U.S. Department of Transportation
Federal Highway Administration

ASCT Systems Engineering

ITE Regional Meeting

June 2014

Rapid City

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Agenda

- First steps
- Operational objectives
- Planning and operations
- Systems engineering basics
- Federal regulations
- Using the Model SE for adaptive signal control technologies (ASCT) documents
- ASCT procurement
- ASCT performance monitoring

Disclaimer

- We will not discuss:
  - Technology
  - Products

What are my next steps?

I manage a large city, with over 1000 traffic signals, I'm considering adaptive signal control for some intersections, but how do I determine the right place for adaptive?

Due to new air quality standards that are out, I need to improve my network. Is it time to consider adaptive control?

I'm a technologist and want to use the latest and greatest. I just heard about adaptive control and it sounds great, I want one! What do I do next to get it?

I been working with my consultant/vendor for many years and they have been telling me about new adaptive traffic control systems that I should consider. What locations would be the best fit for an adaptive control system?

I have very old traffic control system and with my recent grant I think I can afford a new system. Is it time to consider adaptive control?

I am getting calls on a couple of my intersections and I cannot solve the cycle/phase issues. Will adaptive control help?

I have tried time of day coordination and even traffic responsive plan selection, but I feel like there could be something better. Could adaptive control be a better solution?

I have a corridor that I run time of day coordination, but occasionally diverting traffic overwhelms the corridor, could adaptive control provide a better solution?

The planners are telling me that in the next 5-10 years there will be a 50% growth along the main corridor in the city, the current traffic control system will not handle the traffic based on the current capacity. Is it time to consider an adaptive control?

What We Know About ASCT

- Benefits over coordinated TOD operation
  - Travel time, delay, emissions
  - Congestion, Safety
- Most effective where demand conditions are variable and unpredictable
- Linear arterials, limited success within tight grids
- Under saturated

What Are the Risks to Successful Deployment of ASCT?

- Goals are not well understood.
- Problem could be solved with other strategies.
- Functional objectives of the system do not align with agency objectives and needs.
- Loss of other critical functions / features
- Constraints not properly addressed.
- Cost is not managed.
- Maintenance unachievable.

Other Risk Issues

- Technology NEW to most
- Technology still evolving
- Most systems have very limited track record
- Documented history of failed ASCT projects (40%+)
- Significantly increased complexity
- Extremely dependent upon infrastructure
  - Communications systems
  - Detection
  - Staff
- Not “one size fits all”
- Marketing often exceeds performance

Successful Deployment

- Goals well understood
- Agency describes its **NEEDS**
- Positive response to **REQUIREMENTS** in RFP
- Agency **VERIFIES** that contractor/vendor delivers what was required
- Agency **VALIDATES** that the system meets the agencies needs were met
- The Agency operates and maintains the system to ensure effectiveness over the entire life cycle.

Recent Reports

- Roseville, CA (Western ITE)
  - Good TOD Plans just as effective as ASCT
- TRB Paper
  - Issues Affecting the Performance of an Adaptive Traffic Control System in Oversaturated Conditions
- Mesa, AZ
  - ASCT not significant improvement over TOD
- Spokane, WA
  - PM is more important than ASCT
- Florida
  - No statistically significant gains

First Steps

- Identify traffic engineering problems
  - Geometric Constraints
- Identify traffic engineering solutions
- Assess condition of existing stuff
  - Near end of life cycle?
- Fix what you can with existing stuff
  - Does detection work?
  - Communications system working?
  - How reliable is your base line
- This is your backup when ASCT fails

Can't do this overnight!

ASCT is Not “Set and Forget”

- Detection is critical
- Communications is critical
- Operational expertise is required
- Requires higher level of maintenance
- Requires graceful safe fall back mode
- Doesn’t always do the right thing
  - Safety valve required!
- Requires understanding of problem to solve
- Requires **ACTIVE** management

Let’s Plan for Success

- Funding
- Expertise
- Systems engineering
- Procurement process
- Implementation
- Lifecycle management
- Did it solve the problem?

Do Your Homework!

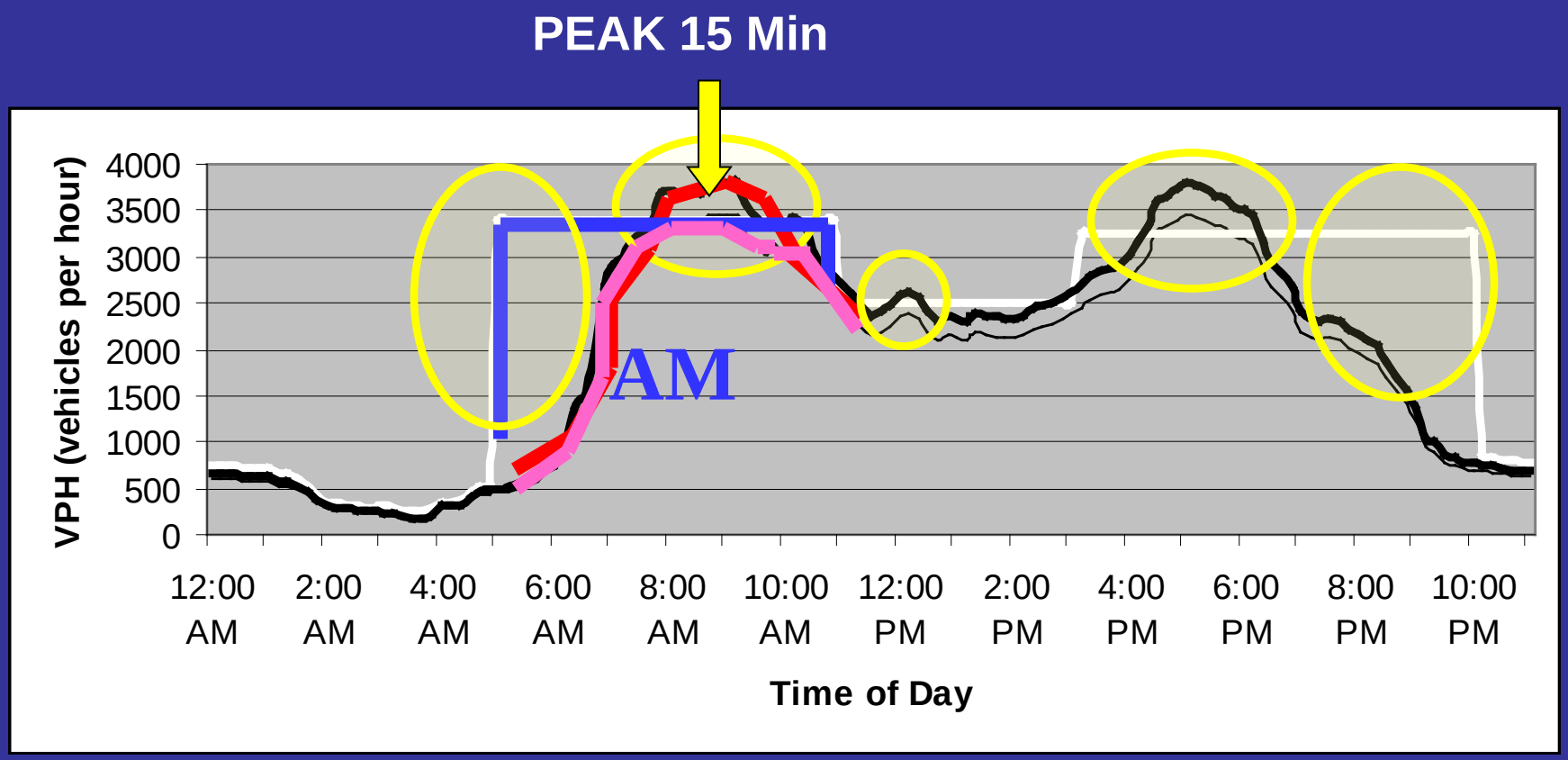
- Document operational objectives
- Document field conditions
- Document what has been tried
- Document existing infrastructure
- Identify available resources
- Included in LRTP
- Secure funding

What Do Motorists Want?

- “Why do I have to wait when there’s nobody else moving?”
  - Translation: Equitable distribution of green time.
- “Can’t I just drive down the street?”
  - Translation: Progression – driving through successive greens.

The Big Box Scenario – Year 1

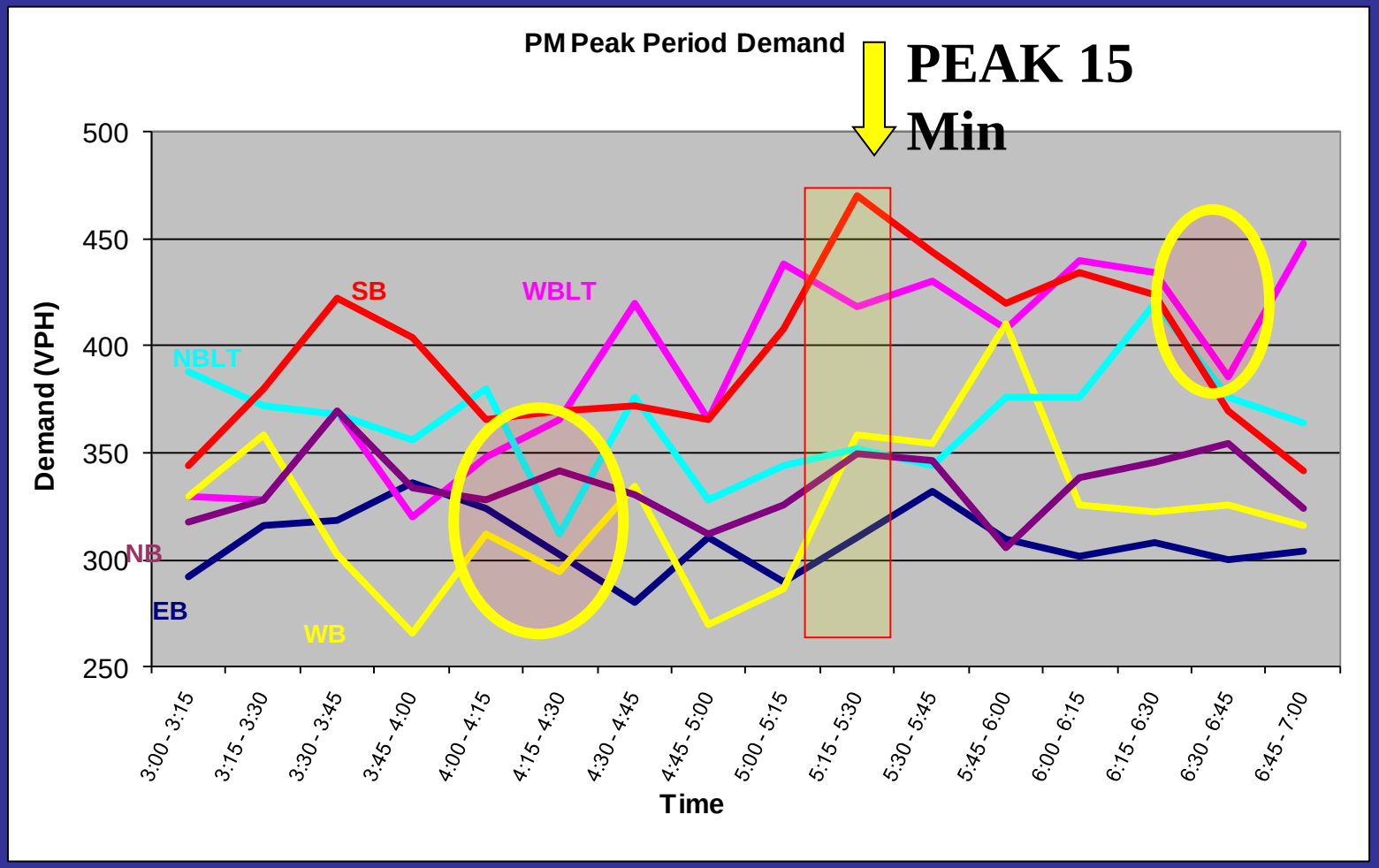
Typical Traffic Signal Timing



Year 5

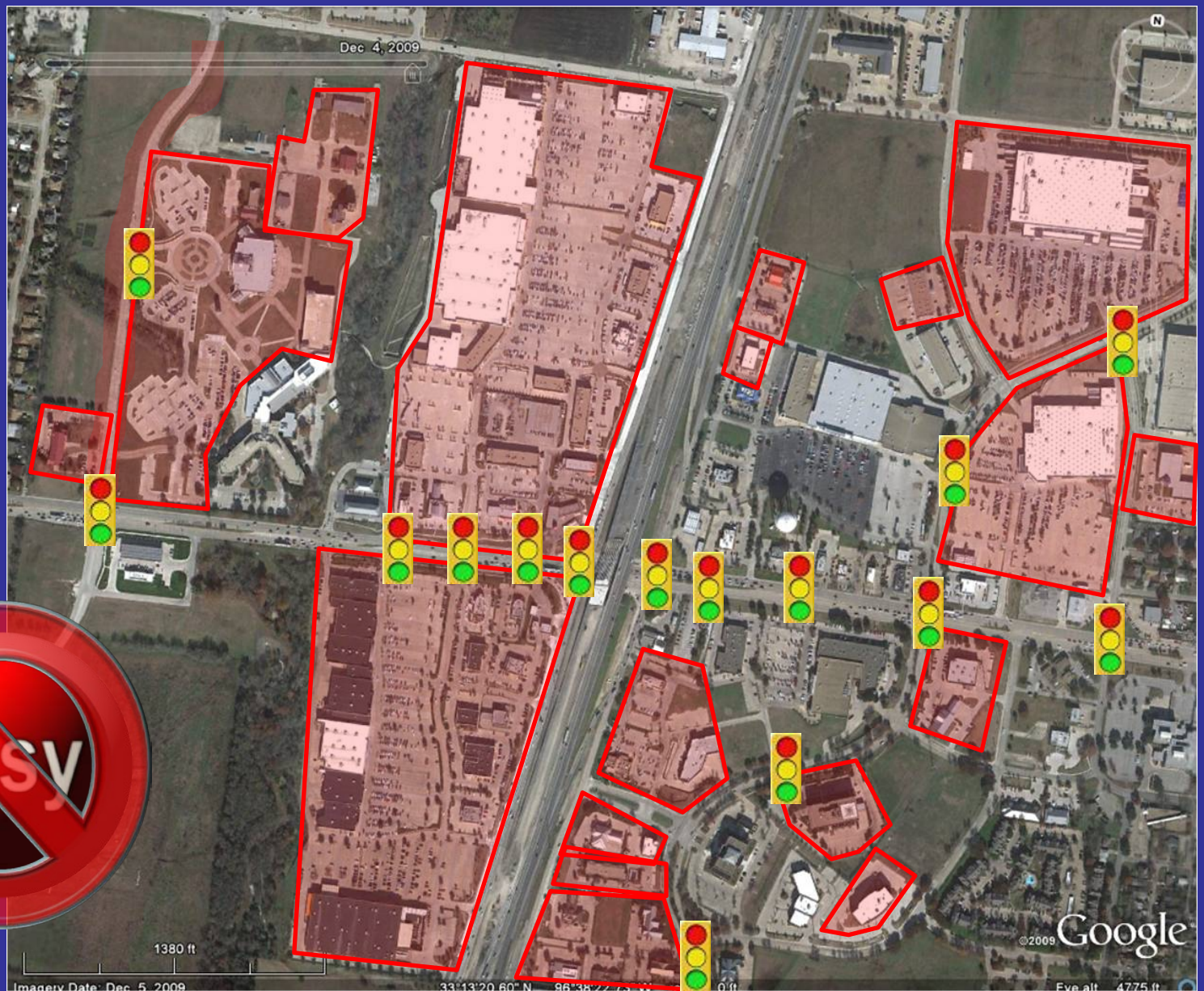
Year 9

Variability is Normal–And the Problem



Year 10

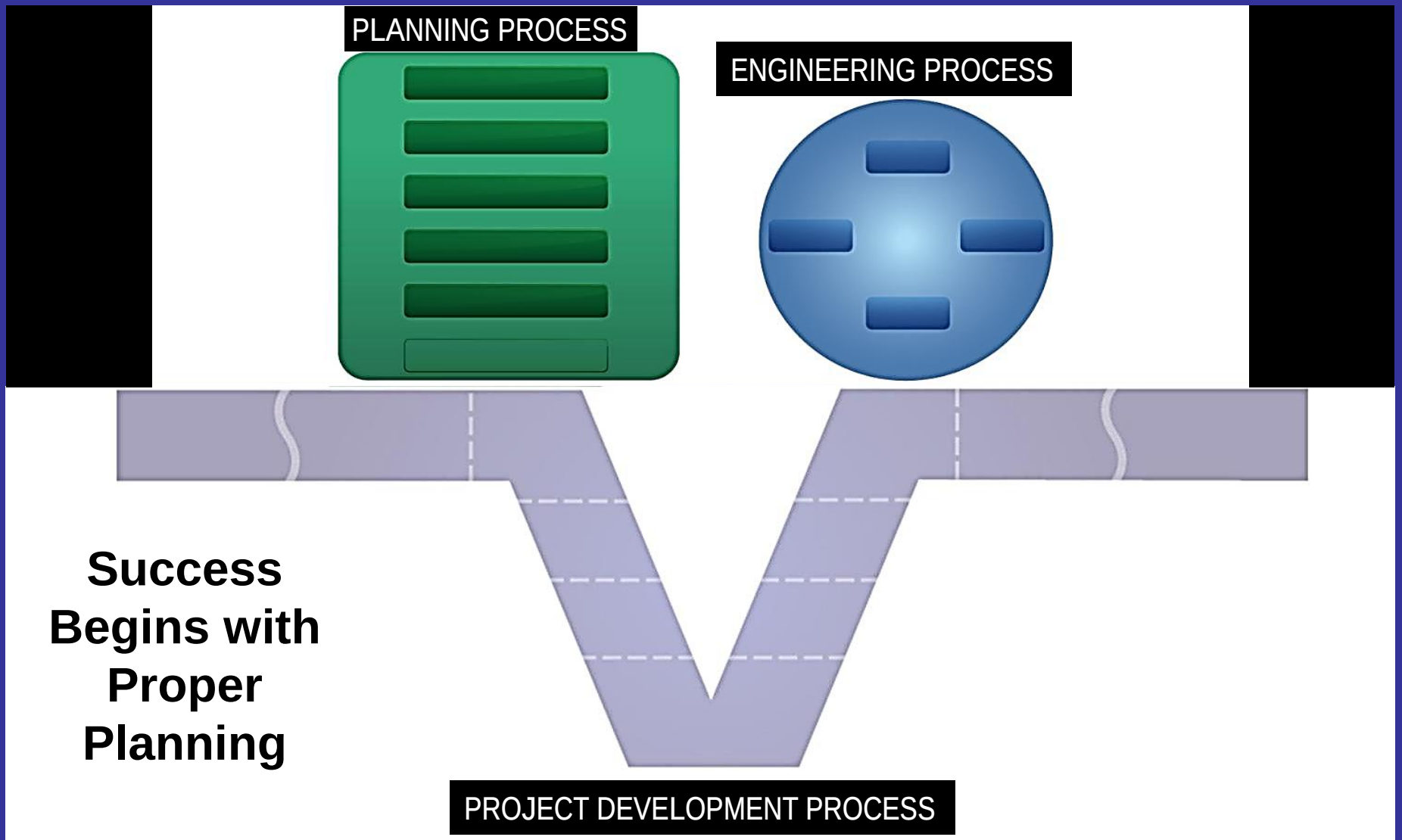
Year 13



Operational Objectives

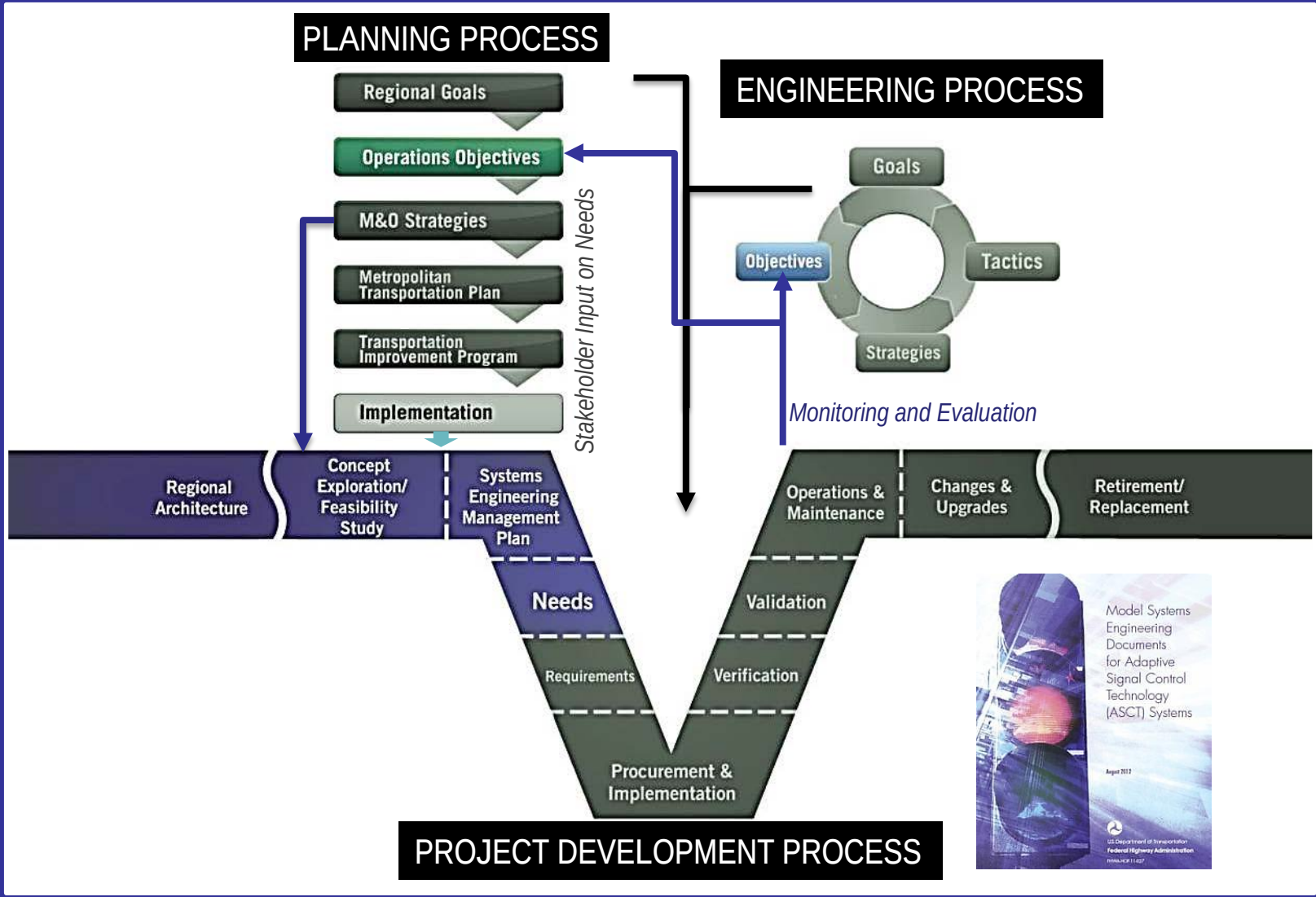
- Smooth flow
- Maximize throughput
- Equitably serve adjacent land use
- Manage queues
- Variable
- Maximize intersection efficiency

Continuum of Management and Operations



Success Begins with Proper Planning

Continuum of Management and Operations (cont.)



Eisenhower Wants to Build Roads

- How fast Germans moved armies during WWII
- America embroiled in the Red Scare
- Post war prosperity presented an opportunity

How Would We Use a New Roadway Network?

- Move armies quickly
- Move people, goods & services efficiently

What Slows Armies Down?

- Intersections
- Narrow roads
- Tight curves
- Incomplete network

Basic Requirements

- Limited access
- Wide lanes with shoulders
- Divided highway
- High design speed
- Comprehensive network

Functional Requirements

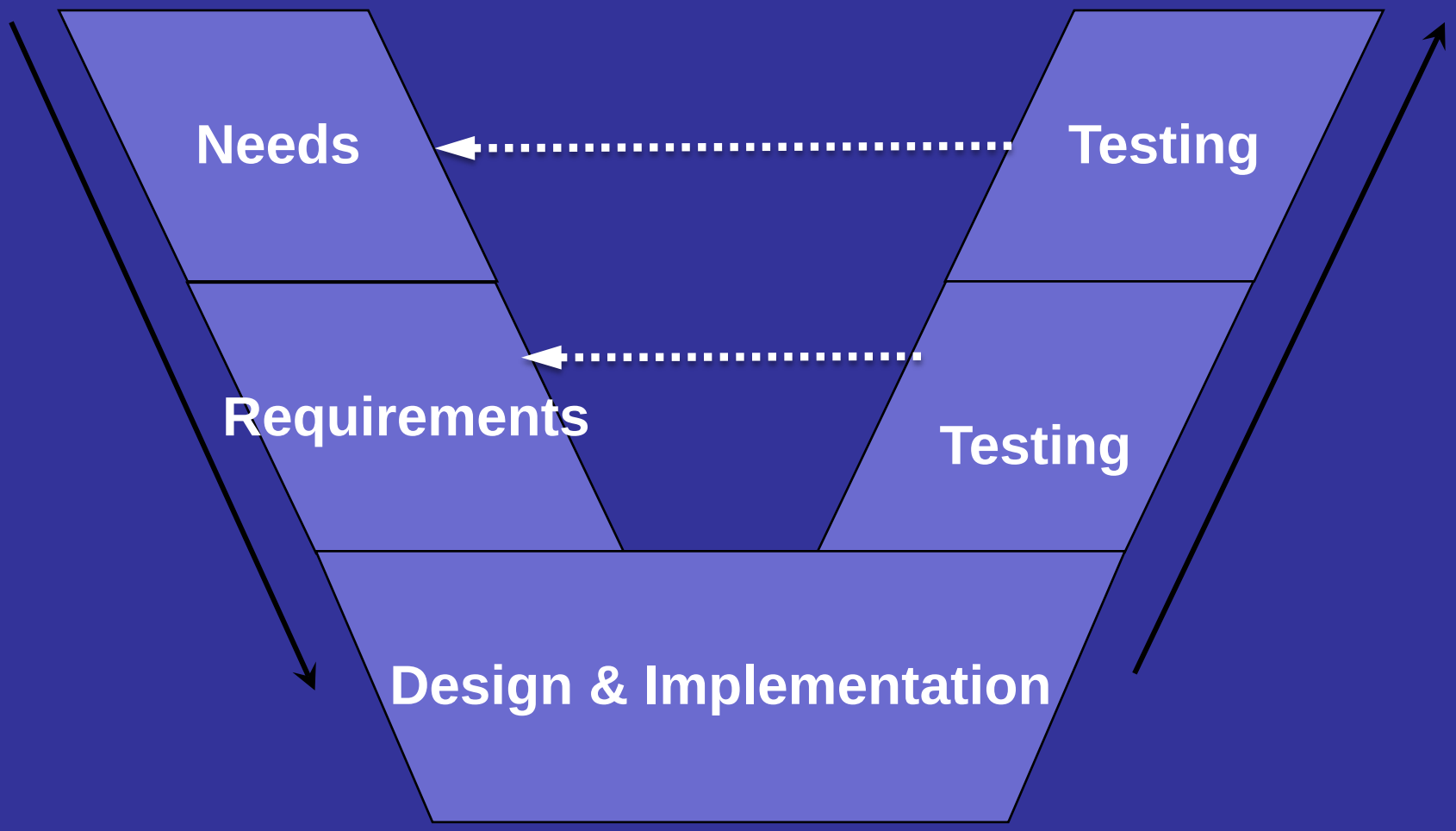
- The highway shall have no at-grade crossings.
- The highway shall separate the two directions of travel.
- The highway shall accommodate vehicles traveling at 70 mph.
- The highway shall have 12-foot lanes.
- The highway shall have vertical clearance of 16.5 feet.
- The highway shall have maximum grade of 6%.
- The highway network should comprise principal east-west and north-south routes.

- Did Eisenhower know anything about building roads?
- Do road builders know anything about moving armies?
- Do they need to?

Did the Road Get Built Right?

Did We Build the Right Roads?

Systems Engineering



Mitigating Risk

- Designing the roads incorrectly
- Designing the wrong roads
- Spending too much
- Taking too long to build
- Responding to challenges

Systems Engineering

- “An inter-disciplinary approach and means to enable the realization of successful systems”
- Focuses on defining stakeholder needs
- Develop required functionality early in the development cycle

Benefits of Systems Engineering

- Reduced risk of schedule and cost overruns
- Improved stakeholder participation
- Verified functionality and fewer defects
- Better documentation
- Increased likelihood that implementation will meet users' needs
- Ensures you "get what you need"

What Are the Risks - ASCT?

- Problem could be solved with other strategies
- Functional objectives of the system do not align with agency operational objectives
- Loss of other critical functions / features
- Constraints not properly addressed
- Cost
- Maintenance

940.11 Rule Requirements

- **All** ITS projects must be developed using a Systems Engineering (SE) analysis
- The analysis shall be on a scale commensurate with the project scope
- SE analysis shall address (7) requirements

Seven Requirements of SE Analysis

- Identify portions of the regional ITS architecture being implemented
- Identification of participating agencies roles and responsibilities
- Requirements definitions
- Analysis of technology options to meet reqs
- Procurement options
- Identification of applicable ITS standards and testing procedures
- Procedures and resources necessary for operations and management of the system.

Basic Systems Engineering Deliverables

- Concept of Operations
- Requirements
- High Level Design
- Verification Plan
- Validation Plan

Procurement Regulations

- Proprietary Materials (23 CFR 635.411)
  - Certification of no available competitive product
    - Uniquely fulfills the requirements imposed on the product
    - Achieves synchronization with existing systems
  - Public Interest Finding for proprietary purchase despite alternative available competitive products
  - Limited experimental application
- Systems Engineering provides justification

The Role of Systems Engineering

- Understanding the problem
- Managing risk
  - Projects getting bogged down with shifting requirements
  - Acquisitions being challenged by unsuccessful bidders/proposers/vendors
  - Projects not meeting agency needs
- It is mandatory for federal-aid projects

Use the ITS Architecture

- Don’t simply supply a hyperlink
- Use it to:
  - Seed the Concept of Operations
  - Identify stakeholders
  - Data flow diagrams
  - Architecture flow diagrams
- Identify and define all required interfaces
- Feed project information back into architecture

Purpose of SE Model Documents

- Usual process too much work for small projects…
- …but small projects still impose big risk to small agencies
- Model documents greatly reduce effort by providing wording and documentation…
- …but agencies still must identify their needs

Concept of Operations

- The story of HOW the SYSTEM will be USED and:
  - Includes viewpoints from stakeholders
  - Is written from the perspective of the system operator
  - Defines high-level system concept to justify alternatives
  - Allows requirements to be derived
  - Provides criteria for validation

Requirements

- Describes **WHAT** needs to be achieved by the system, not **HOW**
- Must be linked to a need in the Concept of Operations
- Functional requirement
  - What the system is to do
- Performance requirement
  - How well it is to perform
- Non-functional
  - Under what conditions it must perform
- Enabling requirement
  - Actions taken for system to be fully operational

Testing

- Verification Plan
  - Verifies that the **SYSTEM** fulfills the requirements
- Validation Plan
  - Validates that the user needs have been met

Concept of Operations Template & Questions

- 1.0 – Purpose
- 2.0 – Scope
- 3.0 – Referenced Documents
- 4.0 – Background
  - Network characteristics
  - Traffic characteristics
  - Signal grouping
  - Land use
  - Operating agencies
  - Existing architecture / infrastructure
  - Limitations and proposed changes

Alternative Non-Adaptive Strategies

- Features you are not using that could be used to improve your operation
  - Traffic responsive
  - Complex coordination
    - Actuated coordinated
    - Phase re-service
    - Variable phase sequence
    - Omit phase
    - Early release of hold
    - Dynamic max

Envisioned Adaptive Operations (Chap. 6)

- **HOW** the adaptive system will accomplish the goals and objectives.
- Also describes:
  - Tactics
  - Strategies
  - Policies
  - Constraints
- ** Should not describe equipment*

Operational Objectives / Adaptive Scenarios

- Pipeline
- Access equity
- Manage queues
- Variable

Specific Adaptive System and User Needs (Chap. 7)

- Needs that will drive requirements for the system:
  - Vision, goals and objectives
  - Operational features
  - User interface, reporting, monitoring and maintenance

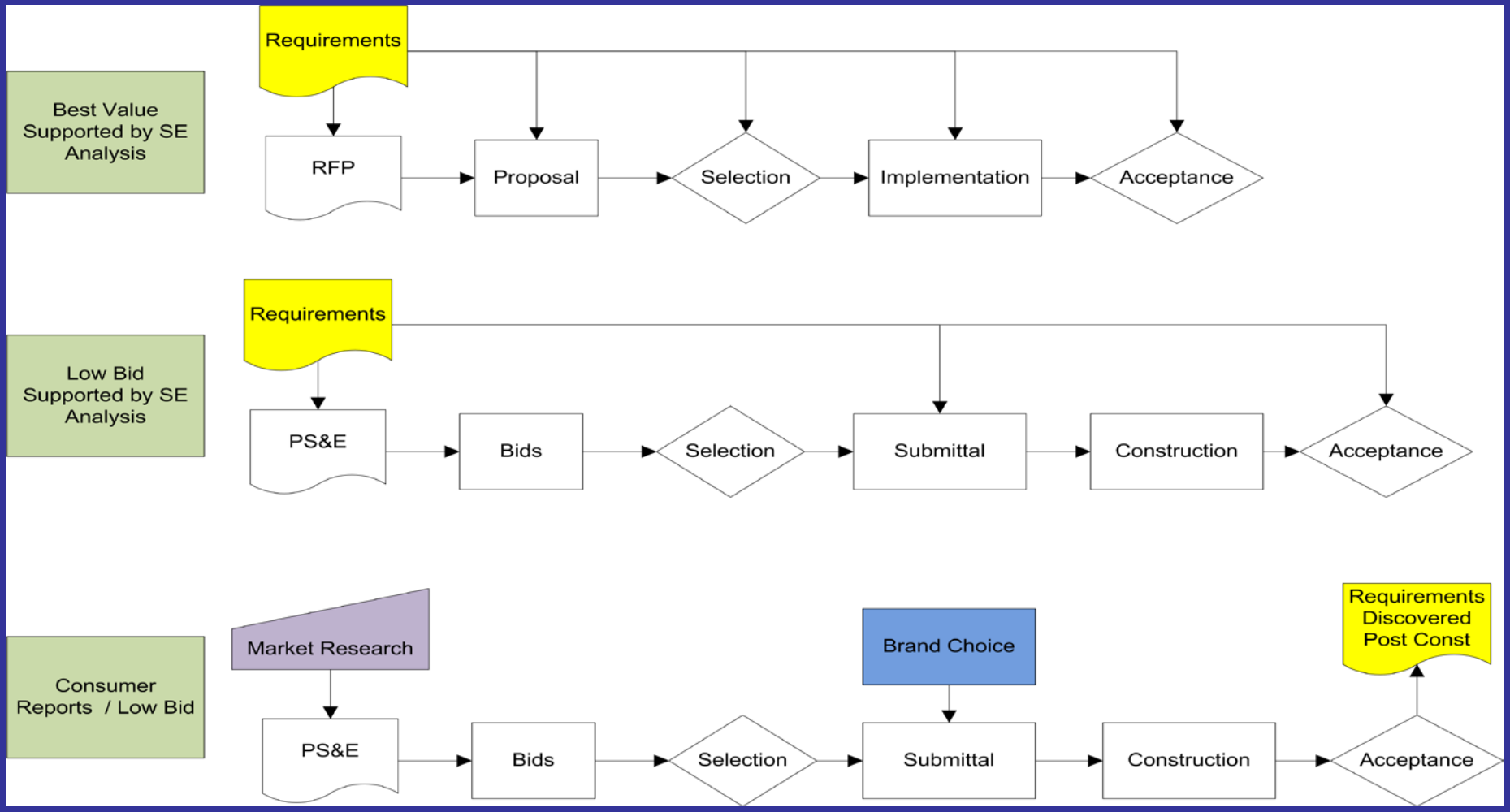
Envisioned Adaptive System Overview (Chap. 8)

- Network characteristics
- Type of adaptive operation
- Crossing arterial coordination
- Institutional boundaries

System Procurement

- Myth
  - FHWA requires Low Bid
- Fact
  - FHWA recommends Best Value
  - Separate ASCT from heavy field construction

Procurement Plan



Model SE Documents for ASCT (Final)—Now Online

- http://ops.fhwa.dot.gov/publications/fhwahop11027/index.htm

Is It Working?

- Traditional before/after study
  - Small slices in time
  - Expensive
  - Not sustainable
  - Sometimes not credible
  - Not tied to operational objectives
- Build performance measurement into system
  - Maps to operational objectives
  - Continuous measurements
  - Actionable information

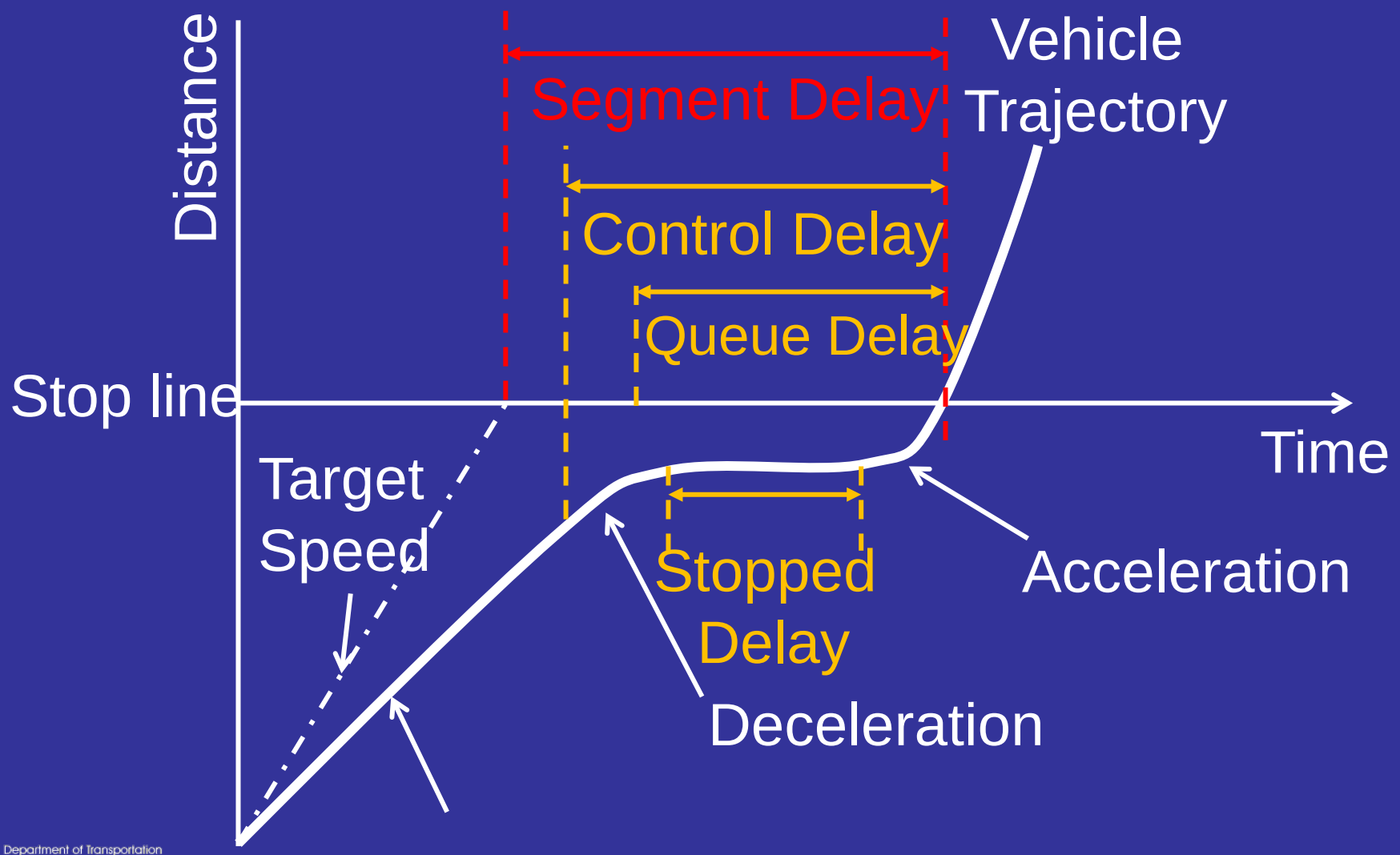
FHWA Report FHWA-HOP-13-031

- Measures of effectiveness and validation guidance for adaptive signal control technologies (ASCT)
  - Map MOEs to objectives then select data source
  - On/Off study

Potential Performance Measures

MOEs	Operational Objectives
• Route travel time • Route travel delay • Route average speed • Route travel time reliability	• Pipeline • Multiple objectives by time of day (TOD) • Accommodate long-term variability
• Link travel time, delay • Number of stops per mile on route	• Pipeline • Manage queues • Prevent oversaturation • Handle incidents and events • Multiple objectives by TOD
• Traffic volume on route (throughput) • Time to process equivalent volume	• Pipeline • Manage queues • Prevent oversaturation • Handle incidents and events • Multiple objectives by TOD
• % arrivals on green, by link • V/C ratio by movement • Platoon ratio, by link • Phase green to occupancy ratio by movement • Reliability of phase metrics	• Pipeline • Access equity • Multiple objectives by TOD • Accommodate long-term variability

Intersection Delay



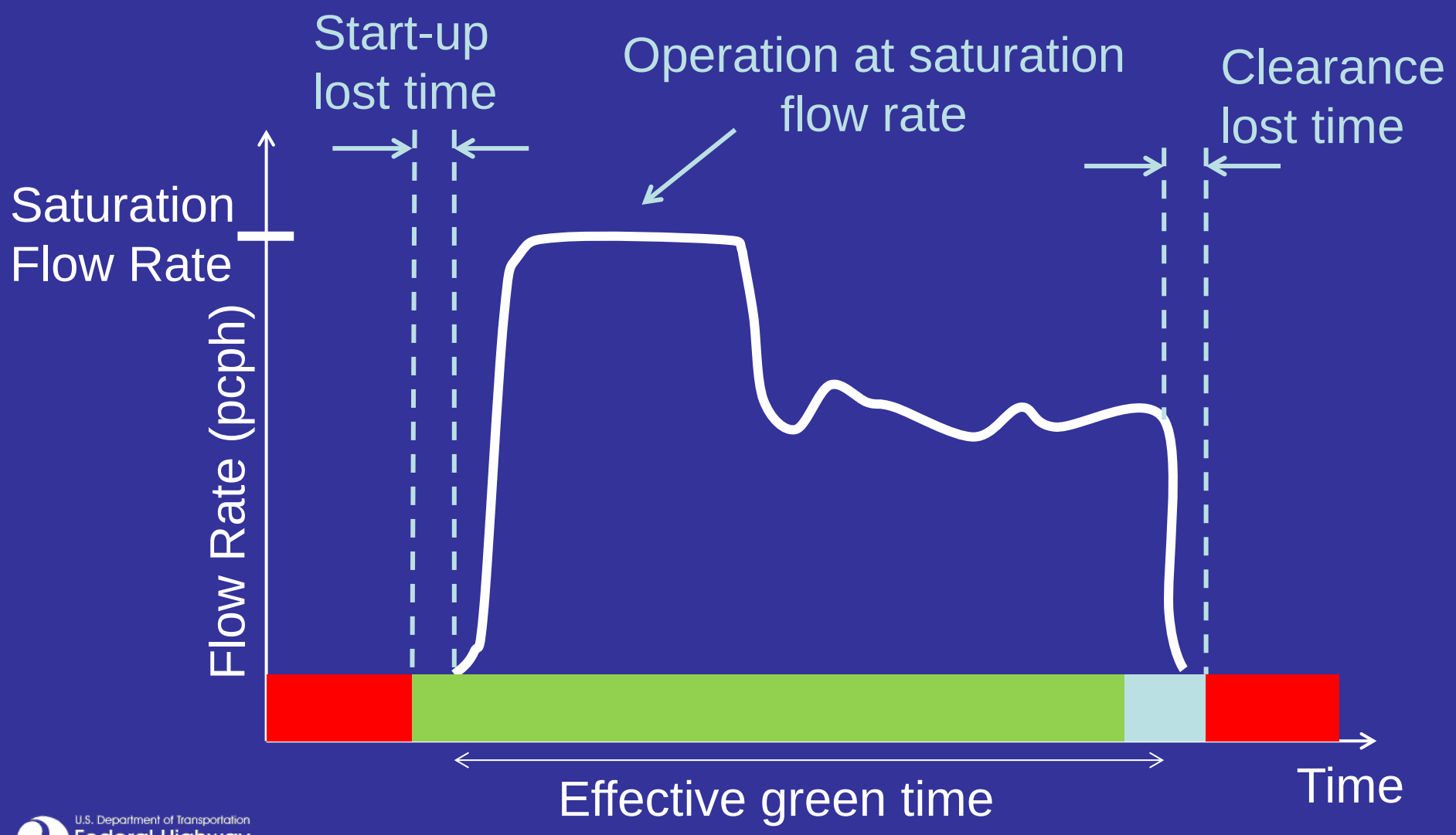
Estimation of Control Delay

- Highway Capacity Manual (HCM) methodology
- Track end of queue each cycle
- At regular intervals, record # of vehicles in queue
- Count total volume served
- Compute time-in-queue per vehicle and control delay

Queue Length

- Measure of physical space occupied by vehicles waiting to proceed
- Average queue
- 95th percentile queue
- HCM → back of queue

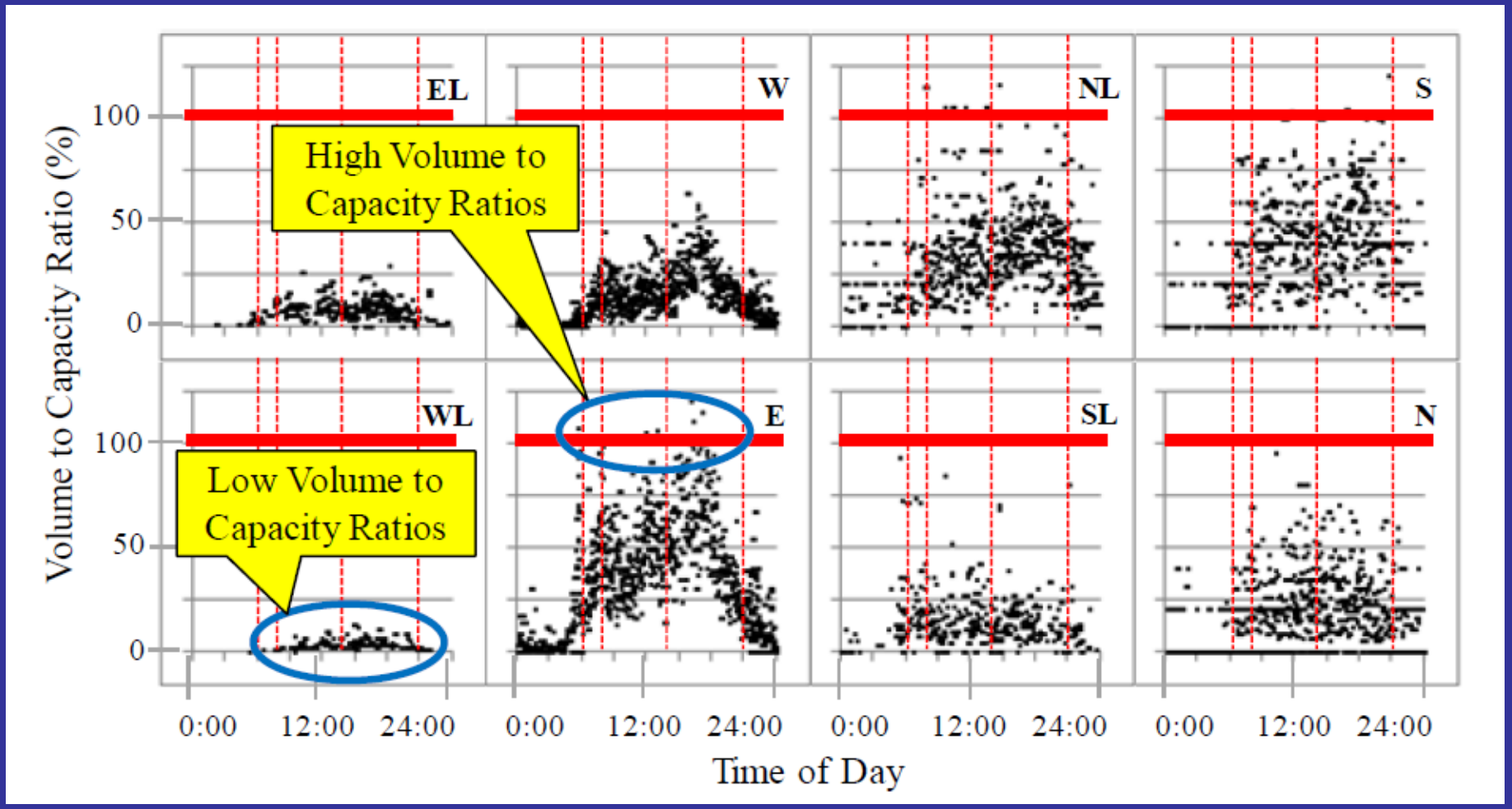
Saturation Flow Rate



Volume-to-Capacity (v/c) Ratio

- Measure of utilization of available capacity
- By lane group or intersection as a whole
- V/c ratios < 1.0 imply under saturated, > 1.0 imply oversaturated
- Low values of v/c imply potential wasted time
- To maximize throughput, ideal is around 0.85 to 0.95

Plots of v/c Ratio



Intersection Throughput

- Number of vehicles serviced at intersection
- Demand served versus demand present
- Time to resolve residual queues

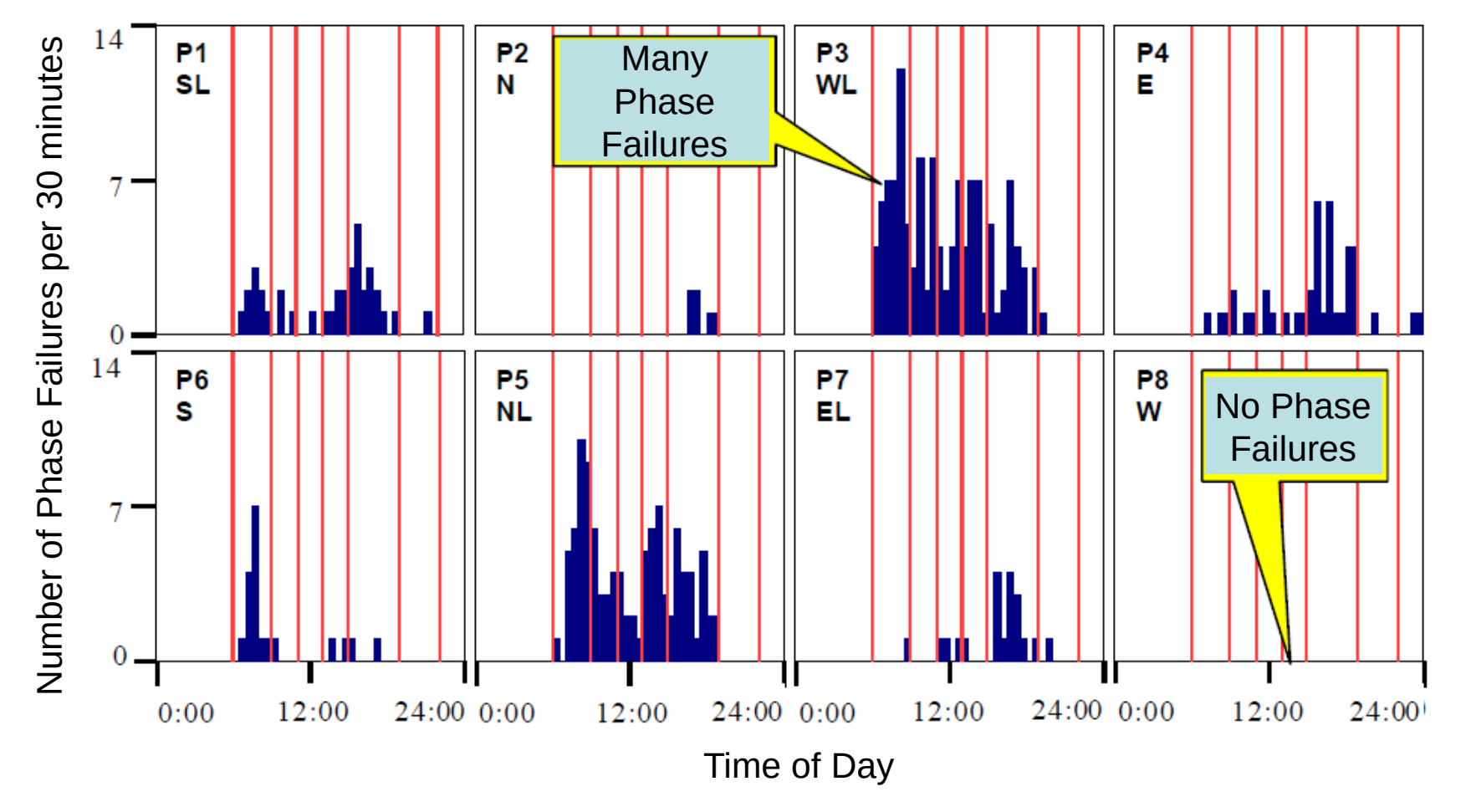
Other Common Performance Measures

- “Gap outs” and “max outs”
- Intersection sight distance
- Traffic counts

Common Controller Reports and Logs

- Phase status
- Event
- Detector status
- Communication
- Phase utilization
- Split
- Volume-to-capacity

Phase Failures



Corridor Throughput

- Number of vehicles traversing a roadway section in one direction per unit of time
- Evaluate ability to serve a given vehicular demand in a given period of time
- Doesn’t necessary tell whole story

Measures of Stops

- Number of stops → quality of progression
- Stops per mile → HCM measure
- High impact on emissions
- Driver frustration

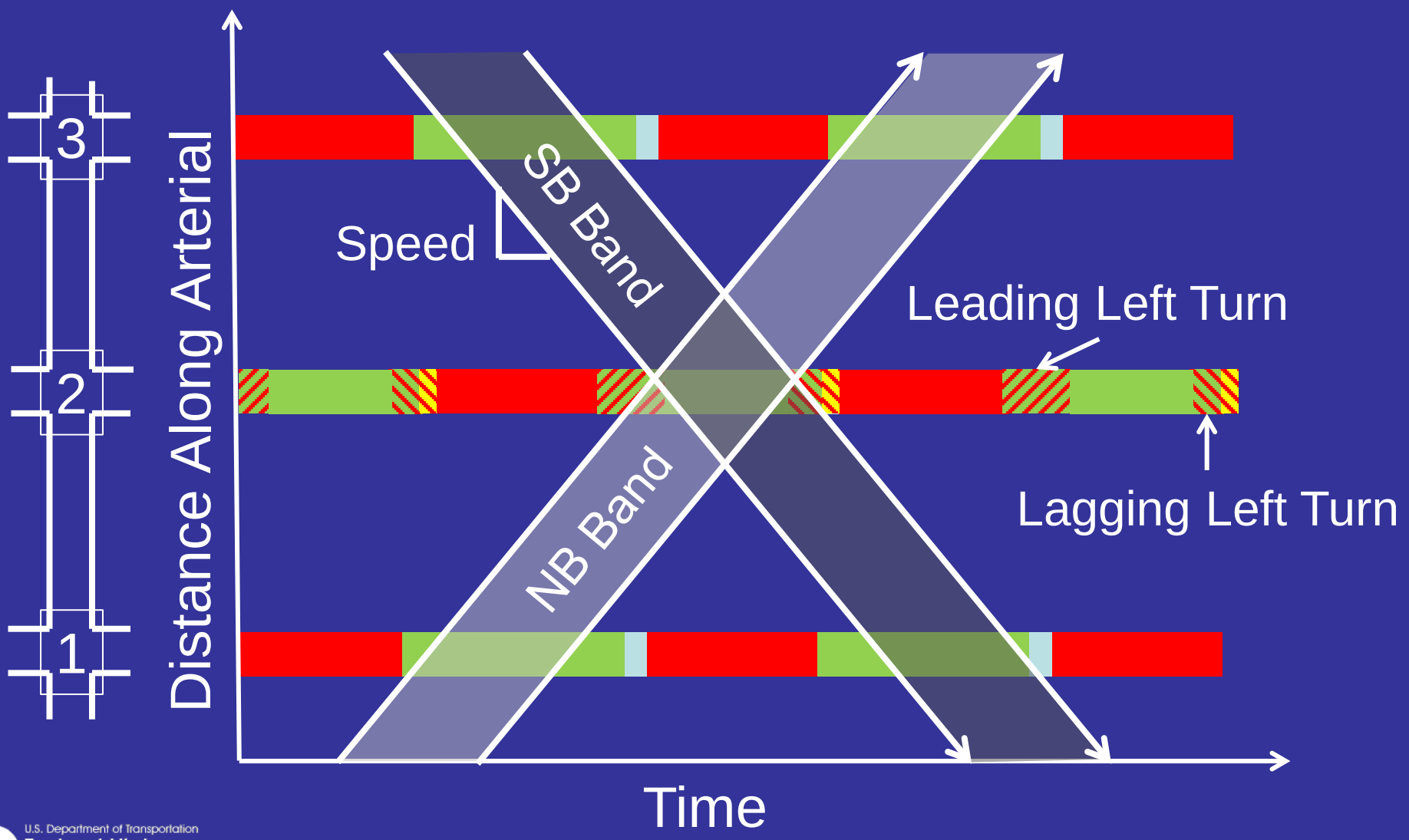
Travel Time

- Most popular measure of arterial performance
- Travel speed can be derived from it
- Transit running speed
- Bicycle and pedestrian travel speeds

Techniques for Measuring Travel Time

- Test Vehicles
- Floating car studies
- GPS-equipped probe
- Distance Measuring Instrument (DMI)
- Vehicle re-identification
- License-plate matching
- Bluetooth
- Cell phone/private data providers

Bandwidth

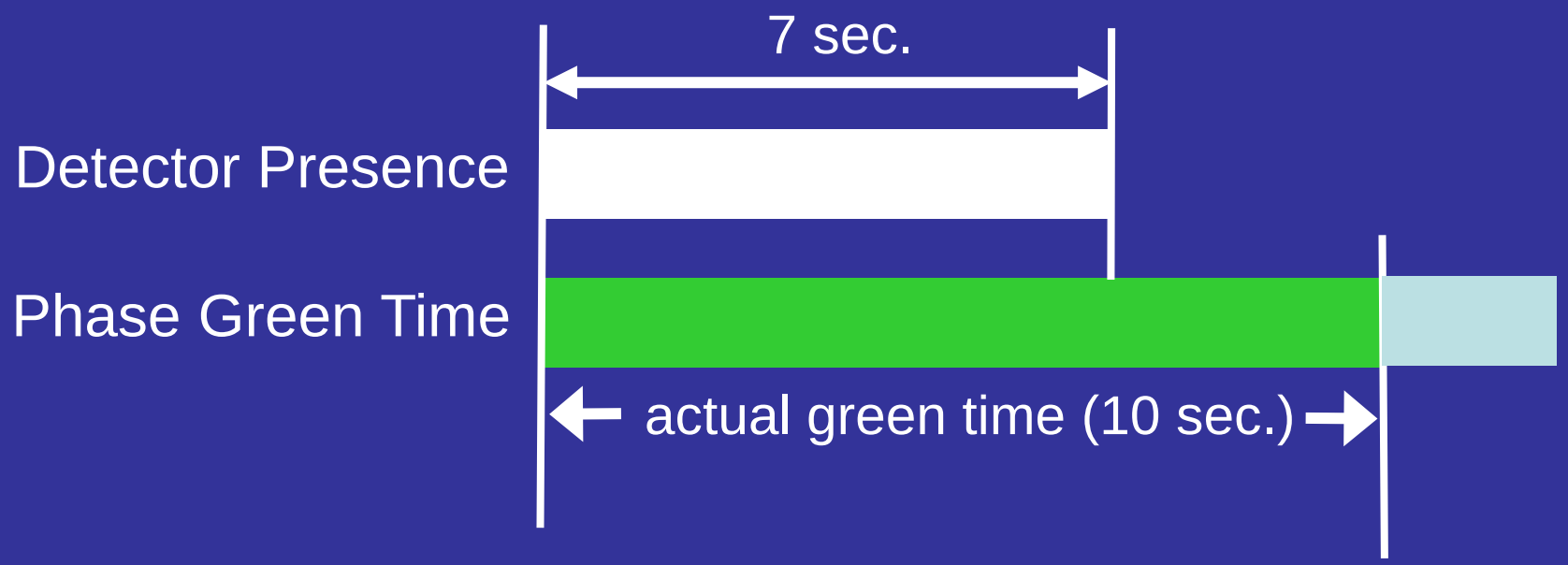

3
2
1
Distance Along Arterial
Speed
SB Band
NB Band
Leading Left Turn
Lagging Left Turn
Time

Quality of Progression – Bandwidth

- Bandwidth efficiency – average fraction of the cycle length used for progression
- Bandwidth attainability – how well the bandwidth makes use of the available green time
- Efficiency cannot exceed attainability

Phase (Green) Utilization

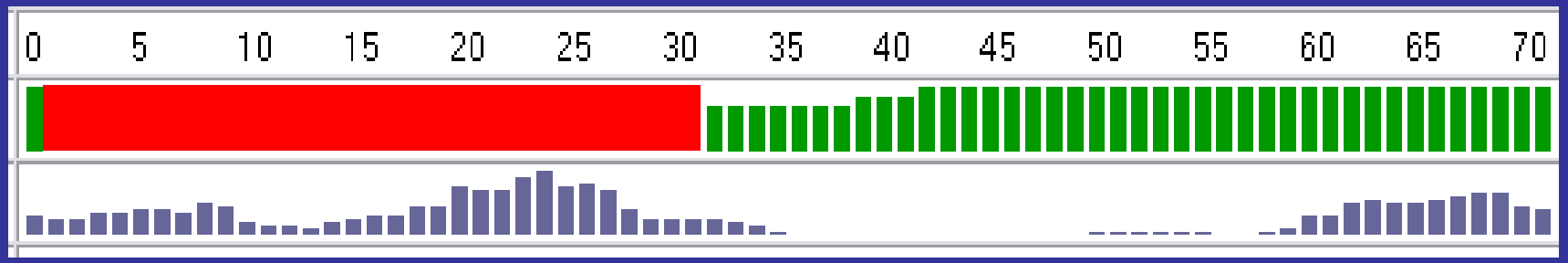
- Ratio of used green to available green



Green Utilization = 7 sec/10 sec = 70%

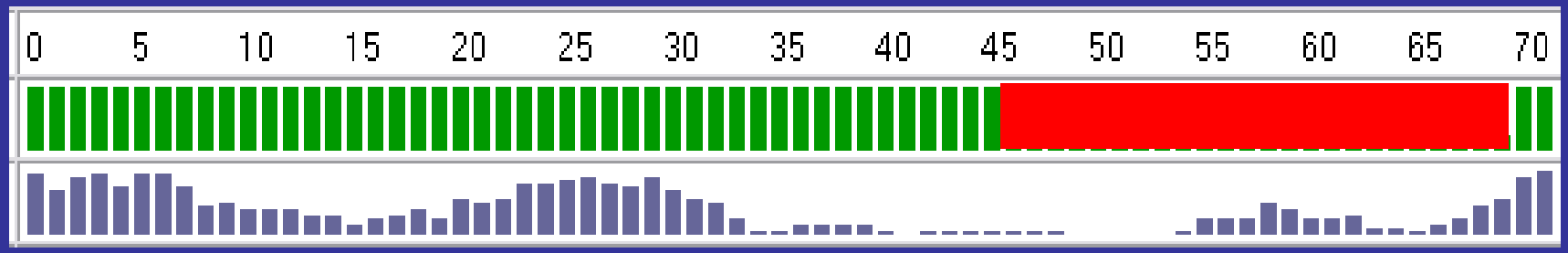
% Arrival on Green

Poor Progression

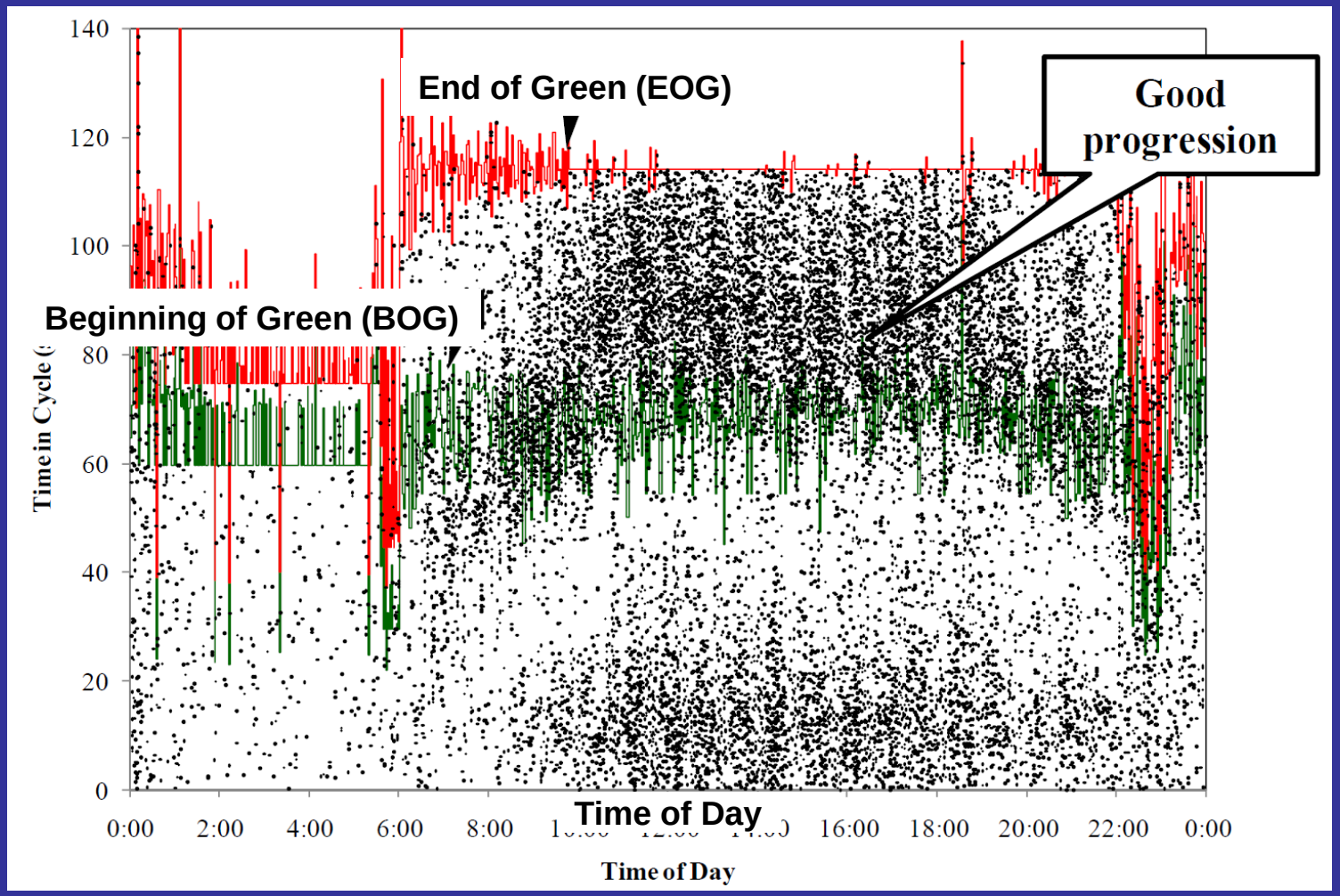


Arrivals

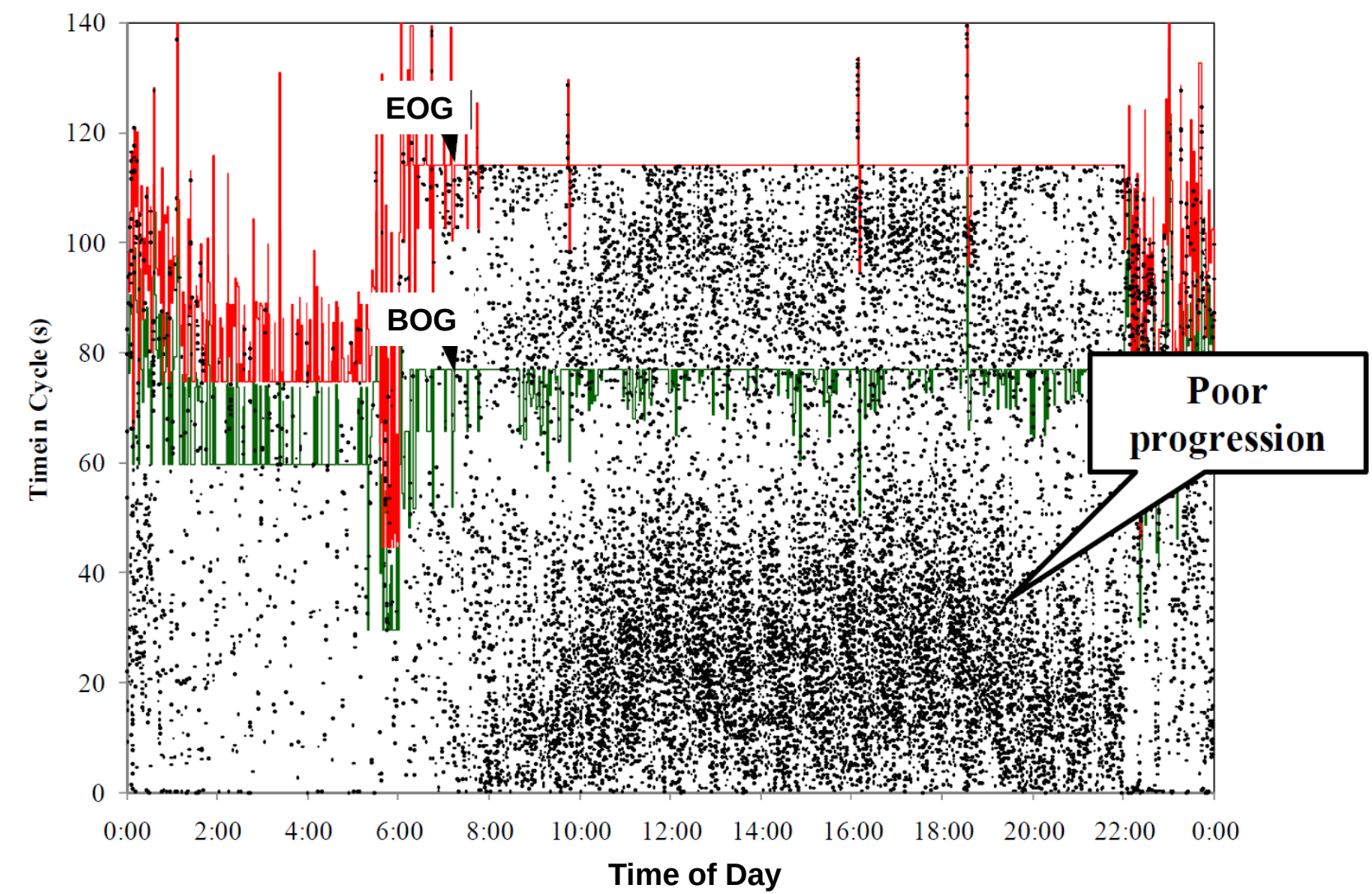
Good Progression



Purdue Coordination Diagram – Good Progression



Purdue Coordination Diagram – Poor Progression



Other Potential Measures

- Queue storage ratio by movement
- Total delay for all vehicles served by the system
- Number of street segments with spillback
- Duration of over-saturation
- Total travel time for all vehicles served by the system

Evaluation Document Online

- Measures of effectiveness and validation guidance for adaptive signal control technologies (ASCT)
- http://www.ops.fhwa.dot.gov/publications/fhwahop13031/index.htm

What did we discuss?

- Where to and not to install ASCT
- First Steps
- Operational objectives
- Planning and operations
- Systems engineering basics
- Federal regulations
- Using the Model SE for ASCT documents
- ASCT procurement
- ASCT performance monitoring

NHI Traffic Signal Courses

- Traffic Signal Design and Operation (133121)
- Traffic Signal Timing Concepts (133122)
- Systems Engineering for Signal Systems Including Adaptive Control (133123)
- Evaluating Performance of Traffic Signal Systems (133124)
- Successful Traffic Signal Management: The Basic Service Approach (133125)

Questions?

- http://www.ops.fhwa.dot.gov/

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