STRIDE
Workforce Development Summit

Session Workbook

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About the STRIDE Workforce Development Summit

U.S. Department of Transportation sponsored the first Workforce Development Summit through the Southeastern Transportation Research, Innovation, Development & Education Center (STRIDE) consortium housed in the University of Florida Transportation Institute (UFTI). The UFTI Technology Transfer (T2) Center, The Citadel, and Tennessee Technical University collaborated to plan, coordinate and deliver valuable sessions on traffic signal-related topics to form the first Workforce Development Summit. The goal of the Workforce Development Summit is to assist transportation agencies to address congestion. Prior to the summit, the STRIDE research teams identified the critical need for a robust workforce, knowledge transfer of retirees to incoming professionals, and technology-related education and training opportunities critical to an efficient and safe transportation network with multimodal infrastructure components. Summit sessions were held to develop the necessary skills in technology in the transportation field related to updated traffic signal systems, equipment, resources, and approaches.

UFTI-T2 hosted a pilot eight-day summit for working professionals as well as college students and those interested in transitioning to a career in transportation. Summit sessions were delivered through live instructor-led webinars held in May of 2023. Nine sessions included topics of transportation engineering fundamentals, traffic signal basics, equity fundamentals, uniform devices, traffic signal asset management, signal safety, capacity analysis, and signal timing. Recorded sessions are available for viewing at the UFTI-T2 center website: www.techtransfer.ce.ufl.edu.

Table of Contents

Course Outline with Session Objectives

Session 1 - Traffic Engineering Fundamentals **2 hours**

The Traffic Engineering Fundamentals course introduces the STRIDE Workforce Development Summit and familiarizes participants with basic traffic engineering vocabulary, concepts, and principles.

The course learning objectives include learning the fundamentals of the following topics:

- Characteristics of transportation systems
- Traffic descriptors, safety, and control devices
- Traffic data collections and visualizations

Session 2 - MUTCD Traffic Signals **3 hours**

The Manual on Uniform Traffic Control Devices Traffic Signals course introduces key principles of the uniform manual for practical application to intersections along public roads. Differences in past versions and the 2009 11th Edition Manual on Uniform Traffic Control Devices (MUTCD) are discussed. In addition, the proposed changes in the 12th edition of the MUTCD are also previewed by an active member of the National Committee on Uniform Traffic Control Devices (NCUTCD) which is responsible for formulating rules and recommendations to be incorporated into the MUTCD.

The course learning objectives include gaining knowledge of the following topics:

- Explain the history and purpose of the MUTCD
- Discuss 9 parts of the MUTCD
- Describe the differences between National and State of Florida standards
- Practical application of MUTCD concepts
- Discuss proposed changes to the MUTCD

Session 3 - Traffic Signal Systems Asset Management **3 hours**

The Traffic Signal Systems Asset Management course provides the fundamentals to develop and maintain a transportation asset management (TAM) program. Attendees will be presented with available tools to identify infrastructure assets like pavement, sidewalks, signs, drainage structures, guardrails, and green spaces.

The course learning objectives include reference of details on the following:

- Industry practices in transportation asset management programs
- Processes to ensure quality assurance and control in data collected and maintained
- Data necessary for a robust TAM program to be used for decision making
- Asset lifecycle through design to replacement
- Resources to develop goals, policies, and asset inventory

Course Outline with Session Objectives

Session 4 - Highway Safety Analysis of Traffic Signals and Their Timing 3 hours

The Highway Safety Analysis of Traffic Signals and their Timing course familiarizes participants with the Predictive Methods of the Highway Safety Manual and its application.

The course learning objectives include learning opportunities on the following topics:

- Fundamental concepts of safety and the importance of safety assessments
- Overview of Highway Safety Manual (HSM)
- HSM predictive methods and crash modification factors

Session 5 - Basic Traffic Signal Timing 2 hours

The Basic Traffic Signals Timing course is designed for those with an interest in a transportation career from a technician to an engineer. The course introduces topics in traffic signal fundamentals, timing, safety for signals, and efficiency methods to avoid congestion.

The course learning objectives include participants learning about the following topics:

- Describe how a traffic signal works
- Define key traffic signal timing terms
- Design safety intervals for traffic signals for motoring traffic and pedestrians
- Design efficiency intervals for traffic signal cycles

Session 6 - Intro to Transportation Equity 2 hours

The Intro to Transportation Equity course is designed for engineers, planners, policymakers, and professionals whose work intersects transportation policies and practices. Strategic equitable transportation planning will aid practitioners and decision-makers to mitigate potential adverse impacts of transportation projects on communities.

This course learning objectives provide participants with an insightful perspective on the following concepts:

- Types of equity and their implications
- Strategies to mitigate potential adverse impacts of transportation projects
- Effective and inclusive community outreach program
- Equitable Accessibility through AI in Transportation
- Case studies of successful initiatives and notable practices

Course Outline with Session Objectives

Session 7 - Traffic Signal Basics 14 hours

The Traffic Signal Basics course familiarizes participants with the configuration and operation of traffic signals. This course was designed for new signal technicians, engineers, and other municipal employees interested in an introduction to traffic signals.

The course learning objectives include the following topics:

- The purpose of traffic signals
- Traffic signal field infrastructure
- Basics of signal operations
- Controller programming
- Intersection performance monitoring
- Safety considerations
- Arterial performance monitoring

Session 8 - Highway Capacity Analysis with Signalized Intersections 3 hours

The Highway Capacity Analysis with Signalized Intersections introductory session includes lectures, software demonstrations, and application examples on the HCM 7th Edition procedures. Step-by-step instructions of methodologies, followed by application examples, are presented for different HCM chapters.

This course learning objects provides knowledge of the following learning outcomes:

- Understand the scope of HCM analyses for signalized intersections and urban streets
- Understand analysis inputs and interpret results
- Use the basics of Highway Capacity Software to perform HCM analysis

Session 9 - Advanced Traffic Signal Timing 2 hours

The Advanced Traffic Signal Timing course provides attendees with a brief review of Traffic Signal Timing Basics, common occurrences of congestion, design parameters for individual signals and complete networks, and techniques to manage congestion caused by traffic signal timing.

This course learning objectives provide participants with the opportunity to learn about the following topics:

- Identify the four causes of congestion
- Design traffic signal timing values for a congested intersection
- Design traffic signal timing values for a network of congested intersections
- Identify methods for managing queues in a network of congested intersections

Introduction

The University of Florida Transportation Institute's Technology Transfer (T2) Center, The Citadel, and Tennessee Technical University have collaborated to provide informative sessions on traffic signal-related topics during the Workforce Development Summit. These summit sessions started on May 9, 2023, and concluded on May 22, 2023. The Workforce Development Summit, sponsored by the U.S. Department of Transportation (DOT), features free webinars that include live instructor-led presentations.

These courses encompass various subjects within the realm of traffic engineering and signals. They are designed to equip administrators, professionals, and individuals seeking an introduction to advanced traffic engineering concepts with the necessary skills and knowledge. Participants can enhance their understanding of traffic engineering principles through interactive online sessions led by experienced instructors.

The Workforce Development Summit organized by STRIDE Center, aims to foster professional growth and promote the exchange of expertise in the field of traffic signal management. Attendees can take advantage of these valuable webinars to expand their knowledge base and stay up-to-date with the latest advancements in traffic engineering practices.

Webinar Organization

The 9-session webinar series was presented by approved instructors using curriculum materials including provided readings, demonstrations, and various visual aids such as computer-generated slides, flip charts, handouts, and similar tools.

This summit was divided into distinct sessions as shown in the Agenda section. The sessions were held over the span of multiple days from May 9, 2023, to May 22, 2023.

Class Size and Organization

In order to achieve the learning objectives for this course, the target maximum course size is 100 participants per unassisted instructor.

Target Audience

Session 1 Traffic Engineering Fundamentals: This course is designed for engineers, technicians, graduate, or undergraduate students, and generally any individual interested in the fundamentals of traffic engineering.

Session 2 MUTCD Traffic Signals: This workshop is designed for traffic engineers, road designers, construction inspectors, engineering consultants, construction engineers, traffic designers, maintenance supervisors, public works directors, elected officials, and those who reference the MUTCD.

Session 3 Traffic Signal Systems Asset Management: This introductory training is designed for those building a career within public agencies including elected officials, new engineers, transportation professionals, technicians, and those with a responsibility to maintain public assets within transportation networks.

Session 4 Highway Safety Analysis Traffic Signals and their Timing: The course is intended for those interested in transportation and civil engineering, technicians, and students with limited exposure to highway safety.

Session 5 Basic Traffic Signal Timing: The intended audience for this session includes: new hires in traffic signal operations, longer-term hires that want a refresher on basic traffic signal operations, administrators, managers, or anyone else who wants a basic grasp of how signal timing works, and engineering students and recent grads who are interested in a transportation career.

Session 6 Intro to Transportation Equity: This course is designed for engineers, planners, policymakers, and professionals whose work intersects transportation policies and practices.

Session 7 Traffic Signal Basics: This course is designed for engineers, technicians, or students interested in transportation and traffic signal operations with limited or no previous experience in traffic signal fundamentals.

Session 8 Highway Capacity Analysis with Signalized Intersections: This course is designed for engineering and planning professionals who wish to gain a deeper understanding of HCM methods and their applications.

Session 9 Advanced Traffic Signal Timing: The intended audience for this session includes: those who completed the Basic Signal Timing workshop and want exposure to advanced timing, especially related to operations in congested conditions, current signal technicians interested in advanced signal timing concepts, especially those related to operations in congested conditions, and administrators, managers, or anyone else who are looking for an introduction to advanced signal timing concepts, especially those related to operations in congested conditions.

Course Goals and Objectives

The overall goal of the summit is to deliver valuable sessions on traffic signal-related topics such as data analysis, signal interpretation, and traffic technology utilization during the Workforce Development Summit. Course objectives can be found in each session objective under the Course Outlines section.

Lesson Plans

The lesson plans are designed to involve the participants interactively in the learning process. The detailed, interactive lesson plans for the course sessions are presented in individual sessions. Attainment of each course objective is evaluated through discussion periods at the end of each session.

Agenda

Session No	Course Name	Date	Start Time (EST)	Duration
Session 1	Traffic Engineering Fundamentals	May 9, 2023	9:00 AM	2 hours
Session 2	MUTCD Traffic Signals	May 11, 2023	9:00AM	3 hours
Session 3	Traffic Signal Systems Asset Management	May 12, 2023	9:00AM	3 hours
Session 4	Highway Safety Analysis Traffic Signals and their Timing	May 12, 2023	1:00PM	3 hours
Session 5	Basic Traffic Signal Timing	May 15, 2023	9:00AM	2 hours
Session 6	Intro to Transportation Equity	May 15, 2023	1:00PM	3 hours
Session 7	Traffic Signal Basics	May 16 & May 17, 2023	9:00AM	12 hours
Session 8	Highway Capacity Analysis with their Signalized Intersections	May-19, 2023	9:00AM	3 hours
Session 9	Advanced Traffic Signal Timing	May 22, 2023	9:00AM	2 hours

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Training Slides

Traffic Engineering Fundamentals


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Session 1
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Course Schedule
https://techtransfer.ce.ufl.edu/training/stride-workforce-development-summit/
MUTCD Traffic Signals Overview May 11
Traffic Signal Systems Asset Management May 12
Highway Safety Analysis Traffic Signals and their Timing May 12
Basic Traffic Signal Timing May 15
Transportation Equity Fundamentals May 15
Traffic Signal Basics May 16-17
Highway Capacity Analysis with Signalized Intersections May 19
Advanced Traffic Signal Timing May 22
Traffic Engineering Fundamentals Kickoff Summit May 9
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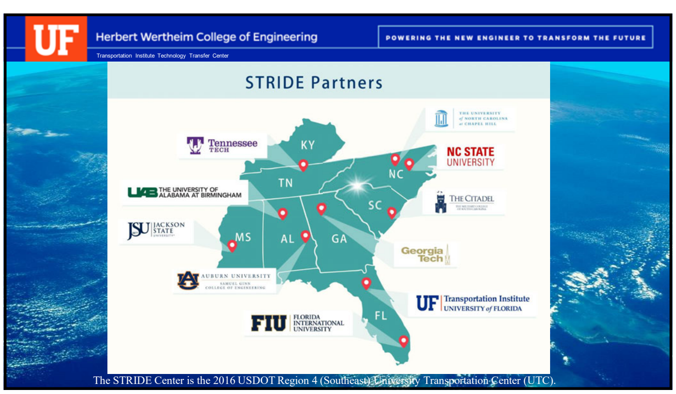
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AUBURN UNIVERSITY
FIU FLORIDA INTERNATIONAL UNIVERSITY
NC STATE UNIVERSITY
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The STRIDE Center is the 2016 USDOT Region 4 (Southeast) University Transportation Center (UTC).

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Traffic Engineering Fundamentals
Dr. Dimitra Michalaka
Associate Professor
Civil, Environmental, and Construction Engineering
The Citadel
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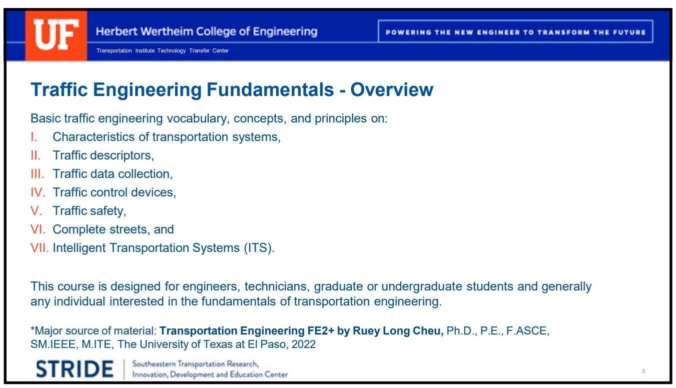
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Traffic Engineering Fundamentals - Overview
Basic traffic engineering vocabulary, concepts, and principles on:
I. Characteristics of transportation systems,
II. Traffic descriptors,
III. Traffic data collection,
IV. Traffic control devices,
V. Traffic safety,
VI. Complete streets, and
VII. Intelligent Transportation Systems (ITS).
This course is designed for engineers, technicians, graduate or undergraduate students and generally any individual interested in the fundamentals of transportation engineering.
*Major source of material: Transportation Engineering FE2+ by Ruey Long Cheu, Ph.D., P.E., F.ASCE, SM.IEEE, M.ITE, The University of Texas at El Paso, 2022
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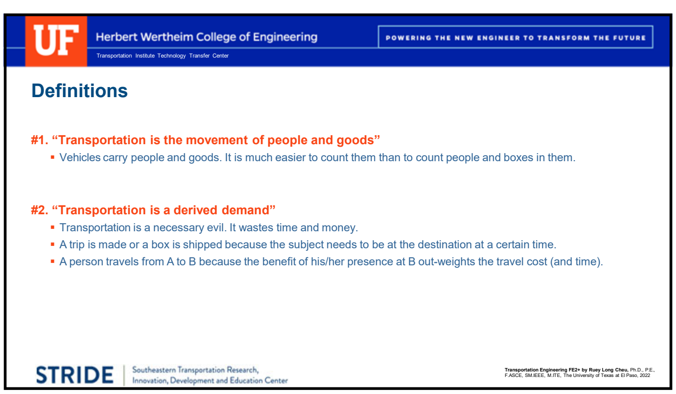
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Definitions
#1. "Transportation is the movement of people and goods"
• Vehicles carry people and goods. It is much easier to count them than to count people and boxes in them.
#2. "Transportation is a derived demand"
• Transportation is a necessary evil. It wastes time and money.
• A trip is made or a box is shipped because the subject needs to be at the destination at a certain time.
• A person travels from A to B because the benefit of his/her presence at B out-weights the travel cost (and time).
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Definitions

#3. "A transportation system has four interacting components: the users, the vehicles, the infrastructures, and the policies."

- Users: drivers, passengers, shippers, receivers, service providers
- Vehicles: cars, buses, trucks, trains, bicycles, aircraft, vessels, etc.
- Infrastructures: highways, airports, ports, bus stops, depots, etc.
- Policies: design standards, traffic rules, etc.

#4. "Transportation engineering is the application of scientific principles and data-driven approaches in the planning, design, construction, operations, maintenance, and management of transportation systems and their infrastructures."

- Goals: safe, efficient, sustainable

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I. Characteristics of Transportation Systems

Transportation Engineering interesting discipline because:

- Multidiscipline:
  - Everyone is an "expert".
- Human factors:
  - Inconsistent, unpredictable.
- Political factors:
  - Engineering decision vs political decision.
- Media:
  - Reports in TV, newspaper, Internet.
- Customer service:
  - Customer complaints, public involvement.

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I. Characteristics of Transportation Systems

- Networks:
  - Nodes (terminals) and links (highways, routes).
- Dynamic:
  - Demand = function of time (hour, day, month).
  - Supply = function of time (depends on the system).
  - Outcome of demand-supply interaction.
- Geographical spread.
- Open to numerous users, stakeholders:
  - Consequence of failure.
  - Non-deterministic human behavior.

https://www.searates.com/blog/post/world-transport-system-and-logistics-the-main-directions-of-development

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I. Characteristics of Transportation Systems

- Openness and accessibility:
  - Designed and organized for efficient, convenient, and expeditious movement of large volumes.
- Extent and ubiquity:
  - Require vast amounts of physical infrastructure and assets.
- Emphasis on efficiency and competitiveness:
  - Driven by the demands of private users.
- Diversity of owners, operators, users, and overseers:
  - Controlled by thousands.
- Entwinement in society and the global economy:
  - Movement of products and commodities.

National Academies of Sciences, Engineering, and Medicine. 2002. Making the Nation Safer: The Role of Science and Technology in Countering Terrorism. Washington, DC: The National Academies Press. https://doi.org/10.17226/10415.

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Transportation Modes

Person-highway/surface/land		Person-others	Freight
Private	Public		
Car (drive alone)	Bus (regular bus transit)	Air	Truck
Car (carpool, get a ride)	Bus rapid transit	Commuter rail	Freight train
Motorcycle	Light rail transit	Intercity rail	Air
Bicycle	Mass rapid transit	Ferry	Ship
Walking	Tram		
	Taxi		
	Ridesharing		
	Carsharing		
	Bike sharing		

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Stakeholders

Regulators	Service providers	End users
Federal departments, agencies State departments, agencies Regional agencies County, city, and local agencies	Bus companies Mass transit companies Taxi companies Ridesharing companies Parcel/express delivery companies Trucking companies Airlines Train companies Shipping lines	Travelers Shippers, recipients
Law enforcement agencies	Vehicle manufacturers, dealers Parts suppliers Fuel companies Traffic control equipment manufacturers Consulting engineers, planners Educators Researchers Insurance providers	Special interest groups Professional organizations

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II. Traffic Descriptors

a) Microscopic.
b) Macroscopic.
c) Steady state macroscopic traffic flow.
d) Microscopic and macroscopic relationships.

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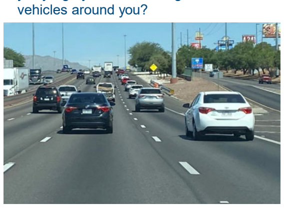
II.a) Driver's Perception of Traffic

- Imagine you are driving a vehicle. How do you judge your own driving and the vehicles around you?



- Your speed:
  - Speed
- Distance between you and the car ahead:
  - Distance Headway/Spacing/Gap
- Time (seconds) the car ahead has passed:
  - Headway/Time Headway
- These above are microscopic (individual vehicle level) descriptors.

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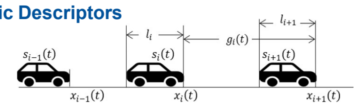
II.a) Microscopic Traffic Descriptors



Microscopic descriptors	Notation	Formula	Unit
Vehicle length	l_i	-	ft, m
Position	$x_i(t)$	-	ft, m
Speed	$s_i(t)$	-	ft/s, mph, m/s, km/h
Spacing/Gap	$g_i(t)$	$x_{i+1}(t) - x_i(t)$	ft, m
Headway	$h_i(t)$	$\frac{x_{i+1}(t) - x_i(t)}{s_i(t)}$	s

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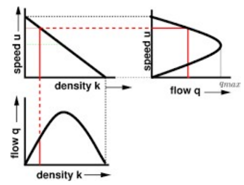
II.b) Macroscopic Descriptors

- Big picture of traffic stream.
- Condition of traffic.
- Quantify with macroscopic descriptors:
  - Volume.
  - Speed.
  - Density.



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Volume, V

- Vehicles that pass by a certain point of the road over a time interval ➔ volume, V.
- Typical count time interval is 15 minutes.
- Standard unit of V is vehicles per hour (veh/h) or vehicles per hour per lane (veh/h/ln).
- Volume may be counted for both directions combined, or all lanes in one direction. Read the data description carefully.
- Final number is usually rounded to the nearest integer value.

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Volume, V - Examples

- Example 1: What is the Volume (veh/hr) equal to if you counted 160 vehicles in 15 minutes?
- Example 2: What is the Volume (veh/hr) if you counted 135 vehicles in 15 minutes in one direction of a street that has 2 lanes?

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Volume, V

- Sometimes the numbers of cars and trucks are counted separately.
- If the total number of vehicles (cars+trucks) is of interest, V is expressed in veh/h or veh/h/ln.
- If trucks are converted to cars equivalent, V is expressed in passenger cars per hour (pc/h) or passenger cars per hour per lane (pc/h/ln).

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Volume, V – Examples (Contd.)

- Example 3: Calculate the volume in pc/h/ln if in one direction of a highway if you counted 224 cars and 35 trucks in 15 minutes. Assume 1 truck is equivalent to 2.5 cars.
- The conversion factor 2.5 is called passenger car equivalency factor for truck (E_T).
  - # of trucks × E_T ➔ equivalent # of passenger cars .
- Remember
  - In urban streets max V is 1800 pc/h/ln.
  - In rural highways, max V is 2000 pc/h/ln.
  - In urban freeways, max V is 2200 to 2500 pc/h/ln.

These are approximate values

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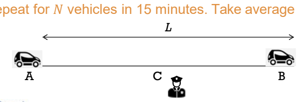
Speed, S

- Most drivers relate to and use speed to determine traffic conditions.
- Speed here means average speed.
- Standard unit: mph or mi/h.
- 2 ways of measuring average speed:
  - Stand at the same spot C, use a device to measure spot speed of all N vehicles in 15 minutes. From individual speeds s_i for $i = 1, \ldots, N$, take average,
  - Mark points A and B at distance L apart. Record t_i, time for vehicle i to travel from A to B. Calculate speed $s_i' = L\text{T}t_i$. Repeat for N vehicles in 15 minutes. Take average of s_i' for $i = 1, \ldots, N$.
  - Which way is better?



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Speed, S

Time-mean speed, S_t

- $S_t = \frac{\sum_{i=1}^{N} S_i}{N}$.
- $S_i, i = 1 \ldots, N$, are measured at the same spot.
- If S_i is constant over a distance L, then $S_i = \frac{L}{t_i}$, and $S_t = S_S$ (see S_S ➔)

Space-mean speed, S_s

- Ave. speed of N vehicles over same distance L.
- $S_s = \frac{1}{N}\sum_{i=1}^{N}\frac{L}{t_i} = \frac{1}{N}\sum_{i=1}^{N} s_i'$.
- Can be estimated from harmonic mean of S_i.
- $S_s = \frac{1}{\frac{1}{N}\sum_{i=1}^{N}\frac{1}{S_i}}$.
- $S_t \geq S_s$.
- $S_t = S_s$ only if $S_t = S_s = S_i$ for all i.

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Speed, S – Example

- 4 vehicles, $S_i = 45, 50, 54, 61$ mph.

$$S_t = \frac{\sum_{i=1}^{N} S_i}{N}$$

- $S_t = \frac{1}{4}[45 + 50 + 54 + 61] = 52.5$ mph

$$S_s = \frac{1}{\frac{1}{N}\sum_{i=1}^{N}\frac{1}{S_i}}$$

- $S_s = \frac{1}{\frac{1}{4}\left[\frac{1}{45}+\frac{1}{50}+\frac{1}{54}+\frac{1}{61}\right]} = 51.9$ mph

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Density, D

- In physics, density is mass per unit volume.
- In traffic, density D is no. of vehicle units per unit length of a road.
- Standard unit: pc/mi/ln, veh/mi/ln.
- Maximum D ➔ jam density D_j.
- Max D is limited by the length of vehicle:
  - If min length of a car is 16 ft from bumper to bumper,1 mile can fit 5280/16 = 330 pc/mi/ln.
  - In practice D_j = 200 to 220 pc/mi/ln, because of min. space between 2 vehicles.
- Density is hard to measure, e.g., satellite photo.

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II.c) Steady State Condition

If we assume that V, D, S remain constant during the measurement interval → steady state condition.

- $V = D * S$
  - V is in pc/h/ln, D is in pc/mi/ln, S is in mph.

Since V and S are easier to measure than D → knowing V and S, $D = \frac{V}{S}$ can be solved.

- Steady state → all vehicles are the same, behave the same.
- Steady state 1-lane traffic, all cars no truck:
  - V → cars arrives at uniform (fixed) time intervals.
  - D → all cars of the same length, keeping the same following distance.
  - S → $S_i = S_t = S_s$ → all cars move at the same speed.
  - Cars move in a convoy like a train of infinite length, no lane change.

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II.d) Microscopic-Macroscopic Relationships

- Volume $V = \frac{N}{T}$, headway $h = \frac{T}{N}$ → $V = \frac{1}{h}$
- Density $D = \frac{N}{L}$, gap $g = \frac{L}{N}$ → $D = \frac{1}{g}$
- In steady state condition, microscopic speed $s_1(t) = s_2(t) = \cdots = s_N(t) = s$, then macroscopic speed $S = s$.

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III. Traffic data collections and visualizations

- Volume
  - Vehicle types
  - Average Annual Daily Traffic (AADT)
  - Design Hourly Volume (DHV), K and D factors
  - Intersection turning counts
  - Peak Hour Factor (PHF)
- Travel time
- "active" test vehicle techniques
- license plate matching techniques
- "passive" ITS probe vehicle techniques
- emerging and non-traditional techniques

- Vehicle detection systems
  - Inductive loop detectors
  - Tube counters
  - Video detection systems
  - Concept of detections and measurements

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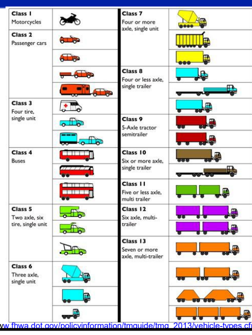
Vehicle Types

- FHWA classifies vehicles into 13 classes.
- Most automated counting devices are able to count in these 13 classes.
- For practical purpose, we usually count vehicles in 2 or 3 classes:
  - 2 classes: passenger cars (including motorcycles), trucks (including buses).
  - 3 classes: passenger cars (including motorcycles), light trucks, heavy trucks (including buses).
- The difference between light trucks and heavy trucks are 2 versus >2 axles.



https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_2013/vehicle-types.cfm

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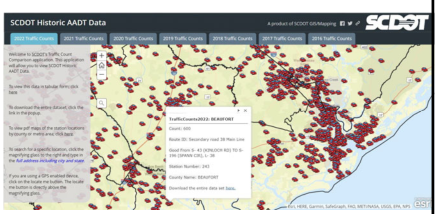
Average Annual Daily Traffic (AADT)

- AADT is used to classify road types.
- FHWA has 4 major road function classifications: interstates, arterials, collectors, and local roads.
- AADT's unit is veh/day
  - Count for 365 days in a year then take average of 365 days ➔ average annual.



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Design Hourly Volume, K, and D factors

- DHV (veh/hr) is the 30th highest hourly volume of the target/design year.
- K factor is the proportion of AADT on a roadway segment or link during the Design Hour, i.e. the hour in which the 30th highest hourly traffic flow of the year takes place.
- The K factor is given by, DHV = K * AADT
- D is the proportion of DHV occurring in the heavier direction, and is called the Directional Split.
- $D \geq 0.5$
- The Directional Design Hourly Volume, denoted by DDHV, is given by, DDHV = D * DHV

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K and D Factor Ranges

Facility Type	K Factor	D Factor
Rural	0.15 – 0.25	0.65 – 0.80
Suburban	0.12 – 0.15	0.55 – 0.65
Urban	0.07 – 0.12	0.50 – 0.60

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Intersection Turning Counts

- Important inputs in the design of signal timing plan.
- Each approach can have up to 4 turning movements: U-turn, left turn, through, right turn.
- Count all possible movements at all the approaches.
- Record the counts at 15-minute intervals.
- May or may not distinguish vehicle types.
- Two-way pedestrian count at the sidewalk parallel and next to the through movement are also recorded as the fifth movement of the approach.

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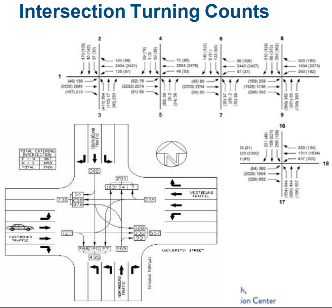
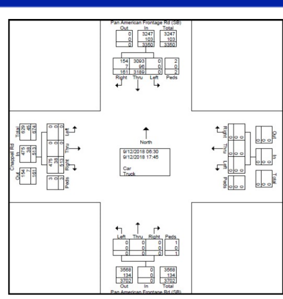
Intersection Turning Counts





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Peak Hour Factor (PHF)

- Many transportation engineering design problems use 15-minute volume as input.
- One hour has four 15-minute intervals. The highest 15-minute volume is used in the design.
- That is, the system is designed for the highest 15-minute demand within the peak hour.
- PHF converts one hour volume into 15-minute design volume.
- $PHF = \frac{V}{4 \times V_{15}}$
- V is the hourly volume (veh/h).
- V_{15} is the highest 15-minute count (veh/15-minute).

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Peak Hour Factor (PHF) – Example

- Calculate the PHF given the following data:

Solution

- Peak Hour 5-6 pm, V=2550 veh/hr
- V15=700 veh
- PHF = 2550/(700*4) = 0.911

- $0.25 < PHF \leq 1$.

Traffic Counts on Urban Arterial

Time	Volume (veh)
4:30-4:45 pm	600
4:45-5:00 pm	500
5:00-5:15 pm	600
5:15-5:30 pm	700
5:30-5:45 pm	650
5:45-6:00 pm	600
6:00-6:15 pm	500

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Travel Time

Table 2-5. Qualitative Comparison of Travel Time Data Collection Techniques

Technique	Initial or Capital Costs	Operating Costs (per unit of data collected)	Required Skill or Knowledge Level	Data Reduction and/or Processing	Route Flexibility	Accuracy and Representativeness[a]	Sampling Rate		
							Time	Space	Vehicles
Test Vehicle									
Manual	low	high	low	poor	excellent	fair	low	moderate	low
DMI	moderate	moderate	moderate	good	excellent	good	low	high	low
GPS	moderate	moderate	moderate	good	excellent	good	low	high	low
License Plate Matching									
Manual	low	high	low	poor	good	fair	low	low	moderate
Portable Computer	moderate	moderate	moderate	good	good	good	moderate	low	high
Video with Manual Transcription	low	moderate	moderate	fair	fair	excellent	high	low	high
Video with Character Recognition[b]	high	low	high	good	fair	excellent	high	low	high
ITS Probe Vehicle[c]									
Signpost-Based	high	moderate	high	good	poor	good	moderate	low	low
AVI	high	low	high	good	poor	excellent	high	low	moderate
Ground-based Radio Navigation	high	low	high	fair	good	good	moderate	moderate	moderate
GPS	moderate	low	high	fair	good	good	moderate	high	moderate
Cellular Phone Tracking	high	low	high	fair	good	good	high	moderate	moderate

https://www.fhwa.dot.gov/ohim/tvtw/natmec/00020.pdf

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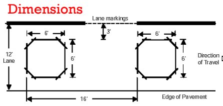
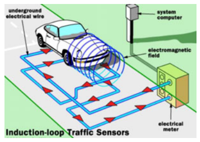
Vehicle Detection Systems

- Inductive Loop Detectors

Dimensions





- Tube or Pneumatic Counters

- Video Image Detection (VID)

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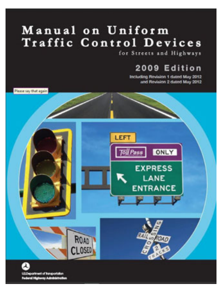
IV. Traffic Control Devices

- All devices (signals, signs, markings, etc.) used to regulate, warn, or guide traffic.
- Basic requirements for effectiveness:
  - Fulfill a need.
  - Command attention.
  - Convey a clear, simple meaning.
  - Command respect from road users.
  - Give adequate time for proper responses.

MUTCD

"On November 15, 2021, President Biden signed into law the *Infrastructure Investment and Jobs Act* which directs USDOT to **update the MUTCD** by no later than May 15, 2023, and at least every 4 years thereafter. FHWA is working to issue the 11th Edition of the MUTCD within the statutory timeframe and, thereafter, regular updated editions to keep pace with innovation and current practices and, in accordance with the new statutory language, to promote the safety, inclusion, and mobility of all road users."



https://mutcd.fhwa.dot.gov/index.htm

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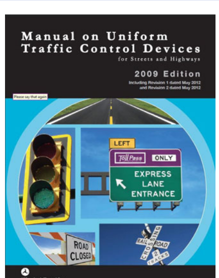
IV. Traffic Control Devices

MUTCD

- Design
- Placement
- Operation
- Maintenance
- Uniformity
- Request

Let's take a look : https://mutcd.fhwa.dot.gov/pdfs/2009r1r2r3/pdf_index.htm



https://mutcd.fhwa.dot.gov/index.htm

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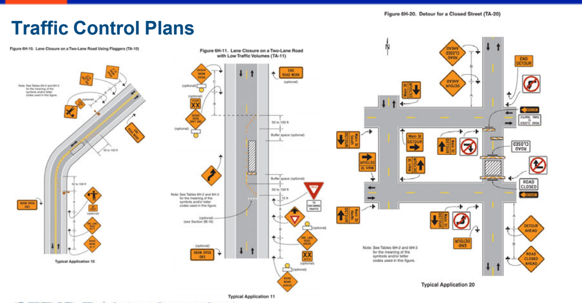
Traffic Control Plans



From TxDOT

https://www.charleston-sc.gov/387/Typical-Traffic-Control-Plans

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V. Traffic Safety

- Vision Zero
- Highway Safety Improvement Program
- Highway crash reports and databases
- Crash risk indicators
- Crash countermeasures
- Traffic calming

- Important: ~~accident~~ → CRASH
  DO NOT USE THE WORD ACCIDENT. INSTEAD USE CRASH.

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Vision Zero

VISION ZERO NETWORK

- https://visionzeronetwork.org/about/what-is-vision-zero/

TRADITIONAL APPROACH		VISION ZERO
Traffic deaths are **INEVITABLE**		Traffic deaths are **PREVENTABLE**
PERFECT human behaviour	VS	Integrate **HUMAN FAILING** in approach
Prevent **COLLISIONS**		Prevent **FATAL AND SEVERE CRASHES**
INDIVIDUAL responsibility		**SYSTEMS** approach
Saving lives is **EXPENSIVE**		Saving lives is **NOT EXPENSIVE**

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Zero Deaths and Safe System
THE
SAFE
SYSTEM
APPROACH
Zero is our goal. A Safe System
is how we get there.
https://highways.dot.gov/safety/zero-deaths
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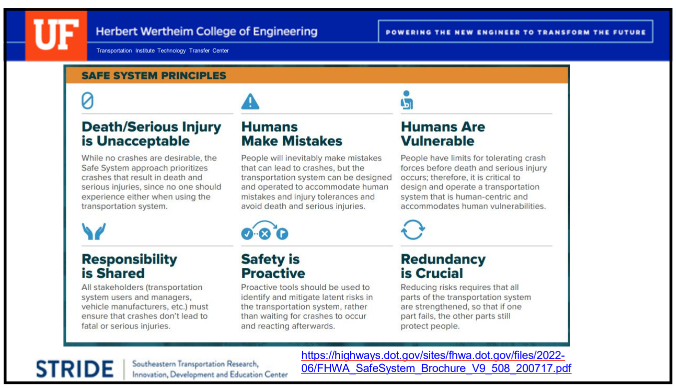
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SAFE SYSTEM PRINCIPLES
Death/Serious Injury is Unacceptable
While no crashes are desirable, the Safe System approach prioritizes crashes that result in death and serious injuries, since no one should experience either when using the transportation system.
Humans Make Mistakes
People will inevitably make mistakes that can lead to crashes, but the transportation system can be designed and operated to accommodate human mistakes and injury tolerances and avoid death and serious injuries.
Humans Are Vulnerable
People have limits for tolerating crash forces before death and serious injury occurs; therefore, it is critical to design and operate a transportation system that is human-centric and accommodates human vulnerabilities.
Responsibility is Shared
All stakeholders (transportation system users and managers, vehicle manufacturers, etc.) must ensure that crashes don't lead to fatal or serious injuries.
Safety is Proactive
Proactive tools should be used to identify and mitigate latent risks in the transportation system, rather than waiting for crashes to occur and reacting afterwards.
Redundancy is Crucial
Reducing risks requires that all parts of the transportation system are strengthened, so that if one part fails, the other parts still protect people.
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https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/FHWA_SafeSystem_Brochure_V9_508_200717.pdf

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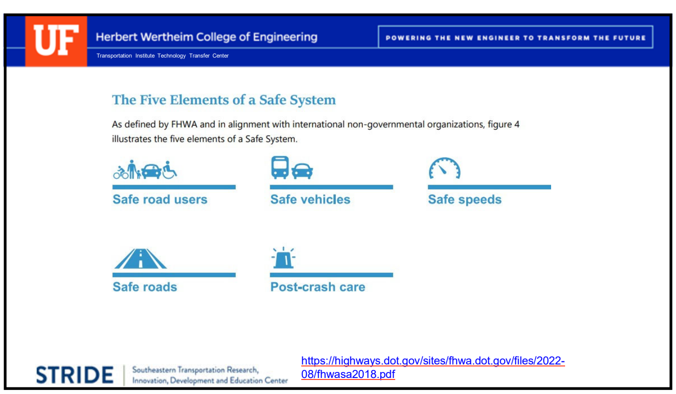
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The Five Elements of a Safe System
As defined by FHWA and in alignment with international non-governmental organizations, figure 4 illustrates the five elements of a Safe System.
Safe road users
Safe vehicles
Safe speeds
Safe roads
Post-crash care
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https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-08/fhwasa2018.pdf

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Highway Safety Improvement Program (HSIP)

- National effort authorized by the past and present Transportation Bills.
- FHWA provides annual HSIP funding and training resources
- Each state DOT has its own HSIP to distribute funds to projects within its state.
- As part of the mechanism to distribute the HSIP funds, the FHWA has established a Safety Performance Management program.

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Highway Safety Improvement Program (HSIP)

- This program requires all the state DOTs to report the following five crash risk indicators to FHWA every year:
  1. Number of fatalities per year in the past five years.
  2. Fatalities RVMT in the past five years.
  3. Number of serious injuries per year in the past five years.
  4. Serious injuries RVMT in the past five years.
  5. Number of non-motorized fatalities and serious injuries per year in the past five years.
- To request financial support for a safety improvement project, a local agency, city, county, or state DOT must submit a project proposal that includes safety/crash analysis, along with the five crash risk indicators.

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Integrating the Safe System Approach with the Highway Safety Improvement Program

- https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-08/fhwasa2018.pdf

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Active Safety and Passive Safety

Active safety - Focuses on prevention.

- User:
  - Driver education (defensive driving course).
  - Law enforcement.
- Vehicle:
  - Annual safety inspection.
  - Adjustable headlight, antilock brakes.
  - Collision warning.
  - Speed limiter.
  - Tire pressure monitoring.
  - CAV.
- Road:
  - Design code and practice.
  - Road safety audit.

Passive safety - Focuses on after the crash.

- User:
  - Legal action.
- Vehicle:
  - Seat belts.
  - Airbags.
- Road:
  - Traffic calming.

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Average Economic Cost by Injury Severity or Crash, 2021

Death (K)	$1,778,000
Disabling (A)	$155,000
Evident (B)	$40,000
Possible (C)	$24,000
No injury observed (O)	$6,700
Property damage only (cost per vehicle)	$5,700

https://injuryfacts.nsc.org/all-injuries/costs/guide-to-calculating-costs/data-details/

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Crash Reports and Databases

- HSIS (Highway Safety Information Systems):
  - Crash records, highway inventory (geometric designs), volume data from several states, e.g., CA, IL, NC, MN, WA.
- FARS (Fatality Analysis Reporting System) by NHTSA:
  - U.S. national data set.
  - All fatality cases from police reports.
- GES (General Estimates System):
  - U.S. national data set.
  - Sample of 45,000 police reports per year.
  - Includes all kinds of crashes.

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Crash Risk Indicators

- Usually expressed as "rate", i.e., no. of occurrences of certain type of events per year per denominator or base (population, exposure}.
- Event type:
  - Severity of crashes = {all crashes, fatal crashes, injury cashes, PDO crashes, etc}.
  - No. of persons involved = {fatalities, injuries, etc}.
  - Vehicle involved = {all crashes involved pedestrians, car-car crashed, car-truck crashes, car alone crashes, etc}.
  - Manner of crash = {rear-end, side swipe, angled, right angle}.
  - Causes of crash ={crashes attributed to DUI, to running red light, etc}.
  - Other event types and conditions are possible, e.g., fatal crashed involved driver aged <25 and DUI.

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Crash Risk Indicators

- Population-based rates, examples:

	Fatal	injury	PDO
Area population	No. of fatal crashes per year per 100,000 population	No. of injury crashes per year per 100,000 population	No. of PDO crashes per year per 100,000 population
No. of registered vehicles	No. of fatal crashes per year per 10,000 registered vehicles	No. of injury crashes per year per 10,000 registered vehicles	No. of PDO crashes per year per 10,000 registered vehicles
No. of licensed drivers	No. of fatal crashes per year per 10,000 licensed drivers	No. of injury crashes per year per 10,000 licensed drivers	No. of PDO crashes per year per 10,000 licensed drivers
Highway mileage	No. of fatal crashes per year per 10,000 highway-miles	No. of injury crashes per year per 10,000 highway-miles	No. of PDO crashes per year per 10,000 highway-miles

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Crash Risk Indicators

- Exposure-based rates, examples:

	Fatalities	Motorcycle	DWI
Vehicle-Miles Traveled, VMT	No. of fatalities per year per million VMT	No. of motorcycle crashes per year per 100,000 population	No. of DWI related crashes per year per 100,000 VMT3
Vehicle-Hours Traveled	No. of fatalities per year per million VHT	No. of motorcycle crashes per year per 10,000 registered vehicles	No. of DWI related crashes per year per 10,000 registered vehicles
Volume	No. of fatalities per year per 100,000 vehicles	No. of motorcycle crashes per year per 10,000 licensed drivers	No. of DWI related crashes per year per 10,000 licensed drivers

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Crash Risk Indicators - Example

Example:
In one year in a city:

- # of fatal crashes = 60
- # of injury crashes = 298
- # of PDO crashes = 499
- # of fatalities = 74
- City's population = 230,100
- # of registered vehicles = 54,560
- # of licensed drivers = 67,660

→Calculate the # of crashes per year per 10,000 registered veh:

$\frac{60+298+499}{5.4560}$ =157 crashes/yr/10000 reg. veh.

→Calculate the # of fatalities per year per 10,000 licensed drivers:

$\frac{74}{6.7660}$ =10.9 fatalities/yr/10,000 licensed drivers.

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Crash Risk Indicators

Crash rate at intersections

Crash rate per million entering vehicles:

$$RMEV = \frac{A}{V / 10^6}$$

- $A =$ number of crashes total or by type at the study location in a year.
- $V = ADT \times no. of\ days\ in\ study\ period.$
- $ADT =$ Average Daily Traffic entering the intersection.

Crash rate for roadway segments

No. of crashes total or by type at the study location during the period:

$$RMVM = \frac{A}{VMT / 10^6}$$

- $VMT =$ vehicle miles traveled during the period $= ADT \times$ no. of days in the study period $\times$ length of road.
- $ADT =$ Average Daily Traffic on the road segment.

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Crash Risk Indicators – Crash Rates – Examples

- Example 1: Calculate the crash rate if there were 46 crashes observed in two years. The ADT for the minor approach was 3000 and the major approach was 6000. Note - volumes include both directions.
- Example 2: Calculate the crash rate if there were 40 crashes on a 17.5 mile segment in one year. The ADT was 5,000.

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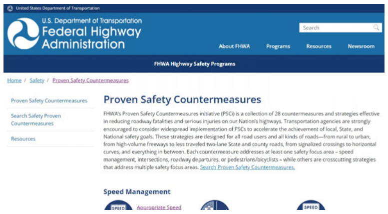
Safety Countermeasures



https://highways.dot.gov/safety/proven-safety-countermeasures

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Traffic Calming

- Primary purpose of traffic calming is to support the livability and vitality of residential and commercial areas through improvements in non-motorist safety, mobility, and comfort.
- These objectives are typically achieved by reducing vehicle speeds or volumes on a single street or a street network.
- Traffic calming measures consist of horizontal, vertical, lane narrowing, roadside, and other features that use self-enforcing physical or psycho-perception means to produce desired effects.



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Traffic Calming

- A traffic calming measure needs to be integrated with the pedestrian network and system.
- A sidewalk is comprised of four distinct zones: frontage zone, pedestrian (or walking) zone, furniture zone, and curb (or edge) zone.

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Traffic Calming Measures

Selected traffic calming measures	
Lateral shift	Corner Extension
Chicane	Choker
Realigned intersection	Median Barrier and Forced Turn Island
Roundabout	Median Island
Speed Hump	On-Street Parking
Speed Cushion	Diagonal Diverter
Raise crosswalk	Full Closure
Raised Intersection	Half Closure



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VI. Complete Streets

Complete Streets are streets for everyone!!!

Designed and operated to enable safe access for all users:

- pedestrians,
- bicyclists,
- motorists and
- transit riders

of all ages and abilities.

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- https://highways.dot.gov/complete-streets

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VII. Intelligent Transportation Systems (ITS)

- USDOT ITS JPO:

  ITS improves transportation safety and mobility and enhances American productivity by integrating advanced communication technologies into vehicles and infrastructure.
- First generation:
  - ATMS, ATIS, APTS, AVCS, CVO, ITS architecture, GPS, FSP,
- Second generation:
  - NGSIM, smartphone.
- Third generation:
  - NDS, ICM

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1st Generation ITS Systems

- Advanced Traffic Management Systems (ATMS).
- Advanced Traveler Information Systems (ATIS).
- Advanced Vehicle Control Systems (AVCS).
- Advanced Public Transportation Systems (APTS).
- Commercial Vehicle Operations (CVO).

- Isolated, independent systems.
- To demonstrate what technologies are capable of.

https://www.openaccessgovernment.org/smart-cities-new-power-dynamics-intelligent-transport-systems/112128/

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Development in Past -20 to -10 Years (2001-2010) – 2nd Gen

- Smartphone:
  - As sensors, crowdsourcing.
  - Disseminations of real-time info to users.
- Social media:

  → IT companies moved into transportation business.

- Carsharing.
- Bike sharing.
- Hybrid vehicles.
- Managed lanes.
- Value pricing.

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New Development in Past 10 Years (2011-2020) – 3rd Gen

- 4G LTE.
- Increased market share of smartphones.
- Private companies (Google, Verizon, etc.) have more data than DOT.
- IoT.
- Smart cities (smart mobility).
- UAVs.
- Tesla.
- Uber, Lyft.
- Vehicle automation.

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USDOT Connected Vehicle Testbeds

The Mission: Provide a facility where users can test new hardware and software for the advancement of connected vehicle technology.

- Testbed facilities paid for by USDOT.
- Partnerships with state DOTs, MPOs, cities.
- Opened for industry to test products.
- Concept of living lab – testing in real-live environment.
- Each site has a unique focus.

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ITS - Future

- 5G applications in CAVs.
- Mobility services:
  - Do we still need to own cars?
- Automated vehicles:
  - Do we still need driver license?
- New power source:
  - Wireless EV charging.
  - Hydrogen powered vehicles.
  - Nuclear powered vehicles.
- New definition:
  - Movement of information, people and goods.
- ITS for public health.
- ITS for equitable transportation.
- ITS for climate resilience.

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The Future of Transportation

Sustainable transportation:
"Meeting, and sometimes re-defining, the mobility needs of the present without compromising the ability of future generations to meet their needs." ITS America

Resilience:
Resilience of a transportation system is defined as the ability for a transportation system's operation to withstand and rapidly recover from a disruptive event.

Livability:
"using the quality, location, and type of transportation facilities and services available to help achieve broader community goals, such as increasing travel choices, improving economic competitiveness, and enhancing unique community characteristics." – FHWA.

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The Future of Transportation

Transportation Equity

Automated Vehicles

Cybersecurity

Others?

https://bernardmarr.com/the-future-trends-in-mobility-and-transportation/

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2023 Workforce Development Summit
Register at www.techtransfer.ce.ufl.edu.

Course Schedule

May 9	Traffic Engineering Fundamentals Kickoff Summit
May 11	MUTCD Traffic Signals Overview
May 12	Traffic Signal Systems Asset Management
May 12	Highway Safety Analysis Traffic Signals and their Timing
May 15	Basic Traffic Signal Timing
May 15	Transportation Equity Fundamentals
May 16-17	Traffic Signal Basics
May 19	Highway Capacity Analysis with Signalized Intersections
May 22	Advanced Traffic Signal Timing

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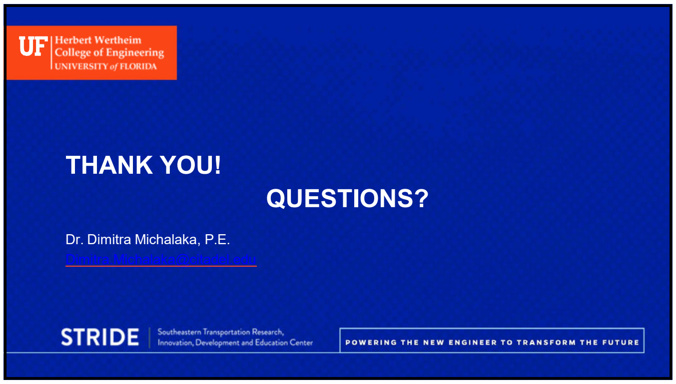
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THANK YOU!
QUESTIONS?
Dr. Dimitra Michalaka, P.E.
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Training Slides

MUTCD Traffic Signals Overview


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Manual on Uniform Traffic Control Devices - Traffic Signal Systems Overview
A Basic Guide to Understanding the MUTCD and Traffic Signals
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1


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Workforce Development Summit
Course Schedule
Traffic Engineering Fundamentals Kickoff Summit May 9
MUTCD Traffic Signals Overview May 11
Traffic Signal Systems Asset Management May 12
Highway Safety Analysis Traffic Signals and their Timing May 12
Basic Traffic Signal Timing May 15
Transportation Equity Fundamentals May 15
Traffic Signal Basics May 16-17
Highway Capacity Analysis with Signalized Intersections May 19
Advanced Traffic Signal Timing May 22
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2023 Workforce Development Summit
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Course Schedule
May 9 Traffic Engineering Fundamentals Kickoff Summit
May 11 MUTCD Traffic Signals Overview
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May 15 Basic Traffic Signal Timing
May 15 Transportation Equity Fundamentals
May 16-17 Traffic Signal Basics
May 19 Highway Capacity Analysis with Signalized Intersections
May 22 Advanced Traffic Signal Timing
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A Basic Guide to Understanding the MUTCD and Traffic Signals
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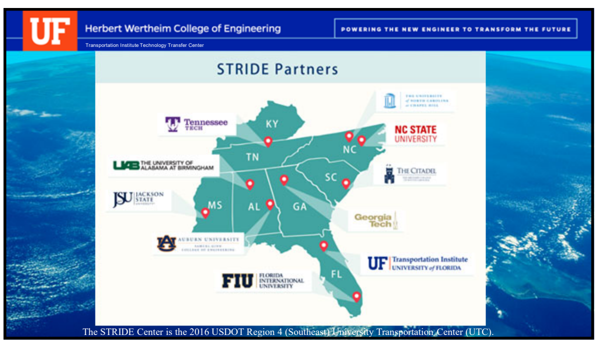
4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NC
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Tennessee Tech
NC STATE UNIVERSITY
THE CITADEL
Georgia Tech
UF Transportation Institute UNIVERSITY of FLORIDA
FIU FLORIDA INTERNATIONAL UNIVERSITY
JSU JACKSON STATE
UAB THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
The STRIDE Center is the 2016 USDOT Region 4 (Southeast) University Transportation Center (UTC).

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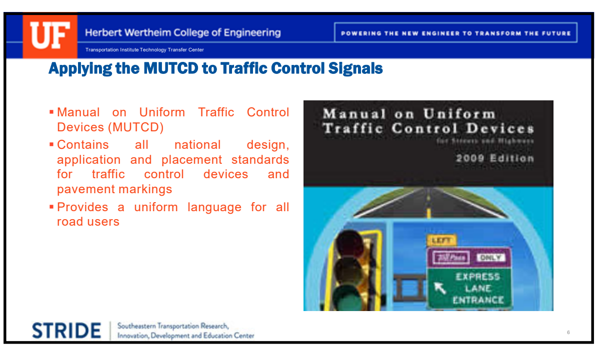
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Applying the MUTCD to Traffic Control Signals
▪ Manual on Uniform Traffic Control Devices (MUTCD)
▪ Contains all national design, application and placement standards for traffic control devices and pavement markings
▪ Provides a uniform language for all road users
Manual on Uniform Traffic Control Devices
2009 Edition
LEFT
ONLY
EXPRESS LANE ENTRANCE
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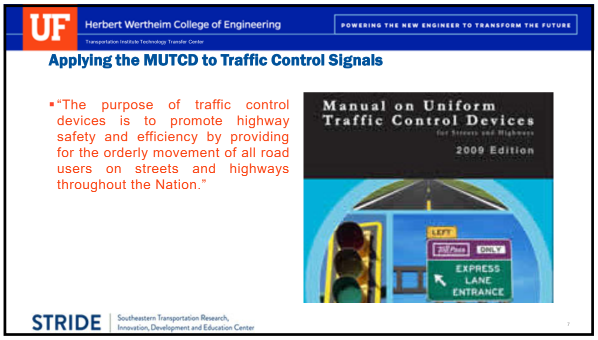
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Applying the MUTCD to Traffic Control Signals
▪"The purpose of traffic control devices is to promote highway safety and efficiency by providing for the orderly movement of all road users on streets and highways throughout the Nation."
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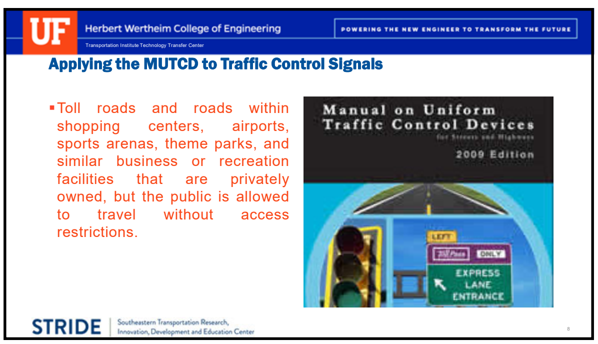
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▪Toll roads and roads within shopping centers, airports, sports arenas, theme parks, and similar business or recreation facilities that are privately owned, but the public is allowed to travel without access restrictions.
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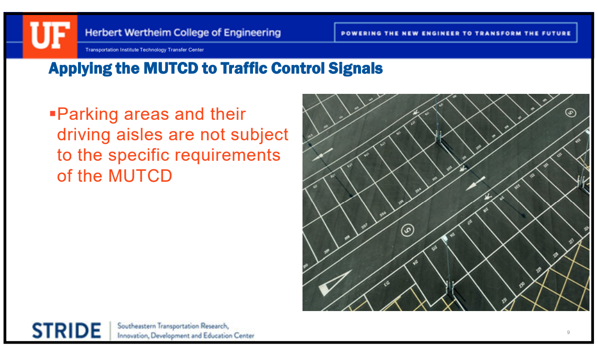
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Applying the MUTCD to Traffic Control Signals
▪Parking areas and their driving aisles are not subject to the specific requirements of the MUTCD
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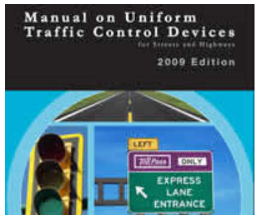
Applying the MUTCD to Traffic Control Signals

- Standard (“shall”)
- A mandatory condition, compliance required
- Guidance (“should”)
- An advisory condition, compliance recommended
- Option (“may”)
- A permissive condition or practice, permitted



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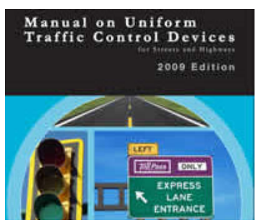
Applying the MUTCD to Traffic Control Signals

- Section 2B.10 STOP Sign or YIELD Sign Placement Standard:

01 The STOP or Yield sign shall be installed on the near side of the intersection on the right-hand side of the approach to which it applies.



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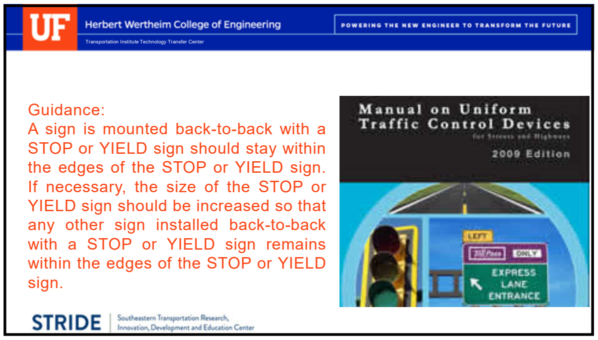
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Guidance:
A sign is mounted back-to-back with a STOP or YIELD sign should stay within the edges of the STOP or YIELD sign. If necessary, the size of the STOP or YIELD sign should be increased so that any other sign installed back-to-back with a STOP or YIELD sign remains within the edges of the STOP or YIELD sign.
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13


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STOP
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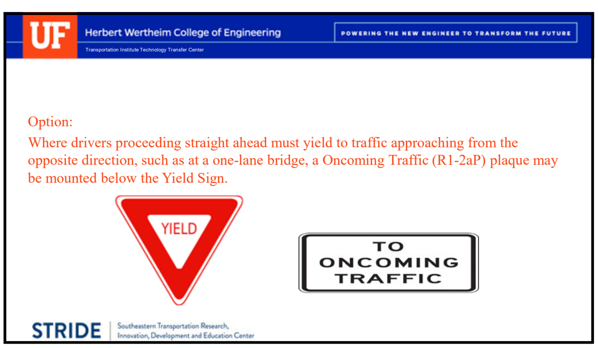
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Option:
Where drivers proceeding straight ahead must yield to traffic approaching from the opposite direction, such as at a one-lane bridge, a Oncoming Traffic (R1-2aP) plaque may be mounted below the Yield Sign.
YIELD
TO ONCOMING TRAFFIC
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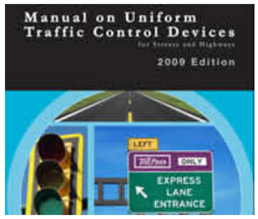
States were given the option of fully adopting the MUTCD or writing their own version of the MUTCD in substantial conformance with the national MUTCD.

Additionally, states were given the option of adopting the national MUTCD for use along with a State supplement.



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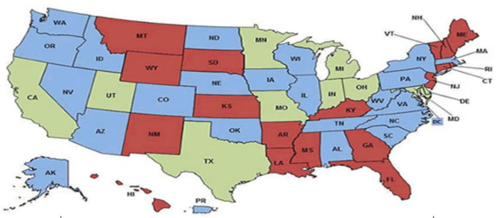
How Does the MUTCD Apply?



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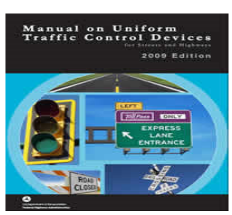
Part 1 – General
Part 2 - Signs
- 2A - General
- 2B - Regulatory Signs, Barricades, and Gates
- 2C - Warning Signs and Object Markers
- 2D - Guide Signs – Conventional Roads
- 2E - Guide Signs – Freeways and Expressways



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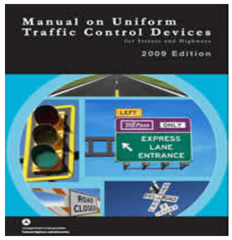
Part 2 - Signs
- 2F - Toll Road Signs
- 2G-2H - Preferential and Managed Lane Signs and General Information Signs
- 2I-2N - General Service Signs, Specific Service Signs, Tourist-Oriented Directional Signs, Changeable Message Signs, Recreational and Cultural Interest Area Signs and Emergency Management Signing.



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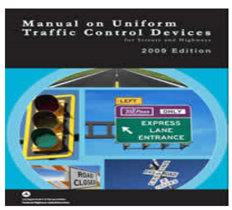
Part 3 - Pavement Markings
Part 4 – Highway Traffic Signals
Part 5 – Traffic Control Devices for Low-Volume Roads
Part 6 – Temporary Traffic Control
Part 7 – Traffic Control for School Areas
Part 8 – Traffic Control for Railroad and Light Rail Transit Grade Crossings
Part 9 – Traffic Control for Bicycle Facilities



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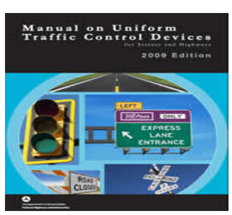
To be effective, traffic control devices must meet five basic requirements:

1. Fulfill a need;
2. Command attention;
3. Convey a clear, simple meaning;
4. Command respect;
5. Give adequate reaction time



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STOP
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LEFT
LANE
AHEAD
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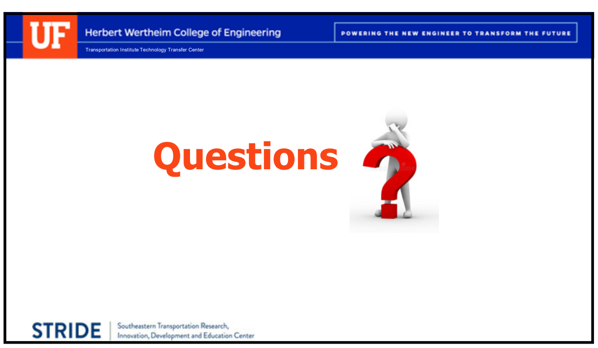
23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A Basic Guide to Understanding the MUTCD and Traffic Signals
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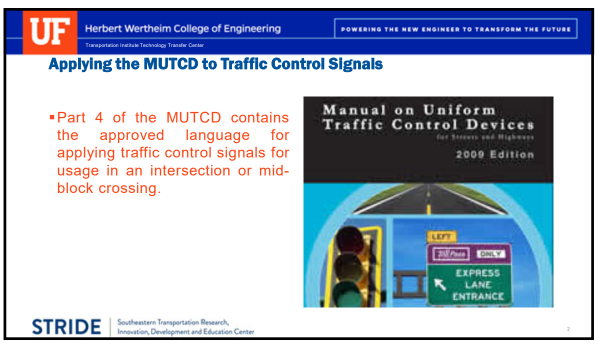
1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Applying the MUTCD to Traffic Control Signals
▪Part 4 of the MUTCD contains the approved language for applying traffic control signals for usage in an intersection or mid-block crossing.
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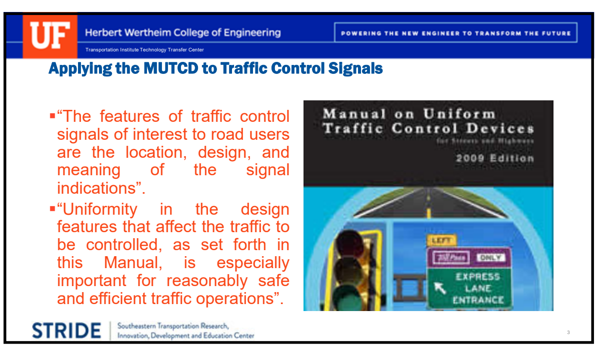
2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Applying the MUTCD to Traffic Control Signals
▪"The features of traffic control signals of interest to road users are the location, design, and meaning of the signal indications".
▪"Uniformity in the design features that affect the traffic to be controlled, as set forth in this Manual, is especially important for reasonably safe and efficient traffic operations".
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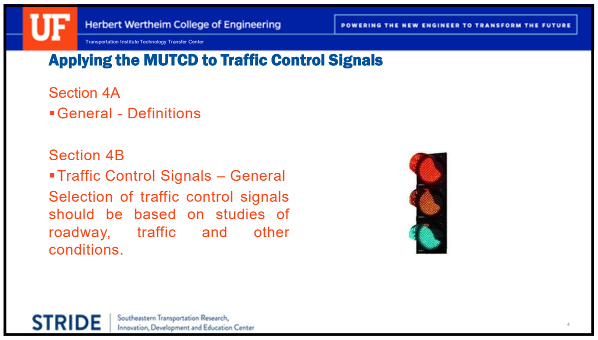
3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Applying the MUTCD to Traffic Control Signals
Section 4A
▪General - Definitions
Section 4B
▪Traffic Control Signals – General
Selection of traffic control signals should be based on studies of roadway, traffic and other conditions.
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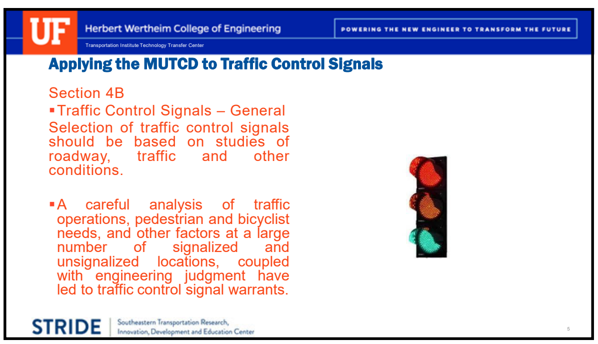
4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Applying the MUTCD to Traffic Control Signals
Section 4B
▪Traffic Control Signals – General
Selection of traffic control signals should be based on studies of roadway, traffic and other conditions.
▪A careful analysis of traffic operations, pedestrian and bicyclist needs, and other factors at a large number of signalized and unsignalized locations, coupled with engineering judgment have led to traffic control signal warrants.
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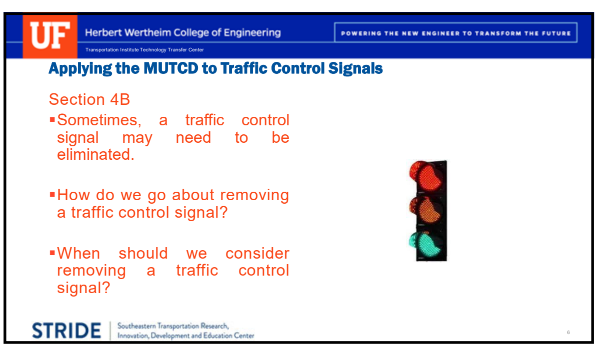
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Section 4B
▪Sometimes, a traffic control signal may need to be eliminated.
▪How do we go about removing a traffic control signal?
▪When should we consider removing a traffic control signal?
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- If the engineering study indicates that the traffic control signal is no longer justified, removal may be accomplished using the following steps:
- Determine the appropriate traffic control to be used after removal of the signal.
- Remove any sight-distance restrictions as necessary.

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Section 4B

- Inform the public of the removal study, for example by installing an informational sign (or signs) with the legend TRAFFIC SIGNAL UNDER STUDY FOR REMOVAL at the signalized location in a position where it is visible to all road users.
- Flash or cover the signal heads for a minimum of 90 days, and install the appropriate stop control or other traffic control devices.

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Section 4B

- Remove the signal if the engineering data collected during the removal study period confirms that the signal is no longer needed.
- Instead of total removal of the traffic control signal, the poles and cables may remain in place after removal of the signal heads for continued analysis.

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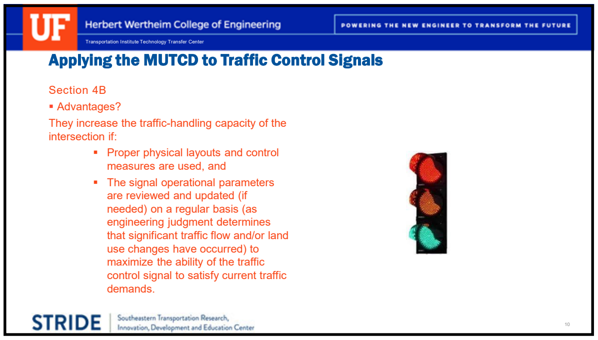
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Section 4B
▪ Advantages?
They increase the traffic-handling capacity of the intersection if:
▪ Proper physical layouts and control measures are used, and
▪ The signal operational parameters are reviewed and updated (if needed) on a regular basis (as engineering judgment determines that significant traffic flow and/or land use changes have occurred) to maximize the ability of the traffic control signal to satisfy current traffic demands.
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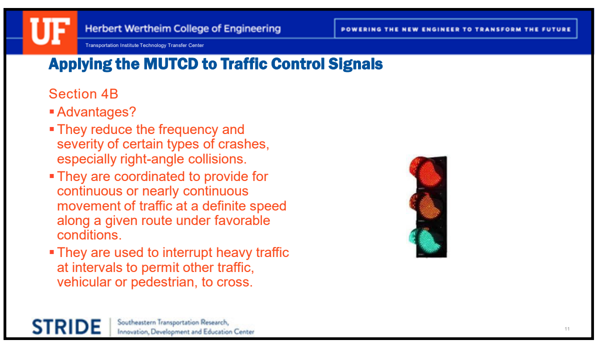
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Section 4B
▪ Advantages?
▪ They reduce the frequency and severity of certain types of crashes, especially right-angle collisions.
▪ They are coordinated to provide for continuous or nearly continuous movement of traffic at a definite speed along a given route under favorable conditions.
▪ They are used to interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to cross.
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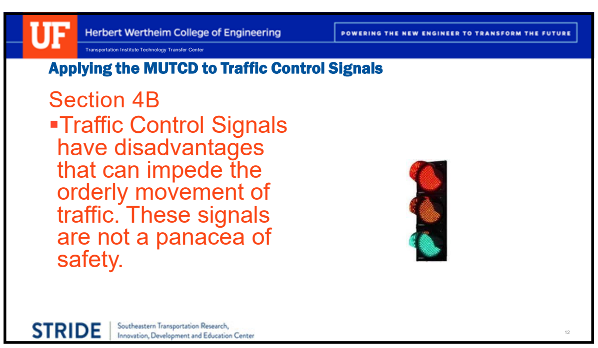
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Section 4B
▪ Traffic Control Signals have disadvantages that can impede the orderly movement of traffic. These signals are not a panacea of safety.
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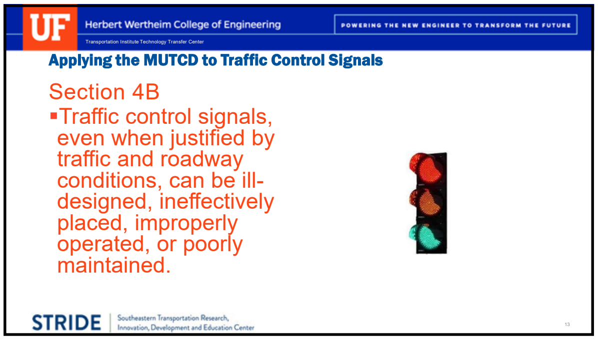
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Section 4B
▪Traffic control signals, even when justified by traffic and roadway conditions, can be ill-designed, ineffectively placed, improperly operated, or poorly maintained.
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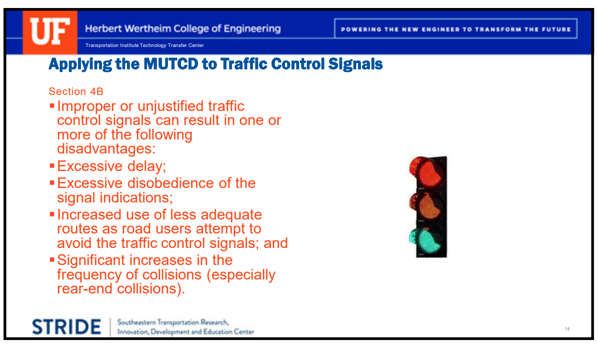
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Section 4B
▪Improper or unjustified traffic control signals can result in one or more of the following disadvantages:
▪Excessive delay;
▪Excessive disobedience of the signal indications;
▪Increased use of less adequate routes as road users attempt to avoid the traffic control signals; and
▪Significant increases in the frequency of collisions (especially rear-end collisions).
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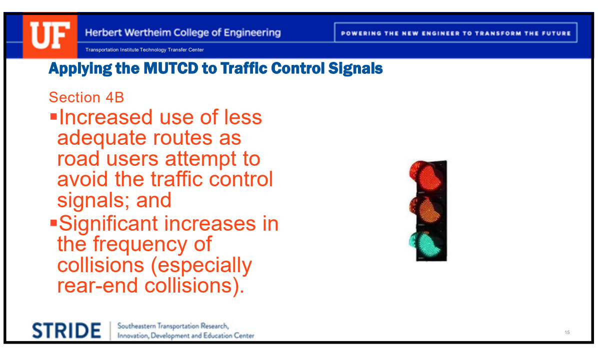
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Section 4B
▪Increased use of less adequate routes as road users attempt to avoid the traffic control signals; and
▪Significant increases in the frequency of collisions (especially rear-end collisions).
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- Are there alternatives to signals being placed in the roadway?
- Yes, there are alternatives.

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- Installing signs along the major street to warn road users approaching the intersection;
- Relocating the stop line(s) and making other changes to improve the sight distance at the intersection;
- Installing measures designed to reduce speeds on the approaches;

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Section 4B

- Installing a flashing beacon at the intersection to supplement STOP sign control;
- Installing flashing beacons on warning signs in advance of a STOP sign controlled intersection on major- and/or minor-street approaches;
- Adding one or more lanes on a minor-street approach to reduce the number of vehicles per lane on the approach;

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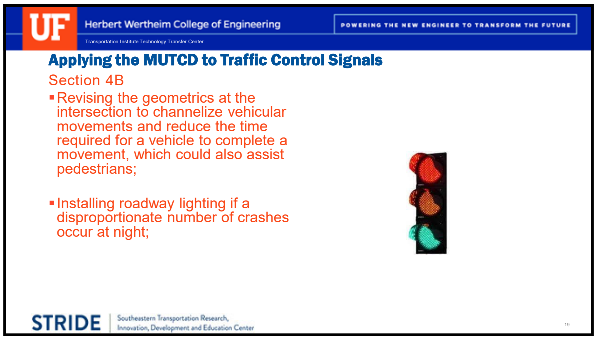
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Section 4B
▪Revising the geometrics at the intersection to channelize vehicular movements and reduce the time required for a vehicle to complete a movement, which could also assist pedestrians;
▪Installing roadway lighting if a disproportionate number of crashes occur at night;
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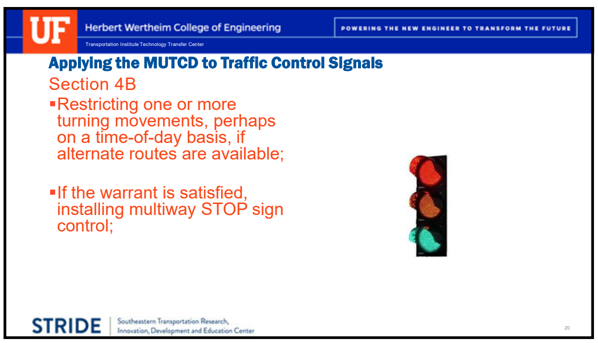
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Section 4B
▪Restricting one or more turning movements, perhaps on a time-of-day basis, if alternate routes are available;
▪If the warrant is satisfied, installing multiway STOP sign control;
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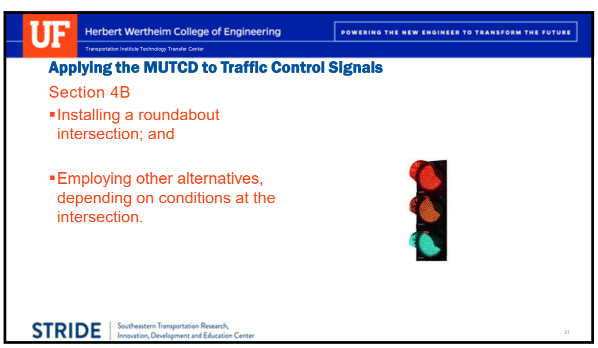
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Section 4B
▪Installing a roundabout intersection; and
▪Employing other alternatives, depending on conditions at the intersection.
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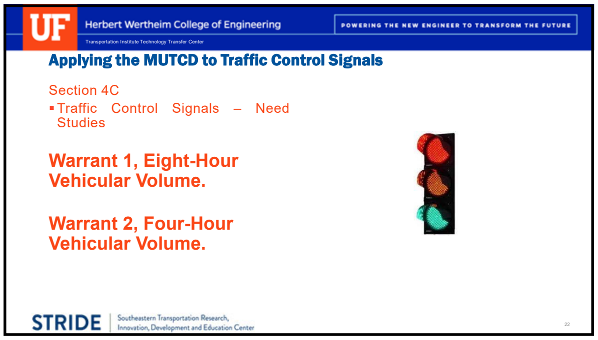
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Section 4C
▪Traffic Control Signals – Need Studies
Warrant 1, Eight-Hour Vehicular Volume.
Warrant 2, Four-Hour Vehicular Volume.
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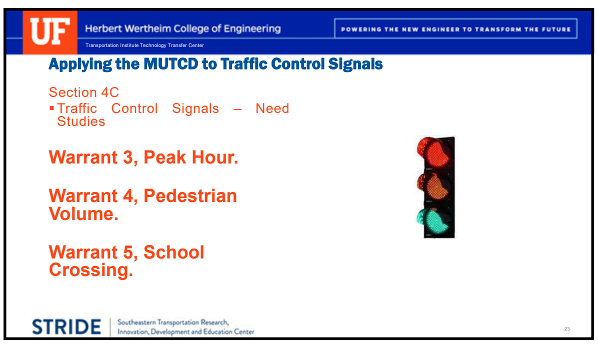
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Section 4C
▪Traffic Control Signals – Need Studies
Warrant 3, Peak Hour.
Warrant 4, Pedestrian Volume.
Warrant 5, School Crossing.
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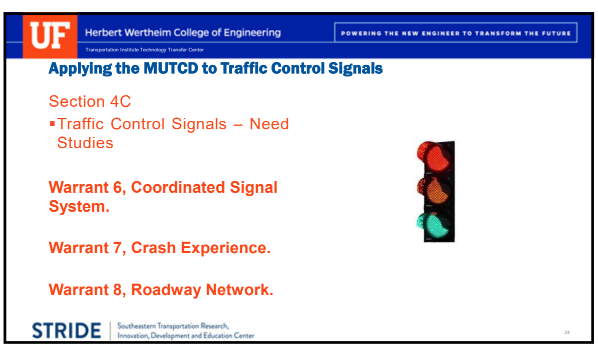
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Section 4C
▪Traffic Control Signals – Need Studies
Warrant 6, Coordinated Signal System.
Warrant 7, Crash Experience.
Warrant 8, Roadway Network.
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Transportation Technology Transfer (T2) Center
Manual on Uniform Traffic Control Devices - Traffic Signal Systems Overview – Module 3
A Basic Guide to Understanding the MUTCD and Traffic Signals
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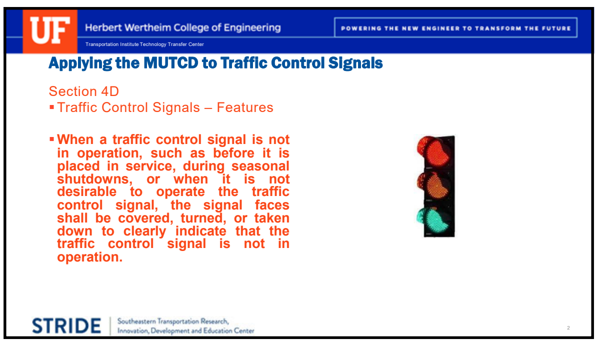
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Section 4D
▪ Traffic Control Signals – Features
▪ When a traffic control signal is not in operation, such as before it is placed in service, during seasonal shutdowns, or when it is not desirable to operate the traffic control signal, the signal faces shall be covered, turned, or taken down to clearly indicate that the traffic control signal is not in operation.
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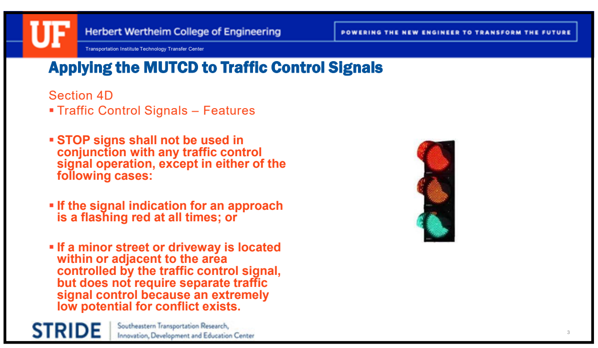
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Section 4D
▪ Traffic Control Signals – Features
▪ STOP signs shall not be used in conjunction with any traffic control signal operation, except in either of the following cases:
▪ If the signal indication for an approach is a flashing red at all times; or
▪ If a minor street or driveway is located within or adjacent to the area controlled by the traffic control signal, but does not require separate traffic signal control because an extremely low potential for conflict exists.
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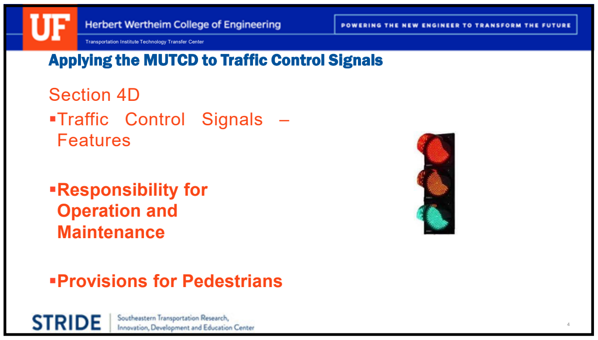
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Section 4D
▪Traffic Control Signals – Features
▪Responsibility for Operation and Maintenance
▪Provisions for Pedestrians
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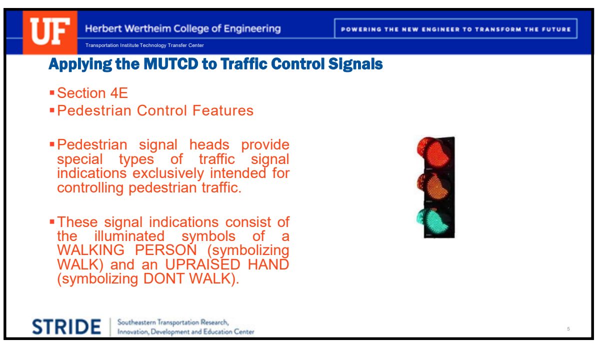
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▪Section 4E
▪Pedestrian Control Features
▪Pedestrian signal heads provide special types of traffic signal indications exclusively intended for controlling pedestrian traffic.
▪These signal indications consist of the illuminated symbols of a WALKING PERSON (symbolizing WALK) and an UPRAISED HAND (symbolizing DONT WALK).
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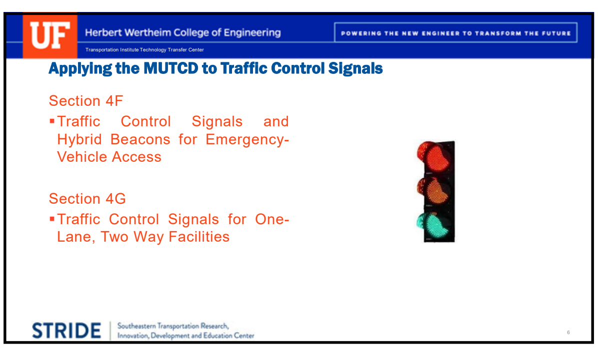
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Section 4F
▪Traffic Control Signals and Hybrid Beacons for Emergency-Vehicle Access
Section 4G
▪Traffic Control Signals for One-Lane, Two Way Facilities
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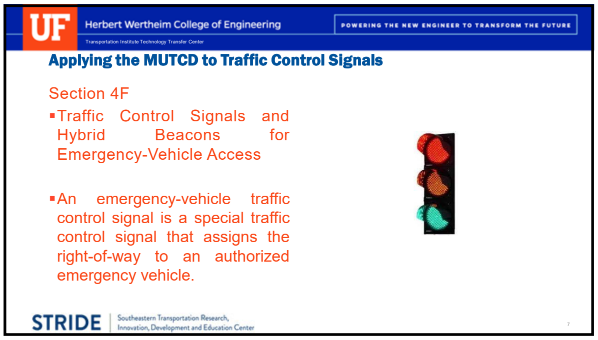
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Section 4F
▪Traffic Control Signals and Hybrid Beacons for Emergency-Vehicle Access
▪An emergency-vehicle traffic control signal is a special traffic control signal that assigns the right-of-way to an authorized emergency vehicle.
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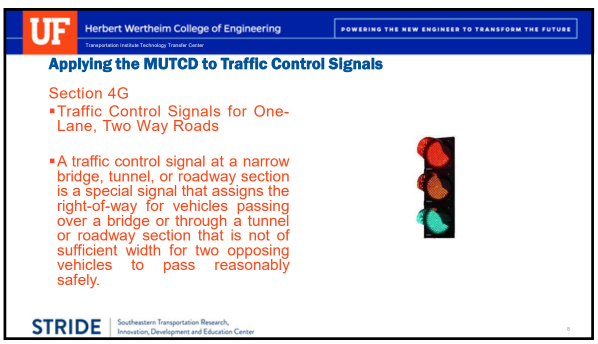
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Section 4G
▪Traffic Control Signals for One-Lane, Two Way Roads
▪A traffic control signal at a narrow bridge, tunnel, or roadway section is a special signal that assigns the right-of-way for vehicles passing over a bridge or through a tunnel or roadway section that is not of sufficient width for two opposing vehicles to pass reasonably safely.
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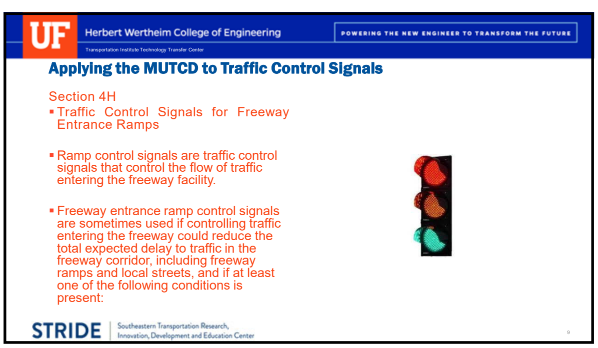
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Section 4H
▪Traffic Control Signals for Freeway Entrance Ramps
▪Ramp control signals are traffic control signals that control the flow of traffic entering the freeway facility.
▪Freeway entrance ramp control signals are sometimes used if controlling traffic entering the freeway could reduce the total expected delay to traffic in the freeway corridor, including freeway ramps and local streets, and if at least one of the following conditions is present:
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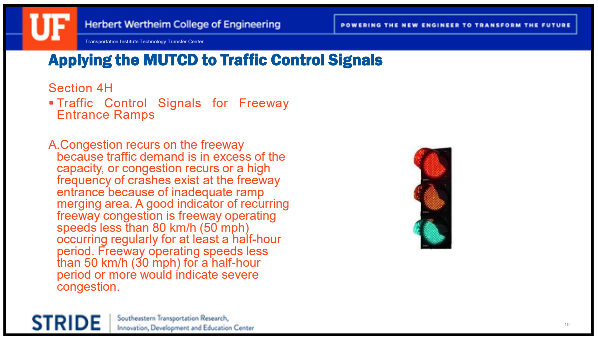
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Section 4H
▪ Traffic Control Signals for Freeway Entrance Ramps
A. Congestion recurs on the freeway because traffic demand is in excess of the capacity, or congestion recurs or a high frequency of crashes exist at the freeway entrance because of inadequate ramp merging area. A good indicator of recurring freeway congestion is freeway operating speeds less than 80 km/h (50 mph) occurring regularly for at least a half-hour period. Freeway operating speeds less than 50 km/h (30 mph) for a half-hour period or more would indicate severe congestion.
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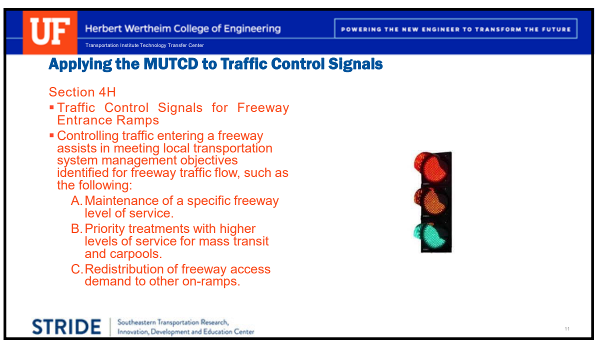
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Section 4H
▪ Traffic Control Signals for Freeway Entrance Ramps
▪ Controlling traffic entering a freeway assists in meeting local transportation system management objectives identified for freeway traffic flow, such as the following:
A. Maintenance of a specific freeway level of service.
B. Priority treatments with higher levels of service for mass transit and carpools.
C. Redistribution of freeway access demand to other on-ramps.
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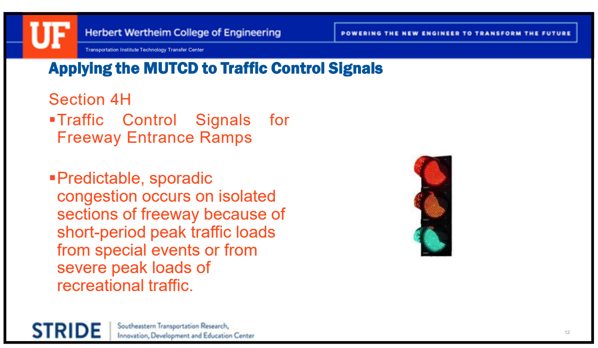
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Section 4H
▪ Traffic Control Signals for Freeway Entrance Ramps
▪ Predictable, sporadic congestion occurs on isolated sections of freeway because of short-period peak traffic loads from special events or from severe peak loads of recreational traffic.
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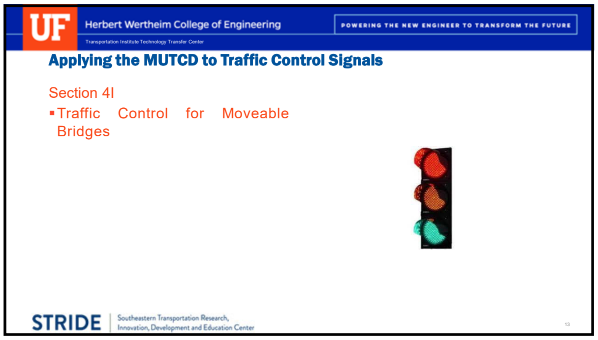
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Section 4I
▪ Traffic Control for Moveable Bridges
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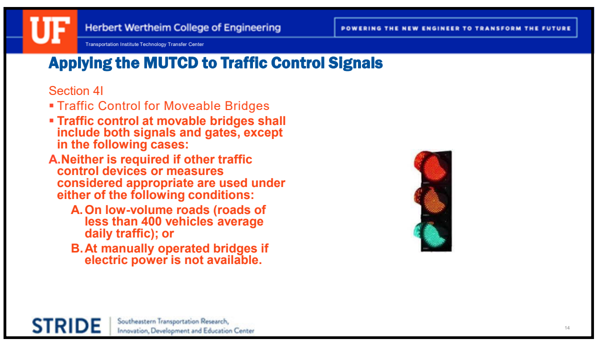
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Section 4I
▪ Traffic Control for Moveable Bridges
▪ Traffic control at movable bridges shall include both signals and gates, except in the following cases:
A. Neither is required if other traffic control devices or measures considered appropriate are used under either of the following conditions:
A. On low-volume roads (roads of less than 400 vehicles average daily traffic); or
B. At manually operated bridges if electric power is not available.
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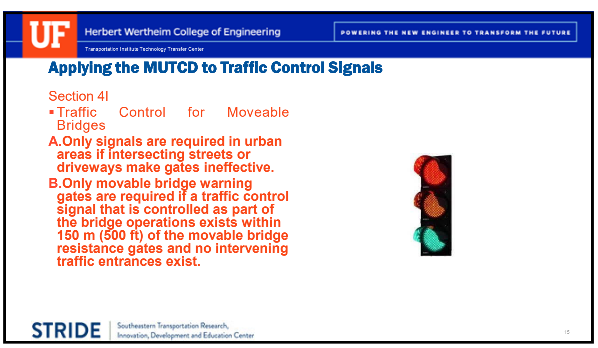
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Section 4I
▪ Traffic Control for Moveable Bridges
A. Only signals are required in urban areas if intersecting streets or driveways make gates ineffective.
B. Only movable bridge warning gates are required if a traffic control signal that is controlled as part of the bridge operations exists within 150 m (500 ft) of the movable bridge resistance gates and no intervening traffic entrances exist.
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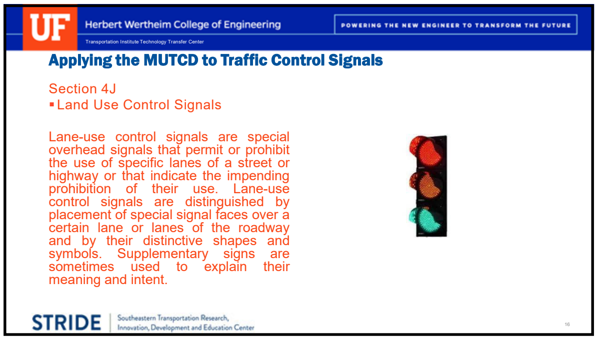
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Section 4J
▪Land Use Control Signals
Lane-use control signals are special overhead signals that permit or prohibit the use of specific lanes of a street or highway or that indicate the impending prohibition of their use. Lane-use control signals are distinguished by placement of special signal faces over a certain lane or lanes of the roadway and by their distinctive shapes and symbols. Supplementary signs are sometimes used to explain their meaning and intent.
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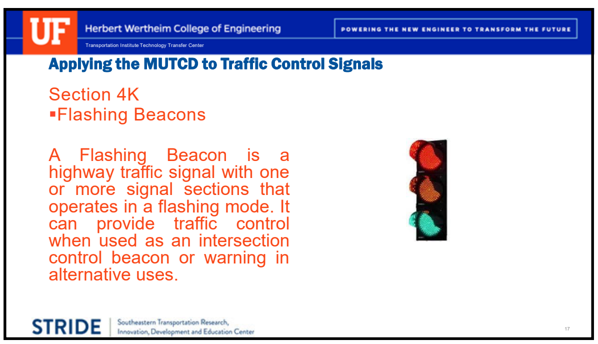
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Section 4K
▪Flashing Beacons
A Flashing Beacon is a highway traffic signal with one or more signal sections that operates in a flashing mode. It can provide traffic control when used as an intersection control beacon or warning in alternative uses.
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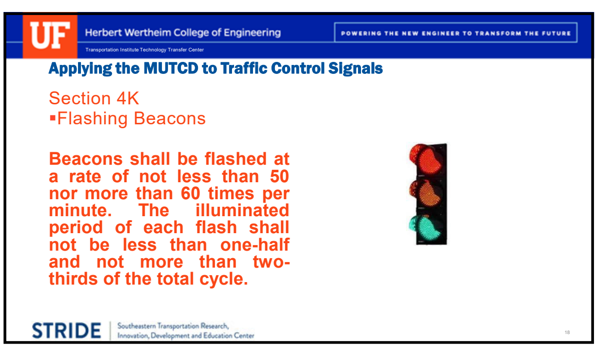
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Section 4K
▪Flashing Beacons
Beacons shall be flashed at a rate of not less than 50 nor more than 60 times per minute. The illuminated period of each flash shall not be less than one-half and not more than two-thirds of the total cycle.
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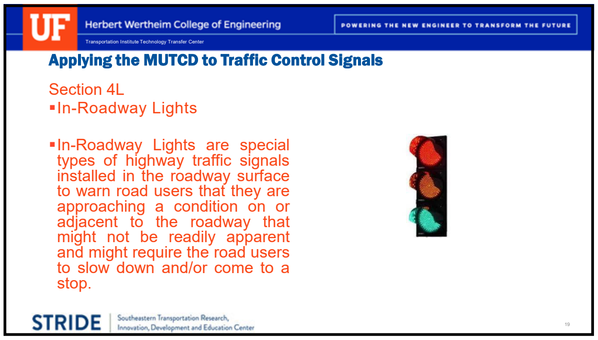
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Section 4L
▪In-Roadway Lights
▪In-Roadway Lights are special types of highway traffic signals installed in the roadway surface to warn road users that they are approaching a condition on or adjacent to the roadway that might not be readily apparent and might require the road users to slow down and/or come to a stop.
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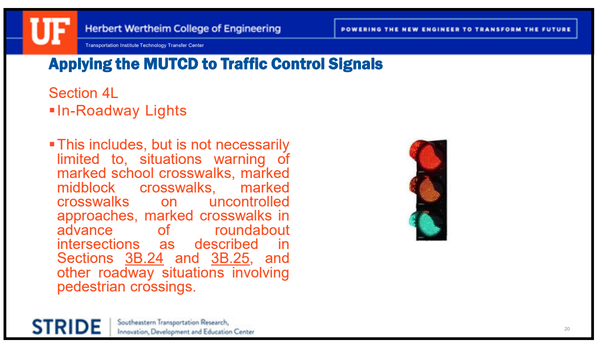
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Applying the MUTCD to Traffic Control Signals
Section 4L
▪In-Roadway Lights
▪This includes, but is not necessarily limited to, situations warning of marked school crosswalks, marked midblock crosswalks, marked crosswalks on uncontrolled approaches, marked crosswalks in advance of roundabout intersections as described in Sections 3B.24 and 3B.25, and other roadway situations involving pedestrian crossings.
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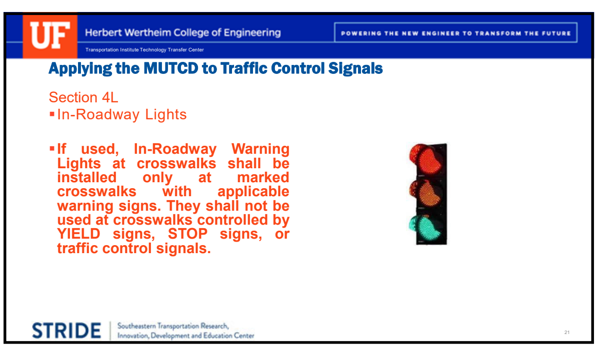
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Applying the MUTCD to Traffic Control Signals
Section 4L
▪In-Roadway Lights
▪If used, In-Roadway Warning Lights at crosswalks shall be installed only at marked crosswalks with applicable warning signs. They shall not be used at crosswalks controlled by YIELD signs, STOP signs, or traffic control signals.
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Training Slides

Traffic Signal Systems Asset Management


UF Herbert Wertheim College of Engineering
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Traffic Signal Systems Asset Management – Module 1
A Basic Guide to Understanding the Value of Asset Management of Traffic Signals Inventory
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1


UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA
Workforce Development Summit
Course Schedule
Traffic Engineering Fundamentals Kickoff Summit May 9
MUTCD Traffic Signals Overview May 11
Traffic Signal Systems Asset Management May 12
Highway Safety Analysis Traffic Signals and their Timing May 12
Basic Traffic Signal Timing May 15
Transportation Equity Fundamentals May 15
Traffic Signal Basics May 16-17
Highway Capacity Analysis with Signalized Intersections May 19
Advanced Traffic Signal Timing May 22
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UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA
2023 Workforce Development Summit
Register at www.techtransfer.ce.ufl.edu.
Course Schedule
May 9 Traffic Engineering Fundamentals Kickoff Summit
May 11 MUTCD Traffic Signals Overview
May 12 Traffic Signal Systems Asset Management
May 12 Highway Safety Analysis Traffic Signals and their Timing
May 15 Basic Traffic Signal Timing
May 15 Transportation Equity Fundamentals
May 16-17 Traffic Signal Basics
May 19 Highway Capacity Analysis with Signalized Intersections
May 22 Advanced Traffic Signal Timing
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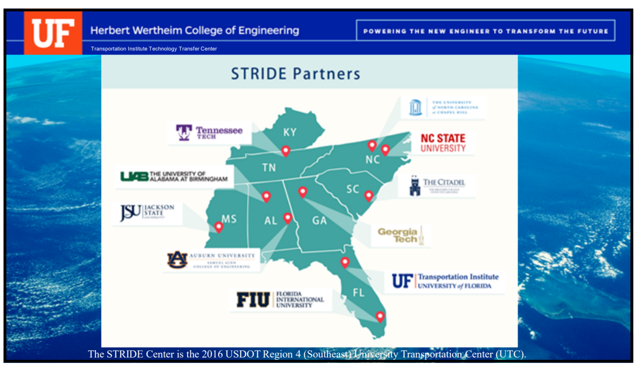
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The STRIDE Center is the 2016 USDOT Region 4 (Southeast) University Transportation Center (UTC).

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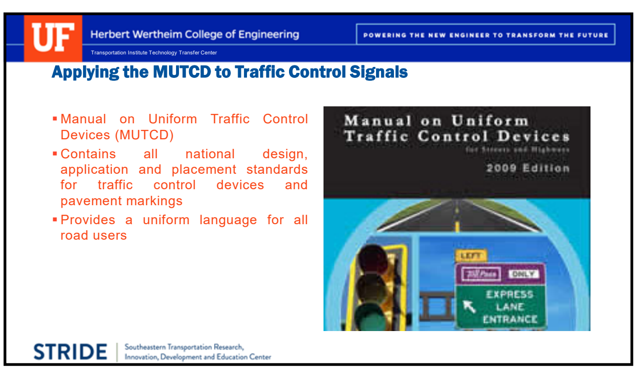
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Applying the MUTCD to Traffic Control Signals
▪ Manual on Uniform Traffic Control Devices (MUTCD)
▪ Contains all national design, application and placement standards for traffic control devices and pavement markings
▪ Provides a uniform language for all road users
Manual on Uniform Traffic Control Devices
2009 Edition
LEFT
ONLY
EXPRESS LANE ENTRANCE
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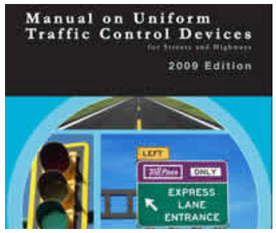
Applying the MUTCD to Traffic Control Signals

- Standard ("shall")
  - A mandatory condition, compliance required
- Guidance ("should")
  - An advisory condition, compliance recommended
- Option ("may")
  - A permissive condition or practice, permitted



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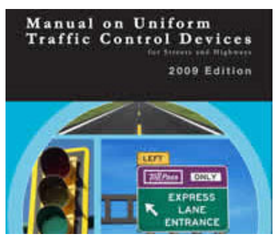
States were given the option of fully adopting the MUTCD or writing their own version of the MUTCD in substantial conformance with the national MUTCD.

Additionally, states were given the option of adopting the national MUTCD for use along with a State supplement.



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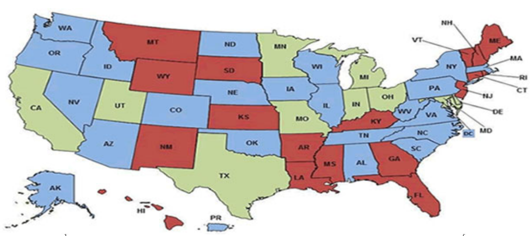
How Does the MUTCD Apply?



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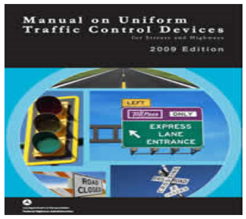
Part 1 – General
Part 2 - Signs
Part 3 - Pavement Markings
Part 4 – Highway Traffic Signals
Part 5 – Traffic Control Devices for Low-Volume Roads
Part 6 – Temporary Traffic Control
Part 7 – Traffic Control for School Areas
Part 8 – Traffic Control for Railroad and Light Rail Transit Grade Crossings
Part 9 – Traffic Control for Bicycle Facilities



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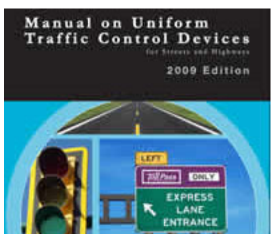
Applying the MUTCD to Traffic Control Signals

- Part 4 of the MUTCD contains the approved language for applying traffic control signals for usage in an intersection or mid-block crossing.



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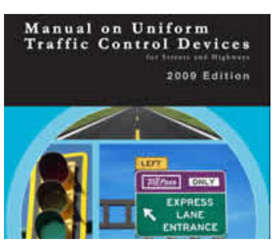
Applying the MUTCD to Traffic Control Signals

- "The features of traffic control signals of interest to road users are the location, design, and meaning of the signal indications".
- "Uniformity in the design features that affect the traffic to be controlled, as set forth in this Manual, is especially important for reasonably safe and efficient traffic operations".



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- Whether you are new to asset management, a seasoned practitioner or an executive, this course will help to further your understanding of asset management techniques and advance asset management practices at your agency.

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- This introductory module provides an overview of the organization and identifies some of the basic elements of Asset Management.

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- Asset Management is a way of conducting a transportation agency's business to deliver more value in its activities so that the transportation system performs best with the available resources. Most agencies have elements of asset management principles in their existing practice.

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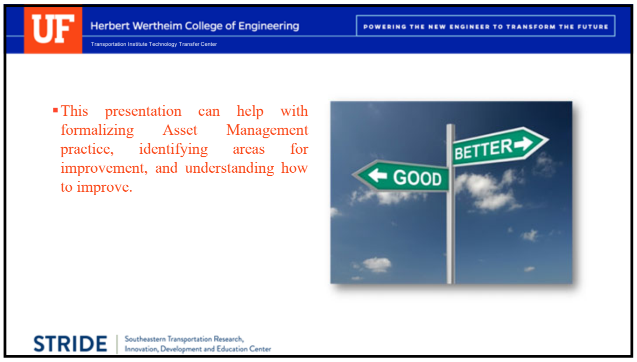
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▪ This presentation can help with formalizing Asset Management practice, identifying areas for improvement, and understanding how to improve.
GOOD
BETTER
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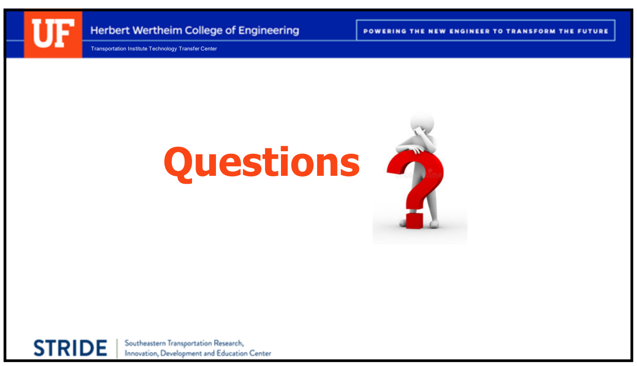
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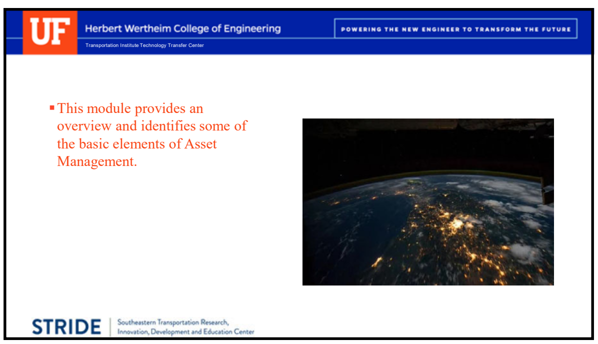
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This module provides an overview and identifies some of the basic elements of Asset Management.
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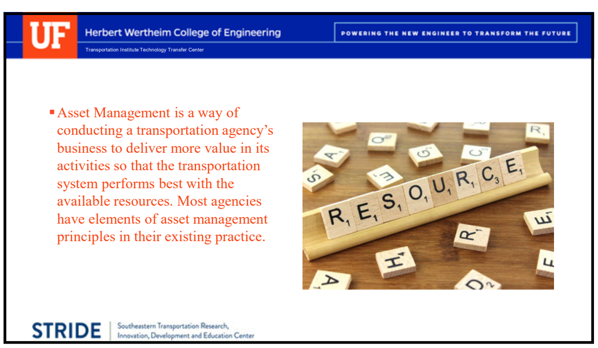
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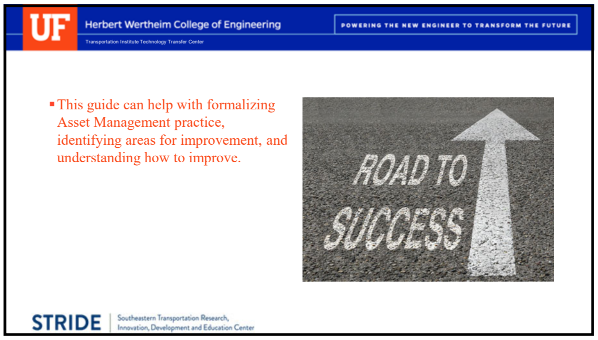
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▪ This guide can help with formalizing Asset Management practice, identifying areas for improvement, and understanding how to improve.
ROAD TO SUCCESS
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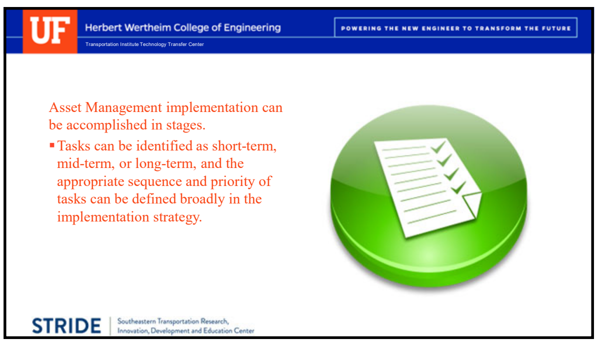
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Asset Management implementation can be accomplished in stages.
▪ Tasks can be identified as short-term, mid-term, or long-term, and the appropriate sequence and priority of tasks can be defined broadly in the implementation strategy.
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▪ Asset management implementation can be accomplished in stages.
▪ Work can begin in one program area or type of investment (e.g., preservation or maintenance) to demonstrate principles and techniques and to establish the organizational linkages and business process interactions needed to make the approach work.
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- Asset Management implies change, and change in an organization can be difficult to deal with.
- Be aware that organizational and institutional changes in asset management will likely present greater challenges than changes in technical or analytic capabilities.
- Discuss strategies that can be put in place to bring about change more effectively, establishing support and confidence among managers and staff.

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- Policy-based asset management programs tend to support a long-term, life-cycle approach to evaluating investment benefits and costs.
- Policy-based decisions on programs for different assets, modes, or types of investments may be based on historical funding baselines, formula-based splits, or deal-making rather than on current performance objectives or targets.

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- Performance-based asset management programs support the preservation of existing highway assets through the use of identified measures and targets.

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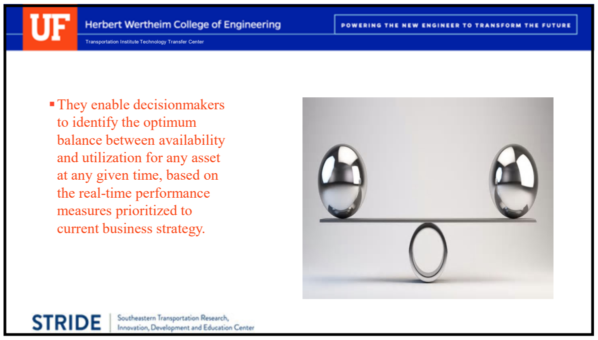
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▪ They enable decisionmakers to identify the optimum balance between availability and utilization for any asset at any given time, based on the real-time performance measures prioritized to current business strategy.
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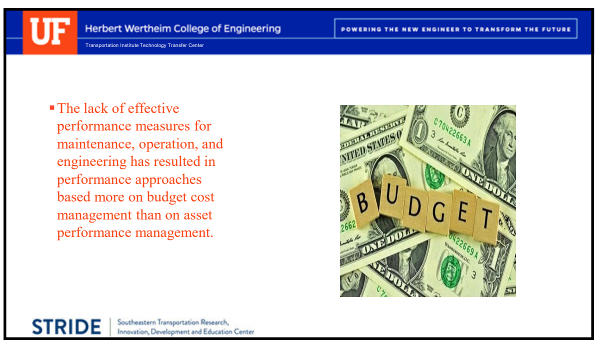
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▪ The lack of effective performance measures for maintenance, operation, and engineering has resulted in performance approaches based more on budget cost management than on asset performance management.
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▪ Performance-based asset management is a process of managing an infrastructure system in order to optimize its behavior when evaluated against specified objectives.
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- It is risk based, in that the costs of alternative investments are weighed against their benefits.
- It also has to take account of the multiple objectives for highway assets, including economic efficiency, the environment, and safety.

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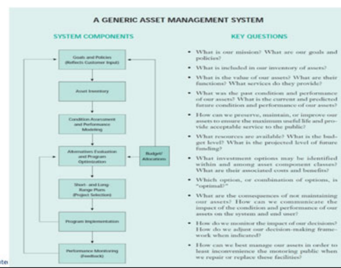
The Generic Asset Management System, which serves as a framework and guide to the asset management process, shows the importance of defining Goals and Policies at the start and using Performance Monitoring as a check.



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- For example, an agency may adjust its policies higher or lower based on the feedback gathered by performance monitoring that is used to check conformance to the policy.
- When the data come back, an agency may find that it is already doing better than its stated policy objectives or it may find that the policy objectives are not realistic or need to be placed on a longer time track.

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1. What is our mission?
2. What are our goals and policies?
3. What is included in our inventory of assets?
4. What is the value of our assets?
5. What are their functions?
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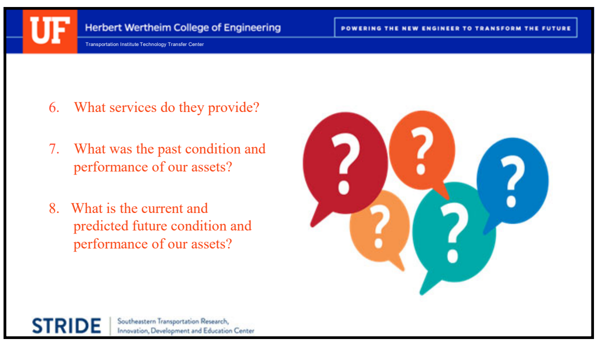
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6. What services do they provide?
7. What was the past condition and performance of our assets?
8. What is the current and predicted future condition and performance of our assets?
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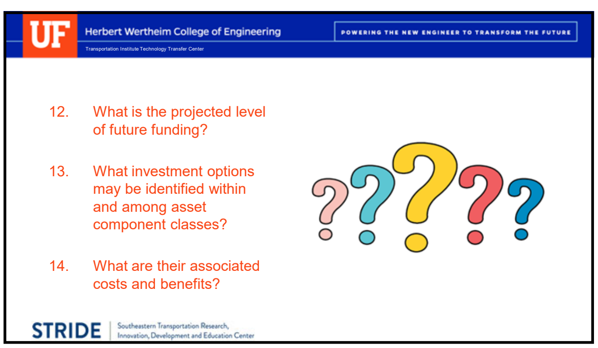
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12. What is the projected level of future funding?
13. What investment options may be identified within and among asset component classes?
14. What are their associated costs and benefits?
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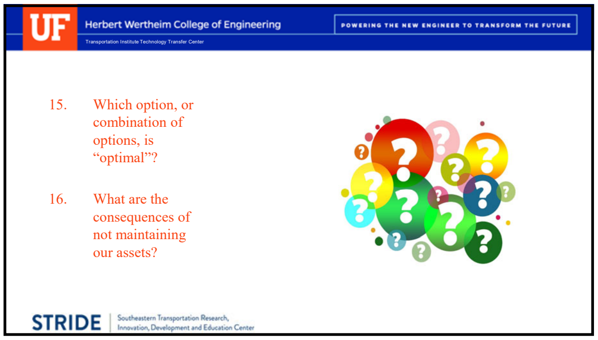
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15. Which option, or combination of options, is "optimal"?
16. What are the consequences of not maintaining our assets?
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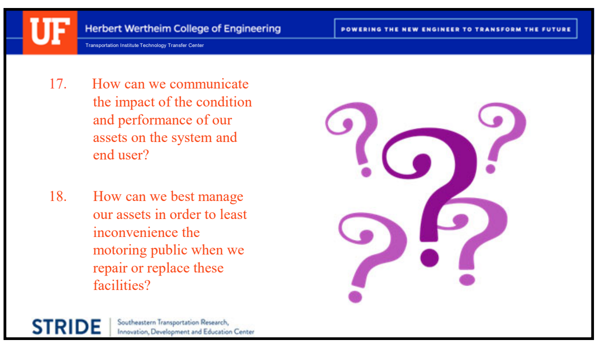
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17. How can we communicate the impact of the condition and performance of our assets on the system and end user?
18. How can we best manage our assets in order to least inconvenience the motoring public when we repair or replace these facilities?
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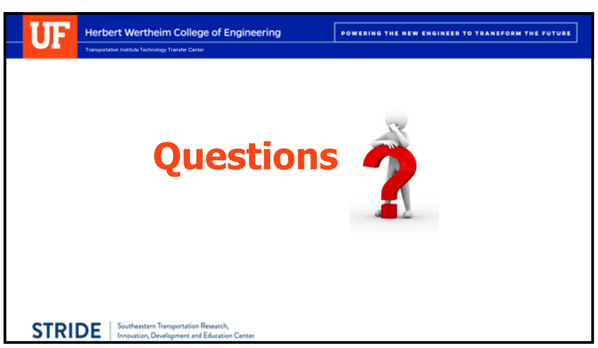
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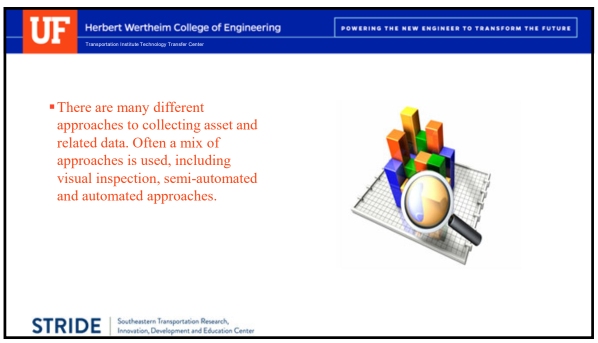
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There are many different approaches to collecting asset and related data. Often a mix of approaches is used, including visual inspection, semi-automated and automated approaches.
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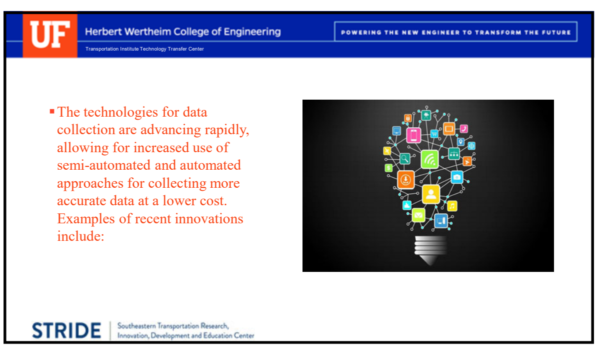
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The technologies for data collection are advancing rapidly, allowing for increased use of semi-automated and automated approaches for collecting more accurate data at a lower cost. Examples of recent innovations include:
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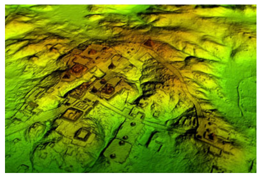
- Improvements in machine vision that allow extracting some forms of asset inventory data from video or LiDAR.
- Use of unmanned aerial vehicles (UAV, also called drones) for allowing bridge inspectors to obtain video of hard-to-reach areas of a bridge.



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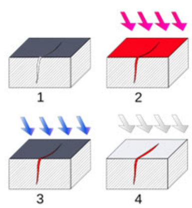
- Improvements in non-destructive evaluation (NDE), allowing for greater use of techniques such as ground penetrating radar (GPR) for pavement and bridge decks and instrumenting bridges to monitor performance over time.



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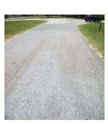
- Pavement
- Bridges
- Signals



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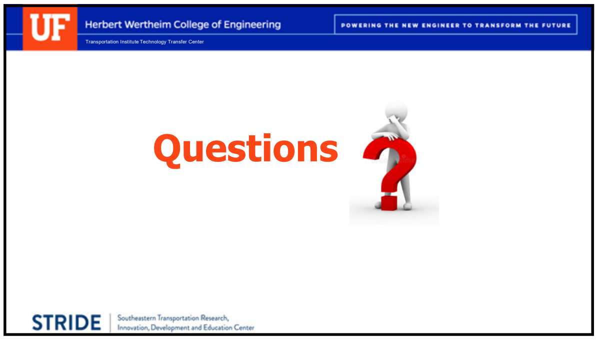
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Traffic Signal Systems Asset Management – Module 4
A Basic Guide to Understanding the Value of Asset Management of Traffic Signals Inventory
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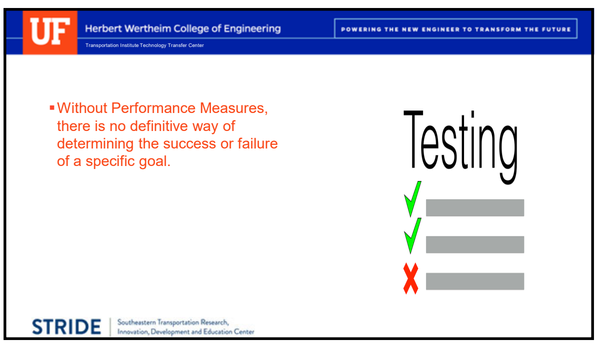
1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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Without Performance Measures, there is no definitive way of determining the success or failure of a specific goal.
Testing
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2


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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Improving Employee Injury Rate
Improving Client Injury Rate
INJURY PREVENTION
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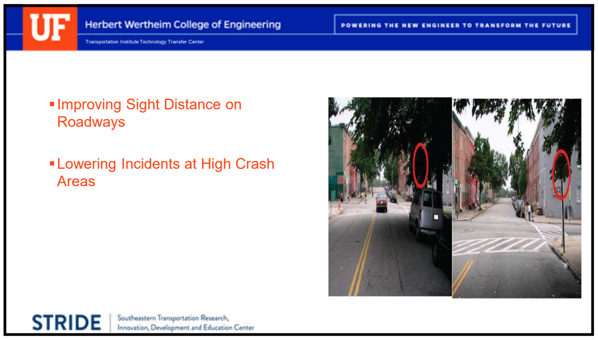
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
▪ Improving Sight Distance on Roadways
▪ Lowering Incidents at High Crash Areas
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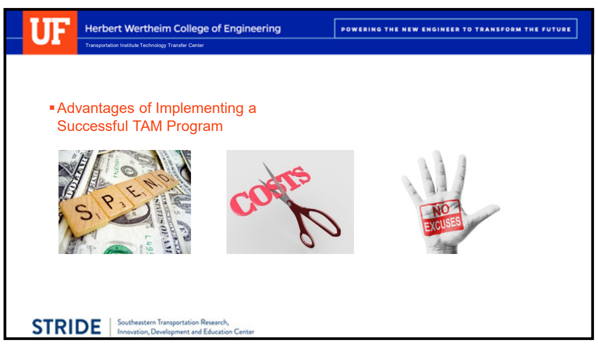
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
▪ Advantages of Implementing a Successful TAM Program
SPEND
COSTS
NO EXCUSES
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
▪ Engage Stakeholders and Identify Priorities
CHANGED PRIORITIES AHEAD
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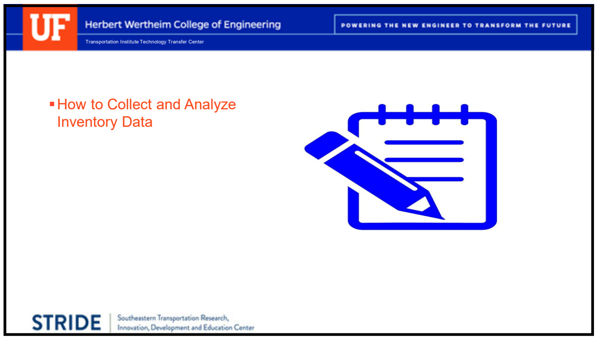
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▪ How to Collect and Analyze Inventory Data
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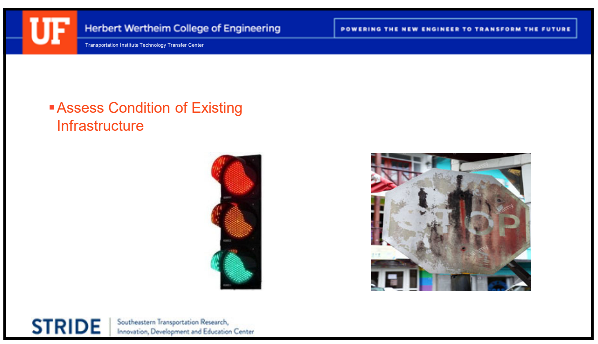
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▪ Assess Condition of Existing Infrastructure
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▪ Preserve Valuable Assets using Low-cost Improvement Techniques
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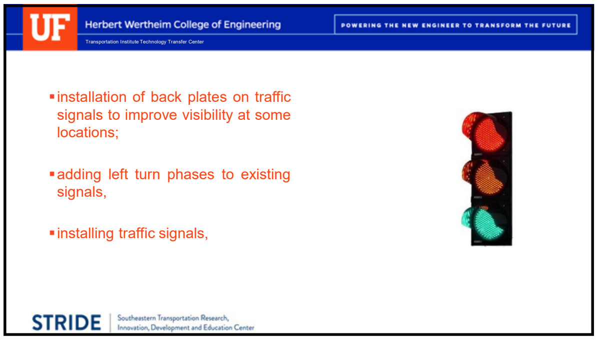
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▪installation of back plates on traffic signals to improve visibility at some locations;
▪adding left turn phases to existing signals,
▪installing traffic signals,
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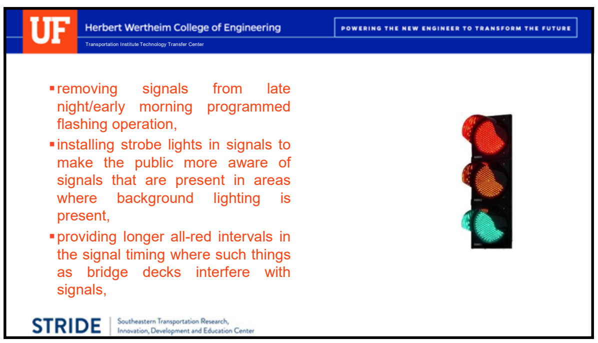
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▪removing signals from late night/early morning programmed flashing operation,
▪installing strobe lights in signals to make the public more aware of signals that are present in areas where background lighting is present,
▪providing longer all-red intervals in the signal timing where such things as bridge decks interfere with signals,
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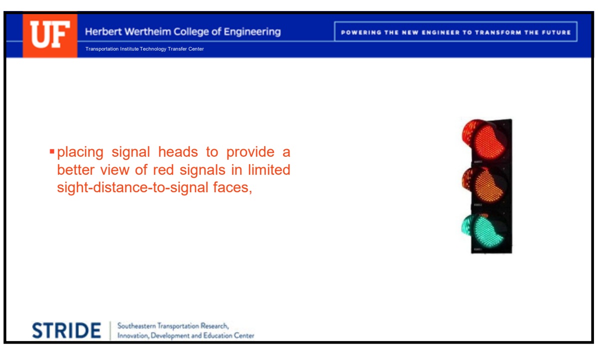
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▪placing signal heads to provide a better view of red signals in limited sight-distance-to-signal faces,
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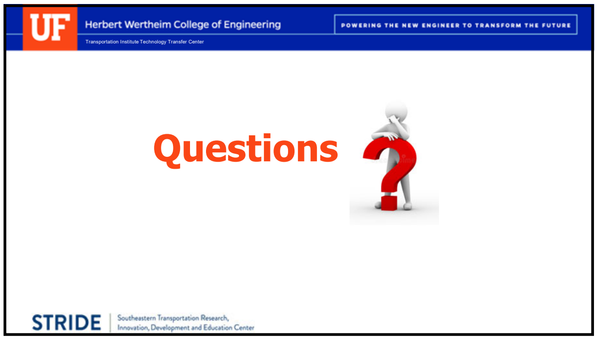
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Questions
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Training Slides

Highway Safety Analysis of Traffic Signals and Their Timing


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Highway Safety Analysis -
Traffic Signals and their Timing
Shraddha Sagar
Assistant Engineer Faculty
UFTI T2-Center
University of Florida
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Workforce Development Summit
Course Schedule
https://techtransfer.ce.ufl.edu/training/stride-workforce-development-summit/
MUTCD Traffic Signals Overview May 11
Traffic Signal Systems Asset Management May 12
Highway Safety Analysis Traffic Signals and their Timing May 12
Basic Traffic Signal Timing May 15
Transportation Equity Fundamentals May 15
Traffic Signal Basics May 16-17
Highway Capacity Analysis with Signalized Intersections May 19
Advanced Traffic Signal Timing May 22
Traffic Engineering Fundamentals Kickoff Summit May 9
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2023 Workforce Development Summit
Register at
Course Schedule
May 9 Traffic Engineering Fundamentals Kickoff Summit
May 11 MUTCD Traffic Signals Overview
May 12 Traffic Signal Systems Asset Management
May 12 Highway Safety Analysis Traffic Signals and their Timing
May 15 Basic Traffic Signal Timing
May 15 Transportation Equity Fundamentals
May 16-17 Traffic Signal Basics
May 19 Highway Capacity Analysis with Signalized Intersections
May 22 Advanced Traffic Signal Timing
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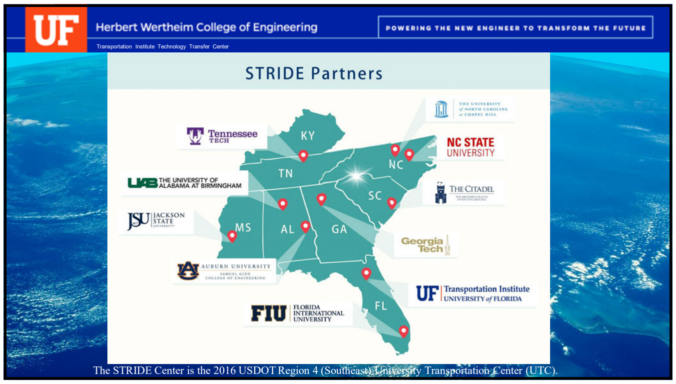
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NC STATE UNIVERSITY
THE CITADEL
Georgia Tech
Tennessee Tech
THE UNIVERSITY OF ALABAMA AT BIRMINGHAM
JACKSON STATE UNIVERSITY
AUBURN UNIVERSITY
FIU FLORIDA INTERNATIONAL UNIVERSITY
UF Transportation Institute UNIVERSITY of FLORIDA
The STRIDE Center is the 2016 USDOT Region 4 (Southeast) University Transportation Center (UTC).

4


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Learning Objective
What is road safety?
Science of Road Safety
Measuring Safety
Highway Safety Manual
Road Safety Management
Road Safety Audits
Countermeasures and Tools
Road safety
STOP
SAFETY FIRST
HAZARD AHEAD
ONLY
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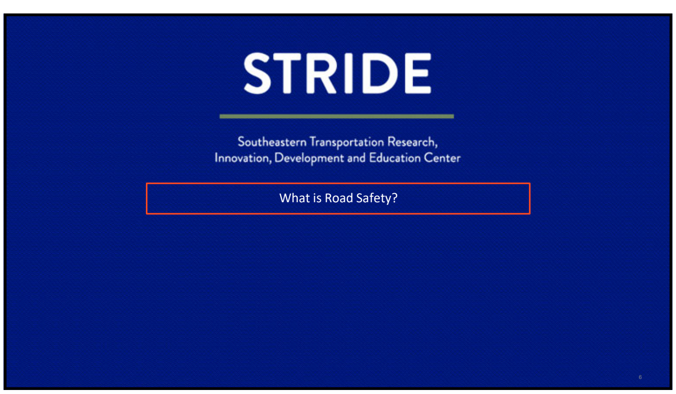
5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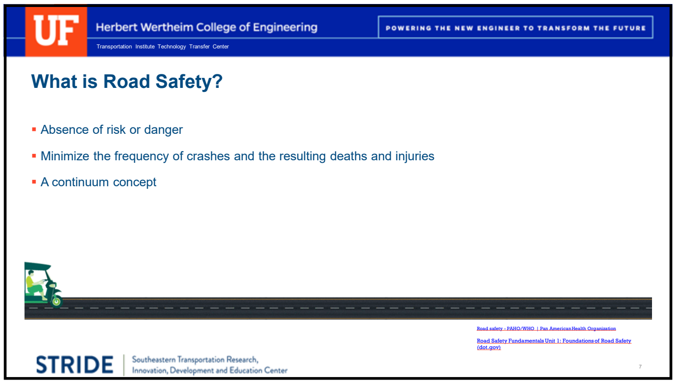
What is Road Safety?

6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What is Road Safety?
Absence of risk or danger
Minimize the frequency of crashes and the resulting deaths and injuries
A continuum concept
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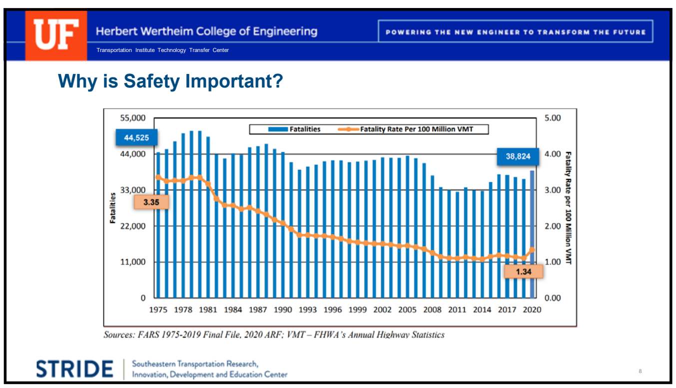
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Why is Safety Important?
Fatalities
Fatality Rate Per 100 Million VMT
44,525
38,824
3.35
1.34
Fatality Rate per 100 Million VMT
Sources: FARS 1975-2019 Final File, 2020 ARF; VMT – FHWA's Annual Highway Statistics
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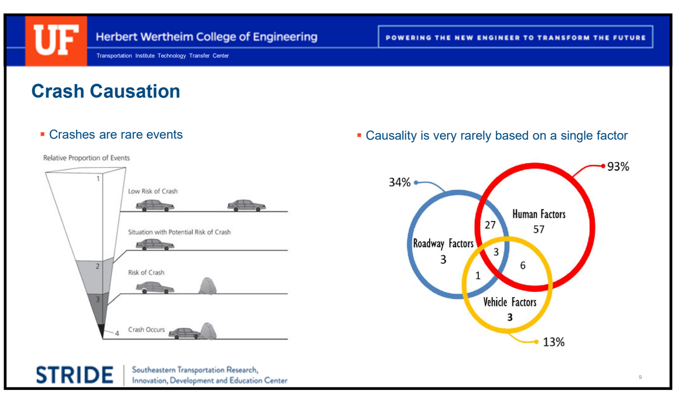
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Crash Causation
Crashes are rare events
Relative Proportion of Events
Low Risk of Crash
Situation with Potential Risk of Crash
Risk of Crash
Crash Occurs
Causality is very rarely based on a single factor
34%
93%
Human Factors
57
Roadway Factors
3
27
3
6
1
Vehicle Factors
3
13%
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Crash Severity

- Maximum Abbreviated Injury Scale (MAIS)
  - 0: No injury (0)
  - 1: Minor (0)
  - 2: Moderate (1-2)
  - 3: Serious (8-10)
  - 4: Severe (5-50)
  - 5: Critical (5-50)
  - 6: Maximum/Fatal (100)
- KABCO Scale for Injury Severity
  - K: Fatal injury
  - A: Incapacitating injury
  - B: Non-incapacitating evident injury
  - C: Possible injury
  - O: No Injury/Property Damage Only

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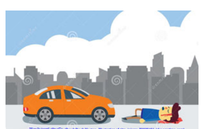
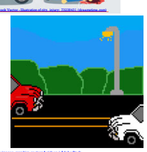
Crash Types

- Crash types with greatest likelihood of fatality or serious injury:
  - Head-on crashes
  - Run-off-road crashes
  - Pedestrian and bike crashes
  - Motorcyclist crashes
  - Commercial vehicle crashes
  - Intersection crashes





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Intersection Safety

- Intersection safety is a growing issue
- Annually, 25% of traffic fatalities and 50% of traffic injuries are attributed to intersections
- Since 2020, fatal and injury crashes of vulnerable road user rising
  - pedestrian fatalities up 13%
  - pedal cyclist fatalities up 5% since 2020

About | Intersection Safety - Safety | Federal Highway Administration (dot.gov)

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Crash Causation - Traffic Signals

- Helps achieve effective operations
- Separates most of the conflicting movements
- Safer performance at intersections
- Reduce the number and severity of crashes

- About 1/3rd of all intersection fatalities occurring at signalized intersections
  - Trade off between safety and mobility
  - Large proportion involving red-light running

Year	Total Traffic Fatalities	Traffic Fatalities Involving an Intersection	Traffic Fatalities Involving a Signalized Intersection	Percent of intersection fatalities occurring at signalized intersections
2015	35,484	9,664	2,923	30%
2016	37,806	10,414	3,298	32%
2017	37,133	10,301	3,271	32%
2018	36,835	10,011	3,274	33%

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Why Safety is important in traffic operations? Case Study

	2020		LOS			Npred		
Segment	LOS	Npred	2021	2022	2023	2021	2022	2023
1	B	50	B	C	C	54	59	65
2	D	46	D	D	D	48	50	52
3	B	60	B	C	C	54	56	58
4	C	92	C	C	D	95	99	103
5	C	34	C	C	C	35	36	38
6	C	17	C	C	C	18	19	20
7	B	16	B	B	B	17	17	18
8	B	19	B	B	B	19	20	21

Level of service or Number of crashes?

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Road Safety Management

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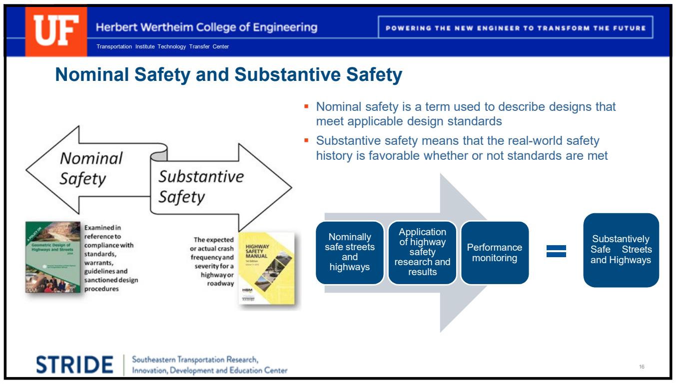
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Nominal Safety and Substantive Safety
Nominal safety is a term used to describe designs that meet applicable design standards
Substantive safety means that the real-world safety history is favorable whether or not standards are met
Nominal Safety
Substantive Safety
Examined in reference to compliance with standards, warrants, guidelines and sanctioned design procedures
The expected or actual crash frequency and severity for a highway or roadway
Nominally safe streets and highways
Application of highway safety research and results
Performance monitoring
=
Substantively Safe Streets and Highways
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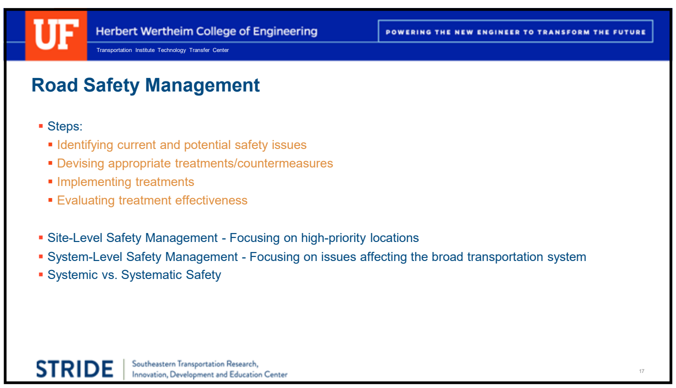
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Road Safety Management
Steps:
Identifying current and potential safety issues
Devising appropriate treatments/countermeasures
Implementing treatments
Evaluating treatment effectiveness
Site-Level Safety Management - Focusing on high-priority locations
System-Level Safety Management - Focusing on issues affecting the broad transportation system
Systemic vs. Systematic Safety
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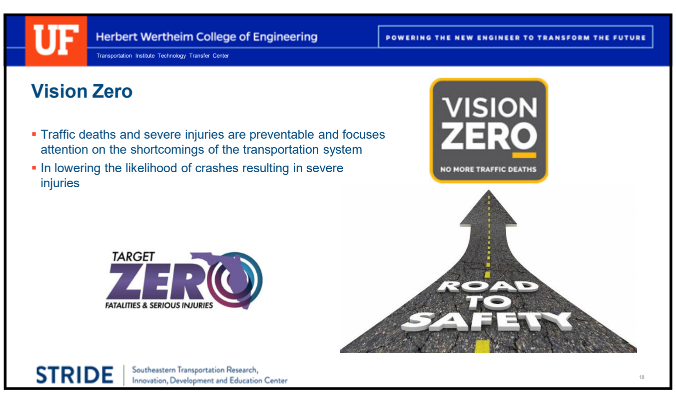
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Vision Zero
Traffic deaths and severe injuries are preventable and focuses attention on the shortcomings of the transportation system
In lowering the likelihood of crashes resulting in severe injuries
VISION ZERO
NO MORE TRAFFIC DEATHS
TARGET ZERO
FATALITIES & SERIOUS INJURIES
ROAD TO SAFETY
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Safe System Approach

- An approach to achieve Vision Zero
- Guiding paradigm to address roadway safety
- A national vision of zero roadway fatalities and identifies priority actions in pursuit of five Safe System objectives:
  - Safer people
  - Safer vehicles
  - Safer speeds
  - Safer roads
  - Post-crash care

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Quiz

Which of the following definitions best describe Nominal Safety?

A) The historic and long-term objective safety of a location based on crash data
B) A measure of safety (e.g., crash frequency) that is not adjusted for long-term growth in traffic volumes
C) An absolute statement about the safety of a location based only on its adherence to asset of design standards
D) A subjective description of a location's safety based on public opinion surveys

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Measuring Safety

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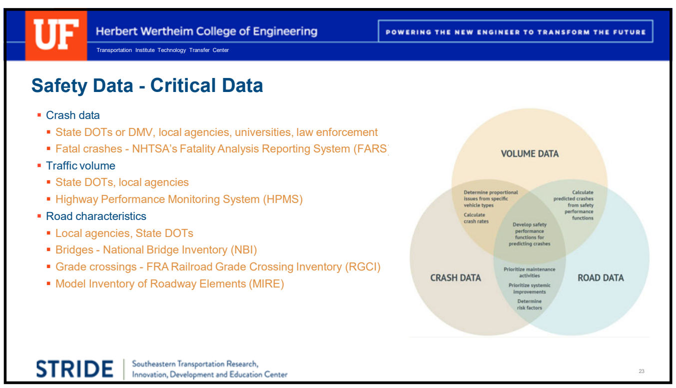
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Safety Data - Critical Data
▪ Crash data
▪ State DOTs or DMV, local agencies, universities, law enforcement
▪ Fatal crashes - NHTSA's Fatality Analysis Reporting System (FARS
▪ Traffic volume
▪ State DOTs, local agencies
▪ Highway Performance Monitoring System (HPMS)
▪ Road characteristics
▪ Local agencies, State DOTs
▪ Bridges - National Bridge Inventory (NBI)
▪ Grade crossings - FRA Railroad Grade Crossing Inventory (RGCI)
▪ Model Inventory of Roadway Elements (MIRE)
VOLUME DATA
Determine proportional issues from specific vehicle types
Calculate crash rates
Calculate predicted crashes from safety performance functions
Develop safety performance functions for predicting crashes
CRASH DATA
ROAD DATA
Prioritize maintenance activities
Prioritize systemic improvements
Determine risk factors
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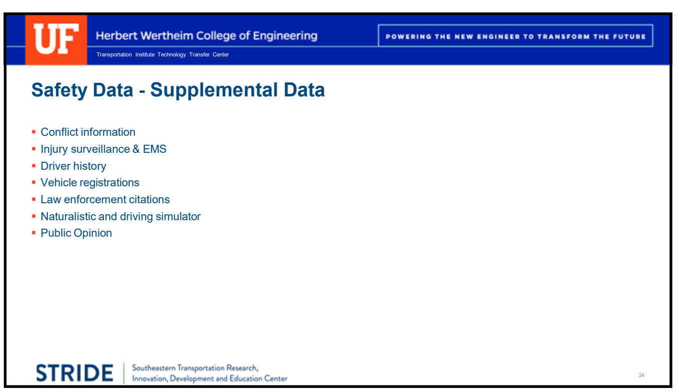
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Safety Data - Supplemental Data
▪ Conflict information
▪ Injury surveillance & EMS
▪ Driver history
▪ Vehicle registrations
▪ Law enforcement citations
▪ Naturalistic and driving simulator
▪ Public Opinion
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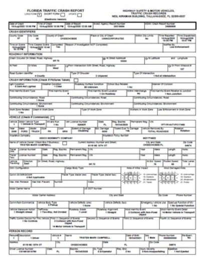
Crash Data

- Crash-related variable
  - Time/date, Identifier
  - Location – city, place, latitude and longitude, distance of intersection
  - Manner of collision
- Contributing circumstances
  - Road surface conditions
  - Weather conditions
  - Environmental conditions
- Driver Information, Vehicle information, Crash Narrative, Crash Diagram



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Measuring Safety

- **Crash frequency** - the number of crashes occurring per year or other unit of time
- **Crash rates** - numbers of crashes normalized by a particular population or metric of exposure
  - crashes per 100,000 people living in a particular State, city or country.
  - Crashes per miles traveled or licensed drivers.
- **Crash outcomes** - types of injuries, typically, fatalities and injury severity.

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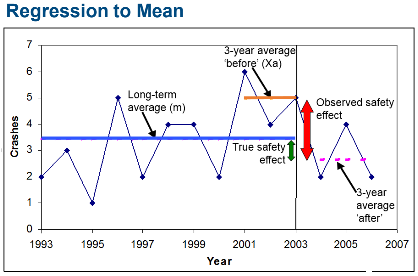
Regression to Mean



Short term crash averages will vary depending on the time period analyzed

Actual crash average over extended period

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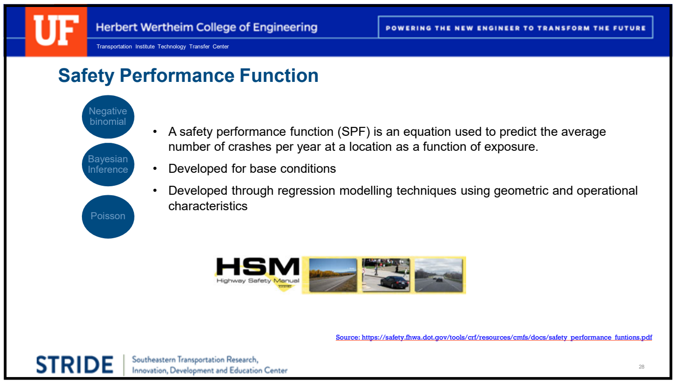
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Safety Performance Function
Negative binomial
Bayesian Inference
Poisson
• A safety performance function (SPF) is an equation used to predict the average number of crashes per year at a location as a function of exposure.
• Developed for base conditions
• Developed through regression modelling techniques using geometric and operational characteristics
HSM
Highway Safety Manual
Source: https://safety.fhwa.dot.gov/tools/crf/resources/cmfs/docs/safety_performance_funtions.pdf
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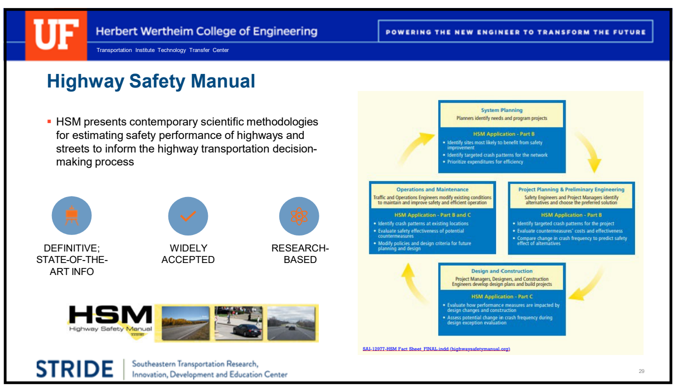
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Highway Safety Manual
▪ HSM presents contemporary scientific methodologies for estimating safety performance of highways and streets to inform the highway transportation decision-making process
DEFINITIVE; STATE-OF-THE-ART INFO
WIDELY ACCEPTED
RESEARCH-BASED
HSM
Highway Safety Manual
System Planning
Planners identify needs and program projects
HSM Application - Part B
• Identify sites most likely to benefit from safety improvement
• Identify targeted crash patterns for the network
• Prioritize expenditures for efficiency
Project Planning & Preliminary Engineering
Safety Engineers and Project Managers identify alternatives and choose the preferred solution
HSM Application - Part B
• Identify targeted crash patterns for the project
• Evaluate countermeasures' costs and effectiveness
• Compare change in crash frequency to predict safety effect of alternatives
Design and Construction
Project Managers, Designers, and Construction Engineers develop design plans and build projects
HSM Application - Part C
• Evaluate how performance measures are impacted by design changes and construction
• Assess potential change in crash frequency during design exception evaluation
Operations and Maintenance
Traffic and Operations Engineers modify existing conditions to maintain and improve safety and efficient operation
HSM Application - Part B and C
• Identify crash patterns at existing locations
• Evaluate safety effectiveness of potential countermeasures
• Modify policies and design criteria for future planning and design
SAI-12977-HSM Fact Sheet_FINAL.indd (highwaysafetymanual.org)
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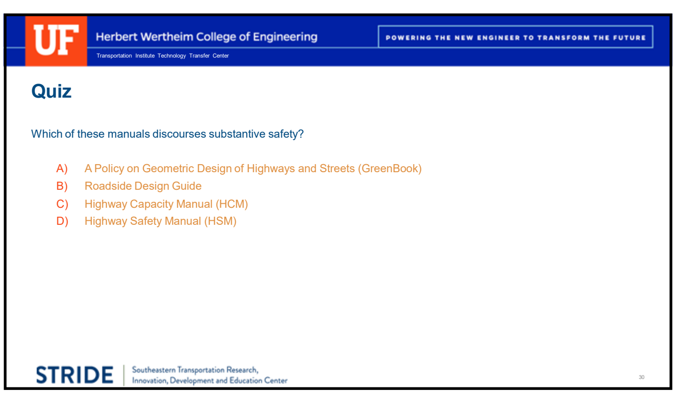
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Quiz
Which of these manuals discourses substantive safety?
A) A Policy on Geometric Design of Highways and Streets (GreenBook)
B) Roadside Design Guide
C) Highway Capacity Manual (HCM)
D) Highway Safety Manual (HSM)
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Safety Performance Function - Example

Example: Use the given SPF, predict the number of multi-vehicle crashes at an urban, four-legged signalized intersection.
The major road traffic volume is 25,000 vehicles per day and the minor road traffic volume is 10,000 vehicles per day

$$N_{\text{predicted}} = \exp(-10.99 + 1.07 \ln(AADT_{maj}) + 0.23 \ln(AADT_{min}))$$

Solution:

$$N_{\text{predicted}} = \exp(-10.99 + 1.07 \ln(25{,}000) + 0.23 \ln(10{,}000))$$

= 7.13 multi-vehicle crashes per year

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Empirical Bayes Method

The Empirical Bayes (EB) method consists of weighting the predicted crash frequency by the observed crashes.

$$N_{expected} = w \times N_{predicted} + (1.00 - w) \times N_{observed}$$

where: $N_{expected}$ = expected crash number for a specific period.
$N_{predicted}$ = predicted average crash frequency
$N_{observed}$ = observed average crash number of previous time.
w = weight factor related to the SPF

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Empirical Bayes Method

Advantages of the EB method:

- Accounts for the tendency for high-crash sites to have a lower frequency of crashes in subsequent periods due to regression to the mean.
- Incorporates the unique characteristics of the site into the analysis and accounts for any potential biases.
- Uses statistical analysis to estimate the expected crashes at a site, which provides a more objective and data-driven approach

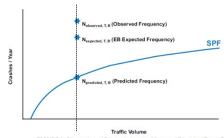

FIGURE 3. Illustration of Regression-to-the-Mean and Empirical Bayes Estimate.

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Empirical Bayes Method - Hands-on Example

A road segment is 1.8 mi long, has AADT of 4000, and recorded 12 crashes in the last year. The SPF for similar roads is $N = 0.0224 \times AADT^{0.564}$ crashes/mi/year, w = 0.460. Calculate Expected Average Crash Frequency

$$N_{expected} = w \times N_{predicted} + (1.00 - w) \times N_{observed}$$

- **Step-1 Predict Safety on Similar Segments**

  $N'_{predicted} = 0.0224 \times 4000^{0.564} = 2.41$ crashes/mi/year

  $N_{predicted} = N'_{predicted} \times 1.8 \text{ mi} = 4.34$ crashes/year

- **Step-2 Weight**

  $w = 1 / (1 + \alpha N_{predicted})$

  α = overdispersion parameter for the SPF

- **Step-3 Calculate Expected Average Crash frequency**

  $N_{expected} = w \times 4.34 + (1 - w) \times 12 = 8.48$ crashes/year

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Predicted and Expected Crashes

Predicted Crashes -

- Estimates of long-term average crash frequency which is forecast to occur at a location using a predictive model found in Part C of HSM

Expected Crashes -

- Estimates of long-term average cash frequency of a location under a given set of geometric conditions and traffic volumes (AADT) in a given period of year using observed crash data

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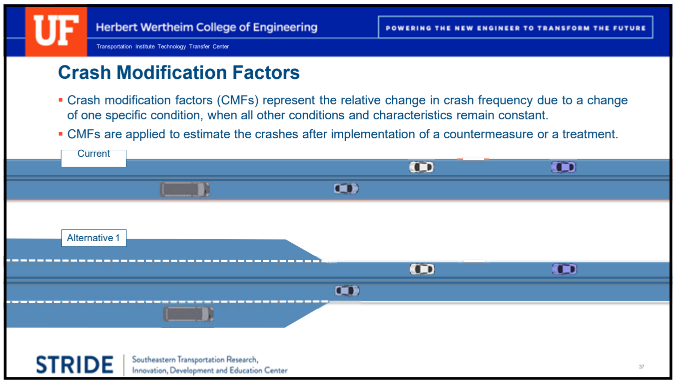
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Crash Modification Factors
Crash modification factors (CMFs) represent the relative change in crash frequency due to a change of one specific condition, when all other conditions and characteristics remain constant.
CMFs are applied to estimate the crashes after implementation of a countermeasure or a treatment.
Current
Alternative 1
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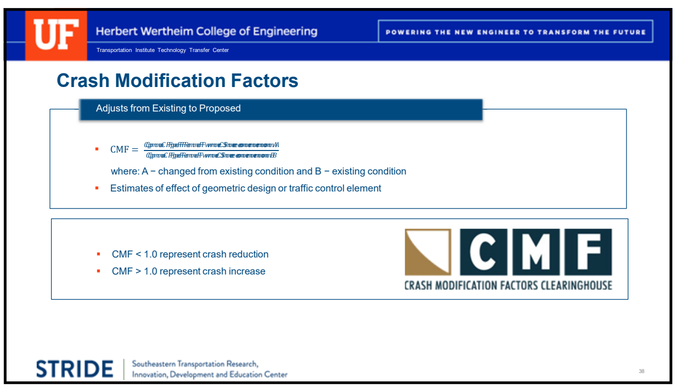
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Crash Modification Factors
Adjusts from Existing to Proposed
CMF =
where: A – changed from existing condition and B – existing condition
Estimates of effect of geometric design or traffic control element
CMF < 1.0 represent crash reduction
CMF > 1.0 represent crash increase
CMF
CRASH MODIFICATION FACTORS CLEARINGHOUSE
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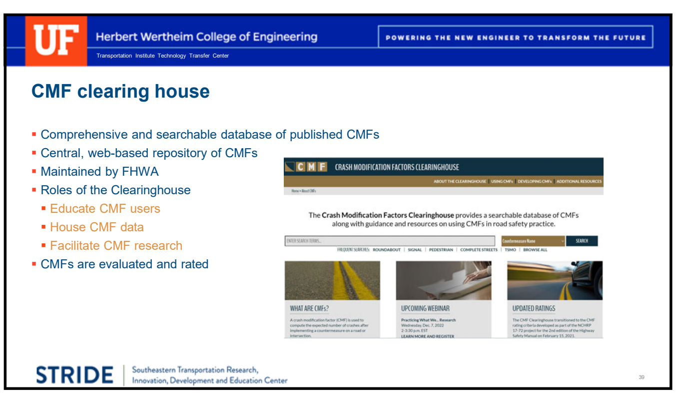
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CMF clearing house
Comprehensive and searchable database of published CMFs
Central, web-based repository of CMFs
Maintained by FHWA
Roles of the Clearinghouse
Educate CMF users
House CMF data
Facilitate CMF research
CMFs are evaluated and rated
CRASH MODIFICATION FACTORS CLEARINGHOUSE
The Crash Modification Factors Clearinghouse provides a searchable database of CMFs along with guidance and resources on using CMFs in road safety practice.
WHAT ARE CMFs?
UPCOMING WEBINAR
UPDATED RATINGS
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Selecting CMFs

- Primary Goal: Select a CMF that was developed under the same (or very similar) conditions as the location for which the countermeasure is being applied.

- Characteristics to consider:
  - Countermeasure type
  - Crash type
  - Crash severity
  - Facility type
  - Area type
  - AADT ranges
  - Prior conditions
  - Star rating

Countermeasure: Conversion of intersection to roundabout

Compare	CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
☐	1.346	-34.6	★★★★★	All	All	All	, 2011	Note: CMF applies only to loss...[READ MORE]
☐	0.488	51.2	★★★★☆	All	A (serious injury),B (minor injury),C (possible injury)	All	, 2011	Note: CMF applies only to loss...[READ MORE]
☐	0.583	41.7	★★★★☆	All	A (serious injury),B (minor injury),C (possible injury)	All	, 2011	Note: CMF applies only to loss...[READ MORE]
☐	1.002	-0.2	★★★★☆	All	All	All	, 2011	Note: CMF applies only to loss...[READ MORE]
☐	0.467	53.3	★★★☆☆	All	K (fatal),A (serious injury),B (minor injury),C (possible injury)	All	GBOLOGAH ET AL., 2019	Note: CMF applies only to loss...[READ MORE]
☐	0.623	37.7	★★★☆☆	All	All	All	GBOLOGAH ET AL., 2019	Note: CMF applies only to loss...[READ MORE]

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Crash Modification Factors

- Use of multiple CMFs - generally multiplicative
  Combined CMF = CMF_1 x CMF_2 ..... x CMF_x

Example:
CMF for Treatment #1 = 0.86, CMF for Treatment #2 = 0.75
CMF for Treatment #1 + #2 = 0.86 x 0.75 = 0.65

But what if the CMF for #2 was 1.16?
Combined CMF = 0.86 x 1.16 = 1.0 (is this really the same as no treatment at all?)

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Crash Reduction Factor (CRF)

Same as CMF	Estimates of effect of geometric design or traffic control element Expressed as a percentage
CMF = 1 – (CRF/100)	CMF = 0.75 → CRF = 25% (fewer crashes) CMF = 1.25 → CRF = (-) 25% (more crashes)

Example :
Studies have found that converting a 4-legged urban intersection from stop control to signal control will have an CMF for all fatal and injury crashes of 0.77.

This means that there will be an anticipated reduction in crashes of 23 percent if a traffic signal were installed.

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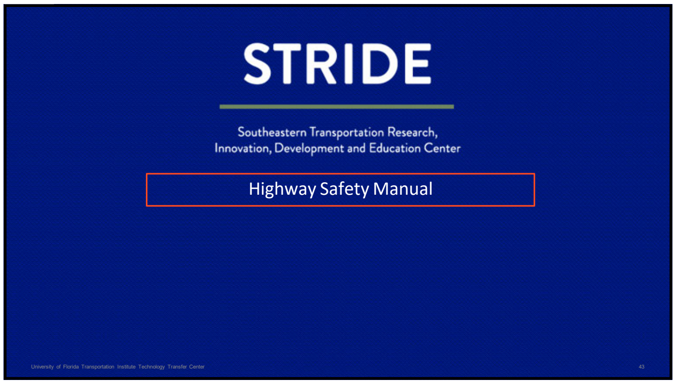
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Highway Safety Manual

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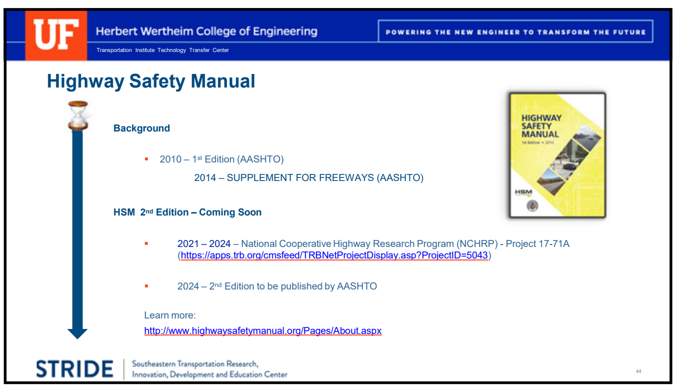
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Highway Safety Manual
Background
2010 – 1st Edition (AASHTO)
2014 – SUPPLEMENT FOR FREEWAYS (AASHTO)
HSM 2nd Edition – Coming Soon
2021 – 2024 – National Cooperative Highway Research Program (NCHRP) - Project 17-71A (https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5043)
2024 – 2nd Edition to be published by AASHTO
Learn more:
http://www.highwaysafetymanual.org/Pages/About.aspx
HIGHWAY SAFETY MANUAL
HSM
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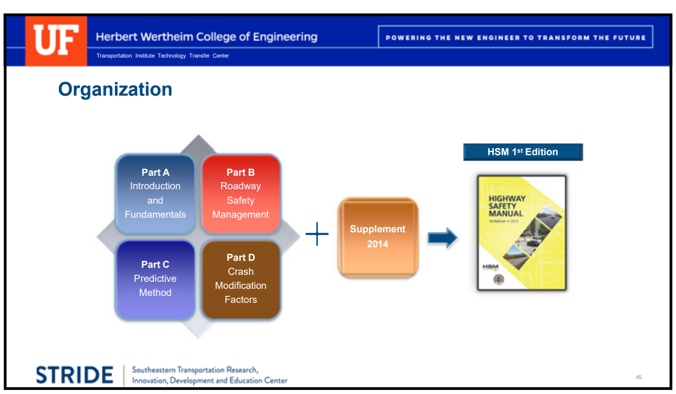
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Organization
Part A Introduction and Fundamentals
Part B Roadway Safety Management
Part C Predictive Method
Part D Crash Modification Factors
Supplement 2014
HSM 1st Edition
HIGHWAY SAFETY MANUAL
HSM
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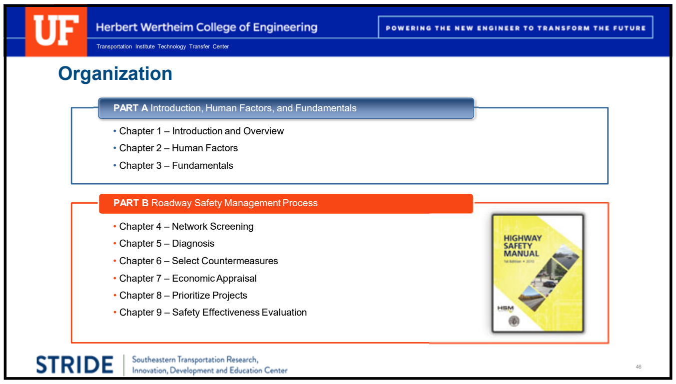
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Organization
PART A Introduction, Human Factors, and Fundamentals
• Chapter 1 – Introduction and Overview
• Chapter 2 – Human Factors
• Chapter 3 – Fundamentals
PART B Roadway Safety Management Process
• Chapter 4 – Network Screening
• Chapter 5 – Diagnosis
• Chapter 6 – Select Countermeasures
• Chapter 7 – Economic Appraisal
• Chapter 8 – Prioritize Projects
• Chapter 9 – Safety Effectiveness Evaluation
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HSM
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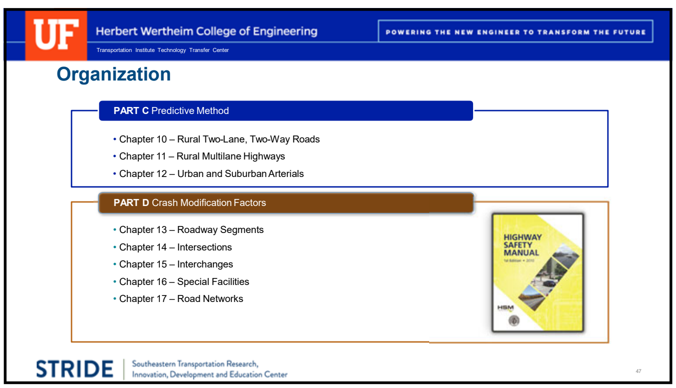
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PART C Predictive Method
• Chapter 10 – Rural Two-Lane, Two-Way Roads
• Chapter 11 – Rural Multilane Highways
• Chapter 12 – Urban and Suburban Arterials
PART D Crash Modification Factors
• Chapter 13 – Roadway Segments
• Chapter 14 – Intersections
• Chapter 15 – Interchanges
• Chapter 16 – Special Facilities
• Chapter 17 – Road Networks
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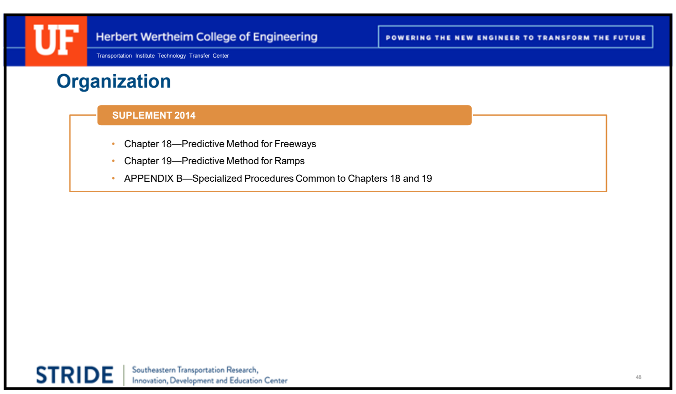
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Organization
SUPLEMENT 2014
• Chapter 18—Predictive Method for Freeways
• Chapter 19—Predictive Method for Ramps
• APPENDIX B—Specialized Procedures Common to Chapters 18 and 19
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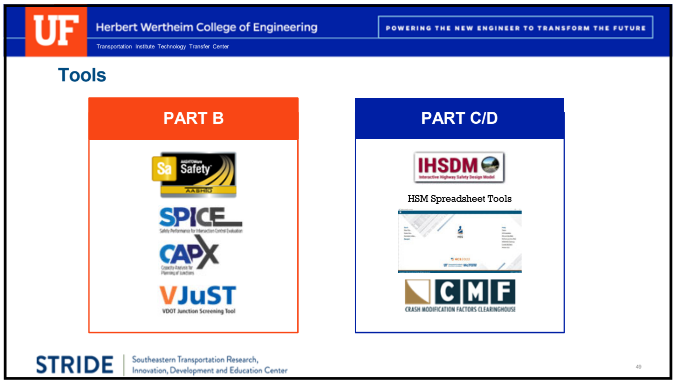
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Tools
PART B
Safety
AASHTO
SPICE
CAPX
VJuST
VDOT Junction Screening Tool
PART C/D
IHSDM
HSM Spreadsheet Tools
CMF
CRASH MODIFICATION FACTORS CLEARINGHOUSE
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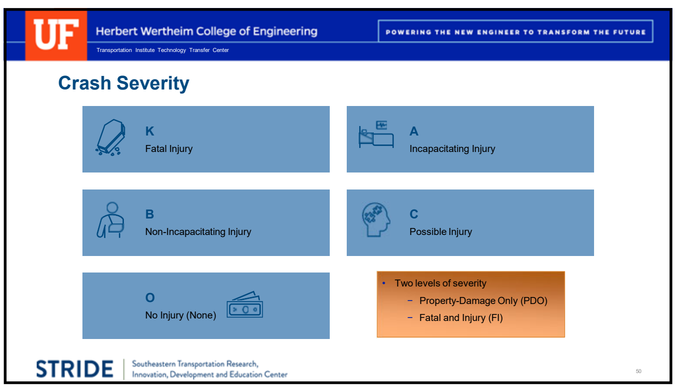
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Crash Severity
K
Fatal Injury
A
Incapacitating Injury
B
Non-Incapacitating Injury
C
Possible Injury
O
No Injury (None)
• Two levels of severity
– Property-Damage Only (PDO)
– Fatal and Injury (FI)
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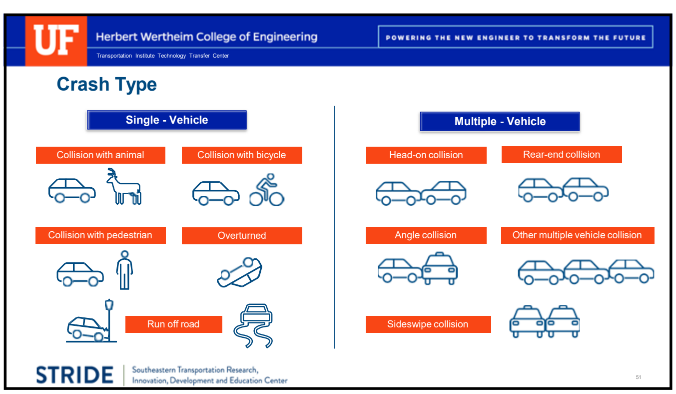
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Crash Type
Single - Vehicle
Collision with animal
Collision with bicycle
Collision with pedestrian
Overturned
Run off road
Multiple - Vehicle
Head-on collision
Rear-end collision
Angle collision
Other multiple vehicle collision
Sideswipe collision
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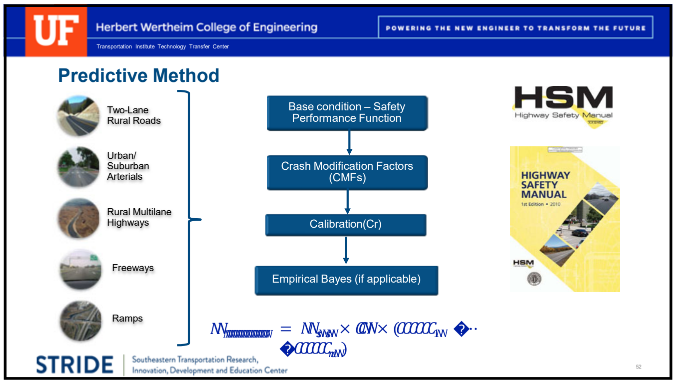
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Predictive Method
Two-Lane Rural Roads
Urban/ Suburban Arterials
Rural Multilane Highways
Freeways
Ramps
Base condition – Safety Performance Function
Crash Modification Factors (CMFs)
Calibration(Cr)
Empirical Bayes (if applicable)
HSM
Highway Safety Manual
HIGHWAY SAFETY MANUAL
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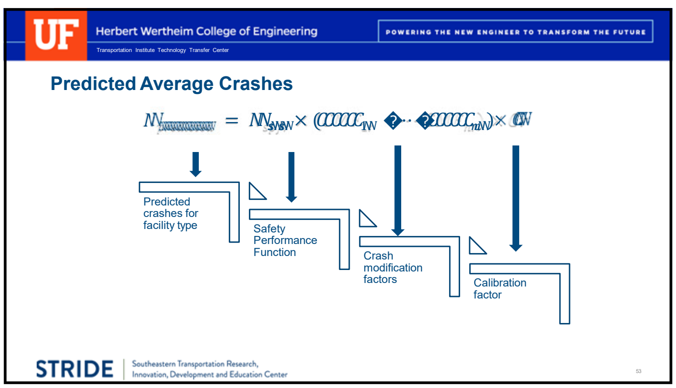
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Predicted Average Crashes
Predicted crashes for facility type
Safety Performance Function
Crash modification factors
Calibration factor
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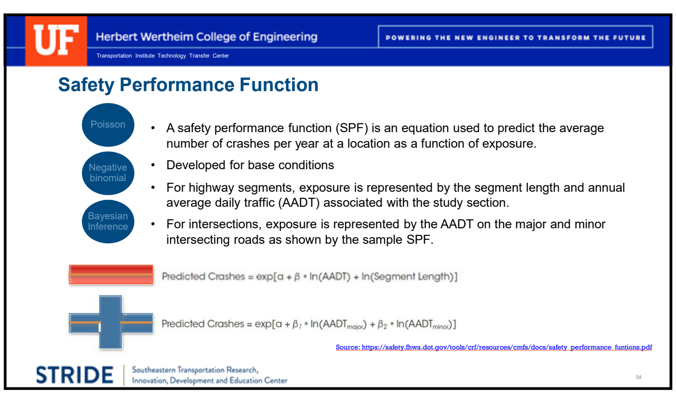
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Safety Performance Function
Poisson
Negative binomial
Bayesian Inference
• A safety performance function (SPF) is an equation used to predict the average number of crashes per year at a location as a function of exposure.
• Developed for base conditions
• For highway segments, exposure is represented by the segment length and annual average daily traffic (AADT) associated with the study section.
• For intersections, exposure is represented by the AADT on the major and minor intersecting roads as shown by the sample SPF.
Predicted Crashes = exp[α + β * ln(AADT) + ln(Segment Length)]
Predicted Crashes = exp[α + β1 * ln(AADTmajor) + β2 * ln(AADTminor)]
Source: https://safety.fhwa.dot.gov/tools/crf/resources/cmfs/docs/safety_performance_funtions.pdf
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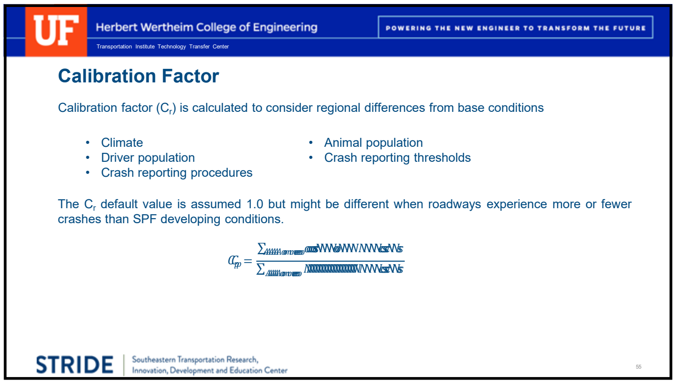
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Calibration Factor
Calibration factor (C_r) is calculated to consider regional differences from base conditions
• Climate
• Driver population
• Crash reporting procedures
• Animal population
• Crash reporting thresholds
The C_r default value is assumed 1.0 but might be different when roadways experience more or fewer crashes than SPF developing conditions.
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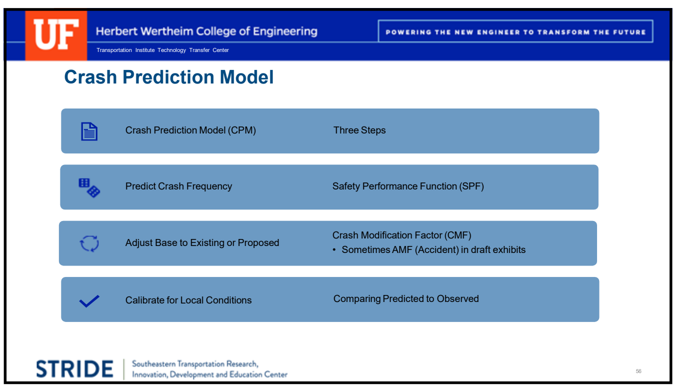
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Crash Prediction Model
Crash Prediction Model (CPM)
Three Steps
Predict Crash Frequency
Safety Performance Function (SPF)
Adjust Base to Existing or Proposed
Crash Modification Factor (CMF)
• Sometimes AMF (Accident) in draft exhibits
Calibrate for Local Conditions
Comparing Predicted to Observed
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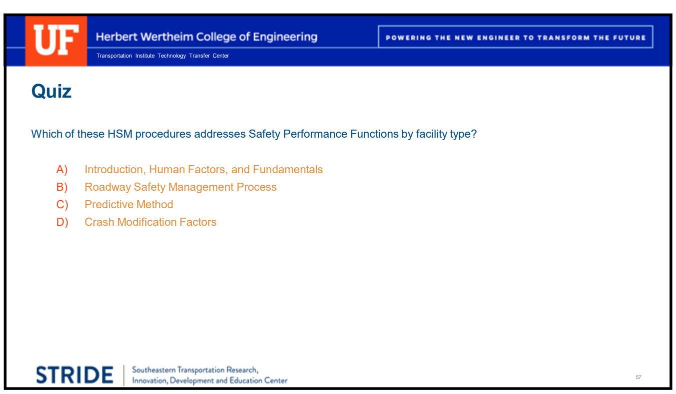
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Quiz
Which of these HSM procedures addresses Safety Performance Functions by facility type?
A) Introduction, Human Factors, and Fundamentals
B) Roadway Safety Management Process
C) Predictive Method
D) Crash Modification Factors
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Quiz

Which of these HSM procedures addresses Safety Performance Functions by facility type?

A) Introduction, Human Factors, and Fundamentals
B) Roadway Safety Management Process
C) **Predictive Method**
D) Crash Modification Factors

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Safety Performance Functions by Facility Type

HSM Chapters/Facility Type	Undivided Roadway Segment	Divided Roadway Segment	Intersections			
			Stop Control on Minor Leg(s)		Signalized	
			3-Leg	4-Leg	3-Leg	4-Leg
Chapter 10 - Rural Two-Lane, Two Way Roads	✓	-	✓	✓	-	✓
Chapter 11 - Rural Multilane Highways	✓	✓	✓	✓	-	✓
Chapter 12 - Urban and Suburban Arterials	✓	✓	✓	✓	✓	✓

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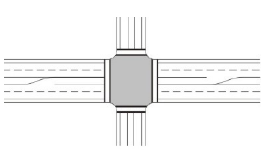
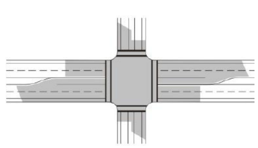
Intersection Areas



Intersection Physical Area



Intersection Functional Area

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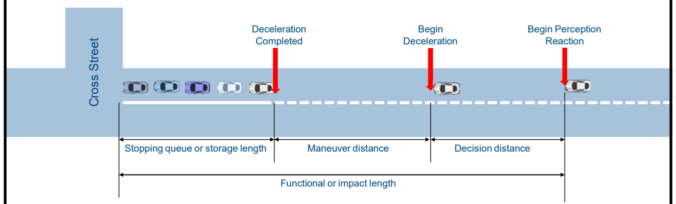
Intersection Function



Intersection Crashes

Crash Type?

Within 250 ft?

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Quiz

Which of the following would generally be considered the best practice to ensure the accuracy of output from a Safety Performance Function (SPF)?

A) Calculate the output from at least three different SPFs, and average them together
B) Calibrate the SPF with local information on crashes, traffic volumes and geometric characteristic of the roadway
C) Conduct a survey of existing intersection types prior to using the SPF, and select the SPF with the greatest correlation coefficient relative to the desired output
D) Select the SPF with the greatest number of verified citations from the Transportation Research Board's Integrated Database (TRID)

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Quiz

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C) Conduct a survey of existing intersection types prior to using the SPF, and select the SPF with the greatest correlation coefficient relative to the desired output
D) Select the SPF with the greatest number of verified citations from the Transportation Research Board's Integrated Database (TRID)

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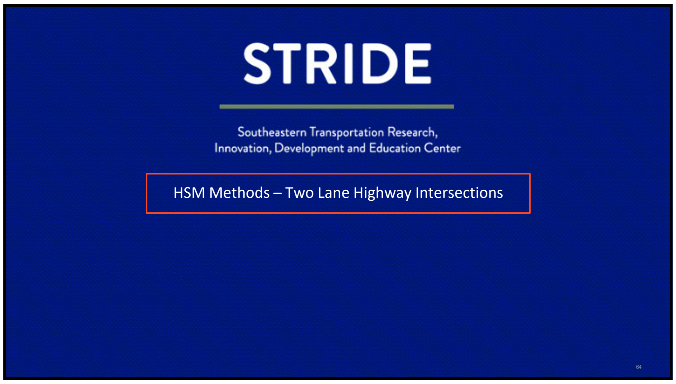
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HSM Methods – Two Lane Highway Intersections

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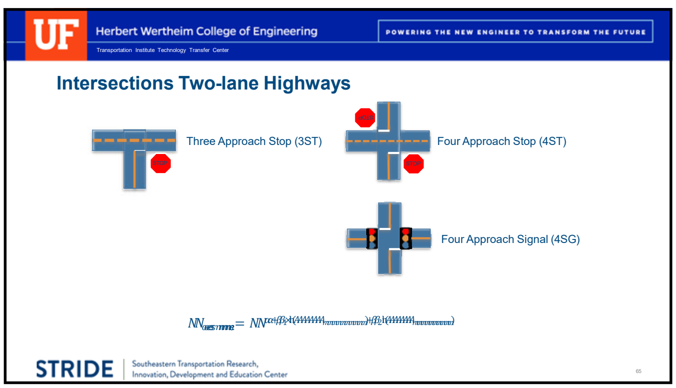
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Intersections Two-lane Highways
Three Approach Stop (3ST)
Four Approach Stop (4ST)
Four Approach Signal (4SG)
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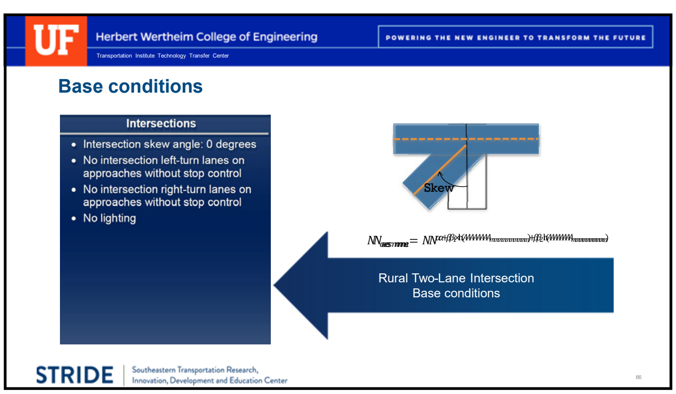
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Base conditions
Intersections
Intersection skew angle: 0 degrees
No intersection left-turn lanes on approaches without stop control
No intersection right-turn lanes on approaches without stop control
No lighting
Skew
Rural Two-Lane Intersection
Base conditions
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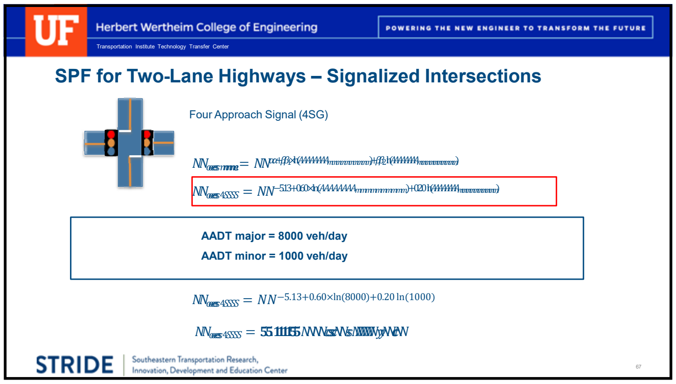
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SPF for Two-Lane Highways – Signalized Intersections
Four Approach Signal (4SG)
AADT major = 8000 veh/day
AADT minor = 1000 veh/day
−5.13+0.60×ln(8000)+0.20 ln(1000)
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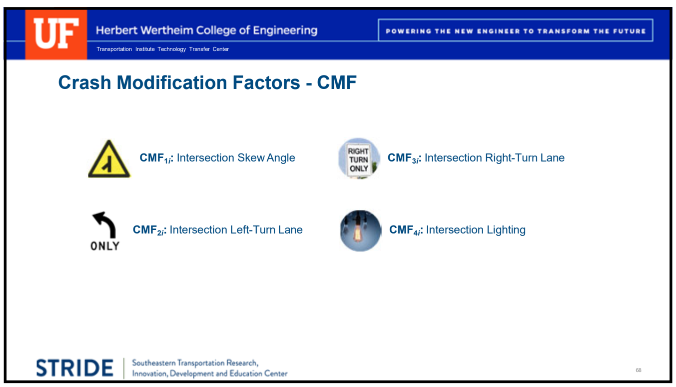
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Crash Modification Factors - CMF
CMF1i: Intersection Skew Angle
CMF3i: Intersection Right-Turn Lane
RIGHT TURN ONLY
ONLY
CMF2i: Intersection Left-Turn Lane
CMF4i: Intersection Lighting
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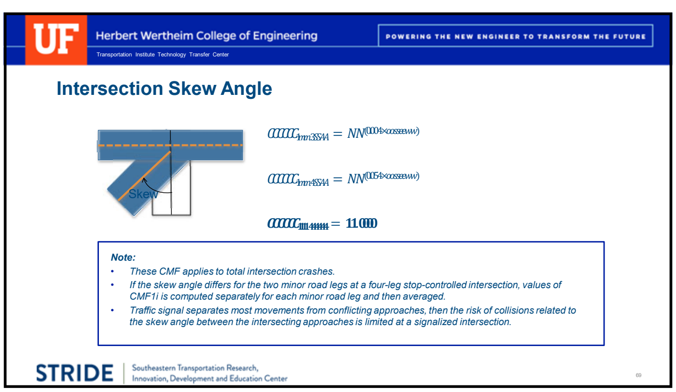
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Intersection Skew Angle
Skew
Note:
These CMF applies to total intersection crashes.
If the skew angle differs for the two minor road legs at a four-leg stop-controlled intersection, values of CMF1i is computed separately for each minor road leg and then averaged.
Traffic signal separates most movements from conflicting approaches, then the risk of collisions related to the skew angle between the intersecting approaches is limited at a signalized intersection.
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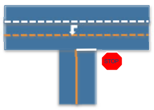
Intersection Left-Turn Lane



CMF_{2i}

Intersection Type	Intersection Traffic Control	Number of Approaches with Left-Turn Lanes[a]			
		One	Two	Three	Four
Three-leg Intersection	Minor road stop control[b]	0.56	0.31		
Four-leg Intersection	Minor road stop control[b]	0.72	0.52		
	Traffic signal	**0.82**	**0.67**	**0.55**	**0.45**

[a] Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes
[b] Stop signs present on minor road approaches only.

Note:
- *These CMFs apply to installation of left-turn lanes on any approach to a signalized intersection, but only on uncontrolled major road approaches to a stop-controlled intersection.*
- *The CMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for the installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes.*
- *There is no indication of any safety effect of providing a left-turn lane on an approach controlled by a stop sign, so the presence of a left-turn lane on a stop-controlled approach is not considered in applying Table*
- *Absence of left turn lane CMF = 1.00*

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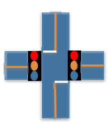
Intersection Left-Turn Lane – Hands-on Example

Four-leg signalized intersection located on a rural two-lane roadway.
One approach left turn lane



CMF_{2i}

Intersection Type	Intersection Traffic Control	Number of Approaches with Left-Turn Lanes[a]			
		One	Two	Three	Four
Three-leg Intersection	Minor road stop control[b]	0.56	0.31		
Four-leg Intersection	Minor road stop control[b]	0.72	0.52		
	Traffic signal	$\boxed{\textbf{0.82}}$	**0.67**	**0.55**	**0.45**

[a] Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes
[b] Stop signs present on minor road approaches only.

$CCCC_{2m3SSAA} = 0.82$

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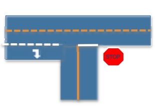
Intersection Right-Turn Lane



CMF_{3i}

Intersection Type	Intersection Traffic Control	Number of Approaches with Right -Turn Lanes[a]			
		One	Two	Three	Four
Three-leg Intersection	Minor road stop control[b]	0.86	0.74		
Four-leg Intersection	Minor road stop control	0.86	0.74		
	Traffic signal	0.96	0.92	0.88	0.85

[a] Stop-controlled approaches are not considered in determining the number of approaches with Right-turn lanes
[b] Stop signs present on minor road approaches only.

Note:
- *These CMFs apply to installation of right-turn lanes on any approach to a signalized intersection, but only on uncontrolled major road approaches to a stop-controlled intersection.*
- *The CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a right-turn lane on one approach raised to a power equal to the number of approaches with right-turn lanes.*
- *There is no indication of any safety effect for providing a right-turn lane on an approach controlled by a stop sign, so the presence of a right-turn lane on a stop-controlled approach is not considered in applying Table.*
- *Absence of right turn lane CMF = 1.00*

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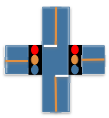
Intersection Right-Turn Lane - Hands-on example

Three-leg stop-controlled intersection located on a rural two-lane roadway.
One approach Right-turn lane



CMF_{3i}

Intersection Type	Intersection Traffic Control	Number of Approaches with Right-Turn Lanes[a]			
		One	Two	Three	Four
Three-leg Intersection	Minor road stop control[b]	0.86	0.74		
Four-leg Intersection	Minor road stop control	0.86	0.74		
	Traffic signal	0.96	0.92	0.88	0.85

[a] Stop-controlled approaches are not considered in determining the number of approaches with right-turn lanes
[b] Stop signs present on minor road approaches only.

$$CMF_{3i} = 0.96$$

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Lighting

$$CMF_{4i} = 1.0 - 0.38 \times p_{ni}$$

p_{ni}: proportion of total crashes for unlighted intersections that occur at night

Intersection Type	p_{ni}
3ST	0.260
4ST	0.244
4SG	**0.286**

Note:
This CMF applies to total intersection crashes

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Hands on Example (1/2)

What is the predicted average crash frequency of the signalized intersection for a particular year?

- 4 legs
- 1 right-turn lane on one approach
- 90-degree intersection angle
- No lighting present
- AADT of major road = 10,000 veh/day
- AADT of minor road = 2,000 veh/day
- 1 left-turn lane on each of two approaches

Step 1: Apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features

$$N_{spf\ 4SG} = e^{-5.13+0.60 \times \ln(AADT_{maj})+0.20\ \ln(AADT_{min})}$$

$$= e^{-5.13+0.60 \times \ln(10,000)+0.20\ \ln(2000)}$$

$$= 6.796\ crashes/year$$

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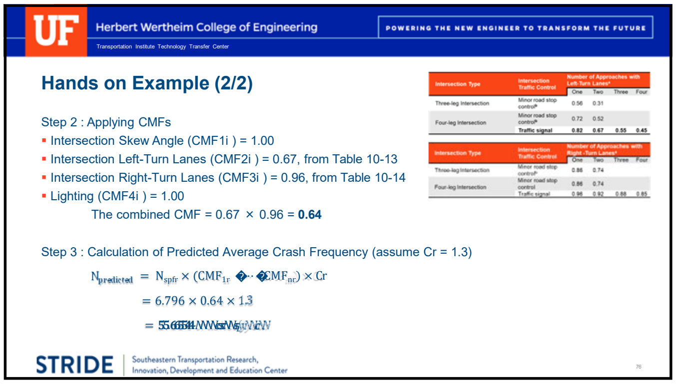
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Hands on Example (2/2)
Step 2 : Applying CMFs
Intersection Skew Angle (CMF1i) = 1.00
Intersection Left-Turn Lanes (CMF2i) = 0.67, from Table 10-13
Intersection Right-Turn Lanes (CMF3i) = 0.96, from Table 10-14
Lighting (CMF4i) = 1.00
The combined CMF = 0.67 × 0.96 = 0.64
Intersection Type | Intersection Traffic Control | Number of Approaches with Left-Turn Lanes* | One | Two | Three | Four
Three-leg Intersection | Minor road stop control* | 0.56 | 0.31
Four-leg Intersection | Minor road stop control* | 0.72 | 0.52
Traffic signal | 0.82 | 0.67 | 0.55 | 0.45
Intersection Type | Intersection Traffic Control | Number of Approaches with Right -Turn Lanes* | One | Two | Three | Four
Three-leg Intersection | Minor road stop control* | 0.86 | 0.74
Four-leg Intersection | Minor road stop control | 0.86 | 0.74
Traffic signal | 0.96 | 0.92 | 0.88 | 0.85
Step 3 : Calculation of Predicted Average Crash Frequency (assume Cr = 1.3)
$N_{predicted} = N_{spfr} \times (CMF_{1r} \cdots CMF_{nr}) \times Cr$
$= 6.796 \times 0.64 \times 1.3$
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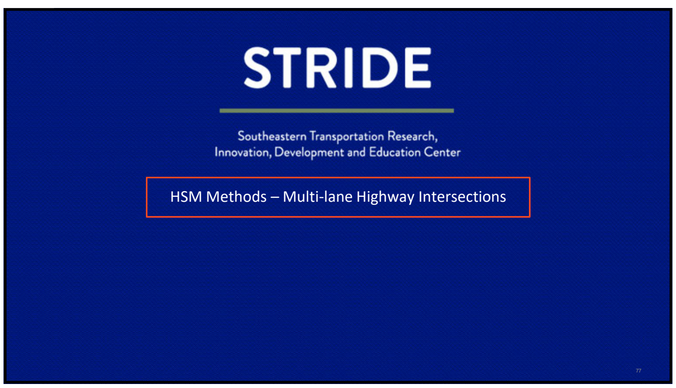
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HSM Methods – Multi-lane Highway Intersections

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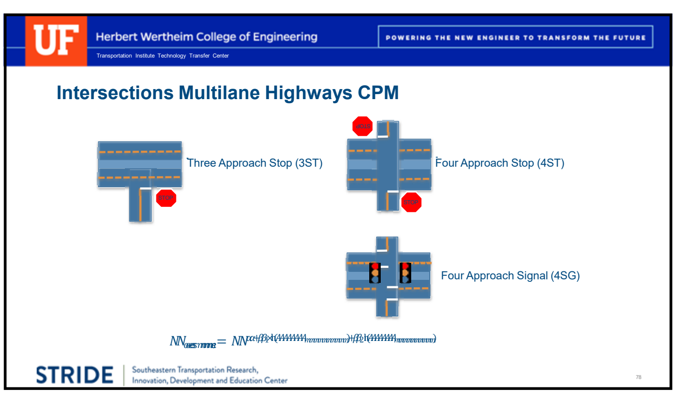
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Intersections Multilane Highways CPM
Three Approach Stop (3ST)
Four Approach Stop (4ST)
Four Approach Signal (4SG)
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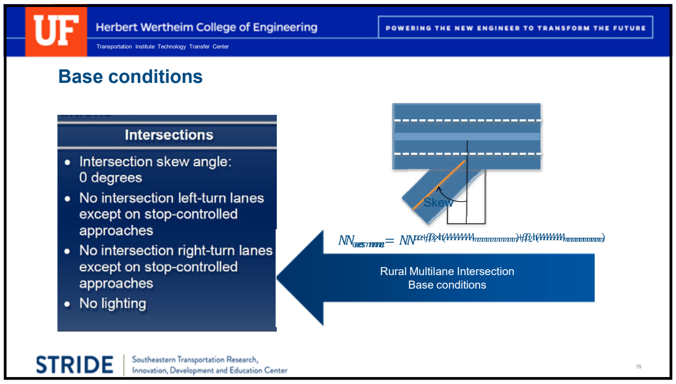
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Base conditions
Intersections
• Intersection skew angle: 0 degrees
• No intersection left-turn lanes except on stop-controlled approaches
• No intersection right-turn lanes except on stop-controlled approaches
• No lighting
Skew
Rural Multilane Intersection
Base conditions
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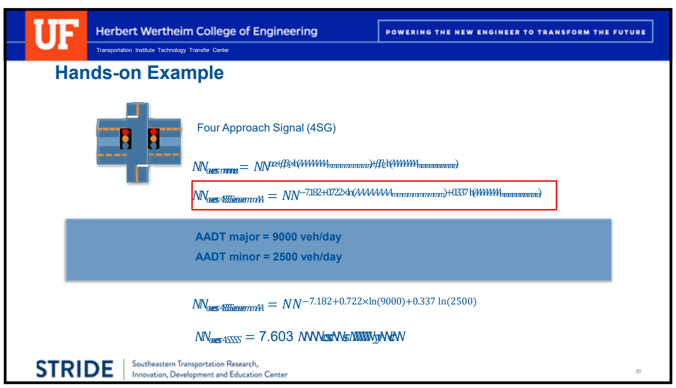
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Hands-on Example
Four Approach Signal (4SG)
AADT major = 9000 veh/day
AADT minor = 2500 veh/day
−7.182+0.722×ln(9000)+0.337 ln(2500)
= 7.603
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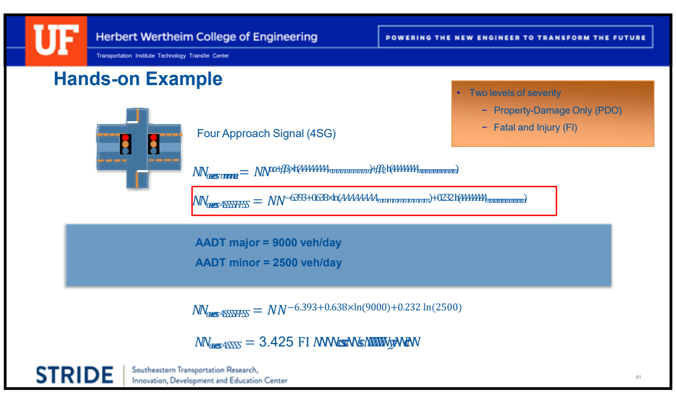
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Hands-on Example
• Two levels of severity
– Property-Damage Only (PDO)
– Fatal and Injury (FI)
Four Approach Signal (4SG)
AADT major = 9000 veh/day
AADT minor = 2500 veh/day
−6.393+0.638×ln(9000)+0.232 ln(2500)
= 3.425 FI
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HSM Methods – Urban and Suburban Arterial Intersections

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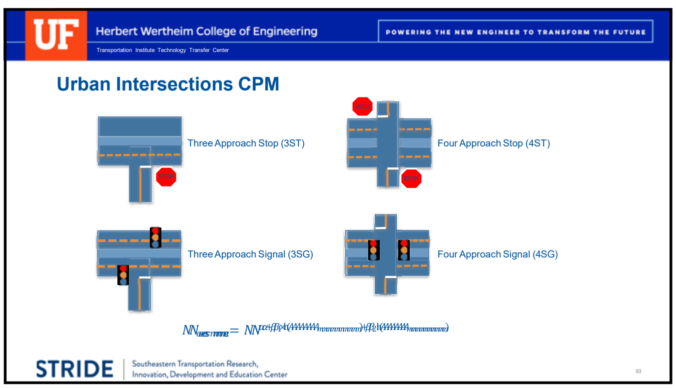
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Urban Intersections CPM
Three Approach Stop (3ST)
Four Approach Stop (4ST)
Three Approach Signal (3SG)
Four Approach Signal (4SG)
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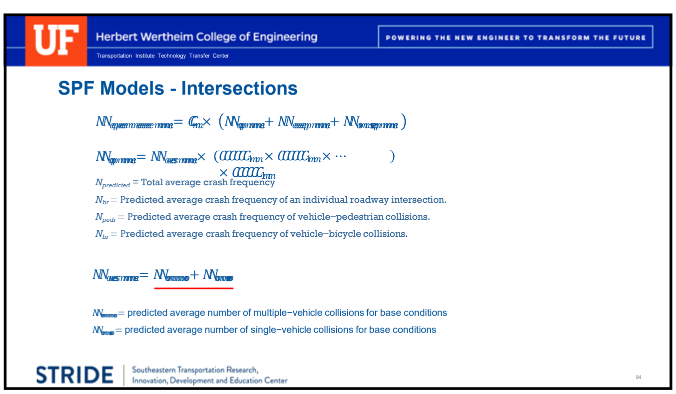
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SPF Models - Intersections
$N_{predicted}$ = Total average crash frequency
N_{br} = Predicted average crash frequency of an individual roadway intersection.
N_{pedr} = Predicted average crash frequency of vehicle–pedestrian collisions.
N_{br} = Predicted average crash frequency of vehicle–bicycle collisions.
= predicted average number of multiple–vehicle collisions for base conditions
= predicted average number of single–vehicle collisions for base conditions
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SPF Models - Intersections

Multiple-vehicle crashes - N_{bimv}

$$N_{bimv} = \exp(a + b\ln(AADT_{maj}) + c\ln(AADT_{min}))$$

N_{bimv} = expected number of multiple vehicle intersection−related crashes/ year base

$AADT_{maj}$ = AADT for the major road (vpd)

$AADT_{min}$ = AADT for the minor road (vpd)

a, b, c = regression coefficients

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Multiple-Vehicle Coefficients

Intersection Type	Coefficients used in Equation 12-21		
	Intercept (a)	$AADT_{maj}$ (b)	$AADT_{min}$ (c)
Total Crashes			
3ST	-13.36	1.11	0.41
3SG	-12.13	1.11	0.26
4ST	-8.90	0.82	0.25
4SG	-10.99	1.07	0.23
Fatal-and-injury crashes			
3ST	-14.01	1.16	0.30
3SG	-11.58	1.02	0.17
4ST	-11.13	0.93	0.28
4SG	-13.14	1.18	0.22
Property-damage-only crashes			
3ST	-15.38	1.20	0.51
3SG	-13.24	1.14	0.30
4ST	-8.74	0.77	0.23
4SG	-11.02	1.02	0.24

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SPF Models

Single-vehicle crashes - N_{bisv}

$$N_{bisv} = \exp(a + b\ln(AADT_{maj}) + c\ln(AADT_{min}))$$

N_{bisv} = expected number of single vehicle intersection−related crashes/ year base

$AADT_{maj}$ = AADT for the major road (veh/day)

$AADT_{min}$ = AADT for the minor road (veh/day)

a, b, c = regression coefficients

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Single-Vehicle Coefficients

Intersection Type	Coefficients used in Equation 12-24		
	Intercept (a)	$AADT_{maj}$ (b)	$AADT_{min}$ (c)
Total Crashes			
3ST	-6.81	0.16	0.51
3SG	-9.02	0.42	0.40
4ST	-5.33	0.33	0.12
4SG	-10.21	0.68	0.27
Fatal-and-injury crashes			
3ST			
3SG	-9.75	0.27	0.51
4ST			
4SG	-9.25	0.43	0.29
Property-damage-only crashes			
3ST	-8.36	0.25	0.55
3SG	-9.08	0.45	0.33
4ST	-7.04	0.36	0.25
4SG	-11.34	0.78	0.25

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SPF Models
Vehicle-Pedestrian Crashes at Signalized Intersections

$$N_{pedi} = N_{pedbase} \times CMF_{1p} \times CMF_{2p} \times CMF_{3p}$$

$$N_{pedbase} = \exp\left(a + b \ln(AADT_{total}) + c \times \ln\left(\frac{AADT_{min}}{AADT_{max}}\right) + d \ln(PedVol) + e \times n_{lanesx}\right)$$

[illegible]

$PedVol$ = sum of daily pedestrian volumes across all intersection legs

n_{lanesx} = maximum number of lanes to be crossed by a pedestrian

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Vehicle-Pedestrian Collisions at Signalized Intersections

SPFs for Vehicle-Pedestrian Collisions at Signalized Intersections

Intersection Type	Model Coefficients				
	Intercept (a)	$AADT_{total}$ (b)	$AADT_{min}/AADT_{max}$ (c)	PedVol (d)	n_{lanesx} (e)
3SG	-6.60	0.05	0.24	0.41	0.09
4SG	-9.53	0.40	0.26	0.45	0.04

Estimates of Pedestrian Crossing Volumes

General Level of Pedestrian Activity	Estimate of PedVol (pedestrians/day)	
	3SG Intersections	4SG Intersections
High	1,700	3,200
Medium-high	750	1,500
Medium	400	700
Medium-low	120	240
Low	20	50

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SPF Models
Vehicle-Bicycle Collisions

$$N_{bikei} = N_{spf\,int} \times f_{bikei}$$

f_{bikei} = bicycle crash adjustment factor

Bicycle Adjustment Factors for Intersections	
Intersection Type	Bicycle Crash Adjustment Factor (f_{bikei})
3ST	0.016
3SG	0.011
4ST	0.018
4SG	0.015

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Urban Intersection CMF
Autos, Peds and Bikes

- Left-Turn Lanes
- Right-Turn on Red
- Left-Turn Phases
- Lighting
- Right-Turn Lanes
- Red Light Running Cameras

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Left Turns CMF

Turn Lane CMF_{1i}

Intersection Type	Intersection Traffic Control	Number of approaches with left-turn lanes			
		One approach	Two approaches	Three approaches	Four approaches
Three-leg intersection	Minor-road STOP control	0.67	0.45	-	-
	Traffic signal	**0.93**	**0.86**	**0.80**	**-**
Four-leg intersection	Minor-road STOP control	0.73	0.53	-	-
	Traffic signal	**0.90**	**0.81**	**0.73**	**0.66**

Turn Phases CMF_{2i}

Type of left-turn signal phasing	CMF_{2i}
Permissive	1.00
Protected/permissive or permissive/protected	0.99
Protected	0.94

Use CMF_{2i} = 1.00 for all unsignalized intersections. If several approaches to signalized intersection have left-turn phasing, the values of CMF_{2i} for each approach are multiplied together.

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Right Turns CMF

Turn Lanes CMF_{3i}

Intersection Type	Intersection Traffic Control	Number of approaches with right-turn lanes			
		One approach	Two approaches	Three approaches	Four approaches
Three-leg intersection	Minor-road STOP control	0.86	0.74	-	-
	Traffic signal	**0.96**	**0.92**	**-**	**-**
Four-leg intersection	Minor-road STOP control	0.86	0.74	-	-
	Traffic signal	**0.96**	**0.92**	**0.88**	**0.85**

On RTOR CMF_{4i}

$$CMF_{4i} = (0.98)^{n_{prohib}}$$

n_{prohib} = number of signalized intersection approaches for which right turn on red is prohibited

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Lighting CMF

$$CMF_{5i} = 1 - 0.38 p_{ni}$$

Intersection Type	Proportion of crashes that occur at night
	p_{ni}
3ST	0.238
4ST	0.229
3SG and 4SG	**0.235**

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Red - Light Cameras CMF_{6i}

Red-Light Cameras (RLC) Enforcement

$$CMF_{6i} = 1 - p_{ra} \times (1 - 0.74) - p_{re} \times (1 - 1.18)$$

$$p_{ra} = \frac{p_{ramv(FI)} \times N_{bimv(FI)} + p_{ramv(PDO)} \times N_{bimv(PDO)}}{\left(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv}\right)}$$

$$p_{re} = \frac{p_{remv(FI)} \times N_{bimv(FI)} + p_{remv(PDO)} \times N_{bimv(PDO)}}{\left(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv}\right)}$$

CMF_{6i} = crash modification factor for installation of red-light cameras at signalized intersections;
p_{ra} = proportion of crashes that are multiple-vehicle, right-angle collisions;
p_{re} = proportion of crashes that are multiple-vehicle, rear-end collisions;
p_{ramv}(FI) = proportion of multiple-vehicle fatal-and-injury crashes represented by right-angle collisions;
p_{ramv}(PDO) = proportion of multiple-vehicle property-damage-only crashes represented by right-angle collisions;

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Vehicle-Pedestrian Collisions at Signalized Intersections – CMFs

These CMFs apply to total vehicle-pedestrian collisions


Bus Stops


Schools


Alcohol Sales Establishments

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Vehicle-Pedestrian Collisions at Signalized Intersections – CMFs

Bus Stop - CMF_{1p}

Number of Bus Stops within 1,000 ft of the Intersection	CMF_{1p}
0	1.00
1 or 2	2.78
3 or more	4.15

School- CMF_{2p}

Presence of Schools within 1,000 ft of the Intersection	CMF_{2p}
No school present	1.00
School present	1.35

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Vehicle-Pedestrian Collisions at Signalized Intersections – CMFs

Alcohol Sales Establishments CMF_{3p}

Number of Alcohol Sales Establishments within 1,000 ft of the Intersection	CMF_{3p}
0	1.00
1-8	1.12
9 or more	1.56

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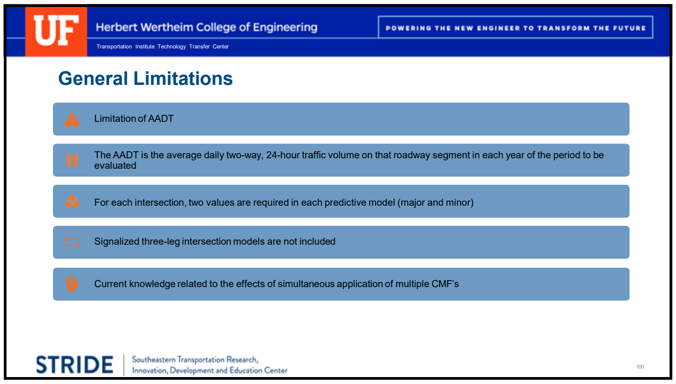
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General Limitations
Limitation of AADT
The AADT is the average daily two-way, 24-hour traffic volume on that roadway segment in each year of the period to be evaluated
For each intersection, two values are required in each predictive model (major and minor)
Signalized three-leg intersection models are not included
Current knowledge related to the effects of simultaneous application of multiple CMF's
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HSM 2nd edition – Coming Soon
Methods for incorporating bike & pedestrian considerations in safety management
New Bike & pedestrian predictive models in Part C
Includes systemic methods for pedestrian and bicycle application
Methods for calibrating safety performance functions with state/regional data
New Predictive Models (Additional Intersections (NCHRP 17-78) and Roundabouts (NCHRP 17-70), New Arterial models (NCHRP 17-58))
New Available Research Summary
Restructured Part D
https://www.highwaysafetymanual.org/Documents/HSM2_GeneralUpdate_20220606b.pdf
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Road Safety Management Process

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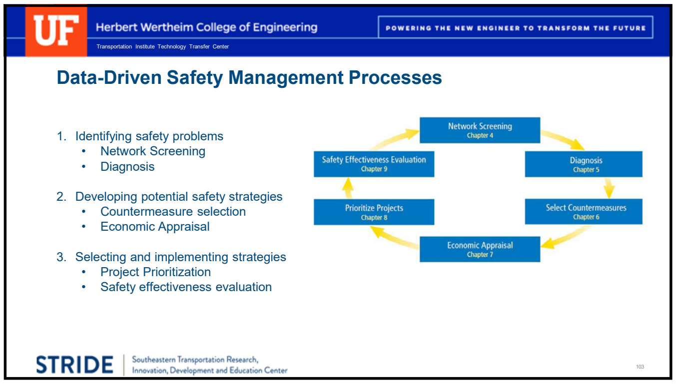
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Data-Driven Safety Management Processes
1. Identifying safety problems
• Network Screening
• Diagnosis
2. Developing potential safety strategies
• Countermeasure selection
• Economic Appraisal
3. Selecting and implementing strategies
• Project Prioritization
• Safety effectiveness evaluation
Network Screening Chapter 4
Diagnosis Chapter 5
Select Countermeasures Chapter 6
Economic Appraisal Chapter 7
Prioritize Projects Chapter 8
Safety Effectiveness Evaluation Chapter 9
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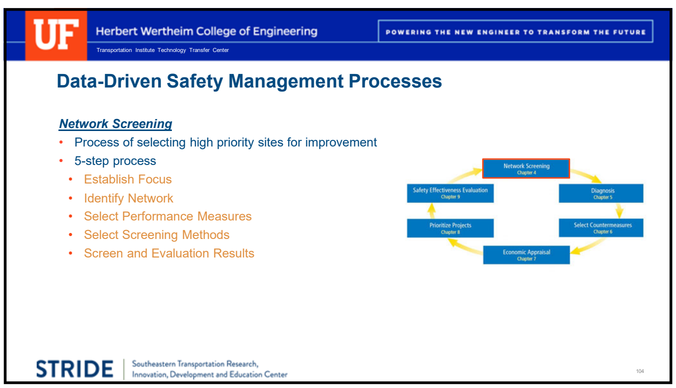
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Data-Driven Safety Management Processes
Network Screening
• Process of selecting high priority sites for improvement
• 5-step process
• Establish Focus
• Identify Network
• Select Performance Measures
• Select Screening Methods
• Screen and Evaluation Results
Network Screening
Diagnosis
Select Countermeasures
Economic Appraisal
Prioritize Projects
Safety Effectiveness Evaluation
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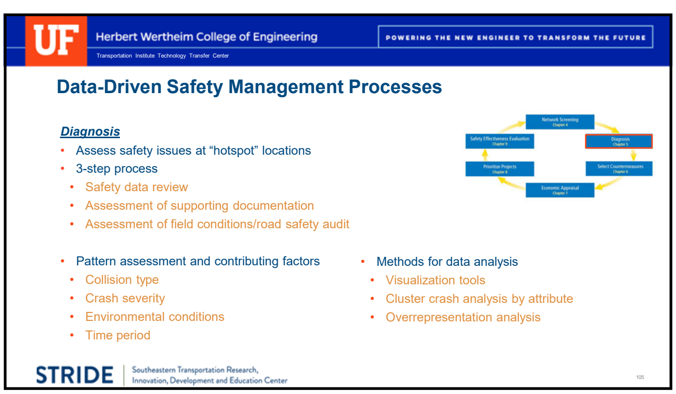
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Data-Driven Safety Management Processes
Diagnosis
• Assess safety issues at "hotspot" locations
• 3-step process
• Safety data review
• Assessment of supporting documentation
• Assessment of field conditions/road safety audit
• Pattern assessment and contributing factors
• Collision type
• Crash severity
• Environmental conditions
• Time period
• Methods for data analysis
• Visualization tools
• Cluster crash analysis by attribute
• Overrepresentation analysis
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Data-Driven Safety Management Processes

Diagnosis – Road Safety Audits

- Formal safety performance examination of a road or intersection
- Road safety audits can be used in any phase of project development

Objective:

- What elements of the road may present a safety concern: to what extent, to which road users, and under what circumstances?
- What opportunities exist to eliminate or mitigate identified safety concerns?

Road Safety Audit (dot.gov)

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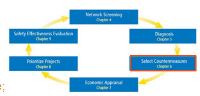
Data-Driven Safety Management Processes



Select Countermeasures

Address contributing factors from "diagnosis"

- Identify factors contributing to the cause of crashes at the subject site;
- Identify countermeasures which may address the contributing factors; and
- Conduct cost-benefit analysis, if possible, to select preferred treatment(s)

Countermeasure resources and tools

- Bicycle Safety Guide and Countermeasure Selection System (BIKESAFE,www.pedbikesafe.org/bikesafe)
- Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices
- Crash Modification Factors Clearinghouse (www.cmfclearinghouse.org)
- FHWA Proven Countermeasures (safety.fhwa.dot.gov/provencountermeasures)
- Highway Safety Manual (www.highwaysafetymanual.org)
- National Cooperative Highway Research Program (NCHRP) Report 500 Series (safety.transportation.org/guides.aspx)
- Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE, www.pedbikesafe.org/pedsafe)

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Data-Driven Safety Management Processes

Select Countermeasures - Summary of crash types and possible signal modifications to benefit safety

Change	Collision with Another Vehicle					Single-Vehicle Collision				
	Angle	Head-On	Rear-End	Sideswipe Same Direction	Sideswipe Opposite Direction	Collision with Bicycle	Collision with Parking Vehicle	Collision with Pedestrian	Overturned	Run Off Road
Provide left-turn signal phasing	x	x	x	x	x					
Optimize clearance intervals	x		x							
Restrict or eliminate turning maneuvers (including right turns on reds)	x	x	x	x		x		x		
Employ signal coordination	x		x					x		
Implement emergency vehicle pre-emption	x	x	x	x	x	x	x	x		
Improve traffic control of pedestrians and bicycles			x			x		x		
Remove unwarranted signal			x			x		x		
Provide/improve left-turn lane channelization*	x	x	x	x	x					
Provide/improve right turn lane channelization*	x		x	x		x		x		

Traffic Signal Timing Manual: Chapter 3 - Office of Operations (dot.gov)

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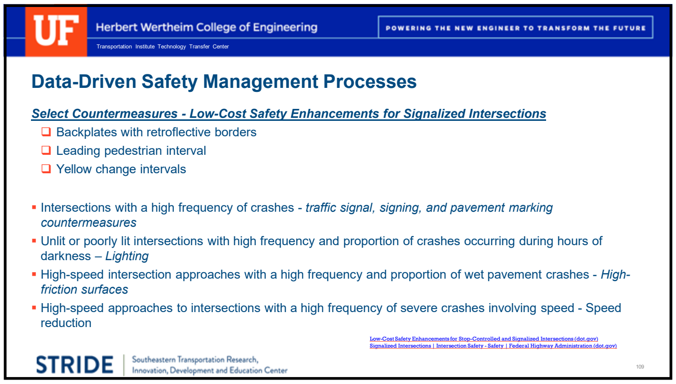
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Data-Driven Safety Management Processes
Select Countermeasures - Low-Cost Safety Enhancements for Signalized Intersections
Backplates with retroflective borders
Leading pedestrian interval
Yellow change intervals
Intersections with a high frequency of crashes - traffic signal, signing, and pavement marking countermeasures
Unlit or poorly lit intersections with high frequency and proportion of crashes occurring during hours of darkness – Lighting
High-speed intersection approaches with a high frequency and proportion of wet pavement crashes - High-friction surfaces
High-speed approaches to intersections with a high frequency of severe crashes involving speed - Speed reduction
Low-Cost Safety Enhancements for Stop-Controlled and Signalized Intersections (dot.gov)
Signalized Intersections | Intersection Safety - Safety | Federal Highway Administration (dot.gov)
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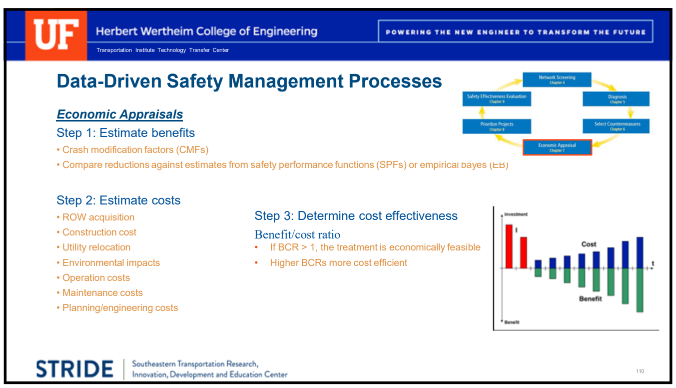
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Data-Driven Safety Management Processes
Network Screening Chapter 4
Diagnosis Chapter 5
Select Countermeasures Chapter 6
Economic Appraisal Chapter 7
Prioritize Projects Chapter 8
Safety Effectiveness Evaluation Chapter 9
Economic Appraisals
Step 1: Estimate benefits
Crash modification factors (CMFs)
Compare reductions against estimates from safety performance functions (SPFs) or empirical bayes (EB)
Step 2: Estimate costs
ROW acquisition
Construction cost
Utility relocation
Environmental impacts
Operation costs
Maintenance costs
Planning/engineering costs
Step 3: Determine cost effectiveness
Benefit/cost ratio
If BCR > 1, the treatment is economically feasible
Higher BCRs more cost efficient
Investment
I
Cost
t
Benefit
Benefit
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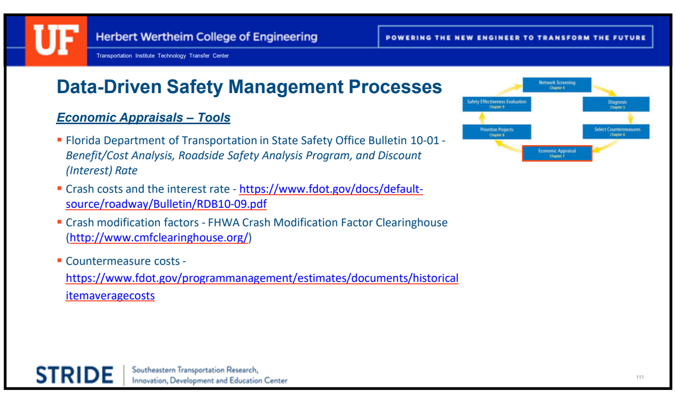
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Network Screening Chapter 4
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Economic Appraisal Chapter 7
Prioritize Projects Chapter 8
Safety Effectiveness Evaluation Chapter 9
Economic Appraisals – Tools
Florida Department of Transportation in State Safety Office Bulletin 10-01 - Benefit/Cost Analysis, Roadside Safety Analysis Program, and Discount (Interest) Rate
Crash costs and the interest rate - https://www.fdot.gov/docs/default-source/roadway/Bulletin/RDB10-09.pdf
Crash modification factors - FHWA Crash Modification Factor Clearinghouse (http://www.cmfclearinghouse.org/)
Countermeasure costs - https://www.fdot.gov/programmanagement/estimates/documents/historicalitemaveragecosts
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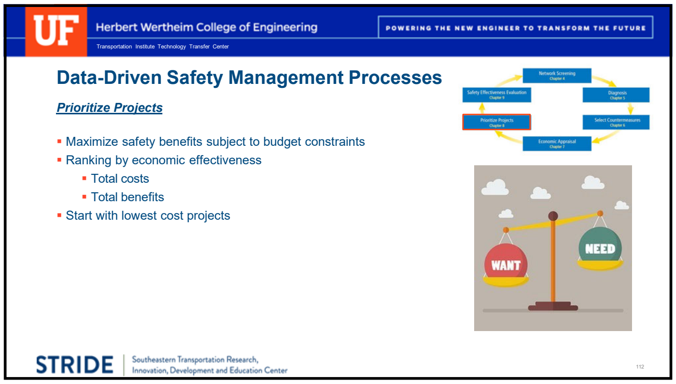
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Data-Driven Safety Management Processes
Prioritize Projects
▪ Maximize safety benefits subject to budget constraints
▪ Ranking by economic effectiveness
▪ Total costs
▪ Total benefits
▪ Start with lowest cost projects
WANT
NEED
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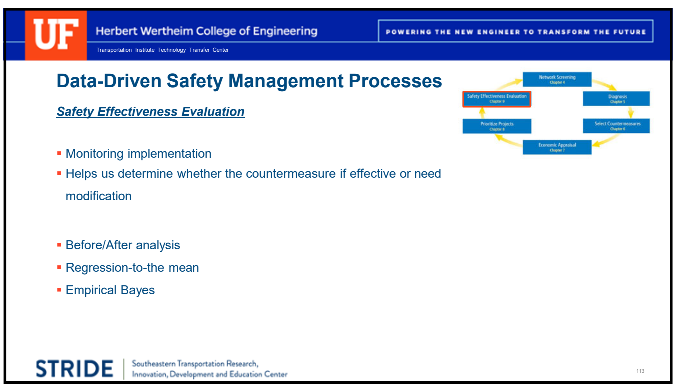
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Data-Driven Safety Management Processes
Safety Effectiveness Evaluation
▪ Monitoring implementation
▪ Helps us determine whether the countermeasure if effective or need modification
▪ Before/After analysis
▪ Regression-to-the mean
▪ Empirical Bayes
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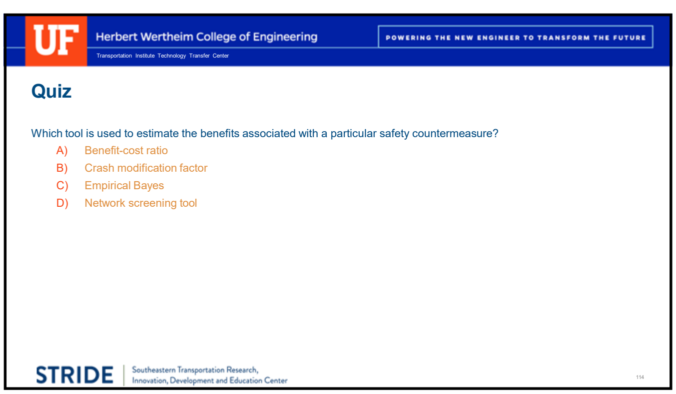
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Quiz
Which tool is used to estimate the benefits associated with a particular safety countermeasure?
A) Benefit-cost ratio
B) Crash modification factor
C) Empirical Bayes
D) Network screening tool
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Quiz

Which tool is used to estimate the benefits associated with a particular safety countermeasure?

A) Benefit-cost ratio
B) Crash modification factor
C) Empirical Bayes
D) Network screening tool

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Tools

Tools	Application					
	HSM Predictive Analysis (SPF-based)	HSM Predictive Analysis (CMF-based)	Rural Roadways	Urban Roadway	Ramps and Freeways	Intersection Evaluations
HSM spreadsheets	✓		✓	✓		✓
IHSDM	✓		✓	✓	✓	✓
ISATe	✓				✓	
SPICE		✓				✓
HSS	✓		✓	✓	✓	✓
TxDOT-specific tools	✓	✓	✓			✓

Traffic Safety and Analysis Procedures Manual (txdot.gov)

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Highway Safety Software

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https://safety.fhwa.dot.gov/intersection/signal/fhwasa13027.pdf
https://www.fdot.gov/traffic/trafficservices/intersection-operations.shtm
https://safety.fhwa.dot.gov/intersection/signal/fhwasa09020.pdf
https://highways.dot.gov/public-roads/winter-2022/03
https://www.its.dot.gov/meetings/pdf/USDOT_Intersection_Safety_Webinar.pdf
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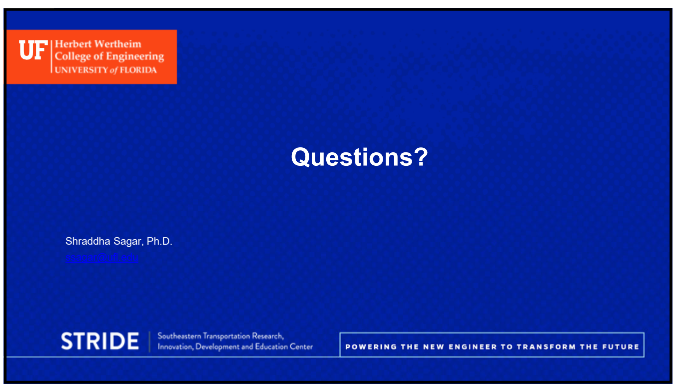
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Questions?
Shraddha Sagar, Ph.D.
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Training Slides

Basic Traffic Signal Timing


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Basic Traffic Signal Timing
Dr. Steven M. Click, PE
sclick@tntech.edu
Get course resources via QR Code or at
https://tinyurl.com/228knzkw
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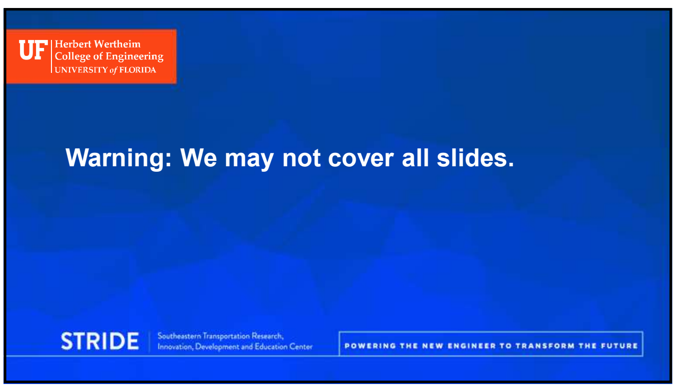
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Warning: We may not cover all slides.
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2


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Traffic Signal Fundamentals
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Learning Outcomes

- At the end of Traffic Signal Fundamentals, you will be able to:
  - Define a traffic signal from a Timing Engineer's point of view
  - Identify compatible and incompatible phases
  - Explain phase numbering and a ring-and-barrier diagram
  - Describe how basic detection and passage time work

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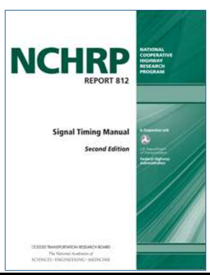
NCHRP Report 812 – Signal Timing Manual – Second Edition

- Free to download
- Referenced throughout
  - Called **STM2** when referencing
- More info than presentation



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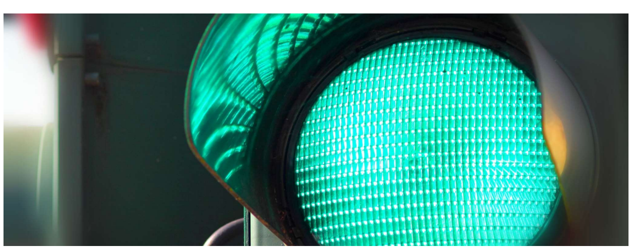
What is a traffic signal?



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What is a Traffic Signal?

- **To Users**: Indications that control an intersection
- **To Maintenance**: Electronics that control an intersection
- **To Signal Timing Engineers**: Collection of timers that control an intersection

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To Signal Timing Engineers: Collection of Timers in the Controller

- Calculated Parameters are entered into the controller
- Outdated estimate: >7000 data entry fields
  - Typically use an extremely small subset
- Most features are ubiquitous, but name and implementation are different
  - Get and keep a controller manual

TIMING PLAN [1] PHASE DATA

PHASE	1	2	3	4	5	6	7	8
MIN GRN	5	5	5	5	5	5	5	5
BK MGRN	0	0	0	0	0	0	0	0
CS MGRN	0	0	0	0	0	0	0	0
DLY GRN	0	0	0	0	0	0	0	0
WALK	0	0	0	0	0	0	0	0
WALK2	0	0	0	0	0	0	0	0
WLK MAX	0	0	0	0	0	0	0	0
PED CLR	0	0	0	0	0	0	0	0
PD CLR2	0	0	0	0	0	0	0	0
PC MAX	0	0	0	0	0	0	0	0
PED CO	0	0	0	0	0	0	0	0
VEH EXT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VH EXT2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MAX 1	35	35	35	35	35	35	35	35
MAX 2	35	35	35	35	35	35	35	35
MAX 3	35	35	35	35	35	35	35	35
DYM MAX	0	0	0	0	0	0	0	0
DYM STP	0	0	0	0	0	0	0	0
YELLOW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RED CLR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RED MAX	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RED RVT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ACT B4	0	0	0	0	0	0	0	0
SEC/ACT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MAX INT	0	0	0	0	0	0	0	0
TIME B4	0	0	0	0	0	0	0	0
CARS WT	0	0	0	0	0	0	0	0
STPTDUC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TTREDUC	0	0	0	0	0	0	0	0
MIN GAP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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Phase Numbering

- Numbering wasn't chosen by traffic engineers
  - Chosen by NEMA – the National Electronics Manufacturing Association
- Even phases typically through movements with associated pedestrian phases
  - 2 & 6 typically major street
  - 4 & 8 typically minor street
- Odd phases typically left turn movements
  - 1 & 5 typically major street
  - 3 & 7 typically minor street

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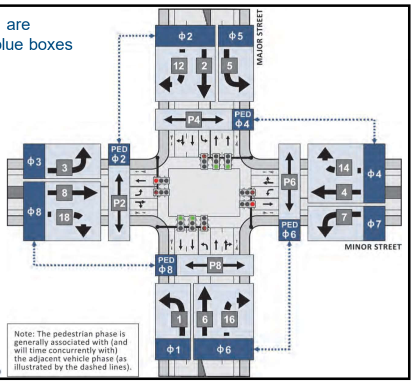
Phase Numbering
STM2 Page 5-3

- Phase numbers are shown in dark blue boxes



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Phase Sequence

Phase sequence is based on…	• Identifying which phases can show together • Grouping those phases for efficient service
Phases are grouped using RINGS and BARRIERS	• Ring = a list of incompatible phases • Barrier = point for changing streets
Common modern application	• 8-phase, dual ring controller

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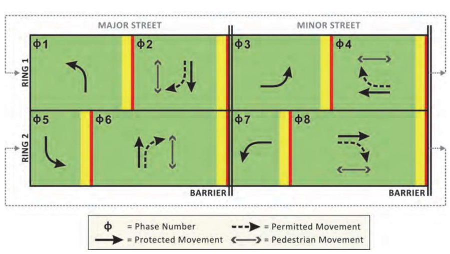
Ring and Barrier Diagram – STM2 Page 5-4



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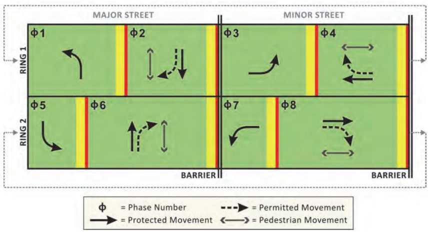
Compatible and Incompatible Phases – STM2 Page 5-4

- Compatible Phases
  - In different rings
    AND
  - In the same barrier
- Incompatible Phases
  - In the same ring
    OR
  - In different barriers



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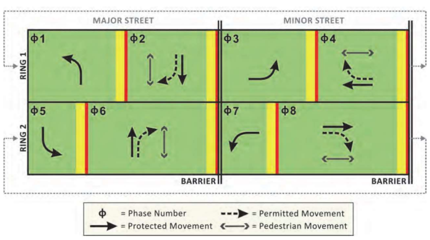
Compatible and Incompatible Phases (cont.) – STM2 Page 5-4

- What phases are compatible with…
  - Phase 4?
  - Phase 5?



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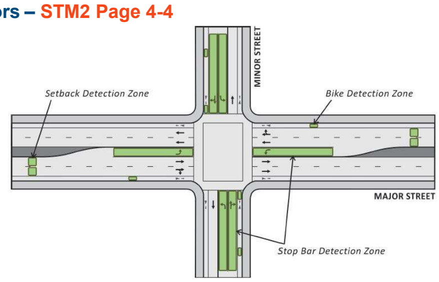
About Vehicle Detectors – STM2 Page 4-4

- Two Different Types
  - **Stop bar detectors** for low-speed and expected stop
  - **Setback detectors** for high-speed



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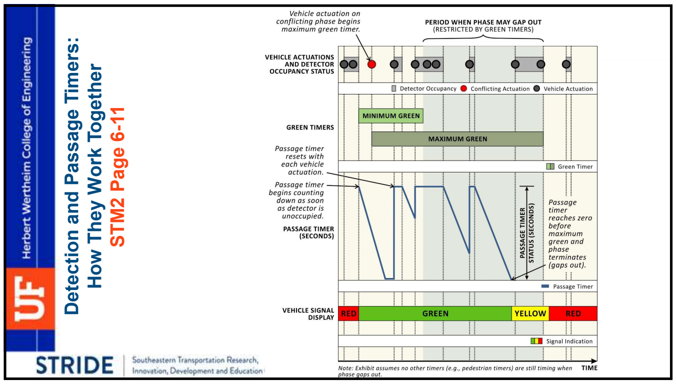

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Learning Outcomes

- Having completed Traffic Signal Fundamentals, you should be able to:
  - Define a traffic signal from a Timing Engineer's point of view
  - Explain phase numbering and a ring-and-barrier diagram
  - Identify compatible and incompatible phases
  - Describe how detection and passage time works

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Check for questions, then start Traffic Signal Timing for Safety

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Learning Outcomes

- After Traffic Signal Timing for Safety, you will be able to:
  - List key safety intervals
  - Calculate key safety intervals

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Safety at Signalized Intersections

- Built in from the ground up
- Always part of the safety discussion

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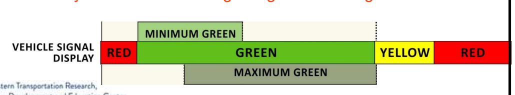
Definitions for Vehicle Intervals
Adapted from STM2 Page 6-9

- Minimum Green (safety interval)
  - The minimum length of time that a phase must be green
- Maximum Green (efficiency interval)
  - The maximum length of time that a phase can be green in the presence of a conflicting call
- Yellow Change (safety interval)
  - Warning that the green has ended and red will begin
- Red Clearance / Red Clear (safety interval)
  - Time after yellow before the beginning of conflicting traffic



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Detector Type Affects Minimum Green

- Stop bar detection will detect queues naturally
  - Only need to account for drivers' expectations
- Setback detectors will have undetected queuing
  - Option 1: Design minimum green for queue clearance
  - Option 2: Variable minimum green

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Minimum Green for Stop Bar Detection – STM2 Page 6-6

- Only need to account for drivers' expectations
  - STM2 Recommendations:

Phase Type	Facility Type	Minimum Green (Seconds)
Through	Major Arterial (> 40 mph)	10 to 15
	Major Arterial (≤ 40 mph)	7 to 15
	Minor Arterial	4 to 10
	Collector, Local, or Driveway	2 to 10
Left Turn	Any	2 to 5

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Setback Detectors Option 1: Design for Queue Clearance
STM2 Page 6-6

$$G_q = 3 + 2n$$

- G_q = minimum green duration for queue clearance (seconds)
- n = number of vehicles between stop bar and nearest setback detector in one lane

$$n = \frac{d}{L_v}$$

- d = distance between the stop bar and the downstream edge of the nearest setback detector (feet)
- L_v = length of vehicle + gap, typically 25 ft

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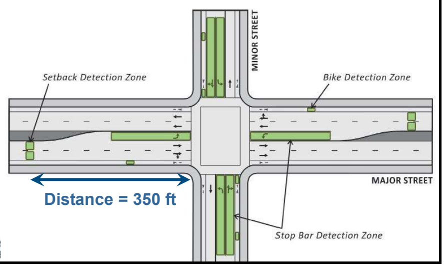
Setback Detectors Option 1: Design for Queue Clearance
Sample Problem – STM2 Pages 4-4, 6-6

$$n = \frac{d}{L_v}$$

$$G_q = 3 + 2n$$



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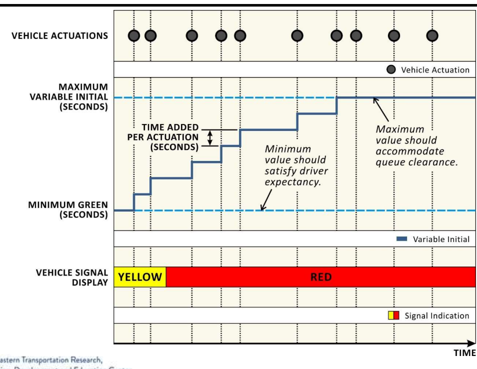
Setback Detectors Option 2:
Variable Min Green – STM2 Page 6-7



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Setback Detectors Option 2:
Suggested Variable Minimum Green Parameters – STM2 Page 6-7

- Table values are based on single lane approaches
- What changes for multilane approaches?

Distance Between Stop Bar and Nearest Setback Detector (Feet)	Minimum Green (Seconds)	Maximum Variable Initial (Seconds)	Seconds Added per Actuation[1]
275	10	25	2.0
350	10	31	2.0
425	10	37	2.0
500	10	43	2.0

[1] Seconds added per actuation assumes approximately 2-second headways.

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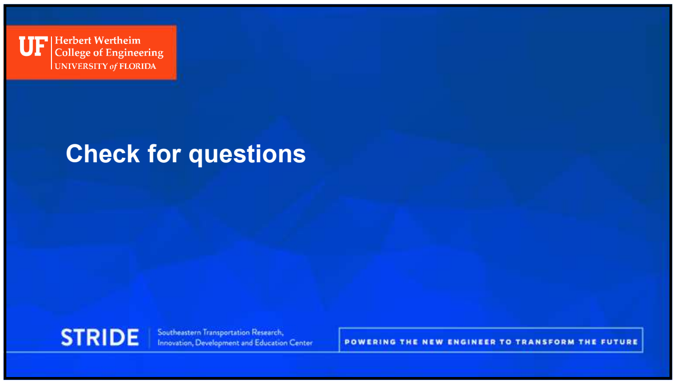
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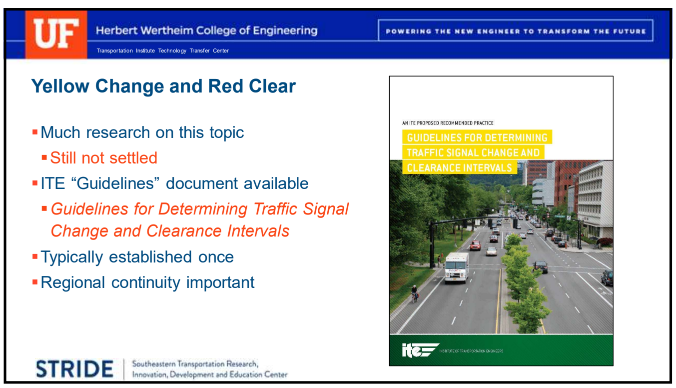
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Yellow Change and Red Clear
▪ Much research on this topic
▪ Still not settled
▪ ITE "Guidelines" document available
▪ *Guidelines for Determining Traffic Signal Change and Clearance Intervals*
▪ Typically established once
▪ Regional continuity important
AN ITE PROPOSED RECOMMENDED PRACTICE
GUIDELINES FOR DETERMINING TRAFFIC SIGNAL CHANGE AND CLEARANCE INTERVALS
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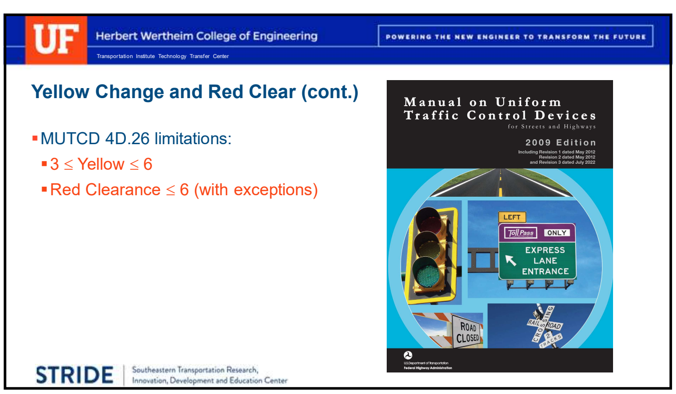
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Yellow Change and Red Clear (cont.)
▪ MUTCD 4D.26 limitations:
▪ 3 ≤ Yellow ≤ 6
▪ Red Clearance ≤ 6 (with exceptions)
Manual on Uniform Traffic Control Devices
for Streets and Highways
2009 Edition
LEFT
ONLY
EXPRESS LANE ENTRANCE
ROAD CLOSED
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Yellow Change Equation – STM2 Page 6-3

$$YellowChange = t + \frac{v}{2a + 2Gg}$$

- t = perception-reaction time (ITE suggests 1.0 sec)
- v = approach speed (**ft/sec**)
- a = deceleration rate (ITE suggests 10 ft/sec^2)
- G = acceleration due to gravity (constant 32.2 ft/sec^2)
- g = grade (ft/ft)

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Yellow Change Sample Problem Inputs

- t = perception-reaction time (ITE suggests) **1.0 sec**
- V = Posted Speed or 85% Speed (field value) **45 mph**
- v = approach speed (must convert from mph to ft/sec)
- a = deceleration rate (ITE suggests) **10 ft/sec^2**
- G = acceleration due to gravity (constant) **32.2 ft/sec^2**
- g = grade (field value) -5% = **-0.05 ft/ft**

- How do we convert from mph to ft/sec?

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Yellow Change Sample Problem Results

- Convert speed from mph to ft/sec

$$FPS = MPH\left(\frac{5280\ ft/mi}{3600\ sec/hr}\right) = 45\left(\frac{5280}{3600}\right) = \mathbf{66}$$

- Calculate Yellow Change

$$Yellow\ Change = t + \frac{v}{2a + 2Gg} = 1 + \frac{66}{2(10) + 2(32.2)(-0.05)} = \mathbf{4.93}$$

- **Do we really use 4.93?**

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Red Clear Equation

$$RedClear = \frac{w + l}{v}$$

- v = approach speed (**ft/sec**)
- w = width of intersection (ft)
- l = length of vehicle (ITE suggests 20 ft.)

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Red Clear Sample Problem Inputs

- V = Posted Speed / 85% Speed (field value) **45 mph**
- v = approach speed (must convert to ft/sec)
- w = width of intersection (field value) **48 ft**
- l = length of vehicle (ITE suggested) **20 ft**

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Red Clear Sample Problem Results

- Convert speed from MPH to FPS

$$FPS = MPH\left(\frac{5280\ ft/mi}{3600\ sec/hr}\right) = 45\left(\frac{5280}{3600}\right) = \mathbf{66}$$

- Calculate Red Clear

$$Red\ Clear = \frac{w+l}{v} = \frac{48 + 20}{66} = \mathbf{1.03}$$

- **Do we really use 1.03?**

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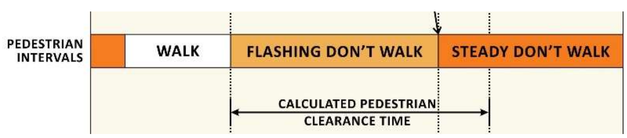
Purpose of Pedestrian Intervals – STM2 Page 6-17

- Purpose of Walk interval?
- Purpose of Flashing Don't Walk interval?
- Purpose of Steady Don't Walk?



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Designing Pedestrian Intervals

- Minimum Walk (safety interval)
  - Min Walk may be affected by STM2 Recommendation for Combined Walk + PCT
- Walk / Maximum Walk (efficiency interval)
- Ped Clear (safety interval)
- Steady Don't Walk (efficiency interval)
  - Not designed - based on timing of other phases

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Choose Minimum Walk – STM2 Page 6-18

- MUTCD **prefers** at least **7** seconds, **allows** as low as **4**
- STM2 provides recommendations (below)
- Remember the purpose of Walk Interval

Conditions	Walk Interval (Seconds)
High-pedestrian-volume area (e.g., school, CBD, or sports and event venue)	10 to 15
Typical pedestrian volume and longer cycle length	7 to 10
Typical pedestrian volume and shorter cycle length	7
Negligible pedestrian volume and otherwise long cycle length	4

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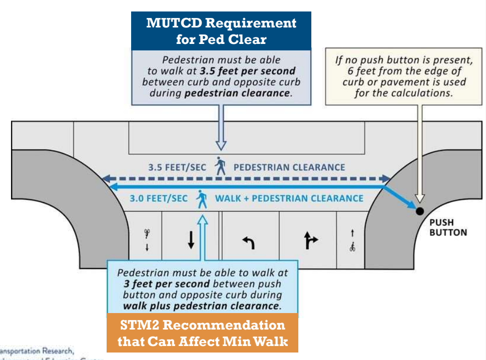
Required Ped Clear Times and Recommended Min Walk
STM2 Page 6-19



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MUTCD Required Ped Clear Equation – STM2 Page 6-18

- $PCT = \frac{D_c}{v_p}$
  - PCT = pedestrian clearance time (seconds)
  - D_c = pedestrian crossing distance (feet)
  - v_p = pedestrian walking speed (MUTCD requires 3.5 ft/sec or slower)

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MUTCD Required Ped Clear Sample Problem

- Crossing Distance (field value) = **36 ft**
- Pedestrian Crossing Speed (MUTCD value) = **3.5 ft/sec**
- Distance from pushbutton to crossing (field value) = **12 ft**

- Design Minimum Walk and PCT
  - Min Walk = 7 preferred, 4 allowed, STM2 recommendations, **Choose 4**
  - $PCT = \frac{36\,ft}{3.5\,{ft}/{sec}} =$ **10.2** so use **11** sec

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Checking Recommended Min Walk – STM2 Page 6-19

- Check Walk+PCT combined condition
  - Initial Min Walk + PCT = *4 + 11* = **15** sec
  - Recommended Min Walk + PCT = $\frac{36\,ft + \quad ft}{3\,{ft}/{sec}} =$ **16**
- Recommended Min Walk
  - (Recommended Walk + PCT) – (Initial Min Walk + PCT) *= 16 - 15 =* **1 sec**
  - Thus, increase Min Walk by 1 sec *= 4 + 1 =* **5 sec**

- If (Recommended Walk +PCT) – (Min Walk + PCT) < 1, no change to Min Walk

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Learning Outcomes

Having completed Traffic Signal Timing for Safety, you should be able to
- List key safety intervals
- Calculate key safety intervals

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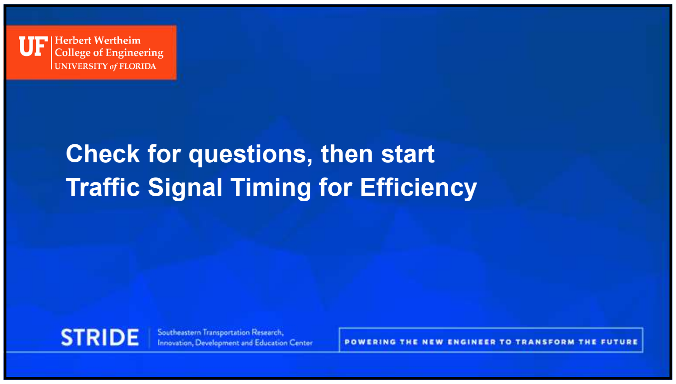
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Traffic Signal Timing for Efficiency
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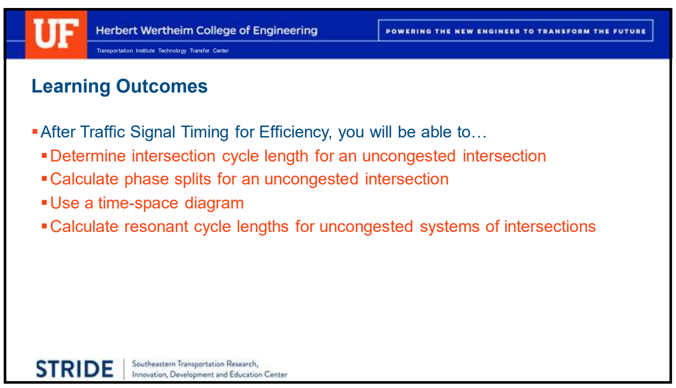
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Learning Outcomes
After Traffic Signal Timing for Efficiency, you will be able to…
Determine intersection cycle length for an uncongested intersection
Calculate phase splits for an uncongested intersection
Use a time-space diagram
Calculate resonant cycle lengths for uncongested systems of intersections
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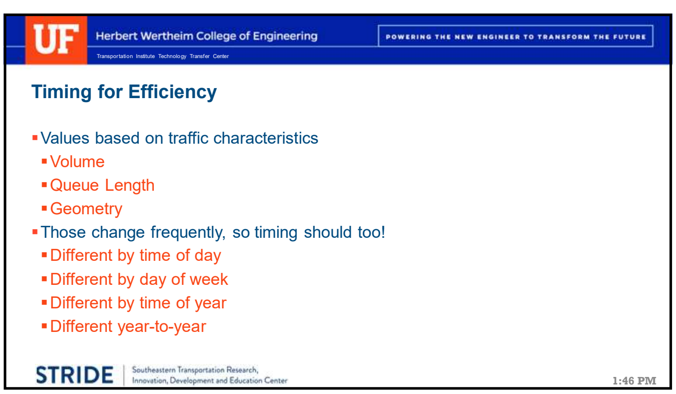
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Timing for Efficiency
Values based on traffic characteristics
Volume
Queue Length
Geometry
Those change frequently, so timing should too!
Different by time of day
Different by day of week
Different by time of year
Different year-to-year
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Uncongested Intersections

- How do we recognize an uncongested intersection?
- What do drivers expect at uncongested intersections?

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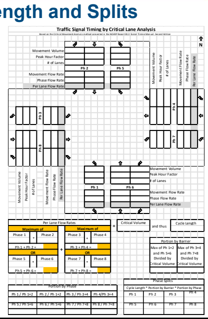
Determining Uncongested Intersection Cycle Length and Splits via Critical Lane Analysis

- Downloadable Worksheet and Sample Problem

https://tinyurl.com/228knzkw



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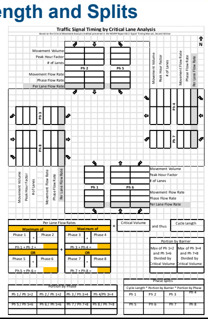
Determining Uncongested Intersection Cycle Length and Splits via Critical Lane Analysis

- Critical Lane Analysis
  - Works using volumes
  - Approximates minimum delay timing
  - Only for uncongested intersections
- Split = G + Y + R for a phase
  - Thus Green = Split - Y - R



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Determine Per Lane Flow Rates – All Movements Have Exclusive Lanes

Movement Volume	300	500	700
Peak Hour Factor	0.95	0.95	0.95
# of Lanes	1	2	2
	Ph 2		Ph 5
Movement Flow Rate	316	526	737
Phase Flow Rate	316	526	737
Per Lane Flow Rate	316	263	369

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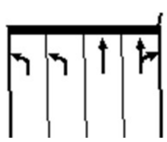
Determine Per Lane Flow Rates – One or More Movements Have Shared Lanes



450	325	225	Movement Volume
0.95	0.95	0.95	Peak Hour Factor
2	2	0	# of Lanes
Ph 1	Ph 6		
474	342	237	Movement Flow Rate
474	579		Phase Flow Rate
237	290		Per Lane Flow Rate

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Combine Per Lane Flow Rates and Calculate Critical Volume

Per Lane Flow Rates								Critical Volume
Maximum of			+	Maximum of			=	1130
Phase 1	+	Phase 2		Phase 3	+	Phase 4		
237		316		247		224		
	Ph 1+2 =	**553**			Ph 3+4 =	**471**		
AND				AND				
Phase 5	+	Phase 6		Phase 7	+	Phase 8		
369		290		118		147		
	Ph 5+6 =	**659**			Ph 7+8 =	**265**		

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Look Up Cycle Length

STM2 Page 5-26

Critical Volume	and thus	Cycle Length
1130		110

Cycle Length (seconds)	Number of Cycles Per Hour	Lost Time Per Cycle (Seconds)	Effective Green Time Per Cycle (Seconds)	Number of Vehicles Per Cycle	Maximum Number of Vehicles Per Hour
60	60	20	40	16	933
70	51	20	50	19	1000
80	45	20	60	23	1050
90	40	20	70	27	1089
100	36	20	80	31	1120
110	33	20	90	35	1145
120	30	20	100	39	1167

1130

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Calculate Portion by Barrier

Portion by Barrier	
Max of Ph 1+2 and Ph 5+6 divided by Critical Volume	Max of Ph 3+4 and Ph 7+8 divided by Critical Volume
0.583	0.417
659 / 1130	471 / 1130

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Calculate Portion by Phase

Portion by Phase			
Ph 1 / Ph 1+2	Ph 2 / Ph 1+2	Ph 3 / Ph 3+4	Ph 4 / Ph 3+4
0.429	0.571	0.524	0.476
Ph 5 / Ph 5+6	Ph 6 / Ph 5+6	Ph 7 / Ph 7+8	Ph 8 / Ph 7+8
0.560	0.440	0.445	0.555
369 / 659	290 / 659	118 / 265	147 / 265

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Calculate Phase Splits

Phase Splits			
Cycle Length x Portion by Barrier x Portion by Phase			
Ph 1	Ph 2	Ph 3	Ph 4
28	37	24	22
Ph 5	Ph 6	Ph 7	Ph 8
36	28	20	25
110 x 0.583 x 0.56			110 x 0.417 x 0.555

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Remember…

- Phase Split = Phase Green + Yellow Change + Red Clear
  - Phase Green = Phase Split - Yellow Change - Red Clear

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Uncongested Systems

- How do we recognize an uncongested system of intersection?
- What do drivers expect in an uncongested system of intersections?

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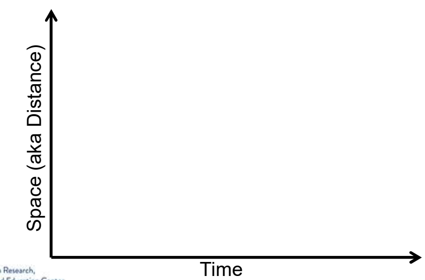
Time-Space Diagrams

- What are they?
  - Graphical depiction of vehicle movement over time
- How do they help us?
  - Allow us to visualize network performance
- Be aware…
  - No standard for which axis is which



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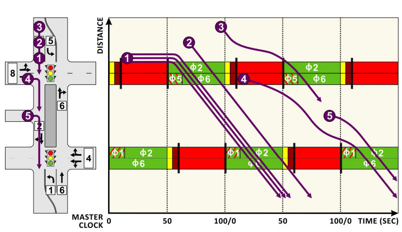
Understanding Traffic Signals and Vehicle Trajectories on Time-Space Diagrams – STM2 Page 7-7

#	Vehicle Condition
	Traffic Signals
1	3 Queued Vehicles Depart on Green
2	Vehicle Travels 2 Signals without Stopping
3	Vehicle Slows Early to Avoid Stopping
4	Side Street Vehicle Entry
5	Midblock Vehicle Entry



63 STRIDE | Southeastern Transportation Research, Innovation, Development and Education Center

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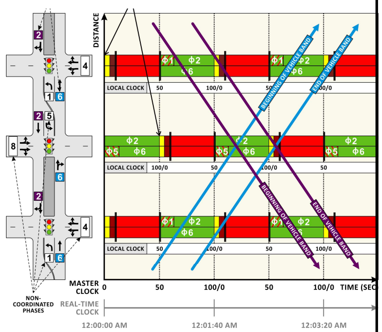
Understanding Time-Space Diagrams Showing Bandwidth STM2 Page 7-20

- Bandwidth
  - Measured in seconds
  - Vehicles entering in the band should not have to stop (theoretically)



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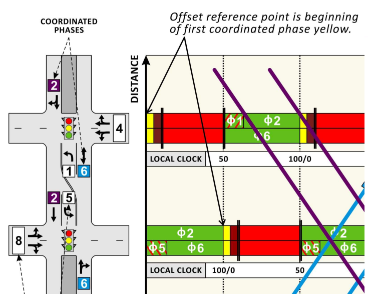
Understanding Offsets and Offset Reference Points – STM2 Page 7-3

- Offset Reference Point
  - Indicate what point in the cycle an offset is measured to
- Offsets
  - Measured in seconds
  - Indicate the difference in schedule between intersections



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Transportation Institute Technology Transfer Center

Resonant Cycle Lengths

- Use geometry to determine cycle lengths
- Use when intersection spacings are similar

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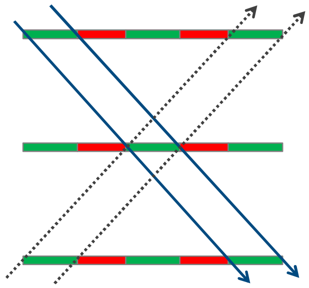
Resonant Cycle Length: Simultaneous

- Travel to next intersection each cycle
- All offsets = 0
- Bandwidth ≈ shortest coordinated green



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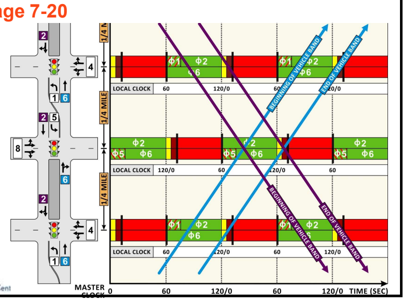
Resonant Cycle Length: Single Alternate – STM2 page 7-20

- Travel **two** intersections each cycle
- Bandwidth ≈ shortest coordinated green
- Offsets alternate: 0, C/2, 0, C/2, 0…



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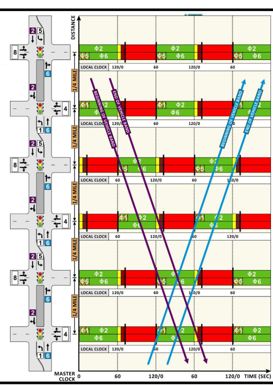
Resonant Cycle Length Double Alternate – STM2 Page 7-21

- Travel **four** intersections each cycle
- Bandwidth ≈ ½ shortest coordinated green
- Offsets alternate: 0, 0, C/2, C/2, 0, …



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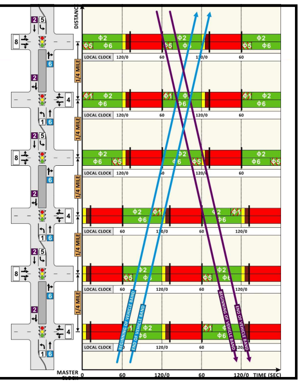
Resonant Cycle Length Triple Alternate – STM2 Page 7-22

- Travel **six** intersections each cycle
  - Bandwidth ≈ $^{1}/_{3}$ shortest coordinated green
- Offsets alternate:
  0, 0, 0,
  C/2, C/2, C/2,
  0, …



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Calculating Cycle Length Options

Resonant Cycle Type	Cycle Length (sec)	Offset Pattern (sec)
Simultaneous	C = (d/v)	All 0
Single Alternate	C = 2 (d/v)	0, C/2, 0…
Double Alternate	C = 4 (d/v)	0, 0, C/2, C/2, 0…
Triple Alternate	C = 6 (d/v)	0, 0, 0, C/2, C/2, C/2, 0…

- d = average intersection spacing in feet
- v = speed in ft/sec

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Calculating Cycle Length Options (cont.)

	Average Spacing (mile)	Average Spacing (ft)	Speed (mph)	Speed (ft/sec)	Cycle Length Options (sec)
Simultaneous	0.25		25		
Single Alternate	0.25		25		
Double Alternate	0.25		25		
Triple Alternate	0.25		25		

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Choosing a Cycle Length

	Average Spacing (mile)	Average Spacing (ft)	Speed (mph)	Speed (ft/sec)	Cycle Length Options (sec)
Simultaneous	0.25	1320	25	36.7	C = d/v = **36**
Single Alternate	0.25	1320	25	36.7	C = 2d/v = **72**
Double Alternate	0.25	1320	25	36.7	C = 4d/v = **144**
Triple Alternate	0.25	1320	25	36.7	C = 6d/v = **216**

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Learning Outcomes

- Having completed Traffic Signal Timing for Efficiency, you should be able to…
  - Determine intersection cycle length for an uncongested intersection
  - Calculate phase splits for an uncongested intersection
  - Use a time-space diagram
  - Calculate resonant cycle lengths for systems of intersections

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Thank you for Participating!

Basic Traffic Signal Timing

Dr. Steven M. Click, PE
Feel free to contact me!
sclick@tntech.edu

Get course resources via QR Code or at
https://tinyurl.com/228knzkw

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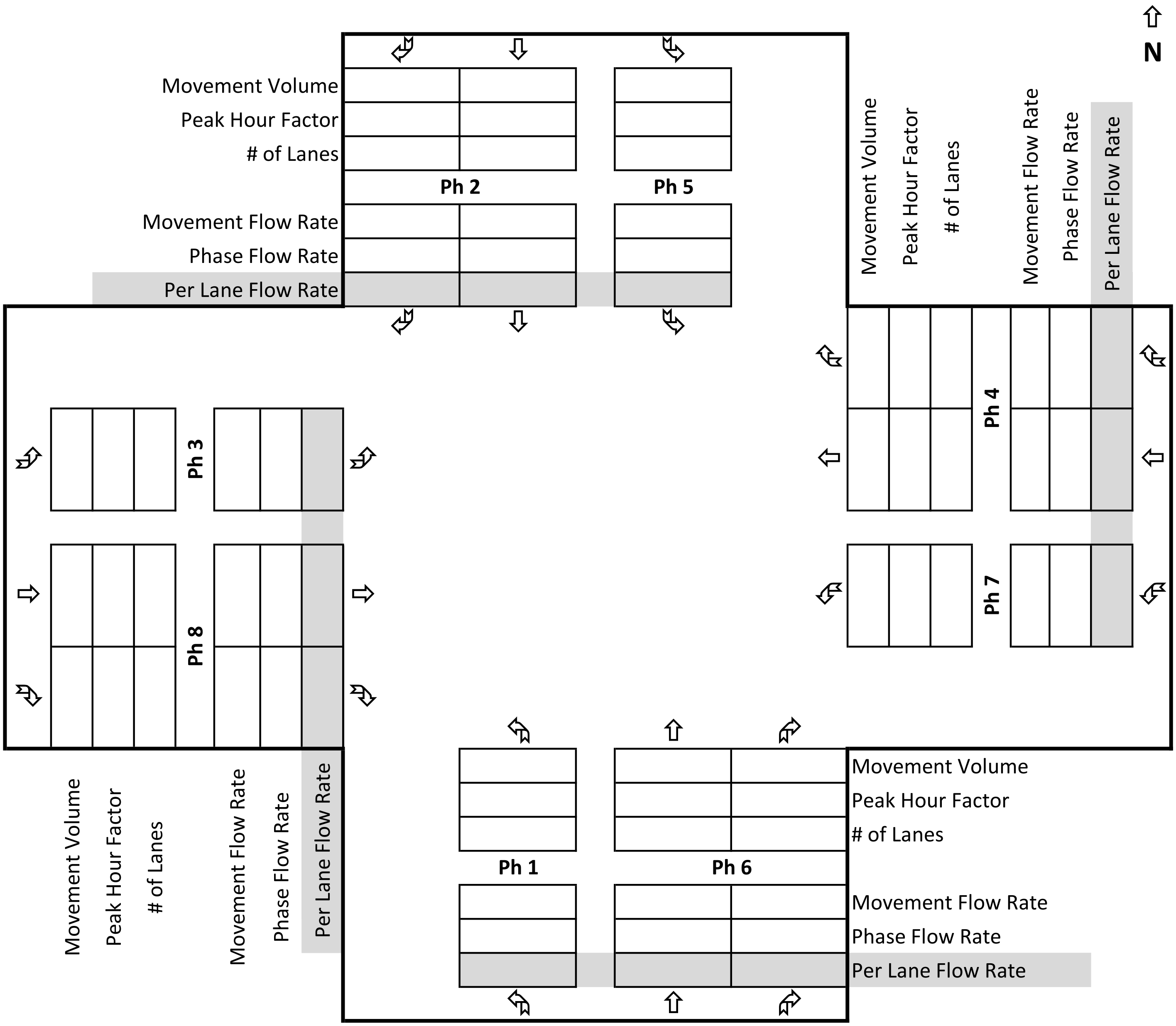
Traffic Signal Timing by Critical Lane Analysis

Based on the Critical Movement Analysis method presented in the NCHRP Report 812: Signal Timing Manual, Second Edition



Per Lane Flow Rates										
Maximum of			+	Maximum of			=	Critical Volume	and thus	Cycle Length
Phase 1	+	Phase 2		Phase 3	+	Phase 4				
Ph 1+2 =				Ph 3+4 =						
AND				AND						
Phase 5	+	Phase 6		Phase 7	+	Phase 8				
Ph 5+6 =				Ph 7+8 =						

Portion by Barrier	
Max of Ph 1+2 and Ph 5+6 divided by Critical Volume	Max of Ph 3+4 and Ph 7+8 divided by Critical Volume

Phase Splits			
Cycle Length x Portion by Barrier x Portion by Phase			
Ph 1	Ph 2	Ph 3	Ph 4
Ph 5	Ph 6	Ph 7	Ph 8

Portion by Phase			
Ph 1 / Ph 1+2	Ph 2 / Ph 1+2	Ph 3 / Ph 3+4	Ph 4 / Ph 3+4
Ph 5 / Ph 5+6	Ph 6 / Ph 5+6	Ph 7 / Ph 7+8	Ph 8 / Ph 7+8

Training Slides

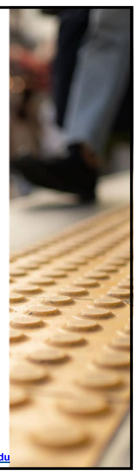
Intro to Transportation Equity

Transportation Equity Fundamentals

Dr. Mehri M. Mohebbi
UF Transportation Institute (UFTI)
Transportation Equity Program Director

1

Types of Equity



2

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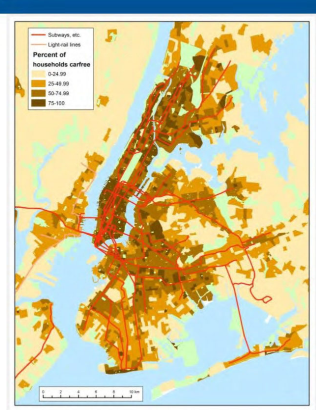
Health Equity:

"Supports the development of accessible, efficient, affordable, and safe alternatives to car travel, and especially to driving solo + **Enable everyone to walk more, travel by bicycle, and use public transportation more**" (Policy Link)



Source: The geography of carfree households in the United States by Chris Winters (2021)

3

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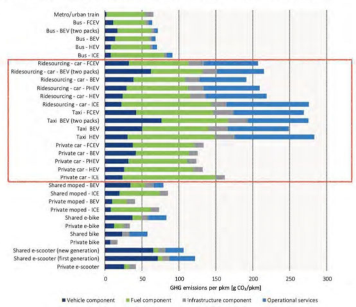
Health Equity

Figure 2. Central estimates of life-cycle greenhouse gas emissions of urban transport modes per pkm



Notes: BEV = battery electric vehicle; HEV = hybrid electric vehicle; ICE = internal combustion engine; FCEV = fuel cell electric vehicle; PHEV = plug-in hybrid electric vehicle. These estimates have been developed using key inputs (such as average number of passengers, the electricity mix and the ratio of operational km per active km) defined by global averages (see Annex A for further details and source used) observed prior to the Covid-19 pandemic. Specific circumstances occurring in different world regions, changes in operational practices and the Covid-19 pandemic should therefore be modelled as individual specific cases, modifying input data accordingly. Sensitivity results are presented in the following sections of this report.

Source: OECD/ITF 2021 - Central estimates of life-cycle greenhouse gas emissions of urban transport modes per pkm

4

Categorization of People

* Understanding the **Historical Legacies** of disparities in the context we work

* Revisiting **Traditional Categorization** methods and take an inclusive approach

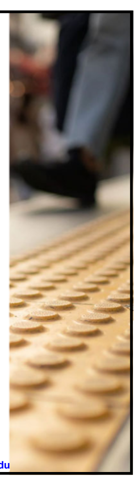
* Investigating **Public Perception** about communities who were historically overburdened with health & social inequities

Source: The State of Equity Measurement (Urban Institute)

mmohebbi@ufl.edu

5

Potential Impacts



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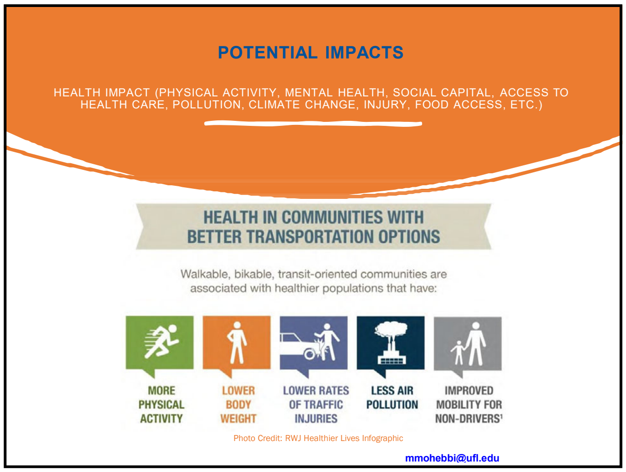
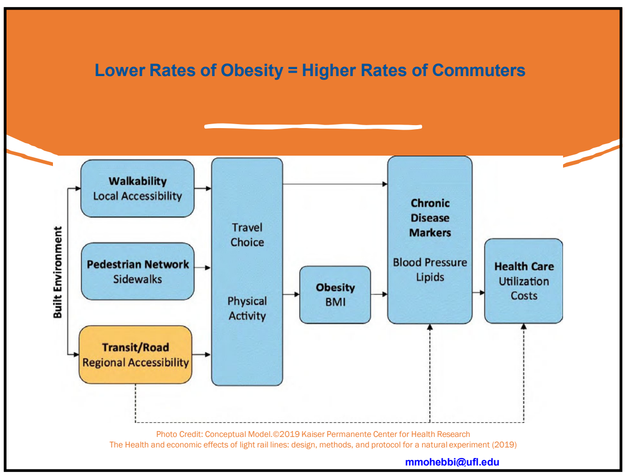
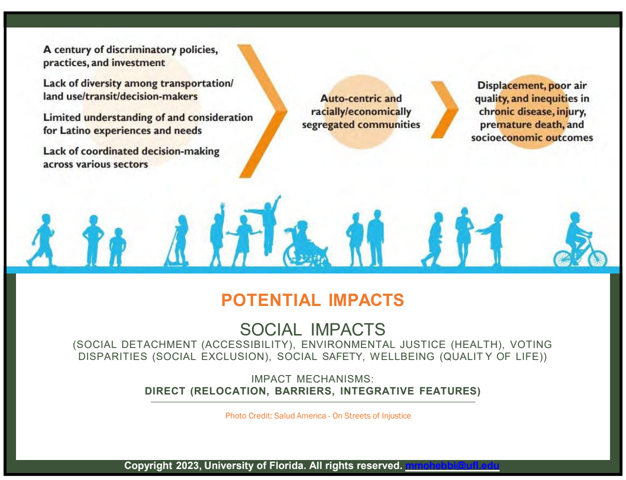
6


POTENTIAL IMPACTS
HEALTH IMPACT (PHYSICAL ACTIVITY, MENTAL HEALTH, SOCIAL CAPITAL, ACCESS TO HEALTH CARE, POLLUTION, CLIMATE CHANGE, INJURY, FOOD ACCESS, ETC.)
HEALTH IN COMMUNITIES WITH BETTER TRANSPORTATION OPTIONS
Walkable, bikable, transit-oriented communities are associated with healthier populations that have:
MORE PHYSICAL ACTIVITY
LOWER BODY WEIGHT
LOWER RATES OF TRAFFIC INJURIES
LESS AIR POLLUTION
IMPROVED MOBILITY FOR NON-DRIVERS
Photo Credit: RWJ Healthier Lives Infographic
mmohebbi@ufl.edu

7


Lower Rates of Obesity = Higher Rates of Commuters
Built Environment
Walkability
Local Accessibility
Pedestrian Network
Sidewalks
Transit/Road
Regional Accessibility
Travel Choice
Physical Activity
Obesity
BMI
Chronic Disease Markers
Blood Pressure
Lipids
Health Care
Utilization
Costs
Photo Credit: Conceptual Model.©2019 Kaiser Permanente Center for Health Research
The Health and economic effects of light rail lines: design, methods, and protocol for a natural experiment (2019)
mmohebbi@ufl.edu

8


A century of discriminatory policies, practices, and investment
Lack of diversity among transportation/land use/transit/decision-makers
Limited understanding of and consideration for Latino experiences and needs
Lack of coordinated decision-making across various sectors
Auto-centric and racially/economically segregated communities
Displacement, poor air quality, and inequities in chronic disease, injury, premature death, and socioeconomic outcomes
POTENTIAL IMPACTS
SOCIAL IMPACTS
(SOCIAL DETACHMENT (ACCESSIBILITY), ENVIRONMENTAL JUSTICE (HEALTH), VOTING DISPARITIES (SOCIAL EXCLUSION), SOCIAL SAFETY, WELLBEING (QUALITY OF LIFE))
IMPACT MECHANISMS:
DIRECT (RELOCATION, BARRIERS, INTEGRATIVE FEATURES)
Photo Credit: Salud America - On Streets of Injustice
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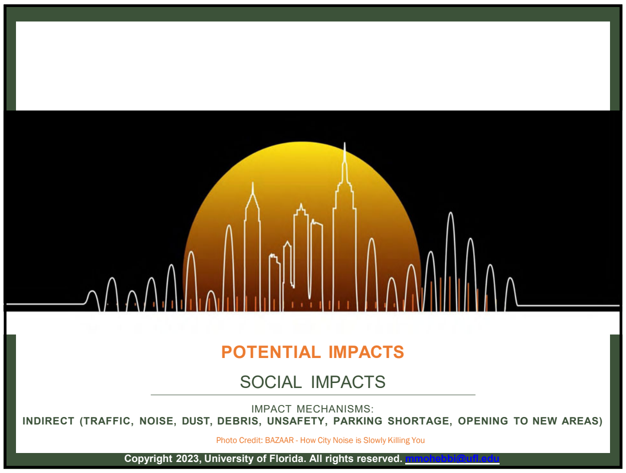
9


POTENTIAL IMPACTS
SOCIAL IMPACTS
IMPACT MECHANISMS:
INDIRECT (TRAFFIC, NOISE, DUST, DEBRIS, UNSAFETY, PARKING SHORTAGE, OPENING TO NEW AREAS)
Photo Credit: BAZAAR - How City Noise is Slowly Killing You
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10


USING PUBLIC TRANSIT SHOULD BE AS DIGNIFIED AS USING A CAR
UNIVERSITY
TRANSIT STOPS NEED ELEVATORS, SHELTERS, & RAMPS for ACCESSIBILITY and COMFORT
POTENTIAL IMPACTS
SOCIAL IMPACTS
IMPACT MECHANISMS: CUMULATIVE
Photo Credit: Philly Transit Equity Day 2021
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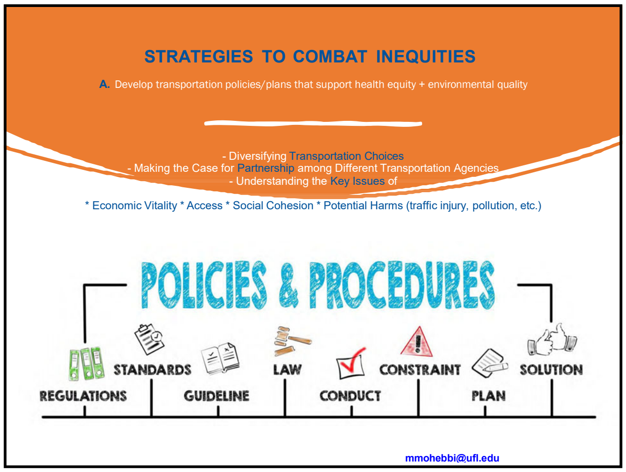
11


Strategies to
Combat Inequities
mmohebbi@ufl.edu

12


STRATEGIES TO COMBAT INEQUITIES
A. Develop transportation policies/plans that support health equity + environmental quality
- Diversifying Transportation Choices
- Making the Case for Partnership among Different Transportation Agencies
- Understanding the Key Issues of
* Economic Vitality * Access * Social Cohesion * Potential Harms (traffic injury, pollution, etc.)
POLICIES & PROCEDURES
STANDARDS
LAW
CONSTRAINT
SOLUTION
REGULATIONS
GUIDELINE
CONDUCT
PLAN
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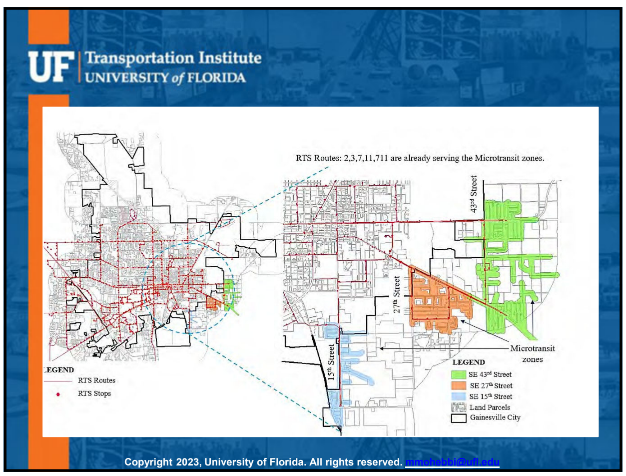
13


UF Transportation Institute
UNIVERSITY of FLORIDA
RTS Routes: 2,3,7,11,711 are already serving the Microtransit zones.
43rd Street
27th Street
15th Street
Microtransit zones
LEGEND
RTS Routes
RTS Stops
LEGEND
SE 43rd Street
SE 27th Street
SE 15th Street
Land Parcels
Gainesville City
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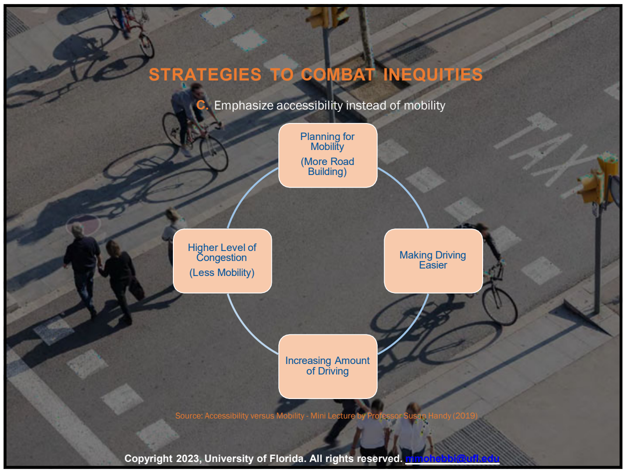
STRATEGIES TO COMBAT INEQUITIES
B. Prioritize investments in distressed regions
- Building Infrastructure that Supports Investments (Transportation investments and service improvements favor low-income economically-distressed areas)
- Bolstering existing economic centers/hubs (which partially contribute to support Social Cohesion and Economic Vitality in the Whole Region)
- Support for Areas with Pronounced Health Disparities
Photo Credit: Housing Matters
mmohebbi@ufl.edu

15


STRATEGIES TO COMBAT INEQUITIES
C. Emphasize accessibility instead of mobility
Planning for Mobility (More Road Building)
Making Driving Easier
Increasing Amount of Driving
Higher Level of Congestion (Less Mobility)
Source: Accessibility versus Mobility - Mini Lecture by Professor Susan Handy (2019)
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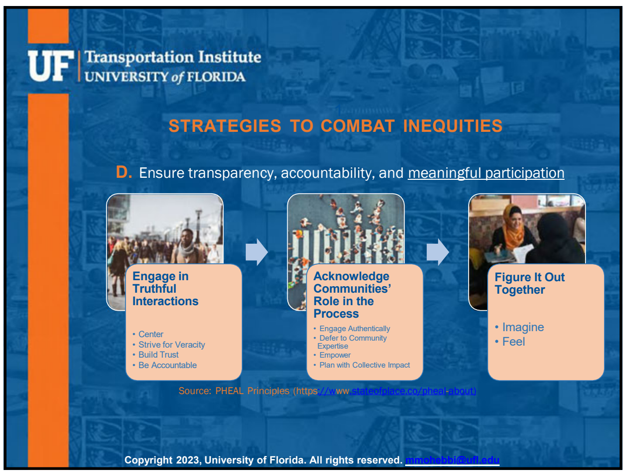
16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STRATEGIES TO COMBAT INEQUITIES
D. Ensure transparency, accountability, and meaningful participation
Engage in Truthful Interactions
• Center
• Strive for Veracity
• Build Trust
• Be Accountable
Acknowledge Communities' Role in the Process
• Engage Authentically
• Defer to Community Expertise
• Empower
• Plan with Collective Impact
Figure It Out Together
• Imagine
• Feel
Source: PHEAL Principles (https://www.stateofplace.co/pheal-about)
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Understanding Social Context
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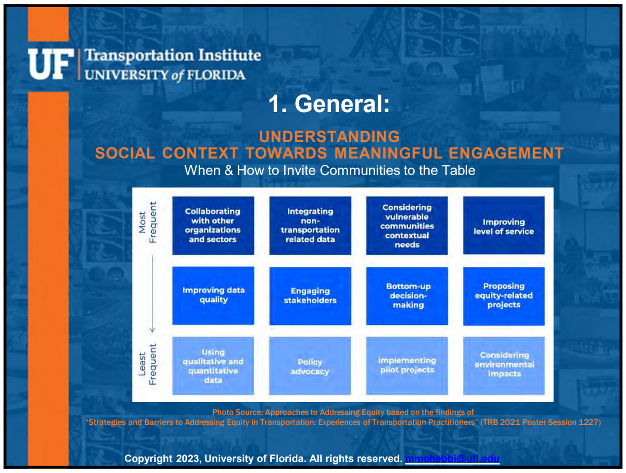
UF Transportation Institute
UNIVERSITY of FLORIDA
1. General:
UNDERSTANDING
SOCIAL CONTEXT TOWARDS MEANINGFUL ENGAGEMENT
When & How to Invite Communities to the Table
Most Frequent
Least Frequent
Collaborating with other organizations and sectors
Integrating non-transportation related data
Considering vulnerable communities contextual needs
Improving level of service
Improving data quality
Engaging stakeholders
Bottom-up decision-making
Proposing equity-related projects
Using qualitative and quantitative data
Policy advocacy
Implementing pilot projects
Considering environmental impacts
Photo Source: Approaches to Addressing Equity based on the findings of
"Strategies and Barriers to Addressing Equity in Transportation: Experiences of Transportation Practitioners" (TRB 2021 Poster Session 1227)
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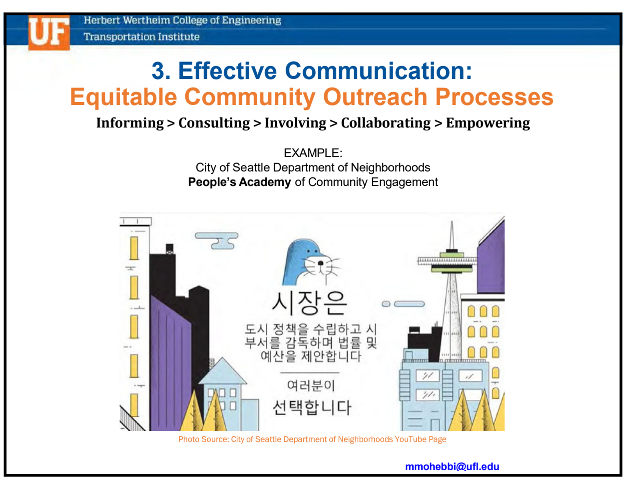
2. Engagement Phase (Early Planning on):
Introduction of Capacity-building &
Equitable Community Outreach Processes
Agency informs community
Agency consults community
Agency engages community in dialogue
Agency and community partner together
Community initiates and directs agency
Increasing Impact on Decision-making and Implementation
Informing > Consulting > Involving > Collaborating > Empowering
Source: Vision Zero Network webinar "Meaningful Community Engagement to Advance Vision Zero" + King County Engagement Guide 2011
mmohebbi@ufl.edu

20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Transportation Institute
3. Effective Communication:
Equitable Community Outreach Processes
Informing > Consulting > Involving > Collaborating > Empowering
EXAMPLE:
City of Seattle Department of Neighborhoods
People's Academy of Community Engagement
시장은
도시 정책을 수립하고 시
부서를 감독하며 법률 및
예산을 제안합니다
여러분이
선택합니다
Photo Source: City of Seattle Department of Neighborhoods YouTube Page
mmohebbi@ufl.edu

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4. Broad Perspective (Workforce):
Equity in Workforce: Healing through Diversifying & Supporting
Diverse Workforce > Understanding Communities
EXAMPLE:
Non-Profit Based Workforce Reentry Programs & Public Transportation Agencies
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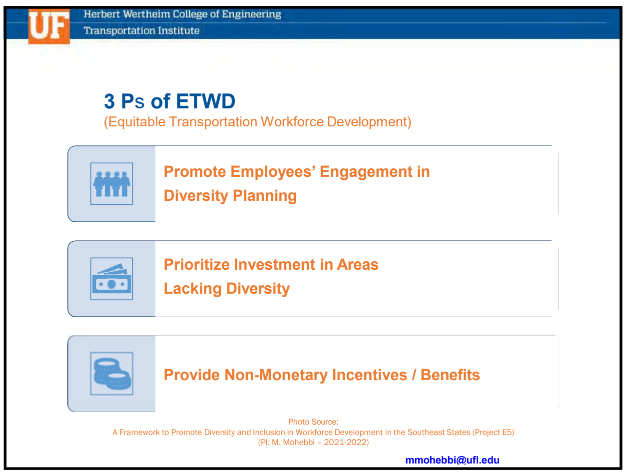
22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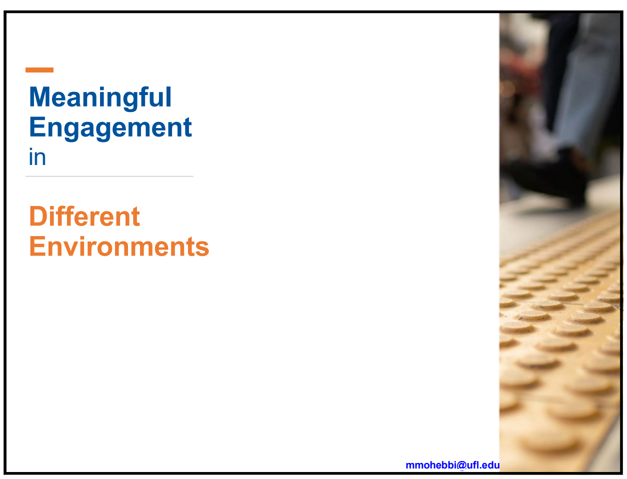
3 Ps of ETWD
(Equitable Transportation Workforce Development)
Promote Employees' Engagement in Diversity Planning
Prioritize Investment in Areas Lacking Diversity
Provide Non-Monetary Incentives / Benefits
Photo Source:
A Framework to Promote Diversity and Inclusion in Workforce Development in the Southeast States (Project E5)
(PI: M. Mohebbi – 2021-2022)
mmohebbi@ufl.edu

23


Meaningful Engagement
in
Different Environments
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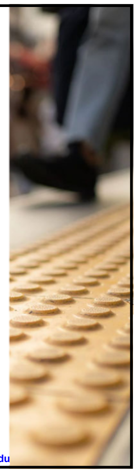
24

AI
&
Community Engagement



* Alternative Data Sources
* Voice & Text-based Interfaces
* Offline Engagement Methods
* Personalized Communication

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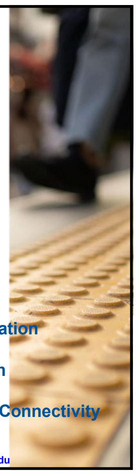
AI
&
Age-Friendly Engagement



* Gamification and Interactive Visualization
* Voice & Visual Recognition
* Educational Resources and Outreach
* Personalized Communication
* Community Engagement and Social Connectivity

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(a) (b)

PUBLIC OUTREACH
TOOLS & TECHNIQUES
COMPUTER GAMES

TO MAXIMIZE ENGAGEMENT

Source: Minecraft as a Tool for Engaging Children in Urban Planning: A Case Study in Tirol Town, Brazil (2021) & UN Habitat USING MINECRAFT FOR YOUTH PARTICIPATION IN URBAN DESIGN AND GOVERNANCE (2015)

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Training Slides

Traffic Signal Basics


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Transportation Technology Transfer (T2) Center
Traffic Signal Basics
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1


UF Herbert Wertheim College of Engineering UNIVERSITY of FLORIDA
Workforce Development Summit
Course Schedule
Traffic Engineering Fundamentals Kickoff Summit May 9
MUTCD Traffic Signals Overview May 11
Traffic Signal Systems Asset Management May 12
Highway Safety Analysis Traffic Signals and their Timing May 12
Basic Traffic Signal Timing May 15
Transportation Equity Fundamentals May 15
Traffic Signal Basics May 16-17
Highway Capacity Analysis with Signalized Intersections May 19
Advanced Traffic Signal Timing May 22
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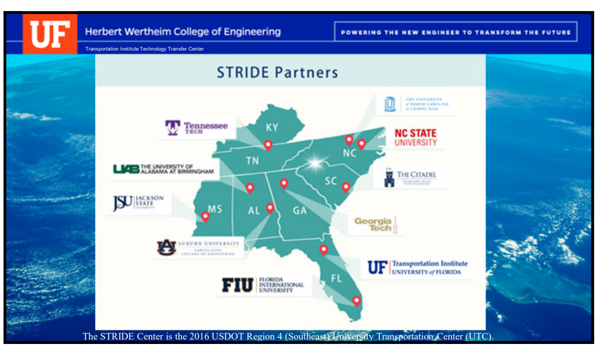
2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Georgia Tech
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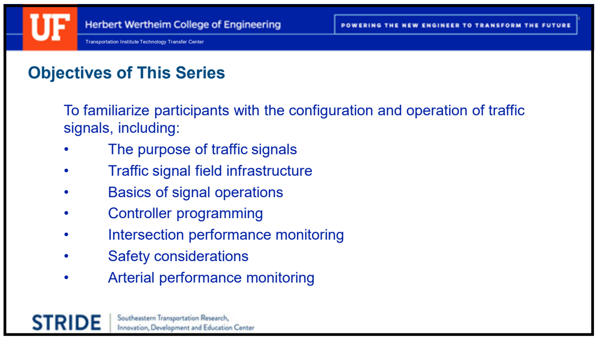
3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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Objectives of This Series
To familiarize participants with the configuration and operation of traffic signals, including:
• The purpose of traffic signals
• Traffic signal field infrastructure
• Basics of signal operations
• Controller programming
• Intersection performance monitoring
• Safety considerations
• Arterial performance monitoring
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Transportation Technology Transfer (T2) Center
Traffic Signal Basics
1. Introduction to Traffic Signals
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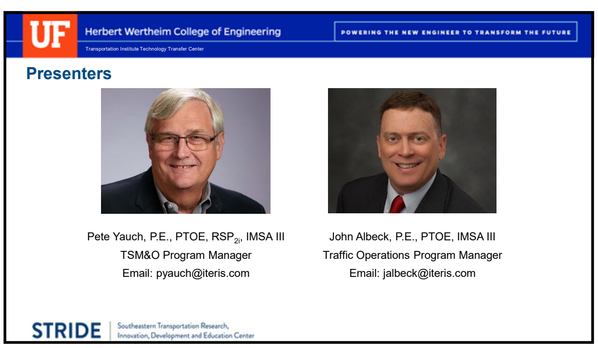
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Presenters
Pete Yauch, P.E., PTOE, RSP$_{2I}$, IMSA III
TSM&O Program Manager
Email: pyauch@iteris.com
John Albeck, P.E., PTOE, IMSA III
Traffic Operations Program Manager
Email: jalbeck@iteris.com
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Objectives of This Session

To familiarize participants with traffic signal applications – including the benefits, advantages, and disadvantages of their use.

The engineering study process needed to justify the installation of a new signal, per the requirements of the Manual on Uniform Traffic Control Devices (MUTCD) will be described.

Additional considerations, such as the need to provide for all road users at a signal, will also be discussed.

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Introduction

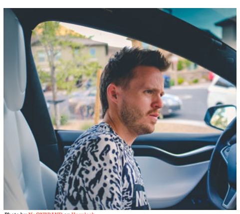

Photo by NeONBRAND on Unsplash

- Traffic signals have a daily impact on nearly every citizen
- Drivers place their confidence in the proper operation of signals
- Drivers accept the necessity of the signal, sometimes demand it
- Overall objective of the signal is to provide safe and efficient operation

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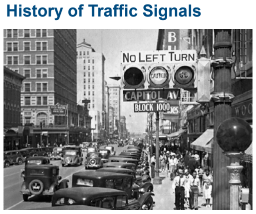
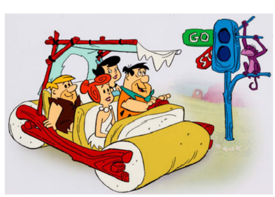
History of Traffic Signals



Oilman Magazine



Hanna-Barbera Productions

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Who Do Traffic Signals Affect?

- Anyone Who Commutes in an Urban / Suburban Area
- Personal Vehicles
- Public Transportation
- Pedestrians
- Bicyclists
- Commercial Vehicles
- Emergency Vehicles

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Traffic Signal Purpose

- The MUTCD defines a traffic control signal as:
  - Any highway traffic signal by which traffic is alternatively directed to stop and permitted to proceed
  - Traffic is defined as pedestrians, bicyclists, ridden or herded animals, vehicles, streetcars, and other conveyances either singularly or together while using any highway for purposes of travel

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Traffic Signal Purpose

- It is with this need to assign the right of way at locations that we consider the dual purpose of traffic signals
  - Efficiency
  - Safety
- In some cases, the above seem to be conflicting

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Traffic Signal Purpose

- The MUTCD describes that traffic control signals can be
  - Ill-designed
  - Ineffectively placed
  - Improperly operated, or
  - Poorly maintained, with resulting outcomes of excessive delay, disobedience of the indication, avoidance and increases in the frequency of collisions

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Advantages of Traffic Signals

- Traffic signals that are properly located and operated are likely to:
  - Provide for orderly movement of traffic
  - Increase traffic capacity of the intersection
  - Reduce the frequency of certain types of crashes (e.g., right-angle crashes)
  - Provide for continuous or nearly continuous movement of traffic along a given route
  - Interrupt heavy traffic to permit other traffic, vehicular or pedestrian, to cross

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Disadvantages of Traffic Signals

- Unjustified or improper traffic control signals can result in one or more of the following disadvantages:
  - Excessive delay
  - Excessive disobedience of the signal indications
  - Increased use of less adequate routes as road users attempt to avoid the traffic control signals
  - Significant increases in the frequency of crashes (especially rear-end crashes)

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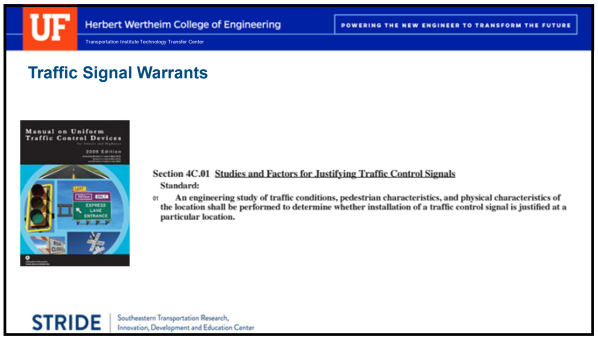
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Traffic Signal Warrants
Section 4C.01 Studies and Factors for Justifying Traffic Control Signals
Standard:
01 An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.
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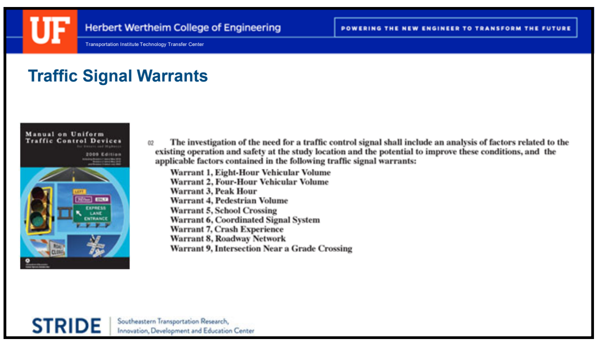
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Traffic Signal Warrants
02 The investigation of the need for a traffic control signal shall include an analysis of factors related to the existing operation and safety at the study location and the potential to improve these conditions, and the applicable factors contained in the following traffic signal warrants:
Warrant 1, Eight-Hour Vehicular Volume
Warrant 2, Four-Hour Vehicular Volume
Warrant 3, Peak Hour
Warrant 4, Pedestrian Volume
Warrant 5, School Crossing
Warrant 6, Coordinated Signal System
Warrant 7, Crash Experience
Warrant 8, Roadway Network
Warrant 9, Intersection Near a Grade Crossing
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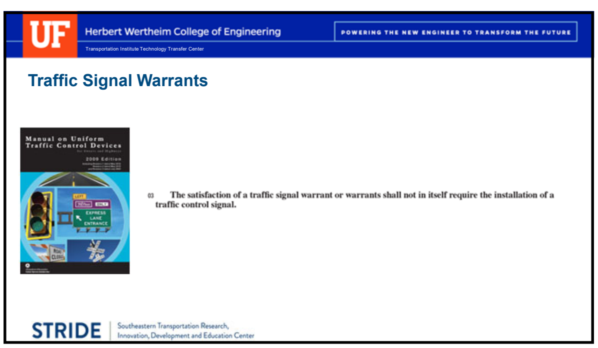
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Traffic Signal Warrants
03 The satisfaction of a traffic signal warrant or warrants shall not in itself require the installation of a traffic control signal.
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Traffic Signal Warrants

Warrant	Name	Description
Warrant 1	Eight-Hour Vehicular Volume	This warrant is used when a large volume of intersecting traffic or where the traffic volume on the major street is so excessive that traffic on the minor street suffers undo delay. This warrant requires at least eight hours' worth of traffic volume data.
Warrant 2	Four-Hour Vehicular Volume	The Four-Hour Vehicular Volume signal warrant conditions are intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic control signal. This warrant requires at least four hours' worth of traffic volume data.

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Traffic Signal Warrants

Warrant	Name	Description
Warrant 3	Peak Hour	The Peak Hour signal warrant is intended for use at a location where traffic conditions are such that for a minimum of 1 hour of an average day, the minor-street traffic suffers undue delay when entering or crossing the major street. This warrant requires just one hour of data and is often used for land use or impact studies; however, Department approval is required if this is the only warrant that is used to justify the signal.
Warrant 4	Pedestrian Volume	The Pedestrian Volume signal warrant is intended for application where the traffic volume on a major street is so heavy that pedestrians experience excessive delay in crossing the major street.

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Traffic Signal Warrants

Warrant	Name	Description
Warrant 5	School Crossing	The School Crossing signal warrant is intended for application where the fact that schoolchildren cross the major street is the principal reason to consider installing a traffic control signal. For the purposes of this warrant, the word "schoolchildren" includes elementary through high school students.
Warrant 6	Coordinated Signal System	Progressive movement in a Coordinated Signal System sometimes necessitates installing traffic control signals at intersections where they would not otherwise be needed in order to maintain proper platooning of vehicles.

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Traffic Signal Warrants

Warrant	Name	Description
Warrant 7	Crash Experience	The Crash Experience signal warrant conditions are intended for application where the severity and frequency of crashes are the principal reasons to consider installing a traffic control signal.
Warrant 8	Roadway Network	Installing a traffic control signal at some intersections might be justified to encourage concentration and organization of traffic flow on a Roadway Network.
Warrant 9	Intersection Near a Grade Crossing	The Intersection Near a Grade Crossing signal warrant is intended for use at a location where none of the conditions described in the other eight traffic signal warrants are met, but the proximity to the intersection of a grade crossing on an intersection approach controlled by a STOP or YIELD sign is the principal reason to consider installing a traffic control signal.

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Removal of Traffic Signals

If changes in traffic patterns eliminate the need for a traffic control signal, consideration should be given to removing it and replacing it with appropriate alternative traffic control devices, if any are needed.

MUTCD

WNBF

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Traffic Signal Budgeting & Costs

- New traffic signals can be expensive and must be warranted (as previously discussed) or they could cause more harm than good
  - A typical span wire signal is approximately $100k
  - A typical mast arm signal is approximately $300k
  - The cost can be more dependent on the situation
- Operation and Maintenance of traffic signals also a budgetary concern

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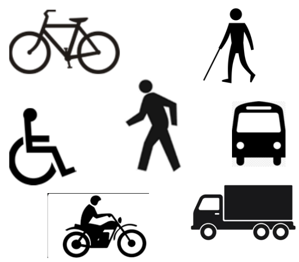
Accommodating All Users

The design and operation of traffic control signals shall take into consideration the needs of pedestrian as well as vehicular traffic.

MUTCD



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Glossary of Terms

- MUTCD
- Controller
- Cabinet
- Detector
- Actuation
- Capacity
- Saturation Flow
- Phase
- Interval
- Movement
- Sequence
- Cycle
- Overlap
- Protected Turns

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Questions?

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Traffic Signal Basics
2 - Field Equipment
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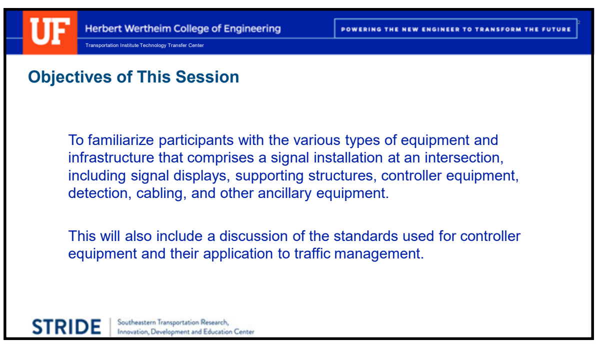
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Objectives of This Session
To familiarize participants with the various types of equipment and infrastructure that comprises a signal installation at an intersection, including signal displays, supporting structures, controller equipment, detection, cabling, and other ancillary equipment.
This will also include a discussion of the standards used for controller equipment and their application to traffic management.
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Vehicular Signal Displays
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Pedestrian Signal Displays
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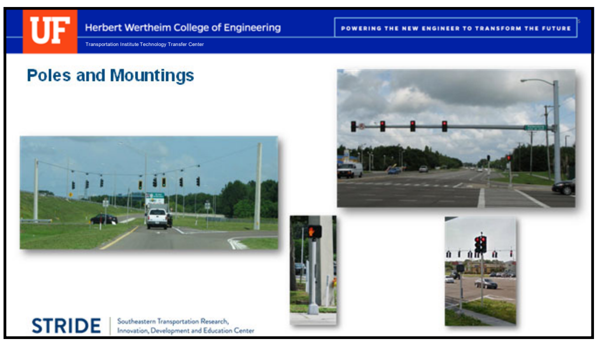
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Poles and Mountings
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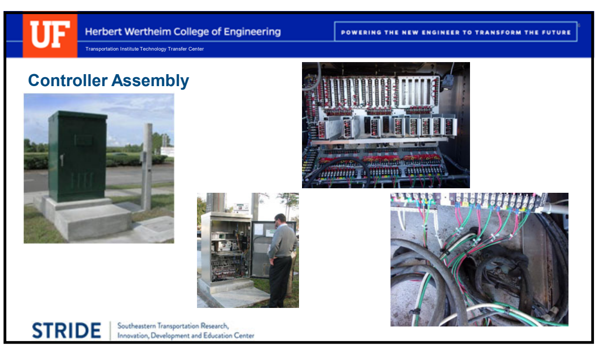
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Controller Assembly
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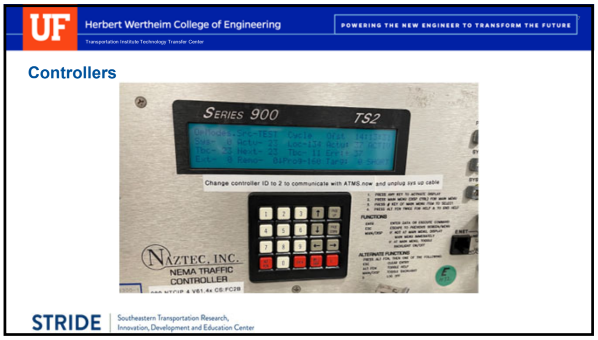
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Controllers
SERIES 900 TS2
Change controller ID to 2 to communicate with ATMS now and unplug sys up cable
NAZTEC, INC.
NEMA TRAFFIC CONTROLLER
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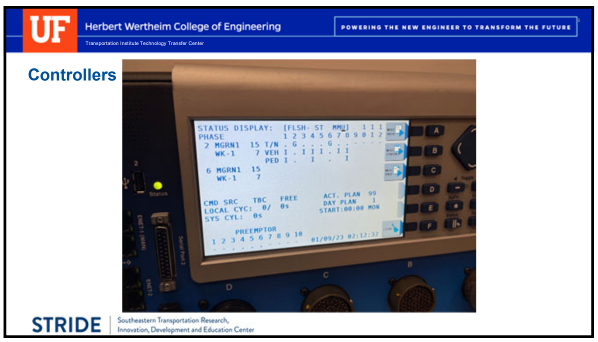
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Controllers
STATUS DISPLAY:
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Detectors
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Detection
Video detector
Microwave detector
Inductive loop detector
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Pedestrian Detection
TO CROSS STREET PUSH BUTTON WAIT FOR WALK SIGNAL
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Output Devices
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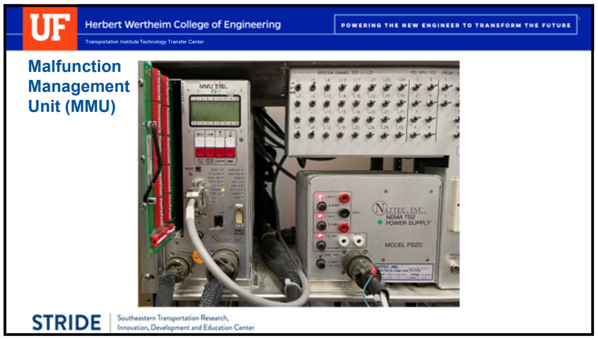
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Malfunction Management Unit (MMU)
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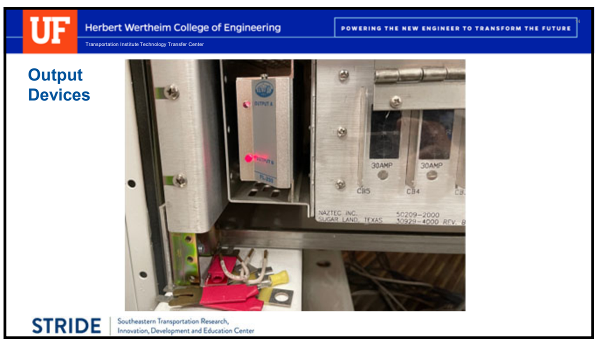
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Output Devices
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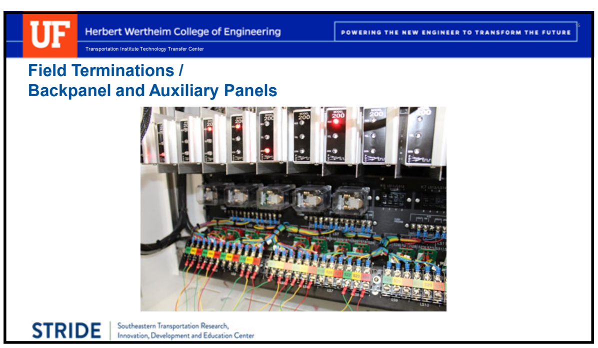
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Field Terminations / Backpanel and Auxiliary Panels
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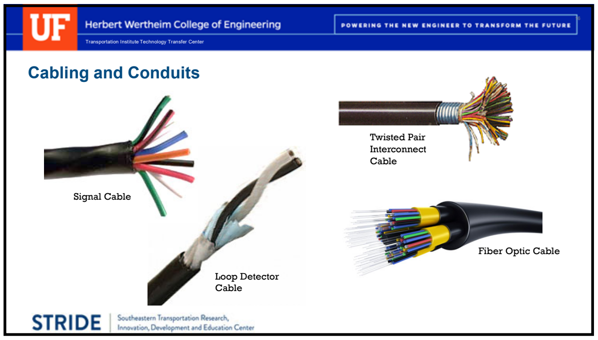
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Cabling and Conduits
Twisted Pair Interconnect Cable
Signal Cable
Fiber Optic Cable
Loop Detector Cable
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Cabling and Conduits
Conduits and Pull Boxes
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Cabling and Conduits
Ground Rod
Electrical Service
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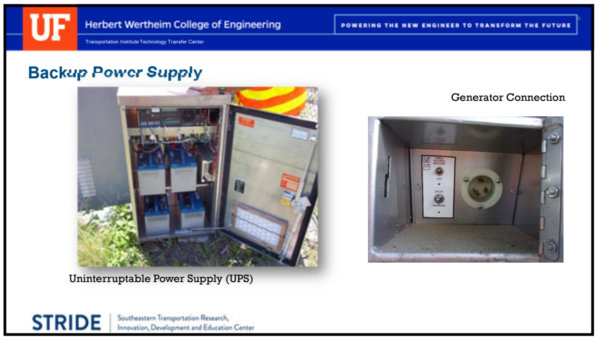
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Backup Power Supply
Generator Connection
Uninterruptable Power Supply (UPS)
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Preemption / Priority
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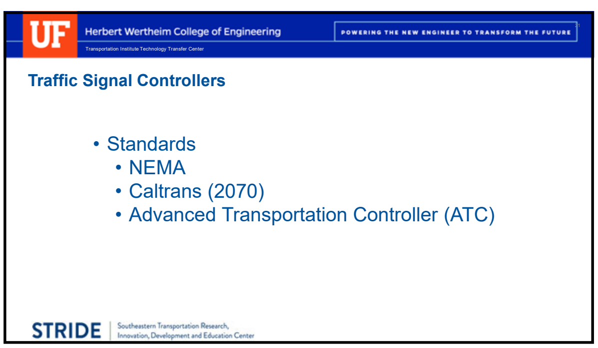
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Traffic Signal Controllers
• Standards
• NEMA
• Caltrans (2070)
• Advanced Transportation Controller (ATC)
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Traffic Signal Controller Standards

- NEMA (National Electrical Manufacturers Association) Controllers
  - Helped greatly to simplify installations
  - Standardization of connectors
  - Set environmental operating limits
  - Standardization of timed intervals

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Traffic Signal Controller Standards

- NEMA (National Electrical Manufacturers Association) Controllers
  - Dedicated Intersection Traffic Signal Controller using Manufacturer Firmware
  - TS-1 (mid-1970s)
    - A, B, and C connectors
  - TS-2 (mid-1990s)
    - Type 1 - serial bus only
    - Type 2 – serial bus and A, B, and C connectors

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Traffic Signal Controller Standards

- The Type 170 / 2070 Controller Family
  - General Purpose Signal Controller
    - Intersections, Ramp Metering, Irrigation
    - Multiple firmware sources
  - Developed by Caltrans and FHWA
  - Type 170 (1970s) now Obsolete

Type 170

Type 2070

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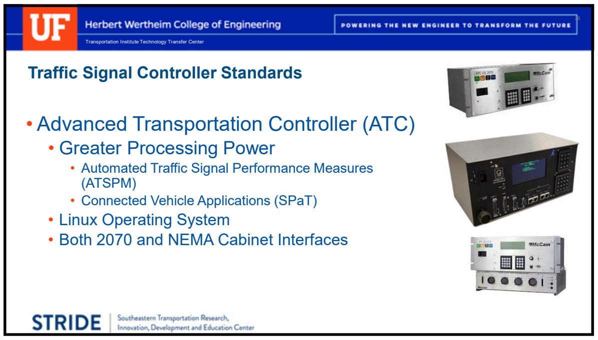
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Traffic Signal Controller Standards
• Advanced Transportation Controller (ATC)
• Greater Processing Power
• Automated Traffic Signal Performance Measures (ATSPM)
• Connected Vehicle Applications (SPaT)
• Linux Operating System
• Both 2070 and NEMA Cabinet Interfaces
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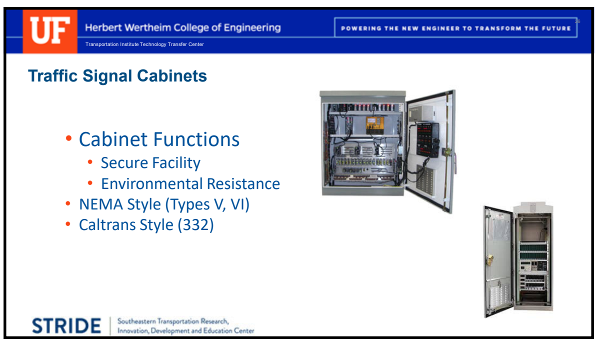
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Traffic Signal Cabinets
• Cabinet Functions
• Secure Facility
• Environmental Resistance
• NEMA Style (Types V, VI)
• Caltrans Style (332)
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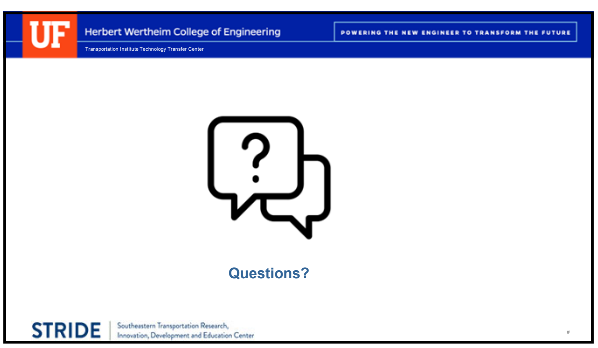
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2023 Workforce Development Summit
Register at www.techtransfer.ce.ufl.edu.
Course Schedule
May 9 Traffic Engineering Fundamentals Kickoff Summit
May 11 MUTCD Traffic Signals Overview
May 12 Traffic Signal Systems Asset Management
May 12 Highway Safety Analysis Traffic Signals and their Timing
May 15 Basic Traffic Signal Timing
May 15 Transportation Equity Fundamentals
May 16-17 Traffic Signal Basics
May 19 Highway Capacity Analysis with Signalized Intersections
May 22 Advanced Traffic Signal Timing
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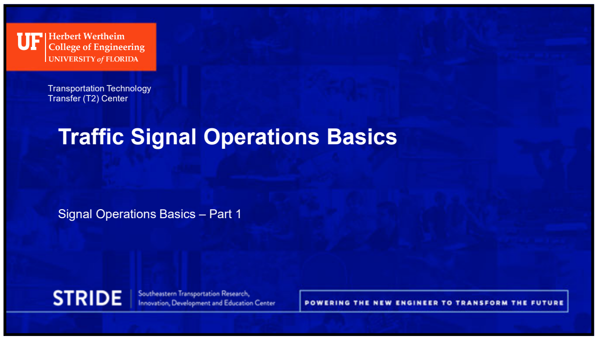
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Traffic Signal Operations Basics
Signal Operations Basics – Part 1
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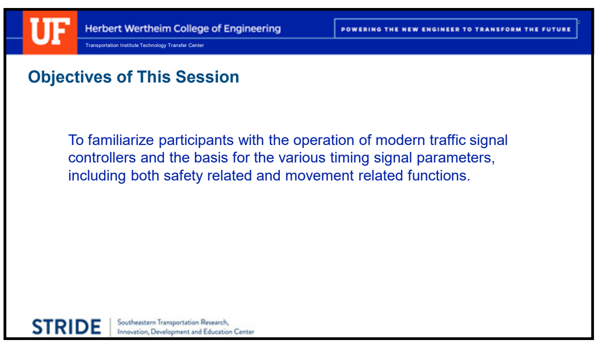
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Objectives of This Session
To familiarize participants with the operation of modern traffic signal controllers and the basis for the various timing signal parameters, including both safety related and movement related functions.
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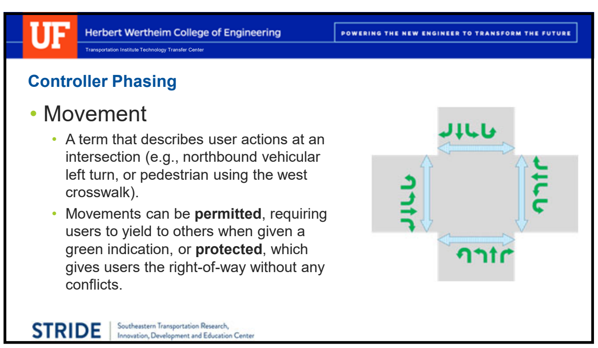
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Controller Phasing
• Movement
• A term that describes user actions at an intersection (e.g., northbound vehicular left turn, or pedestrian using the west crosswalk).
• Movements can be **permitted**, requiring users to yield to others when given a green indication, or **protected**, which gives users the right-of-way without any conflicts.
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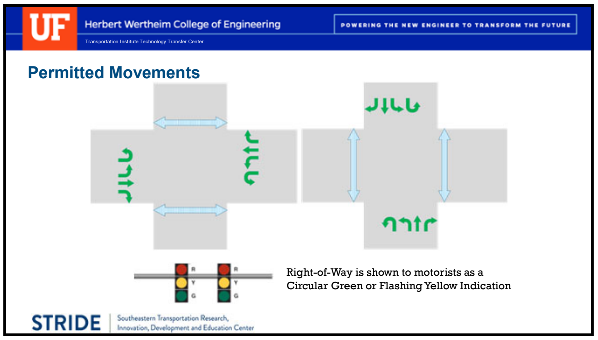
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Permitted Movements
Right-of-Way is shown to motorists as a Circular Green or Flashing Yellow Indication
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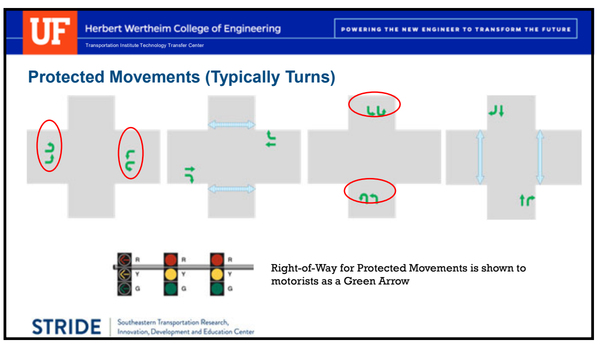
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Protected Movements (Typically Turns)
Right-of-Way for Protected Movements is shown to motorists as a Green Arrow
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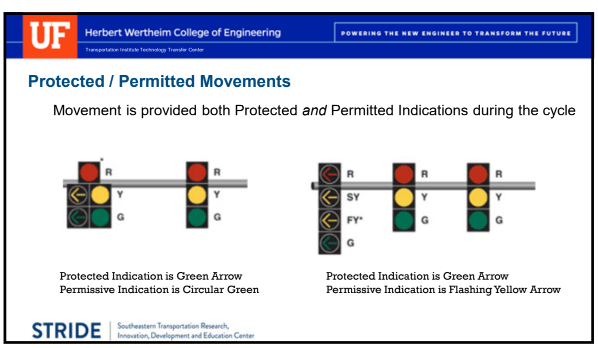
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Protected / Permitted Movements
Movement is provided both Protected and Permitted Indications during the cycle
Protected Indication is Green Arrow
Permissive Indication is Circular Green
Protected Indication is Green Arrow
Permissive Indication is Flashing Yellow Arrow
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Phasing

- Phase
  - A traffic signal phase is a timing process, within the signal controller, that facilitates serving one or more movements at the same time
  - Phases are typically numbered for ease of identification
    - Through movement phases usually even numbered
    - Left turn movement phases usually odd numbered

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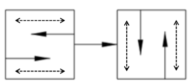
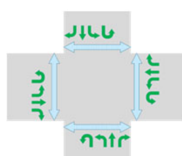
Phasing

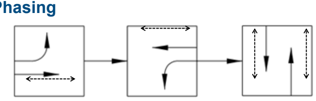


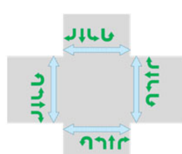


- Two-Phase Intersection
  - Alternating between Two Streets
  - Permissive Turning Movements
  - Concurrent Pedestrians

8

Phasing





- Three-Phase Intersection
  - Serving Opposing Approaches then Crossing Street
  - Protected Turning Movements
  - Concurrent Pedestrians
  - "Split Phased"

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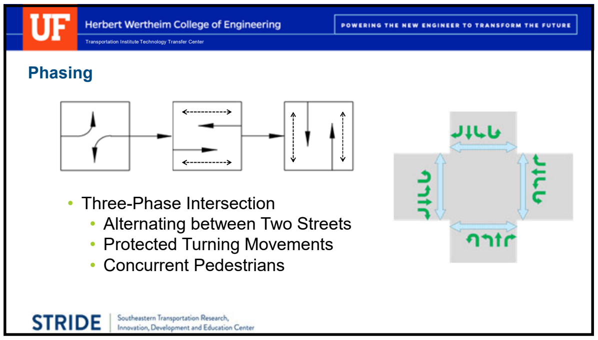
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Phasing
• Three-Phase Intersection
• Alternating between Two Streets
• Protected Turning Movements
• Concurrent Pedestrians
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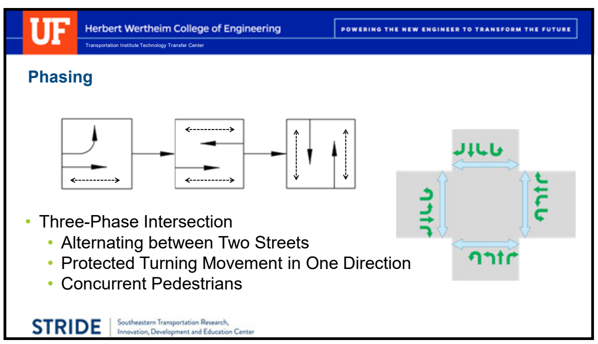
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Phasing
• Three-Phase Intersection
• Alternating between Two Streets
• Protected Turning Movement in One Direction
• Concurrent Pedestrians
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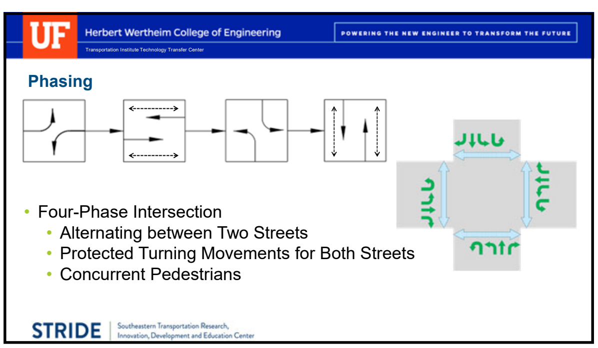
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Phasing
• Four-Phase Intersection
• Alternating between Two Streets
• Protected Turning Movements for Both Streets
• Concurrent Pedestrians
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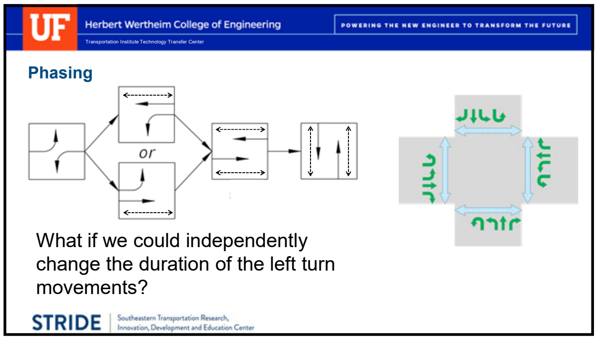
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Phasing
or
What if we could independently change the duration of the left turn movements?
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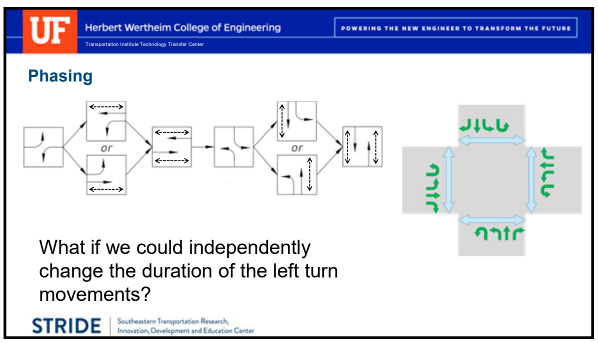
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Phasing
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What if we could independently change the duration of the left turn movements?
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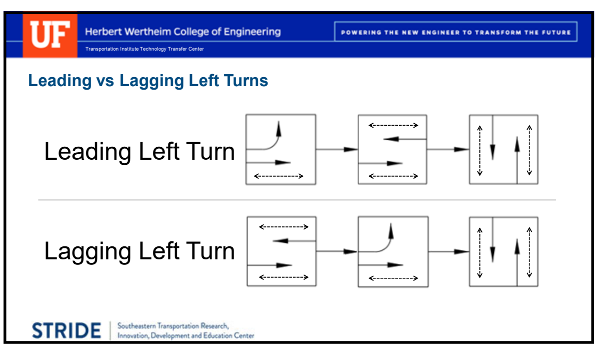
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Leading vs Lagging Left Turns
Leading Left Turn
Lagging Left Turn
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"Left Turn Trap" or "Yellow Trap"

- Occurs when a Circular Yellow indication is displayed to a Permissive Left Turn Movement, while the Opposing Through Movement still has a Circular Green indication.
- Issue of "Driver Expectancy"
  - Driver assumes Opposing Drivers see the same indication and will be stopping
  - Driver makes Left Turn on Yellow and Strikes Opposing Traffic
  - Driver typically ticketed for "Failure to Yield"
- Typically occurs when a Lagging Left Turn is used in one direction

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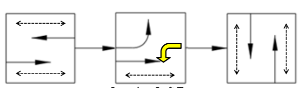
"Left Turn Trap" or "Yellow Trap"



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"Left Turn Trap" or "Yellow Trap"

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"Left Turn Trap" or "Yellow Trap"

- Countermeasures:
  - Avoid Lagging Left Turn Phases with Opposing Permissive Left Turn
    - Make Opposing Left Turn Protected Only
    - Avoid Lagging Left Turn Sequence
  - Use Flashing Yellow Arrow Display
  - Advance to Cross Street Green before serving Left Turn
  - Advance to Brief "All Red"
  - Use W25-1 or W25-2 Sign

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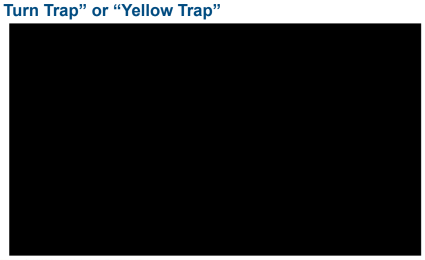
"Left Turn Trap" or "Yellow Trap"



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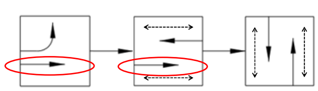
Overlaps

- An Overlap provides a way to operate a movement during one or more phases.



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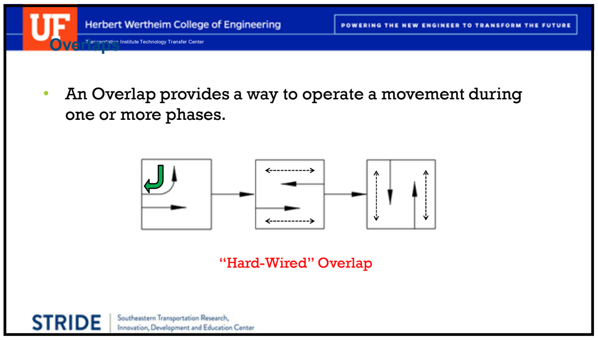
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Overlaps
An Overlap provides a way to operate a movement during one or more phases.
"Hard-Wired" Overlap
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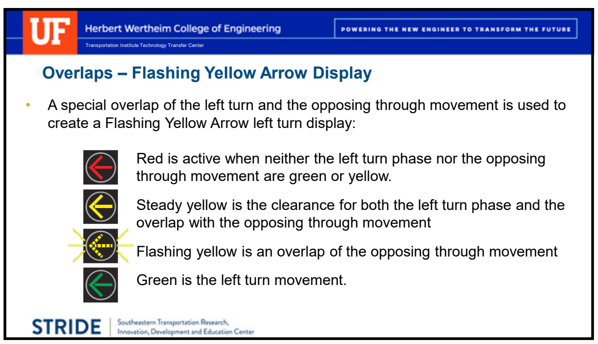
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Overlaps – Flashing Yellow Arrow Display
A special overlap of the left turn and the opposing through movement is used to create a Flashing Yellow Arrow left turn display:
Red is active when neither the left turn phase nor the opposing through movement are green or yellow.
Steady yellow is the clearance for both the left turn phase and the overlap with the opposing through movement
Flashing yellow is an overlap of the opposing through movement
Green is the left turn movement.
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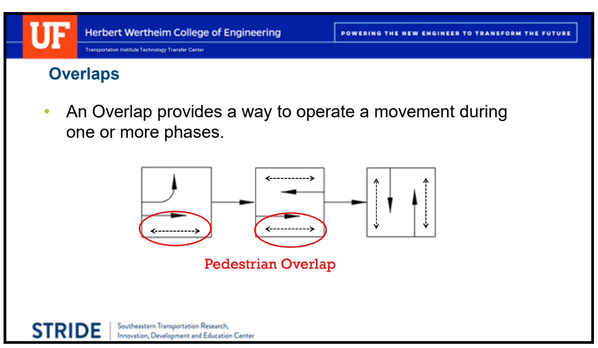
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Overlaps
An Overlap provides a way to operate a movement during one or more phases.
Pedestrian Overlap
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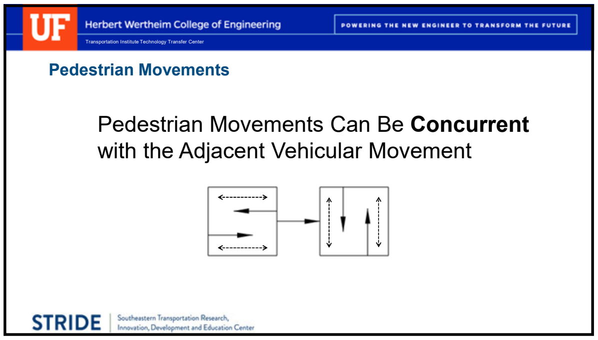
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Pedestrian Movements
Pedestrian Movements Can Be **Concurrent** with the Adjacent Vehicular Movement
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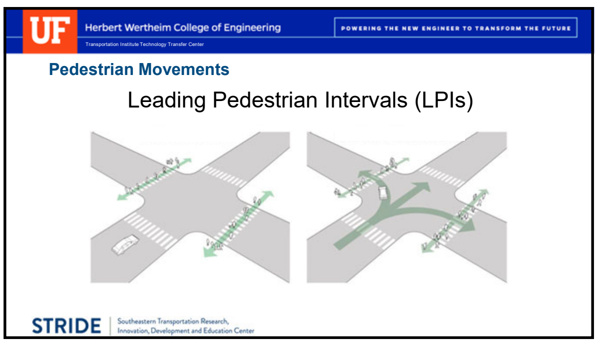
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Pedestrian Movements
Leading Pedestrian Intervals (LPIs)
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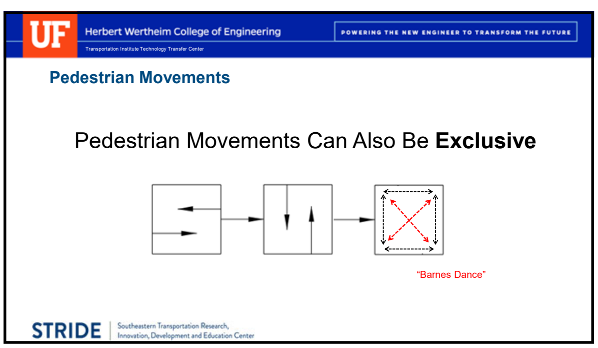
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Pedestrian Movements
Pedestrian Movements Can Also Be **Exclusive**
"Barnes Dance"
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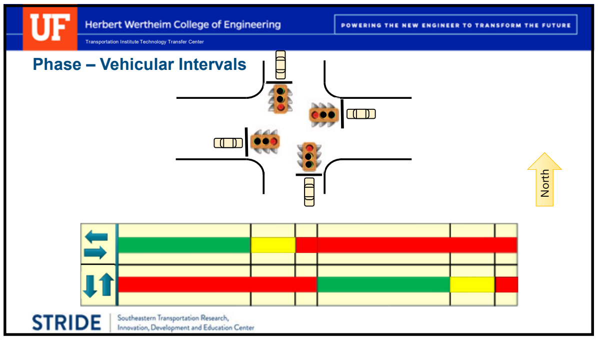

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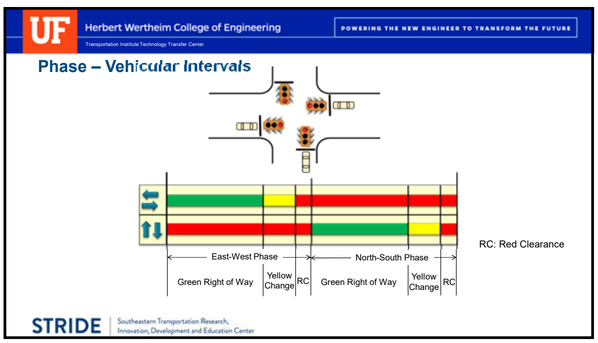

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Phase – Vehicular Intervals

- Green Interval
  - Provides Right of Way Indication.
  - Duration Based on Intersection Design, Traffic Demands, Pedestrian Requirements, and Driver Expectancy
- Yellow Change Interval
  - Provides Indication that Green Movement has Terminated and will be followed by a Red Indication
  - Duration Based on Formula with Considerations for Approach Speeds, an Average Vehicle Length, and Driver Reaction Time
- Red Clearance Interval
  - Provides Indication that Intersection Entry is Prohibited
  - Designed to Allow Vehicles Entering at End of Yellow Change Interval to Clear Path of Conflicting Movements Prior to Their Receiving a Green Indication
  - Duration Based on Formula with Considerations for Approach Speeds and Intersection Width

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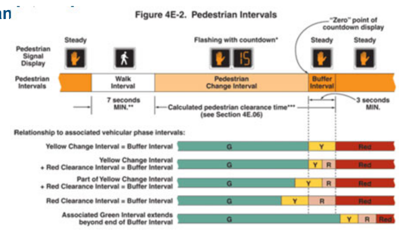
Phase – Pedestrian



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Phase – Pedestrian Intervals

- Walk Interval
  - Provides White "Walking Man" Right of Way Indication to Pedestrian
  - Minimum Duration Based on Pedestrian Leaving Curb and Entering Crosswalk
  - Minimum Duration 7 to 10 Seconds
- Pedestrian Change Interval
  - Provides Flashing Orange "Hand" Indication with Countdown that Walk Indication has Terminated and will be followed by a Don't Walk Indication
  - Duration Based on Formula with Considerations for Walking Speeds, Pushbutton Location, and Crosswalk Length

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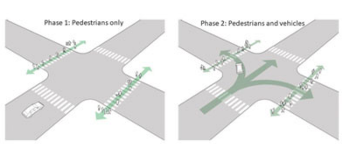
Leading Pedestrian Intervals



- LPIs give pedestrians the opportunity to enter an intersection 3 to 7 seconds before parallel vehicles receive a green indication.
- Proven to have a reduction of pedestrian conflicts and crashes in urbanized areas.

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Rings and Barriers

- Ring
  - A ring is a term that is used to describe a series of conflicting phases that occur in an established order.
- Barrier
  - A barrier (compatibility line) is a reference point in the preferred sequence of a multi-ring controller unit at which all rings are interlocked.

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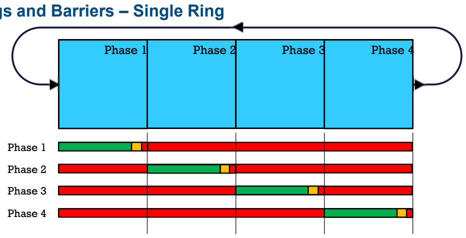
Rings and Barriers – Single Ring



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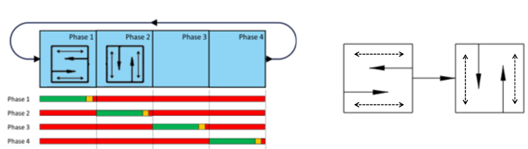
Rings and Barriers – Single Ring



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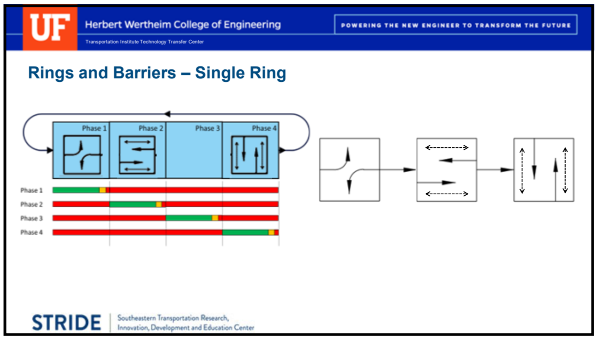
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Rings and Barriers – Single Ring
Phase 1
Phase 2
Phase 3
Phase 4
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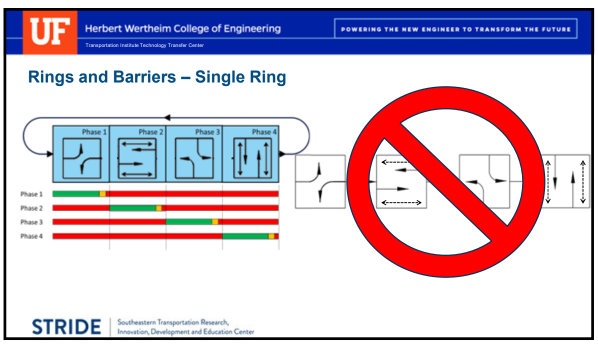
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Rings and Barriers – Single Ring
Phase 1
Phase 2
Phase 3
Phase 4
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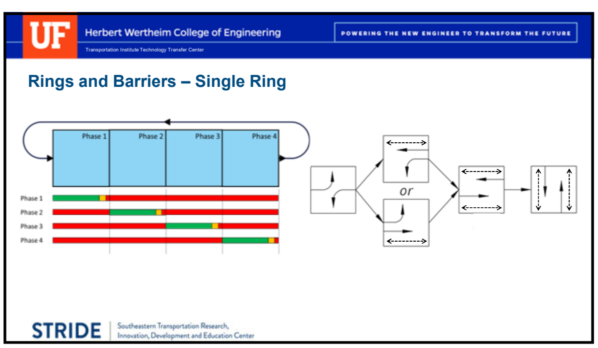
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Rings and Barriers – Single Ring
Phase 1
Phase 2
Phase 3
Phase 4
or
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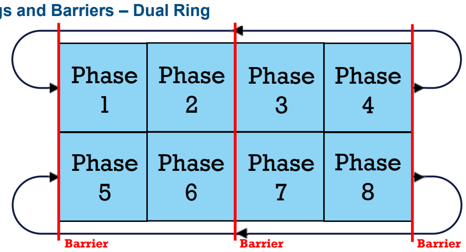
Rings and Barriers – Dual Ring



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Phase Numbering

- Labels assigned to the individual movements around the intersection
- For an eight-phase dual ring controller, it is common to assign the main street through movements as phases 2 and 6
- In addition, it is common to use odd numbers for left turn signals and the even numbers for through signals
- A rule of thumb is that the sum of the through movement and the adjacent left turn is equal to seven or eleven

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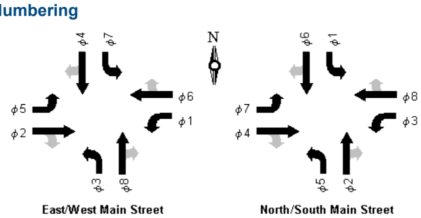
Phase Numbering



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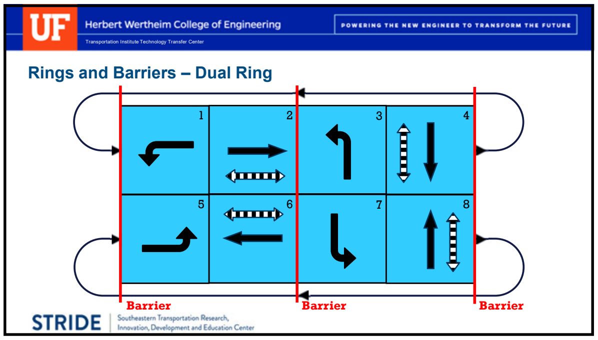
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Rings and Barriers – Dual Ring
1
2
3
4
5
6
7
8
Barrier
Barrier
Barrier
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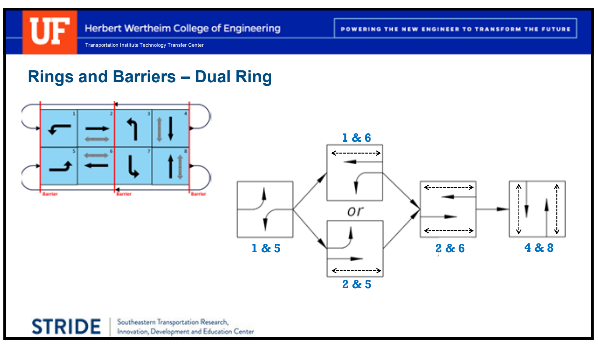
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Rings and Barriers – Dual Ring
1 & 6
or
1 & 5
2 & 5
2 & 6
4 & 8
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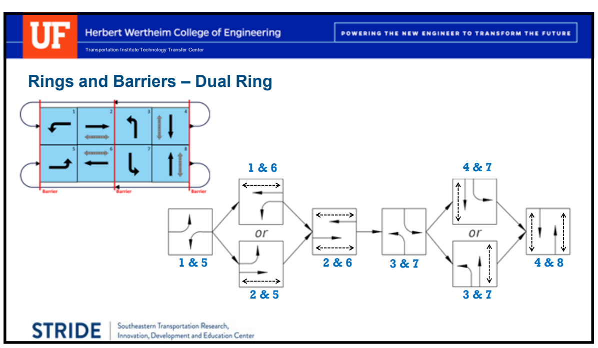
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Rings and Barriers – Dual Ring
1 & 6
or
1 & 5
2 & 5
2 & 6
3 & 7
4 & 7
or
3 & 7
4 & 8
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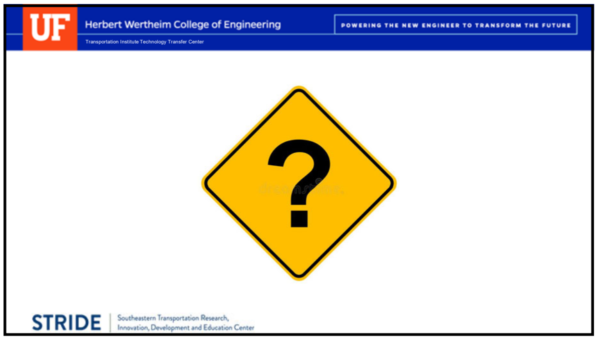
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
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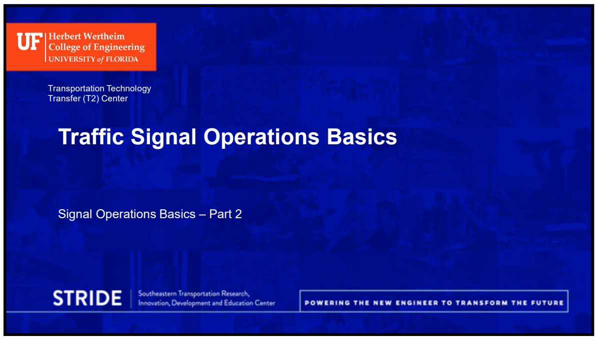

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Transportation Technology Transfer (T2) Center
Traffic Signal Operations Basics
Signal Operations Basics – Part 2
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

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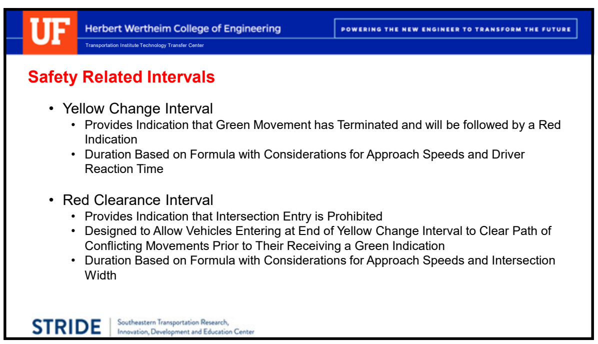

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Safety Related Intervals
• Yellow Change Interval
• Provides Indication that Green Movement has Terminated and will be followed by a Red Indication
• Duration Based on Formula with Considerations for Approach Speeds and Driver Reaction Time
• Red Clearance Interval
• Provides Indication that Intersection Entry is Prohibited
• Designed to Allow Vehicles Entering at End of Yellow Change Interval to Clear Path of Conflicting Movements Prior to Their Receiving a Green Indication
• Duration Based on Formula with Considerations for Approach Speeds and Intersection Width
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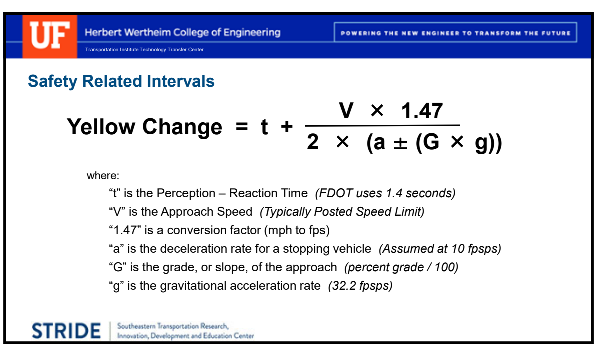
2



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Safety Related Intervals
$$\text{Yellow Change} = t + \frac{V \times 1.47}{2 \times (a \pm (G \times g))}$$
where:
"t" is the Perception – Reaction Time *(FDOT uses 1.4 seconds)*
"V" is the Approach Speed *(Typically Posted Speed Limit)*
"1.47" is a conversion factor (mph to fps)
"a" is the deceleration rate for a stopping vehicle *(Assumed at 10 fpsps)*
"G" is the grade, or slope, of the approach *(percent grade / 100)*
"g" is the gravitational acceleration rate *(32.2 fpsps)*
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Safety Related Intervals

$$\text{Red Clearance} = \frac{W + L}{1.47\,V}$$

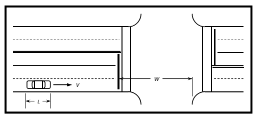
where:

"W" is the Width of the Intersection *(stop bar to far curb, in feet)*

W = Width of the intersection, in feet, measured from the near-side stop line to the far edge of the conflicting traffic lane along the actual vehicle path.

L = Length of vehicle (Use 20 feet)

V = Speed of approaching vehicles, in mph



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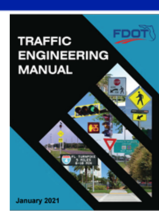
Safety Related Intervals



On Florida Roads:

Yellow Change Interval ≥ 3.4 seconds

Red Clearance Interval ≥ 2.0 seconds

https://www.fdot.gov/traffic/trafficservices/studies/tem/tem.shtm

5

Safety Related Intervals

- Walk Interval
  - Minimum is time for pedestrians to enter intersection
  - Typical value is 7 seconds; where school crossing guards present 10 seconds
  - Rest in Walk mode of operation

Walk ≥ 7 seconds

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Safety Related Intervals

- Pedestrian Change Interval (FLASHING DONT WALK)
  - Allows pedestrians to clear the intersection
  - Per the MUTCD, walking speed of 3.5 fps
  - A separate check is conducted based on location of the pushbutton

$$\textbf{Pedestrian Change} = \frac{L}{S_W}$$

where:
"L" is Length of Crosswalk
"S_W" is Assumed Walking Speed *(3.5 fps)*

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Operational Modes

- Pretimed Control
  - The signal assigns right-of-way at an intersection according to a predetermined schedule
  - The sequence of right-of-way (phases) and the length of the time interval for each signal indication in the cycle is fixed
  - No recognition is given to the current traffic demand on the intersection approaches

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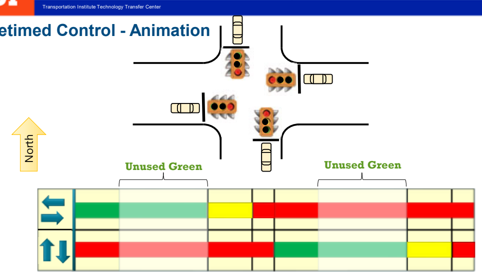
Pretimed Control - Animation



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Advantages of Pretimed Control

- Simplicity of equipment provides relatively easy servicing and maintenance
- Can be coordinated to provide continuous flow of traffic at a given speed along a particular route, thus providing positive speed control
- Timing is easily adjusted in the field
- Under certain conditions can be programmed to handle peak conditions

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Disadvantages of Pretimed Control

- Does not recognize or accommodate short-term fluctuations in traffic
- Can cause excessive delay to vehicles and pedestrians during off-peak periods

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Traffic-Actuated Control

- Traffic-actuated control attempts to adjust green time continuously and, in some cases, the sequence of phasing
- These adjustments occur in accordance with real-time measures of traffic demand obtained from vehicle detectors placed on one or more of the approaches to the intersection

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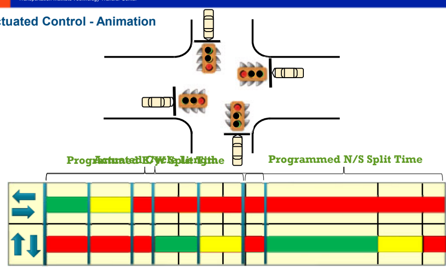
Traffic Actuated Control - Animation



13

Advantages of Actuated Control

- Usually reduce delay (if properly timed)
- Adaptable to short-term fluctuations in traffic flow
- Usually increase capacity (by continually reapportioning green time)
- Provide continuous operation under low volume conditions as an added safety feature, when pre-timed signals may be put on flashing operation to prevent excessive delay
- Especially effective at multiple phase intersections

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Disadvantages of Actuated Control

- The cost of an actuated installation is higher than the cost of a pre-timed installation
- Actuated controllers and detectors are much more complicated than pre-timed signal controllers, increasing maintenance and inspection skill requirements and costs
- Detectors are costly to install and require careful inspection and maintenance to ensure proper operations

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Movement Related Parameters: Actuated Control

- There must be a minimum green time so that a stopped vehicle that receives a green indication has enough time to get started and partially cross the intersection before the yellow signal appears
  - This time is termed the **Minimum Green** (or Minimum Initial) portion of the green interval
- Each following vehicle requires green time
  - This is called **Vehicle Extension**, Passage, or Gap
- There must be a maximum time that the green interval can be extended if opposing cars are waiting
  - This is called the **Maximum** or Extension Limit

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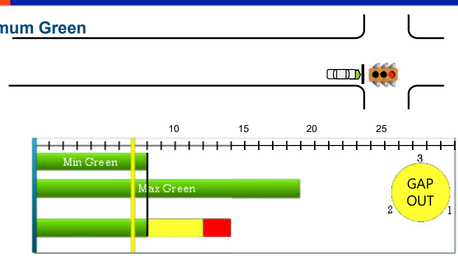
Minimum Green



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Minimum Green

- A stopped vehicle (at or between the detector and the stop bar) has enough time to get started and partially cross the intersection before the yellow signal appears.
  - Use “Greenshield’s Formula” for Queue Discharge -- **Min Green = 4 + 2n**

    …where n is the number of vehicles that can be stored between the detector and stop bar.
- Satisfy drivers’ expectancy – short green lights are not anticipated on higher speed roads.
- Common values:
  - Main street through movements – 15 to 20 seconds
  - Side street through movements – 10 to 12 seconds
  - Left turn movements – 5 to 7 seconds

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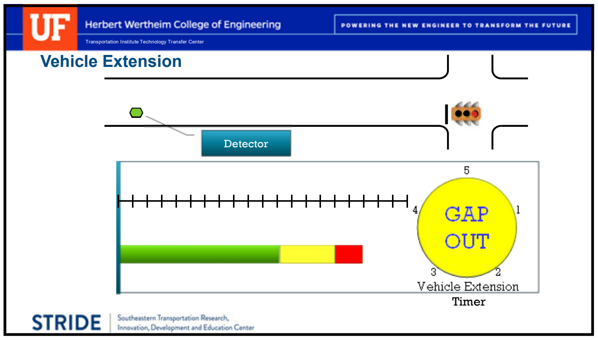

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Vehicle Extension

- Resets the Extension (Gap) timer with every new actuation.
- Extension Values:
  - Should be based on travel time from detector to stop bar.
  - Should also be based on maximum gaps between successive vehicles.
- Typical value: 3.0 seconds
- Special Detector Configuration needed for Higher Speed roadways.

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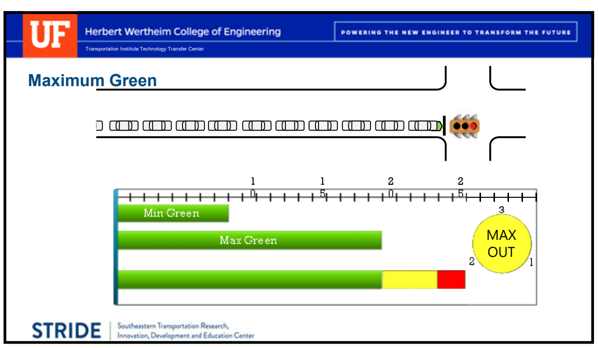

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Maximum Green

- The Maximum Green time starts with the receipt of a call on a conflicting movement.
- Values based on traffic demands
- Typical value: 30 to 50 seconds
- Can change Maximum Values (Max I, Max II, Max III) by schedule.

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Dynamic Maximums

- Allows the controller to automatically increase the Maximum value when multiple “Max Outs” occur.
- Ideal for remote intersection that receives short peaks in traffic.

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Phase Recalls

- Minimum Recall – Acts as if there has been a vehicle call received on an approach; at least the Minimum Green will be timed.
- Maximum Recall – Acts as if there is a constant vehicle call received on an approach; the Maximum Green will be timed.
- Pedestrian Recall – Acts as if there is a constant pedestrian call received at a crosswalk; the pedestrian intervals will be timed.
- “Soft Recall” – Serves to return to a resting phase in the absence of other vehicular or pedestrian calls.

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Detection Memory

- Memory On / Locking Detection – the controller “remembers” a vehicular detection call until it can be served by the controller
- Memory Off / Non-Locking Detection – the controller drops a vehicular detection call once the detection zone is no longer occupied by a vehicle

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Preemption and Priority

- Preemption
  - The transfer of normal operation of a traffic signal to a special control mode of operation
  - Designed to give the most important classes of vehicles the right of way at a signal
    - Railroad
    - Drawbridges
    - Emergency Vehicle
- Priority
  - An operational strategy applied to reduce the delay transit or freight vehicles experience at traffic signals

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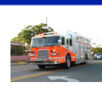
Preemption



- Emergency Vehicle Traffic Signal
  - Used to permit direct access to roadway from a building housing the emergency vehicle
  - Does not need to satisfy other traffic signal warrants
  - Similar to intersection signal operation

- Emergency Vehicle Preemption
  - Modification of intersection traffic signals to accommodate an approaching emergency vehicle

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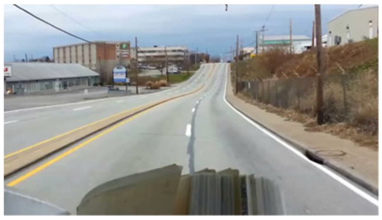
Preemption



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Preemption

- Emergency Vehicle Equipment
  - Preemption Request Transmitter
    - Optical Emitter (Coded Strobe Light)
    - Radio / Wireless Communications
    - Siren
  - GPS Receiver
  - Interface with Vehicle Systems (Transmission, turn signals, emergency lights)
- Intersection Equipment
  - Preemption Request Receiver
    - Optical Emitter (Coded Strobe Light)
    - Radio / Wireless Communications
    - Siren
  - Interface with Intersection Controller
    - Preempt Routine Inputs
    - Optional Confirmation Indicator

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Preemption

Typical Optical Preemption System

Photo Source: FHWA

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Preemption

- EVP Routines
  - Terminate existing conflicting movement
    - Can shorten Walk but not Pedestrian Clearance
  - Advance to selected movements
    - Opposing through movements if protected/permitted left turns
    - Adjacent through and left turn movements if protected left turns
  - Hold until emergency vehicle passes
  - Advance to exit phases

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Preemption

- Railroad Crossing Preemption
  - System which allows trains or light rail vehicles to travel near or through signalized intersections in a safe and timely manner.
  - Railroad Equipment
    - Railroad Grade Crossing signal system
  - Intersection Equipment
    - Interconnect with Railroad Equipment
    - Interface with Intersection Controller

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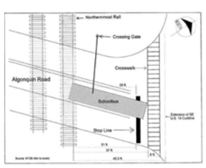
Preemption

- Railroad Preemption Case Study
  - Fox River Grove, Illinois – October 25, 1995
  - Metra Commuter Train versus School Bus
  - Seven on bus killed



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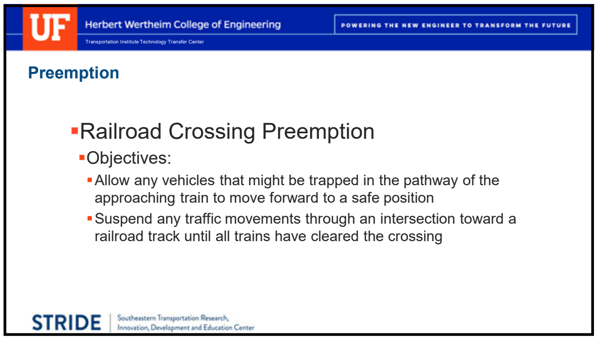
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Preemption
Railroad Crossing Preemption
Objectives:
Allow any vehicles that might be trapped in the pathway of the approaching train to move forward to a safe position
Suspend any traffic movements through an intersection toward a railroad track until all trains have cleared the crossing
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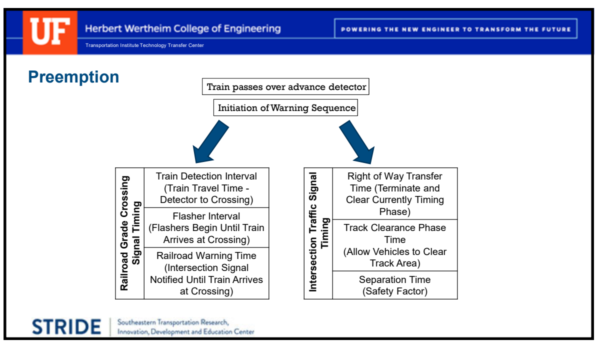
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Preemption
Train passes over advance detector
Initiation of Warning Sequence
Railroad Grade Crossing Signal Timing
Train Detection Interval (Train Travel Time - Detector to Crossing)
Flasher Interval (Flashers Begin Until Train Arrives at Crossing)
Railroad Warning Time (Intersection Signal Notified Until Train Arrives at Crossing)
Intersection Traffic Signal Timing
Right of Way Transfer Time (Terminate and Clear Currently Timing Phase)
Track Clearance Phase Time (Allow Vehicles to Clear Track Area)
Separation Time (Safety Factor)
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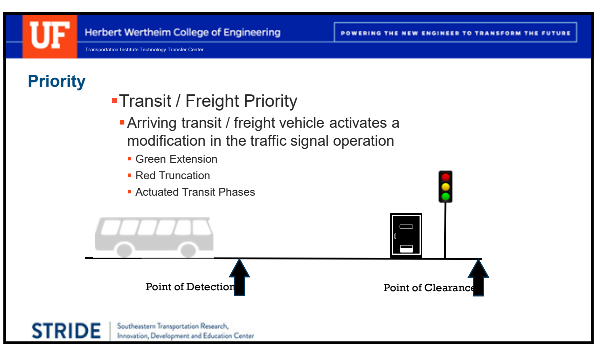
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Priority
Transit / Freight Priority
Arriving transit / freight vehicle activates a modification in the traffic signal operation
Green Extension
Red Truncation
Actuated Transit Phases
Point of Detection
Point of Clearance
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Priority

- Green Extension Strategies
  - Extends the green time for the movement when a transit / freight vehicle is approaching
  - Applies only when the signal is already green for the movement
  - Requires the detection of the approaching transit / freight vehicle
  - Generally will not affect coordination

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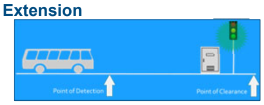
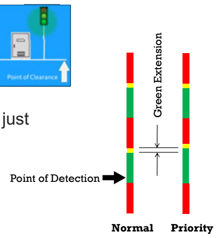
Green Extension



- Vehicle arrival projected for just after the green terminates
- Green is extended



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Priority

- Red Truncation Strategies
  - Advances the onset of green for the movement when a transit / freight vehicle is approaching
  - Applies only when the signal is red for the movement
  - Requires the detection of the approaching transit / freight vehicle
  - Generally will not affect coordination

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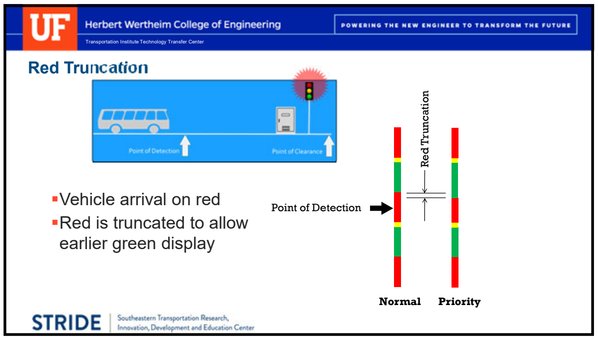
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Red Truncation
Vehicle arrival on red
Red is truncated to allow earlier green display
Point of Detection
Red Truncation
Normal
Priority
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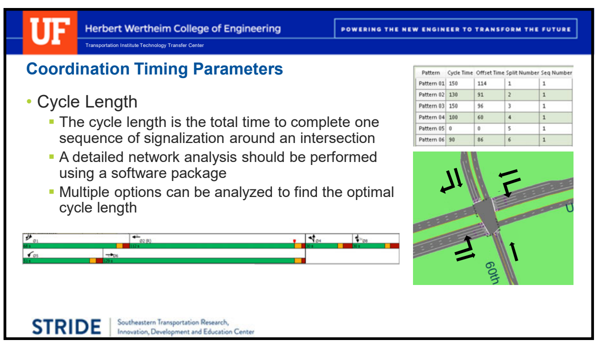
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Coordination Timing Parameters
Cycle Length
The cycle length is the total time to complete one sequence of signalization around an intersection
A detailed network analysis should be performed using a software package
Multiple options can be analyzed to find the optimal cycle length
60th
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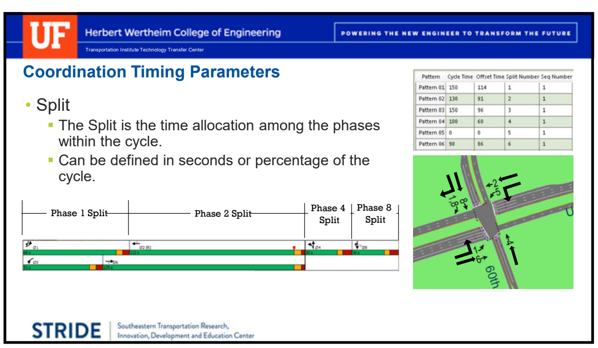
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Coordination Timing Parameters
Split
The Split is the time allocation among the phases within the cycle.
Can be defined in seconds or percentage of the cycle.
Phase 1 Split
Phase 2 Split
Phase 4 Split
Phase 8 Split
60th
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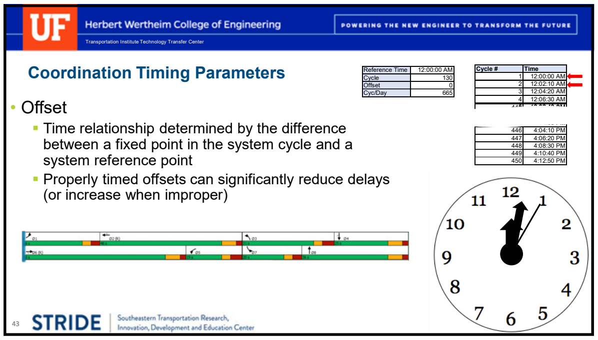
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Coordination Timing Parameters
Offset
Time relationship determined by the difference between a fixed point in the system cycle and a system reference point
Properly timed offsets can significantly reduce delays (or increase when improper)
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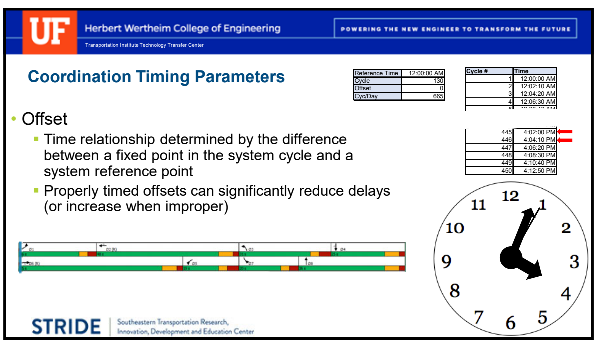
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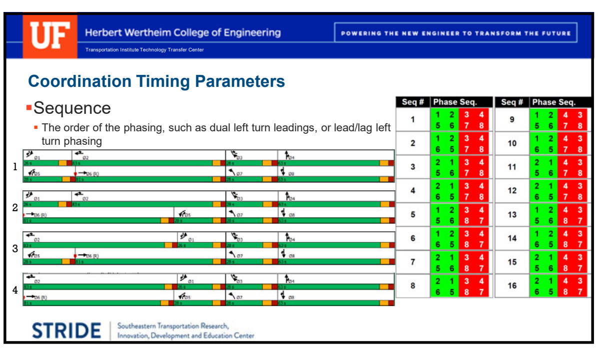
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Coordination Timing Parameters
Sequence
The order of the phasing, such as dual left turn leadings, or lead/lag left turn phasing
Seq #
Phase Seq.
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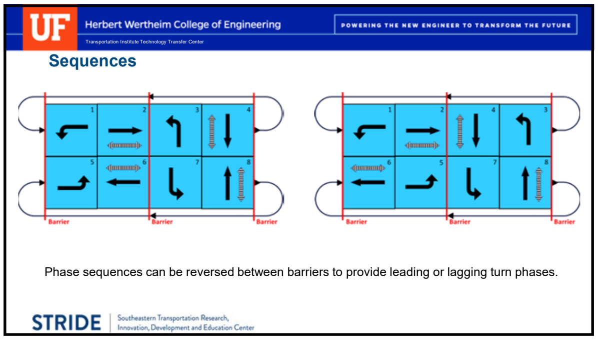
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Sequences
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Phase sequences can be reversed between barriers to provide leading or lagging turn phases.
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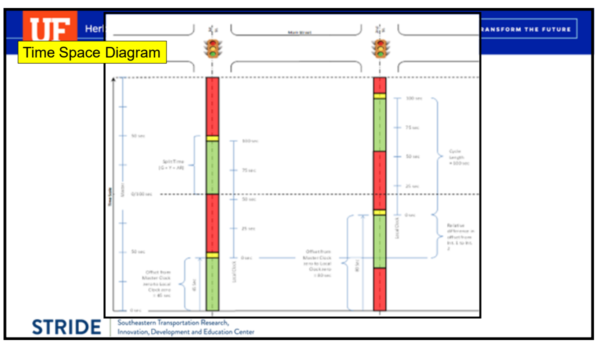
Time Space Diagram
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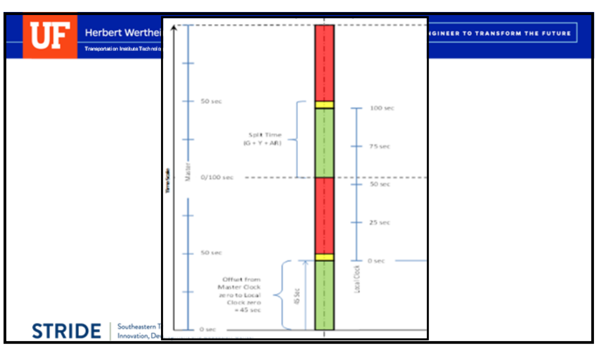
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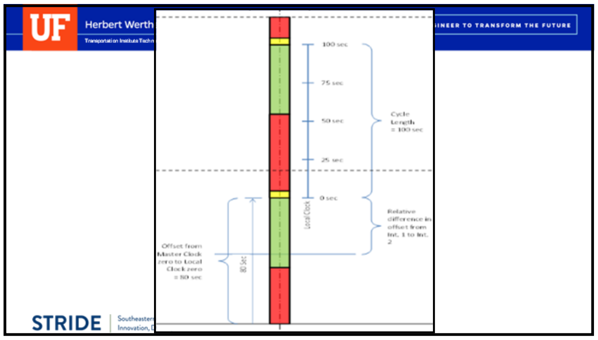
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100 sec
75 sec
50 sec
25 sec
0 sec
Cycle Length = 100 sec
Local Clock
50 sec

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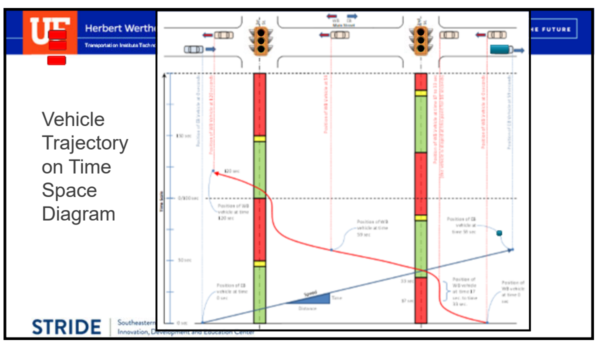
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Vehicle Trajectory on Time Space Diagram
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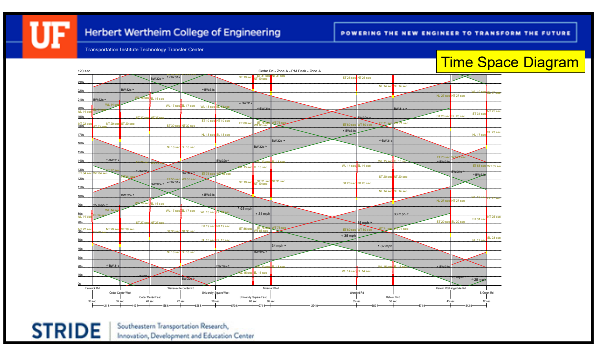
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Time Space Diagram
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Questions?
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Traffic Signal Basics
5 - Controller Programming
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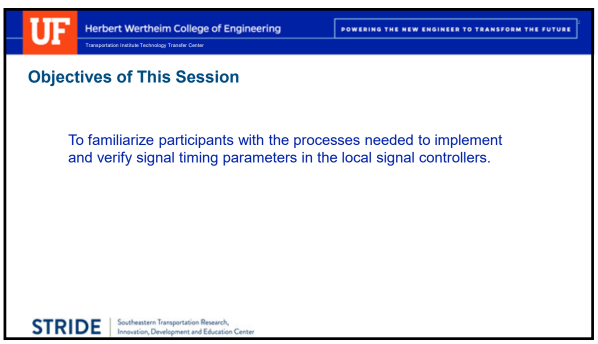
1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Objectives of This Session
To familiarize participants with the processes needed to implement and verify signal timing parameters in the local signal controllers.
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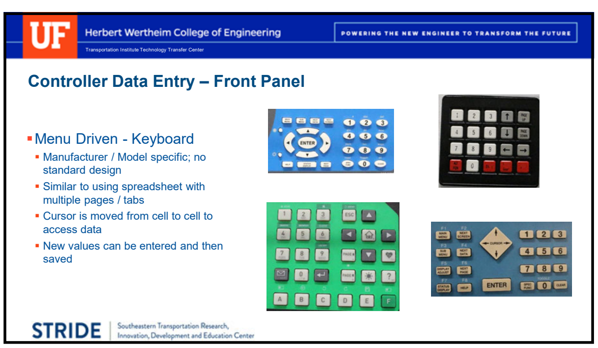
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Controller Data Entry – Front Panel
Menu Driven - Keyboard
Manufacturer / Model specific; no standard design
Similar to using spreadsheet with multiple pages / tabs
Cursor is moved from cell to cell to access data
New values can be entered and then saved
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Controller Data Entry – Front Panel

- Menu Driven - Display
  - Manufacturer / Model specific; no standard design
  - Similar to using spreadsheet
  - Cursor is moved from cell to cell to access data
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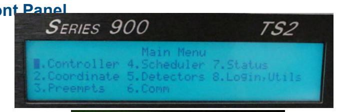

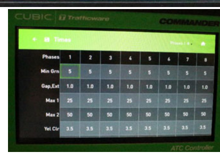

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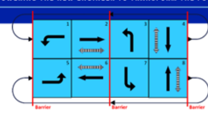
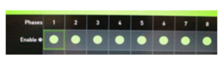
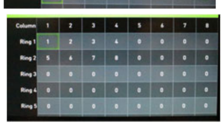
Basic Controller Timings

- Enabled Phases
  - Defines which phases on the controller will be active
- Sequence
  - Defines the ring structure and sequence of phasing







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Basic Controller Timings

- Minimum Green
  - The minimum green time for a phase with a single vehicle demand
- Extension (Passage, Gap)
  - The additional green time for each new actuation during green
- Maximums (Max 1, Max 2, Max 3)
  - The maximum green time on a phase with a conflicting call waiting

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Basic Controller Timings

- Yellow Change
  - The Yellow interval at the end of every phase
- Red Clearance
  - The Red interval at the end of every phase
- Walk
  - The Pedestrian Walk interval for a phase
- Pedestrian Clearance (Flashing Don't Walk)
  - The Flashing Don't Walk interval for a phase

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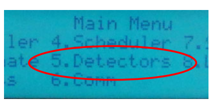
Vehicle Detector Settings

- Detector Channel to Phase Allocation
  - Defines the destination of each detector input; provides for multiple detectors with different functions to input to a single phase



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Vehicle Detector Settings

- Detector Delay
  - Defines the period between when a vehicle first enters a detection zone until the call is placed on the controller
  - Example applications:
    - Right turns on red
    - Left turn lanes on undivided roadways
    - Queue detection

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Vehicle Detector Settings

- Detector Switching
  - Modifies the destination of a detector call based on the current status of the controller
  - Example Application:
    - On an approach with a protected / permitted left turn display, the detector in the left turn lane would call and extend the left turn phase, but when the left turn phase terminates, the detector would extend the adjacent through movement

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Vehicle Detector Settings

- Detector Memory
  - Selects Detector Lock (Memory On) / Non-Lock (Memory Off) mode by phase
    - In Lock mode, when a vehicle enters and then leaves a detection zone while that phase is yellow or red, the controller remembers the call until the phase can be serviced
    - *Example applications:*
      - Small area detection zone in advance of the stop bar
      - Left turn lane at a protected only left turn phase

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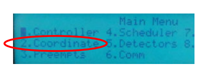
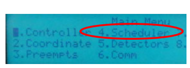
Coordination Settings

- By pattern settings
- Lots of data entry
- Significant process and layout variations from manufacturer to manufacturer and model to model
- Internal error checking desirable





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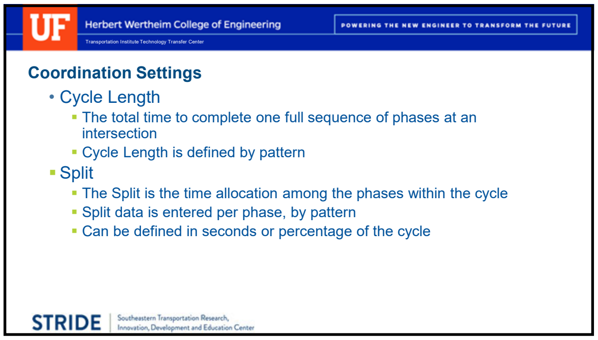
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Coordination Settings
• Cycle Length
▪ The total time to complete one full sequence of phases at an intersection
▪ Cycle Length is defined by pattern
▪ Split
▪ The Split is the time allocation among the phases within the cycle
▪ Split data is entered per phase, by pattern
▪ Can be defined in seconds or percentage of the cycle
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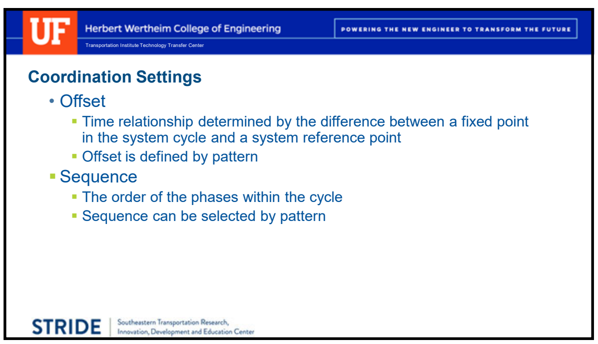
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Coordination Settings
• Offset
▪ Time relationship determined by the difference between a fixed point in the system cycle and a system reference point
▪ Offset is defined by pattern
▪ Sequence
▪ The order of the phases within the cycle
▪ Sequence can be selected by pattern
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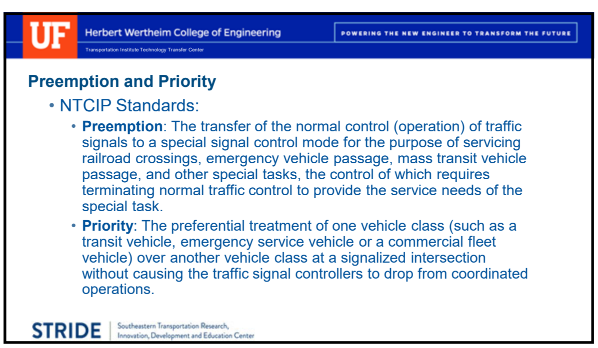
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Preemption and Priority
• NTCIP Standards:
• **Preemption**: The transfer of the normal control (operation) of traffic signals to a special signal control mode for the purpose of servicing railroad crossings, emergency vehicle passage, mass transit vehicle passage, and other special tasks, the control of which requires terminating normal traffic control to provide the service needs of the special task.
• **Priority**: The preferential treatment of one vehicle class (such as a transit vehicle, emergency service vehicle or a commercial fleet vehicle) over another vehicle class at a signalized intersection without causing the traffic signal controllers to drop from coordinated operations.
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Preemption

- NTCIP Standards:
  - When a preempt request is received, the controller terminates the active phase to service the preempt.
  - If coordination is in operation, the preemption call will override coordination.
  - The controller then moves to the preemption sequence programmed to service the programmed dwell phase(s) until the preempt input is released.

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Priority

- NTCIP Standards:
  - Priority may be accomplished by a number of methods including the beginning and end times of greens on identified phases, the phase sequence, inclusion of special phases, without interrupting the general timing relationship between specific green indications at adjacent intersections.

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Preemption / Priority Inputs to Controller

- Ten Preemption / Priority Inputs are defined
  - High-priority inputs PR1 - PR6 are reserved for rail and emergency vehicle preemption.
  - Low-priority inputs PR7 - PR10 may be assigned to low-priority preemption or transit priority.
  - Higher priority preempts always override lower priority preempt requests (PR1 overrides PR2).
  - PR1 and PR2 always override lower priority requests PR3 - PR6 and PR7 - PR10.

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Preemption / Priority Inputs to Controller

Preempt #	Preempt Input	Type (typical)
1	1 (steady low)	Rail
2	2 (steady low)	Rail
3	3 (steady low)	Rail or High Priority Emergency
4	4 (steady low)	Rail or High Priority Emergency
5	5 (steady low)	Rail or High Priority Emergency
6	6 (steady low)	Rail or High Priority Emergency
7	3 (oscillating)	Low Priority Emergency or Transit
8	4 (oscillating)	Low Priority Emergency or Transit
9	5 (oscillating)	Low Priority Emergency or Transit
10	6 (oscillating)	Low Priority Emergency or Transit

The controller recognizes high-priority as a steady ground true input and low-priority as an oscillating 6.25 Hz input on these inputs.

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Preemption / Priority Inputs to Controller

Transit Priority Routines may not be included in the basic controller operation; special firmware and hardware may be required.

Preempt #	Preempt Input	Type (typical)
1	1 (steady low)	Rail
2	2 (steady low)	Rail
3	3 (steady low)	Rail or High Priority Emergency
4	4 (steady low)	Rail or High Priority Emergency
5	5 (steady low)	Rail or High Priority Emergency
6	6 (steady low)	Rail or High Priority Emergency
7	3 (oscillating)	Low Priority Emergency or Transit
8	4 (oscillating)	Low Priority Emergency or Transit
9	5 (oscillating)	Low Priority Emergency or Transit
10	6 (oscillating)	Low Priority Emergency or Transit

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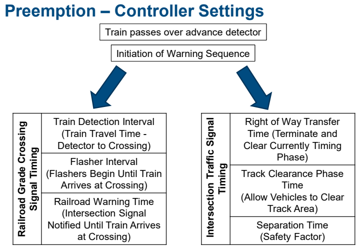
Railroad Preemption – Controller Settings



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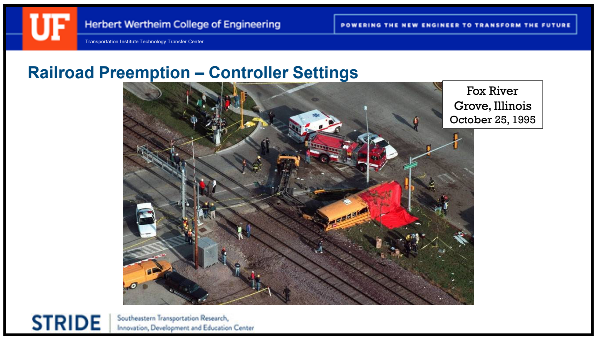
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Railroad Preemption – Controller Settings
Fox River Grove, Illinois October 25, 1995
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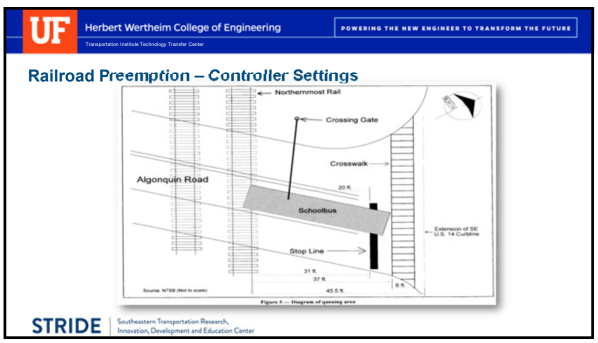
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Railroad Preemption – Controller Settings
Northernmost Rail
Crossing Gate
Crosswalk
Algonquin Road
20 ft
Schoolbus
Stop Line
31 ft
37 ft
45.5 ft
6 ft
Extension of SE U.S. 14 Curbline
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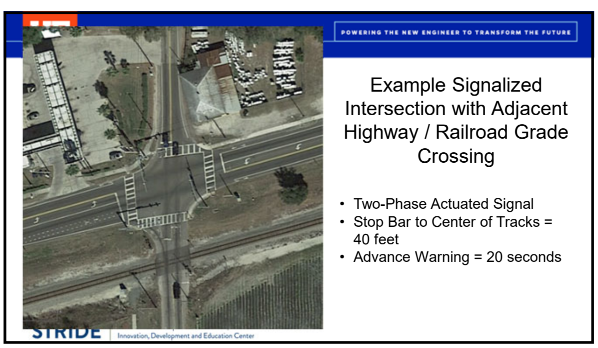
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Example Signalized Intersection with Adjacent Highway / Railroad Grade Crossing
• Two-Phase Actuated Signal
• Stop Bar to Center of Tracks = 40 feet
• Advance Warning = 20 seconds
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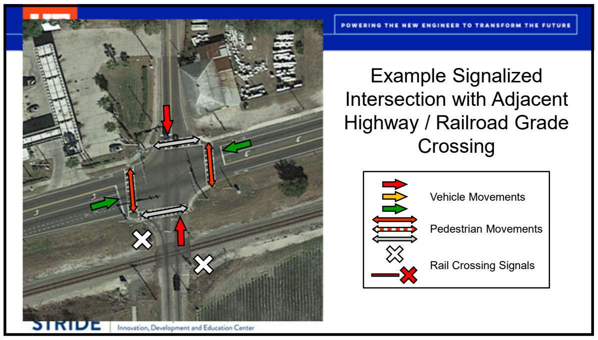
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Example Signalized Intersection with Adjacent Highway / Railroad Grade Crossing
Vehicle Movements
Pedestrian Movements
Rail Crossing Signals
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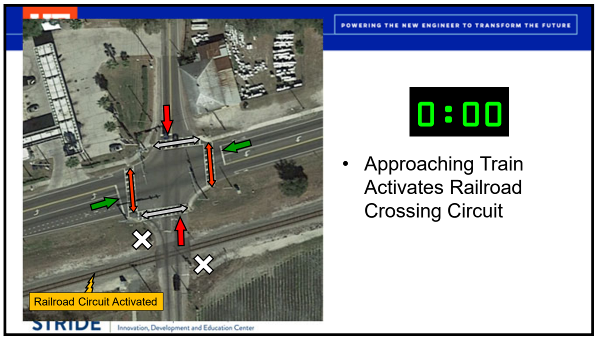
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Railroad Circuit Activated
0:00
• Approaching Train Activates Railroad Crossing Circuit
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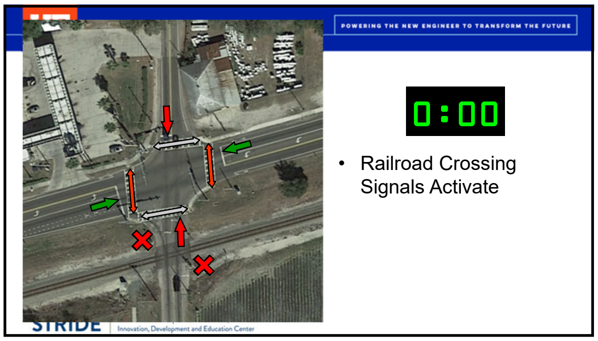
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
0:00
• Railroad Crossing Signals Activate
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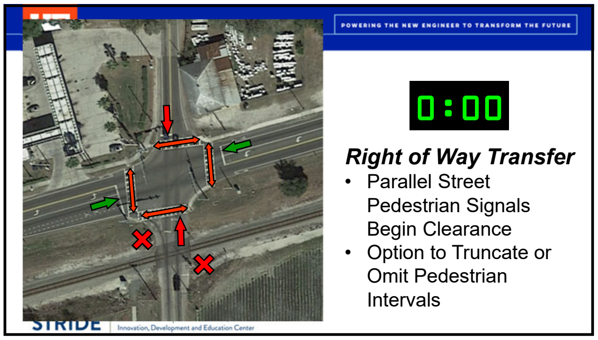
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0:00
Right of Way Transfer
• Parallel Street Pedestrian Signals Begin Clearance
• Option to Truncate or Omit Pedestrian Intervals
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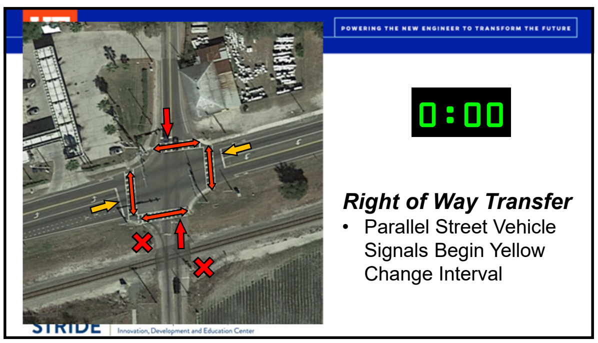
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0:00
Right of Way Transfer
• Parallel Street Vehicle Signals Begin Yellow Change Interval
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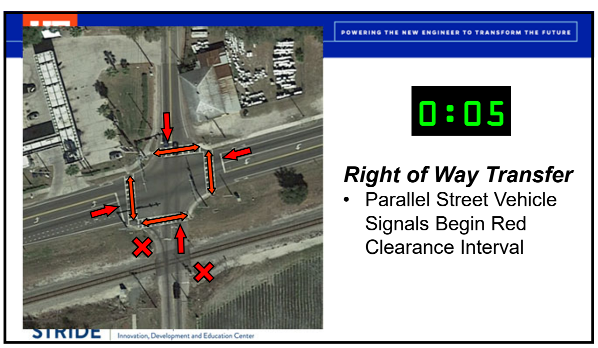
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0:05
Right of Way Transfer
• Parallel Street Vehicle Signals Begin Red Clearance Interval
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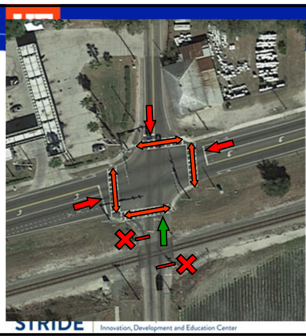

0:07

Track Clearance Phase

- Crossing Street Vehicle Signals Begin Track Clearance Green Interval
- Crossing Gates Begin to Lower

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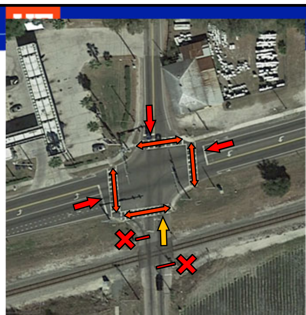

0:12

Track Clearance Phase

- Crossing Street Vehicle Signals Begin Track Clearance Yellow Change Interval
- Crossing Gates Continue to Lower

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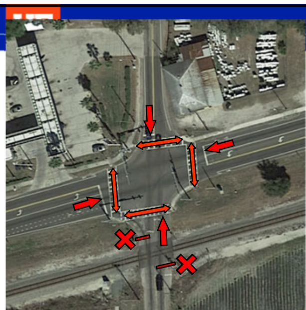

0:14

Track Clearance Phase

- Crossing Street Vehicle Signals Begin Track Clearance Red Clearance Interval
- Crossing Gates Continue to Lower

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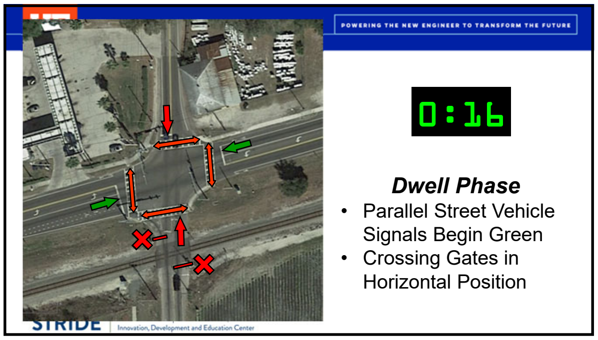
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0:16
Dwell Phase
• Parallel Street Vehicle Signals Begin Green
• Crossing Gates in Horizontal Position

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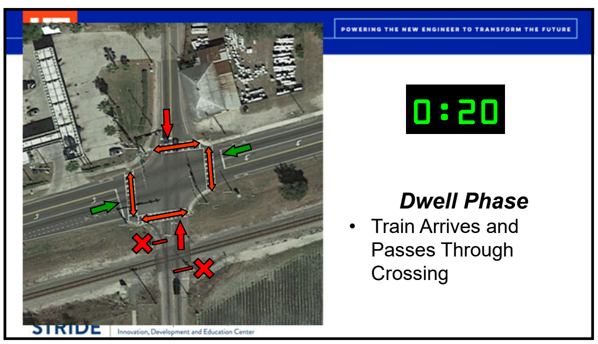
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
0:20
Dwell Phase
• Train Arrives and Passes Through Crossing

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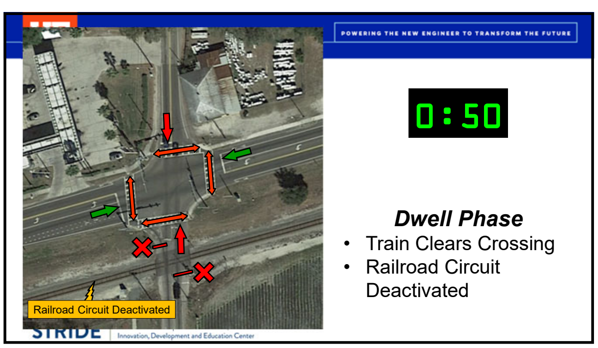
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
0:50
Dwell Phase
• Train Clears Crossing
• Railroad Circuit Deactivated
Railroad Circuit Deactivated

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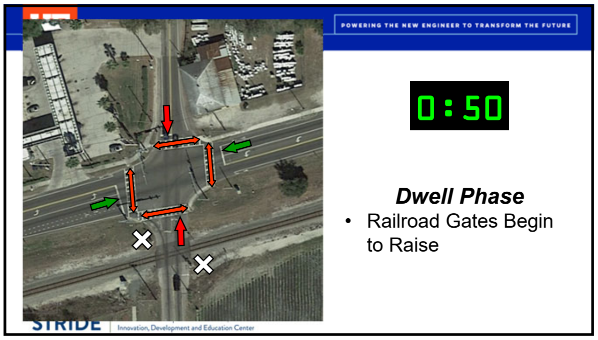
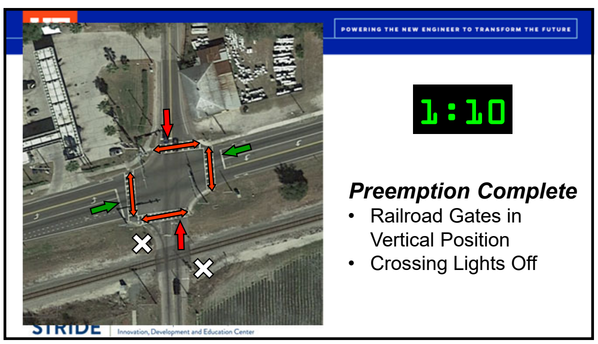

POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
0:50
Dwell Phase
• Railroad Gates Begin to Raise

37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1:10
Preemption Complete
• Railroad Gates in Vertical Position
• Crossing Lights Off

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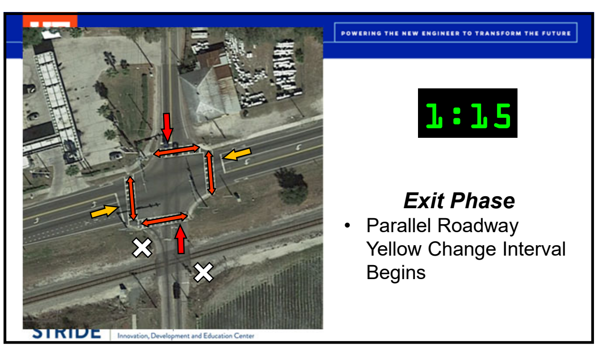
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1:15
Exit Phase
• Parallel Roadway Yellow Change Interval Begins

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1:20

Exit Phase

- Parallel Roadway Red Clearance Interval Begins

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1:22

Return to Normal Operation

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Railroad Preemption – Controller Settings

- Preemption Phases
  - Track Clearance Phases
  - Exit Phases
- Preempt Delay Time – time from receipt of preemption request from the railroad equipment until initiation of preemption routine
- Right of Way Transfer Phase:
  - Minimum Green Interval
  - Pedestrian Walk Interval
  - Pedestrian Clearance Interval
  - Yellow Change Interval
  - Red Clearance Interval

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Railroad Preemption – Controller Settings

- Track Clearance Phase
  - Green Interval
  - Yellow Change Interval
  - Red Clearance Interval
- Exit Phase
  - Minimum Green Time
  - Yellow Change Interval
  - Red Clearance Interval

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Emergency Vehicle Preemption – Controller Settings

- EVP Routines
  - Terminate existing conflicting movement
  - Advance to selected movements
    - Opposing through movements if protected/permitted left turns
    - Adjacent through and left turn movements if protected left turns
  - Hold until emergency vehicle passes
  - Advance to exit phases

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Emergency Vehicle Preemption – Controller Settings

- Preemption Phases
  - Preempt Phases
  - Exit Phases
- Preempt Delay Time – time from receipt of preemption request from the emergency vehicle preemption equipment until initiation of preemption routine
- Right of Way Transfer Phase:
  - Minimum Green Interval
  - Pedestrian Walk Interval
  - Pedestrian Clearance Interval
  - Yellow Change Interval
  - Red Clearance Interval

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Transit Priority – Controller Settings

- Time of Service Desired (TSD)
- Time of Expected Departure (TED)
- Maximum Reduction Time
- Maximum Extension Time
- Priority Strategy Table
- Priority Request Re-service Time

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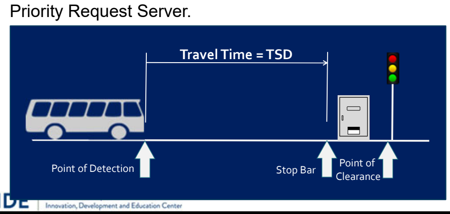
NTCIP Standards - Priority

- **Time of Service Desired (TSD)** - the arrival time of the transit vehicle at the stop bar after it is first detected by the Priority Request Server.



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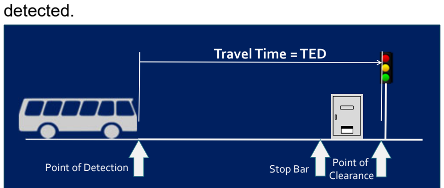
NTCIP Standards - Priority

- **Time of Expected Departure (TED)** - the time required for the transit vehicle to clear the intersection after it is first detected.



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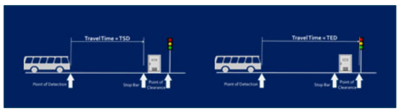
NTCIP Standards - Priority

- Separate TSD and TED countdown timers begin when the service request is received
- In many applications, TSD ≈ TED, as the Yellow Change and Red Clearance intervals carry the transit vehicle through the intersection



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NTCIP Standards - Priority

- **Maximum Reduction Time** - the maximum time that a phase may be reduced by, during a priority service request
  - Used in Red Truncation scenarios
  - Can be programmed per phase, for multiphase signalized intersections
- **Maximum Extension Time** - the maximum time that a phase may be extended by, during a priority service request.
  - Used in Extended Green scenarios.

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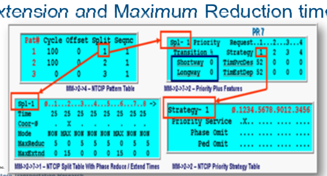
NTCIP Standards - Priority

- **Priority Strategy Table** - a user-defined table that assigns the Priority Service Phases and the remaining Phase's Maximum Extension and Maximum Reduction times.



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NTCIP Standards - Priority

- **Priority Request Re-service Time** – the minimum time that must expire following the completion of one priority strategy before a request for a subsequent priority strategy would be honored.

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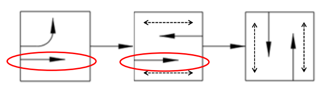
Overlap Programming

- Overlaps
  - An overlap is a vehicle movement that operates with more than one parent phase.
  - Overlap movements will display a green when the phases to which the overlap is assigned is green.



Overlap

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Overlap Programming

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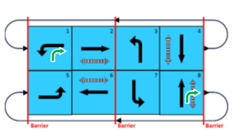

Example – Northbound Right Turn Overlap
- Parent Phases
  - Phase 1 (Westbound Left Turn)
  - Phase 8 (Northbound Through)
- But NOT when Phase 8 Pedestrian is Active

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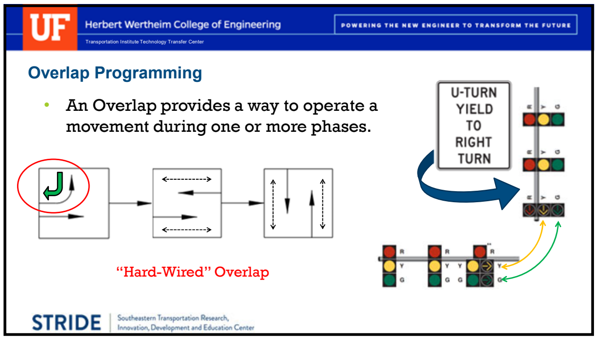
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Overlap Programming
An Overlap provides a way to operate a movement during one or more phases.
U-TURN YIELD TO RIGHT TURN
"Hard-Wired" Overlap
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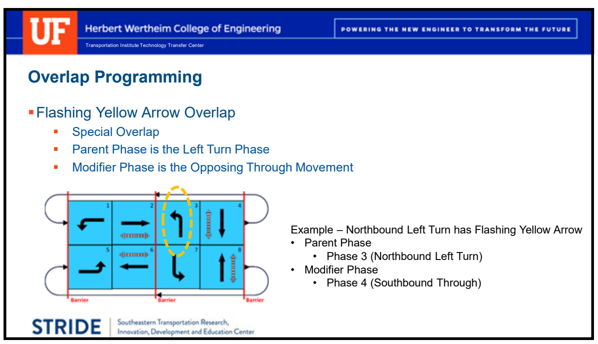
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Overlap Programming
Flashing Yellow Arrow Overlap
Special Overlap
Parent Phase is the Left Turn Phase
Modifier Phase is the Opposing Through Movement
Example – Northbound Left Turn has Flashing Yellow Arrow
Parent Phase
Phase 3 (Northbound Left Turn)
Modifier Phase
Phase 4 (Southbound Through)
Barrier
Barrier
Barrier
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Questions?
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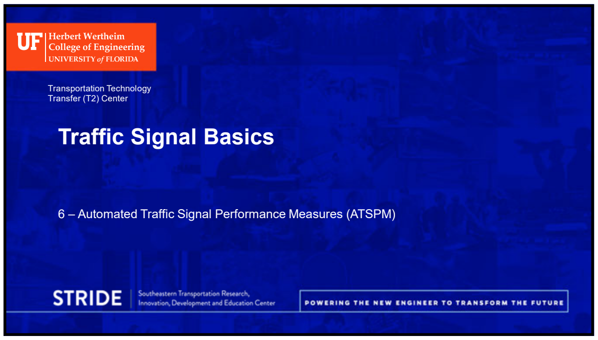
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Traffic Signal Basics
6 – Automated Traffic Signal Performance Measures (ATSPM)
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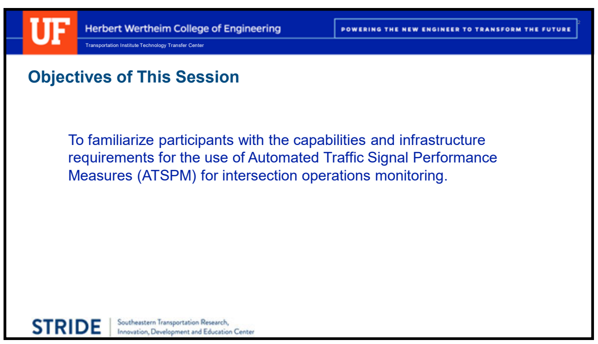
1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Objectives of This Session
To familiarize participants with the capabilities and infrastructure requirements for the use of Automated Traffic Signal Performance Measures (ATSPM) for intersection operations monitoring.
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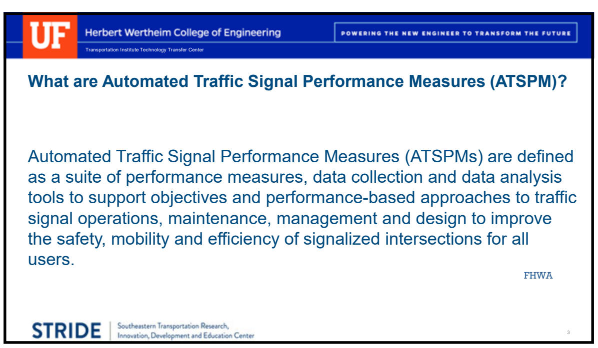
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What are Automated Traffic Signal Performance Measures (ATSPM)?
Automated Traffic Signal Performance Measures (ATSPMs) are defined as a suite of performance measures, data collection and data analysis tools to support objectives and performance-based approaches to traffic signal operations, maintenance, management and design to improve the safety, mobility and efficiency of signalized intersections for all users.
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What are Automated Traffic Signal Performance Measures (ATSPM)?

NCHRP Report 954:
Performance-Based Management of Traffic Signals

https://nap.nationalacademies.org/download/25875#

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What are Automated Traffic Signal Performance Measures (ATSPM)?

SIGNAL PERFORMANCE MEASURES report cycle-bycycle events that can provide automated information for all aspects of traffic signal planning, design, and implementation through better-informed, data-driven decisions as part of a performance-based management approach.

AUTOMATED TRAFFIC SIGNAL PERFORMANCE MEASURES (ATSPMs) are developed using high-resolution controller data allowing for continuous monitoring of traffic flow and traffic signal operations with a high degree of granularity because events are recorded up to 10 times every second.

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ATSPM Flow of Information

Source: NCHRP Report 954: Performance-Based Management of Traffic Signals

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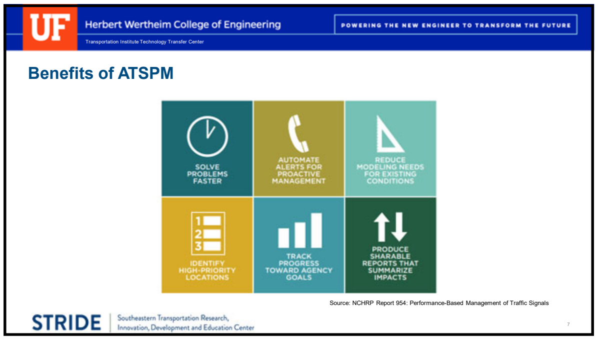

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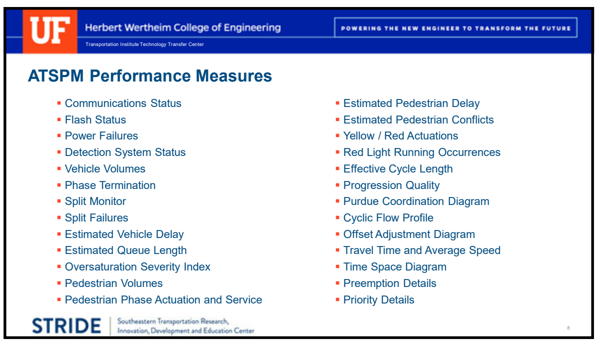

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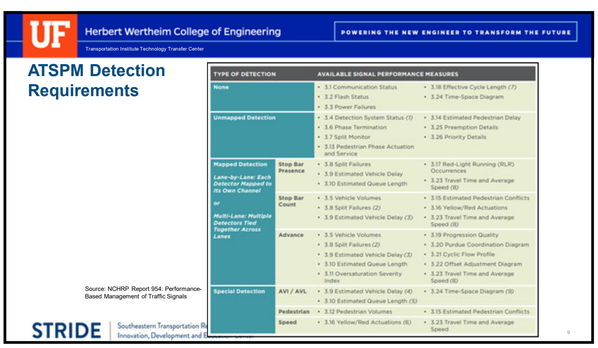
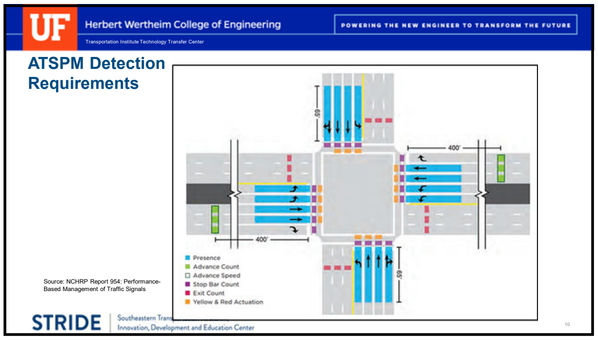


TYPE OF DETECTION		AVAILABLE SIGNAL PERFORMANCE MEASURES	
None		• 3.1 Communication Status • 3.2 Flash Status • 3.3 Power Failures	• 3.18 Effective Cycle Length *(7)* • 3.24 Time-Space Diagram
Unmapped Detection		• 3.4 Detection System Status *(1)* • 3.6 Phase Termination • 3.7 Split Monitor • 3.13 Pedestrian Phase Actuation and Service	• 3.14 Estimated Pedestrian Delay • 3.25 Preemption Details • 3.26 Priority Details
Mapped Detection *Lane-by-Lane: Each Detector Mapped to its Own Channel* *or* *Multi-Lane: Multiple Detectors Tied Together Across Lanes*	Stop Bar Presence	• 3.8 Split Failures • 3.9 Estimated Vehicle Delay • 3.10 Estimated Queue Length	• 3.17 Red-Light Running (RLR) Occurrences • 3.23 Travel Time and Average Speed *(8)*
	Stop Bar Count	• 3.5 Vehicle Volumes • 3.8 Split Failures *(2)* • 3.9 Estimated Vehicle Delay *(3)*	• 3.15 Estimated Pedestrian Conflicts • 3.16 Yellow/Red Actuations • 3.23 Travel Time and Average Speed *(8)*
	Advance	• 3.5 Vehicle Volumes • 3.8 Split Failures *(2)* • 3.9 Estimated Vehicle Delay *(3)* • 3.10 Estimated Queue Length • 3.11 Oversaturation Severity Index	• 3.19 Progression Quality • 3.20 Purdue Coordination Diagram • 3.21 Cyclic Flow Profile • 3.22 Offset Adjustment Diagram • 3.23 Travel Time and Average Speed *(8)*
Special Detection	AVI / AVL	• 3.9 Estimated Vehicle Delay *(4)* • 3.10 Estimated Queue Length *(5)*	• 3.24 Time-Space Diagram *(9)*
	Pedestrian	• 3.12 Pedestrian Volumes	• 3.15 Estimated Pedestrian Conflicts
	Speed	• 3.16 Yellow/Red Actuations *(6)*	• 3.23 Travel Time and Average Speed

9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ATSPM Detection Requirements
65'
400'
400'
65'
Presence
Advance Count
Advance Speed
Stop Bar Count
Exit Count
Yellow & Red Actuation
Source: NCHRP Report 954: Performance-Based Management of Traffic Signals
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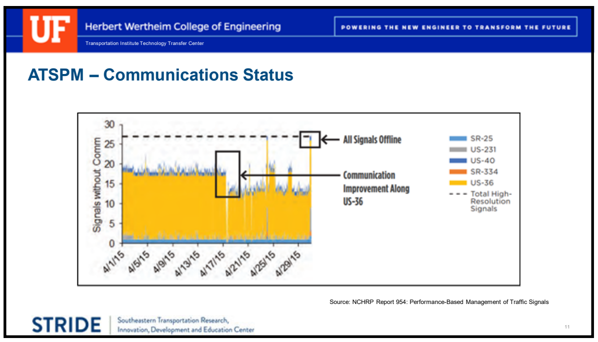
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ATSPM – Communications Status
Signals without Comm
30
25
20
15
10
5
0
4/1/15
4/5/15
4/9/15
4/13/15
4/17/15
4/21/15
4/25/15
4/29/15
All Signals Offline
Communication Improvement Along US-36
SR-25
US-231
US-40
SR-334
US-36
Total High-Resolution Signals
Source: NCHRP Report 954: Performance-Based Management of Traffic Signals
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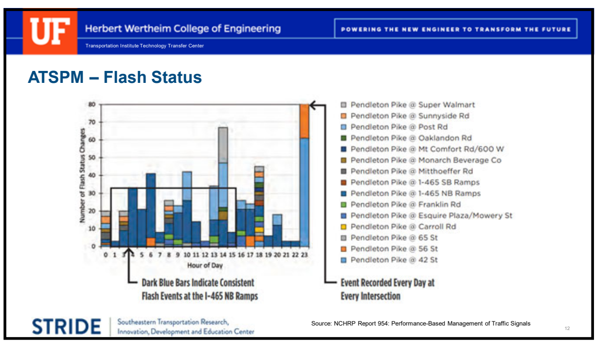
11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ATSPM – Flash Status
Number of Flash Status Changes
80
70
60
50
40
30
20
10
0
0 1 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of Day
Pendleton Pike @ Super Walmart
Pendleton Pike @ Sunnyside Rd
Pendleton Pike @ Post Rd
Pendleton Pike @ Oaklandon Rd
Pendleton Pike @ Mt Comfort Rd/600 W
Pendleton Pike @ Monarch Beverage Co
Pendleton Pike @ Mitthoeffer Rd
Pendleton Pike @ I-465 SB Ramps
Pendleton Pike @ I-465 NB Ramps
Pendleton Pike @ Franklin Rd
Pendleton Pike @ Esquire Plaza/Mowery St
Pendleton Pike @ Carroll Rd
Pendleton Pike @ 65 St
Pendleton Pike @ 56 St
Pendleton Pike @ 42 St
Dark Blue Bars Indicate Consistent Flash Events at the I-465 NB Ramps
Event Recorded Every Day at Every Intersection
Source: NCHRP Report 954: Performance-Based Management of Traffic Signals
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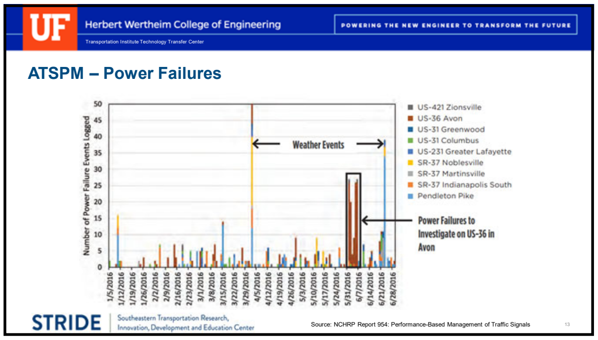
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ATSPM – Power Failures
Number of Power Failure Events Logged
Weather Events
US-421 Zionsville
US-36 Avon
US-31 Greenwood
US-31 Columbus
US-231 Greater Lafayette
SR-37 Noblesville
SR-37 Martinsville
SR-37 Indianapolis South
Pendleton Pike
Power Failures to Investigate on US-36 in Avon
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Source: NCHRP Report 954: Performance-Based Management of Traffic Signals

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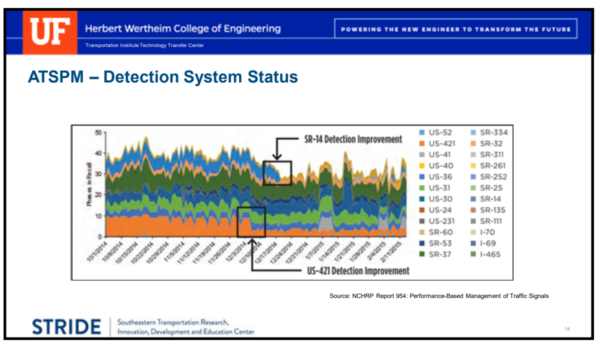
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ATSPM – Detection System Status
SR-14 Detection Improvement
US-421 Detection Improvement
US-52
US-421
US-41
US-40
US-36
US-31
US-30
US-24
US-231
SR-60
SR-53
SR-37
SR-334
SR-32
SR-311
SR-261
SR-252
SR-25
SR-14
SR-135
SR-111
I-70
I-69
I-465
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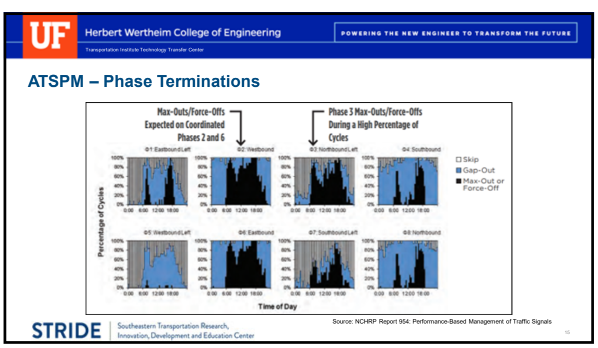
Source: NCHRP Report 954: Performance-Based Management of Traffic Signals

14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ATSPM – Phase Terminations
Max-Outs/Force-Offs Expected on Coordinated Phases 2 and 6
Phase 3 Max-Outs/Force-Offs During a High Percentage of Cycles
Skip
Gap-Out
Max-Out or Force-Off
Percentage of Cycles
Time of Day
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Source: NCHRP Report 954: Performance-Based Management of Traffic Signals

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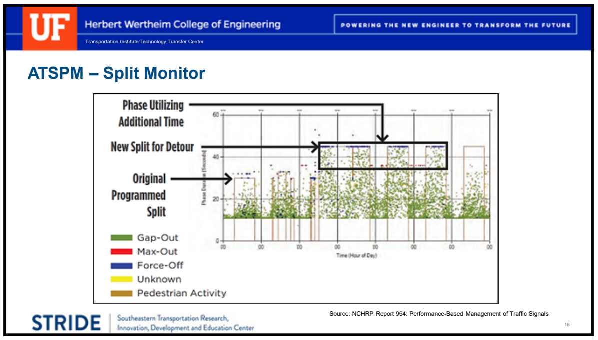
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ATSPM – Split Monitor
Phase Utilizing Additional Time
New Split for Detour
Original Programmed Split
Gap-Out
Max-Out
Force-Off
Unknown
Pedestrian Activity
Time (Hour of Day)
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Source: NCHRP Report 954: Performance-Based Management of Traffic Signals

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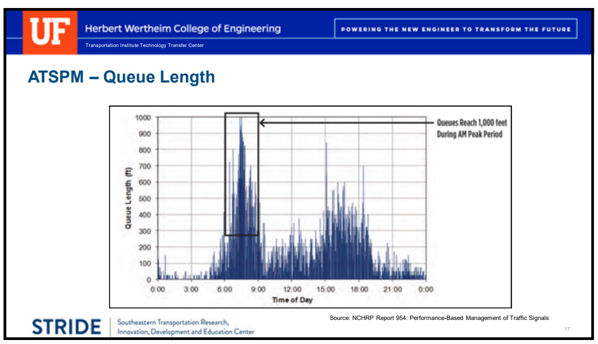
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ATSPM – Queue Length
Queues Reach 1,000 feet During AM Peak Period
Queue Length (ft)
Time of Day
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Source: NCHRP Report 954: Performance-Based Management of Traffic Signals

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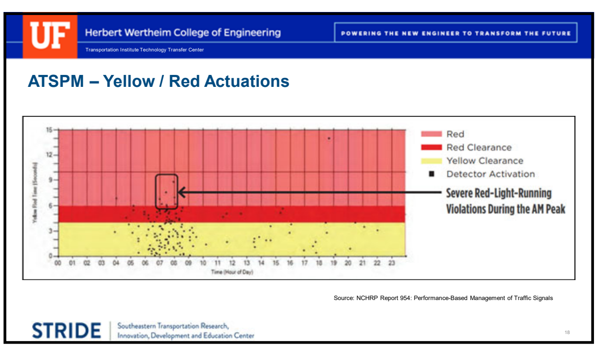
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ATSPM – Yellow / Red Actuations
Red
Red Clearance
Yellow Clearance
Detector Activation
Severe Red-Light-Running Violations During the AM Peak
Source: NCHRP Report 954: Performance-Based Management of Traffic Signals
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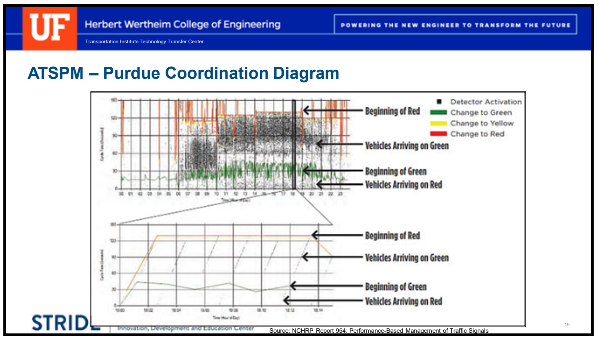
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ATSPM – Purdue Coordination Diagram
Beginning of Red
Vehicles Arriving on Green
Beginning of Green
Vehicles Arriving on Red
Detector Activation
Change to Green
Change to Yellow
Change to Red
Beginning of Red
Vehicles Arriving on Green
Beginning of Green
Vehicles Arriving on Red
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Source: NCHRP Report 954: Performance-Based Management of Traffic Signals
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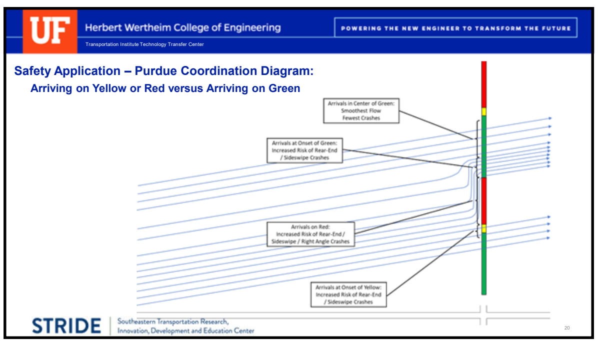
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Safety Application – Purdue Coordination Diagram:
Arriving on Yellow or Red versus Arriving on Green
Arrivals in Center of Green: Smoothest Flow Fewest Crashes
Arrivals at Onset of Green: Increased Risk of Rear-End / Sideswipe Crashes
Arrivals on Red: Increased Risk of Rear-End / Sideswipe / Right Angle Crashes
Arrivals at Onset of Yellow: Increased Risk of Rear-End / Sideswipe Crashes
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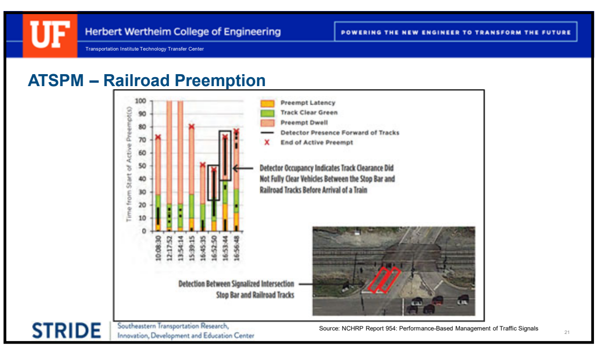
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ATSPM – Railroad Preemption
Time from Start of Active Preempt(s)
100
90
80
70
60
50
40
30
20
10
0
10:08:30
12:17:52
13:54:14
15:39:15
16:45:35
16:52:50
16:53:44
16:56:48
Preempt Latency
Track Clear Green
Preempt Dwell
Detector Presence Forward of Tracks
End of Active Preempt
Detector Occupancy Indicates Track Clearance Did Not Fully Clear Vehicles Between the Stop Bar and Railroad Tracks Before Arrival of a Train
Detection Between Signalized Intersection Stop Bar and Railroad Tracks
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Source: NCHRP Report 954: Performance-Based Management of Traffic Signals
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ATSPM – System Component Descriptions

SYSTEM COMPONENTS & OPTIONS		DESCRIPTION
Communication		Connection between field devices and central office required for automated data collection.
Detection		Equipment used to detect presence of roadway users required for many signal performance measures.
Data Logging	High-Resolution Data	Traffic signal controller with onboard data logger or external data collection unit.
	Other Data Source	Vendor-specific equipment.
Data Storage	Hardware	Servers for hosting and workstations/laptops for accessing applications, services, and data.
	Cloud	Server hosted by private-sector vendor with cloud access.
Software	Operating System Software	Required for basic operation of server hardware.
	Database Software	Required for storing and managing data.
	ATSPM System Software	Required to convert data stored in a database into signal performance measures.
	Central System Software	Some vendors have ATSPM capabilities through modules that can be added onto base software.

Source: NCHRP Report 954: Performance-Based Management of Traffic Signals

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ATSPM – Technical Requirements

- Signal Controller Capable of High-Resolution Data Collection
  - Advanced Transportation Controller (ATC)
  - Firmware that include ATSPM Capabilities
- Suitable Cabinet Facilities
  - NEMA TS2 Type 1 and Type 2
  - ATC 170 / 2070
- Detection
  - Significant Detection Requirements
  - Multiple Technologies Available

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ATSPM – Technical Requirements

- Software
  - FHWA/ Utah DOT Open-Source Software
  - Agency Developed Software
  - Vendor-Developed Software
- Hardware
  - Processing – Speed
  - Memory
    - Approximately one megabyte of data per intersection per day
  - Archiving

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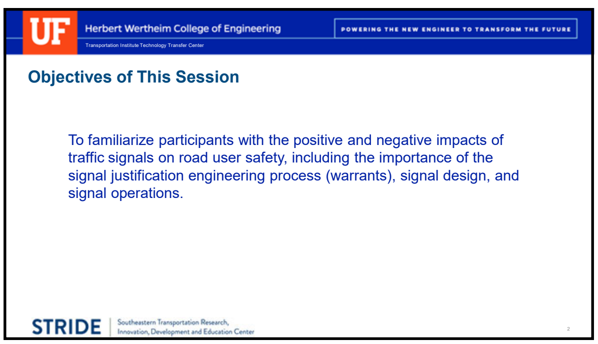
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Objectives of This Session
To familiarize participants with the positive and negative impacts of traffic signals on road user safety, including the importance of the signal justification engineering process (warrants), signal design, and signal operations.
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Do Signals Improve Safety?
A traffic signal that is properly designed and timed can:
Provide for the orderly and efficient movement of people
Effectively maximize the volume movements served at the intersection
Reduce the frequency and severity of certain types of crashes
Provide appropriate levels of accessibility for pedestrians and side street traffic
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Do Signals Improve Safety?

- Traffic control signals can have the following disadvantages:
  - Excessive delay
  - Excessive disobedience
  - Increased use of less adequate routes
  - Significant increases in the frequency of collisions (especially rear-end collisions)

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Do Signals Improve Safety?

Traffic signals do not prevent crashes:

- Some crash types can be reduced (frequency and severity)
- Some crash types will not change
- Some crash types will increase

Is there an existing crash problem?

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Do Signals Improve Safety?

Crash Types:

- Right Angle Crashes
- Pedestrian Crashes

Correctable

Right-Angle crash type.

NCHRP Report 491: Crash Experience Warrant for Traffic Signals

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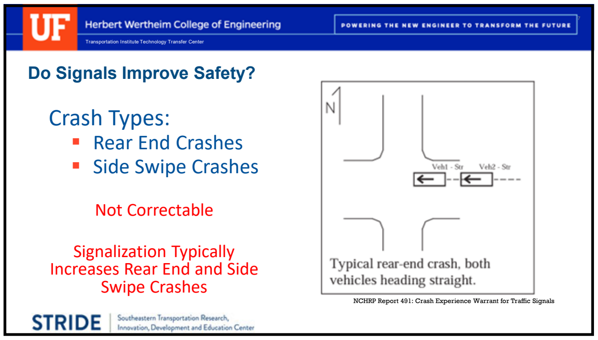
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Do Signals Improve Safety?
Crash Types:
Rear End Crashes
Side Swipe Crashes
Not Correctable
Signalization Typically Increases Rear End and Side Swipe Crashes
N
Veh1 - Str
Veh2 - Str
Typical rear-end crash, both vehicles heading straight.
NCHRP Report 491: Crash Experience Warrant for Traffic Signals
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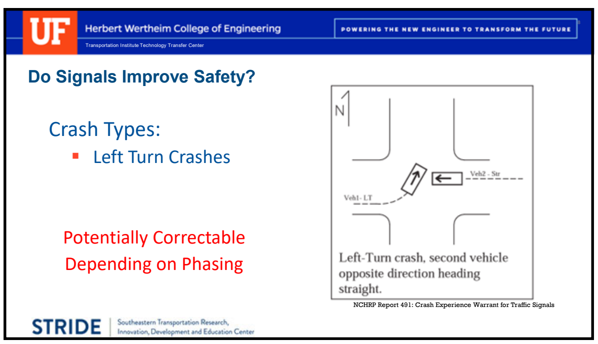
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Do Signals Improve Safety?
Crash Types:
Left Turn Crashes
Potentially Correctable Depending on Phasing
N
Veh1 - LT
Veh2 - Str
Left-Turn crash, second vehicle opposite direction heading straight.
NCHRP Report 491: Crash Experience Warrant for Traffic Signals
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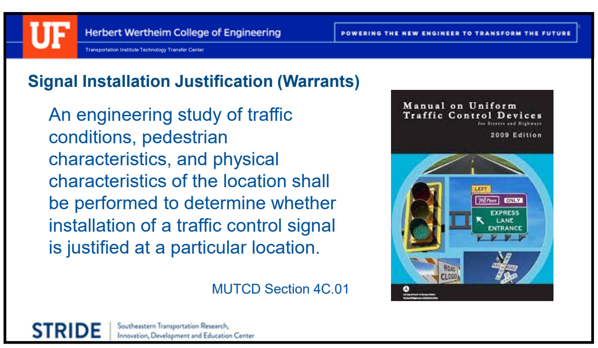
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Signal Installation Justification (Warrants)
An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.
MUTCD Section 4C.01
Manual on Uniform Traffic Control Devices
2009 Edition
EXPRESS LANE ENTRANCE
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Signal Installation Justification (Warrants)

Warrant	Name	Description
Warrant 1	Eight-Hour Vehicular Volume	This warrant is used when a large volume of intersecting traffic or where the traffic volume on the major street is so excessive that traffic on the minor street suffers undo delay. This warrant requires at least eight hours' worth of traffic volume data.
Warrant 2	Four-Hour Vehicular Volume	The Four-Hour Vehicular Volume signal warrant conditions are intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic control signal. This warrant requires at least four hours' worth of traffic volume data.
Warrant 3	Peak Hour	The Peak Hour signal warrant is intended for use at a location where traffic conditions are such that for a minimum of 1 hour of an average day, the minor-street traffic suffers undue delay when entering or crossing the major street. This warrant requires just one hour of data and is often used for land use or impact studies; however, Department approval is required if this is the only warrant that is used to justify the signal.
Warrant 4	Pedestrian Volume	The Pedestrian Volume signal warrant is intended for application where the traffic volume on a major street is so heavy that pedestrians experience excessive delay in crossing the major street.

Warrant	Name	Description
Warrant 5	School Crossing	The School Crossing signal warrant is intended for application where the fact that schoolchildren cross the major street is the principal reason to consider installing a traffic control signal. For the purposes of this warrant, the word "schoolchildren" includes elementary through high school students.
Warrant 6	Coordinated Signal System	Progressive movement in a Coordinated Signal System sometimes necessitates installing traffic control signals at intersections where they would not otherwise be needed in order to maintain proper platooning of vehicles.
Warrant 7	Crash Experience	The Crash Experience signal warrant conditions are intended for application where the severity and frequency of crashes are the principal reasons to consider installing a traffic control signal.
Warrant 8	Roadway Network	Installing a traffic control signal at some intersections might be justified to encourage concentration and organization of traffic flow on a Roadway Network.
Warrant 9	Intersection Near a Grade Crossing	The Intersection Near a Grade Crossing signal warrant is intended for use at a location where none of the conditions described in the other eight traffic signal warrants are met, but the proximity to the intersection of a grade crossing on an intersection approach controlled by a STOP or YIELD sign is the principal reason to consider installing a traffic control signal.

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Signal Installation Justification (Warrants)

Considerations in Warrant Analysis related to safety:

Will the expected decrease in the number of and severity of crashes exceed the expected increase in the number of and severity of crashes due to signalization?

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Crash Modification Factors (CMF)

- A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site.
- Developed in studies that compared crashes "before" implementation of a safety improvement against crashes "after" implementation.
- More information in Highway Safety Manual (HSM), FHWA 2010
- Database of CMFs in Crash Modification Factor Clearinghouse www.cmfclearinghouse.org

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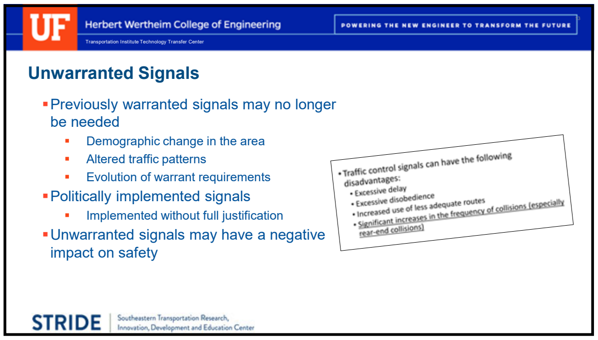

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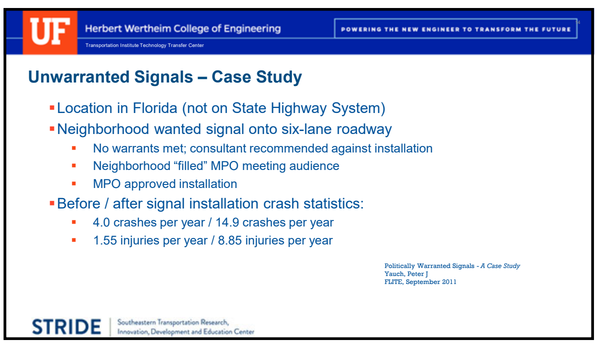

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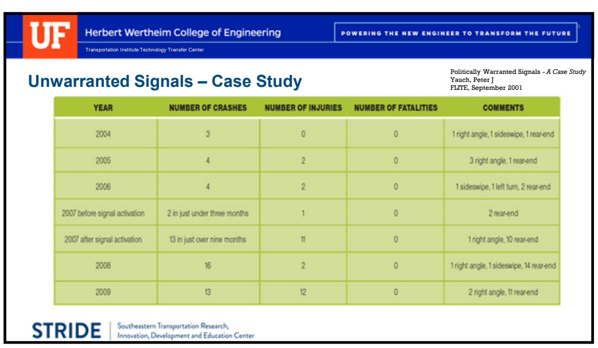

YEAR	NUMBER OF CRASHES	NUMBER OF INJURIES	NUMBER OF FATALITIES	COMMENTS
2004	3	0	0	1 right angle, 1 sideswipe, 1 rear-end
2005	4	2	0	3 right angle, 1 rear-end
2006	4	2	0	1 sideswipe, 1 left turn, 2 rear-end
2007 before signal activation	2 in just under three months	1	0	2 rear-end
2007 after signal activation	13 in just over nine months	11	0	1 right angle, 10 rear-end
2008	16	2	0	1 right angle, 1 sideswipe, 14 rear-end
2009	13	12	0	2 right angle, 11 rear-end

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Crash Modification Factor for Signals

- Install a warranted signal
  - Rural settings:
    - CMF – 0.56 for all crashes, all severities
    - CMF – 0.23 for angle crashes, all severities
    - CMF – 0.40 for left turn crashes, all severities
    - CMF – 1.58 for rear end crashes, all severities
  - Urban settings:
    - CMF – 0.61 for all crashes, all severities
    - CMF – 0.33 for angle crashes, all severities
    - CMF – 0.45 for left turn crashes, all severities
    - CMF – 1.38 for rear end crashes, all severities

Remove an unwarranted signal:
CMF – 0.76 for all crashes in an urban setting

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Intersection Components and Impacts on Safety

- Signal Displays
- Phasing
- Detection
- Preemption
- Operations during malfunctions

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Vehicular Signal Displays

MUTCD Requirements

- "The primary consideration in signal face placement, aiming, and adjustment shall be to optimize the visibility of signal indications to approaching traffic."
- "Road users approaching a signalized intersection or other signalized area, such as a midblock crosswalk, shall be given a clear and unmistakable indication of their right-of-way assignment."
- "The geometry of each intersection to be signalized, including vertical grades, horizontal curves, and obstructions as well as the lateral and vertical angles of sight toward a signal face, as determined by typical driver-eye position, shall be considered in determining the vertical, longitudinal, and lateral position of the signal face."

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Vehicular Signal Displays

MUTCD Requirements

- A minimum of two primary signal faces for the through movement (one per lane recommended)
- Separation between faces – minimum of 8 feet
- Left turn and right turn signals may be added
- Mounting Height
  - 15' – 19' over roadway
  - 8' – 19' over sidewalk
- Between 40 and 180 feet from stop bar
- Located within 40 degree "Cone of Vision" of center of approach
- Must be visible for a minimum defined distance

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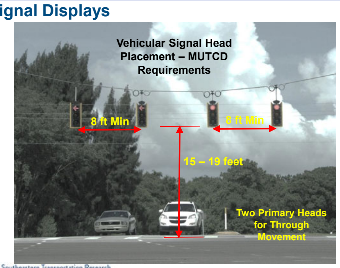
Vehicular Signal Displays



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Vehicular Signal Displays

Table 4D-1. Recommended Minimum Number of Primary Signal Faces for Through Traffic on Approaches with Posted, Statutory, or 85th-Percentile Speed of 45 mph or Higher

Number of Through Lanes on Approach	Total Number of Primary Through Signal Faces for Approach*	Minimum Number of Overhead-Mounted Primary Through Signal Faces for Approach
1	2	1
2	2	1
3	3	2**
4 or more	4 or more	3**

Table 4D-2. Minimum Sight Distance for Signal Visibility

85th-Percentile Speed	Minimum Sight Distance
20 mph	175 feet
25 mph	215 feet
30 mph	270 feet
35 mph	325 feet
40 mph	390 feet
45 mph	460 feet
50 mph	540 feet
55 mph	625 feet
60 mph	715 feet

Vehicular Signal Head Placement MUTCD Requirements

W3-3 Signal Ahead sign

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Vehicular Signal Displays

Backplates improve visibility against a bright sky or advertising lighting

Reflective borders improve visibility at night and when signals dark

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Crash Modification Factors related to Signal Visibility

- Replace 8-inch signals with 12-inch signals (Florida Standard)
  - CMF - 0.58 for angle crashes
- Add backplates
  - CMF – 0.87 for all crashes
- Add 3-inch yellow retroreflective strip on backplates
  - CMF - 0.85 for all crashes
- Convert signal from pedestal mounted to mast arm
  - CMF – 0.71 for all crashes

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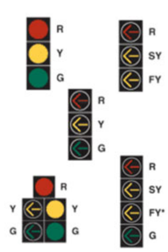
Left Turn Phases

- Permissive – turn left on circular green or flashing yellow arrow after yielding to oncoming traffic
- Protected – turn left on green left arrow
- Protected / Permissive – operation includes both a permissive left turn movement and a protected left turn movement



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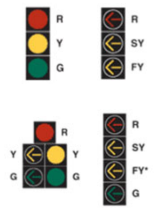
CMFs of Left Turn Displays

- For permissive left turns, change from circular green to flashing yellow arrow: CMF – 0.498 for left turn crashes, all severities
- For protected / permissive left turns, change from 5-section to 4-section flashing yellow arrow face: CMF – 0.838 for left turn crashes, all severities



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CMFs of Left Turn Phasing

- Change from permissive only to flashing yellow arrow protected/permissive left turn: CMF – 0.598 for left turn crashes
- Change from protected/permissive to protected only left turn: CMF – 0.58 for left turn crashes
- Change from protected only to protected/permissive left turn: CMF – 2.73 for left turn crashes

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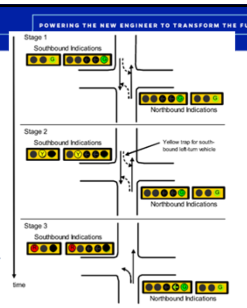
"Left Turn Trap" or "Yellow Trap"

- Safety situation inherent in some signal phasing sequences
- Occurs when a lagging left turn operation is used in one direction



Demonstration of Yellow Trap with Lead-Lag Phasing[1]

[1]Texas Department of Transportation. 2009. *Traffic Signal Operations Handbook*

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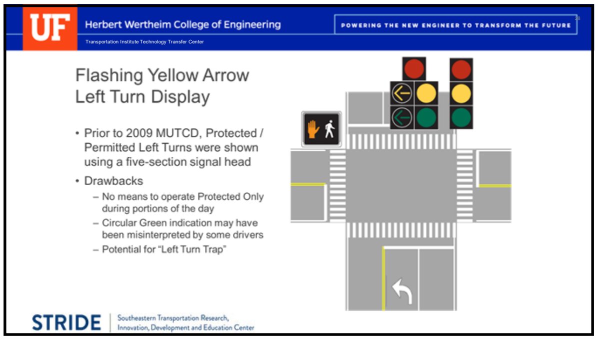
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Flashing Yellow Arrow
Left Turn Display
• Prior to 2009 MUTCD, Protected / Permitted Left Turns were shown using a five-section signal head
• Drawbacks
– No means to operate Protected Only during portions of the day
– Circular Green indication may have been misinterpreted by some drivers
– Potential for "Left Turn Trap"
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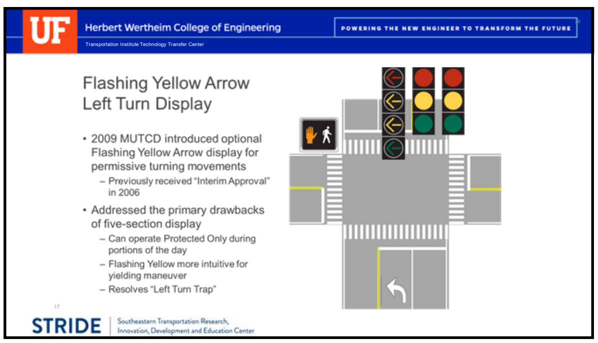
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Flashing Yellow Arrow
Left Turn Display
• 2009 MUTCD introduced optional Flashing Yellow Arrow display for permissive turning movements
– Previously received "Interim Approval" in 2006
• Addressed the primary drawbacks of five-section display
– Can operate Protected Only during portions of the day
– Flashing Yellow more intuitive for yielding maneuver
– Resolves "Left Turn Trap"
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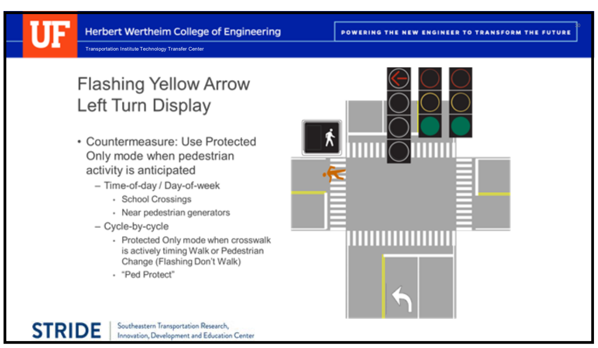
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Flashing Yellow Arrow
Left Turn Display
• Countermeasure: Use Protected Only mode when pedestrian activity is anticipated
– Time-of-day / Day-of-week
• School Crossings
• Near pedestrian generators
– Cycle-by-cycle
• Protected Only mode when crosswalk is actively timing Walk or Pedestrian Change (Flashing Don't Walk)
• "Ped Protect"
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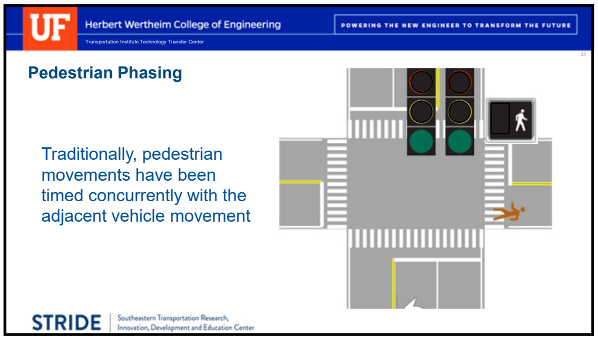
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Pedestrian Phasing
Traditionally, pedestrian movements have been timed concurrently with the adjacent vehicle movement
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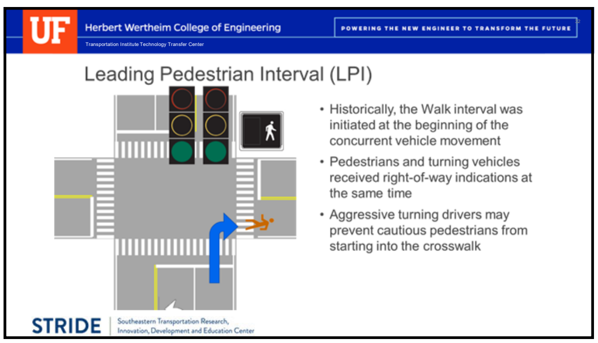
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Leading Pedestrian Interval (LPI)
• Historically, the Walk interval was initiated at the beginning of the concurrent vehicle movement
• Pedestrians and turning vehicles received right-of-way indications at the same time
• Aggressive turning drivers may prevent cautious pedestrians from starting into the crosswalk
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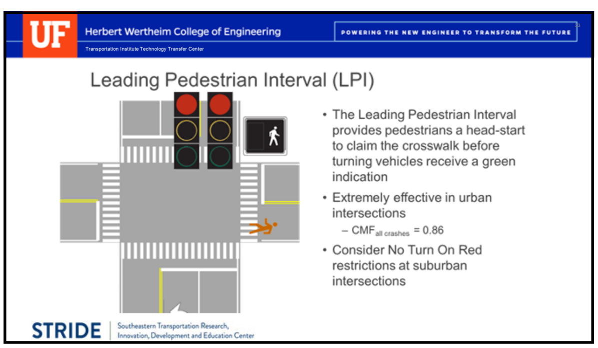
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Leading Pedestrian Interval (LPI)
• The Leading Pedestrian Interval provides pedestrians a head-start to claim the crosswalk before turning vehicles receive a green indication
• Extremely effective in urban intersections
– $CMF_{all\ crashes}$ = 0.86
• Consider No Turn On Red restrictions at suburban intersections
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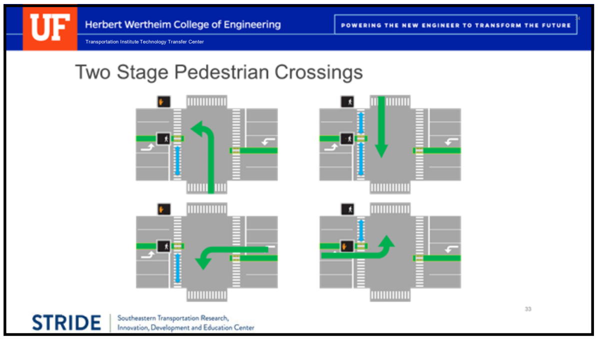

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Two Stage Pedestrian Crossings

Advantages:
- Means of minimizing delays to vehicular operations
- Opportunity to break long pedestrian crossings into shorter segments

Disadvantages:
- Pedestrians usually experience additional delay
- Pedestrians will wait in median
- Requires median of sufficient width

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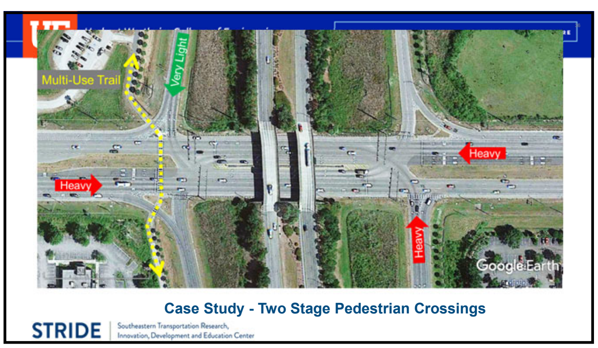

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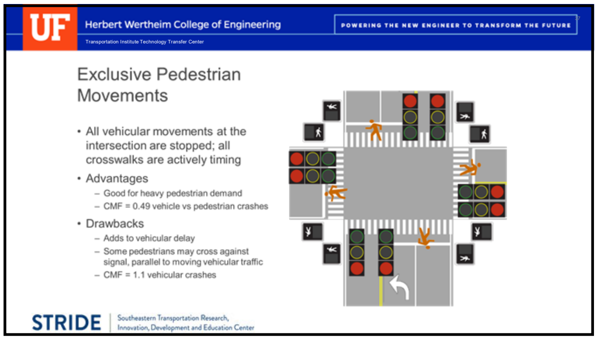
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Exclusive Pedestrian Movements
• All vehicular movements at the intersection are stopped; all crosswalks are actively timing
• Advantages
– Good for heavy pedestrian demand
– CMF = 0.49 vehicle vs pedestrian crashes
• Drawbacks
– Adds to vehicular delay
– Some pedestrians may cross against signal, parallel to moving vehicular traffic
– CMF = 1.1 vehicular crashes
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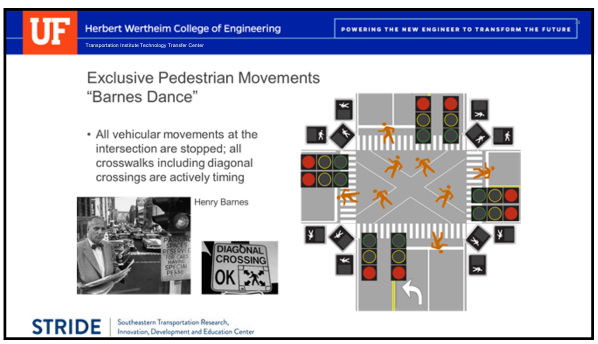
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Exclusive Pedestrian Movements
“Barnes Dance”
• All vehicular movements at the intersection are stopped; all crosswalks including diagonal crossings are actively timing
Henry Barnes
DIAGONAL CROSSING
OK
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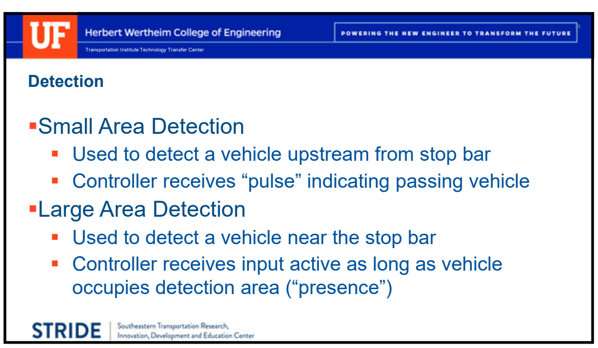
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Detection
▪Small Area Detection
▪ Used to detect a vehicle upstream from stop bar
▪ Controller receives “pulse” indicating passing vehicle
▪Large Area Detection
▪ Used to detect a vehicle near the stop bar
▪ Controller receives input active as long as vehicle occupies detection area (“presence”)
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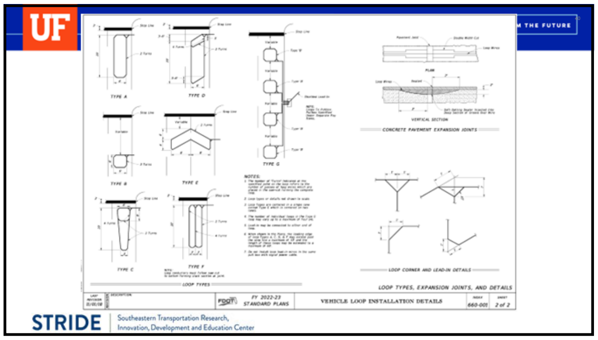

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Detection

- Detection design interrelated with:
  - Approach speeds
    - “Low speed” – under 35 mph
    - “High speed” – 35 mph or greater
  - Controller settings
    - Locking or Non-Locking Detection Mode
    - Minimum green
    - Extension time
  - Operational strategies

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Detection

- Small Area Detection
  - Low speed detection
    - Single detection zone
    - Minimum green timed to clear all vehicles stored between detection zone and stop bar
    - Extension time based on travel time from detection zone to stop bar
  - High speed detection
    - Multiple detection zones to minimize required extension times

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Detection

- Large Area Detection
  - Long detection area (40 – 80 feet)
  - Applications
    - Slow speed approaches (under 35 mph)
    - Left turn lanes
    - Right turn lanes with delay to screen right turn on red vehicles
  - Minimum green based on driver expectancy
  - Extension set low, as vehicle in detection zone extends the call

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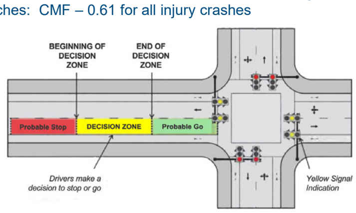
CMF for Detection

- Provide Advanced Dilemma Zone Detection for rural high-speed approaches: CMF – 0.61 for all injury crashes



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Pedestrian Detection

- Pedestrian Push Buttons
  - Unobstructed and adjacent to a level all-weather surface to provide access from a wheelchair;
  - Where there is an all-weather surface, a wheelchair accessible route from the pushbutton to the ramp;
  - Between the edge of the crosswalk line (extended) farthest from the center of the intersection and the side of a curb ramp (if present), but not greater than 5 feet from said crosswalk line;
  - Between 1.5 and 6 feet from the edge of the curb, shoulder, or pavement;
  - With the face of the pushbutton parallel to the crosswalk to be used; and
  - At a mounting height of approximately 3.5 feet, but no more than 4 feet, above the sidewalk

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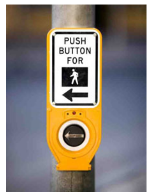
Pedestrian Detection

- Accessible Pedestrian Signals and Detectors
  - Accessible pedestrian signals and detectors provide information in non-visual formats (such as audible tones, speech messages, and/or vibrating surfaces)
  - Locator tone
  - Tactile arrow on pushbutton
  - Vibrotactile and audible Walk indications
    - Tactile arrow vibrates
    - Audible message includes tone or voice message



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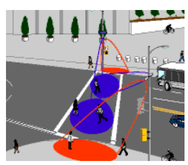
Pedestrian Detection

- Passive Detection
  - Passive detection devices register the presence of a pedestrian in a position indicative of a desire to cross, without requiring the pedestrian to push a button.
  - Some passive detection devices are capable of tracking the progress of a pedestrian as the pedestrian crosses the roadway for the purpose of extending or shortening the duration of certain pedestrian timing intervals.



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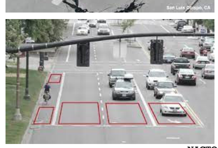
Bicycle Detection

- Standard vehicle detectors (loop, video, microwave, etc.)
- Specially designed vehicle detectors (bicycle loops, video and microwave with algorithms to identify bicycles)
- Potentially used for special phases and timing



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Local Signal Timing Considerations

- Minimum Green
  - Driver expectation
  - Time to clear vehicles stored between detector and stop bar
  - Pedestrian crossing time where pedestrian signals and detectors not present
  - Bicycle crossing time
- Passage / Extension
  - Time for vehicles to travel from detector into intersection
  - Critical for high-speed approaches
  - Bicycle timing considerations

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System Timing Considerations

- Cycle Lengths excessive for conditions
  - Motorist impatience
    - Avoiding stopping for signal changes (early red light running)
    - Aggressive starts
  - Pedestrian impatience
    - After about 30 seconds pedestrians will start considering crossing against the signal if traffic permits
  - Arterial speeding
    - Wide bands allow speeding

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Questions?

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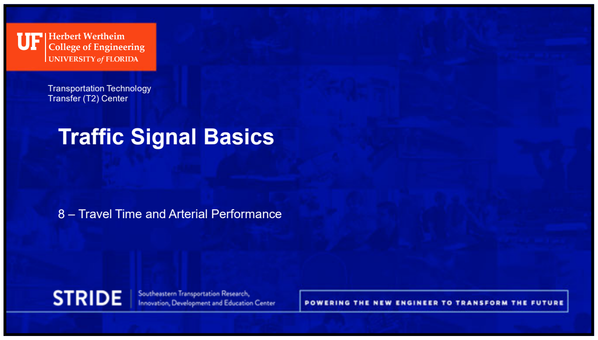
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Transportation Technology Transfer (T2) Center
Traffic Signal Basics
8 – Travel Time and Arterial Performance
STRIDE Southeastern Transportation Research, Innovation, Development and Education Center
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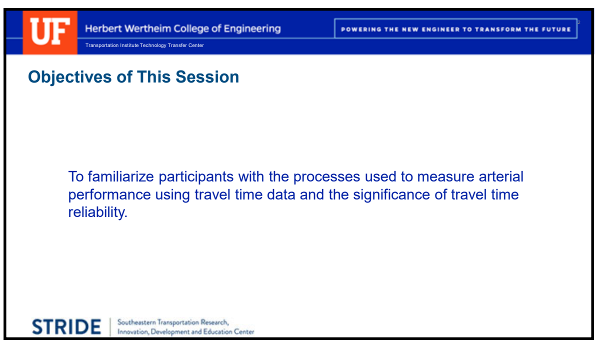
1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Objectives of This Session
To familiarize participants with the processes used to measure arterial performance using travel time data and the significance of travel time reliability.
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2


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How is your system operating?
Monitor the operation of the system
Identify any degradation in operations
Quality of Progression
Number of Stops
Travel Time / Average Speed
Travel Time Reliability
Delay
Phase Failures
Queuing
Vehicle Safety
Throughput
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Data Collection

- Travel Time Data
  - Floating Car Studies
    - Manual time recording
    - GPS-based tracking
  - Bluetooth-Based Travel Times
    - Bluetooth receivers along route
  - “Big Data” Probe Data (HERE, INRIX, etc.)

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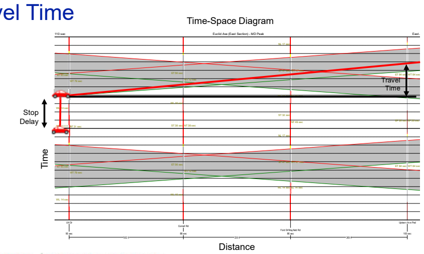
Travel Time



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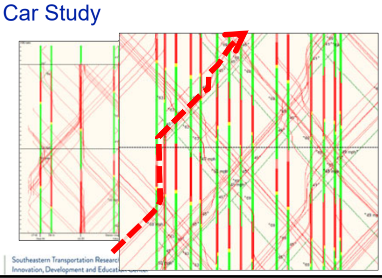
Floating Car Study



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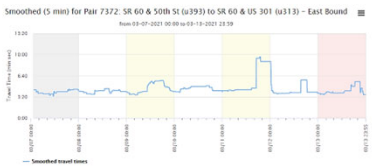
Travel Time Data – BlueTooth



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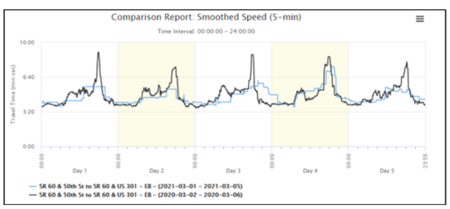
Travel Time Data – BlueTooth



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Travel Time Data – BlueTooth

		Pair/Route 1		Pair/Route 2		% Diff
Day	Time	Date	Travel Time	Date	Travel Time	1 -> 2
1	00:00	03-01-21	04:13	03-02-20	03:50	-9.2%
1	00:05	03-01-21	04:13	03-02-20	03:50	-9.2%
1	00:10	03-01-21	04:13	03-02-20	03:50	-9.2%
1	00:15	03-01-21	04:13	03-02-20	03:50	-9.2%
1	00:20	03-01-21	Not enough matches	03-02-20	03:50	
1	00:25	03-01-21	Not enough matches	03-02-20	03:48	
1	00:30	03-01-21	Not enough matches	03-02-20	03:51	
1	00:35	03-01-21	04:23	03-02-20	03:52	-11.7%
1	00:40	03-01-21	04:10	03-02-20	03:56	-5.6%
1	00:45	03-01-21	04:10	03-02-20	03:56	-5.6%
1	00:50	03-01-21	04:10	03-02-20	03:56	-5.6%
1	00:55	03-01-21	04:10	03-02-20	03:56	-5.6%
1	01:00	03-01-21	04:10	03-02-20	03:58	-4.7%
1	01:05	03-01-21	04:10	03-02-20	04:03	-2.7%
1	01:10	03-01-21	04:10	03-02-20	04:02	-2.9%
1	01:15	03-01-21	04:10	03-02-20	04:02	-2.9%
1	01:20	03-01-21	04:12	03-02-20	04:02	-3.9%

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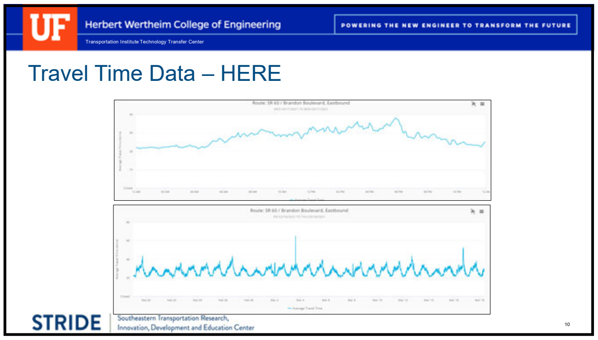
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Travel Time Data – HERE
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10

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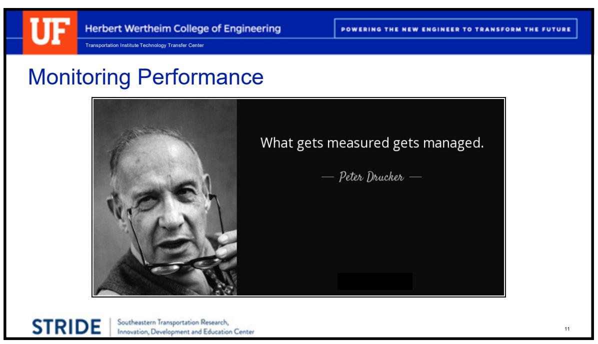
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Monitoring Performance
What gets measured gets managed.
— Peter Drucker —
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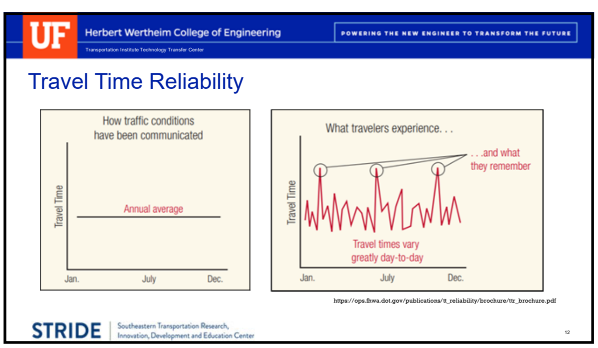
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Travel Time Reliability
How traffic conditions have been communicated
Travel Time
Annual average
Jan.
July
Dec.
What travelers experience. . .
. . .and what they remember
Travel Time
Travel times vary greatly day-to-day
Jan.
July
Dec.
https://ops.fhwa.dot.gov/publications/tt_reliability/brochure/ttr_brochure.pdf
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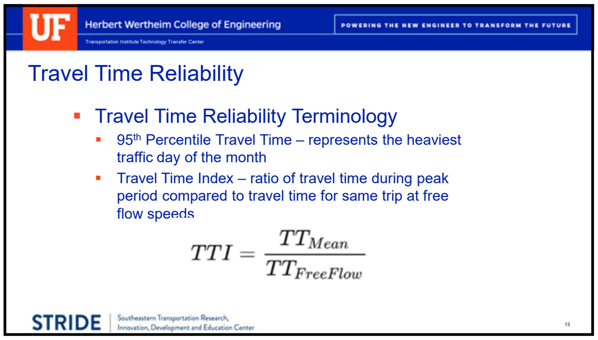
12

12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Travel Time Reliability
Travel Time Reliability Terminology
95th Percentile Travel Time – represents the heaviest traffic day of the month
Travel Time Index – ratio of travel time during peak period compared to travel time for same trip at free flow speeds
$TTI = \frac{TT_{Mean}}{TT_{FreeFlow}}$
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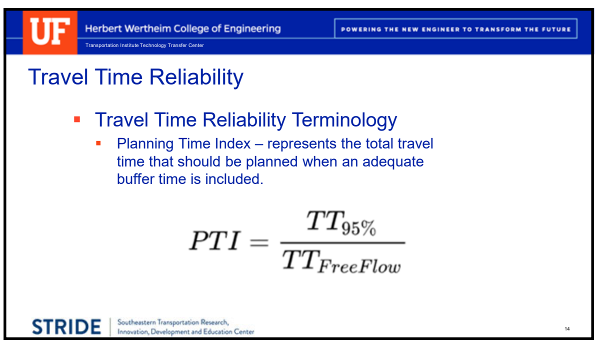
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Travel Time Reliability
Travel Time Reliability Terminology
Planning Time Index – represents the total travel time that should be planned when an adequate buffer time is included.
$PTI = \frac{TT_{95\%}}{TT_{FreeFlow}}$
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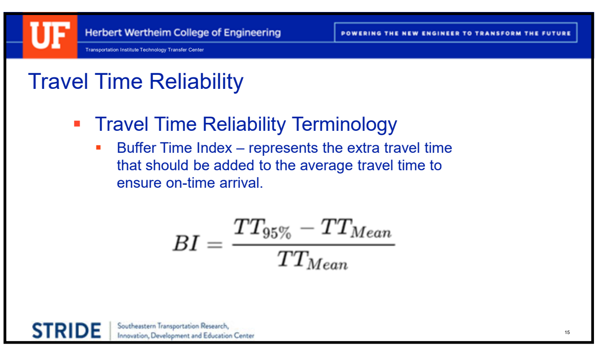
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Travel Time Reliability
Travel Time Reliability Terminology
Buffer Time Index – represents the extra travel time that should be added to the average travel time to ensure on-time arrival.
$BI = \frac{TT_{95\%} - TT_{Mean}}{TT_{Mean}}$
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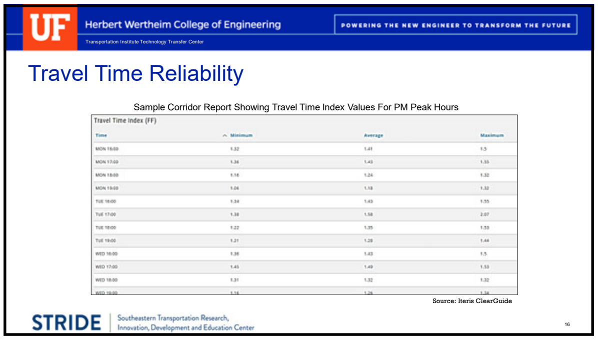
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Travel Time Reliability
Sample Corridor Report Showing Travel Time Index Values For PM Peak Hours
Travel Time Index (FF)
Time | Minimum | Average | Maximum
MON 16:00 | 1.32 | 1.41 | 1.5
MON 17:00 | 1.36 | 1.43 | 1.55
MON 18:00 | 1.16 | 1.24 | 1.32
MON 19:00 | 1.06 | 1.18 | 1.32
TUE 16:00 | 1.34 | 1.43 | 1.55
TUE 17:00 | 1.38 | 1.58 | 2.07
TUE 18:00 | 1.22 | 1.35 | 1.53
TUE 19:00 | 1.21 | 1.28 | 1.44
WED 16:00 | 1.38 | 1.43 | 1.5
WED 17:00 | 1.45 | 1.49 | 1.53
WED 18:00 | 1.31 | 1.32 | 1.32
Source: Iteris ClearGuide
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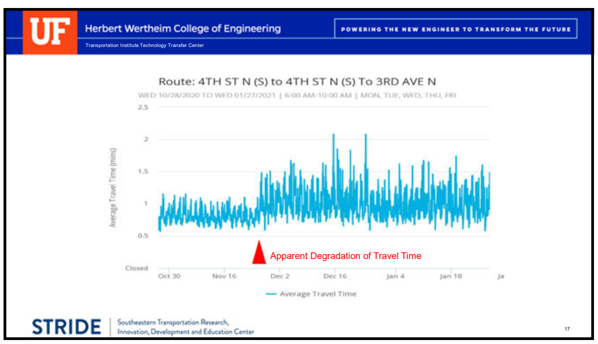
16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Route: 4TH ST N (S) to 4TH ST N (S) To 3RD AVE N
Average Travel Time (mins)
Apparent Degradation of Travel Time
Oct 30
Nov 16
Dec 2
Dec 16
Jan 4
Jan 18
Average Travel Time
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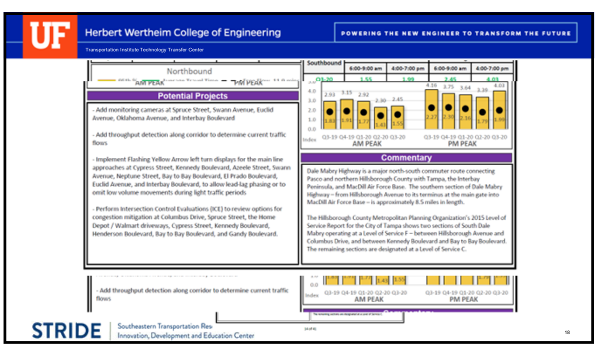
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Northbound
Southbound
Potential Projects
Commentary
AM PEAK
PM PEAK
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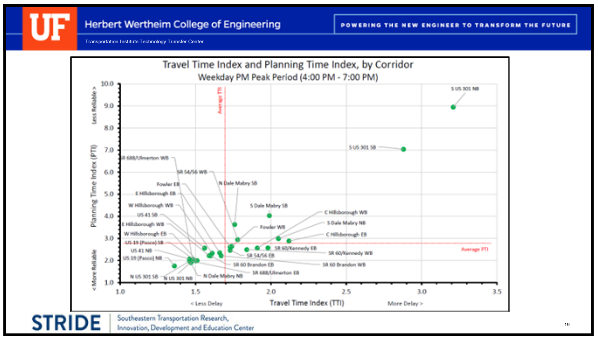
18

18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Travel Time Index and Planning Time Index, by Corridor
Weekday PM Peak Period (4:00 PM - 7:00 PM)
Planning Time Index (PTI)
Travel Time Index (TTI)
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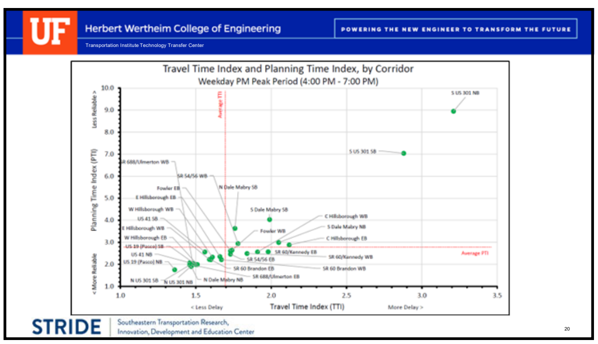
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Travel Time Index and Planning Time Index, by Corridor
Weekday PM Peak Period (4:00 PM - 7:00 PM)
Planning Time Index (PTI)
Travel Time Index (TTI)
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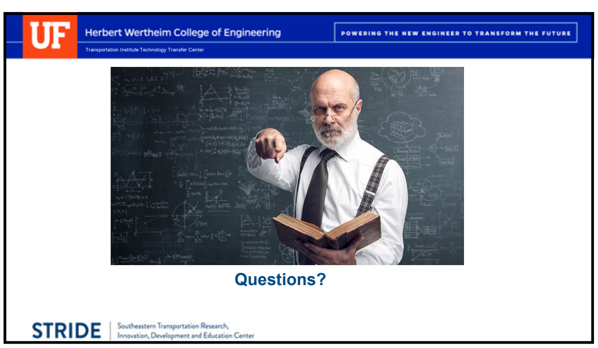
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Questions?
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Training Slides

Highway Capacity Analysis with Signalized Intersections


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McTrans Center – University of Florida
Highway Capacity Analysis with Signalized Intersections
Fabio Sasahara, PhD, PMP
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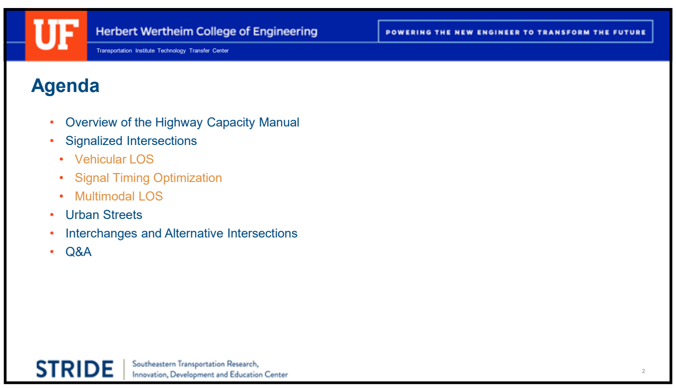
1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Agenda
Overview of the Highway Capacity Manual
Signalized Intersections
Vehicular LOS
Signal Timing Optimization
Multimodal LOS
Urban Streets
Interchanges and Alternative Intersections
Q&A
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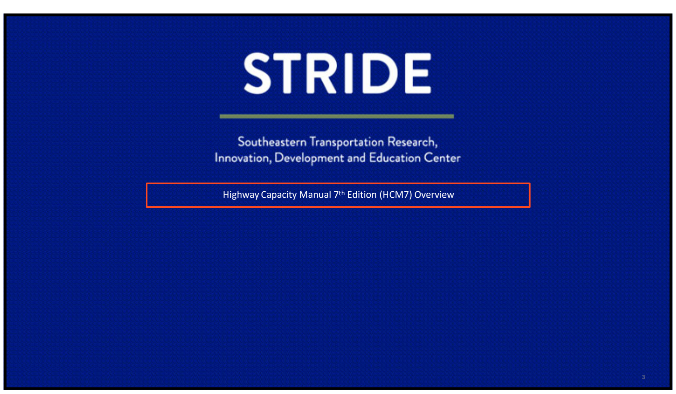
2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Highway Capacity Manual 7th Edition (HCM7) Overview

3

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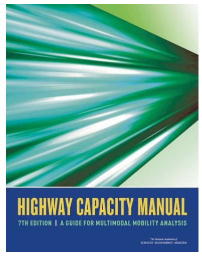
About the HCM

- Overseen by TRB committee on Highway Capacity and Quality of Service (hcqstrb.org)
- Most methods are developed via national level projects such as NCHRPs*.
- Four Volumes:
  - I. Concepts
  - II. Uninterrupted Flow
  - III. Interrupted Flow
  - IV. Applications Guide (Online only)



(*) NCHRP: National Cooperative Highway Research Program

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HCM Organization

Volume 2 – Uninterrupted Flow
- 10 - Freeway Facilities
- 11 - Freeway Facilities Reliability Analysis
- 12 - Basic Freeway and Multilane Highways
- 13 - Freeway Weaving Segments
- 14 - Freeway Merge and Diverge Segments
- 15 - Two-Lane Highways

Volume 3 – Interrupted Flow
- **16 - Urban Street Facilities**
- 17 - Urban Streets Reliability and ATDM
- **18 - Urban Street Segments**
- **19 - Signalized Intersections**
- 20 - Two-Way Stop-Control
- 21 - All-Way Stop-Control
- 22 - Roundabouts
- **23 - Ramp Terminals and Alternative Intersections**
- 24 - Off-Street Pedestrian and Bicycle Facilities

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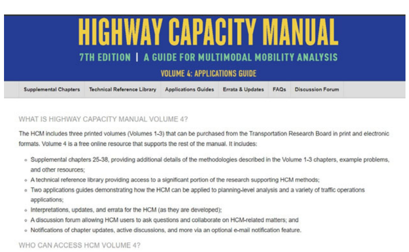
HCM Organization

Volume 4 – Applications
- Available at http://hcmvolume4.org
- Free to everyone
- Contains:
  - Supplemental Chapters
  - Technical Reference Library:
    - Research reports
    - Published papers
    - Useful references
- Application Guides


HIGHWAY CAPACITY MANUAL
7TH EDITION | A GUIDE FOR MULTIMODAL MOBILITY ANALYSIS
VOLUME 4: APPLICATIONS GUIDE

Supplemental Chapters | Technical Reference Library | Applications Guides | Errata & Updates | FAQs | Discussion Forum

WHAT IS HIGHWAY CAPACITY MANUAL VOLUME 4?

The HCM includes three printed volumes (Volumes 1-3) that can be purchased from the Transportation Research Board in print and electronic formats. Volume 4 is a free online resource that supports the rest of the manual. It includes:

- Supplemental chapters 25-38, providing additional details of the methodologies described in the Volume 1-3 chapters, example problems, and other resources;
- A technical reference library providing access to a significant portion of the research supporting HCM methods;
- Two applications guides demonstrating how the HCM can be applied to planning-level analysis and a variety of traffic operations applications;
- Interpretations, updates, and errata for the HCM (as they are developed);
- A discussion forum allowing HCM users to ask questions and collaborate on HCM-related matters; and
- Notifications of chapter updates, active discussions, and more via an optional e-mail notification feature.

WHO CAN ACCESS HCM VOLUME 4?

HCM Volume 4 is free to everyone, but registration is required. Sign up now to take advantage of these resources and join the discussion!

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What is HCS?

- Highway Capacity Software (HCS) is the faithful implementation of HCM methods.
- Developed in 1980s and kept updated based on the updates to the HCM.
  - McTrans Center is actively involved in Highway Capacity and Quality of Service Committee.
- Most users rely on HCS to fulfill requirements HCM applications.
- Around 15,000 users worldwide.

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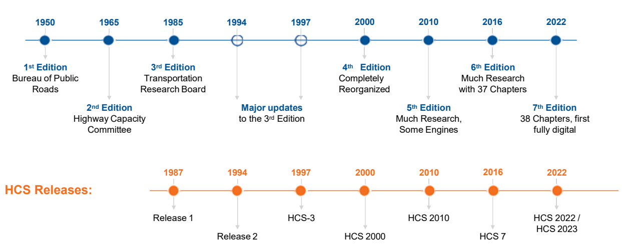
HCM / HCS History



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Level of Service

- Level of service (LOS) is a *quantitative stratification of a performance measure or measures that represent quality of service*
- Facilitates the presentation of results, through the use of a **A (best) to F (worst) scale**
- Defined by one or more service measures that both reflect the traveler perspective and are useful to operating agencies

	LOS by Volume-to-Capacity Ratio*	
Control Delay (s/veh)	≤1.0	>1.0
≤10	A	F
>10–20	B	F
>20–35	C	F
>35–55	D	F
>55–80	E	F
>80	F	F

LOS Criteria – Vehicles - Signalized Intersections

LOS	LOS Score
A	≤1.50
B	>1.50–2.50
C	>2.50–3.50
D	>3.50–4.50
E	>4.50–5.50
F	>5.50

LOS Criteria – Peds & Bikes - Signalized Intersections

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Performance Measures x Service Measures

Performance Measure:

- *A quantitative or qualitative characterization of some aspect of the service provided to a specific road user group*

Service Measure:

- *A performance measure (or group of measures) used to define LOS for a transportation system element*

Example: capacity, flow rates, queues and control are performance measures of signal analyses. However, only control delay is the service measure for signals as it defines LOS.

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HCM Service Measures

System Element	HCM Chapter	Service Measure(s) by Mode			
		Automobile	Pedestrian	Bicycle	Transit
Freeway facility	10	**Density**	--	--	--
Basic freeway segment	12	**Density**	--	--	--
Multilane highway	12	**Density**	--	LOS Score	--
Freeway weaving segment	13	**Density**	--	--	--
Freeway merge and diverge segments	14	**Density**	--	--	--
Two-lane highway	15	**Follower Density**	--	LOS Score	--
Urban street facility	16	**Speed**	LOS Score	LOS Score	LOS Score
Urban street segment	18	**Speed**	LOS Score	LOS Score	LOS Score
Signalized intersection	19	**Delay**	LOS Score	LOS Score	--
Two-way stop	20	**Delay**	Crossing Satisfaction	--	--
All-way stop	21	**Delay**	--	--	--
Roundabout	22	**Delay**	--	--	--
Ramp terminal, alternative intersection	23	**Experienced travel time**	--	--	--
Off-street pedestrian-bicycle facility	24	--	Space, events	LOS Score	--

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Quiz

How many Level of Service (LOS) ranges are used in the Highway Capacity Manual?

a) 3
b) 4
c) 5
d) 6
e) 7

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Quiz

How many Level of Service (LOS) ranges are used in the Highway Capacity Manual?

a) 3
b) 4
c) 5
d) 6
e) 7

Answer: D

The LOS concept facilitates the presentation of results, through the use of **six** ranges (A to F scale)

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About HCM Methods

- **Deterministic**
  - Always produces the same results for a given set of inputs
  - Exception: Travel Time Reliability (can incorporate randomness)
- **Macroscopic**
  - Considers average conditions experienced by vehicles over a period of time (typically 15 minutes or 1 hour)

In contrast, microsimulation models are:
- **Stochastic**: random seeds produce different results
- **Microscopic**: tracks individual vehicles

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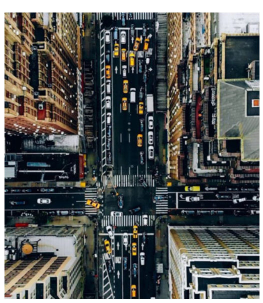
Interrupted Flow

- Interrupted-flow facilities have fixed causes of periodic delay or interruption to the traffic stream, such as traffic signals, roundabouts, and STOP signs.
- Methods presented in Volume 3 of the HCM
- **Control delay (seconds per vehicle)** as the service measure at signalized intersections and at unsignalized intersections
- **Travel speed (mi/h)** as the service measure at urban street segments and facilities



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Peak Hour Factor - Example

A measure of traffic demand fluctuation within the analysis hour

$$PHF = \frac{V}{4 \times V_{15}}$$

PHF = peak hour factor,
V = hourly volume (vph), and
V_{15} = volume during the peak 15 minutes

Time Period	Volume (veh)	Rate of Flow (veh/h)
5:00-5:15	1,000	4,000
5:15-5:30	1,200	4,800
5:30-5:45	1,100	4,400
5:45-6:00	1,000	4,000
5:00-6:00	**4,300**	**4,300**

Traffic movements were counted for the 5-6 PM peak hour. What is the corresponding Peak Hour Factor?

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5:00-5:15	1,000	4,000
5:15-5:30	$\boxed{1,200}$	4,800
5:30-5:45	1,100	4,400
5:45-6:00	1,000	4,000
5:00-6:00	**4,300**	**4,300**

Traffic movements were counted for the 5-6 PM peak hour. What is the corresponding Peak Hour Factor?

PHF = 4,300/(4 x1,200) = 4,300/4,800 = 0.90

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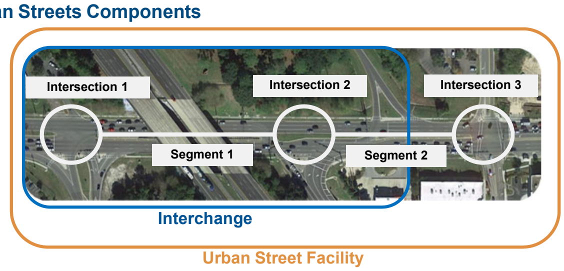
Urban Streets Components



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HCM7 Chapter 19 – Signalized Intersections

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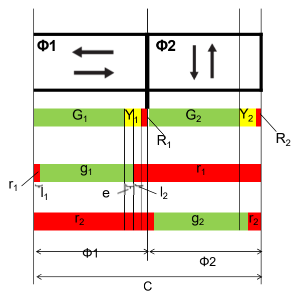
Key Concepts

- **Cycle length (C):** The time to complete one sequence of signal indications
- **Phase (Φ):** The green, yellow change, and red clearance intervals assigned to a specified movement (or movements)
- **Interval duration (G, Y and R):** duration which the interval is displayed to drivers
- **Effective green and red (g, r):** times considered for capacity analyses
- **Extension of effective green (e):** initial portion of yellow considered as part of effective green
- **Start-up lost time (l_1):** lost time of first vehicles in a queue due to reaction time and acceleration
- **Clearance lost time (l_2):** last portion of the change period not used by drivers



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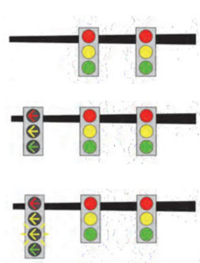
Movement Types

- **Protected:** turning drivers have the right-of-way
- **Permitted:** turning drivers must yield to conflicting traffic streams before completing the turn
- **Protected-Permitted:** combination of the permitted and protected

Obs: Traffic signal designs may vary on different locations



Source: FHWA Traffic Signal Timing Manual

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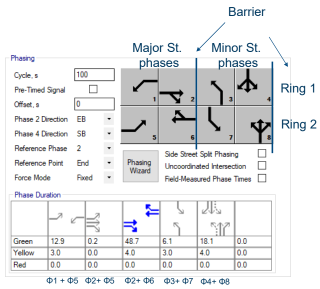
Phasing Sequence

Dual Ring Structure:

- Most common configuration
- Barrier: phases on both rings terminated simultaneously (ex: Φ2 and Φ6; Φ4 and Φ8
- Phasing Sequence: user input
- Phase Duration: automatically calculated based on controller and traffic inputs



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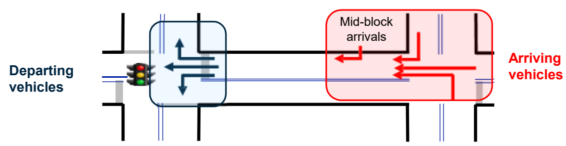
Demand Flow Rate

- Demand flow rate represents the flow rate of vehicles *arriving* at the intersection
- The flow of *departing vehicles* is limited by intersection capacity
- Counting departing vehicles in a congested approach will produce a demand flow rate that is lower than the true rate



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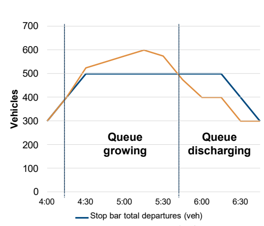
Counts & Demand

Queues building (arrivals > departures)

Analysis period	Stop bar total departures (veh)	Demand arrival volume (veh)	Period end unserved demand (veh)
4:00	300	300	0
4:15	400	400	0
4:30	**500**	**525**	**25**
4:45	**500**	**550**	**75**
5:00	**500**	**575**	**150**
5:15	**500**	**600**	**250**
5:30	**500**	**575**	**325**
5:45	**500**	**475**	**300**
6:00	**500**	**400**	**200**
6:15	**500**	**400**	**100**
6:30	400	300	0
6:45	300	300	0



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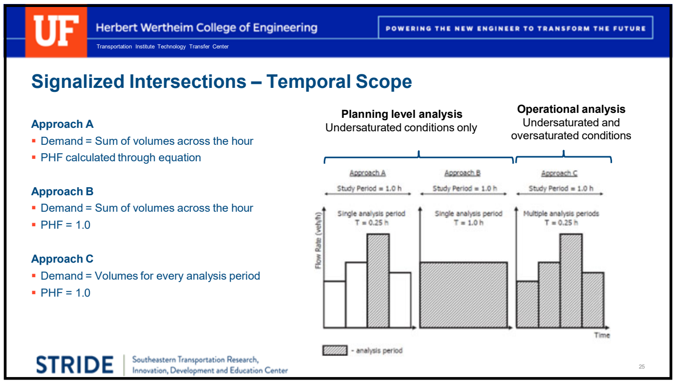
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Signalized Intersections – Temporal Scope
Approach A
Demand = Sum of volumes across the hour
PHF calculated through equation
Approach B
Demand = Sum of volumes across the hour
PHF = 1.0
Approach C
Demand = Volumes for every analysis period
PHF = 1.0
Planning level analysis
Undersaturated conditions only
Operational analysis
Undersaturated and oversaturated conditions
Approach A
Approach B
Approach C
Study Period = 1.0 h
Single analysis period T = 0.25 h
Single analysis period T = 1.0 h
Multiple analysis periods T = 0.25 h
Flow Rate (veh/h)
Time
= analysis period
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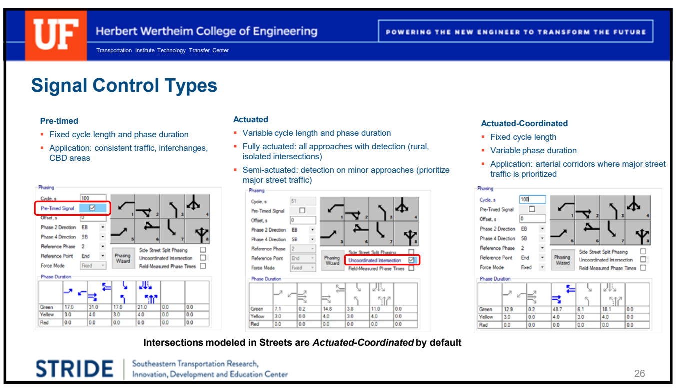
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Signal Control Types
Pre-timed
Fixed cycle length and phase duration
Application: consistent traffic, interchanges, CBD areas
Actuated
Variable cycle length and phase duration
Fully actuated: all approaches with detection (rural, isolated intersections)
Semi-actuated: detection on minor approaches (prioritize major street traffic)
Actuated-Coordinated
Fixed cycle length
Variable phase duration
Application: arterial corridors where major street traffic is prioritized
Intersections modeled in Streets are Actuated-Coordinated by default
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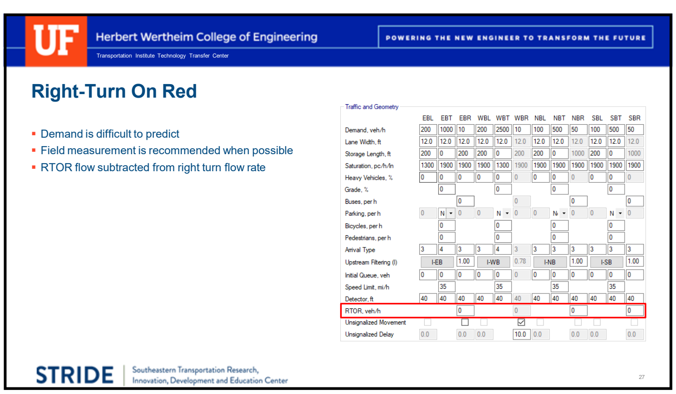
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Right-Turn On Red
Demand is difficult to predict
Field measurement is recommended when possible
RTOR flow subtracted from right turn flow rate
Traffic and Geometry
EBL EBT EBR WBL WBT WBR NBL NBT NBR SBL SBT SBR
Demand, veh/h
Lane Width, ft
Storage Length, ft
Saturation, pc/h/ln
Heavy Vehicles, %
Grade, %
Buses, per h
Parking, per h
Bicycles, per h
Pedestrians, per h
Arrival Type
Upstream Filtering (I)
Initial Queue, veh
Speed Limit, mi/h
Detector, ft
RTOR, veh/h
Unsignalized Movement
Unsignalized Delay
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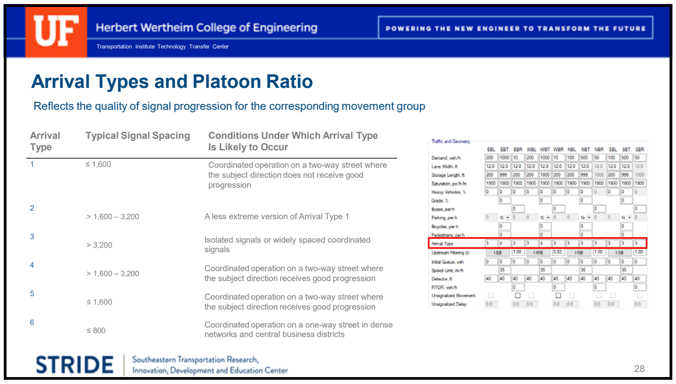
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Arrival Types and Platoon Ratio
Reflects the quality of signal progression for the corresponding movement group
Arrival Type
Typical Signal Spacing
Conditions Under Which Arrival Type Is Likely to Occur
1
≤ 1,600
Coordinated operation on a two-way street where the subject direction does not receive good progression
2
> 1,600 – 3,200
A less extreme version of Arrival Type 1
3
> 3,200
Isolated signals or widely spaced coordinated signals
4
> 1,600 – 3,200
Coordinated operation on a two-way street where the subject direction receives good progression
5
≤ 1,600
Coordinated operation on a two-way street where the subject direction receives good progression
6
≤ 800
Coordinated operation on a one-way street in dense networks and central business districts
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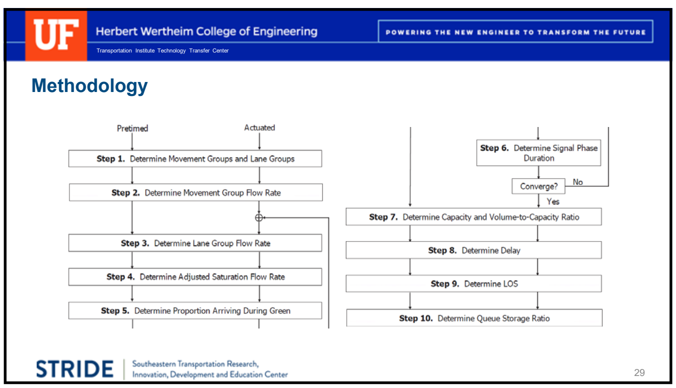
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Methodology
Pretimed
Actuated
Step 1. Determine Movement Groups and Lane Groups
Step 2. Determine Movement Group Flow Rate
Step 3. Determine Lane Group Flow Rate
Step 4. Determine Adjusted Saturation Flow Rate
Step 5. Determine Proportion Arriving During Green
Step 6. Determine Signal Phase Duration
Converge?
No
Yes
Step 7. Determine Capacity and Volume-to-Capacity Ratio
Step 8. Determine Delay
Step 9. Determine LOS
Step 10. Determine Queue Storage Ratio
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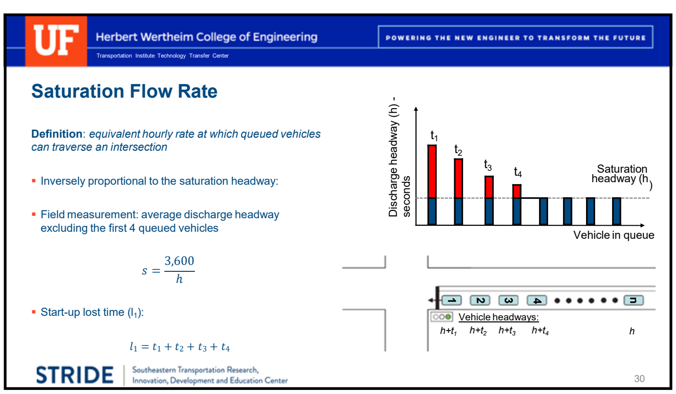
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Saturation Flow Rate
Definition: equivalent hourly rate at which queued vehicles can traverse an intersection
Inversely proportional to the saturation headway:
Field measurement: average discharge headway excluding the first 4 queued vehicles
$s = \frac{3,600}{h}$
Start-up lost time (l_1):
$l_1 = t_1 + t_2 + t_3 + t_4$
Discharge headway (h) - seconds
t_1
t_2
t_3
t_4
Saturation headway (h)
Vehicle in queue
Vehicle headways:
$h+t_1$
$h+t_2$
$h+t_3$
$h+t_4$
h
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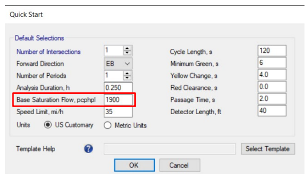
Saturation Flow Rate

Base Saturation Flow Rate (pc/h/ln)

- Default 1,900 (1,750 if population less than 250,000)
- Required user input

Adjusted Saturation Flow Rate (veh/h/ln)

- Applies adjustment factors per lane group
- Directly determines capacity



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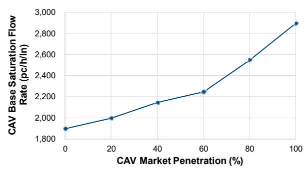
Capacity Impacts for CAVs

Adjustment Factors for Connected and Automated Vehicles (CAVs)

- New addition to HCM7
- Given a market penetration rate of CAVs, what percent increase in capacity can be expected?
- Base Saturation Flow Rate increased as function of % of CAVs



Proportion of CAVs in Traffic Stream	Base Saturation Flow Rate (pc/h/ln)
0	1,900
20	2,000
40	2,150
60	2,250
80	2,550
100	2,900

Saturation Flow Rate adjustments – Through movements

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Adjusted Saturation Flow Rate

$$\underbrace{s}_{\text{Saturation flow rate}} = \underbrace{s_0}_{\text{Base saturation flow rate}} \underbrace{f_w f_{HVg} f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} f_{wz} f_{ms} f_{sp}}_{\text{Adjustment factors}}$$

s = adjusted saturation flow rate (veh/h)
s_0 = base saturation flow rate
f_w = adjustment factor for lane width
f_{HVg} = adjustment factor for heavy vehicles and grade
f_p = adjustment factor for existence of a parking lane and parking activity adjacent to the lane group
f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area
f_a = adjustment factor for the area type
f_{LU} = adjustment factor for lane ultilization
f_{LT} = adjustment for left−turning vehicle presence in the lane group
f_{RT} = adjustment for right−turning vehicle presence in the lane group
f_{Lpb} = pedestrian adjustment factor for left turn groups
f_{Rpb} = pedestrian−bicycle adjustment factor for right turns
f_{wz} = adjustment factor for work zone presence at the intersection
f_{ms} = adjustment for downstream lane blockage
f_{sp} = adjustment for sustained spillback

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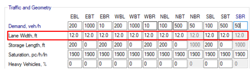
Saturation Flow Rate – Adjustment Factors

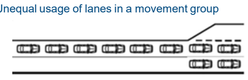
Lane Width:

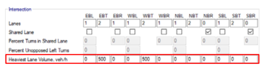
Average Lane Width (ft)	Adjustment Factor (f_w)
<10.0	0.96
≥10.0-12.9	1.00
>12.9	1.04



Lane Utilization:

- Unequal usage of lanes in a movement group





(under DETAILED INPUT DATA)

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Saturation Flow Rate – Adjustment Factors

Heavy Vehicles and Grade:

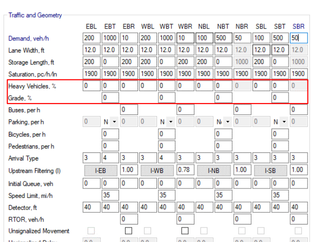
- Negative:

$$f_{HVg} = \frac{100 - 0.79P_{HV} - 2.07P_g}{100}$$

- Non-Negative:

$$f_{HVg} = \frac{100 - 0.78P_{HV} - 0.31P_g^{\,2}}{100}$$

P_{HV} = percent heavy vehicles in the corresponding movement group (%)
P_g = approach grade for the corresponding movement group (%)



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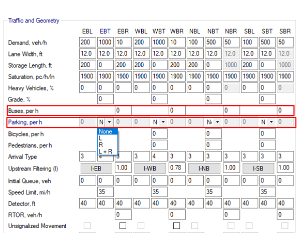
Saturation Flow Rate – Adjustment Factors

Bus Blockage:

- Rate of local buses stopping within 250 ft of the stop line (upstream or downstream)
- Buses traveling through (no stops) must not be counted

On-Street Parking:

- Rate of parking maneuvers within 250 ft upstream the stop bar



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Saturation Flow Rate – Adjustment Factors

Left-turn and Right-Turn adjustments:

- Protected Right Turns:

$$f_{RT} = \frac{1}{E_R} \qquad E_R = 1.18$$

- Protected Left Turns:

$$f_{LT} = \frac{1}{E_L} \qquad E_L = 1.05$$

Movement Group Results	EB		
Approach Movement	L	T	R
Assigned Movement	5	2	12
Adjusted Flow Rate (v), veh/h	200	1000	10
Adjusted Saturation Flow Rate (s), veh/h/ln	1810	1900	1610

These factors are automatically assigned to different movements

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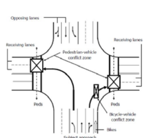
Saturation Flow Rate – Adjustment Factors

Pedestrians and bicycles:

- f_{Lpb} = pedestrian adjustment factor for left–turn groups
- f_{Rpb} = pedestrian–bicycle adjustment factor for right–turn groups



Traffic and Geometry

	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Demand, veh/h	200	1000	10	200	1000	10	100	500	50	100	500	50
Lane Width, ft	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Storage Length, ft	200	0	200	200	0	200	200	0	1000	200	0	1000
Saturation, pc/h/ln	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Heavy Vehicles, %	0	0	0	0	0	0	0	0	0	0	0	0
Grade, %		0			0			0			0	
Buses, per h			0			0			0			0
Parking, per h	0	N	0	0	N	0	0	N	0	0	N	0
Bicycles, per h		0			0			0			0	
Pedestrians, per h		0			0			0			0	
Arrival Type	3	4	3	3	4	3	3	3	3	3	3	3
Upstream Filtering (I)	I-EB		1.00	I-WB		0.78	I-NB		1.00	I-SB		1.00
Initial Queue, veh	0	0	0	0	0	0	0	0	0	0	0	0
Speed Limit, mi/h		35			35			35			35	
Detector, ft	40	40	40	40	40	40	40	40	40	40	40	40
RTOR, veh/h			0			0			0			0
Unsignalized Movement	☐		☐	☐		☐	☐		☐	☐		☐
Unsignalized Delay	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0

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Saturation Flow Rate – Adjustment Factors

Work Zones:

- Closures within 250 ft of stop bar
- Number of open lanes
- Total width of open lanes (ft)

f_{ws} = adjustment factor for work zone presence at the intersection

Intersection

	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes	1	2	1	1	2	1	1	2	0	1	2	0
Shared Lane	☐		☐	☐		☐	☐		☑	☐		☑
Percent Turns in Shared Lane	0		0	0		0	0		0	0		0
Percent Unopposed Left Turns	0			0			0			0		
Heaviest Lane Volume, veh/h	0	500	0	0	500	0	0	0	0	0	0	0
Start-Up Lost Time, s	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Extension of Effective Green, s	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Walk Interval, s		0.0			0.0			0.0			0.0	
Pedestrian Clear Interval, s		0.0			0.0			0.0			0.0	
Receiving Lanes		2			2			2			2	
Turn Radius, ft	112		32	112		32	112		32	112		32
Work Zone Active		☑			☐			☐			☐	
Left/Thru Lanes Open		1			3			3			3	
Approach Width, ft		12.0			36.0			36.0			36.0	
Bus Blockage Time, s			14.4			14.4			14.4			14.4
Parking Maneuver Time, s	18		18	18		18	18		18	18		18
Opposing Right-Turn Lane Influence	☐			☐			☐			☐		
Field Proportion Arriving on Green	0.16	0.65	0.49	0.05	0.45	0.46	0.06	0.18	0.18	0.06	0.18	0.18

(under DETAILED INPUT DATA)

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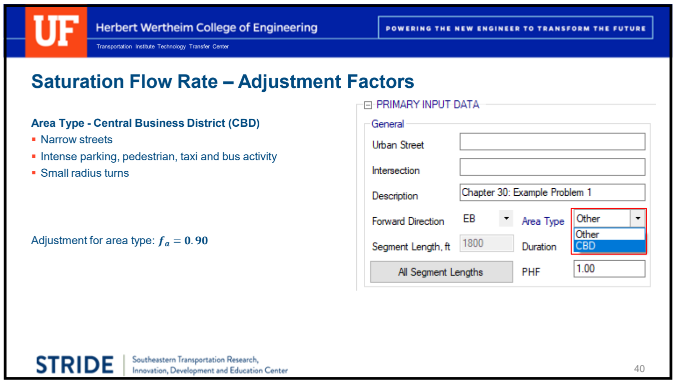
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Saturation Flow Rate – Adjustment Factors
Area Type - Central Business District (CBD)
Narrow streets
Intense parking, pedestrian, taxi and bus activity
Small radius turns
Adjustment for area type: $f_a = 0.90$
PRIMARY INPUT DATA
General
Urban Street
Intersection
Description
Chapter 30: Example Problem 1
Forward Direction
EB
Area Type
Other
Other
CBD
Segment Length, ft
1800
Duration
All Segment Lengths
PHF
1.00
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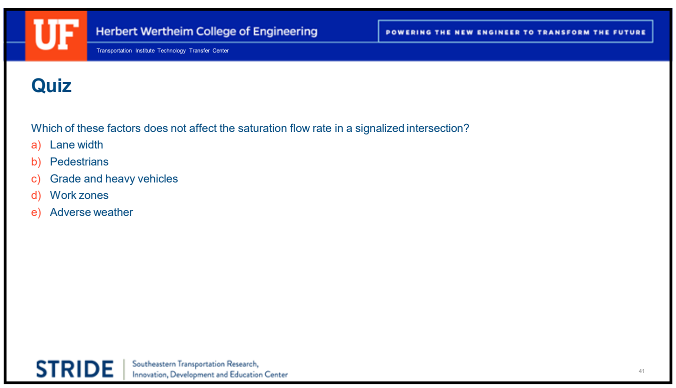
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Quiz
Which of these factors does not affect the saturation flow rate in a signalized intersection?
a) Lane width
b) Pedestrians
c) Grade and heavy vehicles
d) Work zones
e) Adverse weather
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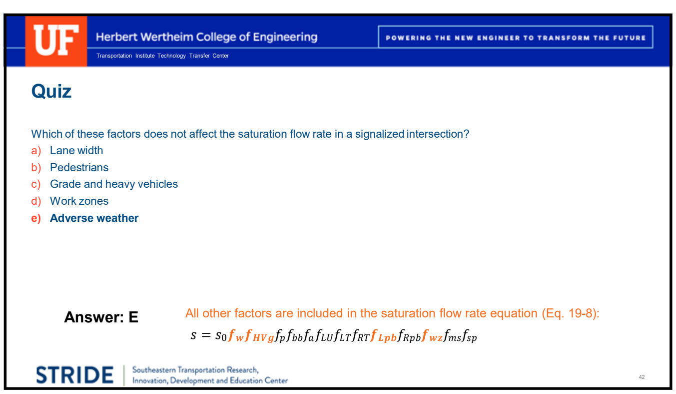
UF Herbert Wertheim College of Engineering
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Quiz
Which of these factors does not affect the saturation flow rate in a signalized intersection?
a) Lane width
b) Pedestrians
c) Grade and heavy vehicles
d) Work zones
e) Adverse weather
Answer: E
All other factors are included in the saturation flow rate equation (Eq. 19-8):
$s = s_0 f_w f_{HVg} f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} f_{wz} f_{ms} f_{sp}$
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Saturation Flow Rate – Permitted Movements

Permitted Left Turns (exclusive lane)

- Same model used in TWSC (lower rank movements)

$$s_p = \frac{v_o e^{-v_o t_{cg}/3,600}}{1 - e^{-v_o t_{fh}/3,600}}$$

s_p = saturation flow rate of a permitted left-turn movement (veh/h/ln)
v_o = opposing demand flow rate (veh/h)
t_{cg} = critical headway = 4.5 (s)
t_{fh} = follow-up headway = 4.5 s if the subject left turn is served in shared lane, 2.5 s if the subject left turn is served in an exclusive lane (s)

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Capacity and v/c Ratio

$$c = N\,s\,\frac{g}{C} \qquad X = \frac{v}{c}$$

N = number of lanes in the lane group
s = saturation flow rate (pc/h/ln)
g = effective green time (s)
C = cycle length (s)
X = volume-to-capacity ratio,
v = demand flow rate (veh/h).

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	5	2	12	1	6	16	3	8	18	7	4	14
Adjusted Flow Rate (v), veh/h	200	1000	10	86	1081	4	100	279	271	100	279	271
Adjusted Saturation Flow Rate (s), veh/h/ln	983	1509	1279	1810	1300	1610	1810	1900	1839	1810	1900	1839
Queue Service Time (g_s), s	19.9	15.4	0.4	4.7	39.7	0.1	4.4	14.1	14.2	4.4	14.1	14.2
Cycle Queue Clearance Time (g_c), s	19.9	15.4	0.4	4.7	39.7	0.1	4.4	14.1	14.2	4.4	14.1	14.2
Green Ratio (g/C)	0.22	0.55	0.55	0.06	0.40	0.40	0.24	0.18	0.18	0.24	0.18	0.18
Capacity (c), veh/h	217	1675	710	113	1032	639	200	345	334	200	345	334
Volume-to-Capacity Ratio (X)	0.922	0.597	0.014	0.765	1.048	0.007	0.500	0.809	0.813	0.500	0.809	0.813

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Control Delay

$$d = d_1 + d_2 + d_3$$

d = control delay (s/veh)
d_1 = uniform delay (s/veh)
d_2 = incremental delay (s/veh)
d_3 = initial queue delay (s/veh)

Movement Group Results	EB		
Approach Movement	L	T	R
Assigned Movement	5	2	12
Adjusted Flow Rate (v), veh/h	304	822	813
Adjusted Saturation Flow Rate (s), veh/h/ln	1767	1969	1929
Queue Service Time (g_s), s	16.2	49.6	50.4
Cycle Queue Clearance Time (g_c), s	16.2	49.6	50.4
Green Ratio (g/C)	0.39	0.42	0.42
Capacity (c), veh/h	330	834	817
Volume-to-Capacity Ratio (X)	0.922	0.986	0.996
Back of Queue (Q), ft/ln (95 th percentile)	351.3	938.2	948.3
Back of Queue (Q), veh/ln (95 th percentile)	13.7	36.6	37.0
Queue Storage Ratio (RQ) (95 th percentile)	0.08	0.23	0.23
Uniform Delay (d_1), s/veh	33.9	34.3	34.5
Incremental Delay (d_2), s/veh	25.7	28.1	30.5
Initial Queue Delay (d_3), s/veh	0.0	0.0	0.0
Control Delay (d), s/veh	59.5	62.3	65.0
Level of Service (LOS)	E	E	E
Approach Delay, s/veh / LOS	63.0		E

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Control Delay

- **Uniform delay (d1)**
  - Assumes uniform arrivals and departures
  - Accounts for the quality of progression
- **Incremental delay (d2)**
  - Effects of random, cycle-by-cycle fluctuations in demand that occasionally exceed capacity
- **Initial queue delay (d3)**
  - Initial queue due to unmet demand (previous analysis period)
  - Only applicable to oversaturated conditions
  - Can be manually provided if needed

Movement Group Results	EB		
Approach Movement	L	T	R
Assigned Movement	5	2	12
Adjusted Flow Rate (v), veh/h	304	822	813
Adjusted Saturation Flow Rate (s), veh/h/ln	1767	1969	1929
Queue Service Time (g_s), s	16.2	49.6	50.4
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Uniform Delay (d_1), s/veh	33.9	34.3	34.5
Incremental Delay (d_2), s/veh	25.7	28.1	30.5
Initial Queue Delay (d_3), s/veh	0.0	0.0	0.0
Control Delay (d), s/veh	59.5	62.3	65.0
Level of Service (LOS)	E	E	E
Approach Delay, s/veh / LOS	63.0		E

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Approach and Intersection Delay

$$d_{A,j} = \frac{\sigma_{i=1}^{m_j} d_i v_i}{\sigma_{i=1}^{m_j} v_i}$$

$$d_I = \frac{\sigma\ d_i v_i}{\sigma\ v_i}$$

- $d_{A,j}$ = approach control delay for approach j (s/veh)
- d_i = control delay for lane group i (s/veh)
- m_j = number of lane groups on approach j
- d_I = intersection control delay (s/veh)

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	5	2	12	1	6	16	3	8	18	7	4	14
Adjusted Flow Rate (v), veh/h	200	1000	10	86	1081	4	100	279	271	100	279	271
Adjusted Saturation Flow Rate (s), veh/h/ln	983	1509	1279	1810	1300	1610	1810	1900	1839	1810	1900	1839
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Cycle Queue Clearance Time (g_c), s	19.9	15.4	0.4	4.7	39.7	0.1	4.4	14.1	14.2	4.4	14.1	14.2
Green Ratio (g/C)	0.22	0.55	0.55	0.06	0.40	0.40	0.24	0.18	0.18	0.24	0.18	0.18
Capacity (c), veh/h	217	1675	710	113	1032	639	200	345	334	200	345	334
Volume-to-Capacity Ratio (X)	0.922	0.597	0.014	0.765	1.048	0.007	0.500	0.809	0.813	0.500	0.809	0.813
Back of Queue (Q), ft/ln (50 th percentile)												
Back of Queue (Q), veh/ln (50 th percentile)	6.0	3.7	0.1	2.3	17.0	0.1	1.9	6.6	6.4	1.9	6.6	6.4
Queue Storage Ratio (RQ) (50 th percentile)	0.75	0.00	0.01	0.28	0.00	0.01	0.24	0.00	0.00	0.24	0.00	0.00
Uniform Delay (d_1), s/veh	38.1	7.8	10.0	47.8	29.3	16.7	31.8	39.3	39.3	31.8	39.3	39.3
Incremental Delay (d_2), s/veh	22.6	1.6	0.0	3.1	38.2	0.0	0.7	1.7	1.8	0.7	1.7	1.8
Initial Queue Delay (d_3), s/veh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control Delay (d), s/veh	60.7	9.4	10.0	51.0	67.5	16.7	32.6	41.0	41.2	32.6	41.0	41.2
Level of Service (LOS)	E	A	B	D	F	B	C	D	D	C	D	D
Approach Delay, s/veh / LOS	17.9		B	66.1		E	39.8		D	39.8		D
Intersection Delay, s/veh / LOS	40.9						D					

- HCM Equations 19-28 & 19-29

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Quiz

This performance measure is used exclusively for analyses of multi-period with oversaturated conditions:

a) Control delay (d)
b) Uniform delay (d1)
c) Incremental delay (d2)
d) Initial queue delay (d3)
e) Back of queue length (Q)

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Quiz

This performance measure is used exclusively for analyses of multi-period with oversaturated conditions:

a) Control delay (d)
b) Uniform delay (d1)
c) Incremental delay (d2)
d) Initial queue delay (d3)
e) Back of queue length (Q)

Answer: D

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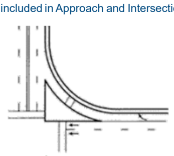
Unsignalized Movements

Delay estimated external to the HCM methodology
- Field Measurement
- Observing Similar Conditions
- Special HCM Application
- Simulation
- Can be included in Approach and Intersection Delay



Traffic and Geometry

	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Demand, veh/h	200	1000	10	200	2500	10	100	500	50	100	500	50
Lane Width, ft	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Storage Length, ft	200	0	200	200	0	200	200	0	1000	200	0	1000
Saturation, pc/h/ln	1300	1900	1900	1900	1300	1900	1900	1900	1900	1900	1900	1900
Heavy Vehicles, %	0	0	0	0	0	0	0	0	0	0	0	0
Grade, %		0			0			0			0	
Buses, per h			0			0			0			0
Parking, per h	0	N	0	0	N	0	0	N	0	0	N	0
Bicycles, per h		0			0			0			0	
Pedestrians, per h		0			0			0			0	
Arrival Type	3	4	3	3	4	3	3	3	3	3	3	3
Upstream Filtering (I)	I-EB		1.00	I-WB		0.78	I-NB		1.00	I-SB		1.00
Initial Queue, veh	0	0	0	0	0	0	0	0	0	0	0	0
Speed Limit, mi/h		35			35			35			35	
Detector, ft	40	40	40	40	40	40	40	40	40	40	40	40
RTOR, veh/h			0			0			0			0
Unsignalized Movement	☐		☐	☐		☑	☐		☐	☐		☐
Unsignalized Delay	0.0		0.0	0.0		10.0	0.0		0.0	0.0		0.0

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Level of Service

Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio*	
	≤ 1.0	> 1.0
≤ 10	A	F
> 10-20	B	F
>20-35	C	F
>35-55	D	F
>55-80	E	F
>80	F	F

*For approach-based and intersection-wide assessments, LOS is defined solely by control delay

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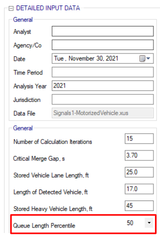
Back of Queue Length

- Average back-of-queue length for a lane group
- A percentile back-of-queue % can be estimated
- Queue storage ratio (RQ)
  - RQ ≤ 1 → available queue storage is sufficient
  - RQ > 1 → queue spillover (HCM limitation)

Movement Group Results	EB		
Approach Movement	L	T	R
Queue Storage Ratio (RQ) (50 th percentile)	1.50	0.12	0.10
Uniform Delay (d_1), s/veh	46.4	29.6	29.9



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Limitations

- Turn-bay overflow and queue spillback
- Delay for movements not under signal control
- RTOR volume prediction and delay
- Lane additions or lane drops
- Multiple advance detectors

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Highway Capacity Software Demo

- Example Problem
- Input and Report

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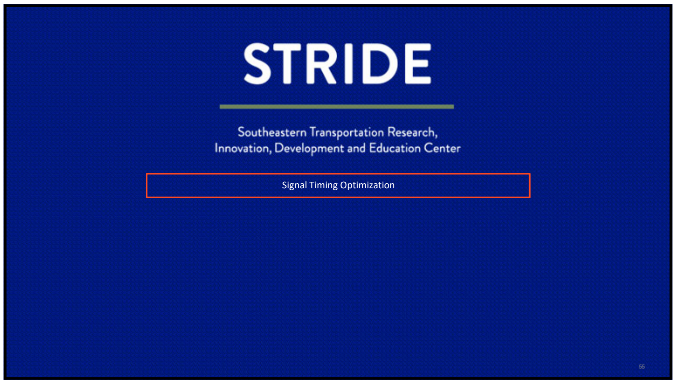
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Signal Timing Optimization

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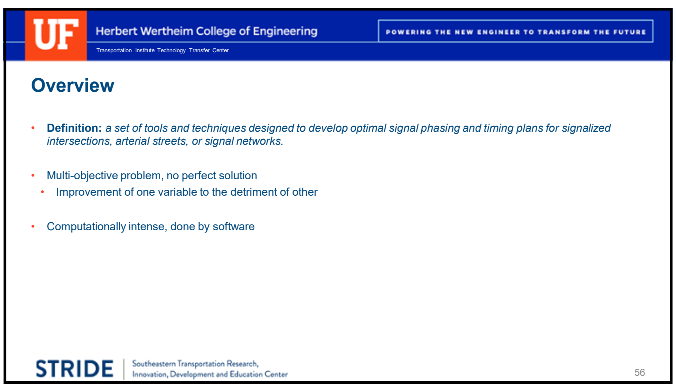
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Overview
Definition: a set of tools and techniques designed to develop optimal signal phasing and timing plans for signalized intersections, arterial streets, or signal networks.
Multi-objective problem, no perfect solution
Improvement of one variable to the detriment of other
Computationally intense, done by software
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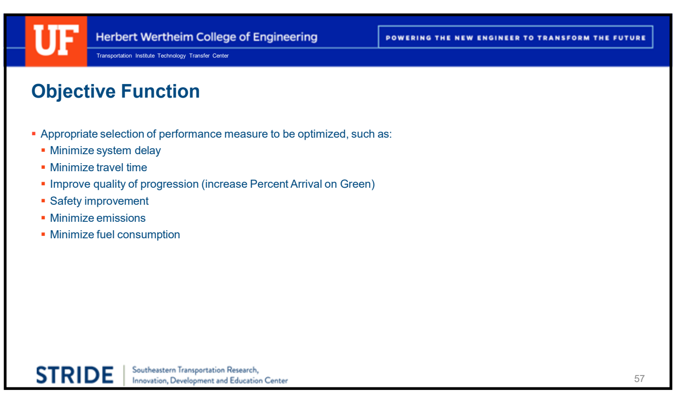
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Objective Function
Appropriate selection of performance measure to be optimized, such as:
Minimize system delay
Minimize travel time
Improve quality of progression (increase Percent Arrival on Green)
Safety improvement
Minimize emissions
Minimize fuel consumption
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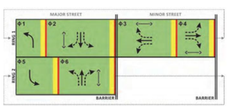
Independent Variables

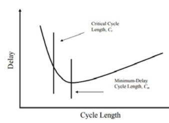
Which variables can be changed by the algorithm to seek the optimal solution?

Phasing Sequence + Phase Splits



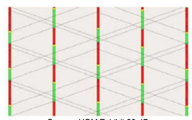
Source: FHWA Signal Timing Manual

Cycle Length



Source: Texas Transportation Institute (TTI)

Offsets



Source: HCM Exhibit 29-17

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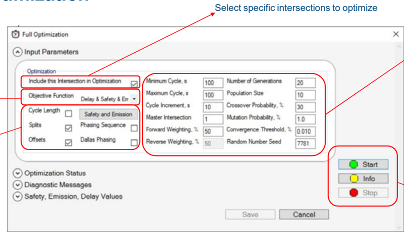
HCS Full Optimization

Select specific intersections to optimize

Adjust optimization parameters

Select objective function

Select independent variables



Start/ stop optimization

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Highway Capacity Software Demo

- Example Problem
- Input and Report

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Signalized Intersections – Multimodal Level of Service

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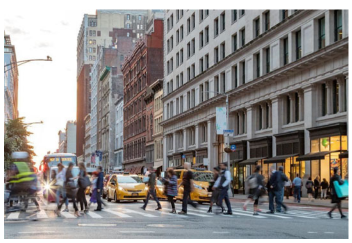
Pedestrian LOS

- Targets pedestrian crossing one or more approaches of a signalized intersection
- Designed for the "typical pedestrian"
  - Not designed for any particular subgroup (e.g. pedestrians with disabilities)
- Service measure: **Pedestrian LOS Score**



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Pedestrian Methodology Overview

Step 1: Determine Pedestrian Delay
↓
Step 2: Determine Pedestrian LOS Score for Intersection
↓
Step 3: Determine LOS

Step 4: Determine Street Corner Circulation Area

Step 5: Determine Crosswalk Circulation Area

HCM 7 update: steps 4 and 5 are now optional and not required to compute Pedestrian LOS

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Pedestrian Delay

- Computes an "effective walk time", as function of:
  - WALK time
  - Ped Clearance time
- Delay computed as function of:
  - Effective walk time
  - Cycle length

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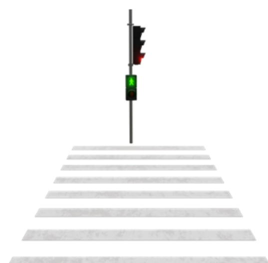
Pedestrian LOS Score

- Sensitive to:
  - Vehicular traffic and speed
  - Number of traffic lanes crossed
  - Presence of right-turn channelized islands



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Pedestrian Level of Service

- Based on Pedestrian LOS Score:

LOS	Pedestrian LOS Score
A	≤ 1.50
B	> 1.50-2.50
C	> 2.50-3.50
D	> 3.50-4.50
E	> 4.50-5.50
F	> 5.50

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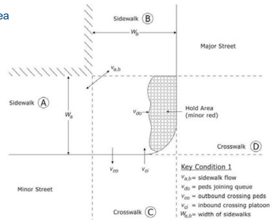
Optional Steps – Corner Circulation Area

- Evaluates pedestrian comfort based on density at the corner area
- Sensitive to:
  - Sidewalk dimensions
  - Signal timing settings
  - Pedestrian flow rate

Pedestrian Space (ft^2/p)	Description
>60	Ability to move in desired path, no need to alter movements
>40–60	Occasional need to adjust path to avoid conflicts
>24–40	Frequent need to adjust path to avoid conflicts
>15–24	Speed and ability to pass slower pedestrians restricted
>8–15	Speed restricted, very limited ability to pass slower pedestrians
≤8	Speed severely restricted, frequent contact with other users



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Optional Steps – Crosswalk Circulation Area

- Evaluates pedestrian comfort based on density at the crosswalk area
- Sensitive to:
  - Pedestrian walking speed
  - Pedestrian flow rate
  - Crosswalk length and width
  - Available walk time
  - Right-turning vehicles demand during pedestrian walk

Pedestrian Space (ft^2/p)	Description
>60	Ability to move in desired path, no need to alter movements
>40–60	Occasional need to adjust path to avoid conflicts
>24–40	Frequent need to adjust path to avoid conflicts
>15–24	Speed and ability to pass slower pedestrians restricted
>8–15	Speed restricted, very limited ability to pass slower pedestrians
≤8	Speed severely restricted, frequent contact with other users

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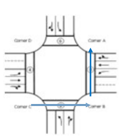
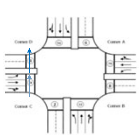
Pedestrian Methodology Extensions

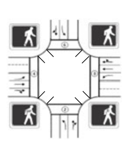
- Multiple-leg and multiple-stage crossings
  - Second stage/leg arrival is not random
- Barnes dance / pedestrian scramble



Two-leg crossing



Two-stage crossing with median refuge



Barnes dance / pedestrian scramble

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Bicycle LOS

- Targets bicycles traveling through a signalized intersection
- Assumes bicycles on the street only, same direction as adjacent motorized vehicles
- Service measure: **Bicycle LOS Score**

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Bicycle Methodology Overview

Step 1: Determine Bicycle Delay

↓

Step 2: Determine Bicycle LOS Score for Intersection

↓

Step 3: Determine LOS

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Bicycle Delay

- Delay computed as function of:
  - Bicycle lane capacity (average 2,000 bikes/h)
  - Cycle length and effective green time (equal to vehicular traffic) for bicycle lanes

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Bicycle LOS Score

- Sensitive to:
  - Vehicular traffic and speed
  - Cross-street width
  - Width of bicycle lane
  - Number of through lanes
  - Width of outside through lane
  - Proportion of on-street parking occupied
  - Width of paved outside shoulder

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Bicycle Level of Service

- Based on Bicycle LOS Score:

LOS	Bicycle LOS Score
A	≤ 1.50
B	> 1.50-2.50
C	> 2.50-3.50
D	> 3.50-4.50
E	> 4.50-5.50
F	> 5.50

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Highway Capacity Software Demo

- Example Problem
- Input and Report

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HCM7 Chapter 18 – Urban Street Segments

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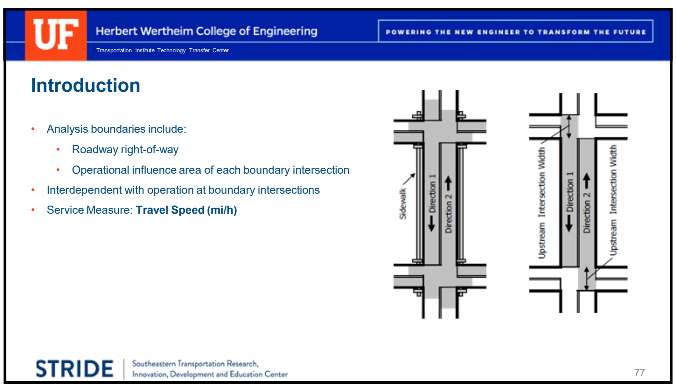
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Introduction
Analysis boundaries include:
Roadway right-of-way
Operational influence area of each boundary intersection
Interdependent with operation at boundary intersections
Service Measure: Travel Speed (mi/h)
Sidewalk
Direction 1
Direction 2
Upstream Intersection Width
Upstream Intersection Width
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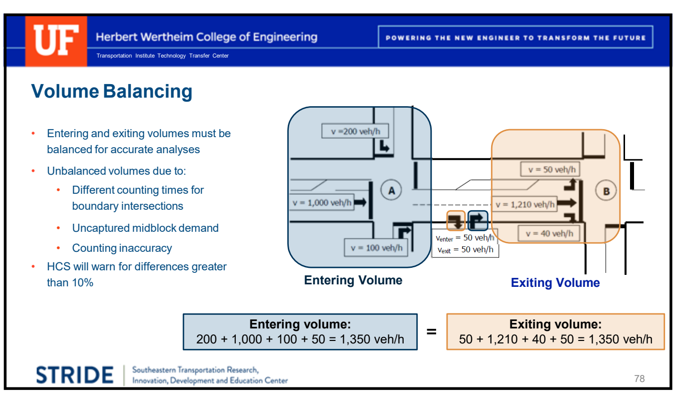
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Volume Balancing
Entering and exiting volumes must be balanced for accurate analyses
Unbalanced volumes due to:
Different counting times for boundary intersections
Uncaptured midblock demand
Counting inaccuracy
HCS will warn for differences greater than 10%
v =200 veh/h
v = 1,000 veh/h
v = 100 veh/h
v = 50 veh/h
v = 1,210 veh/h
v = 40 veh/h
Entering Volume
Exiting Volume
Entering volume: 200 + 1,000 + 100 + 50 = 1,350 veh/h
=
Exiting volume: 50 + 1,210 + 40 + 50 = 1,350 veh/h
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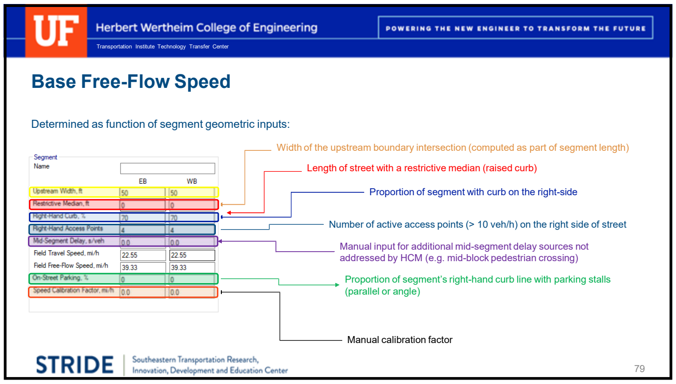
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Base Free-Flow Speed
Determined as function of segment geometric inputs:
Segment Name
EB
WB
Upstream Width, ft
Restrictive Median, ft
Right-Hand Curb, %
Right-Hand Access Points
Mid-Segment Delay, s/veh
Field Travel Speed, mi/h
Field Free-Flow Speed, mi/h
On-Street Parking, %
Speed Calibration Factor, mi/h
Width of the upstream boundary intersection (computed as part of segment length)
Length of street with a restrictive median (raised curb)
Proportion of segment with curb on the right-side
Number of active access points (> 10 veh/h) on the right side of street
Manual input for additional mid-segment delay sources not addressed by HCM (e.g. mid-block pedestrian crossing)
Proportion of segment's right-hand curb line with parking stalls (parallel or angle)
Manual calibration factor
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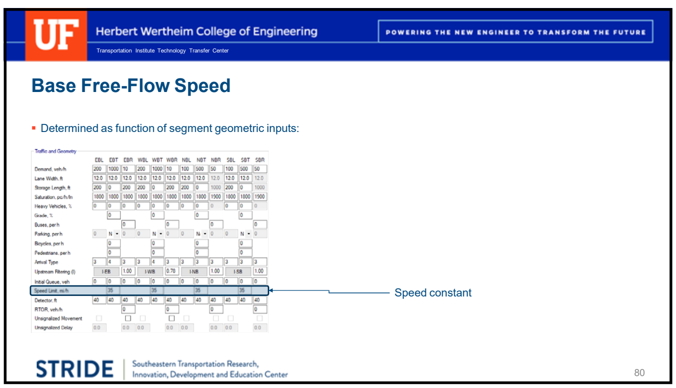
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Base Free-Flow Speed
Determined as function of segment geometric inputs:
Speed constant
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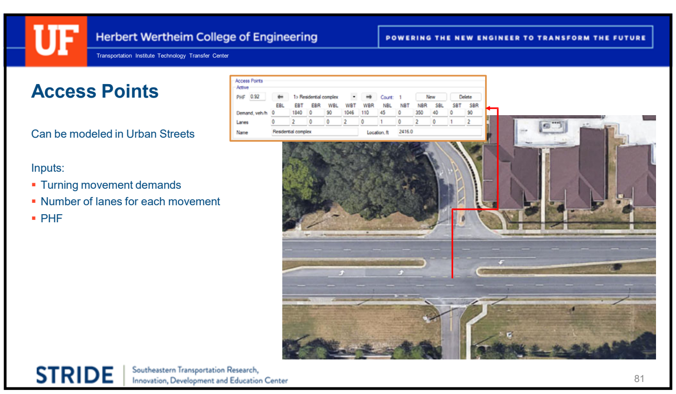
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Access Points
Can be modeled in Urban Streets
Inputs:
Turning movement demands
Number of lanes for each movement
PHF
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Definitions

Running Time
- The time a vehicle spends in motion through the segment

Through delay
- Control delay of the through movement in the boundary downstream intersection

Automobile Traveler Perception Score
- Optional performance measure to indicate traveler's perception of quality of service

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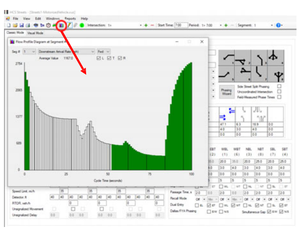
Flow Profile

- Applies for downstream signalized intersection only
- Measures the proportion of traffic arriving downstream during green
- Green part of the graph = vehicles arriving on green
  - The higher the better
  - Improves intersection uniform delay (d1)



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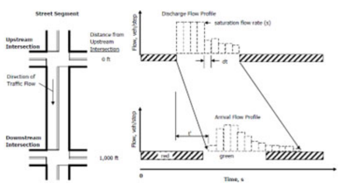
Platoon Dispersion Model

- Platoons from the upstream signal degrade while traveling the segment, due to differing speeds of vehicles
- Arrival flow rate lower than discharge flow rate



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Travel Speed

$$S_{T,seg} = \frac{3{,}600L}{5{,}280(t_R + d_t)}$$

$S_{T,seg}$ = travel speed of through vehicles for the segment (mi/h)
L = segment length (ft)
t_R = segment running time (s)
d_t = through delay at downstream intersection (s/veh)

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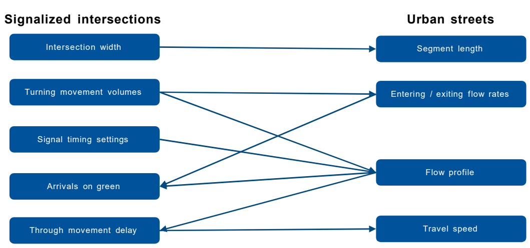
How do signalized intersections and segments relate?



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Level of Service

Service measure: Travel Speed (mi/h) as a percentage of base free-flow speed (BFFS)

LOS	% of BFFS	Travel Speed Threshold by BFFS (mi/h)							Volume-to-Capacity Ratio*
		55	50	45	40	35	30	25	
A	**> 80%**	>44	>40	>36	>32	>28	>24	>20	≤ 1.0
B	**67-80%**	>37	>34	>30	>27	>23	>20	>17	
C	**50-67%**	>28	>25	>23	>20	>18	>15	>13	
D	**40-50%**	>22	>20	>18	>16	>14	>12	>10	
E	**30-40%**	>17	>15	>14	>12	>11	>9	>8	
F	**< 30%**	≤17	≤15	≤14	≤12	≤11	≤9	≤8	
F	**any**	any							> 1.0

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Quiz

Which performance measure is used to evaluate LOS in urban streets segments?

a) Through Stop Rate
b) Running Time
c) Free-flow Speed
d) Segment Delay
e) Travel Speed

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Quiz

Which performance measure is used to evaluate LOS in urban streets segments?

a) Through Stop Rate
b) Running Time
c) Free-flow Speed
d) Segment Delay
e) **Travel Speed**

LOS	% of BFFS	Travel Speed Threshold by BFFS (mi/h)							Volume-to-Capacity Ratio*
		55	50	45	40	35	30	25	
A	> 80%	>44	>40	>36	>32	>28	>24	>20	≤ 1.0
B	67-80%	>37	>34	>30	>27	>23	>20	>17	
C	50-67%	>28	>25	>23	>20	>18	>15	>13	
D	40-50%	>22	>20	>18	>16	>14	>12	>10	
E	30-40%	>17	>15	>14	>12	>11	>9	>8	
F	< 30%	≤17	≤15	≤14	≤12	≤11	≤9	≤8	
F	any	any							> 1.0

Answer: E

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Required Input Data

Required Data and Units	Potential Data Source(s)	Suggested Default Value
Traffic Characteristics Data		
Demand flow rate by movement group at boundary intersection (veh/h)	Field data, past counts	Must be provided
Access point flow rate by movement group (veh/h)	Field data, past counts	See discussion in text
Midsegment flow rate (veh/h)	Field data, past counts	Estimate using demand flow rate at the downstream boundary int. approach

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Required Input Data

Required Data and Units	Potential Data Source(s)	Suggested Default Value
Geometric Data		
Number of lanes by movement group at boundary intersection	Field data, aerial photo	Must be provided
Upstream intersection width (ft)	Field data, aerial photo	Must be provided
Segment approach turn bay length at boundary intersection (ft)	Field data, aerial photo	Must be provided
Number of midsegment through lanes	Field data, aerial photo	Must be provided
Number of lanes at access points – segment approach	Field data, aerial photo	(a) Number of through lanes on approach = number of midsegment through lanes (b) No right-turn lanes (c) If median present, one left-turn lane per approach; otherwise, no left-turn lanes
Number of lanes at access points – access point approach	Field data, aerial photo	One left-turn and one right-turn lane
Segment approach turn bay length at access points (ft)	Field data, aerial photo	40% of the access point spacing, where spacing = 2 x (5,280)/D_a in feet, but not more than 300 ft nor less than 50 ft

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Required Input Data

Required Data and Units	Potential Data Source(s)	Suggested Default Value
Geometric Data, cont.		
Segment length (ft)	Field data, aerial photo	Must be provided
Restrictive median length (ft)	Field data, aerial photo	Must be provided
Proportion of segment with curb (decimal)	Field data, aerial photo	1.0 (curb present on both sides)
Number of access point approaches	Field data, aerial photo	See discussion in text
Proportion of segment with in-street parking (decimal)	Field data	Must be provided
Other Data		
Analysis period duration (h)	Set by analyst	0.25 h
Speed limit (mi/h)	Field data, road inventory	Must be provided
Performance Measure Data		
Through control delay at boundary intersection (s/veh)	HCM method output	Must be provided
Through stopped vehicles at boundary intersection (veh)	HCM method output	Must be provided
2nd and 3rd term back-of-queue size for through movement at boundary intersection (veh/lane)	HCM method output	Must be provided
Capacity by movement group at boundary intersection (veh/h)	HCM method output	Must be provided
Midsegment delay (s/veh)	Field data	0.0 s/veh
Midsegment stops (stops/veh)	Field data	0.0 stops/veh

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Highway Capacity Software Demo

- Example Problem
- Input and Report

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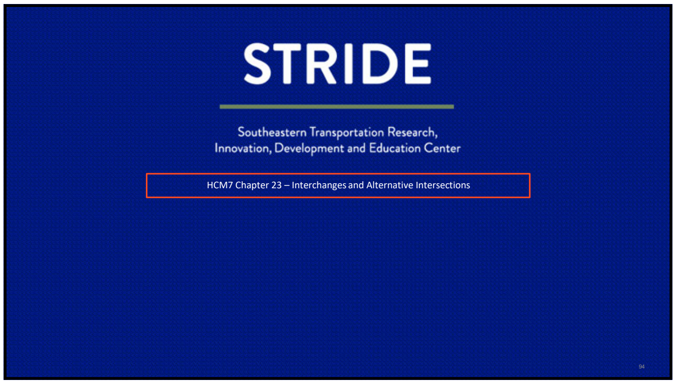
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HCM7 Chapter 23 – Interchanges and Alternative Intersections

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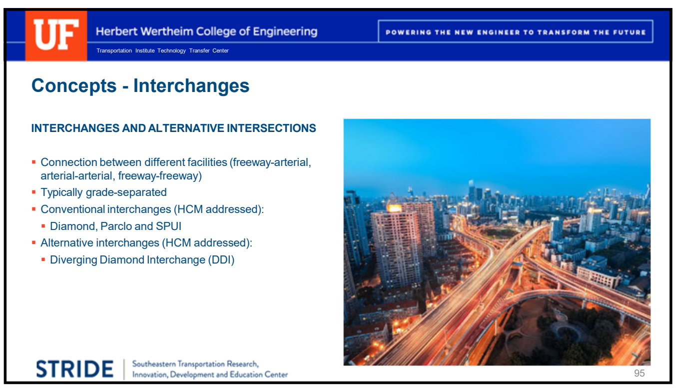
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Concepts - Interchanges
INTERCHANGES AND ALTERNATIVE INTERSECTIONS
Connection between different facilities (freeway-arterial, arterial-arterial, freeway-freeway)
Typically grade-separated
Conventional interchanges (HCM addressed):
Diamond, Parclo and SPUI
Alternative interchanges (HCM addressed):
Diverging Diamond Interchange (DDI)
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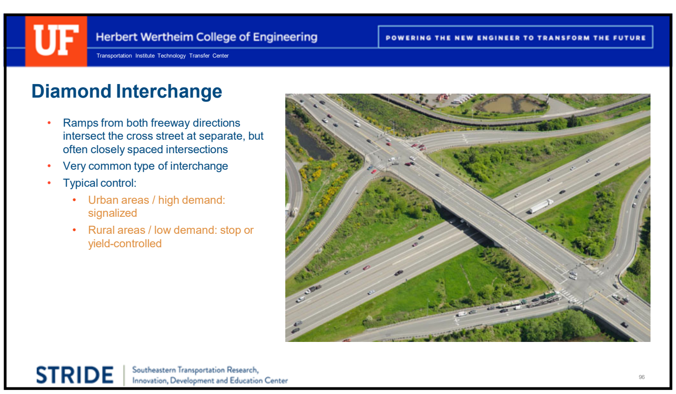
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Diamond Interchange
Ramps from both freeway directions intersect the cross street at separate, but often closely spaced intersections
Very common type of interchange
Typical control:
Urban areas / high demand: signalized
Rural areas / low demand: stop or yield-controlled
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Parclo (Partial Cloverleaf)

- Very common type of interchange
- Variation of Cloverleaf (loops on four quadrants)
- Several variations with one or two loop ramps

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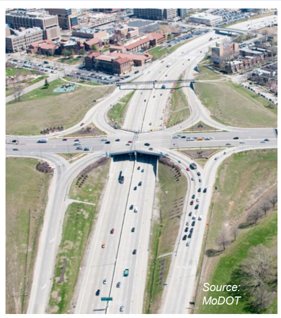
Single Point Urban Interchange (SPUI)

- Only one signalized intersection
- Simpler phasing sequence for signal control
- Higher capacity compared to Diamond
- Requires longer yellow and red times
- May be harder to accommodate pedestrian phases



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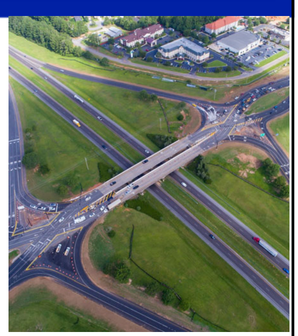
Diverging Diamond Interchange (DDI)

- Also known as "Double crossover diamond"
- Two crossover intersections
- Shifts cross street traffic to the left side of the street between the signalized crossover intersections
- Left-turning vehicles to ramps do not conflict with vehicles from other directions
- Improves safety (only 2 conflict points)



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Concepts – Alternative Intersections

- Rerouting of movements to secondary junctions
- Typically at-grade
- HCM addressed types:
  - Restricted Crossing U-Turn (RCUT)
  - Median U-Turn (MUT)
  - Displaced Left Turn (DLT)

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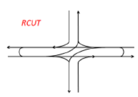
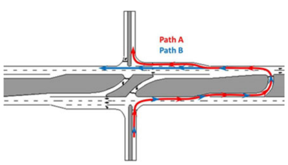
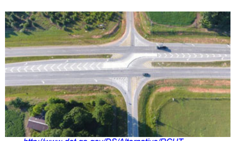
Restricted Crossing U-Turn (RCUT)

- Also known as "Super Street"
- Left and through movements are restricted in the minor approaches







http://www.dot.ga.gov/DS/Alternative/RCUT

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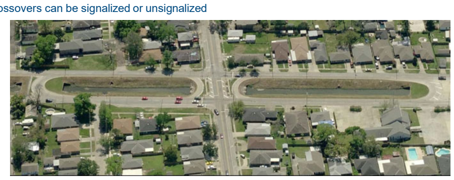
Median U-Turn (MUT)

- Also known as "Michigan Left"
- Left-turns not allowed in the main intersection
- U-turn crossovers can be signalized or unsignalized



Source: FHWA Median U-Turn Intersection Informational Guide

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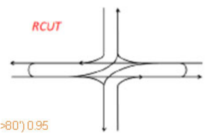
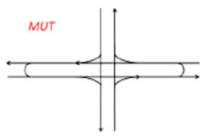
HCM Modeling – RCUT and MUT

HCM Modeling approach:

- Extension of Signal and TWSC Procedures
  - Segments Modeled Independently by Direction
- U-Turn (Signal) Saturation Flow Rate Adjustments
  - Median width: Narrow (< 35') 0.80 Typical (35-80') 0.85 Wide (>80') 0.95





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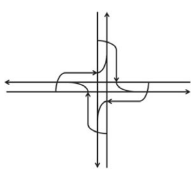
Displaced Left Turn (DLT)

Full DLT:

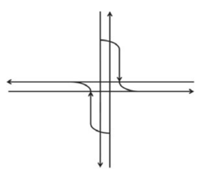
- Upstream crossover on both directions
- 5 signalized intersections

Partial DLT:

- Upstream crossover on one direction
- 3 signalized intersections



(a) Full DLT



(b) Partial DLT

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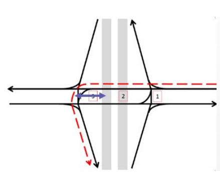
Experienced Travel Time

$$ETT = \square \quad d_i + \square$$
EDTT

$$EDTT = \frac{D_t + D_f}{1.47 \times v_D} + a$$



$EDTT$ = extra distance travel times (s)
D_t = distance traveled along the loop ramp or diverted movement (ft)
1.47 = conversion factor from mi/h to ft/s
v_D = design speed of the loop ramp or diverted movement (mi/h)
a = delay associated with deceleration into a turn and acceleration from the next turns (s); assumed to be 5 s for a loop ramp movement

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LOS Ranges - Interchanges

- Equivalent to 1.5x the LOS ranges for signalized intersections
- Reflects the need to travel through multiple intersections

ETT (s/veh)	Condition		
	v/c ≤ 1 and R_Q ≤ 1 for every lane group	v/c > 1 for any lane group	R_Q > 1 for any lane group
≤15	A	F	F
>15-30	B	F	F
>30-55	C	F	F
>55-85	D	F	F
>85-120	E	F	F
>120	F	F	F

v/c: demand-to-capacity ratio R_Q: queue storage ratio

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LOS Ranges - Alternative Intersections

Same ranges as signalized intersections

ETT (s/veh)	Condition		
	v/c ≤ 1 and R_Q ≤ 1 for every lane group	v/c > 1 for any lane group	R_Q > 1 for any lane group
≤ 10	A	F	F
>10-20	B	F	F
>20-35	C	F	F
>35-55	D	F	F
>55-80	E	F	F
>80	F	F	F

v/c = demand-to-capacity ratio R_Q = queue storage ratio

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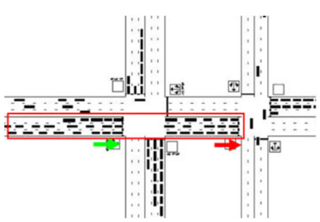
Downstream Queue

- Closely spaced intersections with limited queue storage
- Downstream queues can reduce or completely block the discharge at the upstream intersection
- Effect is computed as an *additional lost time* (L_D)



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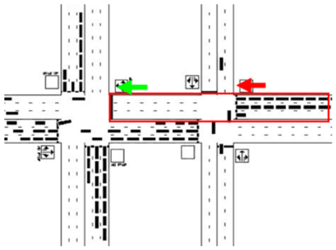
Demand Starvation

- Green at the downstream signal is not used because of upstream signal
- Modeled as an *additional lost time* L_{DS}



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Required Input Data

Parameter	Potential Data Source	Suggest Default Value
Geometric Data		
Area Type	Field data, aerial photo	Must be provided
Number of Lanes (*N*)	Field data, aerial photo	Must be provided
Average lane width (*W*, ft)	Field data, aerial photo	12 ft
Grade (*G*, %)	Field data	Flat approach: 0% Moderate grade: 3% Steep grade: 6%
Existence of exclusive left- or right-turn lanes	Field data, aerial photo	Must be provided
Length of storage for each lane group (L_a, ft)	Field data, aerial photo	Must be provided
Distances corresponding to the internal storage between the two intersections in the interchange (*D*, ft)	Field data, aerial photo	Must be provided
Distances corresponding to the internal storage between interchange intersections and adjacent closely space intersections (ft)	Field data, aerial photo	Must be provided
Turning radii for all turning movements (ft)	Field data, aerial photo	Must be provided
Extra travel distance relative to center line (ft)	Field data, aerial photo	Must be provided

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Required Input Data

Parameter	Potential Data Source	Suggest Default Value
Demand and Traffic Data		
Demand volume by O-D or turning movement (*V*, veh/h)	Field data, past counts	Must be provided
Right-turn-on-red flow rates	Field data, past counts	0.0 veh/h
Base saturation flow rate (s_0, pc/h/ln)	Field data, judgment	Metro pop. ≥ 250,000: 1,900 pc/h/ln Otherwise: 1,750 pc/h/ln
Peak hour factor (PHF)	Field data, judgment	Total entering volume ≥ 1,000 veh/h: 0.92 Total entering volume < 1,000 veh/h: 0.90
Percent heavy vehicles (*HV*, %)	Field data, past counts	3%
Approach pedestrian flow rates (v_{ped}, ped/h)	Field data, past counts	Must be provided
Approach bicycle flow rates (v_b, ped/h)	Field data, past counts	Must be provided
Local bus stopping rate (*NB*, buses/h)	Field data, judgment	CBD bus stop: 12 buses/h Non-CBD: 2 buses/h
Parking Activity (N_m, maneuvers/h)	Field data, judgment	Must be provided
Arrival Type (*AT*)	Field data, judgement	3
Upstream filtering adjustment factor	Field data, judgement	1.0
Approach speed (S_A, mi/h)	Field data, judgment	Speed Limit + 5 mi/h
Travel speed for extra travel distance (mi/h)	Field data, judgment	Speed Limit + 5 mi/h

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Required Input Data

Parameter	Potential Data Source	Suggest Default Value
Signal Data		
Type of signal control	Field Data	Must be provided
Phase sequence	Field Data	Must be provided
Cycle length (if appropriate) (*C*, s)	Field Data	Must be provided
Green times (if appropriate) (*G*, s)	Field Data	Must be provided
Yellow-plus-all-red change-and-clearance interval (intergreen) (*Y*, s)	Field Data	Must be provided
Offset (if appropriate)	Field Data	Must be provided
Maximum, minimum green, passage times, phase recall (for actuated control)	Field Data	Must be provided
Pedestrian push button	Field Data	Must be provided
Minimum pedestrian green (G_p, s)	Field Data	Must be provided
Phase plan	Field Data	Must be provided

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Highway Capacity Software Demo

- Example Problem
- Input and Report

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Q&A / Final comments

Fabio Sasahara, PhD, PMP
McTrans Center
Associate Director
fsasahara@ufl.edu

/company/mctrans-center
HCS User Group
TSIS-CORSIM User Group
HSS User Group

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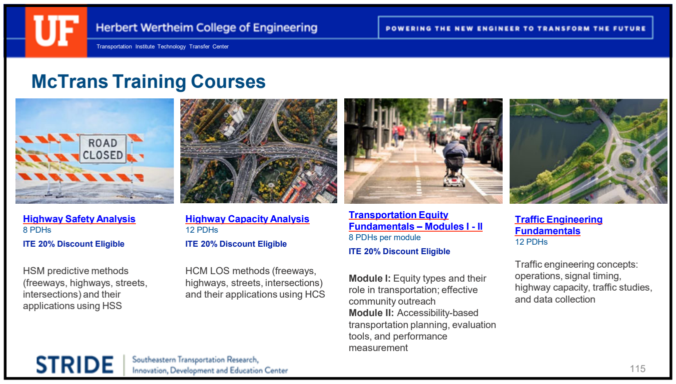
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ROAD CLOSED
Highway Safety Analysis
8 PDHs
ITE 20% Discount Eligible
HSM predictive methods (freeways, highways, streets, intersections) and their applications using HSS
Highway Capacity Analysis
12 PDHs
ITE 20% Discount Eligible
HCM LOS methods (freeways, highways, streets, intersections) and their applications using HCS
Transportation Equity Fundamentals – Modules I - II
8 PDHs per module
ITE 20% Discount Eligible
Module I: Equity types and their role in transportation; effective community outreach
Module II: Accessibility-based transportation planning, evaluation tools, and performance measurement
Traffic Engineering Fundamentals
12 PDHs
Traffic engineering concepts: operations, signal timing, highway capacity, traffic studies, and data collection
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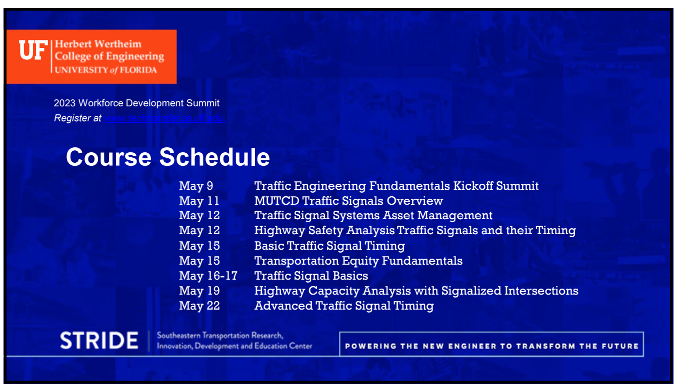
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2023 Workforce Development Summit
Register at
Course Schedule
May 9 Traffic Engineering Fundamentals Kickoff Summit
May 11 MUTCD Traffic Signals Overview
May 12 Traffic Signal Systems Asset Management
May 12 Highway Safety Analysis Traffic Signals and their Timing
May 15 Basic Traffic Signal Timing
May 15 Transportation Equity Fundamentals
May 16-17 Traffic Signal Basics
May 19 Highway Capacity Analysis with Signalized Intersections
May 22 Advanced Traffic Signal Timing
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Training Slides

Advanced Traffic Signal Timing


UF Herbert Wertheim College of Engineering UNIVERSITY of FLORIDA
Advanced Traffic Signal Timing
Dr. Steven M. Click, PE
sclick@tntech.edu
Get course resources via QR Code or at
https://tinyurl.com/228knzkw
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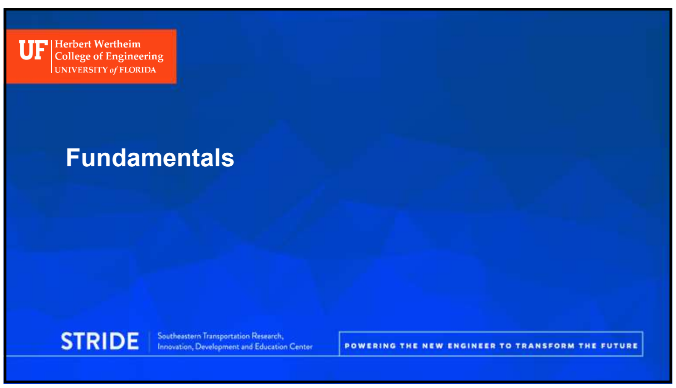
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Fundamentals
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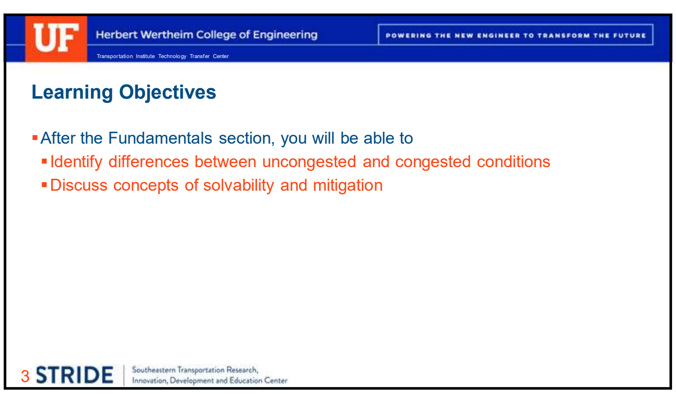
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Learning Objectives
After the Fundamentals section, you will be able to
Identify differences between uncongested and congested conditions
Discuss concepts of solvability and mitigation
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Uncongested Conditions

- Well understood
- Rich selection of strategies and tactics
- Many well-defined calculations for safety and efficiency
  - Including multiple software options

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Congested Conditions are Different

- Not well understood
  - Only “recently” have such research
- Have strategies, but few calculation methods for determining parameters
  - Operational concepts with engineering judgment
  - No software packages for designing congested intersection or system timing
  - Can use simulation to preview effects
- Get worse if uncongested objectives, strategies, or tactics are used
  - What happens if you add green time to one of several congested movements at an intersection?

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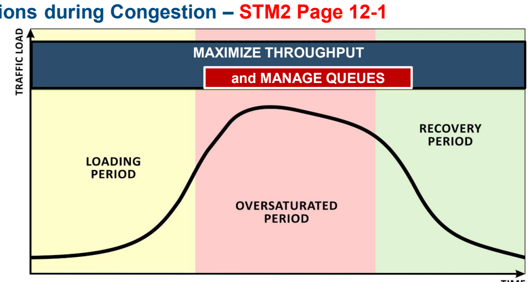
Actions during Congestion – STM2 Page 12-1



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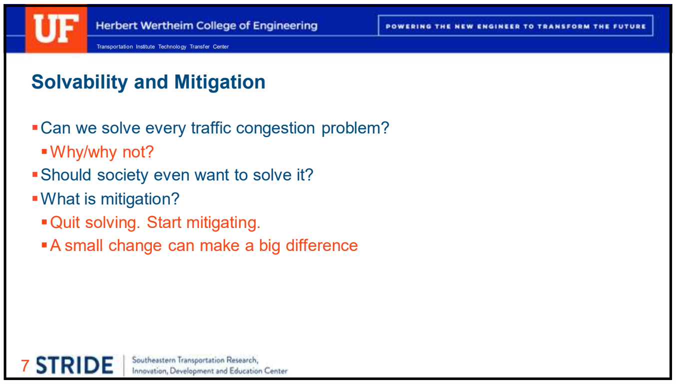
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Solvability and Mitigation
▪Can we solve every traffic congestion problem?
▪Why/why not?
▪Should society even want to solve it?
▪What is mitigation?
▪Quit solving. Start mitigating.
▪A small change can make a big difference
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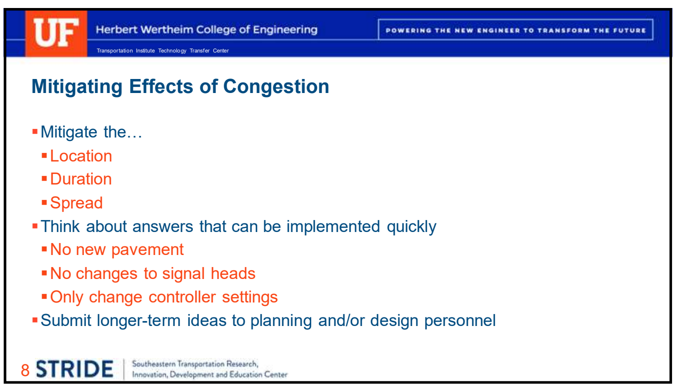
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Mitigating Effects of Congestion
▪Mitigate the…
▪Location
▪Duration
▪Spread
▪Think about answers that can be implemented quickly
▪No new pavement
▪No changes to signal heads
▪Only change controller settings
▪Submit longer-term ideas to planning and/or design personnel
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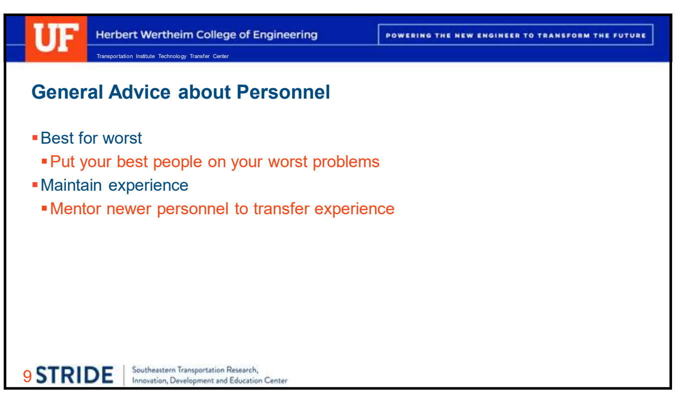
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General Advice about Personnel
▪Best for worst
▪Put your best people on your worst problems
▪Maintain experience
▪Mentor newer personnel to transfer experience
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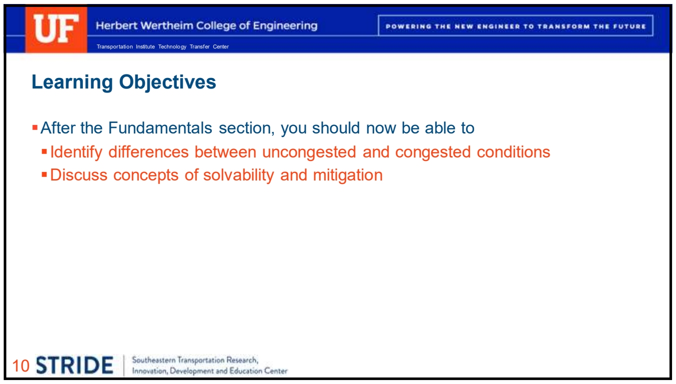
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Learning Objectives
After the Fundamentals section, you should now be able to
Identify differences between uncongested and congested conditions
Discuss concepts of solvability and mitigation
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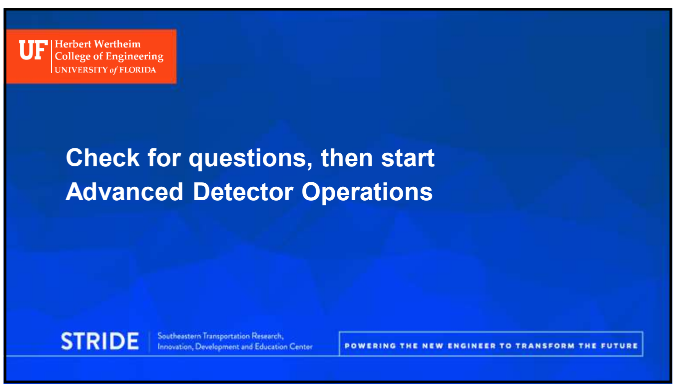
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Check for questions, then start Advanced Detector Operations
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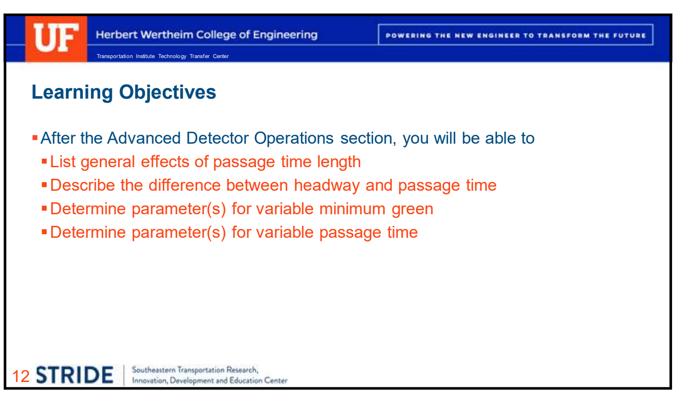
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Learning Objectives
After the Advanced Detector Operations section, you will be able to
List general effects of passage time length
Describe the difference between headway and passage time
Determine parameter(s) for variable minimum green
Determine parameter(s) for variable passage time
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Headway, Passage Time, Gap, and Minimum Gap vs. Controller Manufacturers

- These terms may not be used/may not mean the same thing in all controllers
  - Part of our free-market economy
  - Not intended to be confusing
  - Read the controller manual

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Effects of Passage Time

Headway (sec)	Resulting Flow (vph)	Passage Time Impact on…		
		Phase Fails	Wait Time	Throughput
2	1800	Longer is Better	Moderate is Better	Shorter is Better
2.4	1500			
3	1200			
4	900			
6	600			

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Volume-Density Timing

- Have you heard of it?
- Really 2 features
  - "Volume" part is variable minimum green
  - "Density" part is variable passage time
- Name made people think you had to use both and thus it was complicated
  - Choose the part(s) you need for each intersection
  - Not very complicated

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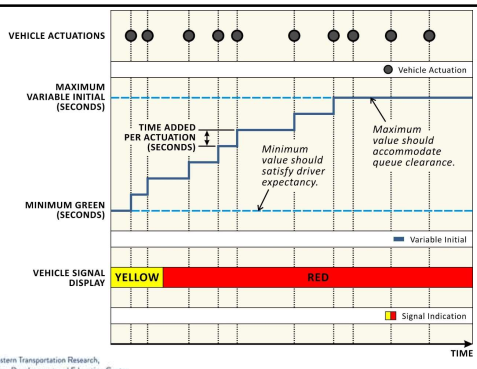
“Volume” Part = Variable Min Green for Setback Detectors STM2 Page 6-7



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Suggested Variable Minimum Green Parameters – STM2 Page 6-7

- Table values are based on single lane approaches
- What changes for multilane approaches?

Distance Between Stop Bar and Nearest Setback Detector (Feet)	Minimum Green (Seconds)	Maximum Variable Initial (Seconds)	Seconds Added per Actuation[1]
275	10	25	2.0
350	10	31	2.0
425	10	37	2.0
500	10	43	2.0

[1] Seconds added per actuation assumes approximately 2-second headways.

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“Density” Part = Variable Passage Time

- At phase start, use a generous passage time to prevent early phase termination
  - Drivers not paying attention
  - Vehicles with poor acceleration
- Later, reduce passage time to improve intersection efficiency
  - Requires higher flow rate to continue green
  - Ends the green as flow becomes inefficient

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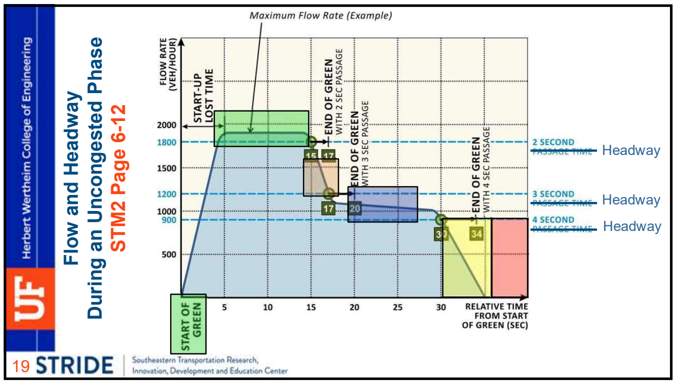
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Flow and Headway
During an Uncongested Phase
STM2 Page 6-12
Maximum Flow Rate (Example)
FLOW RATE (VEH/HOUR)
START-UP LOST TIME
END OF GREEN WITH 2 SEC PASSAGE
END OF GREEN WITH 3 SEC PASSAGE
END OF GREEN WITH 4 SEC PASSAGE
2 SECOND PASSAGE TIME
Headway
3 SECOND PASSAGE TIME
Headway
4 SECOND PASSAGE TIME
Headway
START OF GREEN
RELATIVE TIME FROM START OF GREEN (SEC)
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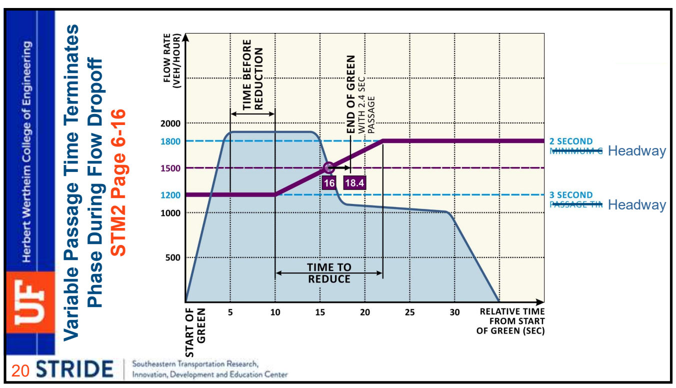
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Variable Passage Time Terminates
Phase During Flow Dropoff
STM2 Page 6-16
FLOW RATE (VEH/HOUR)
TIME BEFORE REDUCTION
END OF GREEN WITH 2.4 SEC PASSAGE
2 SECOND MINIMUM
Headway
3 SECOND PASSAGE TIME
Headway
TIME TO REDUCE
START OF GREEN
RELATIVE TIME FROM START OF GREEN (SEC)
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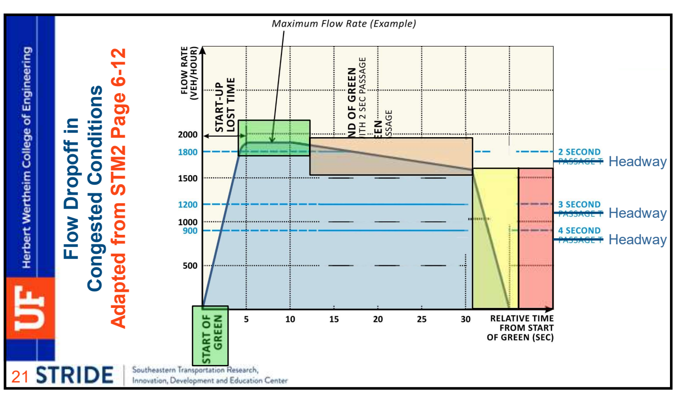
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Flow Dropoff in
Congested Conditions
Adapted from STM2 Page 6-12
Maximum Flow Rate (Example)
FLOW RATE (VEH/HOUR)
START-UP LOST TIME
2 SECOND PASSAGE T
Headway
3 SECOND PASSAGE T
Headway
4 SECOND PASSAGE T
Headway
START OF GREEN
RELATIVE TIME FROM START OF GREEN (SEC)
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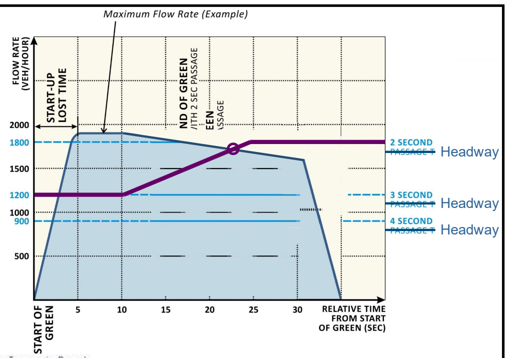
Still Want to Terminate Phase During Flow Dropoff

Adapted from STM2 Page 6-12



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Determining Inputs for Variable Passage Time
1. Choose Generous Headway to Start

Flow (vph)	Headway (sec/veh)
600	6
900	4

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2. Choose Desired Minimum Flow
3. Calculate Associated Headway

Flow (vph)	Headway (sec/veh)
600	6
900	4
1200	3
1500	**2.4**
1800	2

- Choose **1500 vph** as min flow:

$$Headway = \frac{3600\ ^{sec}/_{hr}}{Min\ Flow}$$

$$= \frac{3600\ sec/hr}{1500\ vph} = \mathbf{2.4\ sec/veh}$$

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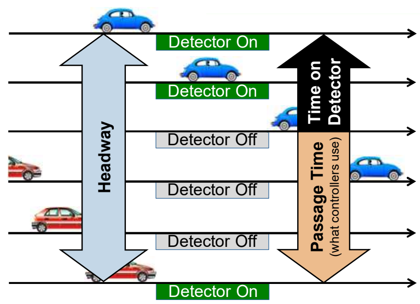
Controllers Use Passage Time, Not Headway



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4. Convert Headway to Passage Time

$$Passage\ Time = Headway\ - Time\ on\ Detector$$

$$= Headway\ - \frac{Vehicle\ Length + Detector\ Length}{Speed\ in\ ft/sec}$$

- Desired Flow = (chosen) 1500 → Desired Headway = (calculated above) **2.4 sec**
- Vehicle Length = (typical) **20 ft.**
- Detector Length = (field value) **30 ft**
- Posted Speed Limit = (field value) **45 mph**
- Speed in ft/sec = (must calculate)

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Headway to Passage Time Sample Problem Results

- Convert speed from MPH to ft/sec

$$ft/sec = mph\ (\frac{5280\ ft/mi}{3600\ sec/hr}) = 45\left(\frac{5280}{3600}\right) = \mathbf{66}$$

- Calculate Passage Time

$$Passage\ Time = Headway\ - \frac{Vehicle\ Length + Detector\ Length}{Speed\ in\ ft/sec}$$

$$= 2.4 - \frac{20+30}{66} = 2.4 - 0.88 = 1.52$$

$$= \mathbf{1.5}\ (flow = 1512)\ \mathbf{or\ 1.6}\ (flow = 1451)$$

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Learning Objectives

- After the Advanced Detector Operations section, you should now be able to
  - List general effects of passage time length
  - Describe the difference between headway and passage time
  - Determine parameter(s) for variable minimum green
  - Determine parameter(s) for variable passage time

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Check for questions, then start Congested Intersections

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Learning Outcomes

- After the Congested Intersections section, you will be able to:
  - Identify 3 causes of congestion
  - Match mitigation methods to intersection conditions

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Before We Begin…

- What does a congested intersection look like?
- What do drivers expect at a congested intersection?
- Does the whole intersection have to be "congested" to call it "congested"?

- Recurring vs. non-recurring congestion
  - Focusing on recurring, but strategies work for both

- What does throughput mean?
- Why is throughput important during congestion?

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Four Causes of Congestion at Traffic Signals

- Inappropriate timing or failed equipment
- Problematic geometry
- Excess demand
- Spillback from downstream issues

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Addressing Inappropriate Timing or Failed Equipment

- **Inappropriate timing or failed equipment**
- Problematic geometry
- Excess demand
- Spillback from downstream issues

- **Fix these**

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Addressing Problematic Geometry

- Inappropriate timing or failed equipment
- **Problematic geometry**
- Excess demand
- Spillback from downstream issues

- Fix these
- **Lead-lag phasing, phase reservice, and short bay method**

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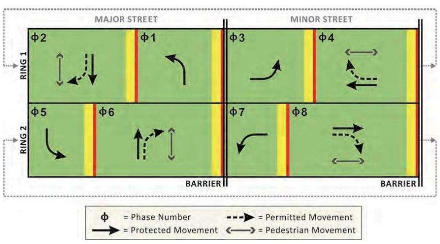
What is lead-lag phasing? – STM2 Page 5-11

- Altering the order in which phases are served
- Phase 1, the NB Left, has been lagged
- Any left turn can lead or lag as needed



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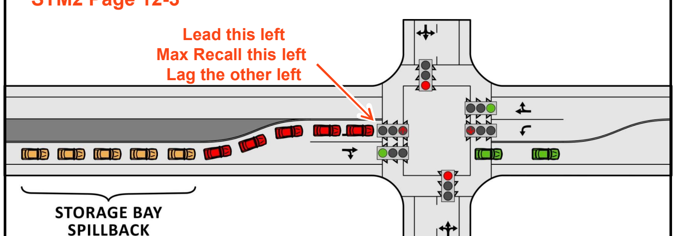
Mitigate Storage Bay Spillback with Lead-Lag Phasing STM2 Page 12-3



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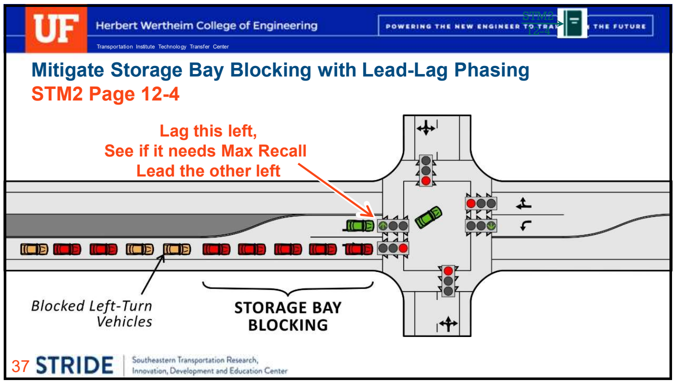
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POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE
Mitigate Storage Bay Blocking with Lead-Lag Phasing
STM2 Page 12-4
Lag this left,
See if it needs Max Recall
Lead the other left
Blocked Left-Turn Vehicles
STORAGE BAY BLOCKING
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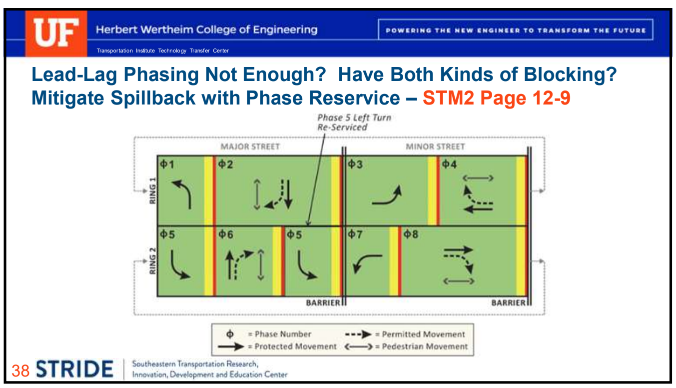
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Lead-Lag Phasing Not Enough? Have Both Kinds of Blocking?
Mitigate Spillback with Phase Reservice – STM2 Page 12-9
Phase 5 Left Turn Re-Serviced
MAJOR STREET
MINOR STREET
RING 1
RING 2
Φ1
Φ2
Φ3
Φ4
Φ5
Φ6
Φ5
Φ7
Φ8
BARRIER
BARRIER
Φ = Phase Number
= Protected Movement
= Permitted Movement
= Pedestrian Movement
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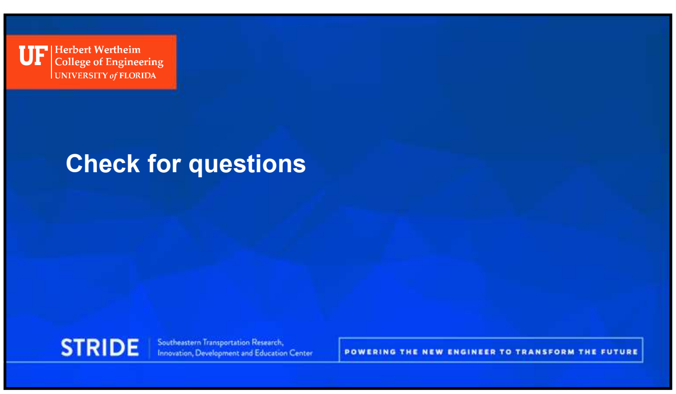
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Check for questions
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Mitigate Storage Bay Spillback with Short Bay Method

Steps		Formula	Known	Example
1.	Convert storage bay length from feet to number of vehicles	$n = \frac{d}{L_v}$	200 ft. bay	200 / 20 = **10 veh**
2.	Convert storage bay flow to seconds between arrivals	$r = \frac{3600\ ^{sec}/_{hr}}{v_b}$	400 vph	3600 / 400 = **9 sec**

d = length of storage bay in feet

L_v = length of vehicle + distance gap in feet (20-25 ft.) – sample problem use **20 ft**

v_b = flow in storage bay, vehicles per hour

r = seconds between arrivals

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Mitigate Storage Bay Spillback via Short Bay Method (cont.)

Steps		Formula	Known	Example
3.	Calculate cycle length	$C = nr$	---	10 * 9 = **90 sec**
4.	Calculate length of green for storage bay	$G_b = 3 + 2n$	---	3 + 2*10 = **23 sec**
5.	Divide remainder of cycle length among other phases	You Choose How		

C = cycle length (sec)

G_b = green for storage bay (sec)

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Addressing Excess Demand

- Inappropriate timing or failed equipment
  - Fix these!
- Problematic geometry
  - Lead-lag phasing, phase reservice, and short bay method
- **Excess demand**
  - **Maximize throughput:**
    - **Minimize unused green, improve lane flow, and priority movements**
- Spillback from downstream issues

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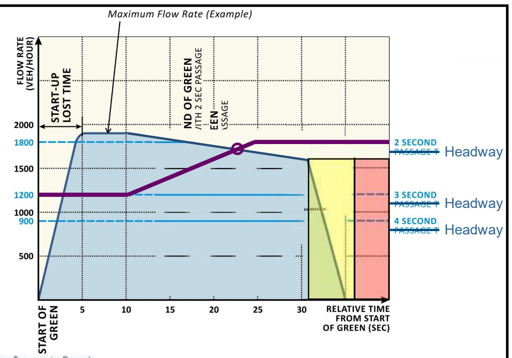
Minimize Unused Green via Variable Passage Time

Adapted from STM2 Page 6-16



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Improve Lane Flow by Dropping Out of Coordination

- Coordination is inherently less efficient
  - Fixed cycle length can cause low flow periods

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Improve Lane Flow Using Lane-by-Lane Detection

- New concept for operations
  - May not be available in all controllers
  - Not all detector configurations are supported
- Requires multilane
- Most efficient when phase terminates when first lane gaps out

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Address Excess Demand by Priority Movements

- Identify movements with space for queuing
- Give less-than-sufficient green times to these movements
  - Makes more green time available for movements without queuing space

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Learning Outcomes

- After the Congested Intersections section, you should now be able to:
  - Identify 3 causes of congestion
  - Match mitigation methods to intersection conditions

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Check for questions, then start Congested Systems

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Learning Outcomes

- At the end of the lesson, you will be able to:
  - Identify a 4th cause of congestion
  - List methods for addressing spillback from downstream issues
  - Explain how those methods work

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Before We Begin…

- What does a network of congested intersections look like?
- What do drivers expect in a congested network?
- Is one congested intersection enough to make a congested network?
  - Why/why not?
- What does managing queues mean?

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Congested Network Conditions

- Are not well understood
- Have methods, but no equations
  - This section presents guiding principles
  - Optimize parameters via engineering judgement and field trials
- Do not respond well to uncongested network methods

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Congested Systems Require a Change in Mindset

- Uncongested Network
  - All about progression
- Congested Network
  - Uses coordination, but rarely provides progression
  - Solutions often non-intuitive

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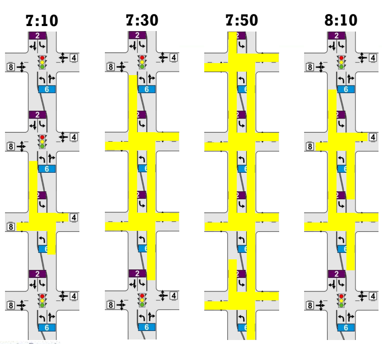
Network Congestion Has Both Temporal and Spatial Effects

Adapted from STM2 Page 7-10



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Addressing Spillback from Downstream Issues

- Inappropriate timing or failed equipment
- Fix these!
- Problematic geometry
- Lead-lag phasing, phase reservice, and short bay method
- Excess demand
- Maximize throughput:
  - Minimize unused green, improve lane flow, and store vehicles
- **Spillback from downstream issues**
- **Manage Queues**
  - **Gating (Metering), Prevent Unsafe Queues, Simultaneous Offsets, Negative Offsets, Double Cycling, and Truncating Phases**

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Addressing Spillback from Downstream Issues via Gating

- Find the bottleneck
  - Where the queueing starts
  - Focus on throughput at the bottleneck
- Upstream of the bottleneck (in multiple directions)
  - Design cycle and splits to limit the flow toward the bottleneck
  - Limit flow to just under bottleneck capacity
  - Bottleneck queues should fit in available space
  - Bottleneck queues should be served every cycle

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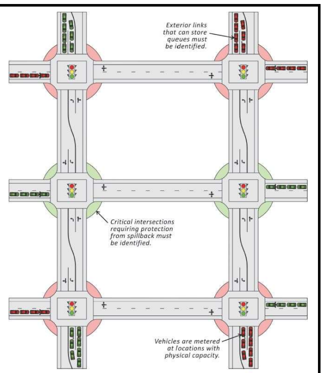
Example of Gating
STM2 Page 12-20

- Green intersections must be protected
- Gating occurs at red intersections



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Addressing Spillback from Downstream Issues by Preventing Unsafe Queues

- Identify priority movements
  - Movements that create safety issues if underserved
- Identify route that serves priority movements
  - All the way through the network
- Give preferential treatment to that route
  - Allocate sufficient green to priority movements
  - Provide smooth flow to priority movements
- Keep doing this until unsafe queueing is no longer an issue
  - Even if it causes other operational issues (it will!)

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Route for Heavy Ramp to Eastbound on Arterial

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Addressing Spillback from Downstream Issues by Using Simultaneous Offsets

- Simultaneous offsets naturally gate traffic
  - Sometimes at good places, sometimes not
- Use longer cycle lengths
  - Get the whole arterial moving before turning all signals red
- Can create stops at most/all intersections

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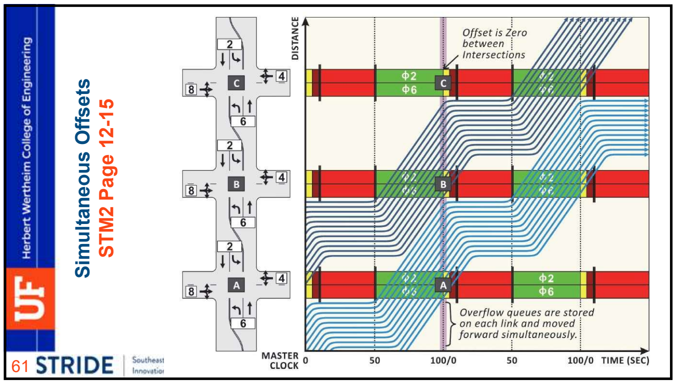

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Addressing Spillback from Downstream Issues by Using Negative Offsets

- Similar to simultaneous offsets
  - Helps some traffic to move more than 1 intersection at a time
- Like simultaneous, negative offsets naturally gate traffic
  - Frequently better locations than simultaneous
- Very difficult to get entire network to move at one time

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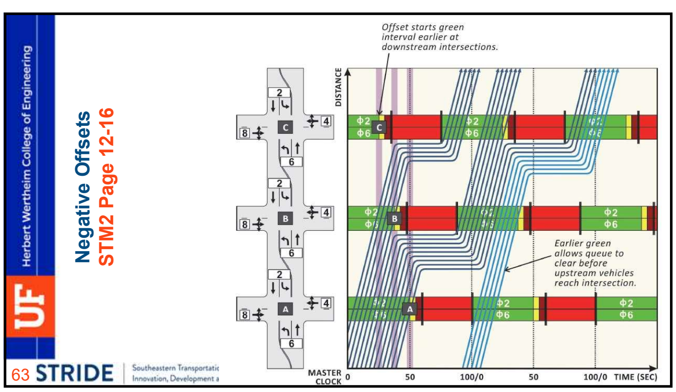

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Addressing Spillback from Downstream Issues by Using Double Cycling

- Essentially creates split side street phasing
  - Serves each side every other cycle
- Can generate calls from the public
  - Don't understand why they were skipped

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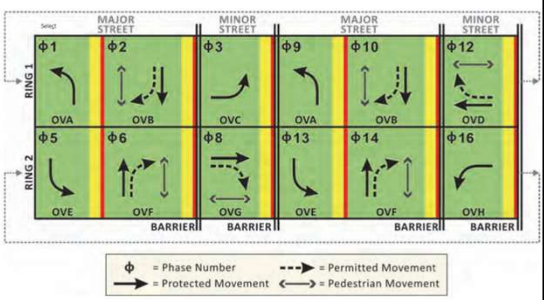
Example of Double Cycling
STM2 Page 12-10



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Addressing Spillback from Downstream Issues by Truncating Phases

- New concept for operations
  - May not be available in all controllers
  - Not all detector configurations are supported
- Detects when a queue is not moving despite having green
  - Terminates the phase to avoid wasting time

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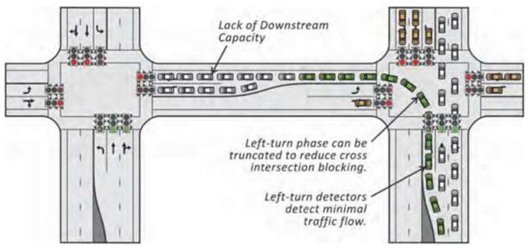
How Truncating Phases Works

STM2 Page 12-11



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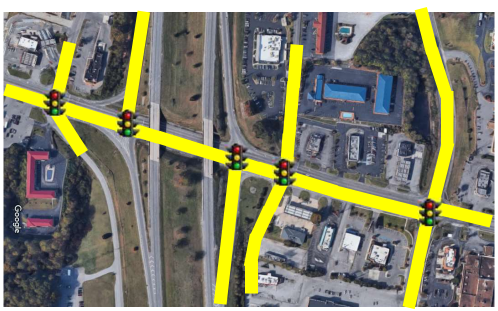
Putting it All Together: Changing Operation as Congestion Spreads



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Learning Outcomes

- At the end of the lesson, should be able to:
  - Identify a 4th cause of congestion
  - List methods for addressing spillback from downstream issues
  - Explain how those methods work

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Thank you for Participating!
Advanced Traffic Signal Timing
Feel free to contact me!
Dr. Steven M. Click, PE
sclick@tntech.edu
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