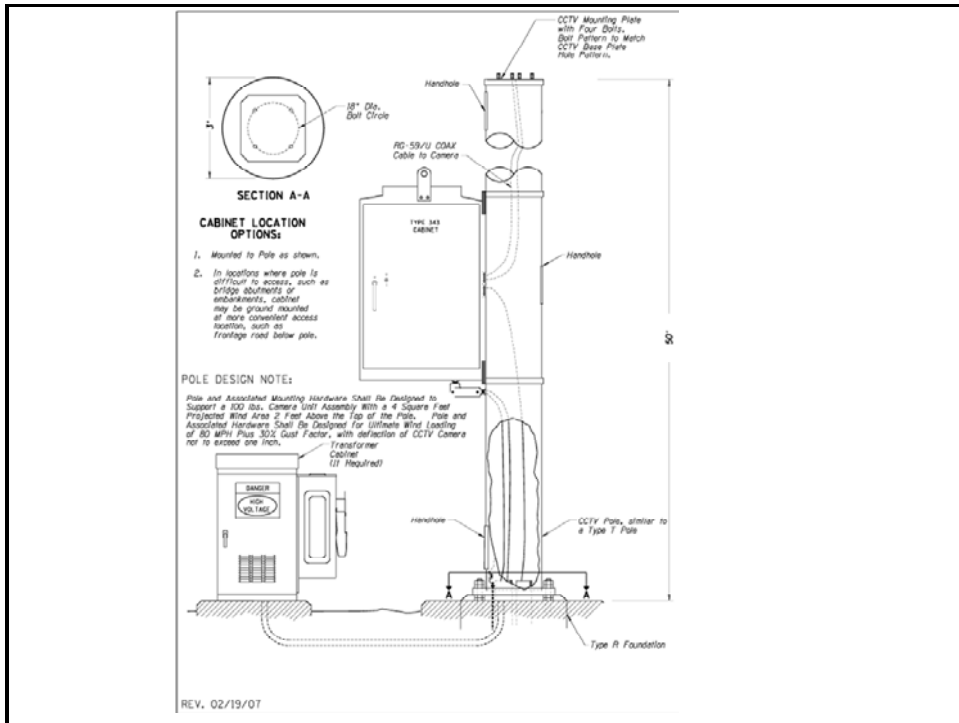
Video

- Color representation
  - Describes each piece of a picture as a color
- Video encoding
  - Reduces space requirements for each picture
- Video transmission
  - Moves the pictures

3-32

Color Representation

- Numerous color models exist
- Can you name some?
  - RGB (red-green-blue)
  - CMYK (cyan-magenta-yellow-black)
  - HSV (hue-saturation-brightness)
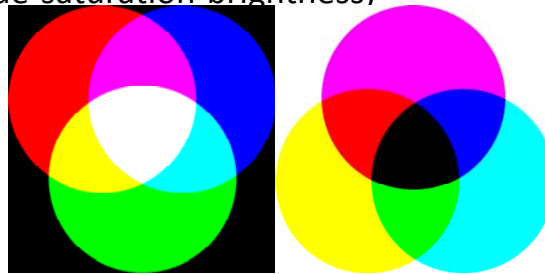
3-33

Video Encoding

- Typical video technologies are analog
- 3 formats:
  - Composite (NTSC)
  - S-video (brightness and color separated)
  - Component (RGB separated)

3-34

Video Encoding

- Digital transmission will require compression
  - Reduces bandwidth requirements
- Encoding is the process of conversion from analog to digital

3-35

Video Encoding Methods

- Motion JPEG (Joint Photographic Experts Group)
- MPEG-1 (Moving Pictures Experts Group)
- MPEG-2
- MPEG-4

3-36

Motion JPEG

- Still images compressed using JPEG compression
- Removes color change information
- Encodes individual video frames into JPEG frames and sends as a video stream
- Least amount of complexity (costs less)
- Doesn't compress as well and requires most bandwidth

3-37

MPEG-1

- Eliminates redundant picture information that exists between adjacent frames
- Well established as a standard (more products can decode and use an MPEG-1 stream than any other standard)
- Not a large variety of options
- Does not easily encode higher quality video streams such as HDTV

3-38

MPEG-2

- Corrects functional limitations of MPEG-1
- Scalable and better picture quality
- Supports interlaced video encoding by design
- Used in many applications including DVDs, HDTV, satellite TV, and DVRs
- Requires more CPU horsepower to decompress

MPEG-4

- Developed to deliver quality video streams over a variety of devices
- Designed to handle low-bandwidth video
- Fewer products that support MPEG-4 than MPEG-2 or MPEG-1
- Encoders and decoders are more expensive because of their newness
- Decompression is slower (possible latency)

Codecs

- Equipment that <u>CO</u>mpresses and <u>DEC</u>ompresses video signals
- Beware of interoperability

Video Communication

- Frame rate
  - How many times picture refreshes in given time
  - Expressed in frames per second
- Resolution
  - Size of picture
  - Measured in pixels
- Color depth
  - Information about each pixel
  - Expressed in bits or bytes

Video Communication

Resolution
1 frame @ 720 x 576 resolution = 414,720 pixels per frame

Color Depth
414,720 ppf x 3 bytes per pixel = 1,244,160 bytes per frame

Frame Rate
1,244,160 bytes per frame x 30 fps = 37,324,800 bytes per second

Bandwidth
37,324,800 Bytes per second = 298,589,400 bps = 298.6 Mbps

5-43

Design/Placement Guidelines

- Viewing distance = ¼ to ½ mile each direction
- Factor affecting camera views
  - Mounting height
  - Terrain
  - Number of horizontal and vertical curves
  - Overpasses and sign supports
  - Environmental
    - Weather
    - Sun angle
  - Camera Stability

Video Transmission

- Transmission Control Protocol/Internet Protocol (TCP/IP) is most common method of transmitting digital video
- Two mechanisms:
  - Unicasting
  - Multicasting

3-45

Unicasting
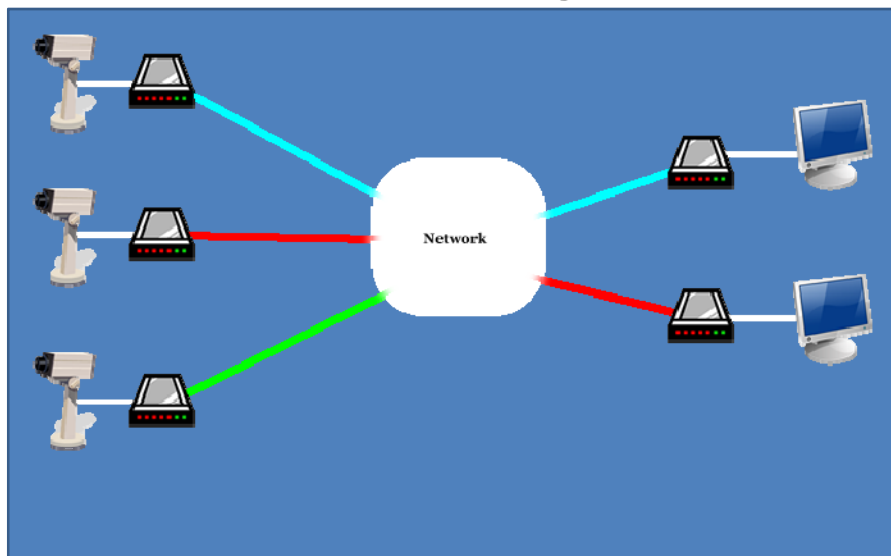
Unicasting
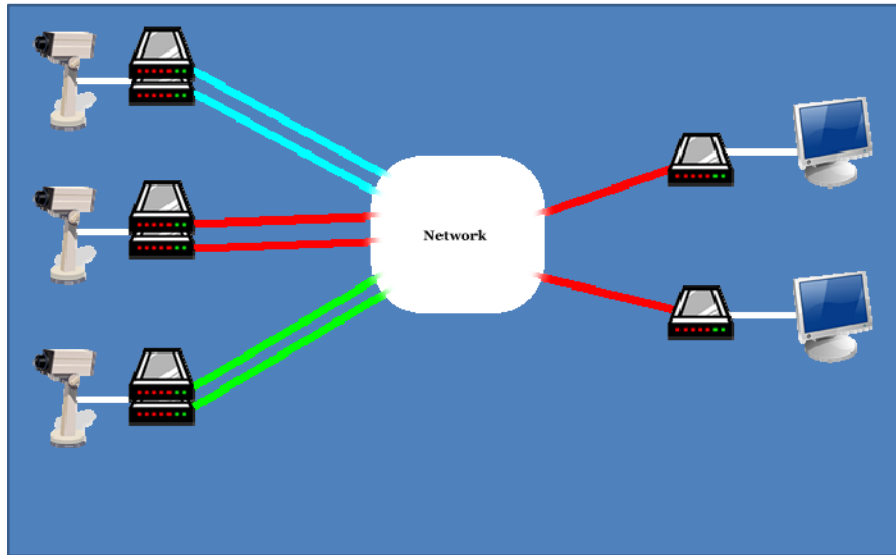
Multicasting
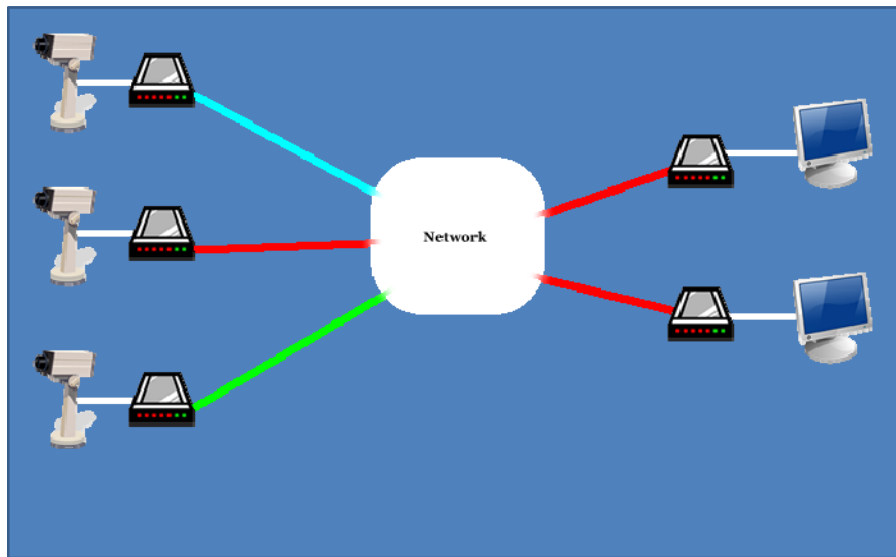
Appendix D: Lecture Slides for Module 4. Communications Systems for ITS Applications

Communications Systems for ITS Applications

Module 4

References

- S. Leader. *Telecommunications Handbook for Transportation Professional: The Basics of Telecommunications.* FHWA-HOP-04-034. Federal Highway Administration, August 2004.

- R. Brydia, B. Brackin, J. Johnson, G. Thomas, and K. Balke. *Wireline Communications: A Design Guidebook for Intelligent Transportation Systems. Training Course.* Product Number 5-4969-01-P1. Texas Transportation Institute, October 2007.

- R. Gordon, R. Reiss, W. Dunn, and D. Morehead. *Communications Handbook for Traffic Control Systems.* FHWA-SA-93-052. Federal Highway Administration, April 1993.

BASIC TERMINOLOGY

Communications Systems for ITS Applications

BASIC TERMINOLOGY

Fundamental Elements of Communications System
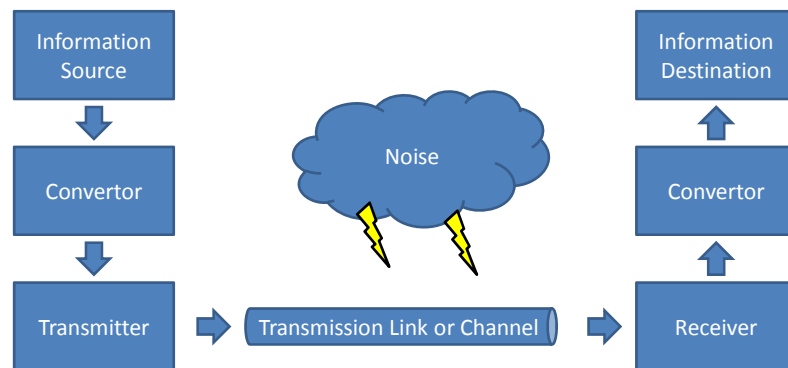
Transmission Media = form factor for pathway

Analog Transmission

Amplitude Modulates
Frequency is Constant

Frequency Modulates
Amplitude is Constant

Analog Signals
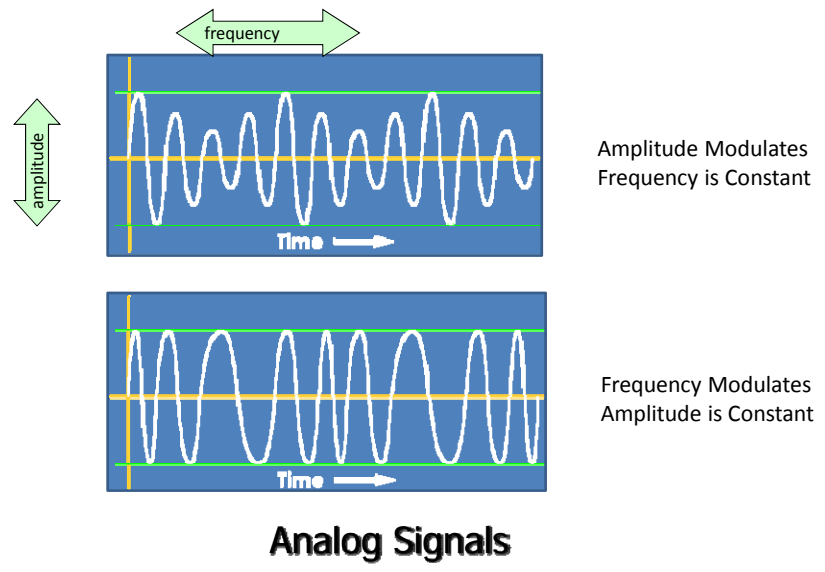
2-5

Digital Transmission

Digital Signal
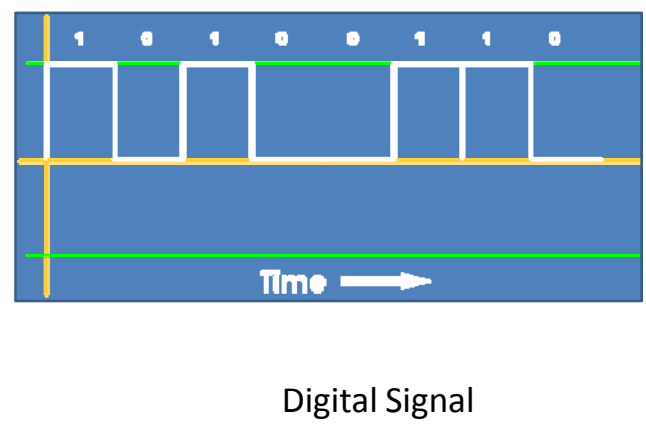
2-6

Bits and Bytes

- A bit is the smallest unit of information
  - Either a "1" (on) or a "0" (off)
- A byte is made up of 8 bits
  - Represents a single character

2-7

Parallel versus Serial Transmission

Parallel Transmission

Serial Transmission

Transmitter

0 1 0 1 0 0 1 0   8 bits sent together

Need 8 connectors

Receiver

Transmitter

01010010   8 bits sent one after another

Need only 1 connector

Receiver
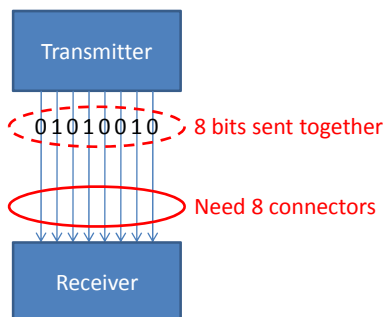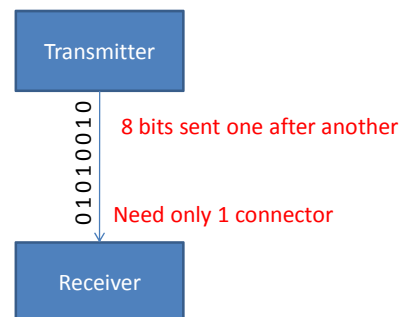
Transmission Mode Characteristics

Mode	Data Flow Detection	Characteristics	Comments
Simplex	Data flow in one direction only	•Does not provide verification that data were received and acted upon •Does not provide answer-back, status reporting or validity	•Commercial radio and television are examples •Traffic control systems provide no return information to a master controller or traffic operations center use this mode
Half Duplex	Data flow in either direction, but only in one direction at a time	•Requires modem at each end of the line •Requires control capability to assume proper operation •Uses latency time or turnaround time (the time period required to turn the line around) for the process in which the direction of data transmission is reversed, which can be time consuming	•In a copper wire transmission media, HDX required two wires but may be used with four wires (four wires provide improved interference characteristics)
Full Duplex	Data flow possible in both directions at the same time	•Acts like two simplex channels in opposite directions •Permits independent, two-way, simultaneous data transmission •May raise cost of channel •Reduces the one-way capacity if frequency multiplexing is used on a single channel.	•In copper wire transmission system, some FDX modems require four wires while others require only two wires. In the later case the modem divides the channel into two subchannels to achieve simultaneous bidirectional service

Signal Attenuation
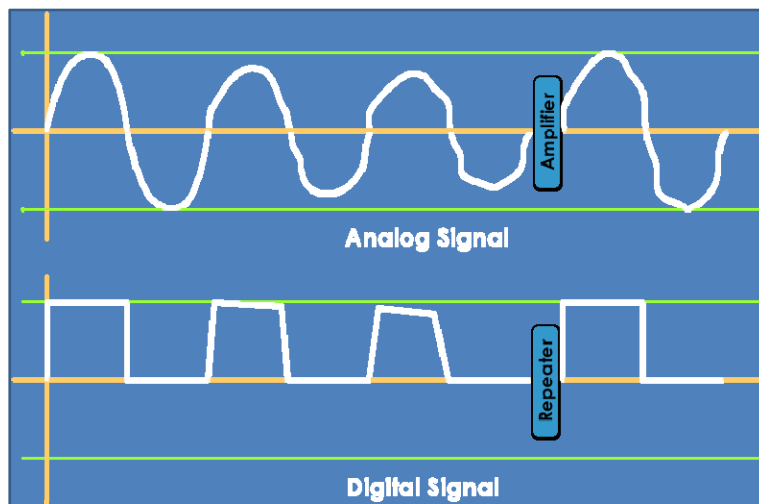
Multiplexing

- Process of combining two or more information channels into a single transmission media

Modem Versus Codec

| Data Transmission Equipment (DTE) | Transmission Medium | Data Communication Equipment | Transmission Medium | Network |

Traffic Signal Controller — RS 232 Cable — **MODULATOR/DEMODULATOR (MODEM)** — Fiber — Network

CCTV — RG-59 Coaxial — **CODER/DECODER (CODEC)** — Fiber — Network
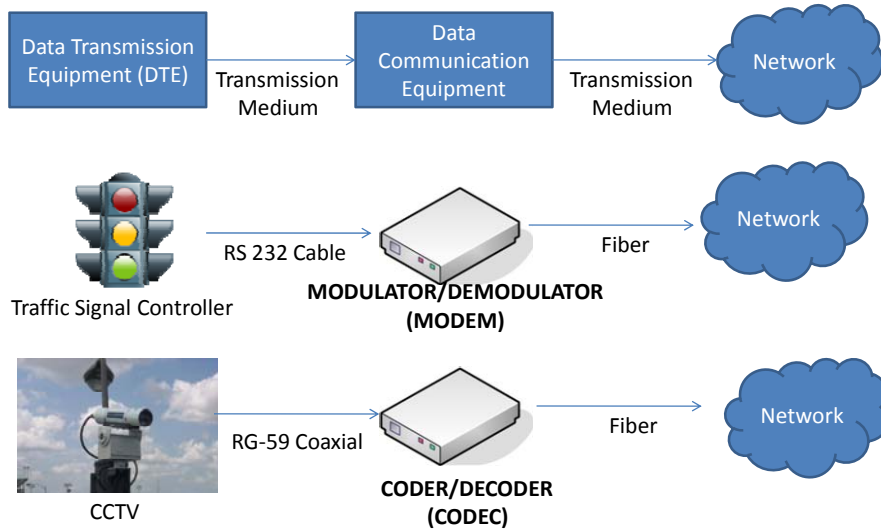
Bandwidth

- How much data can be transmitted in a given amount of time

Serial / Phone

Cable

SONET
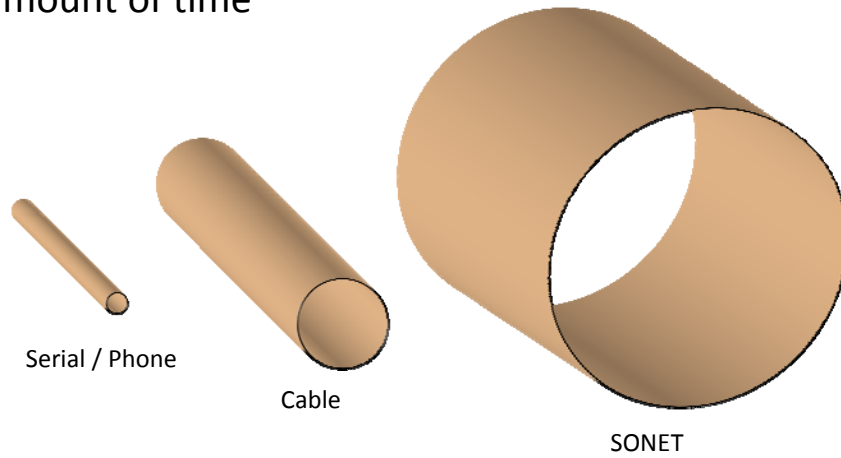
Communications Systems for ITS Applications

TRANSMISSION MEDIA

Transmission Media

- Pathway over which information flows
- Factors to consider
  - Data needs
  - Costs
  - Ease of installation and maintenance
  - Efficiency of transmission
- Pick right transmission media for job!

Media – Twisted Pair

- Literally – pairs of wires twisted together
- Why do they twist?
  - Cancels out electrical "noise"
- Examples
  - Phone line, computer cables
- Six categories
  - "Cat" 1 = voice only (phone wire)
  - "Cat" 6 = high-speed data

Media – Coaxial

- Layered media
  - Copper wire (innermost)
  - Plastic insulation
  - Metal shield
  - Rubber sheath (outermost)
- Various types
  - RG-6, RG-11, RG-59
  - Impedance, loss, outer conductor
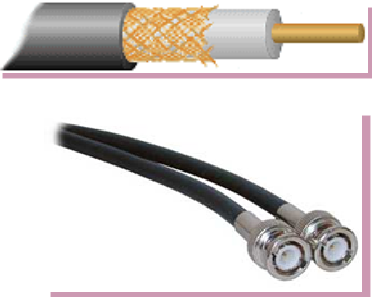
Media – Coaxial

- Various connector types
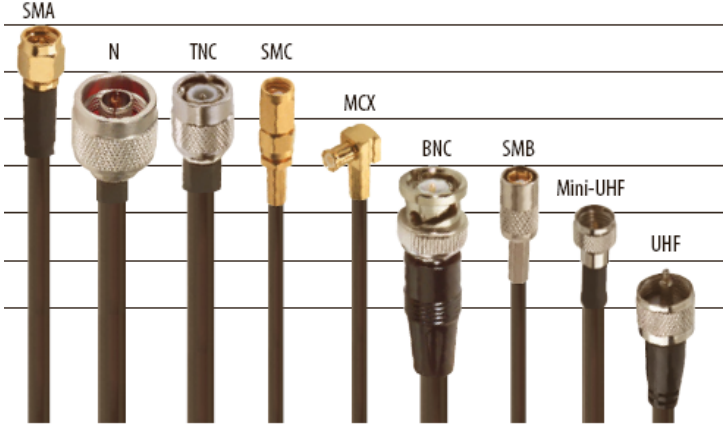
Media – Fiber

- Layered media
  - Jacket (outermost)
  - Strength member
  - Buffer
  - Cladding
  - Glass core (innermost)
- Resistant to light and moisture
- Data can move faster and farther
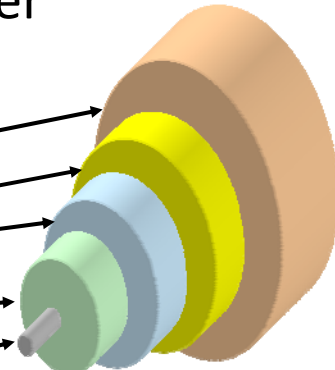
Media – Fiber

- Example cable assemblies
  - Duplex Zipcord
  - Breakout cable
  - Messenger cable
  - Hybrid cable
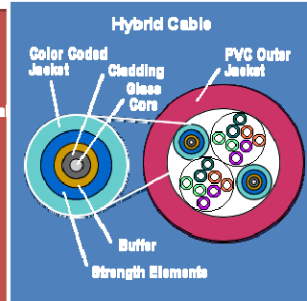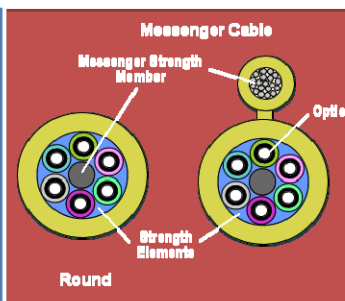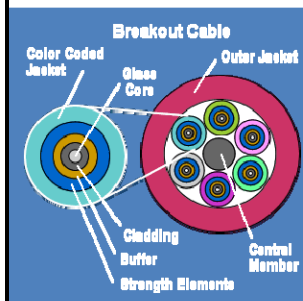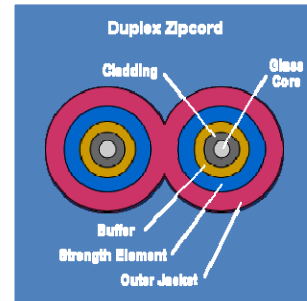
Media – Fiber

- Single mode
  - One stream of light
  - Longer distances
- Multimode
  - Multiple streams of light (different frequencies)
- Special connectors

Comparison of Single and Multimode Fiber

Characteristic	Single Mode	Multimode
Bandwidth	Virtually unlimited	Less than virtually unlimited
Signal Quality	Excellent over long distances	Excellent over short distances
Primary Attenuation	Chromatic Dispersion	Modal Dispersion
Fiber Types	Step Index & Dispersion Shifted	Step & Grade Index
Typical Application	Almost anything (including Ethernet)	Analog Video, Ethernet, Short range communications

Source: *Telecommunications Handbook for Transportation Professionals*

Wireless Communications Needs

- Vehicle-to-Vehicle
- Roadside-to-Vehicle Broadcast
- Mobile wide area
- Fixed wide area
- Short-range

Wireless Technology Options

- Radio frequency communications
  - Spread Spectrum Radio
    - Spreads transmission over group of radio frequencies
      - Direct Sequence
      - "Frequency Hopping"
    - Frequencies: 900 MHz, 2400 MHz and 5800 MHz
- Microwave communications
  - Fixed point-to-point between major communication nodes
  - Frequencies
    - FCC license: 6 and 11 GH
    - Unlicensed: 900 Mhz, 2 and 23 GHz
  - Operate over distances of 20 miles
- Infrared communications

ITS Shared Wireless Systems

System	Spectrum Description	Deployment Situation
DGPS Broadcasting	200-500 kHz	Nationwide deployment
Highway Advisory Radio (HAR)	Licensed system with limited power; Sharing spectrum with AM & FM broadcasts	AM analog HAR widely used; digital HAR and FM HAR started to be deployed
Safety Warning System	24 GHz (shared with police radar detector)	Operational test completed; started to be deployed
Low speed AM & FM subcarriers	Sharing with AM & FM broadcasting	Several commercial vendors started to provide traffic information services
High speed FM subcarriers	Sharing with FM broadcasting	Several commercial vendors started to provide traffic information services; in process of standardizing

Source: Yan, et. al. *TRR 1788*

Existing IS-Related Commercial Wireless Systems

System	Spectrum Description	Deployment Situation
Paging system	150 MHz, 450 MHz, 900 MHz	43.5 million one-way and 150,000 two-way pager users (1998)
Cellular system	800 MHz, 1900 MHz	70% US land mass
Cellular Digital Package Data (CDPD)	Cellular frequency band	> Half of geographic US
E-911 system	Cellular frequency band	
Radio data networks	800 MHz	90% of US business population
ESMR system	800 MHz (e.g., Nextel)	
Satellite communications	GEO System (e.g., OmniTRACS) Little LEO , Big LEO	Several systems have been used in CVO fleet management

Source: Yan, et. al. *TRR 1788*

ITS Dedicated Wireless Systems

System	Spectrum Description	Deployment Situation
Highway maintenance radio	33-37 MHz; 45-47 MHz; 150-159 MHz	Analog voice/data communications for maintenance personnel and traffic controllers
220 MHz	5 narrow-band frequencies assessed by NTIA	Operational field test for advisory information services
Transit wireless communication systems	150 MHz, 400MHz, 800 MHZ, and 900 MHz	From single simplex analog system to sophisticated digital trunked systems; supports AVL and CAD functions
Public safety wireless communications	138-144 MHz; 148-174 MHz; 406-420 MHz; 764-776 MHz; 794-806 MHz; 806-824 MHz; 851-869 MHz	From single simplex analog system to sophisticated digital trunked systems; supports AVL and CAD functions; Some state-wide multi-agency systems
Spread spectrum radio	902-928 MHz (unlicensed) 2.4 GHz (unlicensed)	Remote traffic control data communications
Dedicated short range communications (DSRC)	902-928 MHz LMS band (unlicensed); 2.4 GHz (unlicensed); 5.859-5.925 GHz (pending FCC approval)	Widely used in ETC and AVI system; IntelliDrive
Analog/Digital microwave	11, 23,31 GHz	Alternative for long-haul wireline transmission

Source: Yan, et. al. *TRR 1788*

Communications Systems for ITS Applications

PROTOCOLS

Terminology Review

- Media
  - A physical cable
  - Wireline or Wireless
- Protocol
  - A set of rules for transmitting data
  - Examples: DSL, Ethernet, TCP/IP
- Topology
  - A physical or logical arrangement of devices
  - Examples: Point-to-point, ring, star

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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's going, order
  - Sends it down the line
- At the other end:
  - Reads the stuff
  - Assembles back into usable information

5 Traits of Protocols

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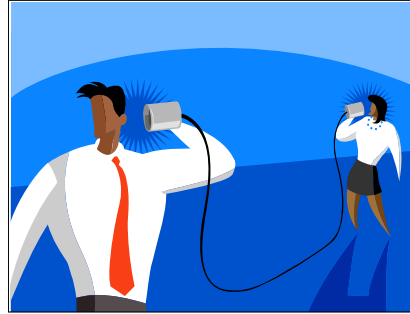
Protocol Stacking

OSI 7-Layer Model

Host Layers

Media Layers

Application · Presentation · Session · Transport · Network · Data Link

Application · Presentation · Session · Transport · Network

Physical Data Transmission
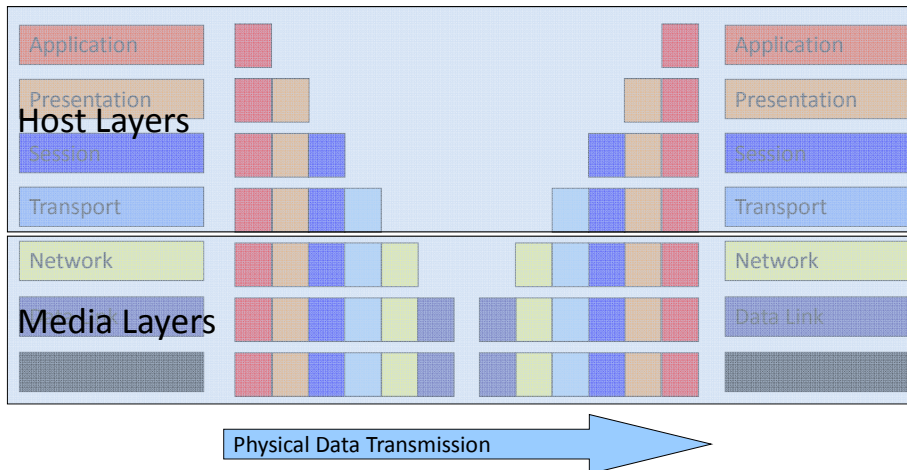
Open System Interconnection (OSI) Reference Model Analogy

Application		Dictates/hand writes the letter
Presentation	Manager	Corrects errors / prepares final version
Session	Assistant	Provides addresses / packages letter
Transport	Secretary	Drives letter to post office
Network	Driver	
Data Link	Intake and sorting	Sorts letter into proper bin
Physical	Packaging	Packages letters for distribution
	Loading	Loads truck
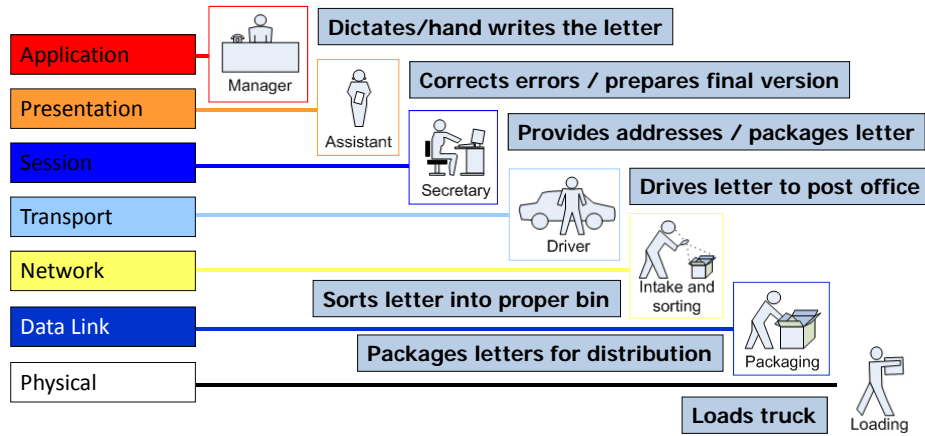
Adapted from: www.wikipedia.org
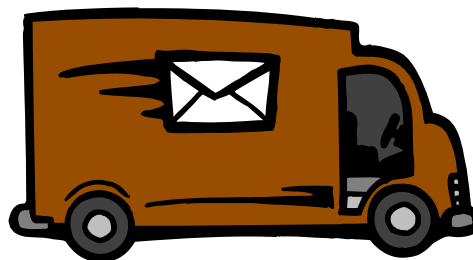
OSI Analogy (cont.)

Physical Data Transmission →

Adapted from: www.wikipedia.org

OSI Analogy (cont.)

Label	Role		OSI Layer
Reads message	Manager		Application
Sorts and prioritizes message	Assistant		Presentation
Opens letter and makes copy	Secretary		Session
Gets letter from PO box	Driver		Transport
	Sorting and distribution	Sorts letters into PO boxes	Network
	Unpacking	Unpacks packages from various directions	Data Link
Unloading	Unloads truck		Physical

Adapted from: www.wikipedia.org

Common ITS Protocols

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

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)

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 acknowledgements and resends to ensure proper delivery

IP – Internet Protocol

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

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 go to zero
- The TTL value of a packet is decreased each time it crosses a router (aka a "hop")
- When TTL = 0, the packet is discarded

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

Network ID	Host ID
165.32.	211.12
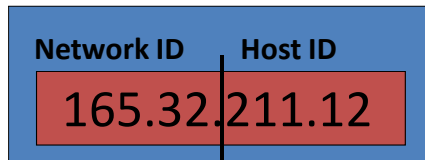
3.3.6

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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IP Addressing

- Every device has a unique address
- Addresses 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

Addressing on Different Classes

- Class A

Network ID	Host ID
124	32.211.12

- Class B

Network ID	Host ID
132.32.	211.12

- Class C

Network ID	Host ID
226.32.211.	12
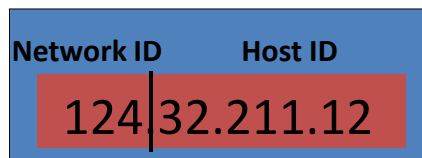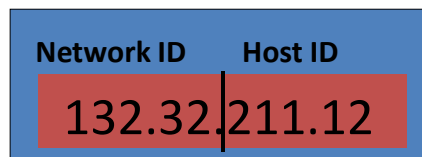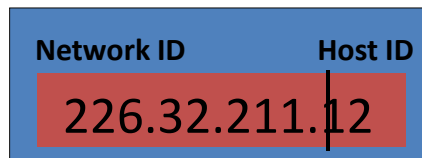
Restricted Address Space

- 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

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 diverge points on the network)

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

3.3.6

Private Address Space

- Doesn't communicate 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

Private Address Space | Public Address Space

To Internet

Unique Public IP Address
(can be static or dynamic)

Unique IP Address on network
(can be static or dynamic)
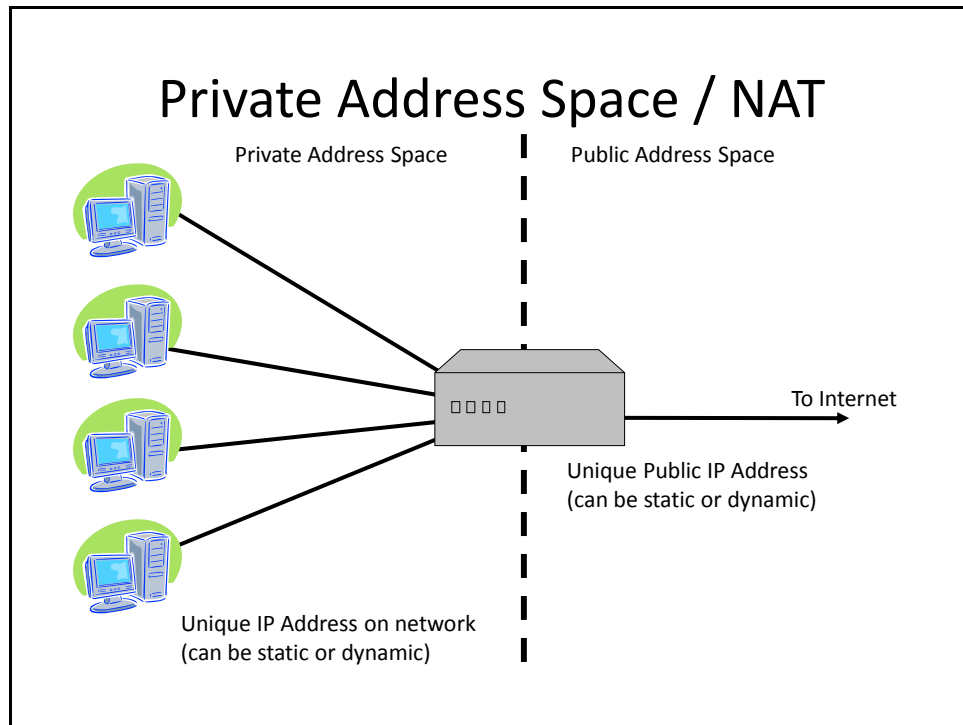
Other Protocols

- Hypertext transfer protocol (HTTP)
- File transfer protocol (FTP)
- Simple object access protocol (SOAP)
- Simple network management protocol (SNMP)
- Network time protocol (NTP)
- Simple mail transfer protocol (SMTP)

What About XML?

- Question: Is XML a protocol?
  - Technically, the answer is no
- What is it then?
  - It is a markup language
  - Emerging approach for transportation applications
  - Widely used by various industries
  - Mechanism for encoding data for exchange
  - All messages are described within tags

HTML vs. XML

	HTML	XML
Tags do what:	Describe how the data will be formatted	Describe what the data are
Examples:	\<b\>This is a bold tag\</b\> \<i\>This is an italics tag\</i\>	\<price\>$2.50\</price\> \<avail\>yes\</avail\>
End result:	**This is a bold tag** *This is an italics tag*	The price of the item is $2.50 The item is available

OSI 7-Layer Model and NTCIP
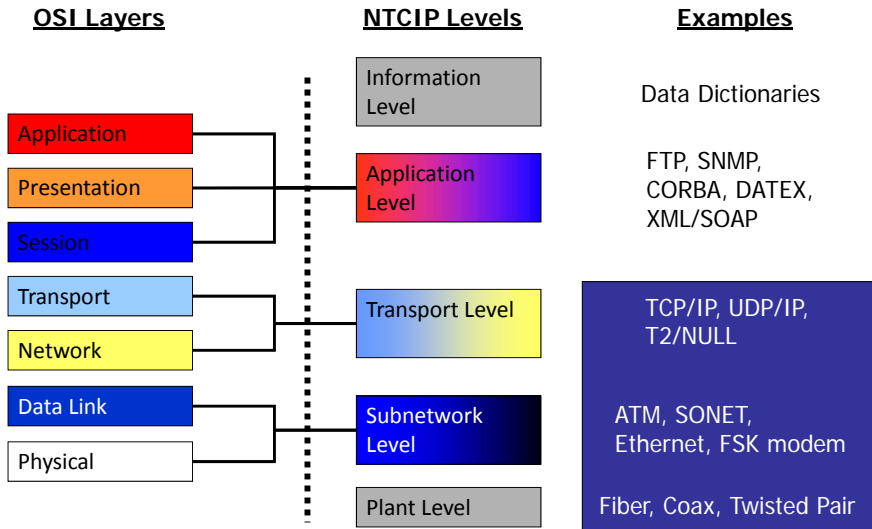
NTCIP Protocols
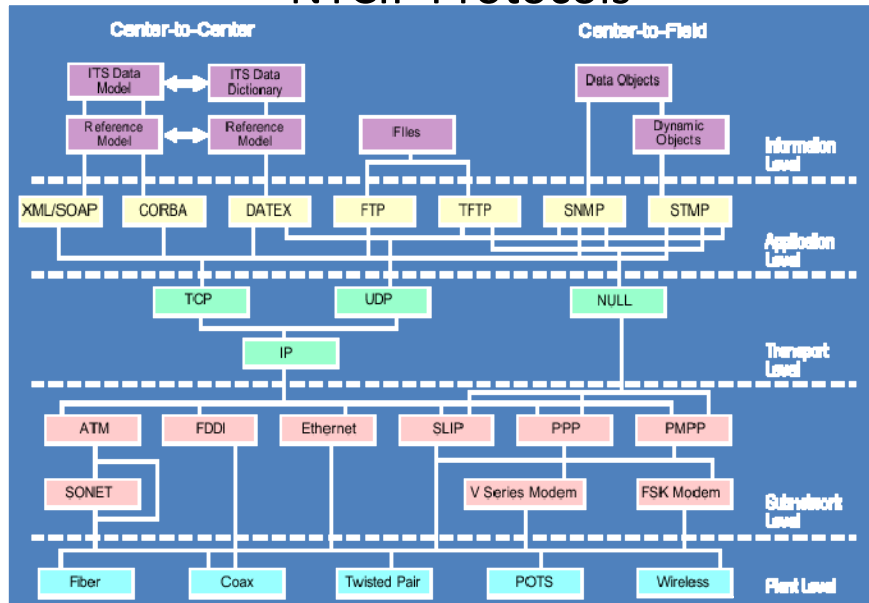
Technology Choices

- Serial
- Plain Old Telephone Service (POTS)
- Integrated Services Digital Network (ISDN)
- Digital Subscriber Line (DSL)
- Cable Modem
- T-1/T-3 Services
- Asynchronous Transfer Mode (ATM)
- Synchronous Optical Network (SONET)
- Ethernet

Serial

- Low (no?) cost
- Shorter distances
- "Simple" technology
- Prone to interference
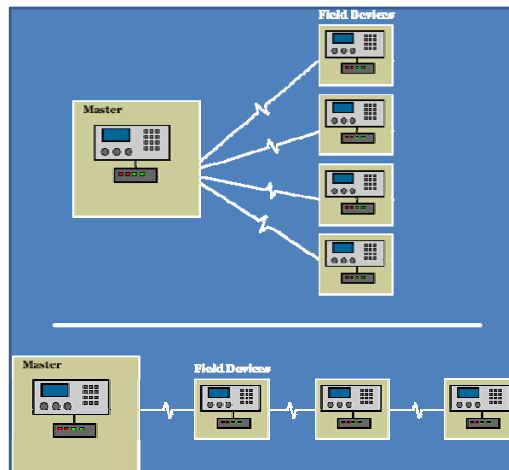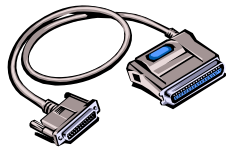
POTS

- Technology has changed, basic principles have not
- Good for low data transmission rates (rates are regulated)
- Good for long distances

Supported Protocols	
☑	TCP
☑	IP
	ATM
	Frame Relay
	SONET
	Ethernet
☑	PPP
	DSL

POTS
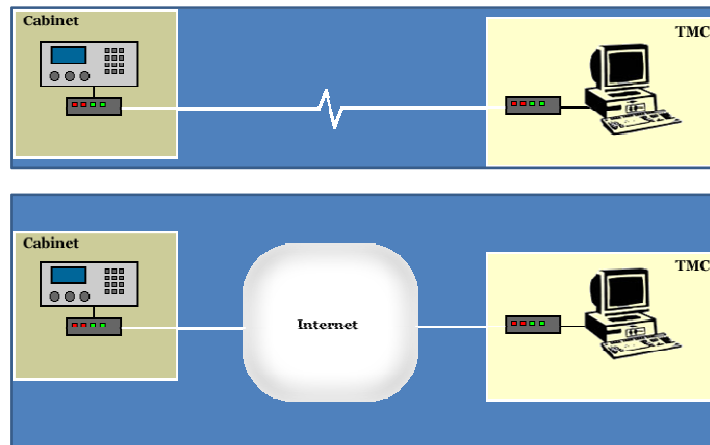
ISDN

- Runs on standard phone lines
- "Integrated" voice and data
- All digital (higher bandwidth)
- Distance limited (not available everywhere)

Supported Protocols	
☑	TCP
☑	IP
	ATM
	Frame Relay
	SONET
	Ethernet
	PPP
	DSL

ISDN
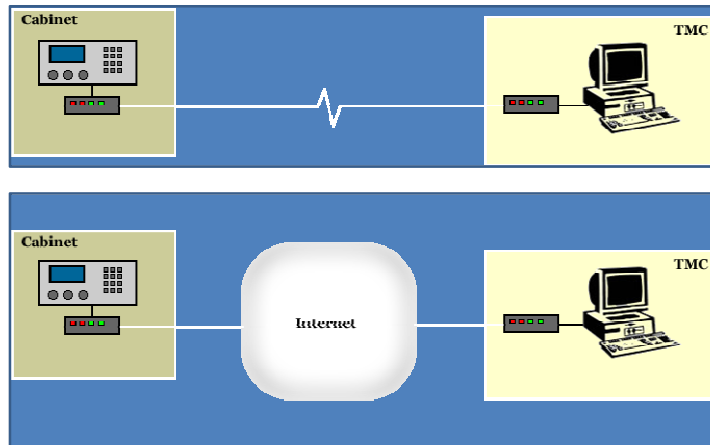
DSL

- Outgrowth of ISDN – data only, faster
- Numerous types of DSL services
  - Not all are available everywhere
- Not as secure as others
- Distance limited
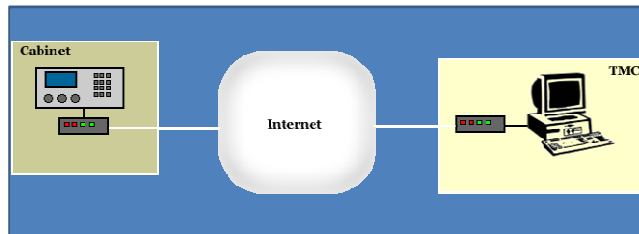
Supported Protocols	
☑	TCP
☑	IP
☑	ATM
	Frame Relay
	SONET
	Ethernet
	PPP
☑	DSL

Cable Modem

- Media originally designed for TV services
- Data services developed later
- Higher transmission speeds
- Not distance limited
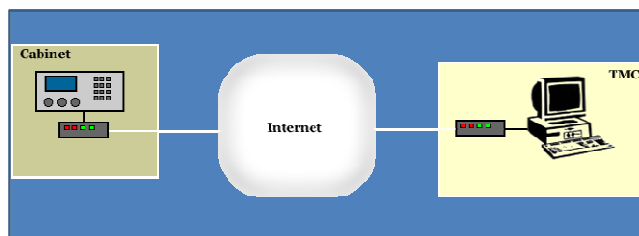
Supported Protocols	
☑	TCP
☑	IP
	ATM
	Frame Relay
	SONET
	Ethernet
	PPP
	DSL

T-1/T-3 Services

- First implemented in 1960s
- Building block of dedicated voice and data services in North America
- Not distance limited
- More expensive
  - Pay for the line whether you use it or not (leased service)

Supported Protocols	
☑	TCP
☑	IP
	ATM
☑	Frame Relay
	SONET
	Ethernet
	PPP
	DSL

T-1/T-3 Services
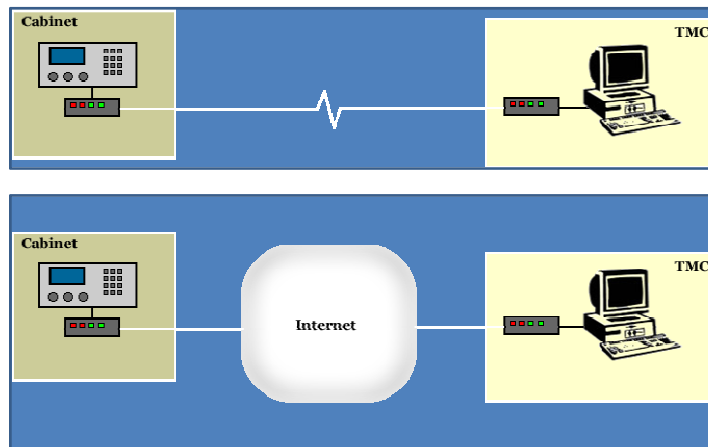
ATM

- High bandwidth, low delay
- Packet switching technology
- Provided over copper or fiber optic cabling
- More expensive
- Higher learning curve

Supported Protocols	
☑	TCP
☑	IP
☑	ATM
	Frame Relay
☑	SONET
☑	Ethernet
	PPP
	DSL

ATM

Copper or Fiber

TMC
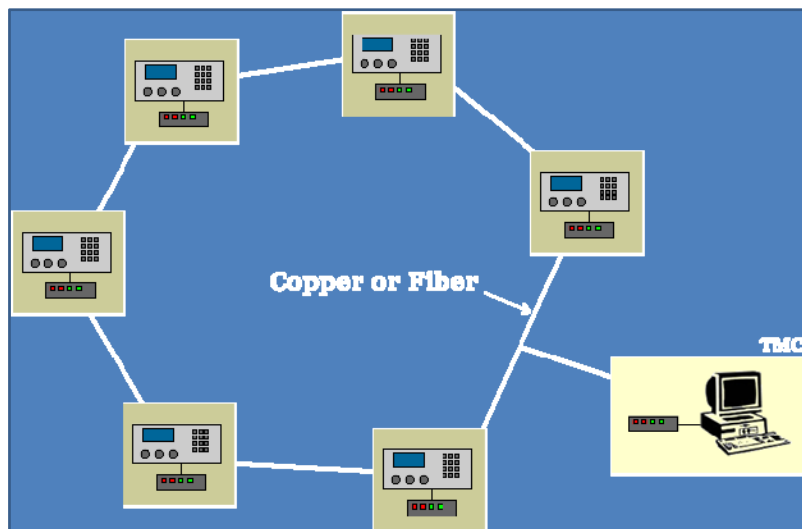
SONET

- Replacement for copper-based transmissions
- Single fiber cable replaced hundreds of copper wires
- Very high speeds
- Most expensive

Supported Protocols	
☑	TCP
☑	IP
☑	ATM
	Frame Relay
☑	SONET
☑	Ethernet
	PPP
	DSL

SONET
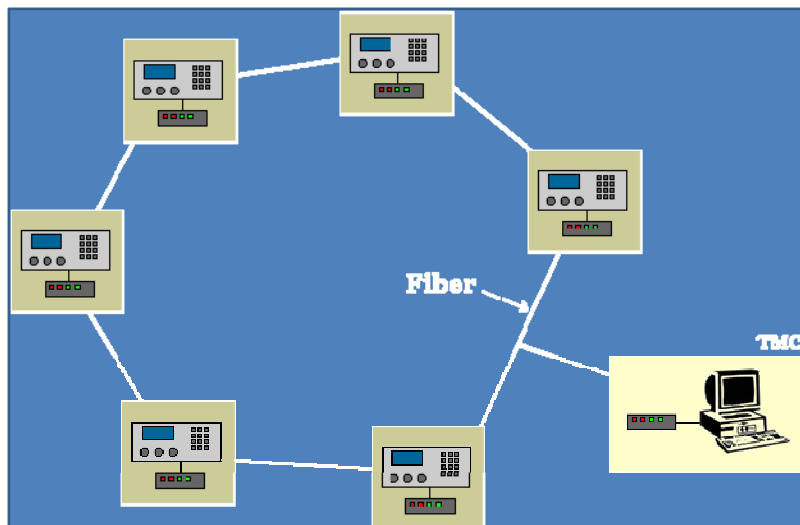
Ethernet

- Developed for local computer networks
- IEEE "802" committee assigned task to develop international standard
- Rapidly evolving
- Supports all wiring types

Supported Protocols	
☑	TCP
☑	IP
☑	ATM
	Frame Relay
	SONET
☑	Ethernet
☑	PPP
	DSL

Ethernet

- Initially a shared communications backbone
- Data collisions were resolved by CSMA/CD algorithms
- Collision domain
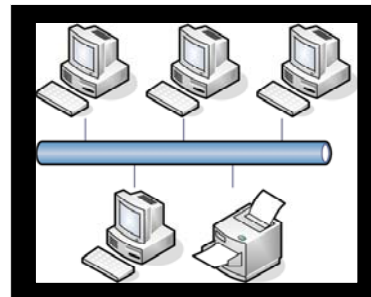
Ethernet

- Full duplex switched Ethernet
- Devices do not "share" wires

Ethernet

Copper or Fiber

TMC

Bandwidth

Cable

Serial / Phone

SONET/ATM/GigE

Ethernet/Fast Ethernet

ISDN

Bandwidth

Cable

Ethernet

POTS

Fast Ethernet

Gigabit Ethernet

10 Gigabit Ethernet

DSL

Serial

ISDN

T-1/T-3

SONET

ATM

| 1Kbps | 10Kbps | 100Kbps | 1Mbps | 10Mbps | 100Mbps | 1Gbps | 10Gbps | 100Gbps |

Typical (Usable) Bandwidths
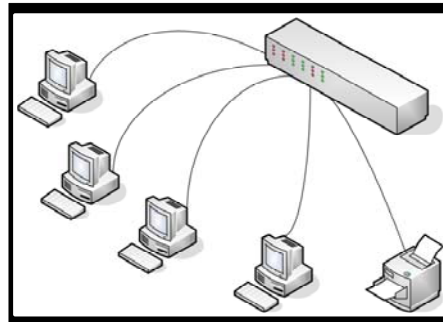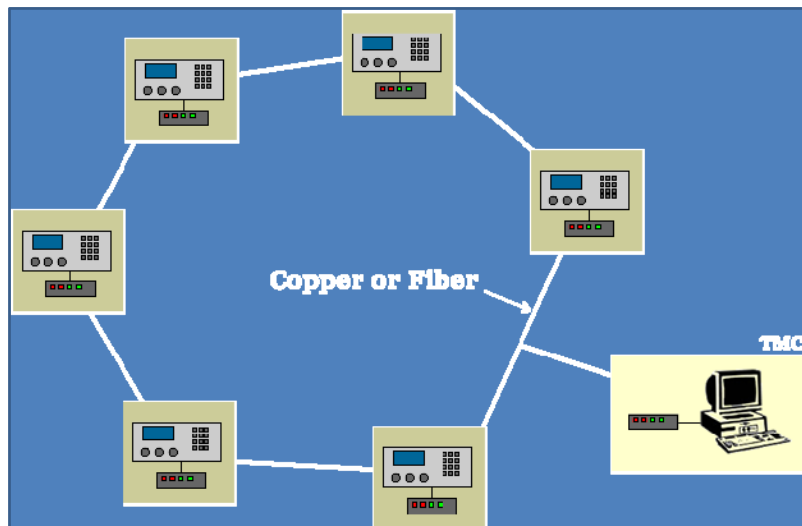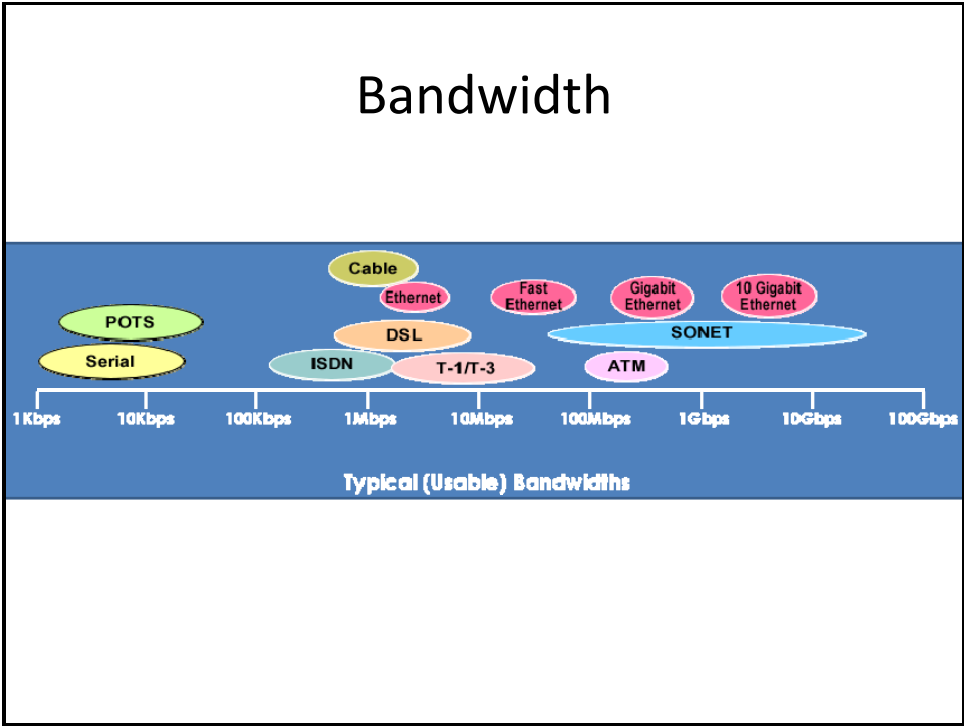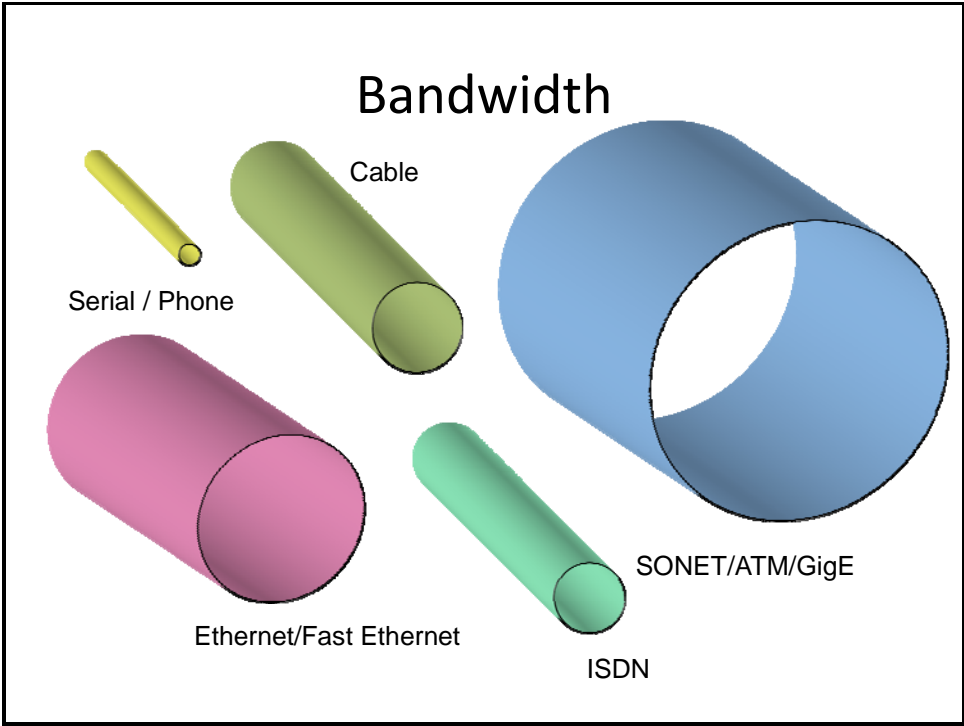
Wiring Choices

Technology	Twisted Pair	Coaxial	Fiber
Serial	☑		
POTS	☑		
ISDN	☑		
DSL	☑		
Cable Modem		☑	
T-1/T-3	☑		☑
ATM	☑		☑
Ethernet	☑	☑*	☑
SONET			☑

* Not common

Deployment Methods

Technology	Direct	Internet	Network
Serial	☑		
POTS	☑	☑	
ISDN	☑	☑	
DSL		☑	
Cable Modem		☑	
T-1/T-3	☑	☑	
ATM			☑
Ethernet			☑
SONET			☑

Distance Limitations

Relative Costs

Relative Costs

Bar chart titled "Relative Costs" with x-axis "Technology" and y-axis "Cost Per Port ($)" ranging from 0 to 10,000. Bars: ATM (~1,000), Ethernet (small), Fast Ethernet (small), Gigabit Ethernet (~1,000), SONET (~5,000, labeled "Up to $5,000").
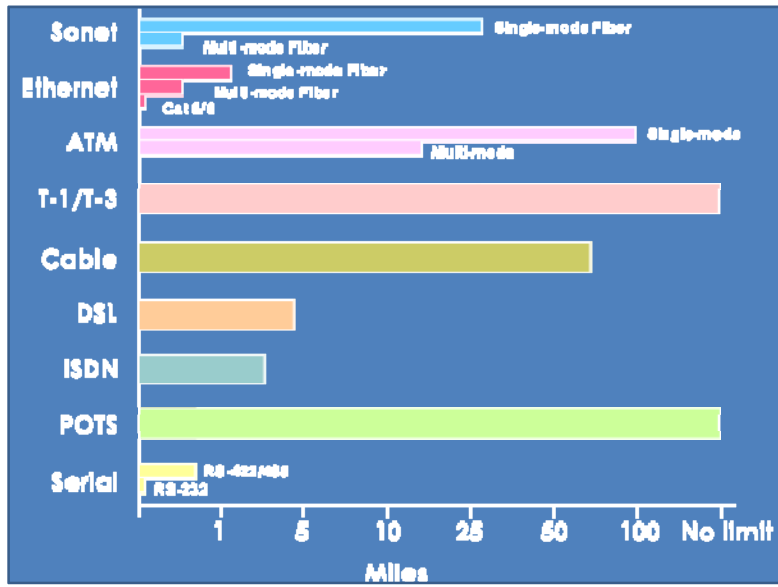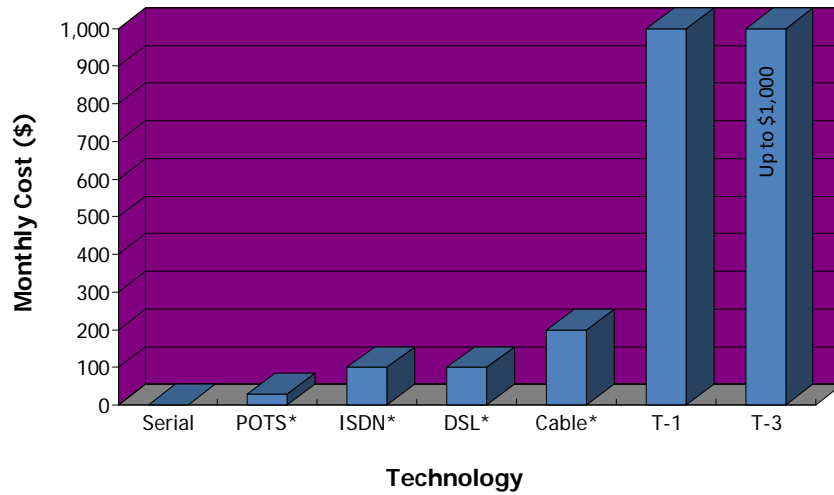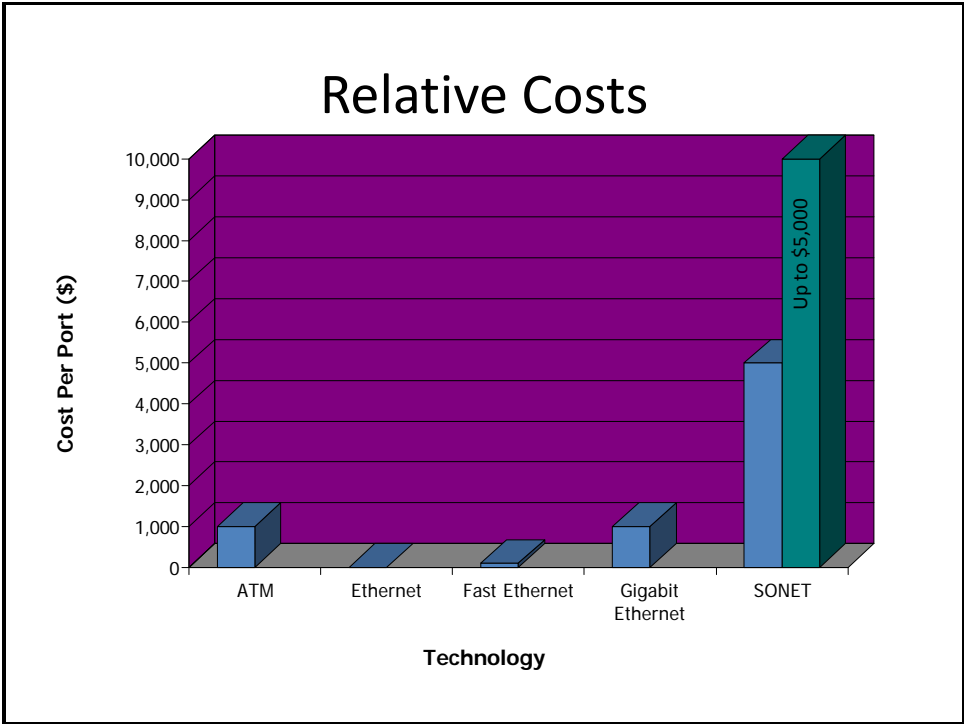
Communications Systems for ITS Applications

ARCHITECTURES AND TOPOLOGY

Architecture

- Topology describes arrangement of devices
- Architecture focuses on ITS component relationships (more abstract)
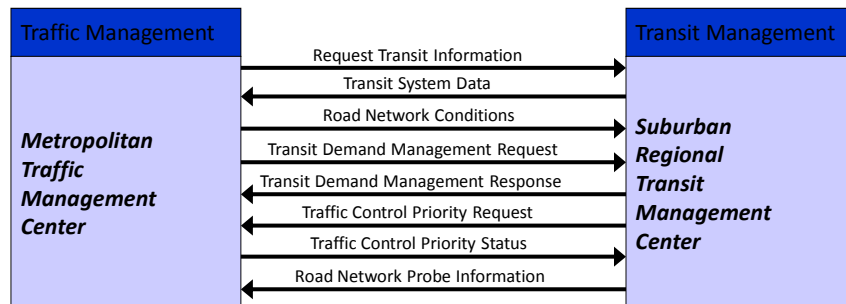
National ITS Architecture
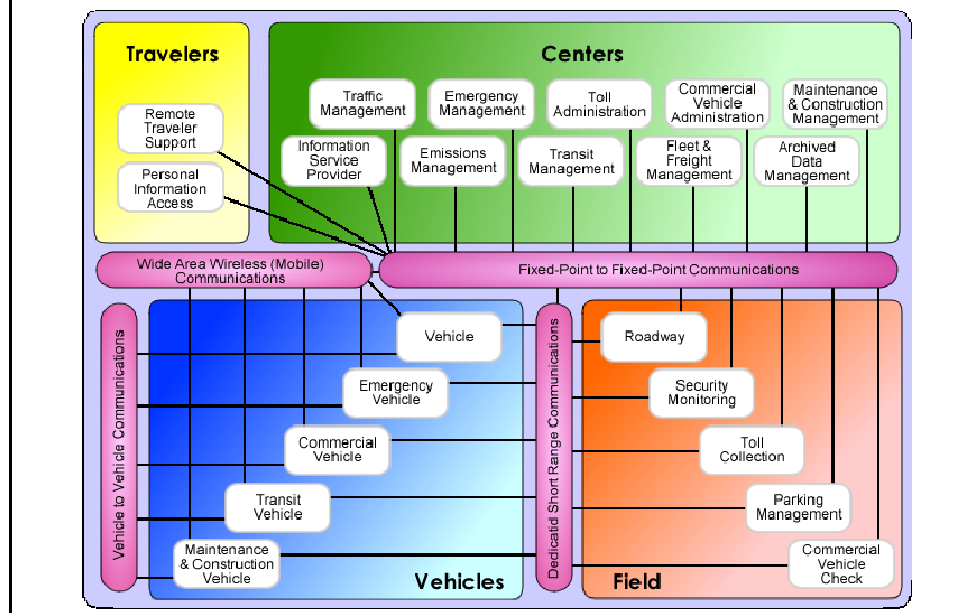
Point-to-Point Topology
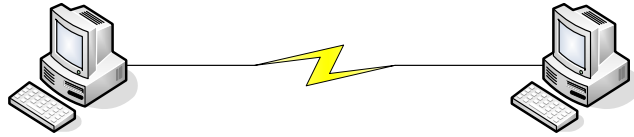
- Direct connection between two devices
  - Direct
  - Internet
- Example: Dial-up connection

Star Topology

- Each device connected to a central node (switch, hub)
- Example: small business computer network

Ring Topology

- Data pass through nodes to get to destination
- More suitable for longer distances
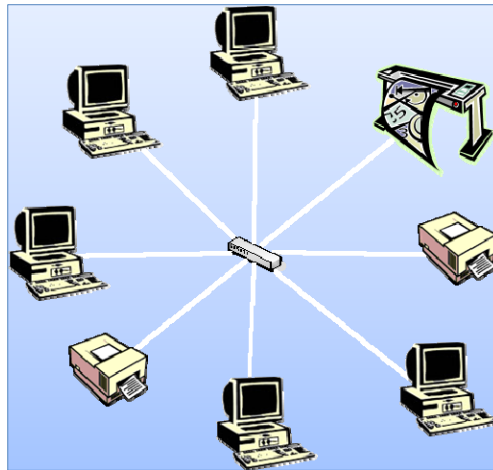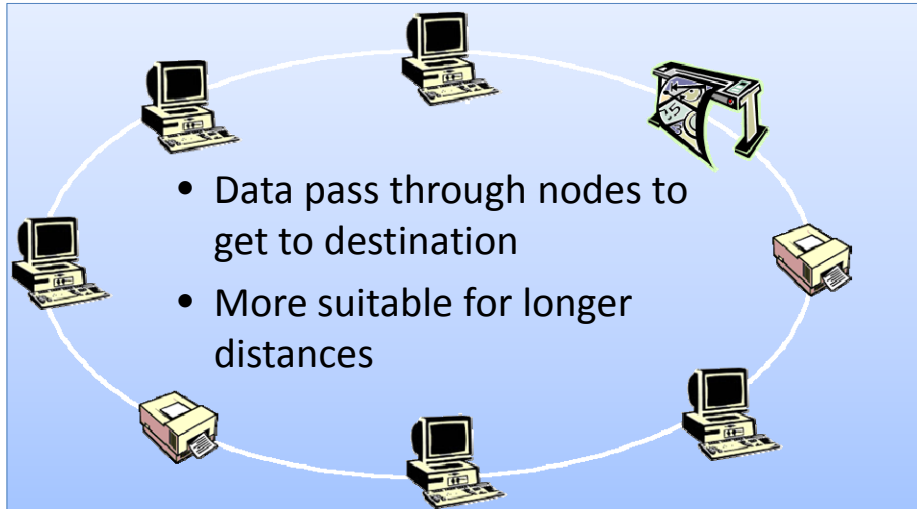
Bus Topology

- All nodes connected on a single line
- One node is a master at any given time
- Only the master can send data
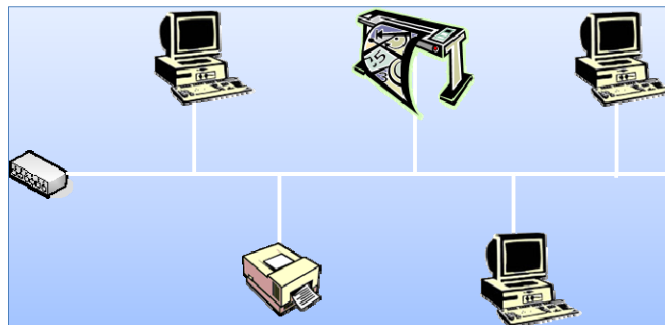
Hybrid Topology

- Combination of two or more topologies
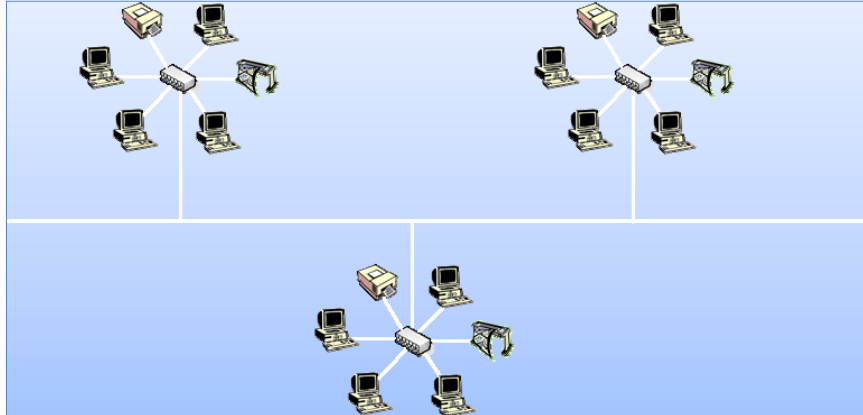
Modern Networks

- Multiple topologies
- Provides redundancy
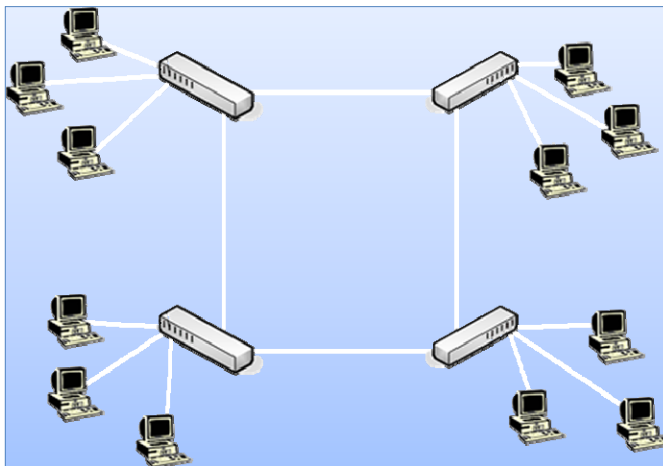
Hubs, Routers, and Switches
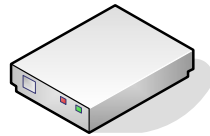
Modem
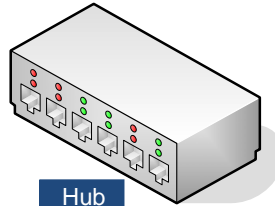
Hub
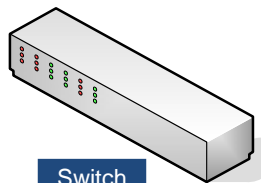
Switch
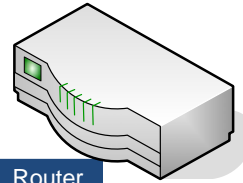
Router

Modem ($)

- <u>Mo</u>dulator / <u>Dem</u>odulator
- Converts analog signal to digital and vice versa

Hub ($)

- Not an "intelligent" device
- Information is not routed to a specific device

Switch ($$)

- "Intelligent" hub
- Information delivered to specific device
- Managed or unmanaged

Router ($$$)

- Similar to switch, but for between networks
- Information delivered to specific network

Hardened Equipment

- Field cabinets are not cooled
- Harsh environment for electronic equipment
- Specifications for:
  - Voltage
  - Frequency
  - Temperature
  - Humidity
  - Vibration
  - Shock
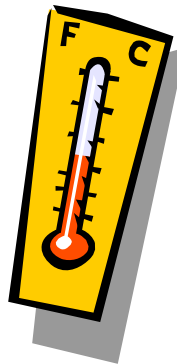
Security

- Cannot be ignored
- Multiple components:
  - Physical access
  - Device security
  - Network design
  - Data encapsulation
- Trade-off with trust
  - Open networks easier to use, but more exposed
- Security monitoring

Spanning Tree

- Networks are:
  - Interconnected, with multiple paths from point A to point B
  - Loops can occur
- Spanning tree protocol (STP) used to prevent loops by calculating "shortest" path
- "shortest" may be measured in multiple ways
  - Typically – minimum time delay
- Also used to recalculate paths in a line failure

Spanning Tree Illustrated
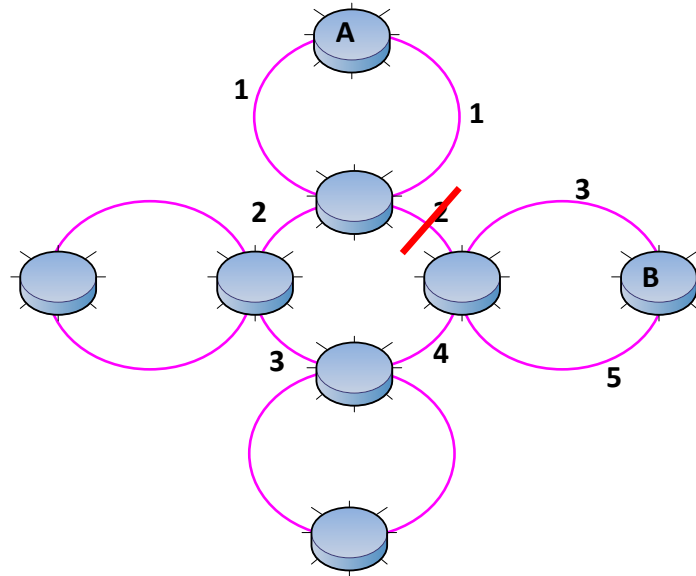
Tunneling

- A network protocol which enables data from one network to be temporarily sent across another network.
- Used for:
  - Security
  - Sharing bandwidth
  - Extending networks over long distances
- VPN (Virtual Private Network) is one example

Appendix E: Lecture Slides for Module 5. Evaluating ITS Projects

Evaluating ITS Projects

Module 5

References

- RITA ITS Evaluation Guidelines
- Traffic Analysis Toolbox Series
  (http://ops.fhwa.dot.gov/trafficanalysistools/index.htm)
  - Volume I: Traffic Analysis Tools Primer
  - Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools
  - Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software
  - Volume IV: Guidelines for Applying CORSIM Microsimulation Modeling Software
  - Volume V: Traffic Analysis Toolbox Case Studies – Benefits and Applications
- *Incorporating ITS into the Transportation Planning Process* (NCHRP Web-Only Document 118)

US DOT's Research and Innovative Technology Administration (RITA) Recommended Evaluation Process

- Step 1. Form the Evaluation Team
- Step 2. Develop an Evaluation Strategy
- Step 3. Develop an Evaluation Plan
- Step 4. Develop one or more Detailed Test Plan
- Step 5. Collect and Analyze Data and Information
- Step 6. Prepare Final Report

Key Strategic Goals and Performance Measures of ITS

Goal Area	Measures
Safety	• Reduction in overall crash rate • Reduction in fatality rate • Reduction in injury rate
Mobility	• Reduction in travel time delay • Reduction in travel time variability
Efficiency	• Increase in freeway and arterial throughput
Productivity	• Cost savings
Energy and the Environment	• Decrease in vehicle emissions • Decrease in vehicle energy consumption
Customer Satisfaction	• Increase customer satisfaction

Criteria for Selecting Traffic Analysis Tool

Source: *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*

Evaluation Tools

- Sketch-planning methodologies
- Travel demand/Planning models
- Analytical/deterministic tools
- Traffic optimization tools
- Macroscopic simulation models
- Mesoscopic models

Sketch-Planning Techniques

- Generally straightforward, parametric, or spreadsheet analysis to approximate potential impacts
- Potential Uses
  - Large number of options to evaluate (screen alternatives)
  - Impacts localized
  - Relatively small projects

Screening for ITS (SCRITS)

- Spreadsheet tool for estimating user benefits and screening options
- Developed by SAIC
- Daily analysis of 16 different types of ITS (fixed)
- Estimates changes in
  - Vehicle hour of travel (VHT)
  - Vehicle miles of travel (VMT)
  - Emissions
  - Vehicle operating costs
  - Energy consumption
  - Number of accidents
  - User economic benefits
- Doesn't estimate system operating or capital costs

ITS Alternatives Supported in SCRITS

- CCTV
- Detection
- HAR
- Dynamic Message Signs
- Pager-Based Systems
- Kiosks
- CVO Kiosks
- Traffic Information through the Internet
- AVL systems for Buses
- Electronic Fare Collection for Buses
- Signal Priority Systems for Buses
- Electronic Toll Collection
- Ramp Metering
- Weigh in Motion
- Highway/Rail Grade Crossing Applications
- Traffic Signalization Strategies

Intelligent Transportation Systems Deployment Analysis System (IDAS)

- Sketch-Planning Tool
- Features of IDAS
  - Works with the output of existing transportation planning models;
  - Compares and screens ITS deployment alternatives;
  - Estimates the impacts and traveler responses to ITS;
  - Develops inventories of ITS equipment needed for proposed deployments and identifies cost sharing opportunities;
  - Estimates life-cycle costs including capital and O&M costs for the public and private sectors;
  - Provides documentation for transition into design and implementation.

ITS Components Evaluated by IDAS

- Arterial Traffic Management Systems
  - Isolated Traffic Actuated
  - Pre-timed Coordinated
  - Actuated Coordinated
  - Central Control
  - Emergency Veh. Priority
  - Transit Priority

- Freeway Management Systems
  - Pre-set Ramp Metering
  - Traffic Actuated Ramp Metering
  - Central Control Ramp Metering

ITS Components Evaluated by IDAS (cont.)

- Advance Public Transit Systems
  - Fixed Route Transit
    - Automated Scheduling
    - AVL
    - Automated Scheduling + AVL
    - Security Systems
  - Paratransit
    - Automated Scheduling
    - AVL
    - Automated Scheduling + AVL

- Incident Management
  - Detection / Verification
  - Response / Management
  - Combination
- Electronic Payment Systems
  - Electronic Transit Fare Payment
 - Basic Electronic Toll Collection

ITS Components Evaluation by IDAS (cont.)

- Regional Multimodal Traveler Information
  - HAR
  - Freeway DMS
  - Transit DMS
  - Telephone-based Traveler Information Systems
  - Web/Internet-based Traveler Information Systems
  - Kiosk w/ Multimodal Traveler Information
  - Kiosk with Transit-only Traveler information
  - Handheld Personal Device – Traveler Information Only
  - Handheld Personal Device – Traveler Information w/ Route Guidance
  - In-vehicle – Traveler Information Only
  - In-vehicle – Traveler Information w/ Route Guidance

- Commercial Vehicle Operations
  - Electronic Screening
  - Weigh-in-Motion
  - Electronic Clearance – Credentials
  - Electronic Clearance – Safety Inspection
  - Electronic Screening/Clearance Combined
  - Safety Information Exchange
  - On-board Safety Monitoring
  - Electronic Roadside Safety Inspection
  - Hazardous Material Incident Response
- Advance Vehicle Control and Safety Systems
  - Motorist Warning – Ramp Rollover
  - Motorist Warning – Downhill Speed
  - Longitudinal Collision Avoidance
  - Lateral Collision Avoidance
  - Intersection Collision Avoidance
  - Vision Enhancement for Crashes
  - Safety Readiness

ITS Components Evaluation by IDAS (cont.)

- Railroad Grade Crossing Monitors
- Emergency Management Services
  - Emergency Vehicle Control Service
  - Emergency Vehicle AVL
  - In-vehicle Mayday System

- Supporting Deployments
  - Traffic Management Center
  - Transit Management Center
  - Emergency Management Center
  - Traffic Surveillance – CCTV
  - Traffic Surveillance – Loop Detectors
  - Traffic Surveillance – Probe System
  - Basic Vehicle Communication
  - Roadway Loop Detector
  - Information Service Provider Center

IDAS Model Structure
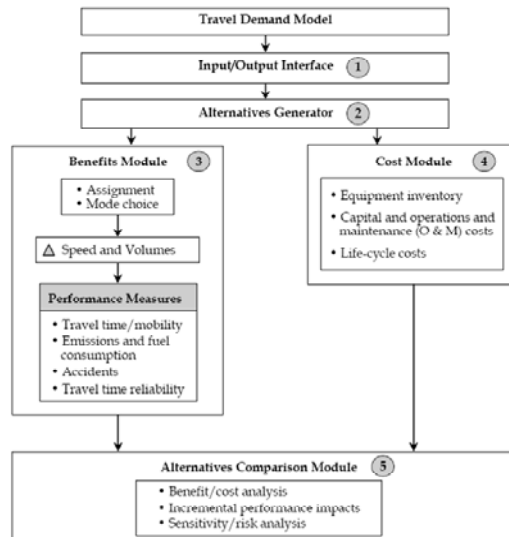
IDAS Performance Measures

- Vehicle miles of Travel (VMT)
- Vehicle hours of Travel (VHT)
- Average Speed
- Person hours of travel (PHT)
- Number of person trips
- Number of accidents
  - Fatality
  - Injury
  - Property damage only
- Travel Time Reliability (hours of unexpected delay)
- Fuel Consumption (gallons)
- Emissions
  - Hydrocarbon and reactive organic gases
  - Carbon monoxide
  - Oxides of nitrogen
  - PM10
  - Carbon dioxide
  - Sulfur dioxide

IDAS Benefit/Cost Summary

- Annual Benefits
  - Change in user mobility
  - Change in user travel time
    - In-vehicle
    - Out-of-vehicle
    - Travel time reliability
  - Change in cost paid by users
    - Fuel costs
    - Non-fuel operating costs
  - Change in external costs
  - Change in public agencies' costs
  - Other calculated benefits
  - User defined additional benefits

- Annual costs
  - Average annual private sector costs
  - Average annual public sector costs
- Net benefits (annual benefits minus annual costs)
- B/C Ratio (annual benefits / annual cost)

Potential Applications for IDAS

- Deployment of regional ITS architectures
- Statewide, regional, and local ITS plans
- ITS alternative analysis for long-range planning
- ITS strategies for corridor studies
- Evaluation of ITS components or systems
- ITS strategic plans or pre-deployment studies

IDAS Demo

- Demonstration of IDAS

Travel Demand / Planning Models

- Forecast average (steady-state) travel and transportation demand and associated impacts over a given time period (daily, peak period, etc.)
- Use some variant of four-step method (trip generation, trip distribution, mode split, and assignment)
- Good for capturing long-range impacts at regional level
- Combined with sketch-planning techniques or post-processing to analyze ITS impacts
- Potential applications
  - Strategies that impact capacity
  - Strategies that cause mode shift

Dynamic Traffic Assignment

- Fundamental Features
  - Time-varying traffic flow
  - Travel behavior decisions (mode, departure time, route choices) dependent upon traffic conditions in the network
- Result
  - Traffic conditions "more representative" of actual conditions
  - Traveler behavior updated in response to information
  - Dynamic OD estimation and prediction
  - Predict future travel conditions

DYNASMART

- One model developed by FHWA
- Planning level model used to evaluate ITS improvements
- DYnamic
- Network
- Assignment
- Simulation
- Model for
- Advanced
- Road
- Telematics
- Two forms
  - P → Planning Version
  - X → Real-Time Detector Data

Principal Features of DYNASMART

- Micro-simulation of individual trip-making decisions
  - Route departure time and mode
  - User responses to varying types of information (such as traveler information, congestion pricing, etc.)
- Hybrid traffic simulation approach – individual vehicles "move" based on speed-density curves
- Includes ability to load trip chains – a trip with several intervening stops with associated duration
- Multiple user classes in terms of:
  - Vehicle operating performance (e.g., trucks, buses, cars)
  - Information availability and type
  - User behavior rules and response to information
- Representation of traffic processes at intersections (stop and signal control)

Potential Applications of DYNASMART

- Assessing infrastructure investments (signals, HOV/HOT lanes, etc.)
- Determining network congestion pricing schemes
- Evaluating ITS deployment alternatives and their geographic coverage (DMS location, information strategies, etc.)
- Verifying incentive strategies for work zone management (shift work to weekend or nights)
- Planning transit/bus routes or services
- Air quality conformity analysis
- Evacuation planning and control strategies

DYNASMART Demo

- Demonstration of DYNASMART

Analytical/Deterministic Models

- Practitioner enters data and after a sequence of processes, produces a single answer
  - Macroscopic – <u>average</u> performance over defined interval (15 minutes or 1 hour)
  - Deterministic – same input <u>always</u> produces same result
  - Static – do not deal with transition from one state to another (i.e., growth of congestion)
- Example: Highway Capacity Manual
- Major Advantage – <u>quickly</u> predict capacity, density, speed, delay, and queuing

Potential Application of Analytical/Deterministic Models

- Analyzing performance of small-scale or isolated improvements (e.g., intersection, arterial, freeway ramp, etc.)
- Limited in ability to analyze network or system effects

Macroscopic Simulation Models

- Traffic behavior based on deterministic relationships of flow, speed, and density
- Analysis takes place on a section-by-section basis (as opposed to at the individual vehicle level)
- Originally developed to model traffic in distinct transportation subnetworks (freeways, corridors, etc.)
- Vehicles considered as "platoons"

Mesoscopic Simulation

- Combine properties of both microscopic and macroscopic simulation
  - Individual vehicle behavior is modeled
  - Movements governed by macroscopic principles (i.e., speed-density relationships)
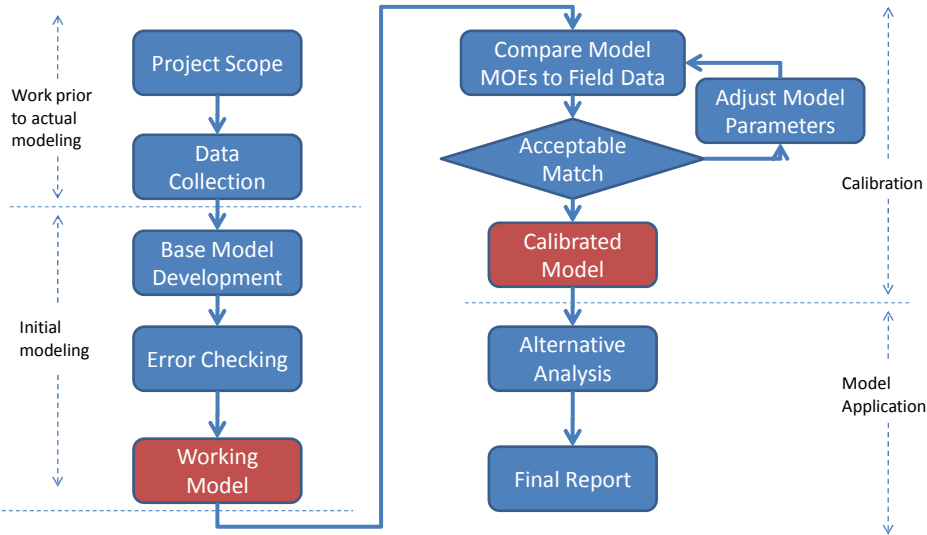- DYNASMART example of Mesoscopic model

Microscopic Simulation

- Simulates the movement of individual vehicles based on car-following and lane-changing theories
- Stochastic – vehicles enter network using a statistical distribution
- Vehicles tracked in brief time intervals (second or subsecond)
- Upon generation, each vehicle assed a destination, a vehicle type, and a driver type
- Vehicle operating characteristics influenced by geometric conditions (grades, etc.)
- Traffic control (e.g., traffic signals) can be explicitly modeled

Potential Applications of Microscopic Simulation

- Important to capture traffic changes over time
- Examine improvements at fine level of detail
- ITS Applications
  - Unusual incidents on system
  - Availability of information to specific travelers
  - Traffic control modifications (signal timing, ramp meterings, transit priority, HOV operations, incident responses, etc.)

Steps in Properly Apply Microscopic Simulation Model

Source: *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*

Examples of Microscopic Simulation

- CORSIM Demo
- VISSIM Demo

NGSIM

- Next Generation Simulation (NGSIM)
- Public-private partnership
- FHWA will support the development of behavior algorithms, validation datasets, and fundamental logic
- Open source
- http://ngsim.fhwa.dot.gov/

Picking the Right Tool for the Job

Planning Needs	Operational Analysis Tools/Methods
Needs assessment/ deficiency analysis	• Travel demand forecasting models • Deterministic models • Traffic signal optimization models • Simulation • Archived operations data • Operations-oriented performance metrics
Preliminary screening	• Sketch planning tools
Alternative analysis	• Sketch planning tools • Travel demand forecasting models • Simulation
Strategic ITS planning	• Sketch planning tools • Travel demand forecasting models
Project scoring/ranking/ prioritizing	• Travel demand forecasting models • Deterministic models • Operations-oriented performance metrics

Source: *Statewide Opportunities for Linking Planning and Operations*

Picking the Right Tool for the Job

Planning Needs	Operational Analysis Tools/Methods
Corridor and environmental analysis	• Travel demand forecasting models • Deterministic models • Traffic signal optimization models • Simulation
Planning for non-recurring congestion	• Sketch planning tools • Travel demand forecasting models • Simulation
Performance monitoring	• Deterministic models • Traffic signal optimization tools • Archived operations data • Operations-oriented performance metrics
Evaluation of deployed projects	• Sketch planning tools • Travel demand forecasting models • Archived operations data • Operations-oriented performance metrics

Source: *Statewide Opportunities for Linking Planning and Operations*

Laboratory Exercise

- Use IDAS to conduct alternatives analysis of Bryan/College Station Mobility Initiative Strategic Areas

University Transportation Center for Mobility

Texas Transportation Institute

The Texas A&M University System

College Station, TX 77843-3135

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Transportation
Institute