



An Applied Technology and Traffic Analysis Program



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School of Engineering

Advanced signal control

Dr. Gang-Len Chang
Professor and Director of
Traffic Safety and Operations Lab.
University of Maryland-College Park



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Major Topics

Lecture-1: Intersection traffic control principles

Fundamental of signal design

Elements of Intersection design and layout

Lecture-2: intersection capacity and analysis

HCM-method

CLV method

Some critical issues

Software applications



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Lecture -3: Data collection technologies

Data needs for signal design

Detector types and operational summary

Detector locations and configurations

Lecture-4: Pretimed signal design for isolated intersections

Conventional methods and numerical examples

Optimization methods

TRANSYT method

Robust optimization methods.

Software applications



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Lecture-5: Actuated intersection signal control

Actuated control and operational features
Actuated control signal timing and design
Detection location strategies
Pedestrian requirements
Design examples

Lecture-6: Arterial signal coordination

Principles of arterial signal coordination
Critical progression on two-way streets
Common progression operations
Maxband progression model
Coordination for oversaturated arterial
intersections
Comments on software applications



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Lecture-7: Bus-priority design for intersection control

Bus-priority operational types

Detection hardware and technology

Priority-design methodology for actuated control

Priority-design methodology for local adaptive signal control

Real-world applications and challenging issues

Lecture-8: Design of unconventional intersections

Design concept for Continuous-Flow intersections (CFI)

Preliminary design method for CFI

Signal design and operational analysis for CFI.

Design concept for Diverge-Diamond interchange (DDI)

Preliminary design method for DDI

Signal design and operational analysis for DDI.

Software applications



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Lecture-9: Adaptive network system control

- Basic adaptive control concepts
- Local adaptive control models
- SCOOT system design logic and analysis
- SCAT system design logic and analysis
- ROHODES system design
- OPAC design logic and analysis
- Comments on adaptive control



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Lecture-1: Intersection traffic control- some general concepts

1. Why control?
2. What data are needed?
3. What type of controls?
4. - no control
5. - two-way stop control
6. - 4-way stop control
7. - isolated signal control
8. - coordinated arterial control
9. - network control



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Signal Timing Steps

- 1) Divide system into sections (zones, subsystems)
- 2) Collect traffic data
- 3) Select measures of effectiveness
- 4) Determine times of day for timing plans
- 5) Determine whether saturated
- 6) Calculate timing
- 7) Simulate & fine tune
- 8) Install in field & observe – fine tune as needed



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Definition of a section

A section is a group of intersections that are analyzed, optimized and operated together.

For example, a timing plan is defined for a section. This plan is implemented simultaneously for all intersections in the section.



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Why are sections needed?

- Operationally – It is necessary to operate groups of signals differently:
 - Different control modes – manual, time-of-day, etc.
 - Different times of day for plan changes
- Mathematically – Optimization of smaller groups of signals tend to give better results
- Practically – Difficult to manage the data collection, data inputs, install, test, etc. for very large numbers of intersections



Selecting Section Boundaries

- Intersection spacing is the primary criterion (depends on midblock friction)
- Natural boundaries can be used as indicators (bridges, RR grade crossings, crossing arterials, etc.)
- Changes in traffic flow characteristics (CBD vs. arterial flow, etc.)
- Political jurisdictions (not a good reason)
- Somewhat subjective



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Measures of Effectiveness (MOEs)

- Stops and Delays
 - Readily quantified
 - Output of most optimization programs
- Emissions (environmentalists want to know)
- Fuel consumption (a passing fancy)
- Travel time
 - Public can relate
 - Politicians most interested



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Identifying Saturation

- Growing queues
- Cycle failures
- Turn lanes blocking thru movements
- Occupancy > 25%



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Under saturated vs. Saturated

- Saturated conditions characterized by changing circumstances (growing queues)
- Under saturated conditions characterized by constant conditions (constant queue lengths)
- MOEs are different
 - Under saturated – minimize stops and delays, maximize bandwidth
 - Saturated – avoid spillback, prevent turn bay overflows, minimize duration of problem
- Signal timing software is designed for under-saturated conditions



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Table 1.1: Important Statistics on U.S. Highways

Statistic	2007	2008
Miles of public roadway	4.05 million	4.04 million
Vehicle-miles traveled	3.05 trillion	2.93 trillion
Total population of United States	301 million	304 million
Licensed drivers	205 million	208 million
Registered vehicles	247 million	248 million
Total receipts: Taxes, fees, tolls, general fund allocations	\$161 billion	
Total expenditures: Federal, state, local	\$161 billion	
Fatalities	41,059	37,261



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Table 20.1 Signal Controllers and Types of Intersection Control

Table 20.1: Signal Controllers and Types of Intersection Control					
Type of Operation	Pretimed		Semi-Actuated	Actuated	
	Isolated	Coordinated		Fully Actuated	Coordinated
Fixed Cycle Length?	Yes	Yes	No	No	Yes
Conditions Where Applicable	Where detection is not available.	Where traffic is consistent, closely spaced intersections, and where cross street is consistent.	Where defaulting to one movement is desirable, major road is posted <40 mi/h and cross road carries light traffic demand.	Where detection is provided on all approaches, isolated locations where posted speed is >40 mi/h.	Arterial where traffic is heavy and adjacent intersections are nearby.
Example Application	Work zones.	Central business districts, interchanges.	Highway operations.	Locations without nearby signals; rural high-speed locations; intersections of two arterials.	Suburban arterial.
Key Benefit	Temporary application keeps signals operational.	Predictable operations. Lowest cost of equipment and maintenance.	Lower cost for highway maintenance.	Responsive to changing traffic patterns, efficient allocation of green time, reduced delay, and improved safety.	Lower arterial delay, potential reduction in delay for the system, depending upon the settings.

(Source: Koonce, P., et al., *Traffic Signal Timing Manual*, Final Report, FHWA Contract No. DTFH61-98-C-00075, Kittelson and Associates Inc, Portland, OR, June 2008, Table 5-1, p. 5-3.)

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**Table 4.2: Minimum Sight Distances
for Signal Faces**

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

*(Source: Manual of Uniform Traffic Control
Devices, Draft, Federal Highway Administration,
Washington DC, December 2007, Table 4D-1.)*

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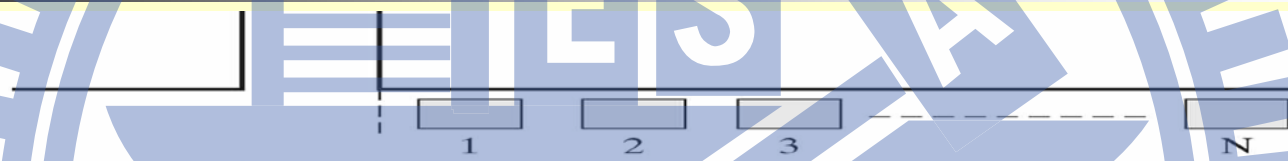
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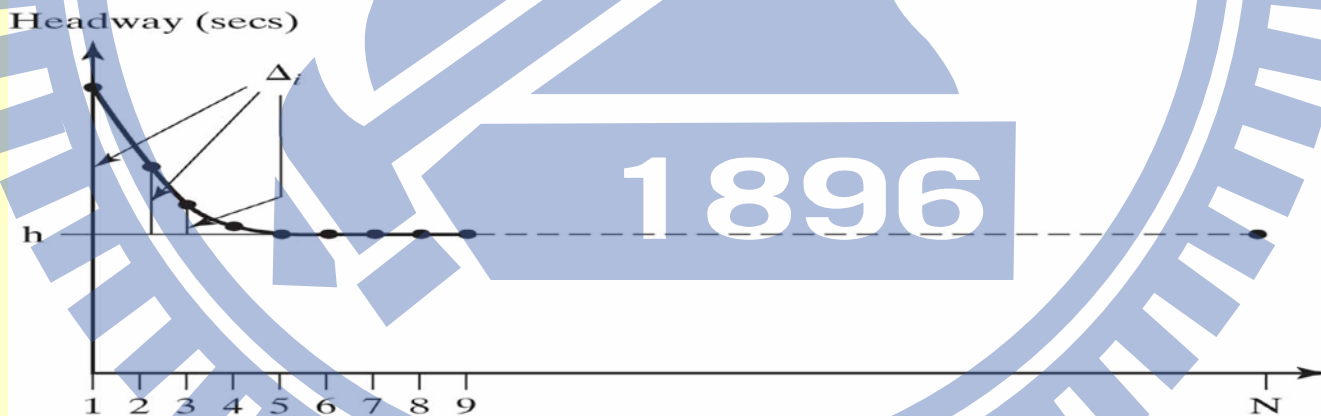
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Flow Departing from a Queue at a Signalized Intersection



(a) Vehicles in an Intersection Queue



(b) Average Headways Departing Signal

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Table 20.2: Saturation Flow Rates from a Nationwide Survey

Item	Single-Lane Approaches	Two-Lane Approaches
Number of Approaches	14	26
Number of 15-Minute Periods	101	156
Saturation Flow Rates		
Average	1,280 veh/hg/ln	1,337 veh/hg/ln
Minimum	636 veh/hg/ln	748 veh/hg/ln
Maximum	1,705 veh/hg/ln	1,969 veh/hg/ln
Saturation Headways		
Average	2.81 s/veh	2.69 s/veh
Minimum	2.11 s/veh	1.83 s/veh
Maximum	5.66 s/veh	4.81 s/veh

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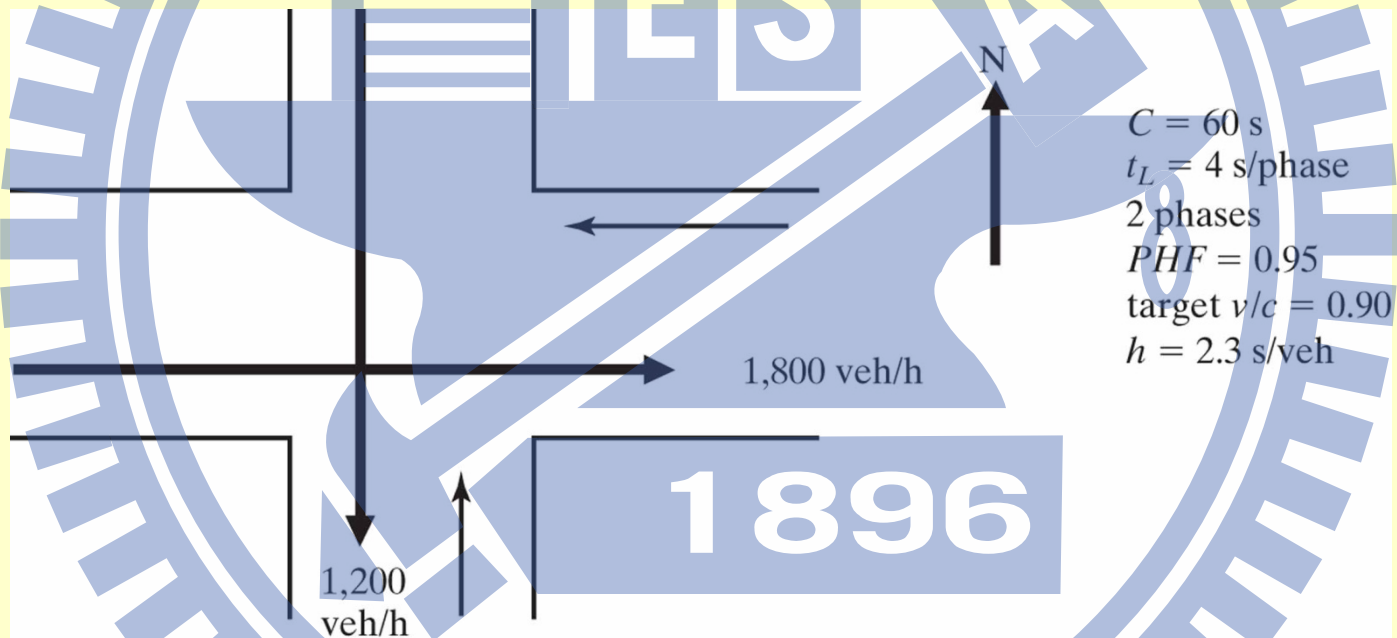
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Critical lane concept



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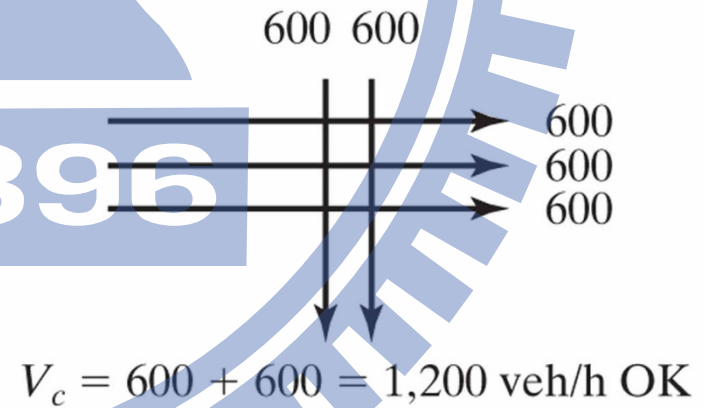
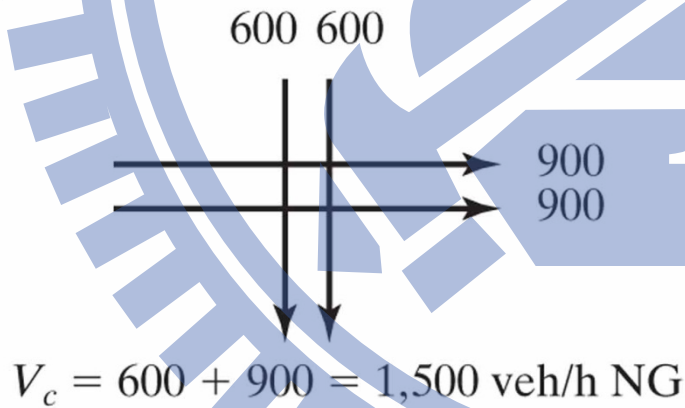
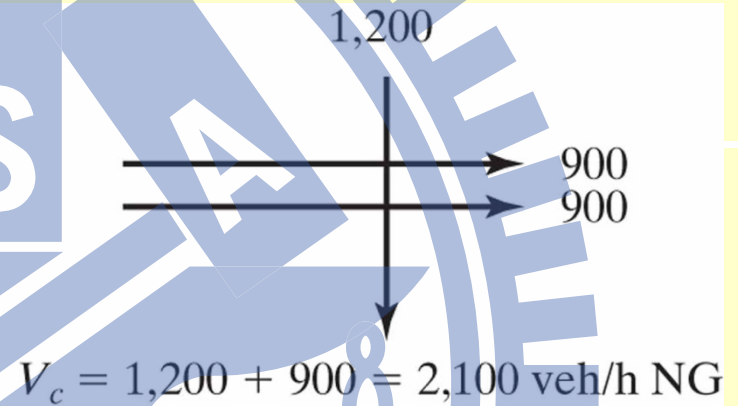
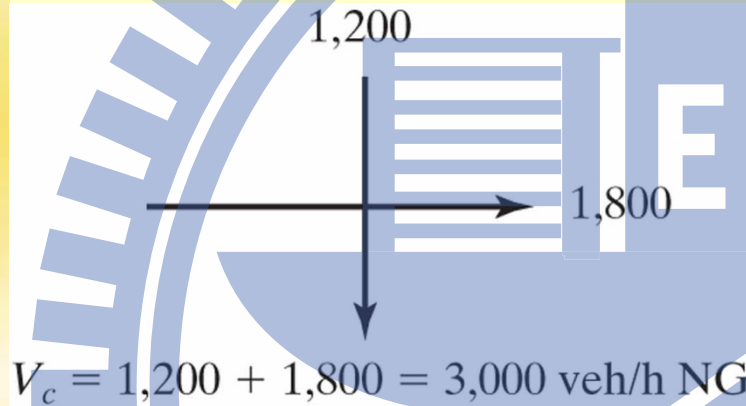
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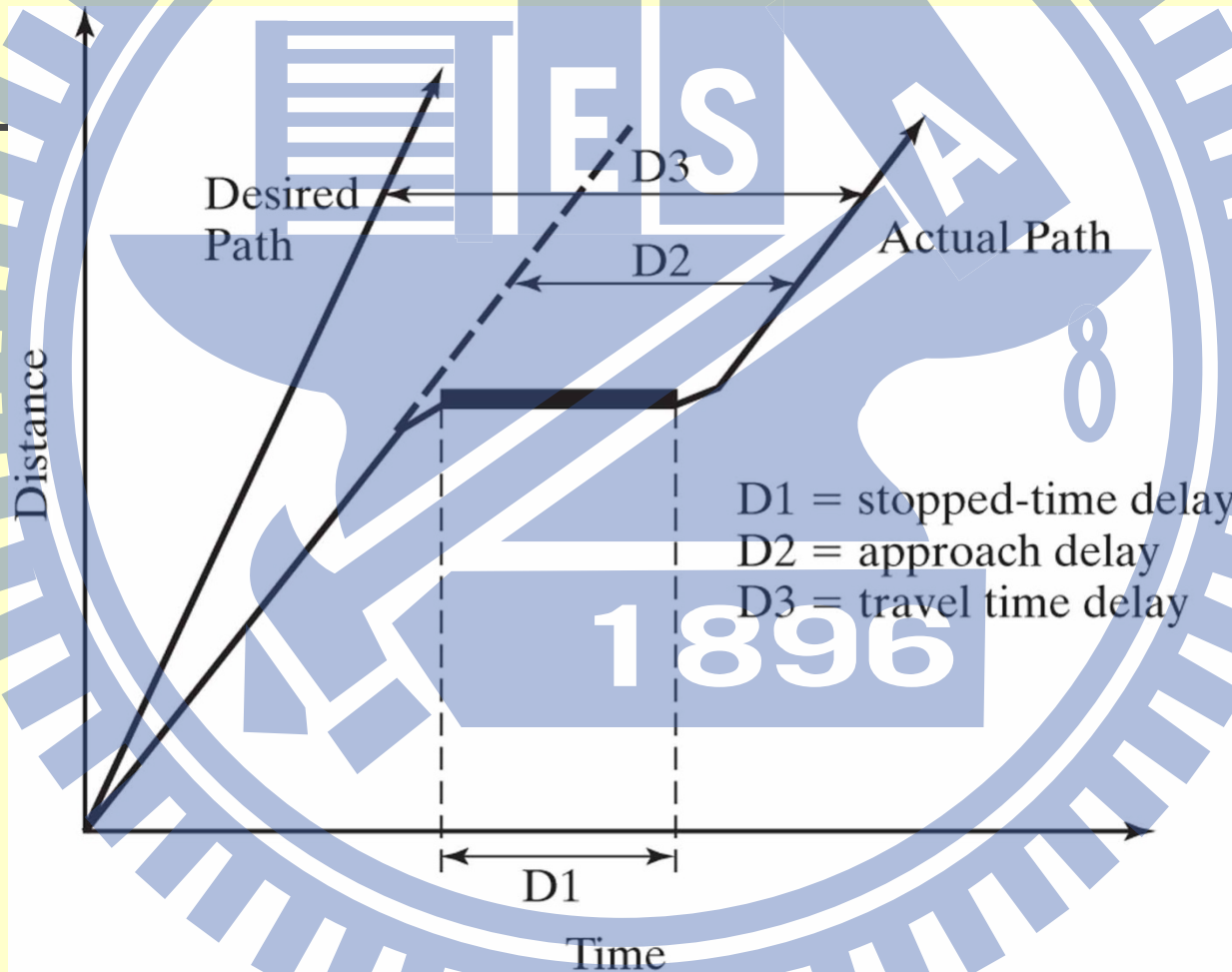
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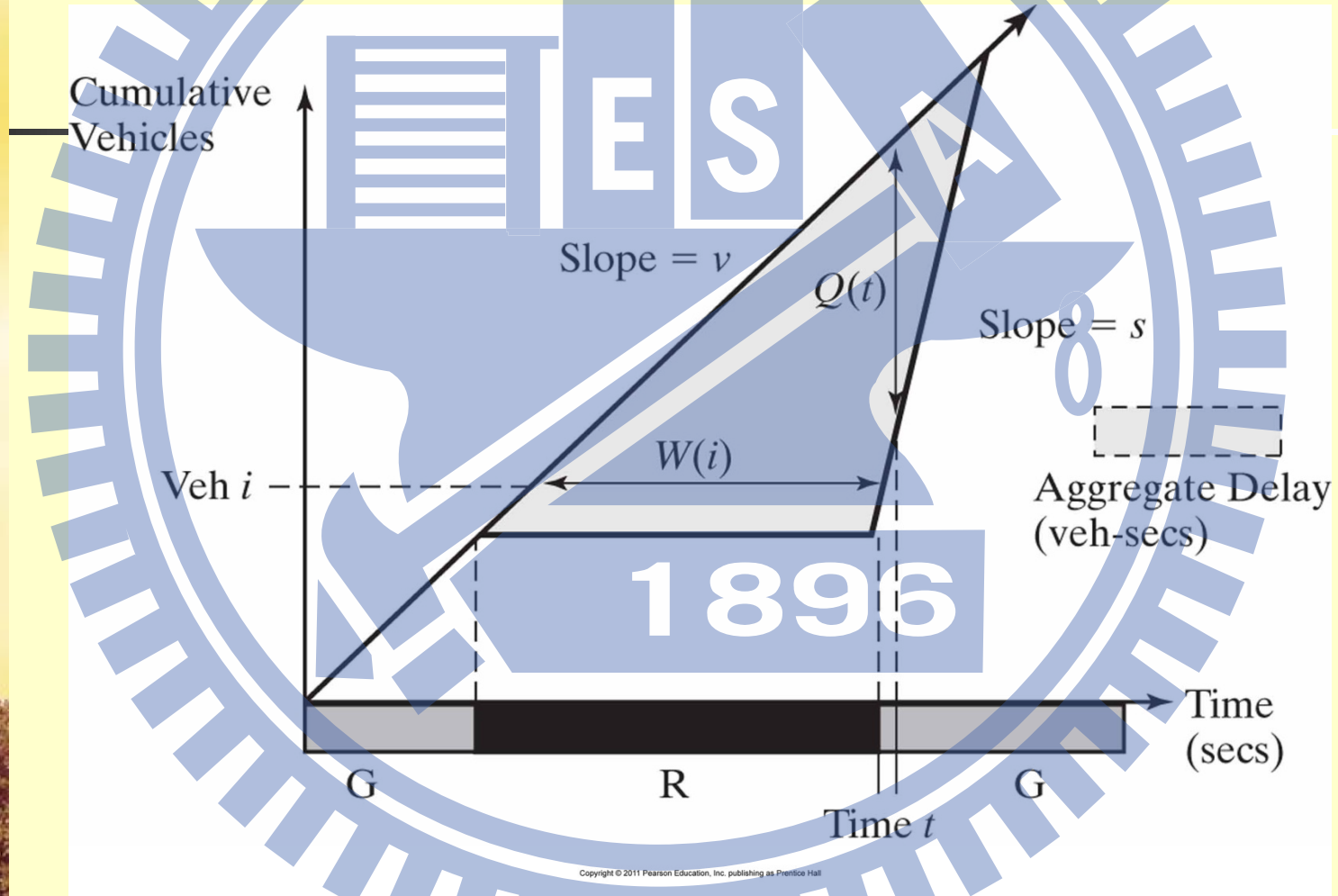
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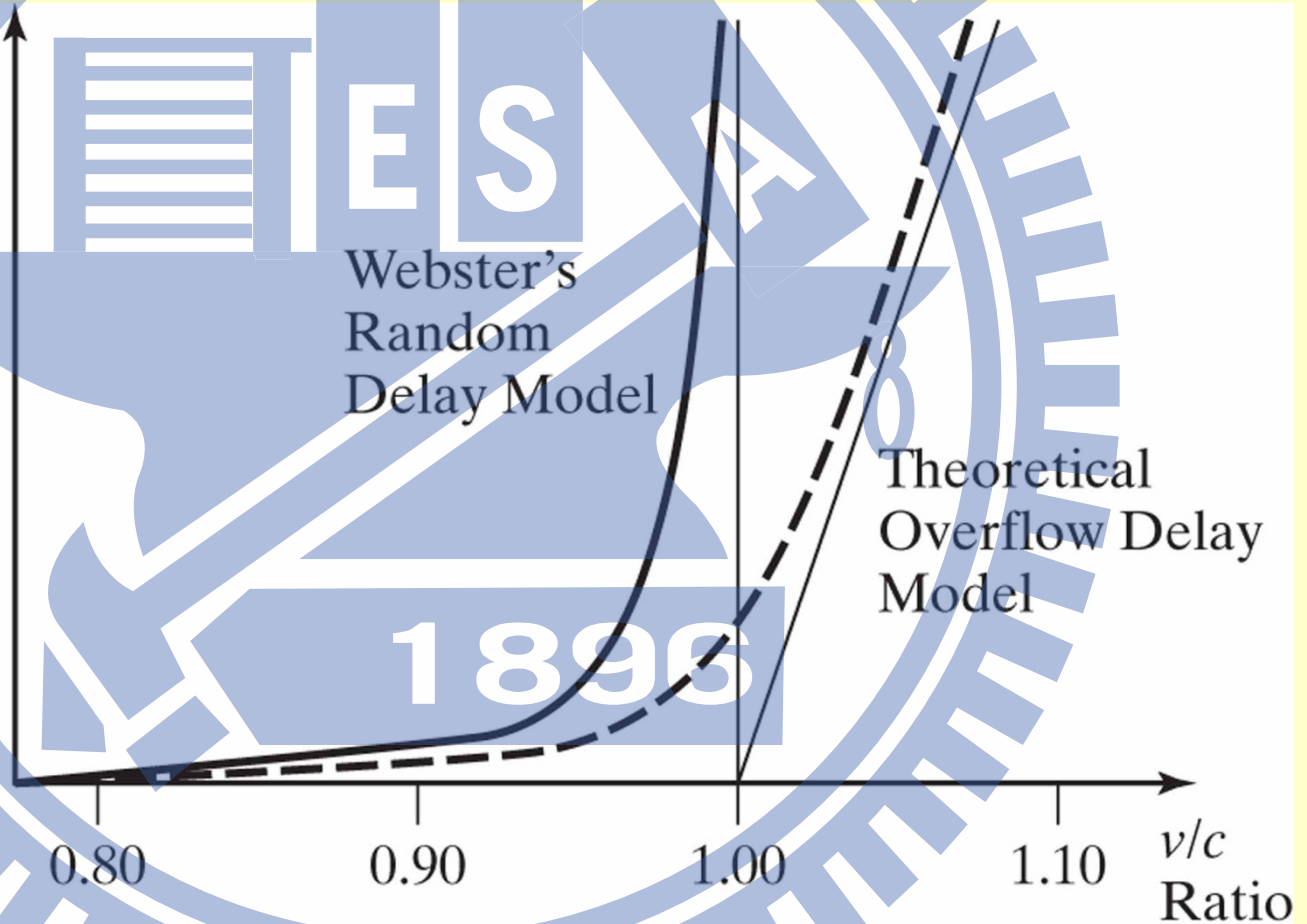
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Average
Overflow
Delay

Webster's
Random
Delay Model

Theoretical
Overflow Delay
Model



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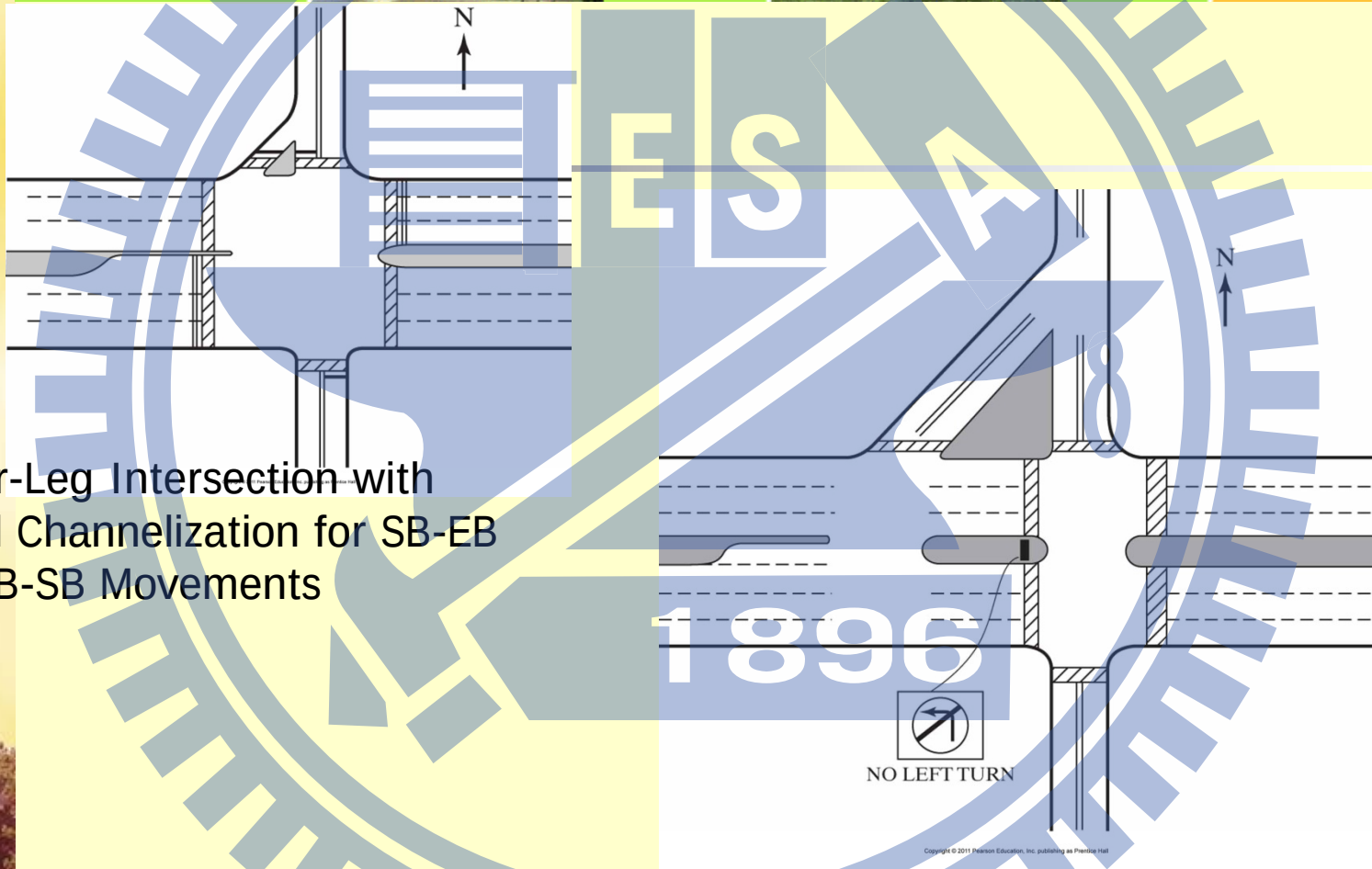
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A Four-Leg Intersection with
Partial Channelization for SB-EB
and EB-SB Movements

A Four-Leg Intersection Channelization for
Major SB-EB and EB-SB Movements





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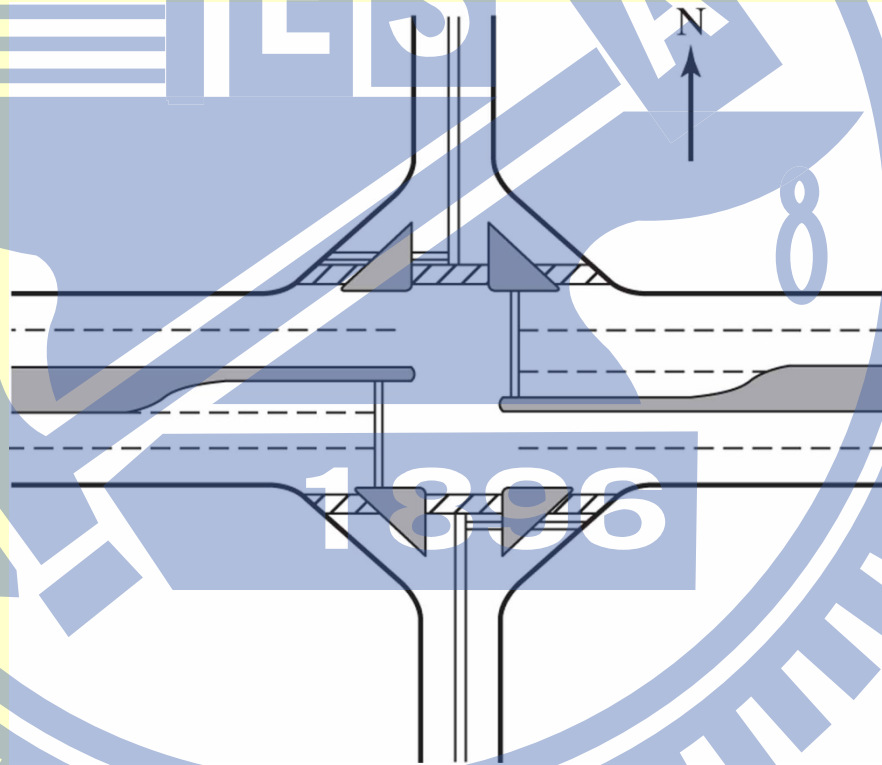
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A Four-Leg Intersection with Full Channelization of Right Turns



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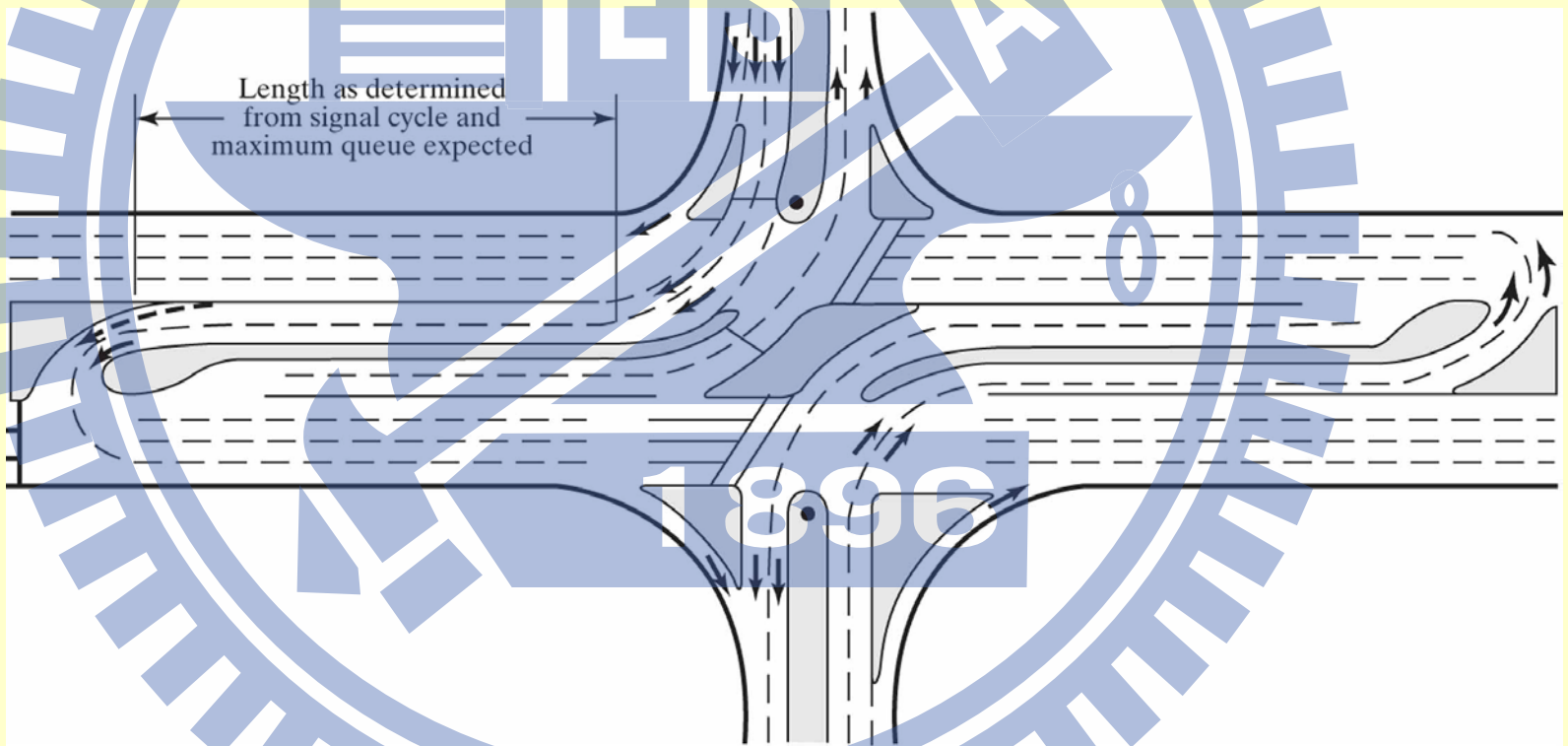


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Figure 19.4 Channelization of a Complex Intersection (*Source:*

Used with permission of Institute of Transportation Engineers, R.P. Kramer, "New Combination of Old Techniques to Rejuvenate Jammed Suburban Arterials," *Strategies to Alleviate Traffic Congestion*, Washington DC, 1988.)



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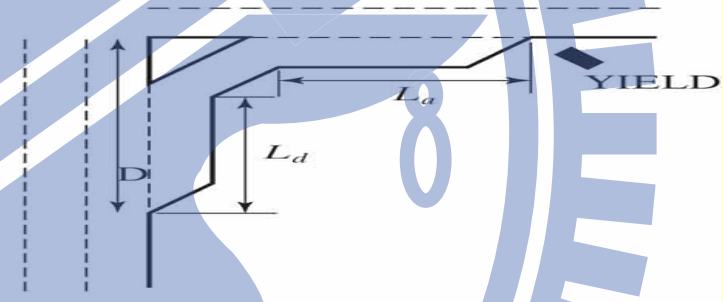


- No acceleration or deceleration lanes.
- Problem: queued vehicles may block access to right-turn lane.



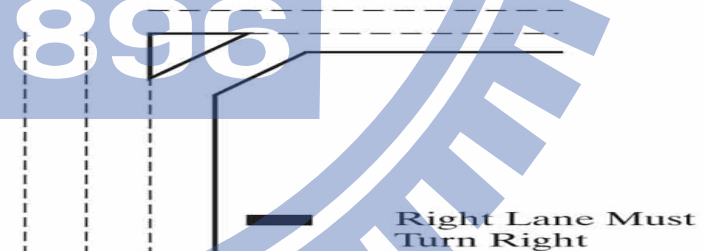
(a) Simple Channelized Right Turn

- "D" should be long enough to encompass the longest expected queue plus one vehicle.
- L_d allows right-turning vehicles to decelerate.
- L_a allows right-turning vehicles to accelerate.



(b) Channelized Right Turn with
Acceleration and Deceleration Lanes

- Generally requires a RT demand of 500 veh/h or more.



(c) Channelized Right Turn with Lane
Drop and Lane Addition

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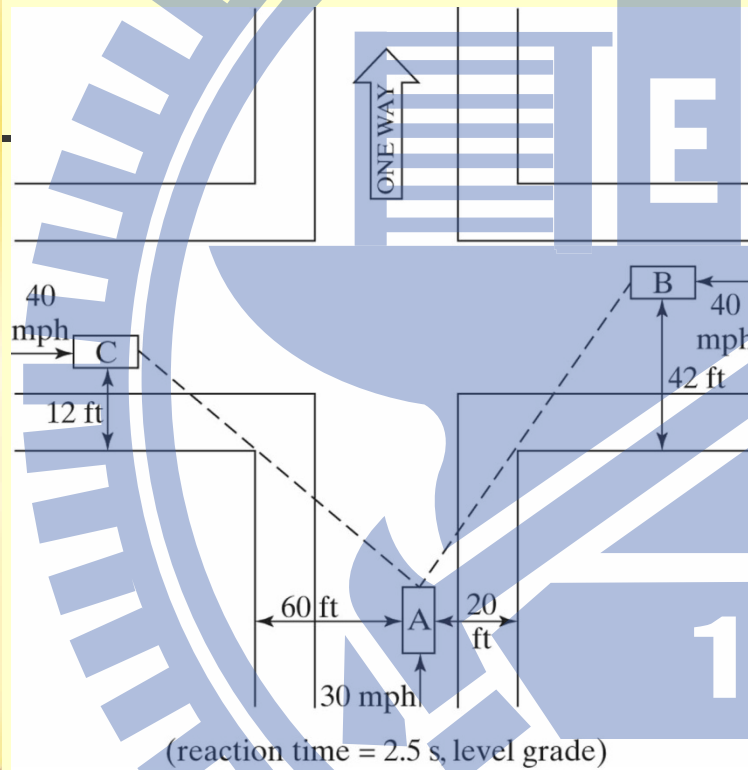
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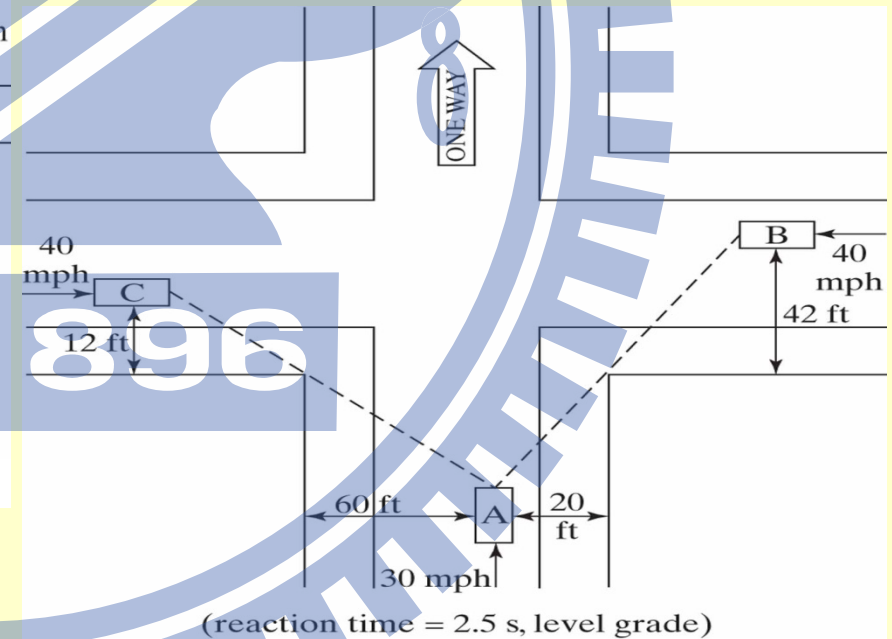
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Intersection Sight Distance



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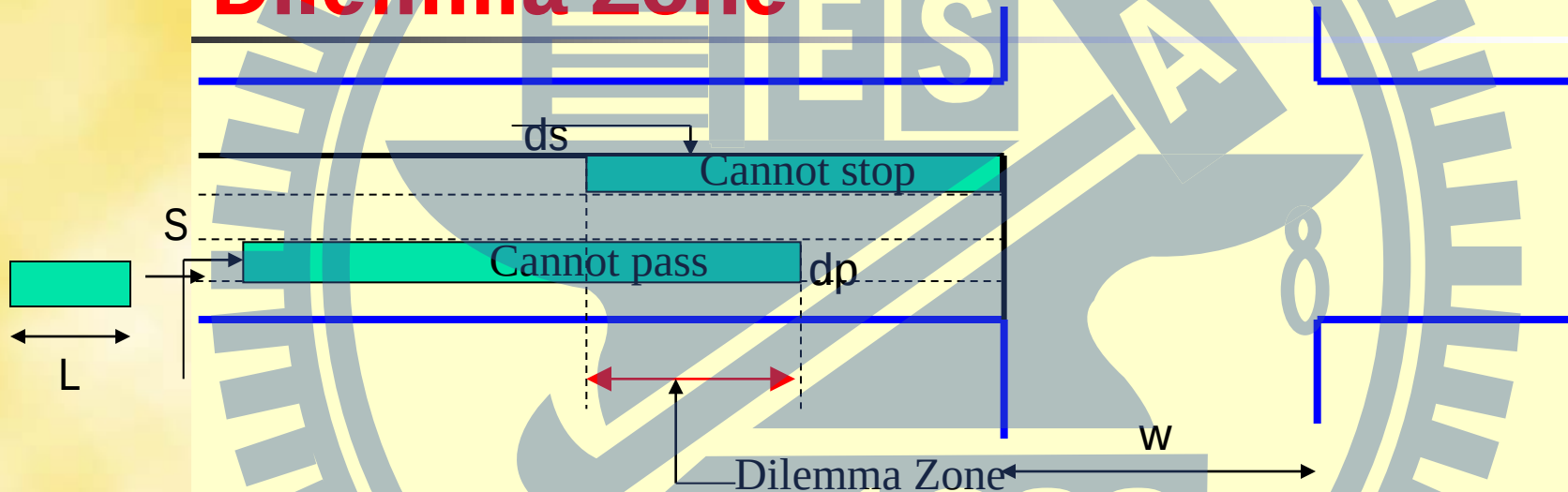
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Dilemma Zone



$$d_p = St - (w + L) + \frac{1}{2} a(\tau - t)^2$$

$$d_s = 1.47S \cdot t + \frac{S^2}{30(0.348 \pm 0.01G)}$$

If $d_p < d_s$, then?

S – initial speed of vehicle (ft/sec)

G – grade (%)

t – PRT (sec)

w – intersection width (ft)

L – vehicle length (ft)

a – max. vehicle acceleration rate (ft/sec²)

τ – Yellow time + all-red time (sec)



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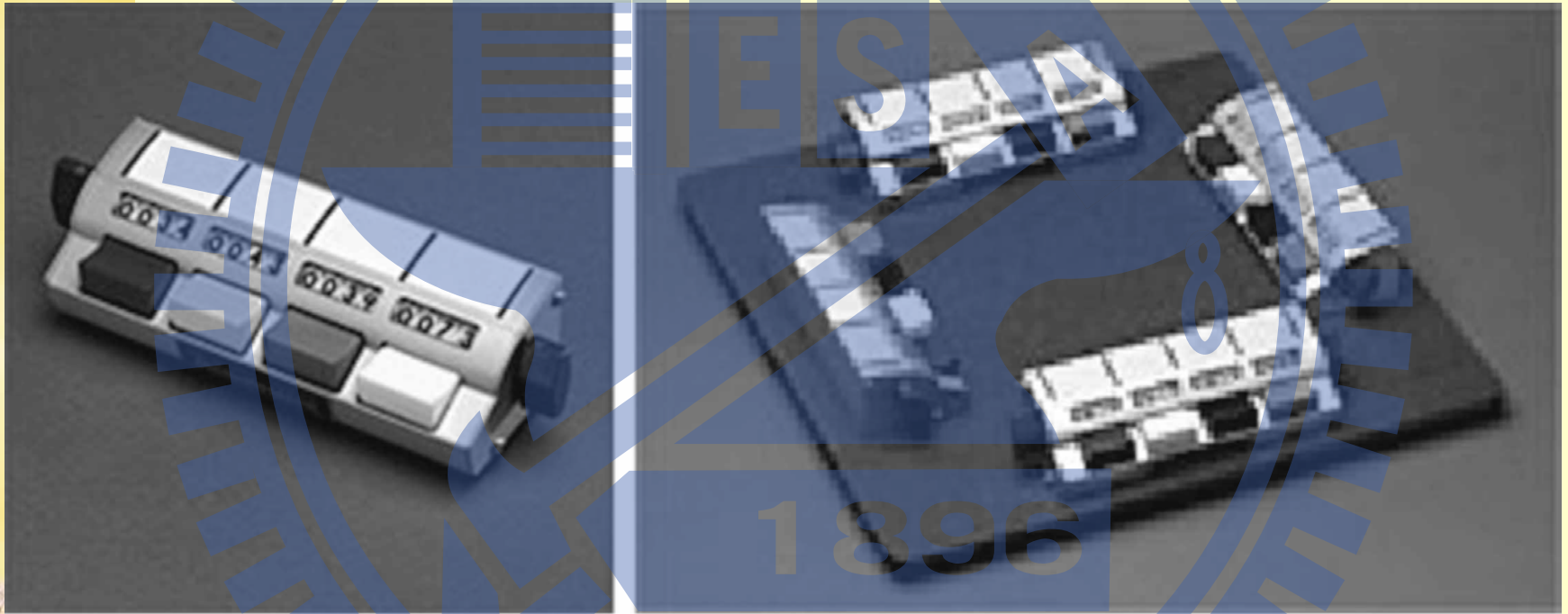
Figure 8.1 Hand Counters Illustrated (Source: Used with permission of the Determinator Company.)

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Figure 8.4 Road Tubes with Portable Counter Illustration

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Figure 8.6 Typical Installation of an Induction Loop Detector (Source: *Traffic Detector Handbook*, 3rd Edition, Federal Highway Administration Publication No. FHWA-HRT-06-108, Washington, DC 2006, Figure 1-4, pp. 1-12.)

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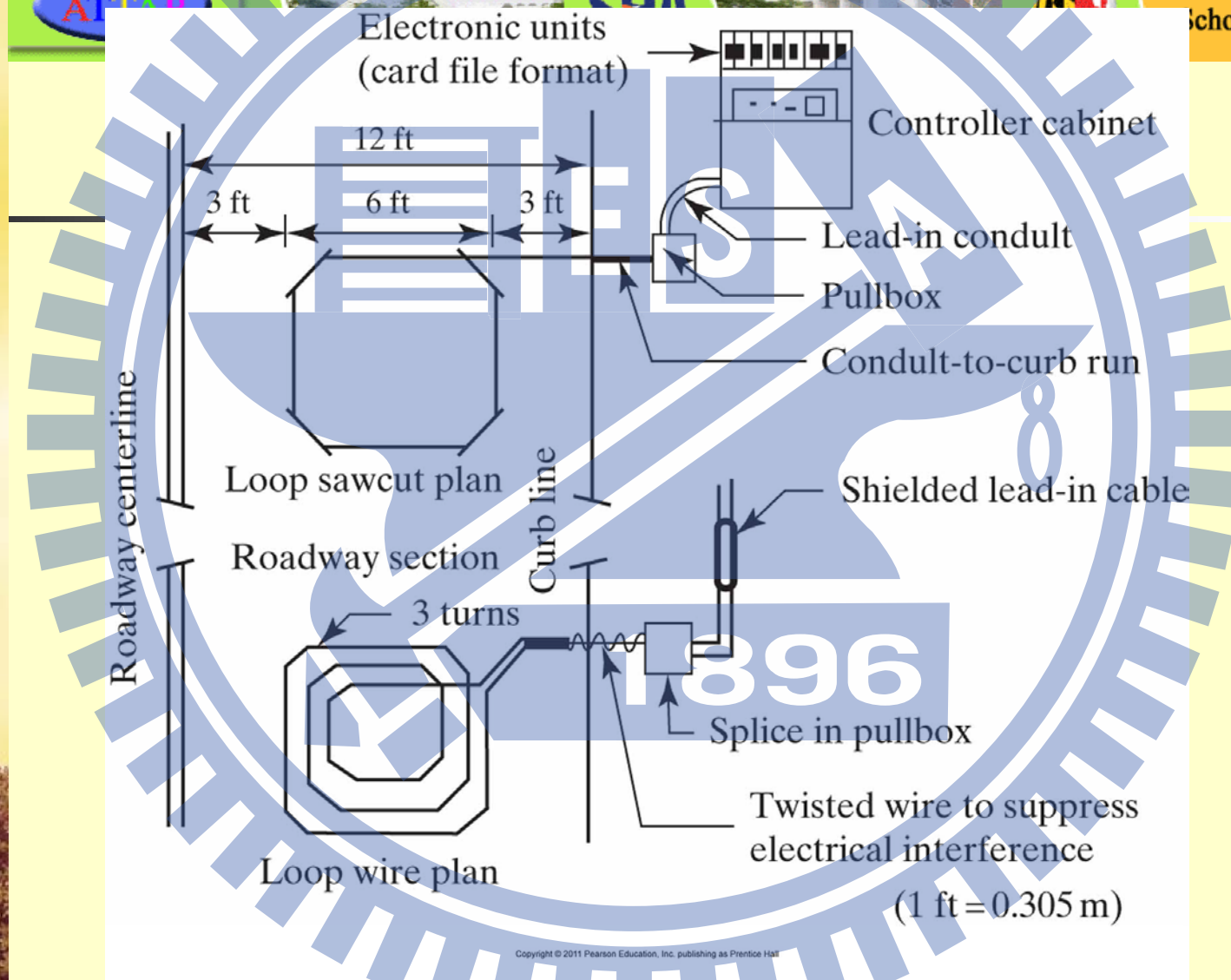




Figure 8.7 Overhead Installation of a Permanent Microwave Radar Detector (*Source: Traffic Detector Handbook, 3rd Edition, Federal Highway Administration, Publication No. FHWA-HRT-06-108, Washington DC, 2006, Figure 1-7, p. 1-16.*)



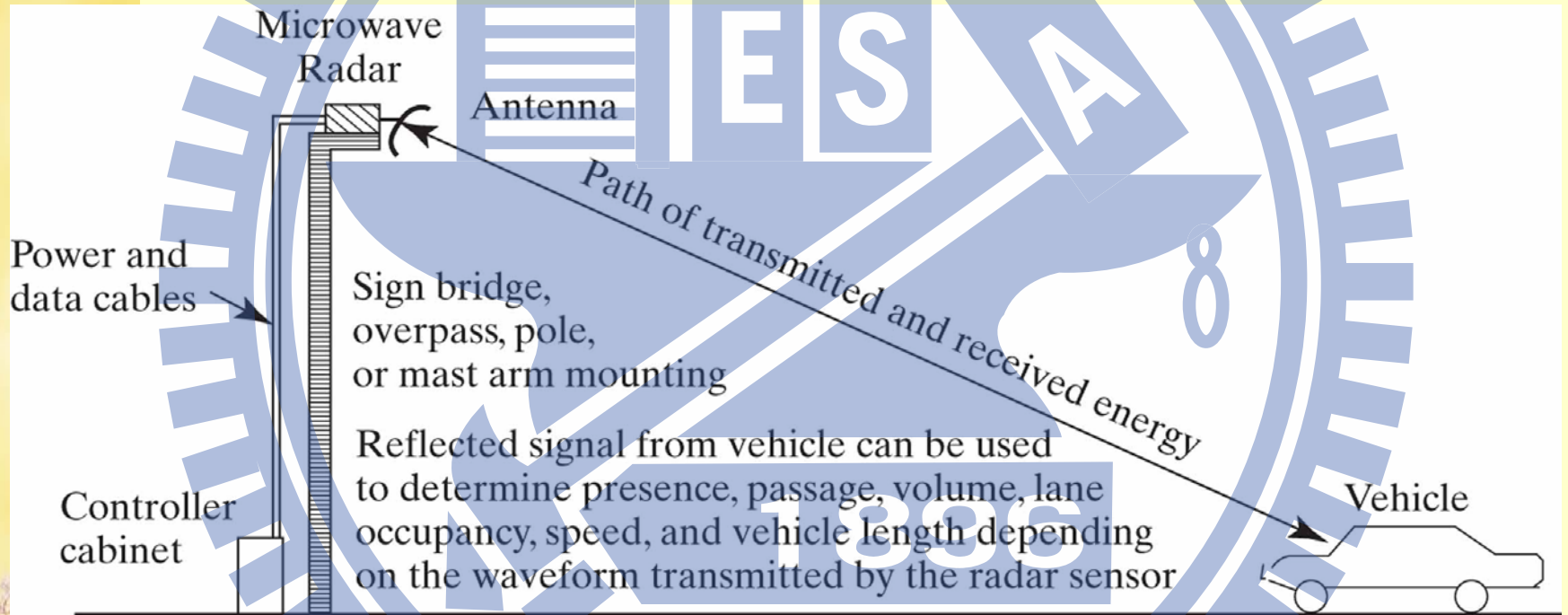
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Figure 8.8 Roadside Installation of Permanent Microwave Radar Detectors (Source: Traffic Detector Handbook, 3rd Edition, Federal Highway Administration, Publication No. FHWA-HRT-06-108, Washington DC, 2006, Figure 1-8, p. 1-17.)



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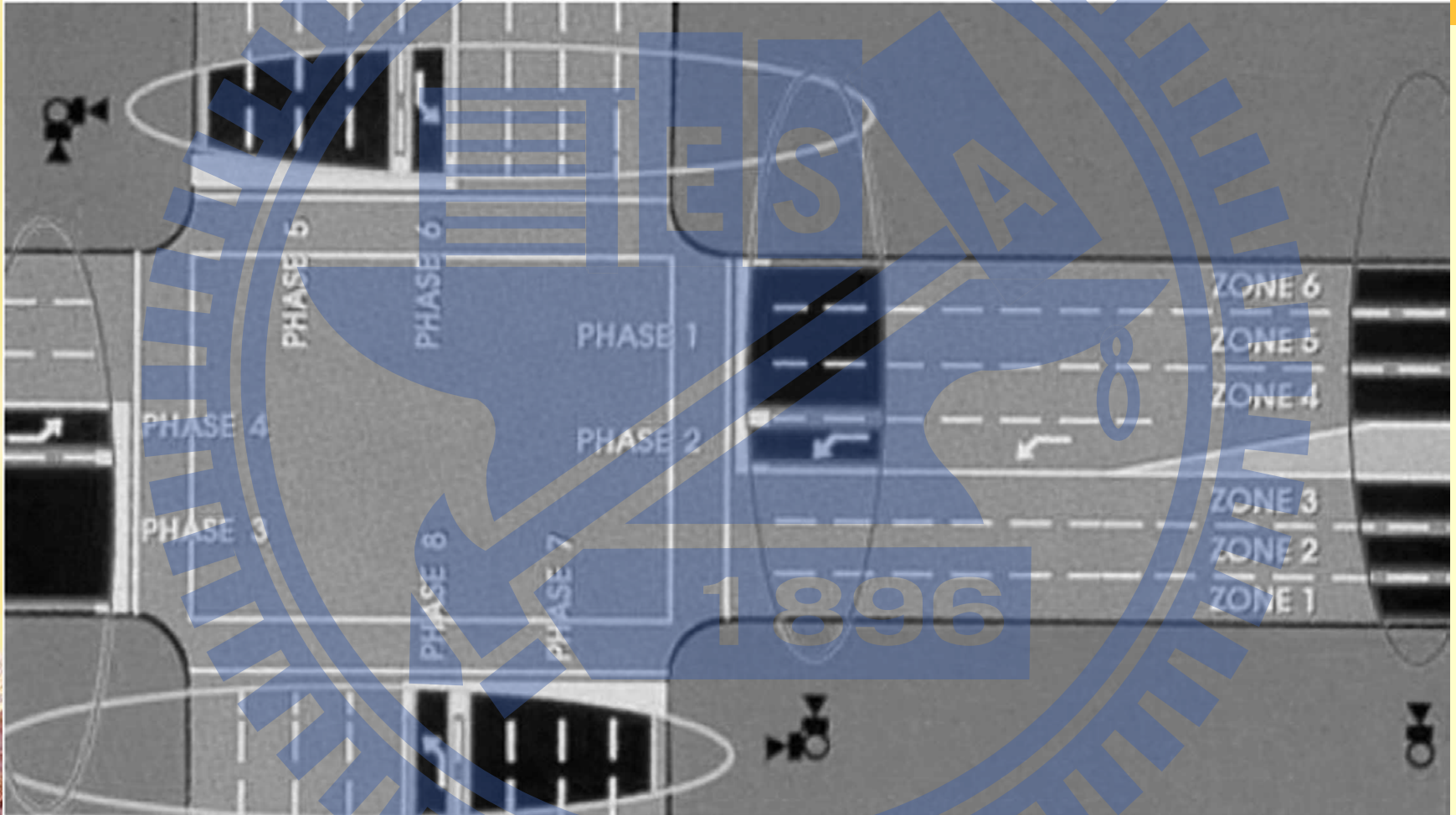
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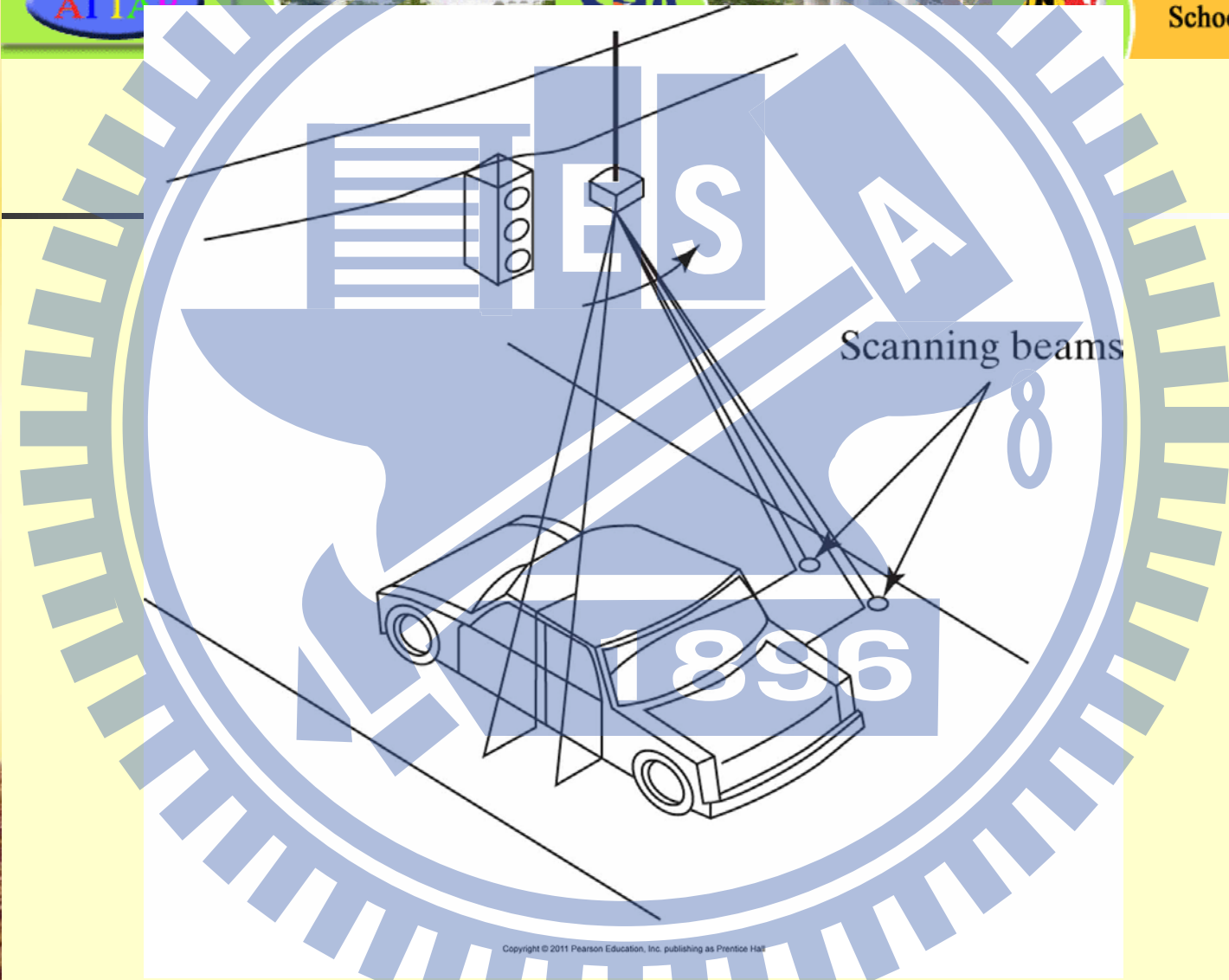


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Figure 8.9 An Overhead Laser Infrared Radar Installation (Source: *Traffic Detector Handbook*, 3rd Edition, Federal Highway Administration, Publication No. FHWA/HRT-06-108, Washington, DC, 2006, Figure 1-8, p. 1-18.)

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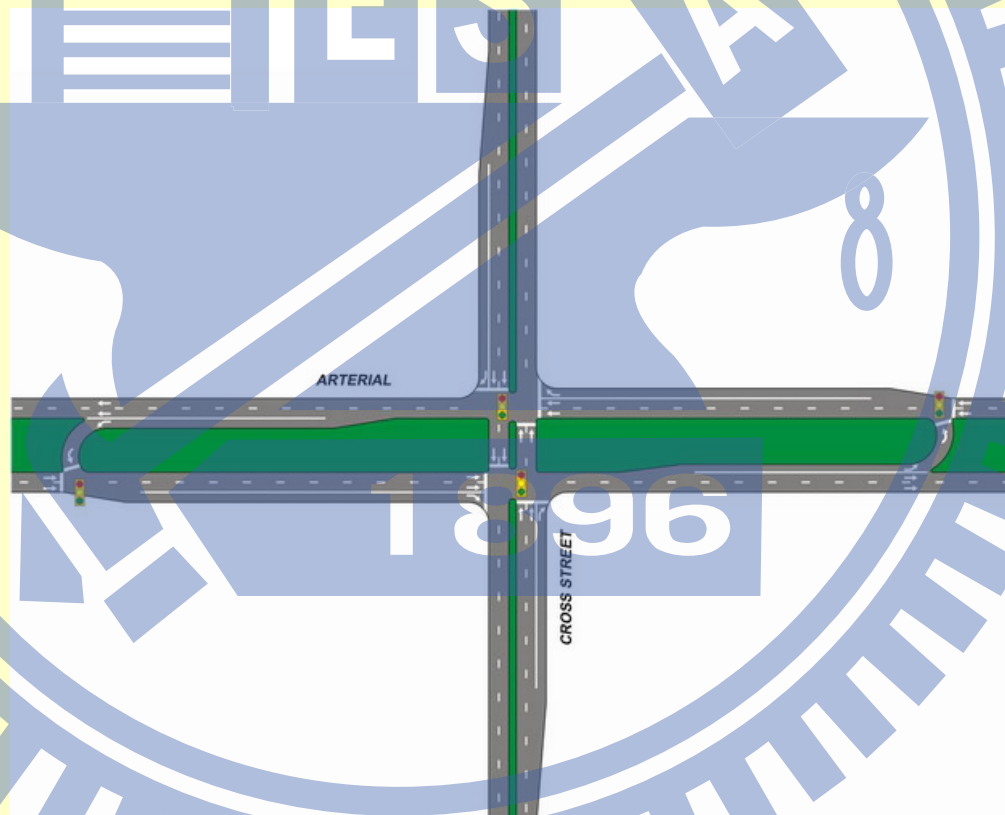
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At Grade Signalized Median U-Turn



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Design Description

- Left turns are made "indirectly" using directional U-turn crossovers closest to the intersection. For example, a vehicle traveling on the arterial that desires to turn left at the cross-street must travel thru the cross-street intersection, make a U-turn at the first median U-turn crossover, and then turn right onto the cross-street.
- Similarly, vehicles turning left from the cross-street must turn right onto the arterial and use the median U-turn crossover



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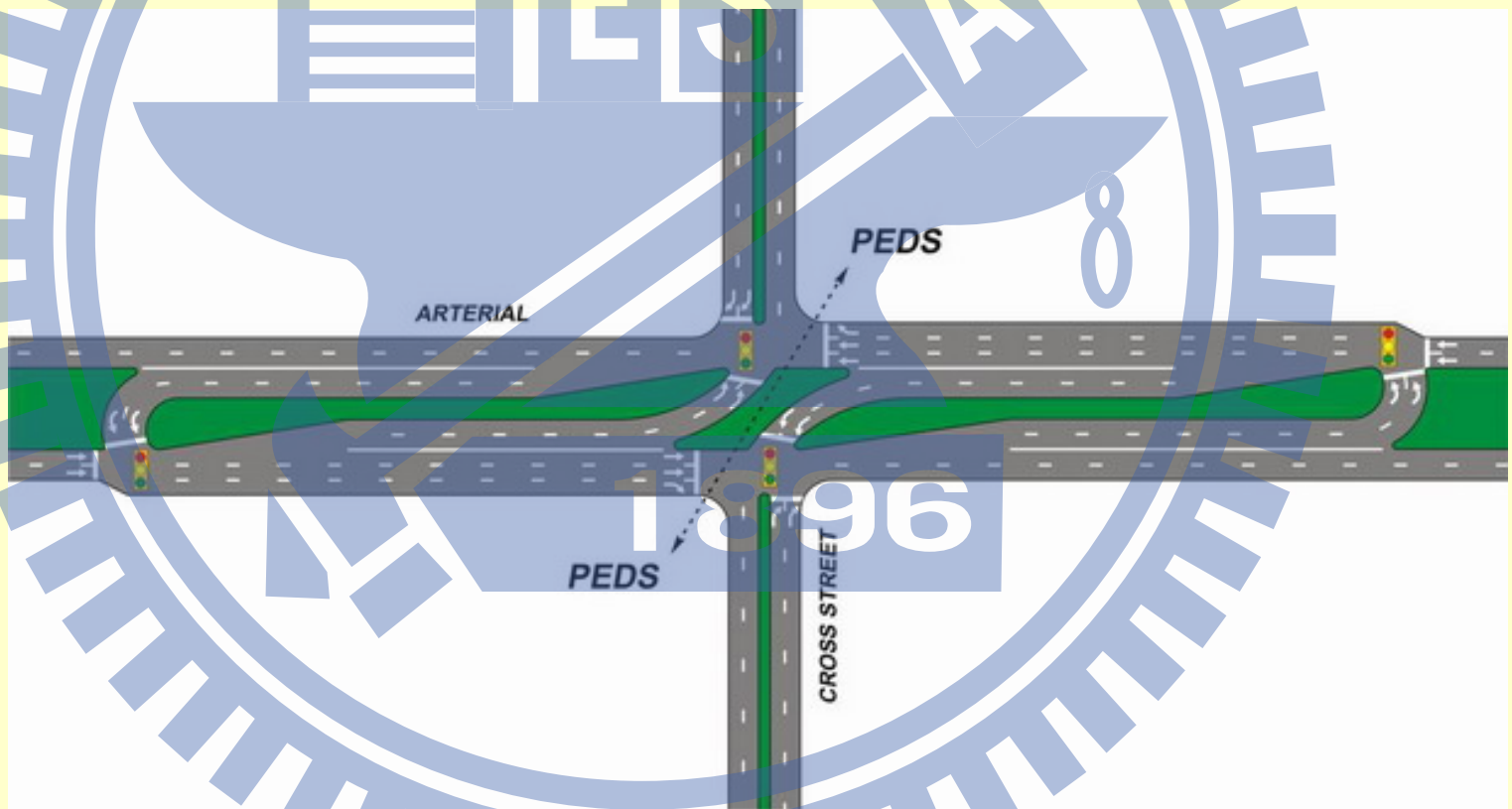
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Superstreet





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Design Description

- The Superstreet design is similar to the Median U-turn Crossover concept but features a break in cross-street traffic that allows the signals on opposite directions of the arterial to operate independently. Left turns from the arterial can make direct left turns onto the cross-street but cross-street thru and left turn movements must use the directional U-turn crossovers.



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- The Superstreet median design is similar to the Median U-Turn concept but features a break in cross-street traffic that allows the signals on opposite directions of the arterial to operate independently.
- The design requires cross street through movements and left turns to and from the arterial to use the directional crossovers.
- A conventional four-approach intersection essentially becomes two independent T-intersections. This independence allows each direction of the arterial to have independent signal control (including different cycle lengths, if desired) so that "perfect" progression can be achieved in both directions at any time at any intersection spacing.



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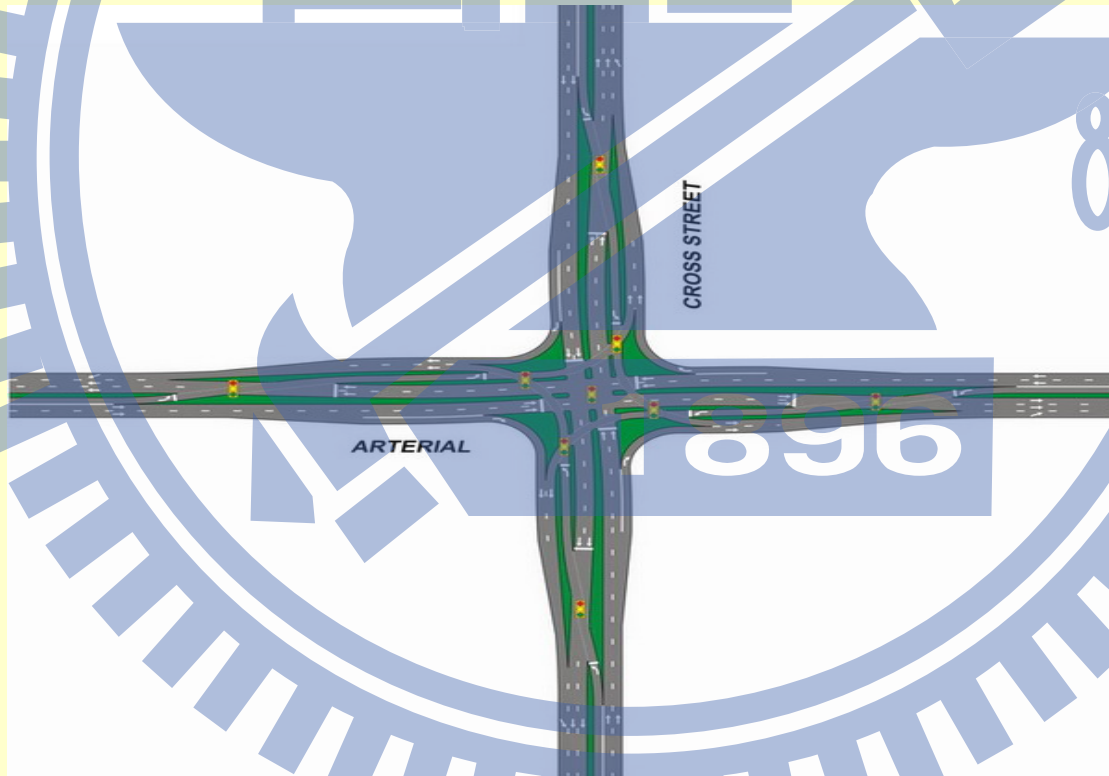
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Continuous Flow



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Design Description

- Left-turning vehicles begin their turn several hundred feet prior to the main intersection at a signalized "crossover" intersection and move into separated lanes to the right of the opposing thru movement. The protected left turns are completed simultaneously with thru movements, allowing simple two-phase intersection signal control.



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- Design and Operation
- The term "Continuous Flow" is a bit of a misnomer, as traffic *may be* required to stop at signals at the intersection; however, the CFI design separates left-turn movements from conflicting through-movements, allowing opposing left-turns to be made at the same time as through-movements.
- Left-turning vehicles begin their turn several hundred feet prior to the main intersection. They are stored in a bay to the left of the opposing through lanes of travel, and complete the left turn movement under the same signal phase as the through-movement; however, under ideal signal control left turns are progressed through all signals along the left turn path.



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- At the main intersection, previously conflicting through- and left-turn movements can operate simultaneously as protected movements under the same signal phase. The signal cycle is reduced to two phases, enabling a reduction in overall cycle lengths and maximizing through-movement green times. The result is a reduction in travel delays and increased capacity at the intersection.
- The left-turn lane crosses the opposing traffic at an intersection 400-500 feet in advance of the cross street. This distance is a balance between the costs of a longer storage area and the spillback potential from the main intersection.
- The CFI design can also improve pedestrian efficiency and safety. Pedestrians cross the intersection in two stages, however without left *or* right-turn vehicle conflicts. The shorter cycle lengths typical at a CFI intersection also shorten the pedestrian's wait for a walk phase.
- U-turns on the arterial are possible at the left-turn crossover if the median is wide enough; however, without U-turn provisions, the arterial median may be narrow.



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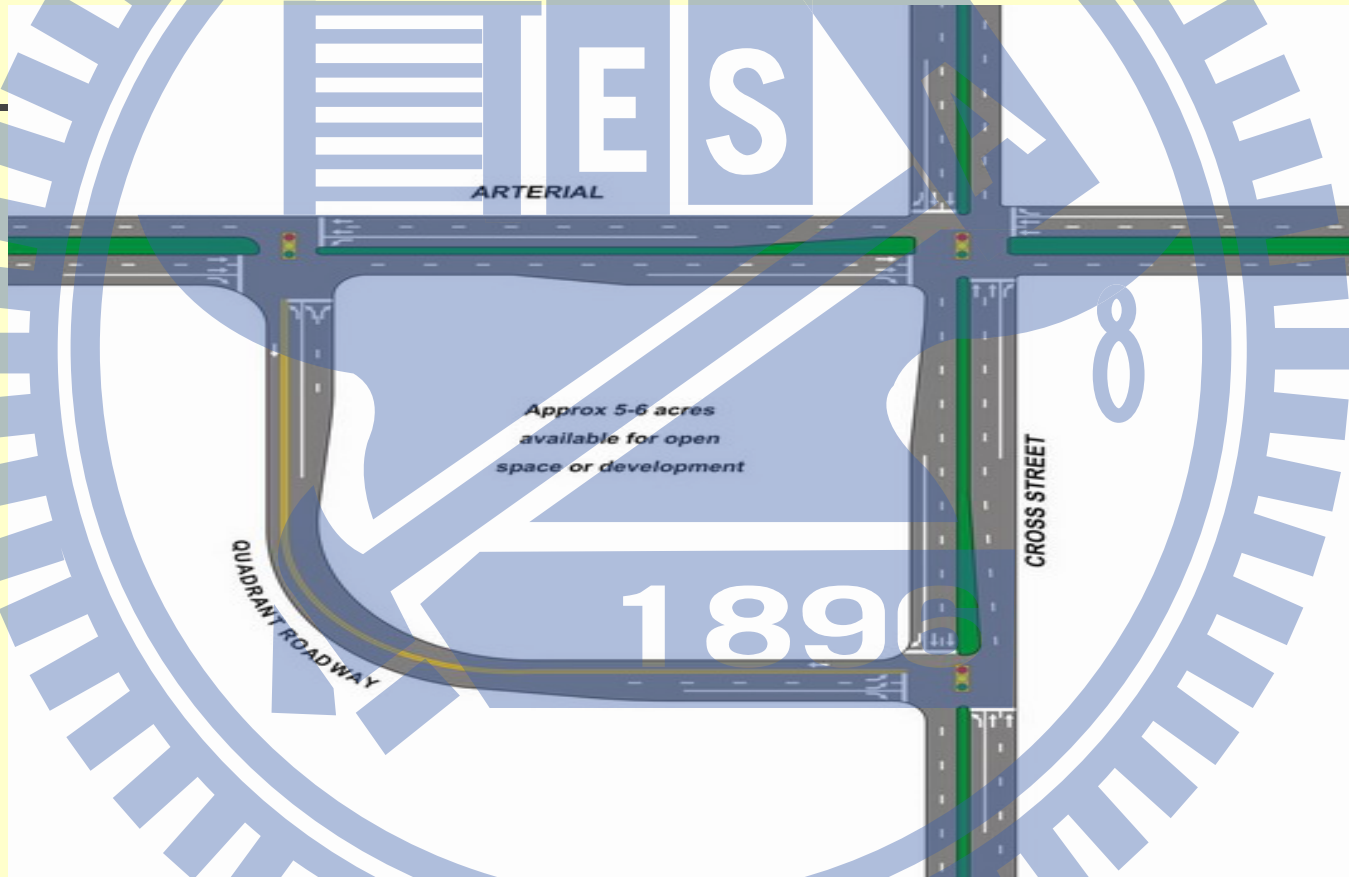
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Quadrant Roadway





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- Design Description
- Left turns are removed from the main intersection by using an additional roadway in one intersection quadrant. Left-turn movements are routed from the arterial and cross-street (using unique turning paths for each approach) onto the quadrant roadway to complete the left turn movement at the quadrant roadway "minor" T-intersections



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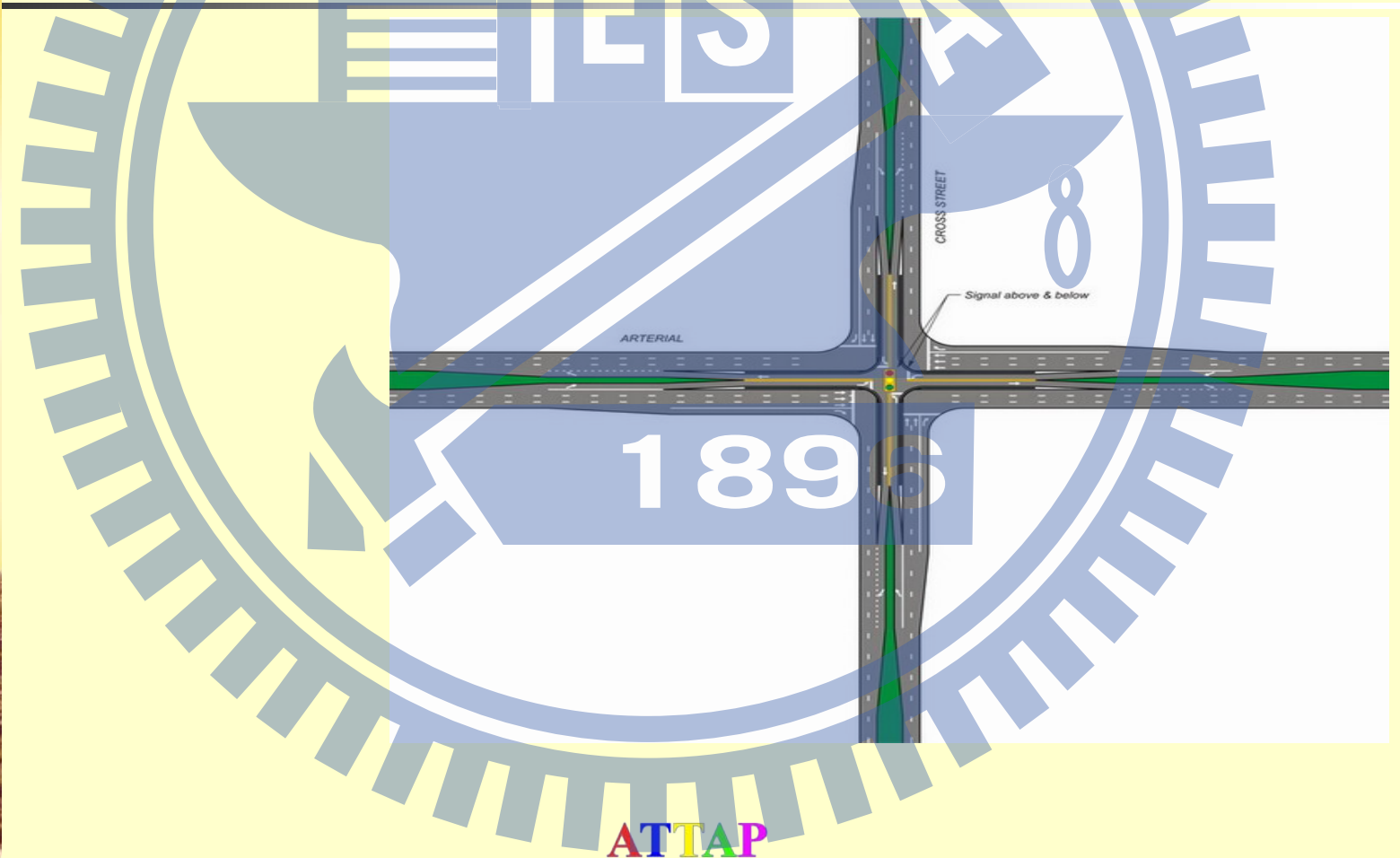
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Center Turn Overpass





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- Design Description
- Left turn traffic is separated from arterial and cross-street thru and right-turn movements by elevating all left turns to a separate, elevated intersection using narrow ramps within the median. Both the elevated and at-grade intersections are controlled by simple two-phase signal. Left turn traffic descends from the elevated intersection and merges into thru traffic lanes.



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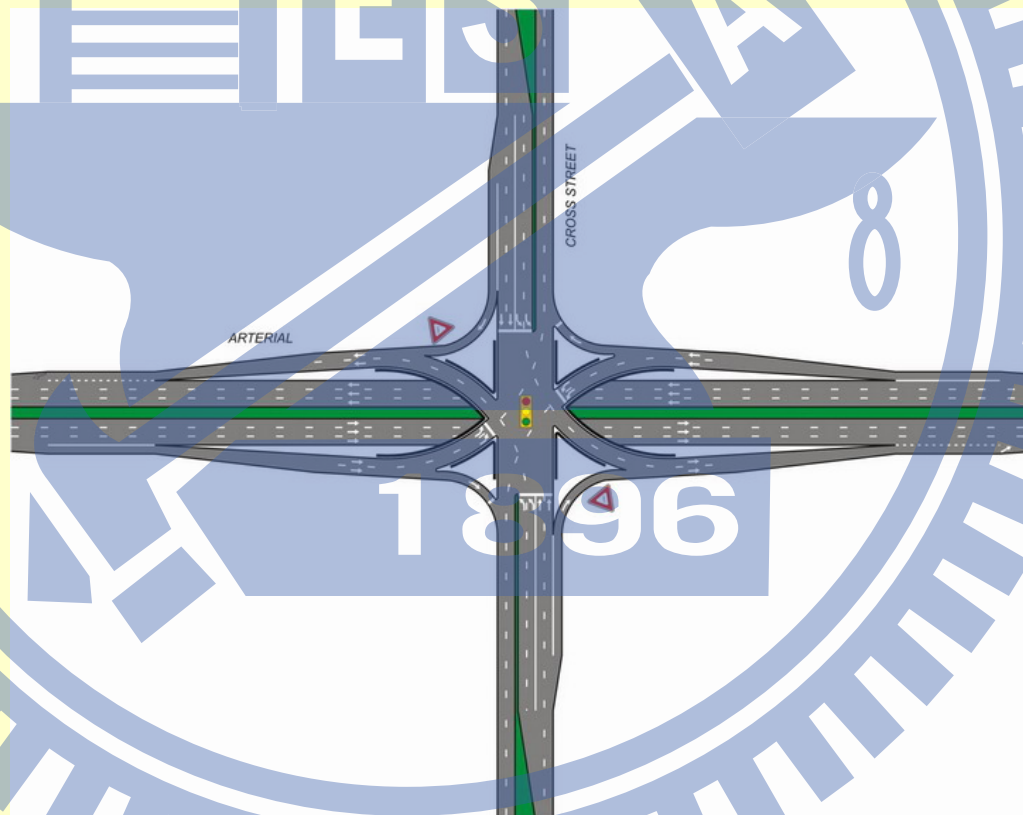
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Single Point Urban Interchange



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- Design Description
- Free-flow arterial thru movements are provided by creating a separate, signalized intersection of arterial turning movements with the cross-street on a separate grade, creating an intersection either under or over the priority thru roadway. Right turns are made at unsignalized ramps separated from the main intersection



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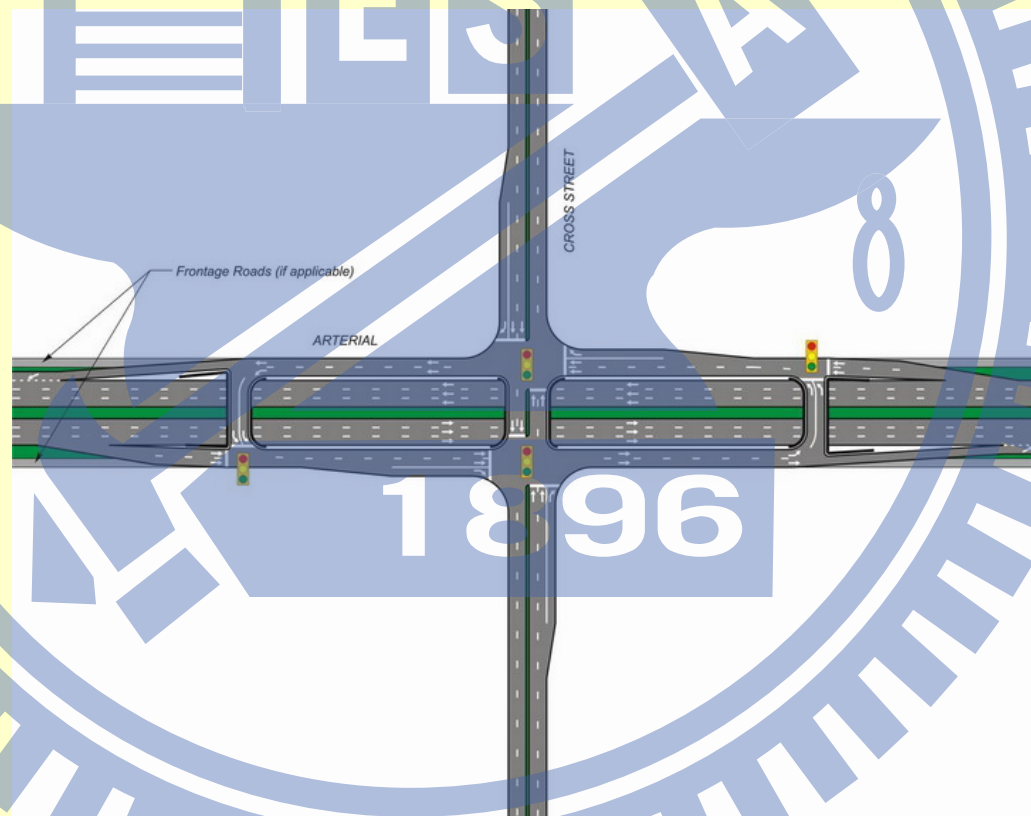
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Michigan Urban Diamond



ATTAP



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State Highway Administration



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- Design Description
- Free-flow arterial thru-movements are provided by using directional crossovers on structural bridges downstream of the main intersection to handle all left-turn movements. The arterial turn movements are diverted onto separate frontage roads on either side of the depressed thru-lanes and arterial off ramps are directed onto these one-way frontage roads prior to the main intersection.



An Applied Technology and Traffic Analysis Program



A. James Clark
School of Engineering



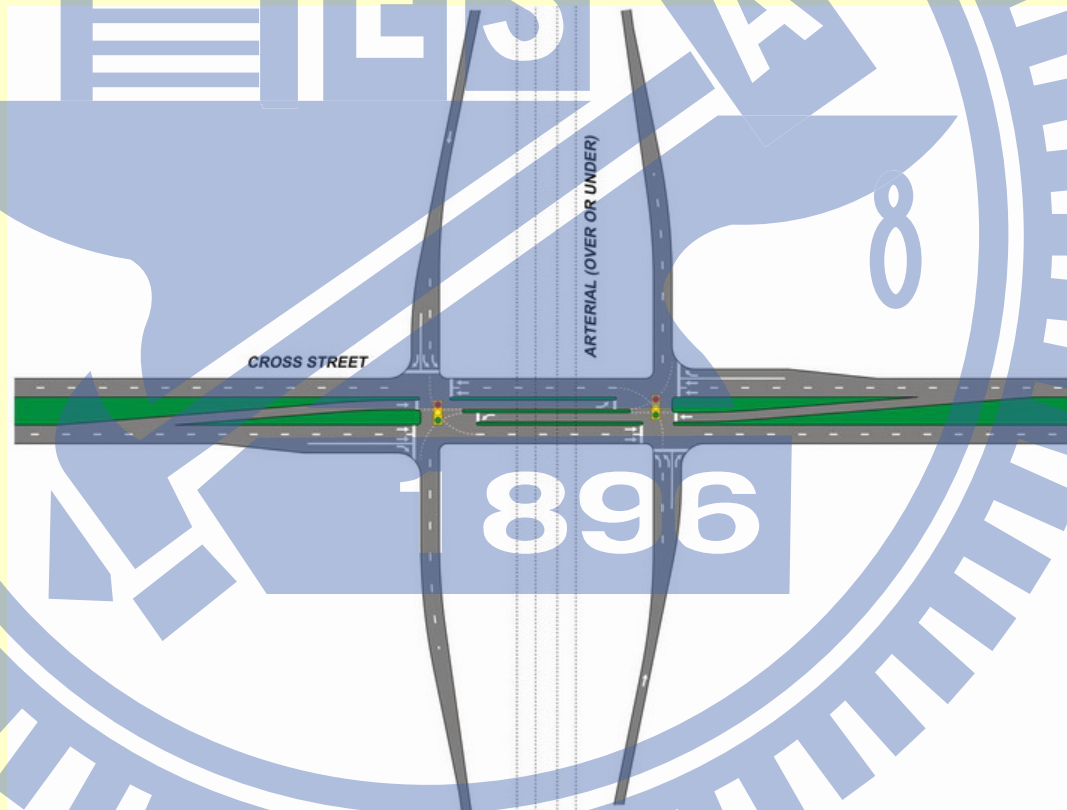
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Contraflow Left Interchange





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- Design Description
- Cross-street left turns cross-over opposing left turn movements in storage bays prior to the first ramp intersection. Vehicles move into contraflow lanes within the interchange, before making the turn onto the ramp. These special lanes run in the opposite direction from the adjacent thru-lanes, and provide additional storage for left turn vehicles.



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School of Engineering



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Diverging Diamond Interchange





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- Design Description
- The concept of the DDI is to "cross" the cross street through lanes on the overpass (or underneath) the main roadway so that left turns can be made without conflicting the opposing through direction of travel. The through lanes are crossed for only a short section between diamond ramp intersections and then cross back to be on the normal (right) side of the roadway.