ISTTT20 Tutorials

Traffic Management
and
Control

Transportation Systems Management - Definition

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Transportation Systems Management

Transportation Systems Management (TSM) is a strategy aimed at improving the overall performance of the transportation network without resorting to large-scale, expensive capital improvements.

TSM integrates techniques from across disciplines to increase safety, efficiency and capacity for all modes in the transportation system.

TSM Objectives

- Reducing road safety risks
- Reducing delays and congestion
- Reducing harmful air emissions and fuel consumption
- Reducing traffic short-cutting through residential neighborhoods
- Reducing and eliminating bottlenecks
- Enabling rapid response to traffic incidents

Typical TSM Actions

- Traffic control tools such as signs, signals, markings and regulations
- Technologically advanced software and hardware
- Signal timing, including special phasing
- Progression and synchronization between signals
- Real-time traffic control monitoring and surveillance
- Special treatment for transit and emergency vehicles
- Incident management
- Maintenance of existing system

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Traffic Management and Control

Traffic Signal Control – Introduction

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Module Objectives:

- Describe the basic operation principles of traffic signal systems
- Present the principal warrants for traffic signals
- Explain fixed-time, and traffic-responsive operation
- Describe performance measures for isolated intersections
- Develop optimal signal timings for isolated intersections

Purpose of Traffic Control Signals

The primary function of ***Traffic Control Signals*** is to assign the right-of-way at intersecting streets or highways where, without such control, a continual flow of vehicles on one roadway would cause excessive delay to vehicles and/or pedestrians waiting on the other roadway.

Freeway Ramp Control Signal are a special application of traffic control signals installed on freeway entrance ramps to limit, or “meter,” the amount of traffic entering the freeway.

Required steps in design:

- investigating the need for a traffic signal
- determining the operational requirements
- translating these requirements into traffic control equipment requirements
- determining optimum operation of the traffic signal and
- operating and maintaining the traffic control signal over its expected life.

Sources:
ITE Transportation and Traffic Engineering Handbook
Manual on Uniform Traffic Control Devices (MUTCD).

Needs Assessment –

Determining the Need for Traffic Signal Control

The first and basic question that must be addressed is whether or not traffic signalization is needed. Since traffic signals are the most restrictive traffic control devices, they should be used only where the less restrictive signs or markings do not provide the necessary level of control.

Warrants for Traffic Signal Installation

Traffic control signals should not be installed unless one or more of the signal warrants in the MUTCD are met:

Volume Warrants

- Warrant 1 –
  Condition A, Minimum Vehicular Volume
  Condition B, Interruption of Continuous Traffic
  Combination of A + B
- Warrant 2 - Four-Hour Vehicular Volume
- Warrant 3 - Peak Hour
- Warrant 4 - Pedestrian Volume

Other Warrants for Traffic Signal Installation

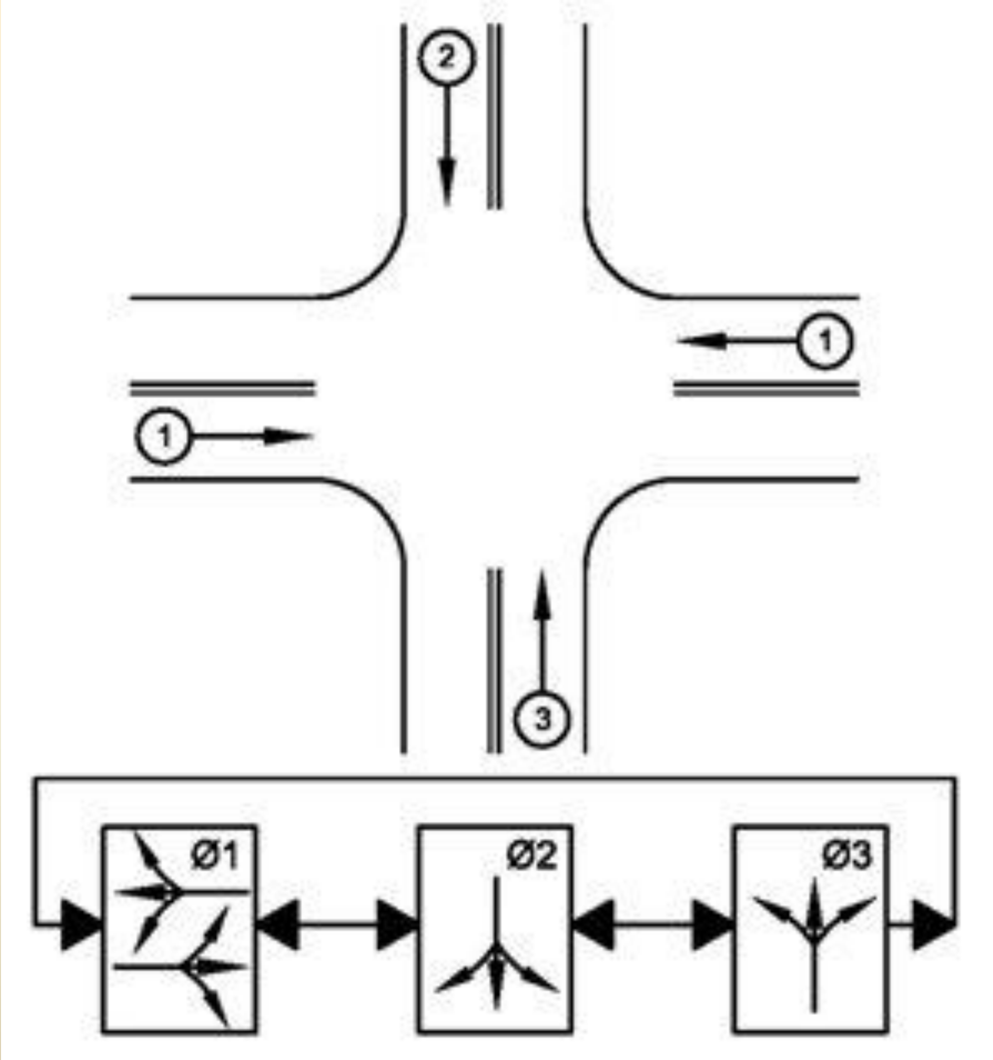
- Warrant 5 - School Crossings
- Warrant 6 - Coordinated Signal System
- Warrant 7 - Crash Experience
- Warrant 8 - Roadway Network

Operational Requirements

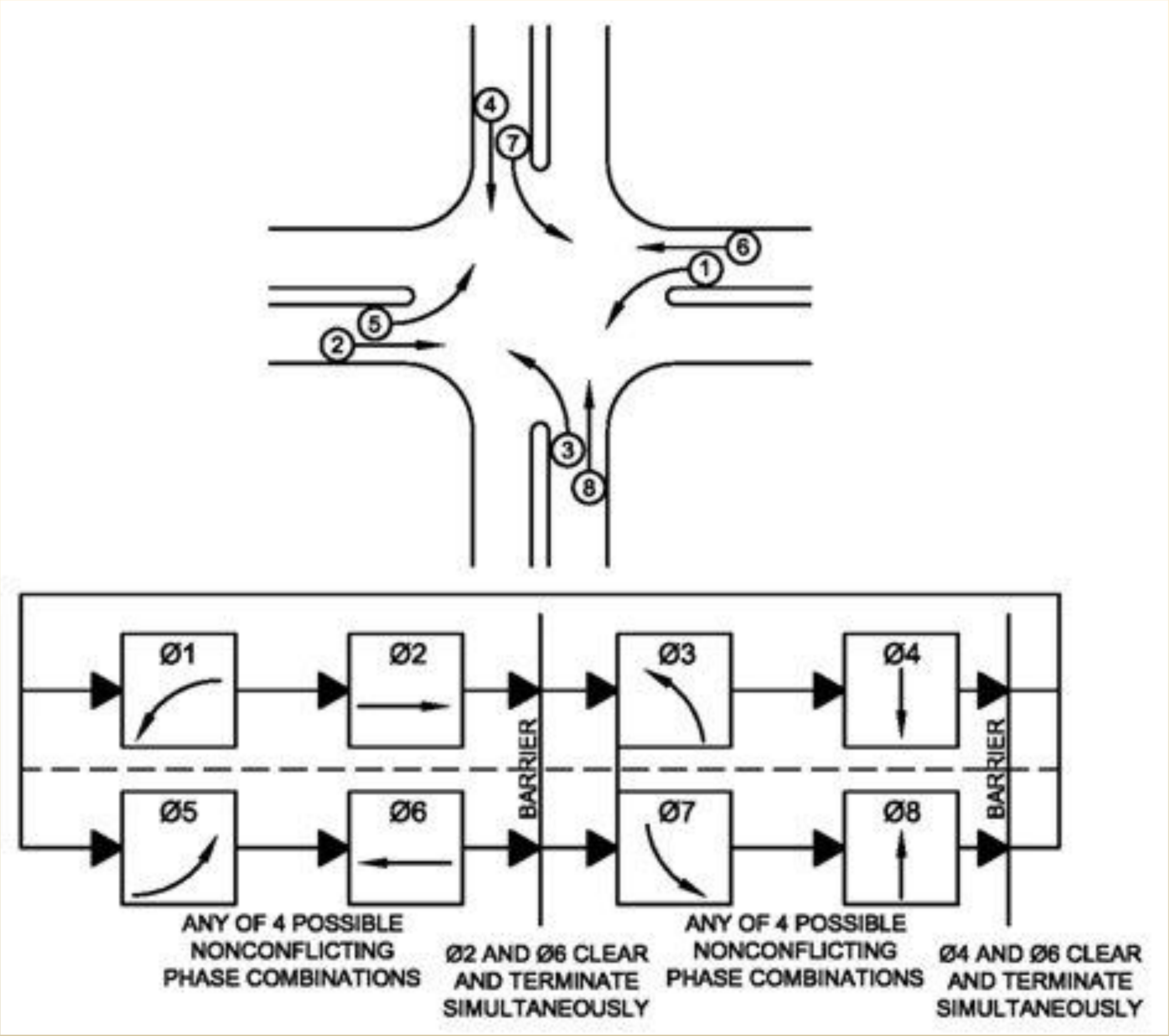
Decisions to be made include:

- Controller phasing
- Pre-timed or actuated operation
- Interconnection considerations

Example: 3-phase controller sequence



Example: 8-phase dual ring controller



Types of Control

The principal types of traffic signal control are: **pre-timed** and **traffic actuated**.

Each type of control has its unique advantages and disadvantages.

Choosing a Type of Control

In general practice, the rule of thumb for choosing the type of intersection control is:

- for predictable traffic demand, use **pre-timed**
- for unpredictable traffic demand, use **actuated control**

Interconnection Considerations

Coordinated operation can provide a significant reduction in stops and delays.

The MUTCD suggests that signals spaced less than ½ miles apart should be coordinated because the cohesion of the platoon can be maintained for this distance.

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Single Intersection Models

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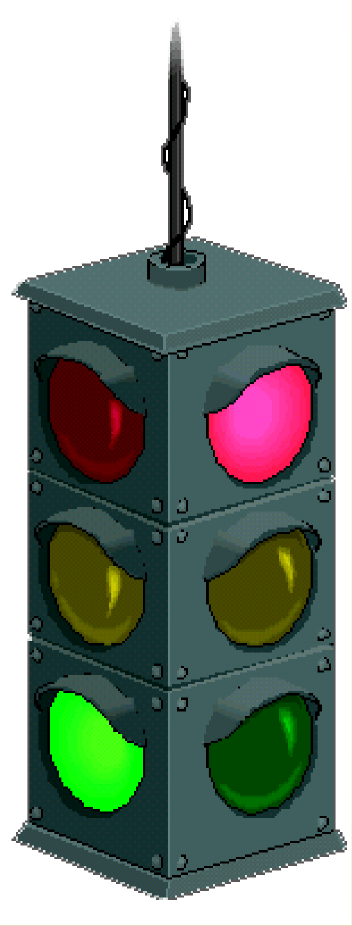
Performance models

The material in this section is based on the methodology developed by **F. V. Webster** at the *British Road Research Laboratory* for estimating the delays to vehicles at fixed-time traffic signals and for computing the optimum settings of such signals (1957).



Two key concepts:

- **delay**
- **saturation flow rate**

Delay: arrival-departure pattern

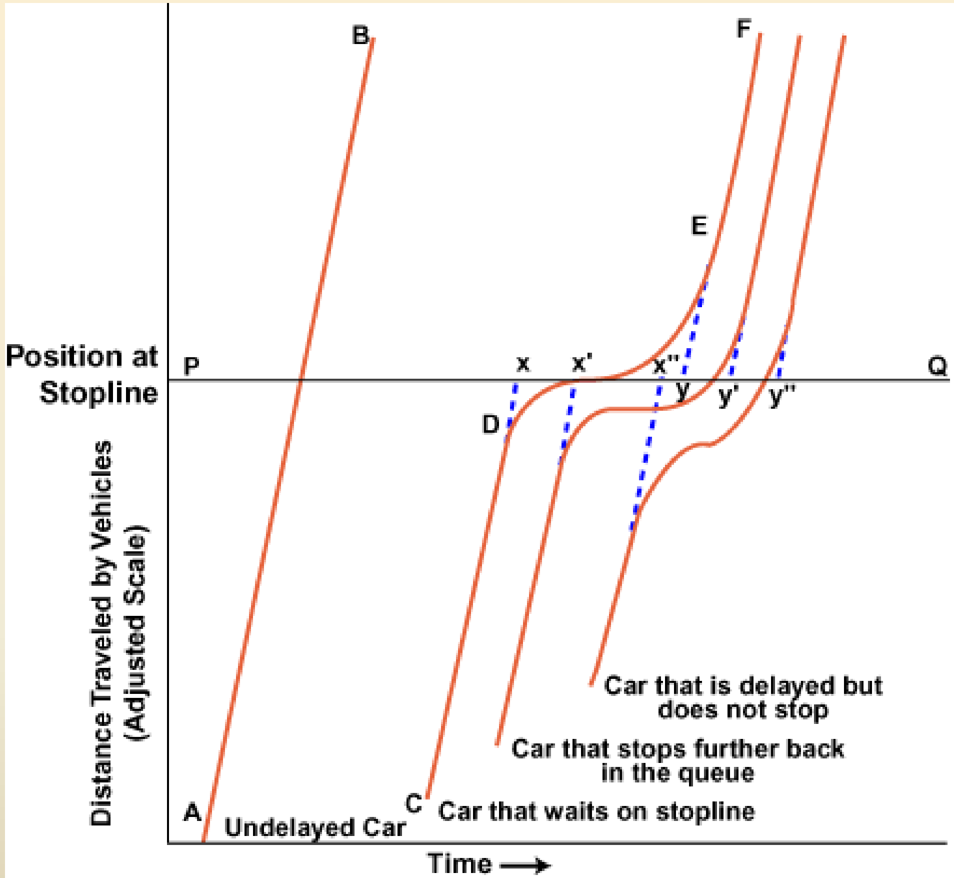
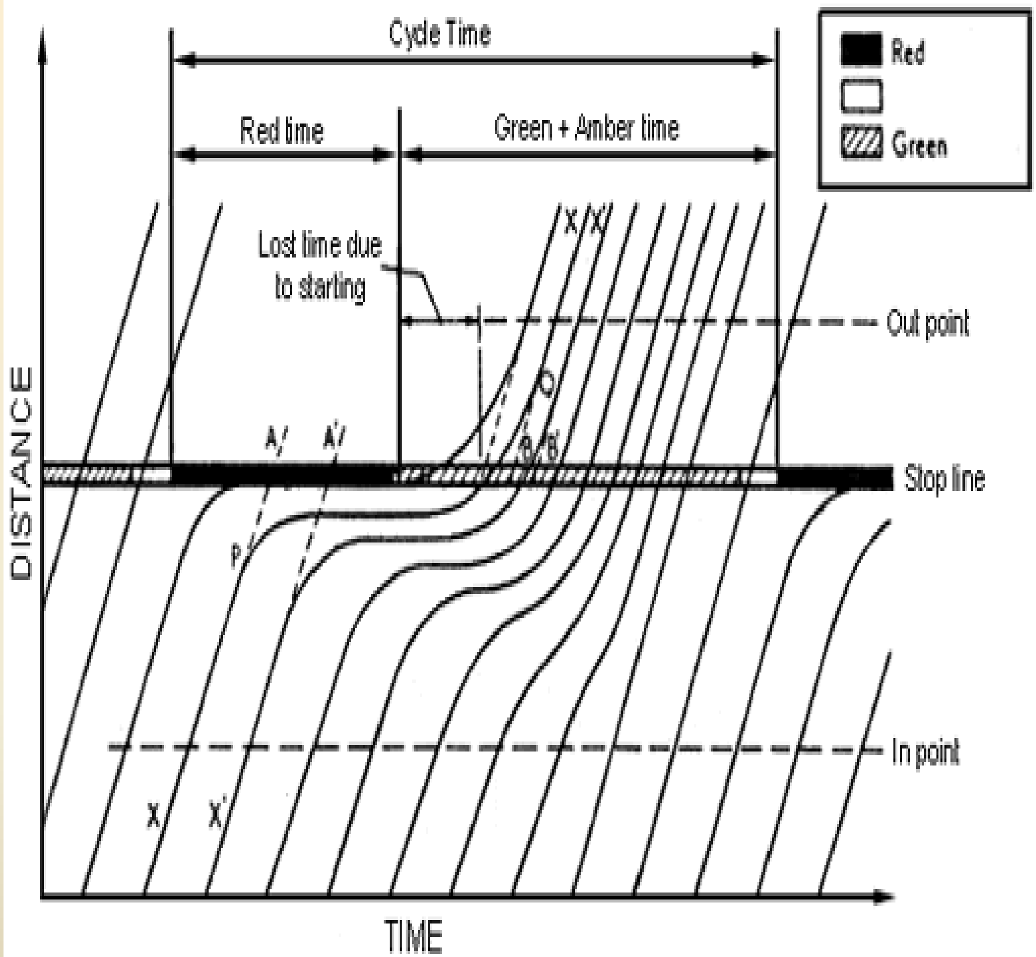


Figure D-3. Vehicle arrival-departure times and delay of the stopline

Saturation Flow Rate



Distance/Time diagram for traffic flowthrough signal-controlled intersection.

Fluid Model: cumulative delay

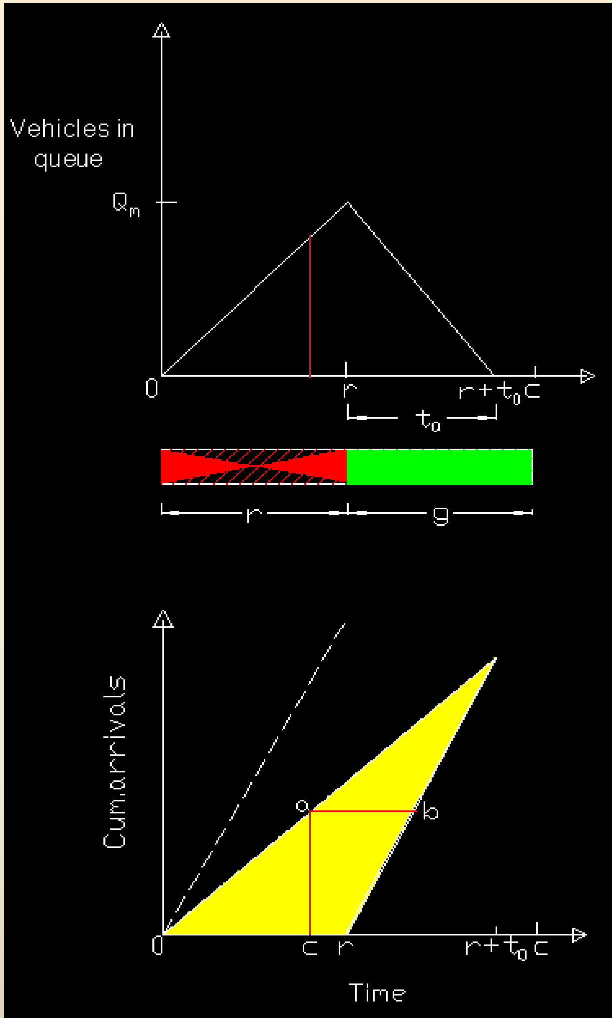


Figure D-4. Cumulative arrival-departure diagrams and queueing at a signal. (Continuum model)

Deterministic Delay

$$d = \left[\frac{qr^2}{2(1-y)}\right]\frac{1}{qc} = \frac{r^2}{2c(1-y)}$$

Average Delay Per Vehicle – WEBSTER Model

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0.65\left(\frac{c}{q^2}\right)^{\frac{1}{3}} x^{(2+5\lambda)}$$

Where:

d = average delay per vehicle on the particular arm of the intersection

c = cycle time

λ = proportion of the cycle which is effectively green for the phase under consideration (i.e. g / c)

q = flow

s = saturation flow

x = the degree of saturation.

This is the ratio of the actual flow to the maximum flow which can be passed through the intersection from this arm, and is given by,

$x = q / \lambda s = q / K$, where

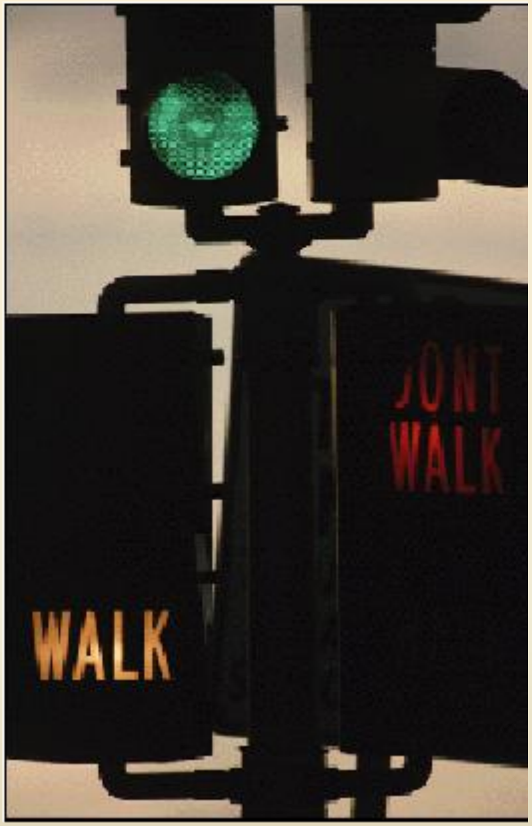
$K = \lambda s$ is the capacity flow

(If d and c are in seconds, q, s and K are in vehicles per second.)

Optimum Settings of Fixed-Time Signals

The objective in setting signal timings for a fixed-time signal is to minimize overall vehicular delay.

This is in addition to the need to meet the warrants described earlier.



Green Time Determination - Example

The available green time during the cycle *(c_0 - L)* should be in proportion to the average *y* values for peak periods .

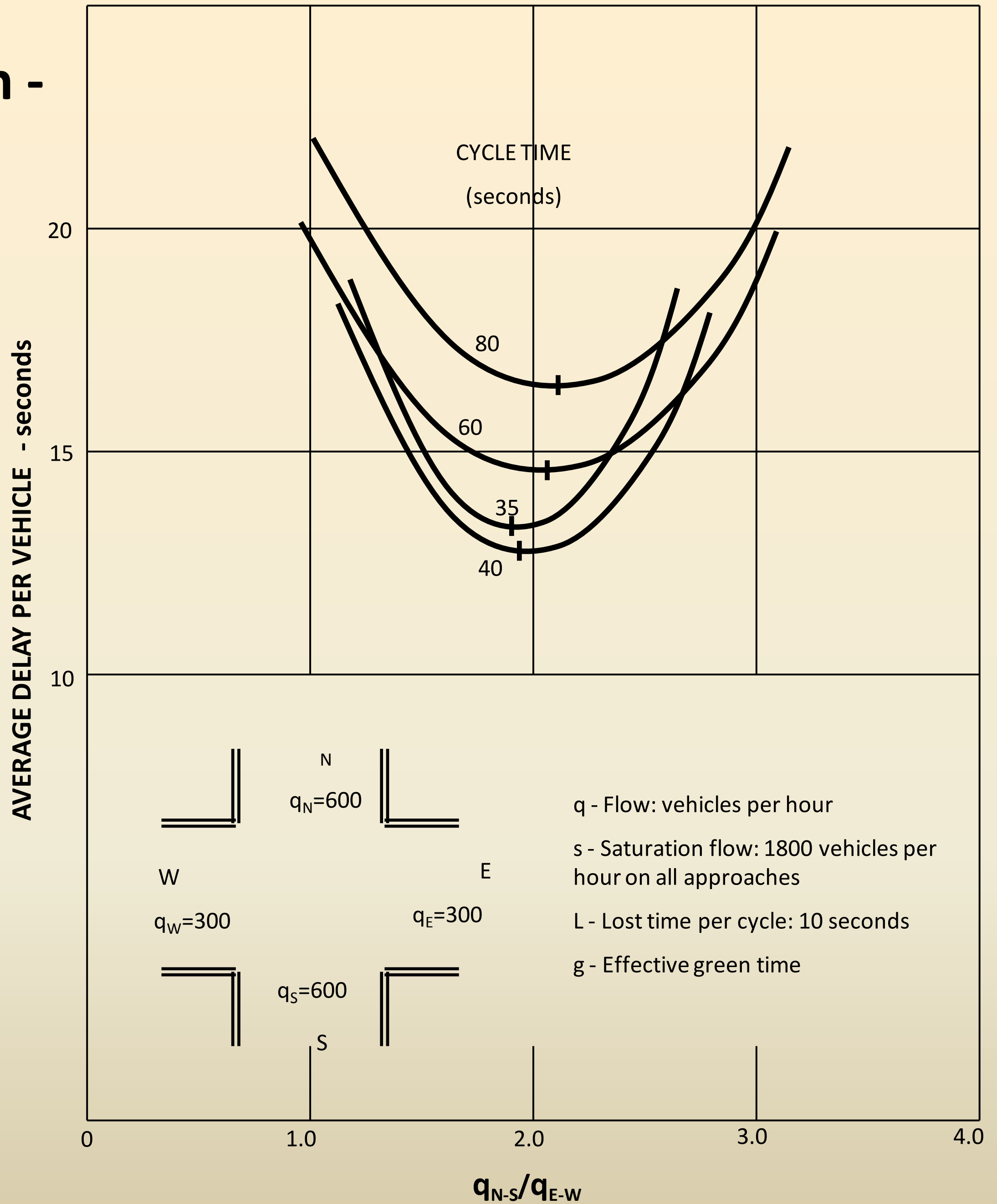


Fig. D-6 Effect on delay of the variation of the ratio of green periods

Optimum Cycle Time

The value of cycle time which gives the least delay of all traffic using the intersection.

$$c_o = \frac{1.5L + 5}{1 - Y} \sec$$

Cycle Time (cont'd)

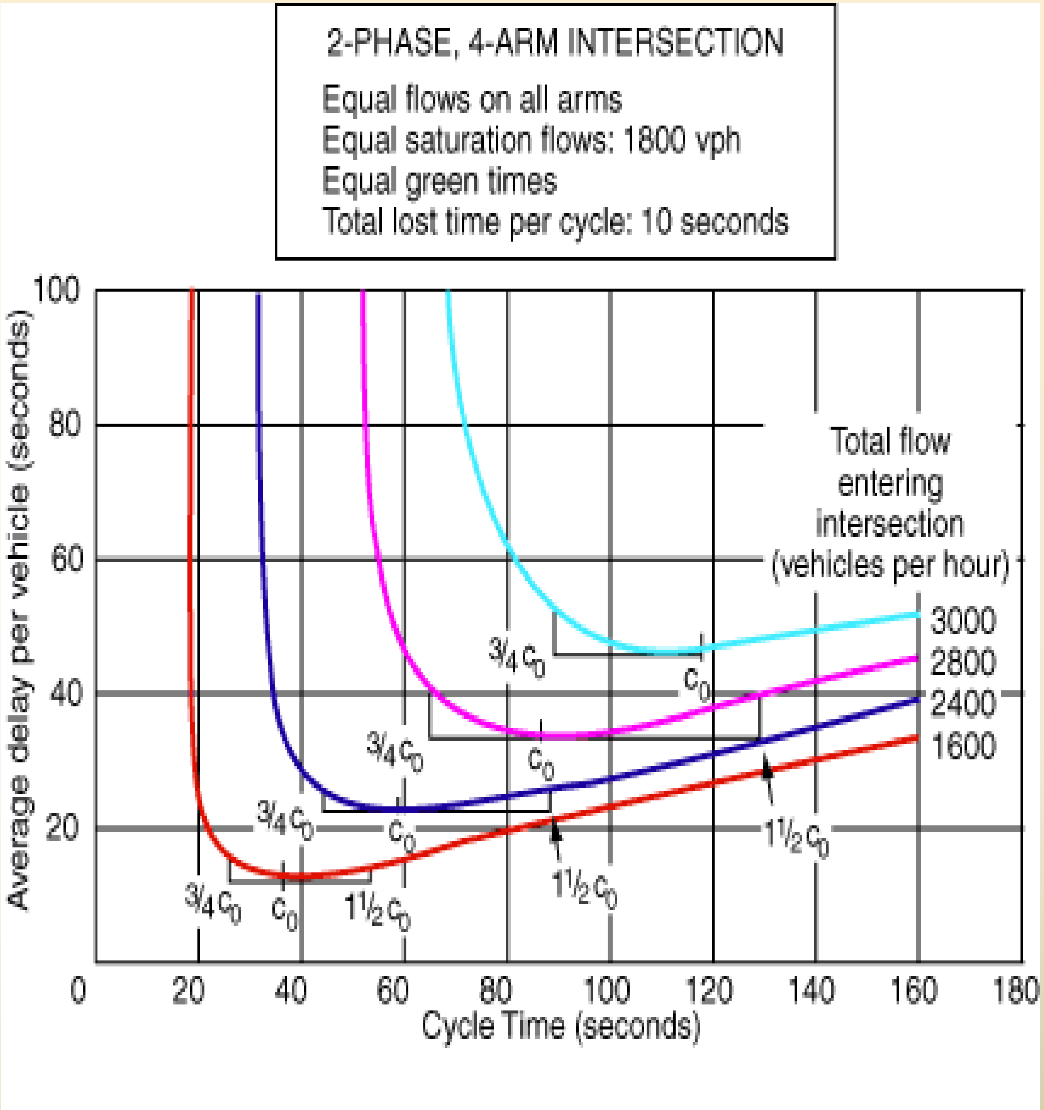


Figure D-8. Effect on delay of variation of the cycle length

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Signal Coordination

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Advantages of Coordination

- Higher level of traffic service: higher overall speeds and reduced number of stops.

- Traffic flows more smoothly, often with an improvement in capacity due to reduced headways.

- Vehicle speeds are more uniform: no incentive to travel at excessively high speeds to reach a green light; slow drivers are encouraged to speed up to avoid having to stop for a red light.

Advantages (cont'd)

- Fewer accidents because platoons arrive at each signal when it is green, reducing red signal violations and rear-end collisions.
- Greater obedience to signal commands by motorists and pedestrians.
- Through traffic tends to stay on the arterial streets instead of diverting onto parallel minor streets in search of alternative routes.

Approaches for Arterial Signal Timings

- Maximize the bandwidth of the progression

or

- Minimize delays and stops

- We want to combine both.

Delay-Based Models – Cyclic Flow Profiles

Performance Index based on delay, stops or combination thereof.

Most popular model:

TRANSYT:

TRAffic Network StudY Tool

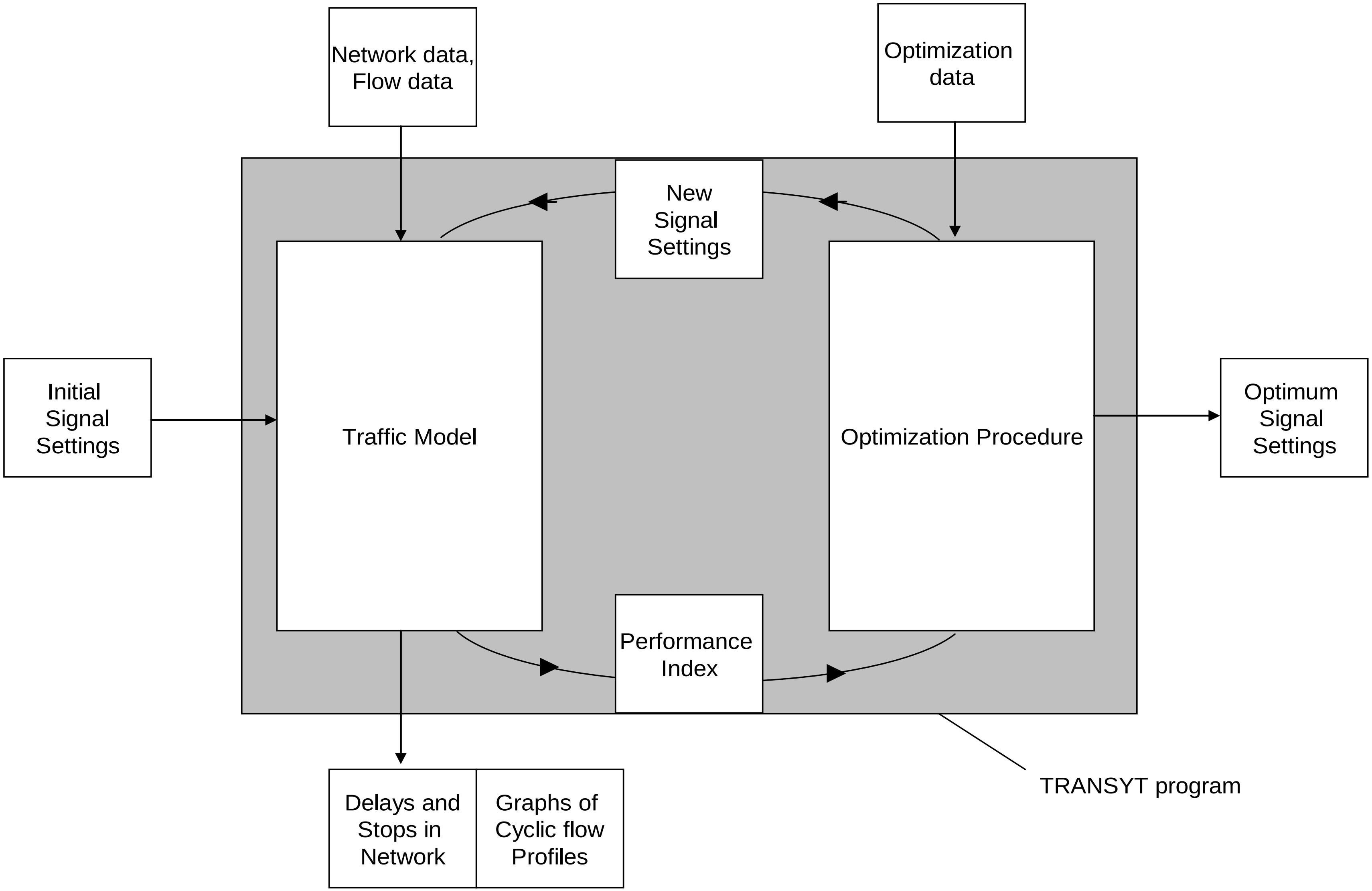
Developed by TRRL (GB)

TRANSYT

TRANSYT, the traffic network study tool, is a computer model to optimize traffic signal timings and perform traffic signal simulation.

TRANSYT has two main elements – the traffic model which is used to calculate the performance index for a given set of signal timings and an optimizing process that makes changes to the settings and determines whether they improve the performance index or not.

Structure of TRANSYT program



TRANSYT

Current Versions

US: TRANSYT-7F

http://mctrans.ce.ufl.edu/featured/transyt-7f/

UK: TRANSYT 14

https://www.trlsoftware.co.uk/products/junction_signal_design/transyt/

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Traffic Management and Control

Progression Models – Arterial Streets

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Traffic Progression Methods

- Bandwidth optimization
- Robust solution of the traffic control problem
- Optimal phase sequencing
- Advance queue clearance
- Progression speed adjustment

14.341 Transportation Engineering Lab
Arterial Signal Coordination: Maximal Bandwidth Progressions

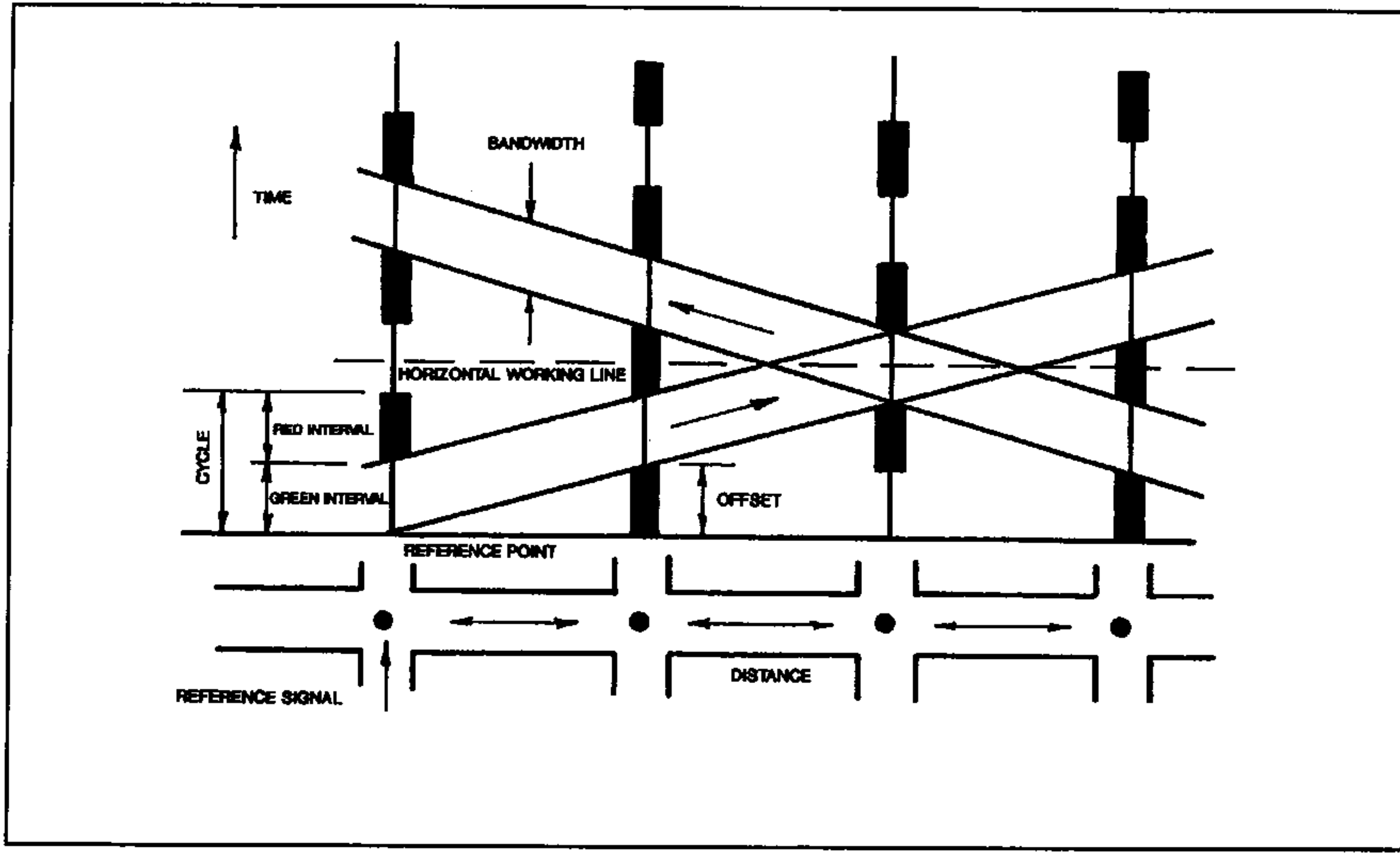
Definitions:

- **Offset** – difference in time between the start of green at adjacent signals along the arterial (seconds)

- **Through band** – a band delineating the difference in time between the passing of the first vehicle, and the last vehicle, in a platoon traveling in accordance with the designed speed of a progressive signal system.

- **B** - Bandwidth (seconds)

- **Progressive signal system** - a system of linked adjacent signals along an arterial street permitting continuous movements of groups of vehicles at a planned rate of speed without stopping.



(a). Time-space diagram.

PERGAMON

Mathematical and Computer Modelling 35 (2002) 657–671

MATHEMATICAL AND COMPUTER MODELLING

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Arterial-Based Control of Traffic Flow in Urban Grid Networks

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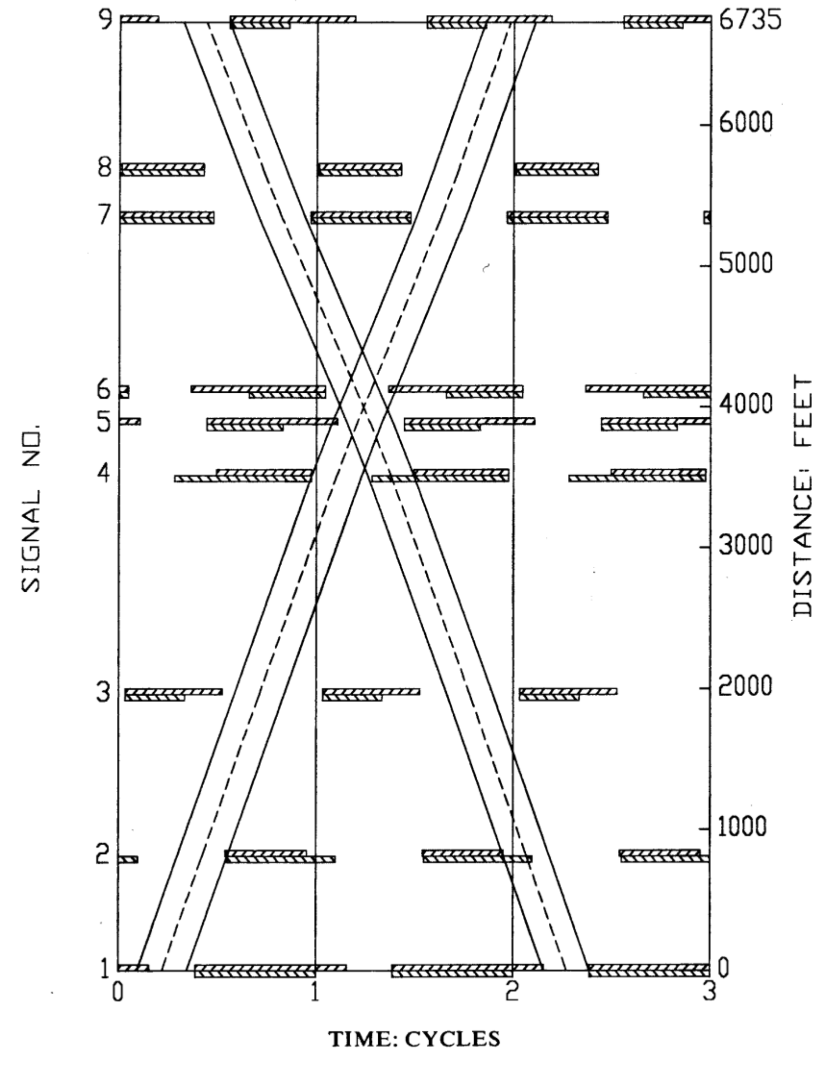
Basic Bandwidth Maximization Problem

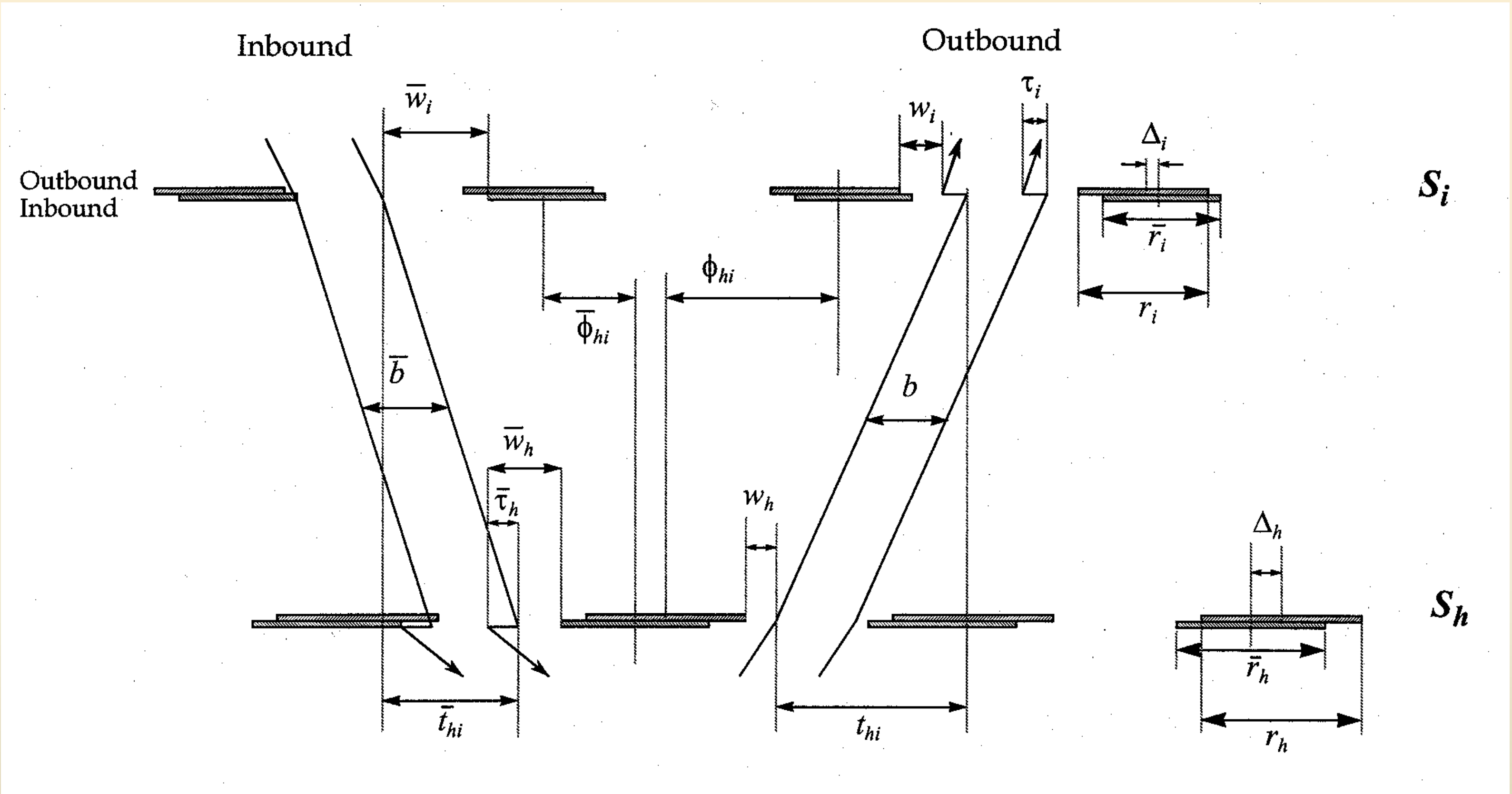


- objective function :

Maximize

$$b + k \cdot \overline{b}$$

Time Space Diagram for MILP-1



Directional Interference Constraints

- Progression bands use only the available green time and do not infringe upon red times.

$$w_i + b_i \leq 1 - r_i$$

$$\overline{w_i} + \overline{b_i} \leq 1 - \overline{r_i}$$

Arterial-Loop Integer Constraint

If we proceed along a loop consisting of the following points:

- Center of inbound red at S_i
- Center of outbound red at S_i
- Center of inbound red at S_h
- Center of outbound red at S_h,

we end up at a point that is removed an integral number of cycle times from the point of departure:

and $$\phi_{hi} + \bar{\phi}_{hi} + \Delta_h - \Delta_i = \nu_{hi}$$

- Cycle time constraint:

$$1/C_2 \le z \le 1/C_1$$

- Progression speed constraints:

$$\frac{d_i}{f_i} z \le t_i \le \frac{d_i}{e_i} z \quad \text{and} \quad \frac{\bar{d}_i}{\bar{f}_i} z \le \bar{t}_i \le \frac{\bar{d}_i}{\bar{e}_i}$$

$$\frac{d_i}{h_i} z \le \frac{d_i}{d_{i+1}} t_{i+1} - t_i \le \frac{d_i}{g_i} z \quad \text{and} \quad \frac{\bar{d}_i}{\bar{h}_i} z \le \frac{\bar{d}_i}{\bar{d}_{i+1}} \bar{t}_{i+1} - \bar{t}_i \le \frac{\bar{d}_i}{\bar{g}_i} z$$

MILP-1. Find $b, \bar{b}, z, w_i, \bar{w}_i, t_i, \bar{t}_i, \nu_i$ **to**

Maximize $b + k \cdot \bar{b}$ **subject to**

$$1/C_2 \le z \le 1/C_1$$

$w_i + b \le 1 - r_i$ and $\bar{w}_i + \bar{b} \le 1 - \bar{r}_i$ $i = 1, \ldots, n$

$$t_i + \bar{t}_i + \frac{r_i + \bar{r}_i}{2} + (w_i + \bar{w}_i) - \frac{r_{i+1} + \bar{r}_{i+1}}{2} - (w_{i+1} + \bar{w}_{i+1}) - (\tau_{i+1} + \bar{\tau}_i) + \Delta_i - \Delta_{i+1} = \nu_i$$

$i = 1, \ldots, n\text{-}1$

$\frac{d_i}{f_i} z \le t_i \le \frac{d_i}{e_i} z$ and $\frac{\bar{d}_i}{\bar{f}_i} z \le \bar{t}_i \le \frac{\bar{d}_i}{\bar{e}_i} z$ $i = 1, \ldots, n\text{-}1$

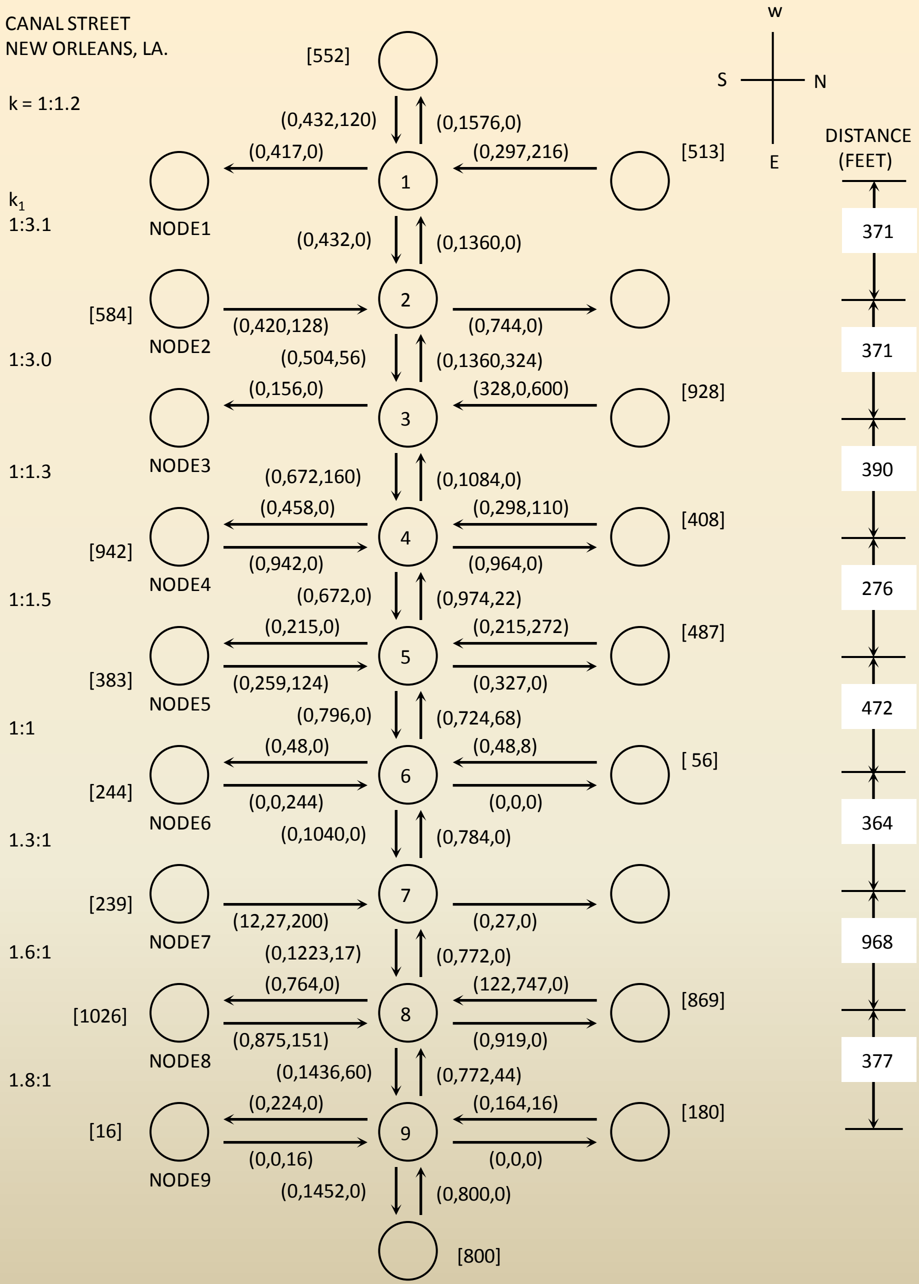
$\frac{d_i}{h_i} z \le \frac{d_i}{d_{i+1}} t_{i+1} - t_i \le \frac{d_i}{g_i} z$ and $\frac{\bar{d}_i}{\bar{h}_i} z \le \frac{\bar{d}_i}{\bar{d}_{i+1}} \bar{t}_{i+1} - \bar{t}_i \le \frac{\bar{d}_i}{\bar{g}_i} z$ $i = 1, \ldots, n\text{-}1$

$b, \bar{b}, z, w_i, \bar{w}_i, t_i, \bar{t}_i \ge 0$ and ν_i integer

Example:

Data for Canal St.

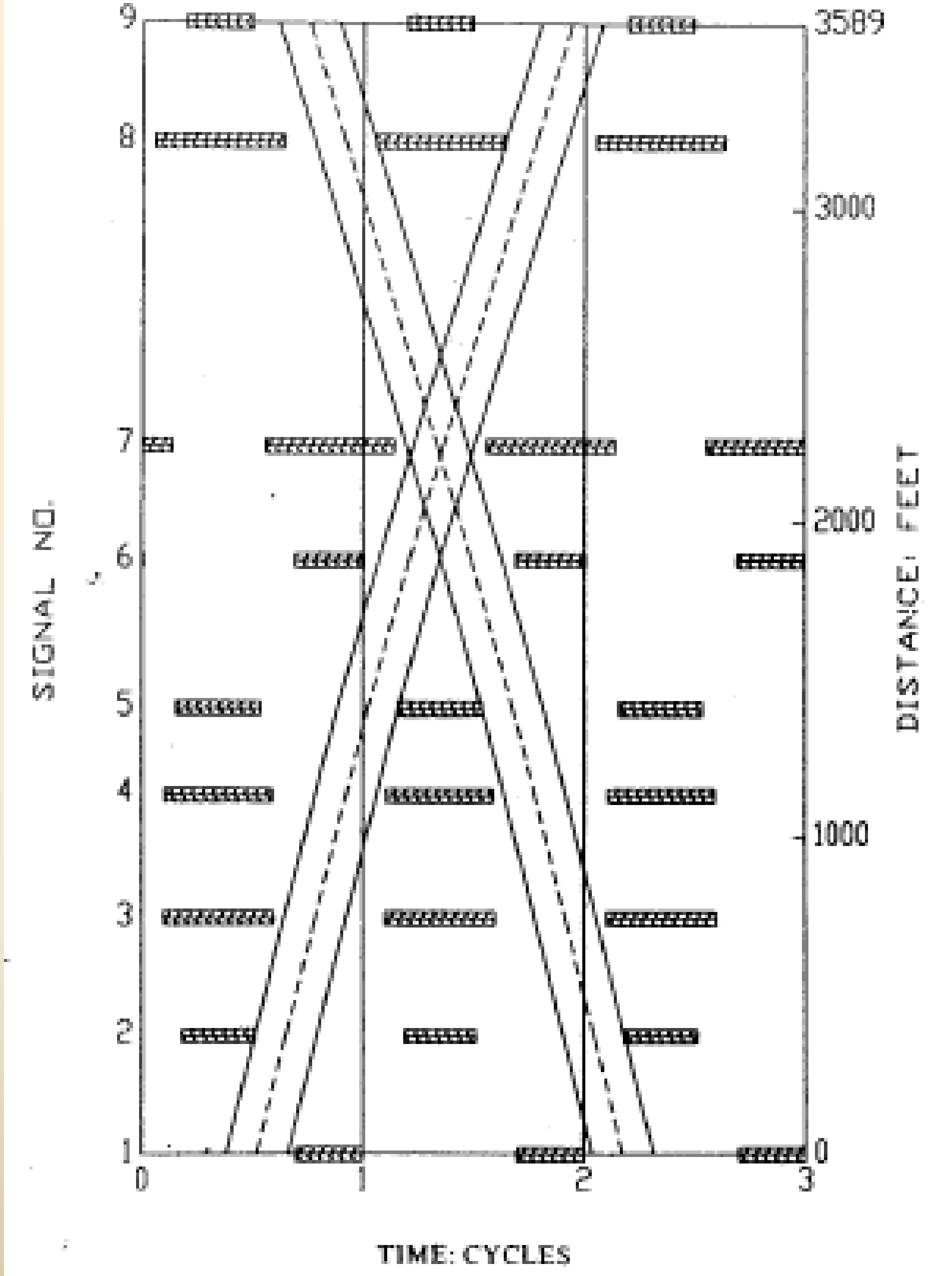
New Orleans, LA



MILP-1

Canal St.

Symmetric Progression

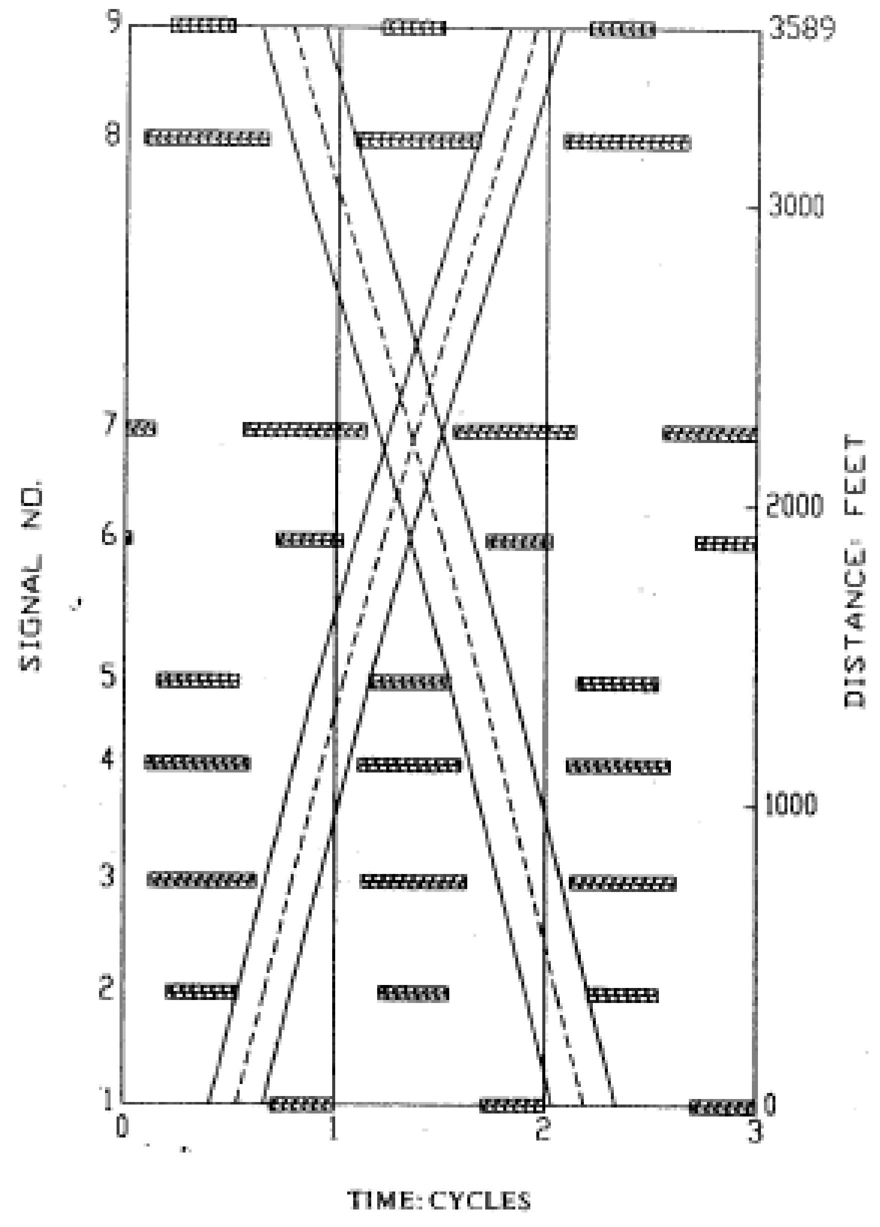


MILP-1

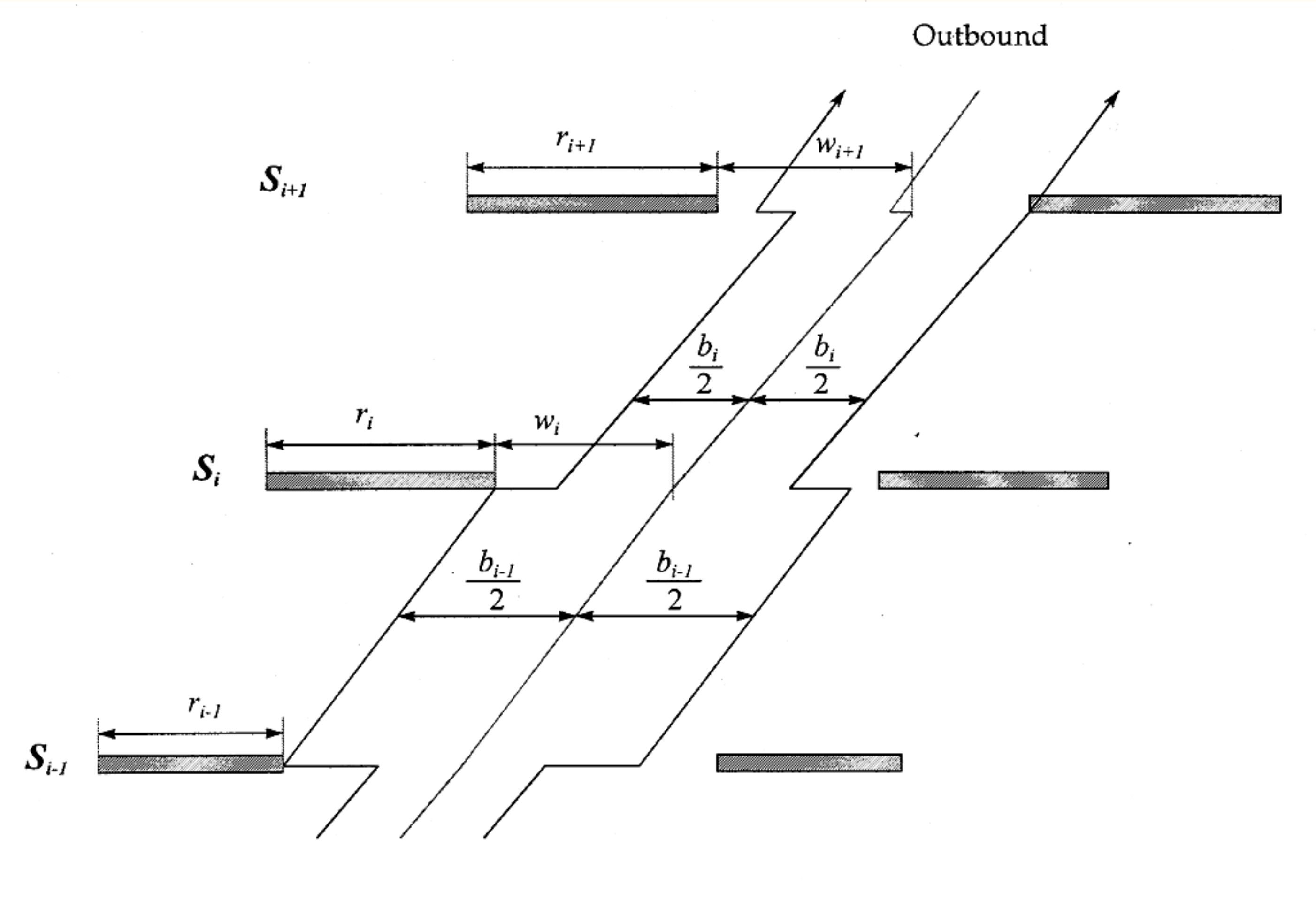
Canal St.

Uniform Weighted Progression

Weight: Total Volume Ratio



Variable Bandwidth



The Variable Bandwidth Problem

- Different bandwidth for each directional road section of the arterial
- Individually weighted with respect to its contribution to the objective function
- Width can vary and adapt to the prevailing traffic volumes on each link
- User can still choose a uniform bandwidth progression if desired.

Directional Interference Constraints

The time reference point at each signal is redefined to the *centerline* of the band (*progression* line), rather than the edge.

- Outbound direction:

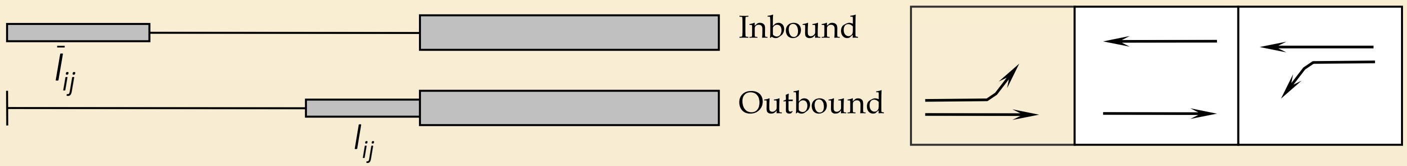
$$\frac{b_i}{2} \le w_i \le (1 - r_i) - \frac{b_i}{2} \qquad \frac{b_i}{2} \le w_{i+1} \le (1 - r_{i+1}) - \frac{b_i}{2}$$

- Inbound direction

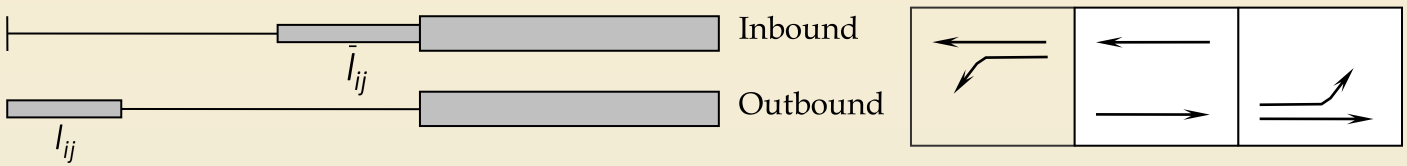
$$\frac{\bar{b}_i}{2} \le \overline{w}_i \le (1 - \bar{r}_i) - \frac{\bar{b}_i}{2} \qquad \frac{\bar{b}_i}{2} \le \overline{w}_{i+1} \le (1 - \bar{r}_{i+1}) - \frac{\bar{b}_i}{2}$$

Phase Sequencing

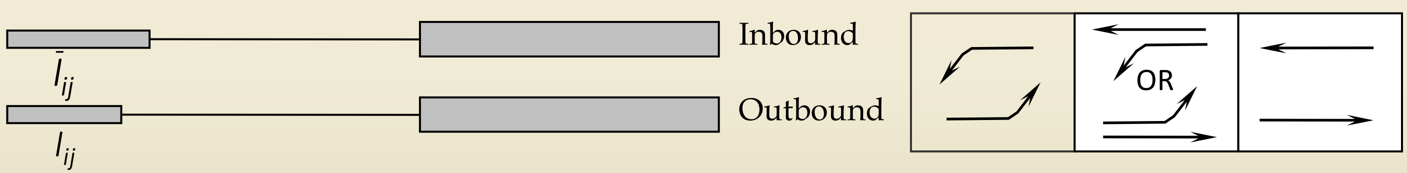
Pattern 1: Outbound left leads; Inbound left lags



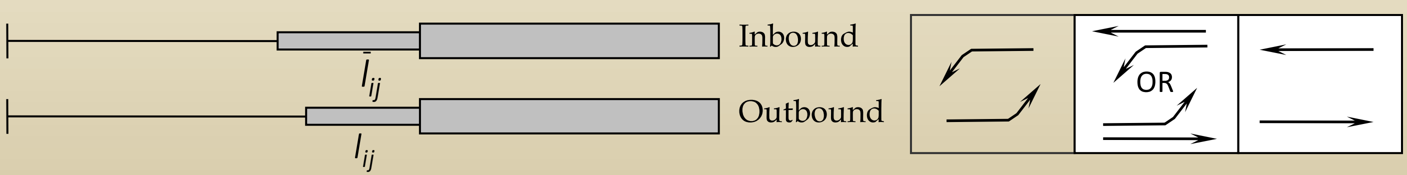
Pattern 2: Outbound left lags; Inbound left leads



Pattern 3: Outbound & Inbound lefts lead



Pattern 4: Outbound & Inbound lefts lag



Objective Function for MULTIBAND

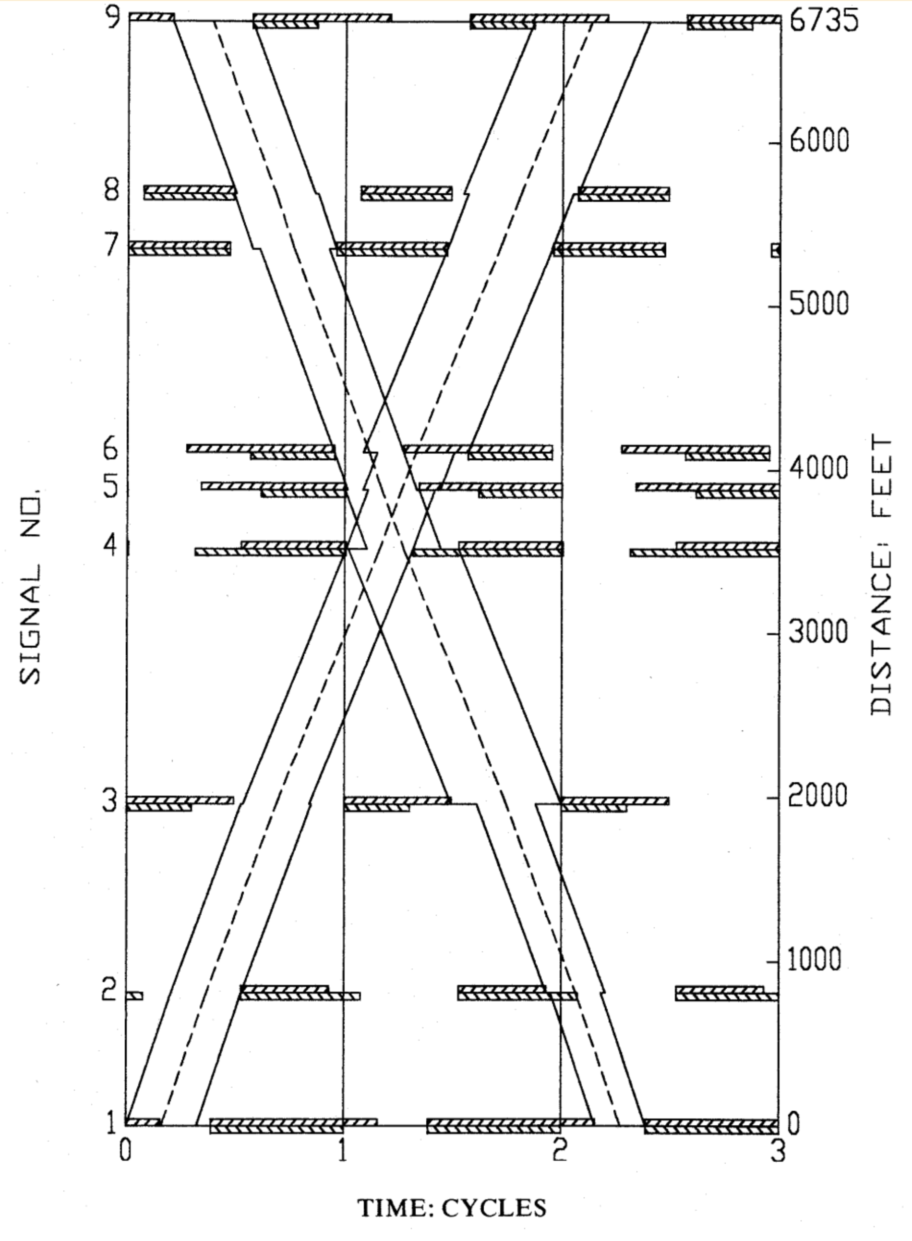
Objective Function

Maximize:

$$\frac{1}{n-1}\sum_{i=1}^{n} a_i \cdot b_i + \overline{a}_i \cdot \overline{b}_i$$

with

$$a_i = \left(\frac{q_i}{s_i}\right)^p \quad \overline{a}_i = \left(\frac{\overline{q}_i}{\overline{s}_i}\right)^p$$



MILP-2. Find $b_i, \overline{b}_i, z, w_i, \overline{w}_i, t_i, \overline{t}_i, \nu_i$ **to**

Maximize $\dfrac{1}{n-1}\sum_{i=1}^{n} a_i \cdot b_i + \overline{a}_i \cdot \overline{b}_i$ **subject to**

$$1/C_2 \le z \le 1/C_1$$

$$\frac{b_i}{2} \le w_i \le (1-r_i) - \frac{b_i}{2}, \qquad \frac{b_i}{2} \le w_{i+1} \le (1-r_{i+1}) - \frac{b_i}{2},$$

$$\frac{\overline{b}_i}{2} \le \overline{w}_i \le (1-\overline{r}_i) - \frac{\overline{b}_i}{2} \quad \text{and} \quad \frac{\overline{b}_i}{2} \le \overline{w}_{i+1} \le (1-\overline{r}_{i+1}) - \frac{\overline{b}_i}{2} \qquad i = 1, \ldots, n\text{-}1$$

$$t_i + \overline{t}_i + \frac{r_i + \overline{r}_i}{2} + (w_i + \overline{w}_i) - \frac{r_{i+1} + \overline{r}_{i+1}}{2} - (w_{i+1} + \overline{w}_{i+1}) - (\tau_{i+1} + \overline{\tau}_i) + \Delta_i - \Delta_{i+1} = \nu_i \qquad i=1,\ldots,n\text{-}1$$

$$\frac{d_i}{f_i} z \le t_i \le \frac{d_i}{e_i} z \quad \text{and} \quad \frac{\overline{d}_i}{\overline{f}_i} z \le \overline{t}_i \le \frac{\overline{d}_i}{\overline{e}_i} z \qquad i = 1, \ldots, n\text{-}1$$

$$\frac{d_i}{h_i} z \le \frac{d_i}{d_{i+1}} t_{i+1} - t_i \le \frac{d_i}{g_i} z \quad \text{and} \quad \frac{\overline{d}_i}{\overline{h}_i} z \le \frac{\overline{d}_i}{\overline{d}_{i+1}} \overline{t}_{i+1} - \overline{t}_i \le \frac{\overline{d}_i}{\overline{g}_i} z \qquad i = 1, \ldots, n\text{-}1$$

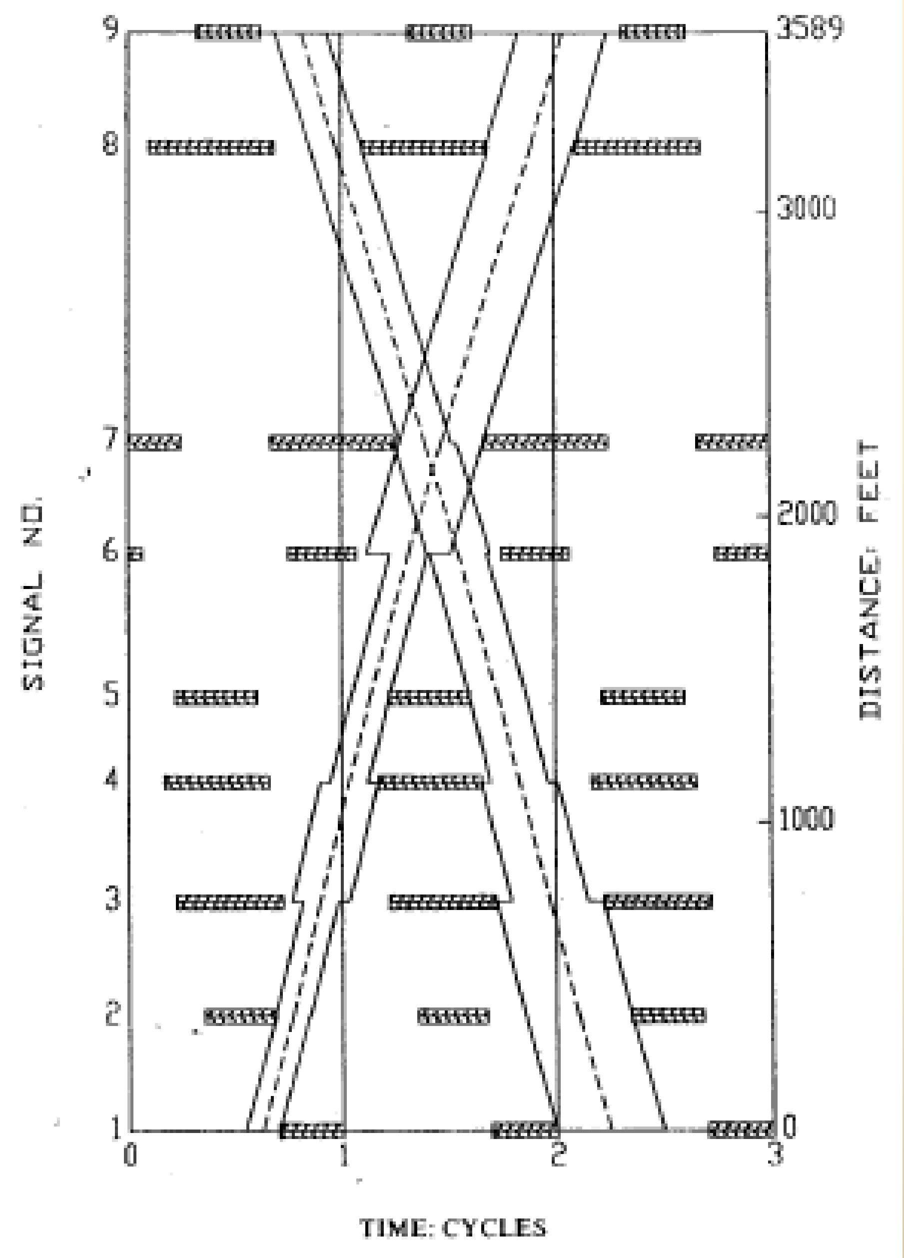
$$b_i, \overline{b}_i, z, w_i, \overline{w}_i, t_i, \overline{t}_i \ge 0 \quad \text{and} \quad \nu_i \text{ integer}$$

MILP-1

Canal St.

Variable Weighted Progression

Weight: (Tot. Volume/Capacity)^2

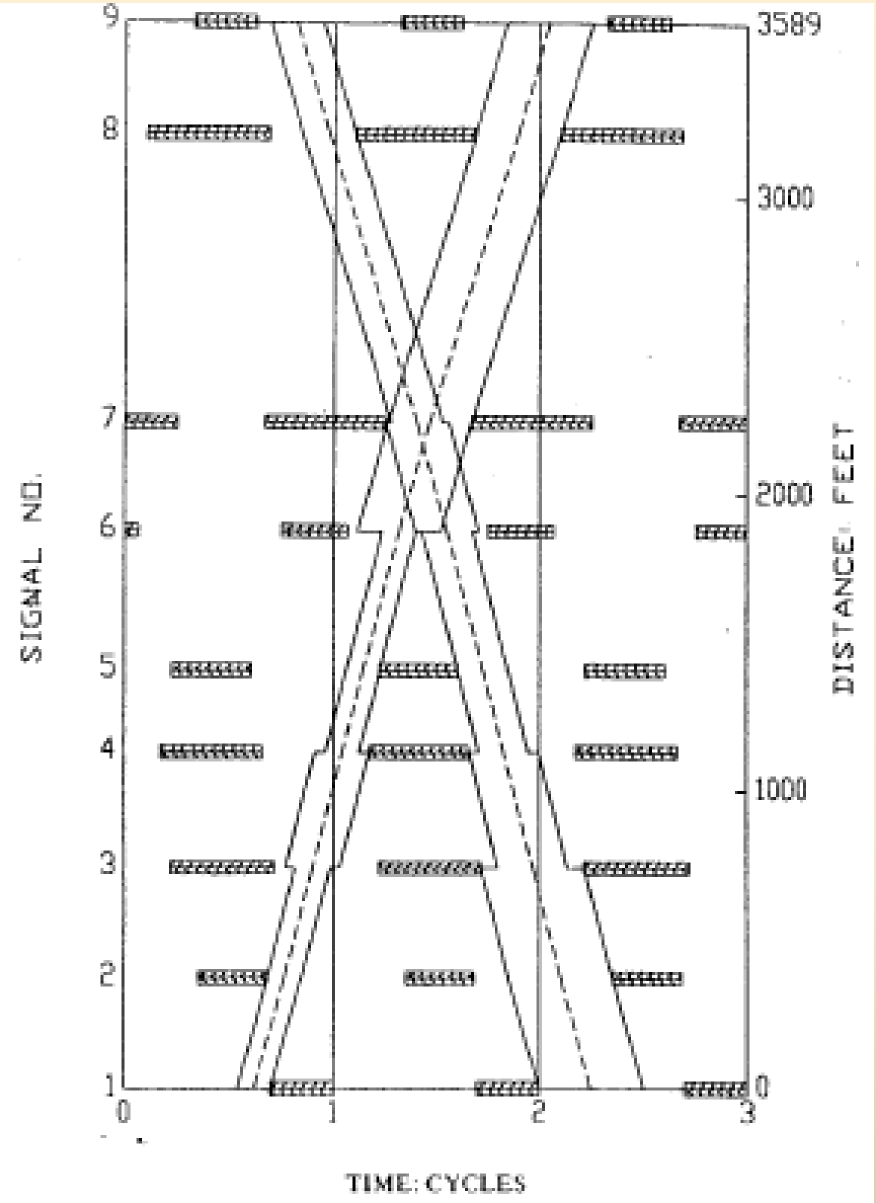


MILP-1

Canal St.

Variable Weighted Progression

Weight: (Tot. Volume/Capacity)^4



Simulation Results, Canal St.

Method	Weighting Coefficient	Average Delay	Average# of Stops	Average Speed	Average M.P.G.	Delay + 20 (Stops)
MAXBAND	1	29.69	1.35	15.98	10.70	56.65
MAXBAND	TVR	28.84	1.35	16.11	10.78	55.84
MULTIBAND	1	25.62	1.13	16.82	11.20	48.30
MULTIBAND	TVC	25.20	1.07	16.96	11.28	46.68
MULTIBAND	PVC	25.08	1.02	16.99	11.30	45.40
MULTIBAND	$(TVC)^2$	25.35	1.20	16.80	11.15	49.31
MULTIBAND	$(TVC)^4$	24.11	1.14	17.08	11.30	46.87
MULTIBAND	$(PVC)^4$	25.25	1.01	16.95	11.29	45.53

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Progression Models – Networks

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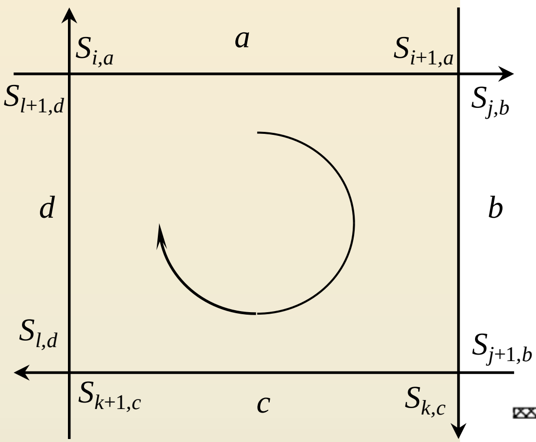
Network Problem

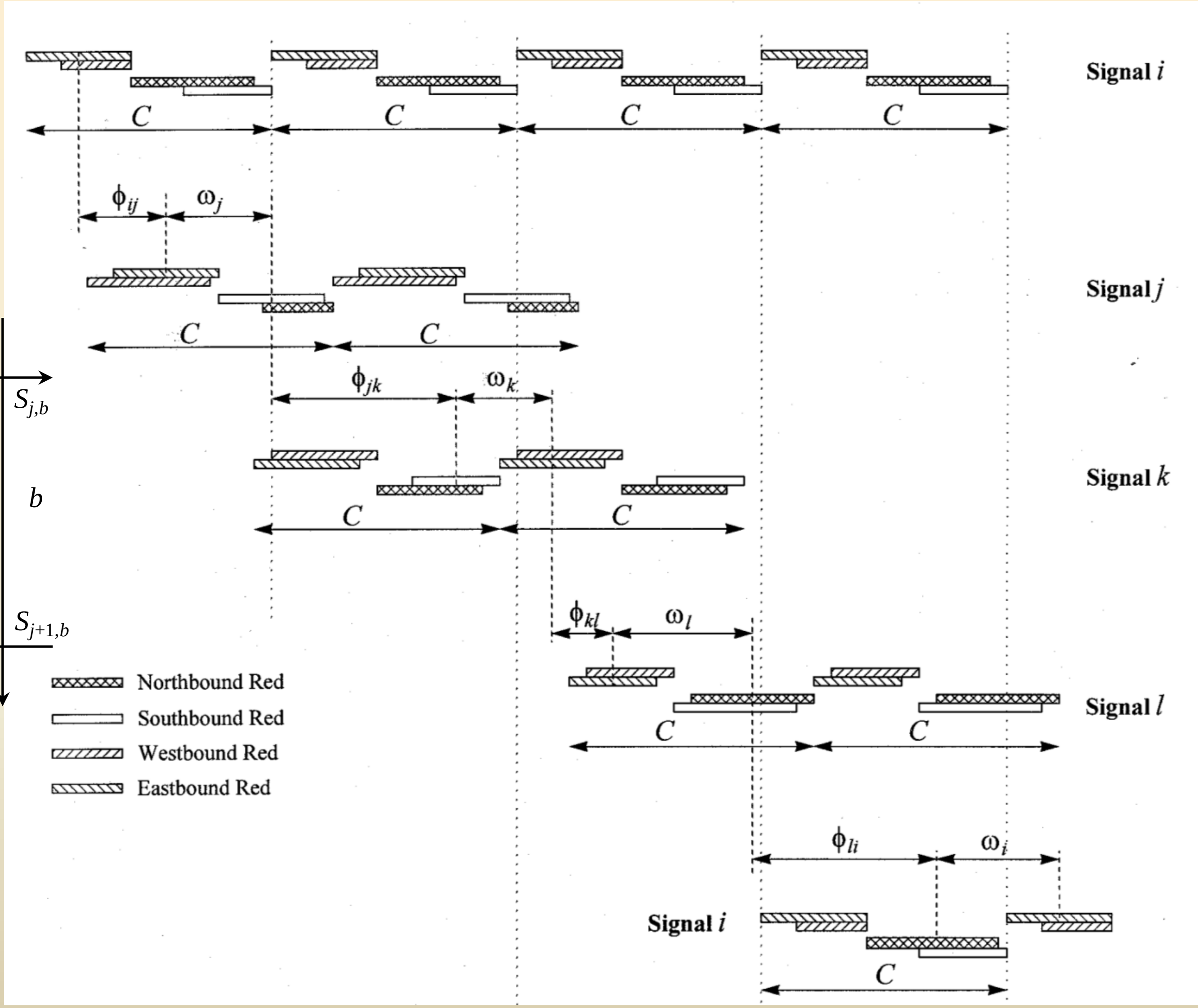
MILP-2 can be extended for controlling traffic flow in a network of intersecting arterials.

Significantly more challenging problem:

Progressions must be provided on all the arterials of the network, simultaneously. The principal difficulty is due to the requirement that the progression bands of intersecting arterials cannot overlap in time at any junction of the network.

Network Loop Constraint Geometry





Network Loop-Integer Constraints

For any closed loops of the network consisting of more than 2 links, the summation of *internode* and *intranode offsets* around a loop of intersecting arterials must be an integer multiple of the cycle time.

MILP-3. Find $b_{ij}, \overline{b}_{ij}, z, w_{ij}, \overline{w}_{ij}, t_{ij}, \overline{t}_{ij}, \nu_{ij}, \mu_i$ **to**

Maximize $\sum_{j=1}^{m} \frac{1}{n-1} \sum_{i=1}^{n} a_{ij} \cdot b_{ij} + \overline{a}_{ij} \cdot \overline{b}_{ij}$ **subject to**

$$1/C_2 \le z \le 1/C_1$$

$$\frac{b_{ij}}{2} \le w_{ij} \le (1-r_{ij}) - \frac{b_{ij}}{2}, \qquad \frac{b_{ij}}{2} \le w_{i+1,j} \le (1-r_{i+1,j}) - \frac{b_{ij}}{2},$$

$$\frac{\overline{b}_{ij}}{2} \le \overline{w}_{ij} \le (1-\overline{r}_{ij}) - \frac{\overline{b}_{ij}}{2} \quad \text{and} \quad \frac{\overline{b}_{i,j}}{2} \le \overline{w}_{i+1,j} \le (1-\overline{r}_{i+1,j}) - \frac{\overline{b}_{ij}}{2}$$

$i = 1, ..., n_j\text{-}1; j = 1, ..., m$

$$t_{ij} + \overline{t}_{ij} + \frac{r_{ij} + \overline{r}_{ij}}{2} + (w_{ij} + \overline{w}_{ij}) - \frac{r_{i+1,j} + \overline{r}_{i+1,j}}{2} - (w_{i+1,j} + \overline{w}_{i+1,j}) - (\tau_{i+1,j} + \overline{\tau}_{i,j}) + \Delta_{i,j} - \Delta_{i+1,j} = \nu_{i,j}$$

$i = 1, ..., n_j\text{-}1; j = 1, ..., m$

$$\phi_{(ia),(i+1,a)} + \omega_{(i+1,a),(jb)} + \phi_{(jb),(j+1,b)} + \omega_{(j+1,b),(kc)} + \phi_{(kc),(k+1,c)} +$$

$$+ \omega_{(k+1,c),(ld)} + \phi_{(ld),(l+1,d)} + \omega_{(ld),(ia)} = \mu_N$$

$i = 1, ..., n_a\text{-}1;\; j = 1, ..., n_b\text{-}1;\; k = 1, ..., n_c\text{-}1;\; l = 1, ..., n_d\text{-}1;$

a, b, c, d arterials forming a fundamental network loop;

$$\frac{d_{ij}}{f_{ij}} z \le t_{ij} \le \frac{d_{ij}}{e_{ij}} z \quad \text{and} \quad \frac{\overline{d}_{ij}}{\overline{f}_{ij}} z \le \overline{t}_{ij} \le \frac{\overline{d}_{ij}}{\overline{e}_{ij}} z \qquad i = 1, ..., n_j\text{-}1; j = 1, ..., m$$

$$\frac{d_{ij}}{h_{ij}} z \le \frac{d_{ij}}{d_{i+1,j}} t_{i+1,j} - t_{ij} \le \frac{d_{ij}}{g_{ij}} z \quad \text{and} \quad \frac{\overline{d}_{ij}}{\overline{h}_{ij}} z \le \frac{\overline{d}_{ij}}{\overline{d}_{i+1,j}} \overline{t}_{i+1,j} - \overline{t}_{ij} \le \frac{\overline{d}_{ij}}{\overline{g}_{ij}} z$$

$i = 1, ..., n_j\text{-}1; j = 1, ..., m$

$$b_{ij}, \overline{b}_{ij}, z, w_{ij}, \overline{w}_{ij}, t_{ij}, \overline{t}_{ij} \ge 0 \quad \text{and} \quad \nu_{ij}, \mu_i \text{ integer}$$

MILP-3 Solutions (Ann Arbor, MI Network)

Model	Weighting Coeff.	Avg. Delay (sec./veh.)	Avg. % of Stops	Avg. Speed (m.p.h)
MAXBAND	1	26.64	53.20	9.40
	AVR[a]	25.52	53.04	9.89
MULTIBAND	V/C [b]	22.93 (-10.1%)	50.02 (-5.7%)	10.23 (3.4%)
	$(V/C)^2$	22.93 (-10.1%)	50.02 (-5.7%)	10.23 (3.4%)
	$(V/C)^4$	23.59 (-7.6%)	51.41 (-3.1%)	10.14 (2.5%)

a. Average directional volume ratio;
b. Volume over capacity ratio.

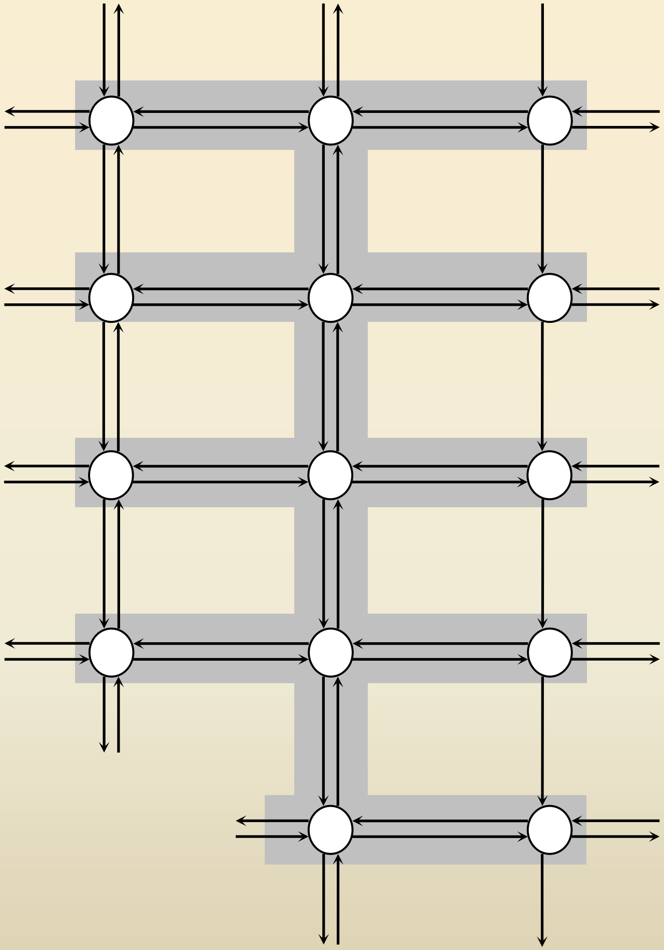
MILP-3 Characteristics

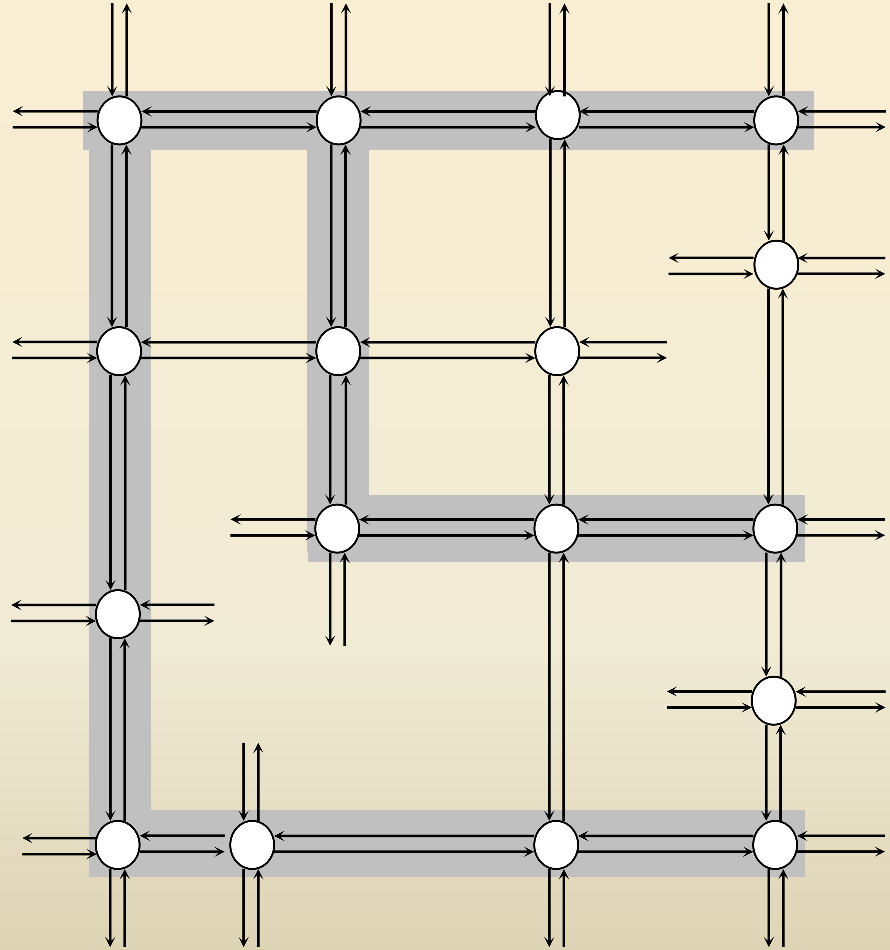
- Mathematical Programming problem (MILP)
- Optimization of offsets, splits, cycle length and phase sequencing
- Single arterial and grid network cases
- Uniform or variable bandwidth optimization
- Computationally demanding solutions

Network Decomposition Approach

- A *priority arterial sub-network* consisting of an arterial tree is selected from the original traffic network based on its *geometry* and on the *traffic volumes* that each link is carrying.
- The priority sub-network is optimized first and the results are then used for the solution of the entire network.
- Alternative sub-networks can be selected in a heuristic procedure if further improvements are desired.

Ann-Arbor, MI and Memphis, TN networks.





Conclusions

- Mathematical programming models can provide optimal arterial-based progression schemes in urban signal networks.
- Produce continuous green bands in each direction along the artery at the desired speed of travel.
- Facilitate movement of principal through flows along the arterials of the network.

ISTTT20 Tutorials

Traffic Management
and
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Adaptive Control Systems

Prof. Nathan H. Gartner
University of Massachusetts
Lowell, MA, USA

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Cost- Effectiveness of Traffic Signal System Improvements [ITE]

Traffic Control Improvement	Project Cost per Dollar Saved/year	B/C Ratio
Optimize Signal Timings	0.035-0.047	21-29
Interconnect & Optimize	0.042-0.15	7-24
Install Advanced Computer Control System	0.19	5
Avg. Program	0.076-0.122	8-13

Fixed-time Systems

Closed-loop systems:

- Pre-stored timing plans in a library
- Developed off line, using historical data
- Control plans are not responsive to dynamic and volatile traffic demands
- Ageing of timing plans - diminished performance over time

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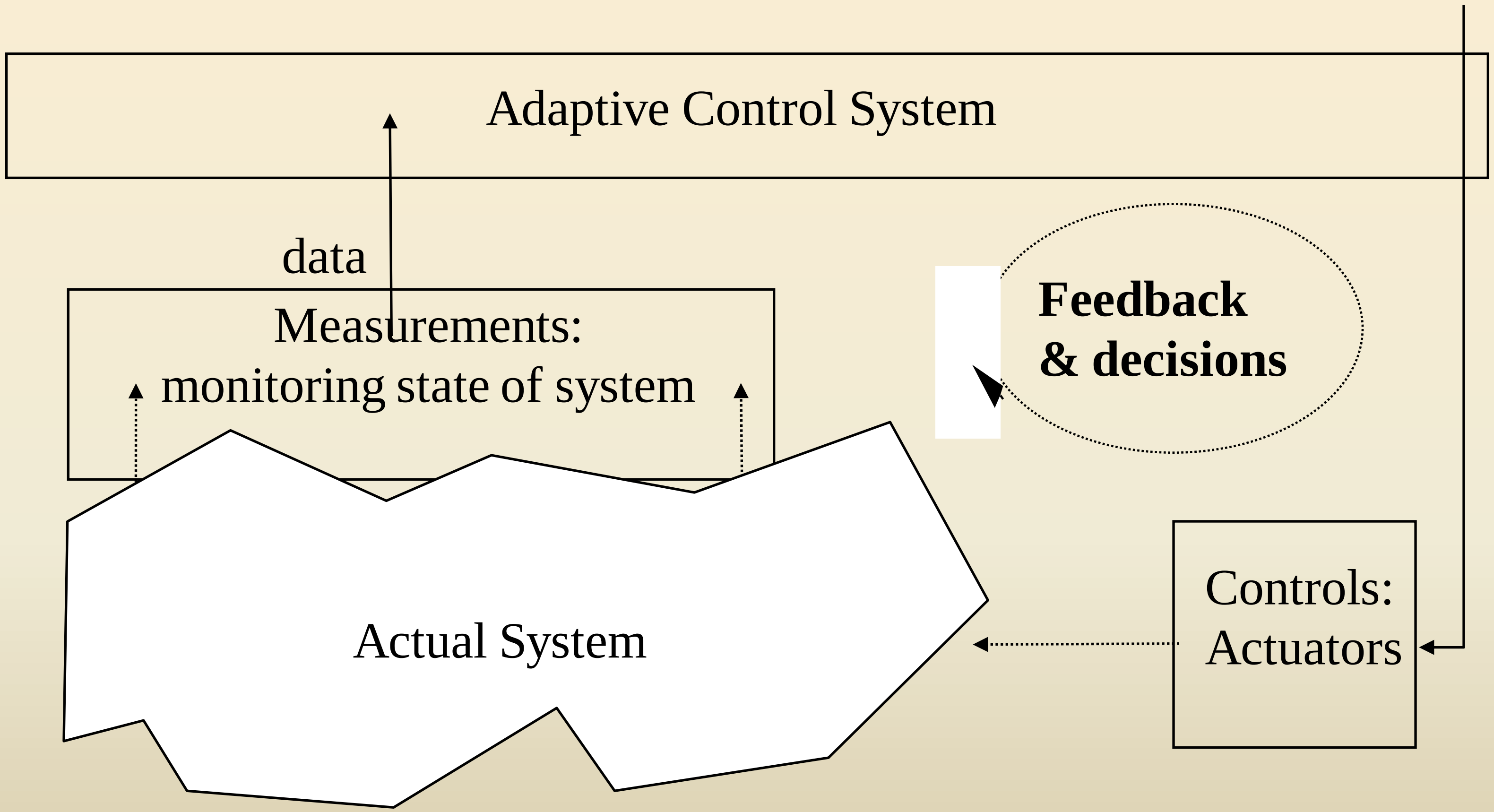
Adaptive Traffic Control:

- Real-time signal timing based on measured and predicted traffic demands
- Seeks continuous optimal system performance in response to both short term and long term variations in traffic
- Can be combined with DTA to optimize signal control and routing (assignment)

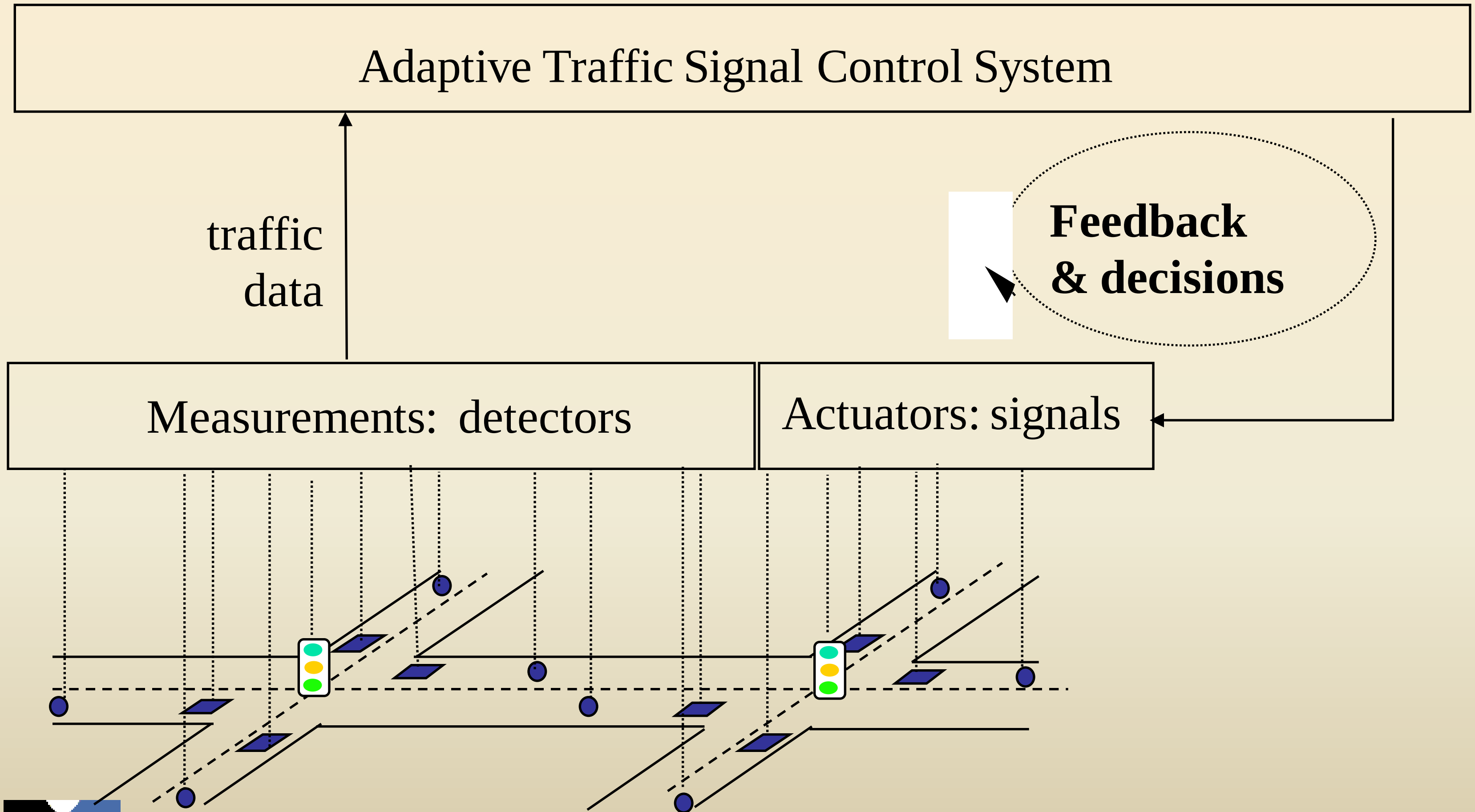
Adaptive Control Systems

- Require extensive deployment of traffic detectors and surveillance equipment
- Eliminate the need for signal re-timing
- Reduce maintenance and operations costs

Adaptive Control System



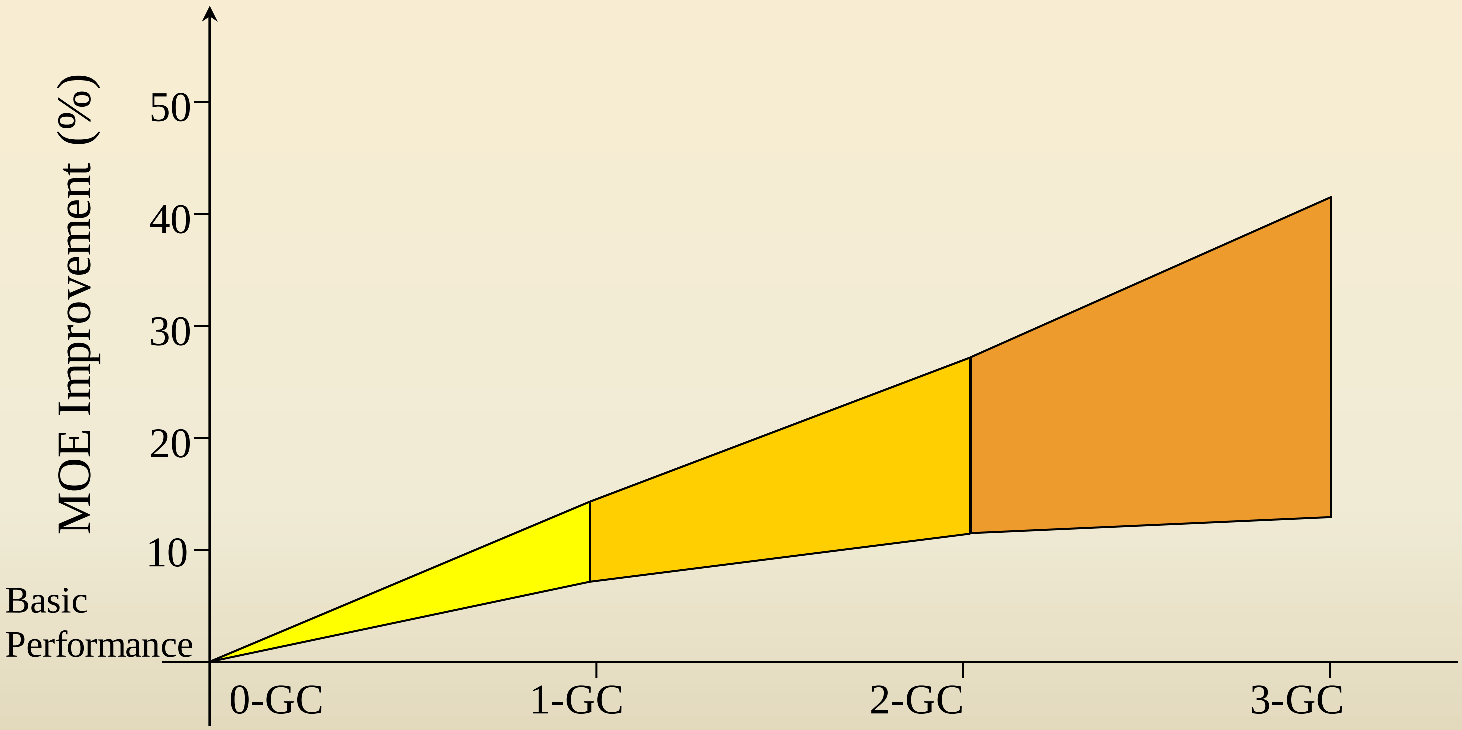
Adaptive Traffic Signal Control System



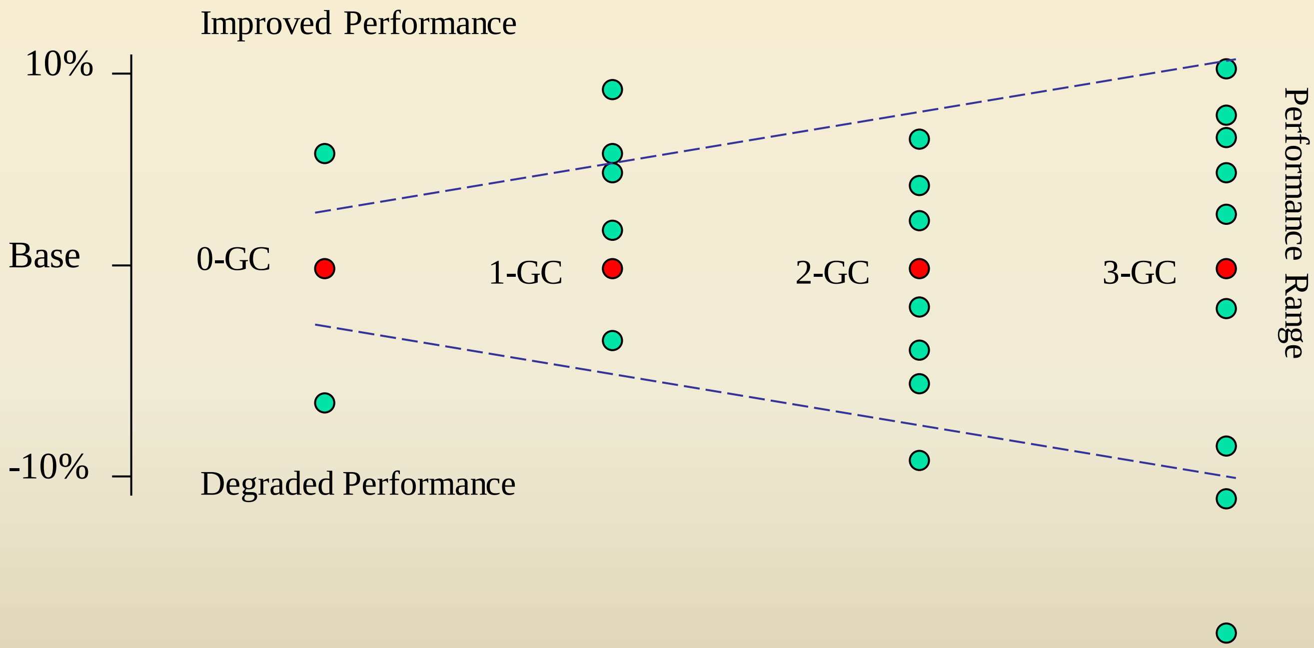
UTCS Generations

- **1-GC**: Off-line optimization,library of plans
- **2-GC**: On-line optimization, 5-min intervals, prediction
- **3-GC**: Variable cycle in time and space, 2-3 min interval optimization

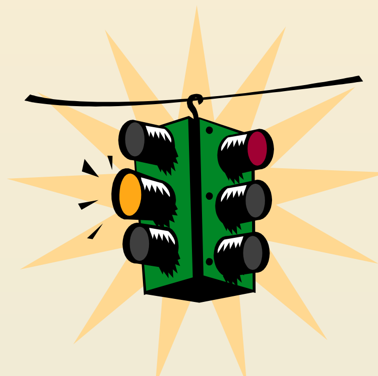
Expected Relative Performance of Control Generations



Reported Relative Performance of Control Generations



Optimization Policies for Adaptive Control (OPAC)



Developed for RT-TRACS at
University of Massachusetts Lowell

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What Is OPAC ?

- OPAC is a distributed real-time traffic signal control system
- Calculates signal timings to minimize a performance function of total intersection delay and number of stops over a pre-specified horizon
- Can operate as an independent smart controller, as well as part of a coordinated system

Principles for Development of OPAC

- Must provide better performance than off-line methods
- Requires development of new concepts
- System must be truly demand-responsive, i.e. adapt to <u>actual</u> traffic conditions
- Must not be restricted to arbitrary control periods, but capable of frequent or continuous updating of plans

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OPAC MODEL DEVELOPMENT
(Optimized Policies for Adaptive Control)

- OPAC I: dynamic programming optimization, infinite horizon (single intersection)
- OPAC II: OSCO search procedure, finite projection horizon length
- OPAC III: rolling horizon approach, real-time implementation
- OPAC IV: network model for real-time traffic-adaptive control (VFC principle)

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OPAC I

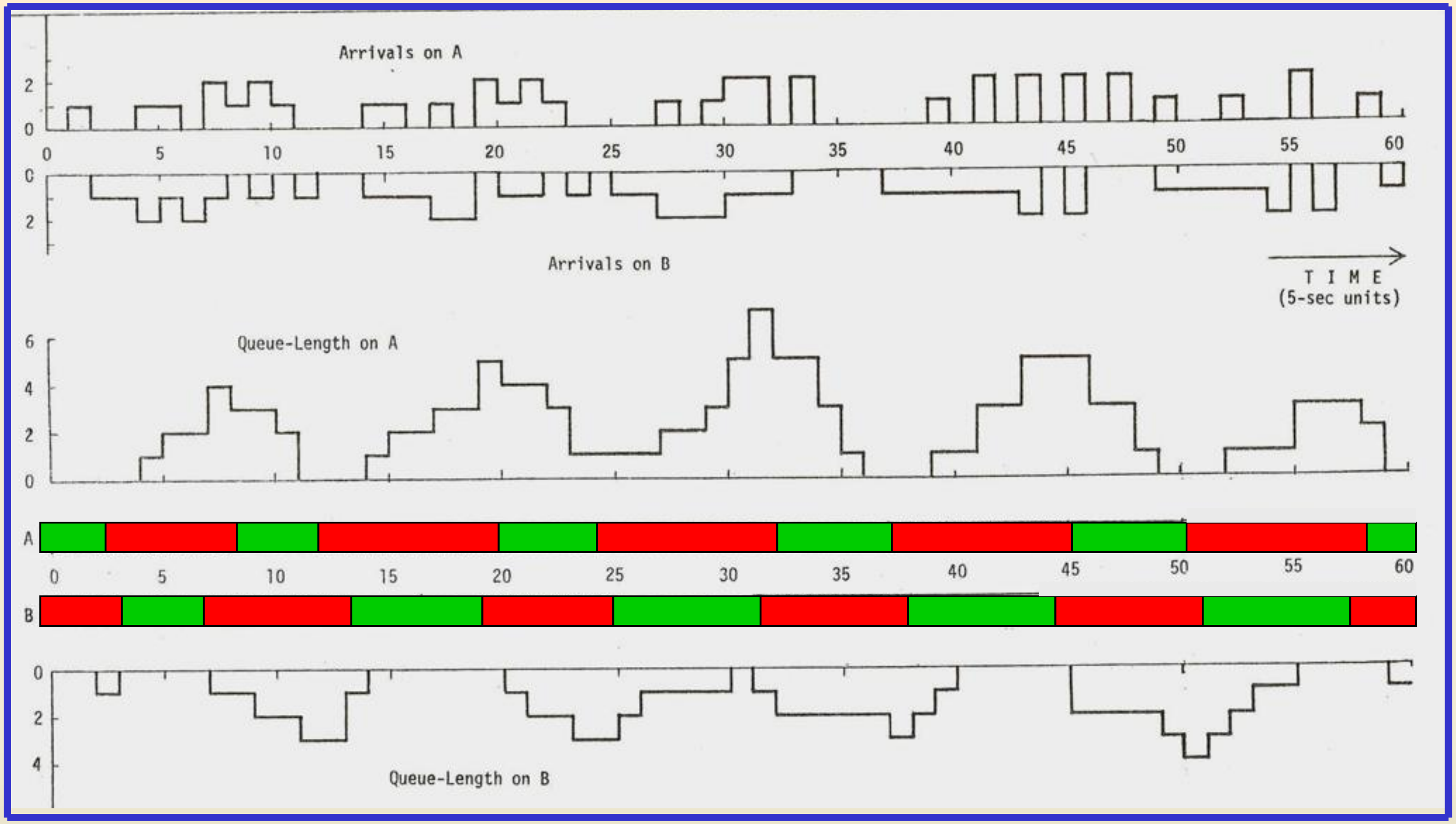
Infinite Horizon (Single Intersection)

Stage Length = One Time Interval

Dynamic Programming Optimization

Dynamic Programming

- The problem is divided into stages, with a **policy decision** required at each stage.
- Each stage has a number of **states** associated with the beginning of that stage.
- A policy decision at each stage transforms the current state to a state associated with the beginning of the next stage.
- The solution procedure is designed to find an **optimal policy** for the overall problem.



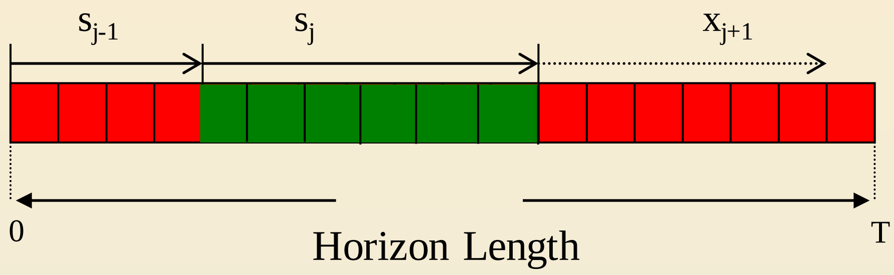
Example: OPAC-1, 5-minute data
(PI = 196 vehicle-intervals)

OPAC II

Finite Projection Horizon

Stage Length = Phase Length

Dynamic Programming Optimization



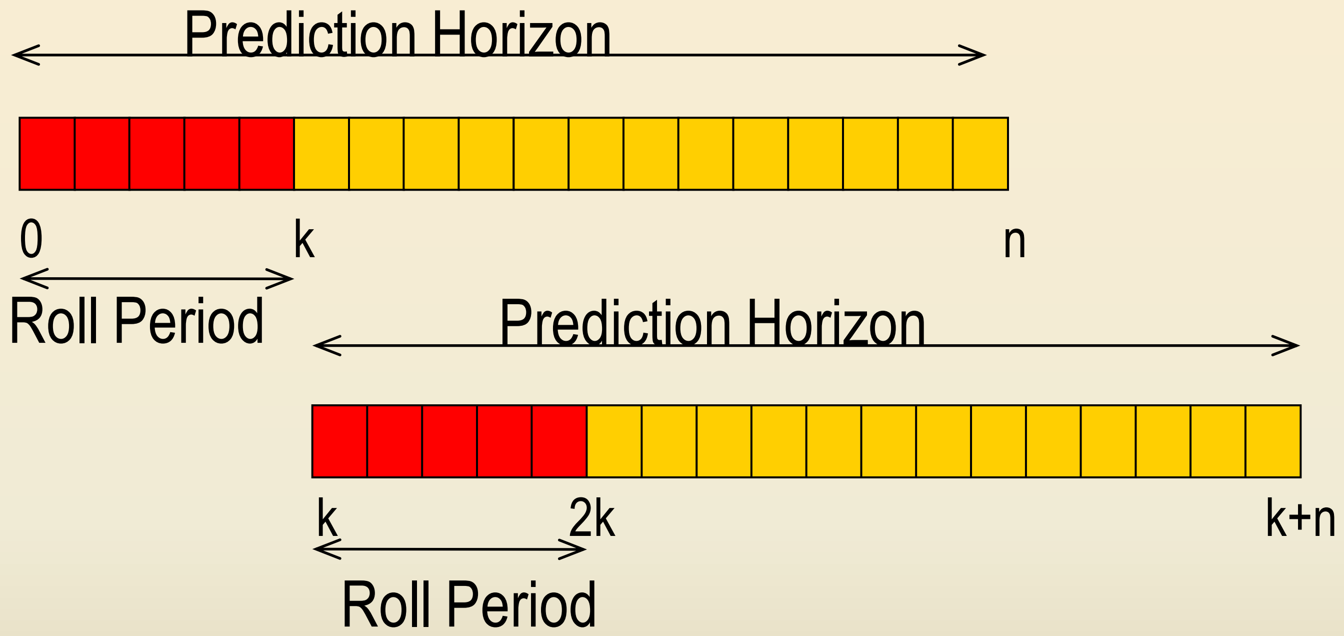
Dynamic Programming stage in OPAC II.

OPAC III

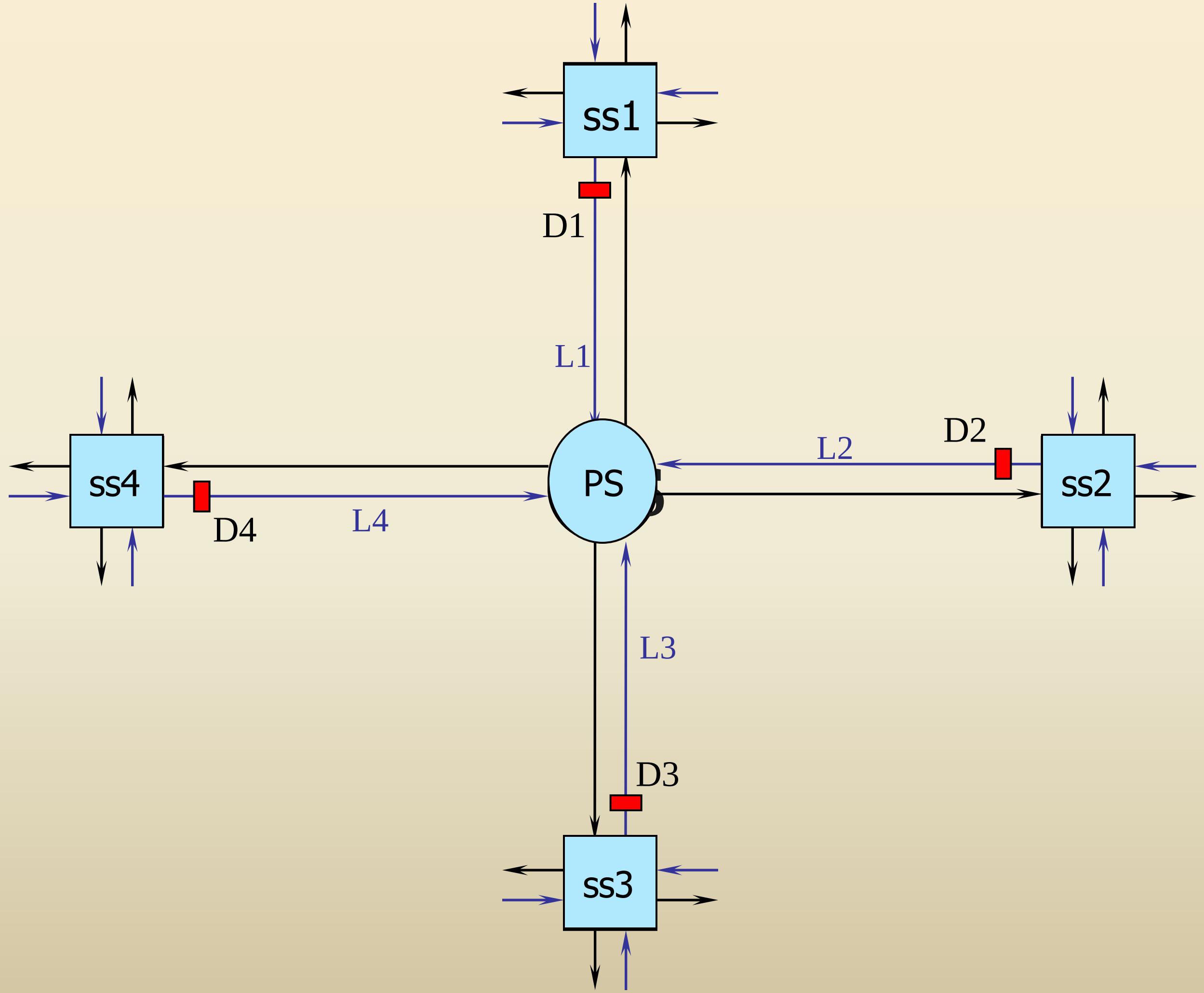
Rolling Horizon Approach

Real-Time Implementation

Rolling Horizon Approach

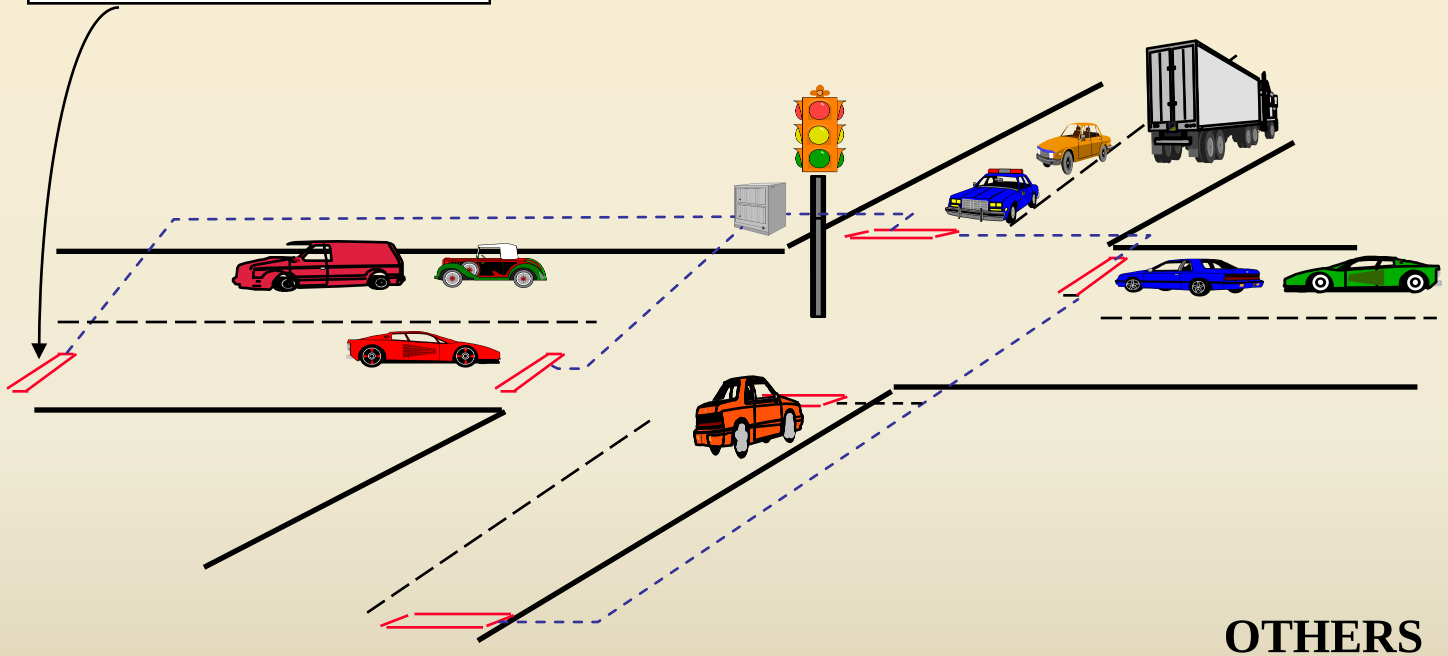


OPAC Information Flow



SENSORS

INDUCTIVE LOOP DETECTORS



<u>OTHERS</u>

- **VIDEO DETECTORS**
- **SONAR DETECTORS**
- **RADAR DETECTORS**

OPAC IV

Network Model

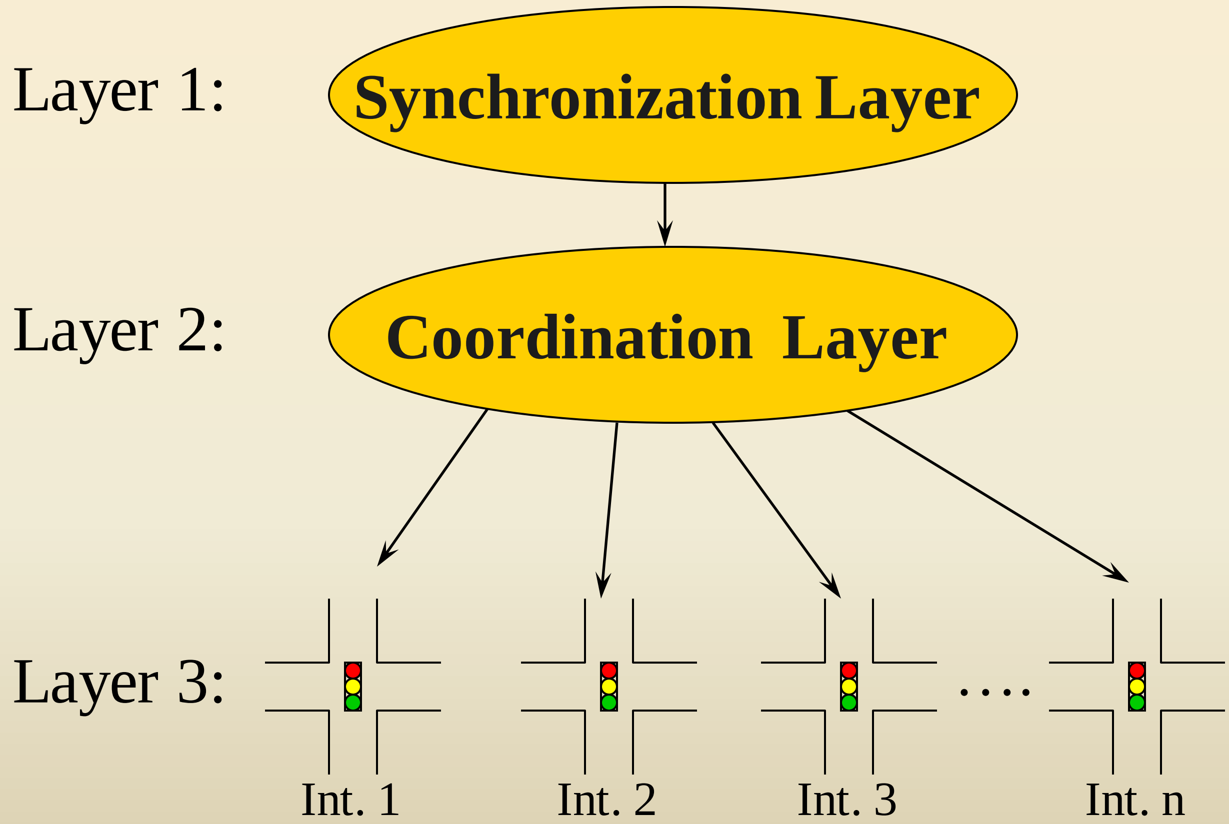
Distributed Dynamic Programming

Virtual-Fixed-Cycle Principle

Characteristics of OPAC IV

- Real-time, traffic adaptive control of signals in a network
- Distributed optimization based on the OPAC smart controller
- Multi-layer network control architecture
- Variable cycle in time and in space (VFC principle)

Multi-layer Network Architecture (Software)



Control Layers in OPAC IV

- Layer 1: optimal switching sequences for projection horizon, subject to VFC constraint
- Layer 2: real-time optimization of offsets at each intersection
- Layer 3: signal synchronization: network-wide calculation of VFC

Other systems:

RHODES

SCATS

SCOOT

RHODES: Real-time Hierarchical Optimized Distributed Effective System

Developed for RT-TRACS at:

The ATLAS Research Center
Systems and Industrial Engineering Department
The University of Arizona, Tucson, Arizona 85721

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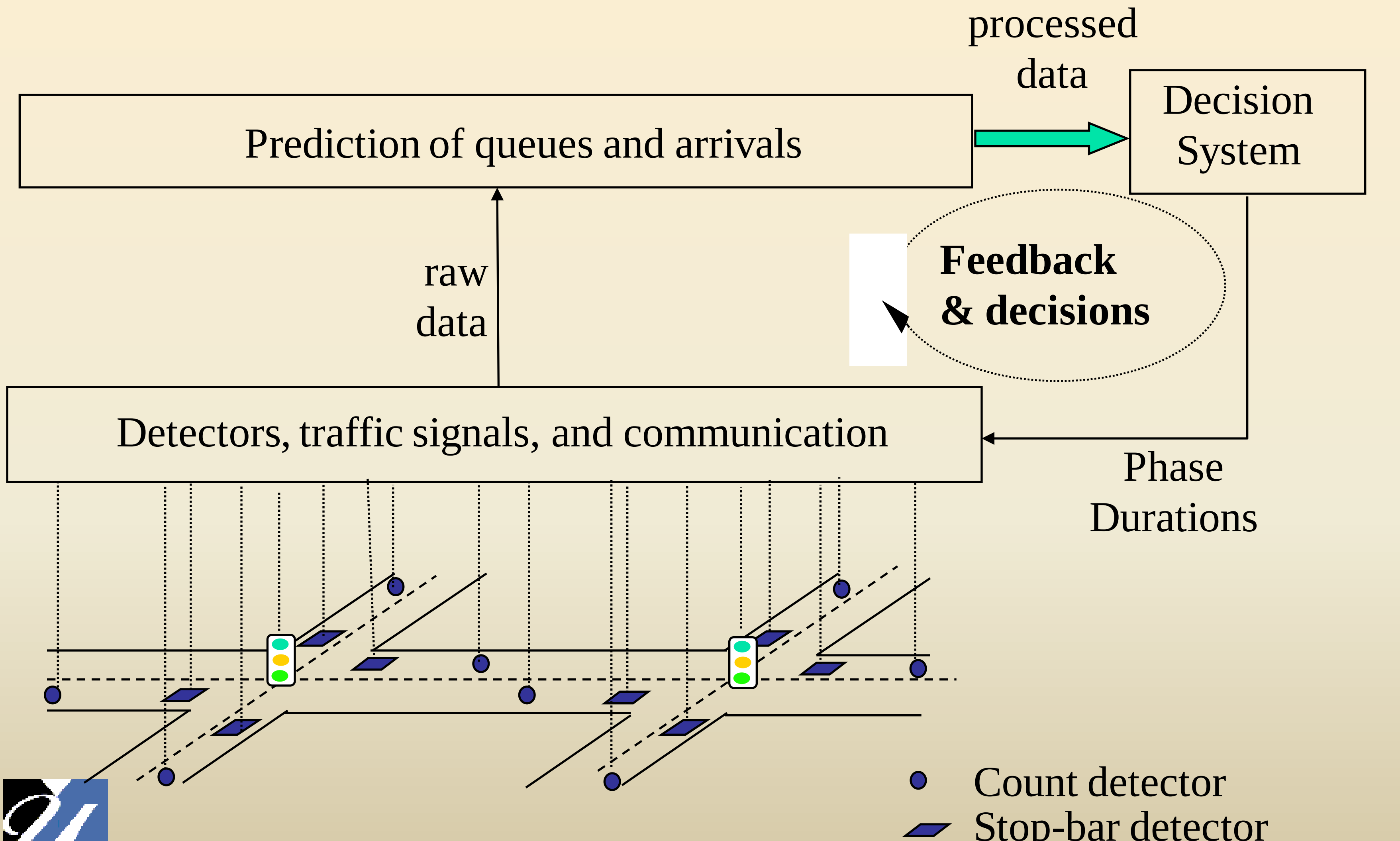
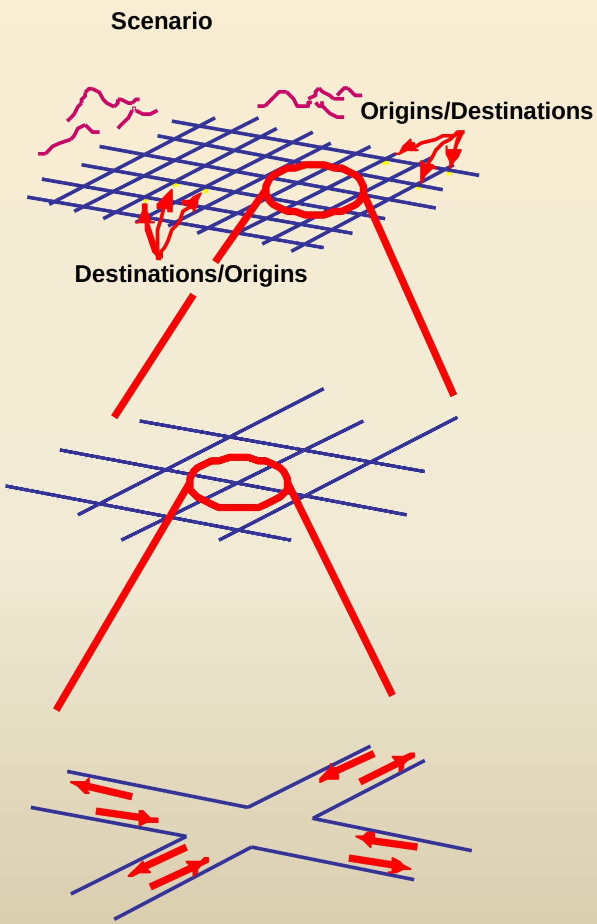
Simplified Architecture for RHODES



RHODES Logical Architecture



EXPECTED BENEFITS

- Improvement in traffic performance
  - responds to recurrent congestion
  - responds to incidents (through "learning")
- Decrease in "traffic operations" effort
  - operators need not "time" signals periodically
- Clear interface with Transit/Emergency/Rail
  - allows for transit priority at intersections
  - allows for preemption for emergency vehicles and railways

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SCATS® (Sydney Coordinated Adaptive Traffic System) is an adaptive urban traffic management system that synchronizes traffic signals to optimize traffic flow across a city, a region or a corridor.

SCATS needs:

- A SCATS-compatible Traffic Signal Controller.
- A centralized computer system to manage the Traffic Signal Controllers.
- A reliable communications network for the centralized computer system to exchange data with all Traffic Signal Controllers in your city.
- Vehicle detectors at each inter-section, usually in the form of loops in the road pavement.

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Adaptive control in SCATS

In response to demands on the traffic network, SCATS can:

- Determine stage splits at intersections
- Alter cycle time of intersections either individually or in groups
- Introduce cycle or plan-dependent options

http://www.scats.com.au/how-scats-works.html

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SCOOT

SPLIT

CYCLE and

OFFSET

OPTIMISATION

TECHNIQUE

Developed at TRL, UK

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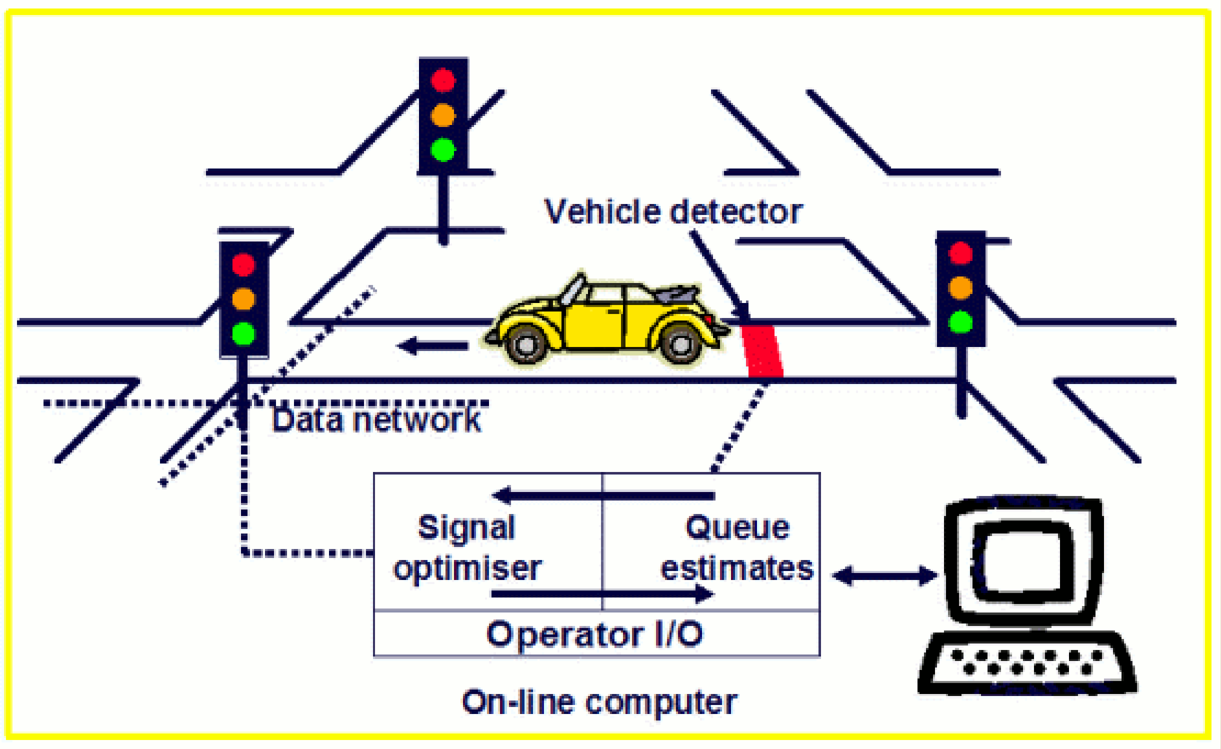
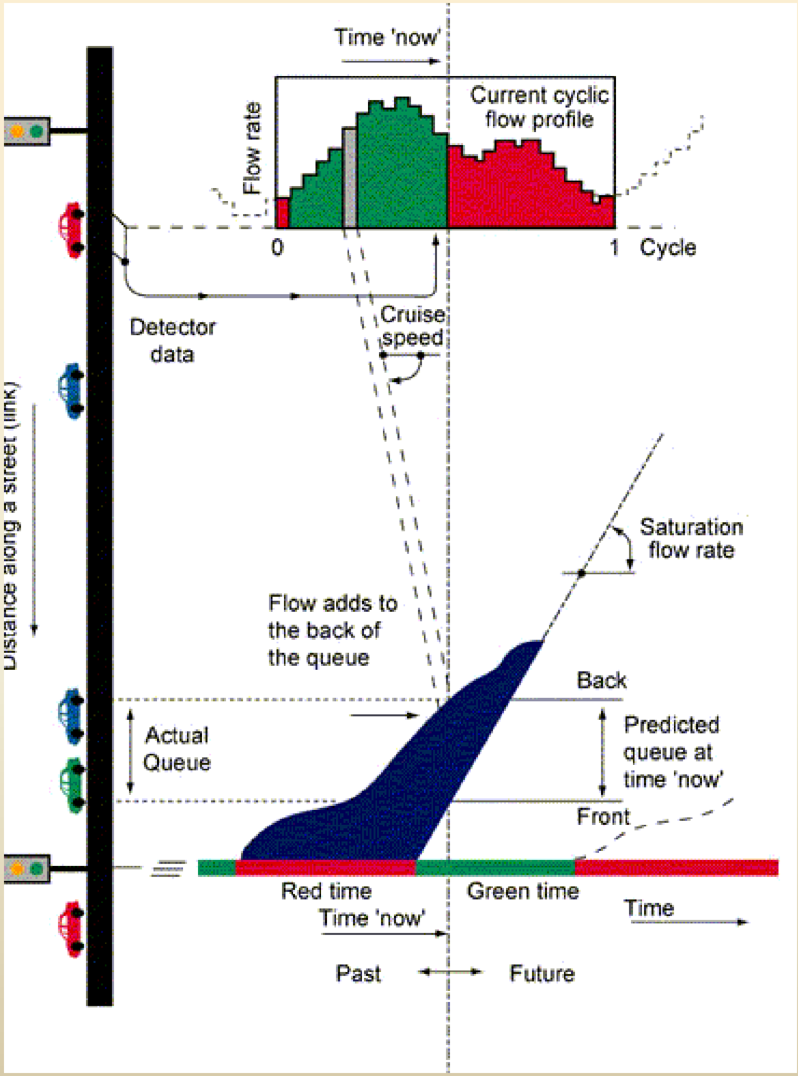
How SCOOT works



How SCOOT works



SCOOT Features

- Best known adaptive control system
- Customized congestion management
- Reductions in delay of over 20%
- Maximise network efficiency
- Flexible communications architecture

Website: www.scoot-utc.com

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SCOOT Features

- Public transport priority
- Traffic management
- Incident detection
- Vehicle emissions estimation
- Comprehensive traffic information

Website: www.scoot-utc.com

ISTTT20 Tutorials

Traffic Management
and
Control

Freeway Ramp Metering

Prof. Nathan H. Gartner
University of Massachusetts
Lowell, MA, USA

Objectives of Freeway Ramp Metering

Objective 1

Optimize freeway throughput, travel speed and travel time reliability. This is achieved by minimizing the possibility of flow breakdown on the freeway.

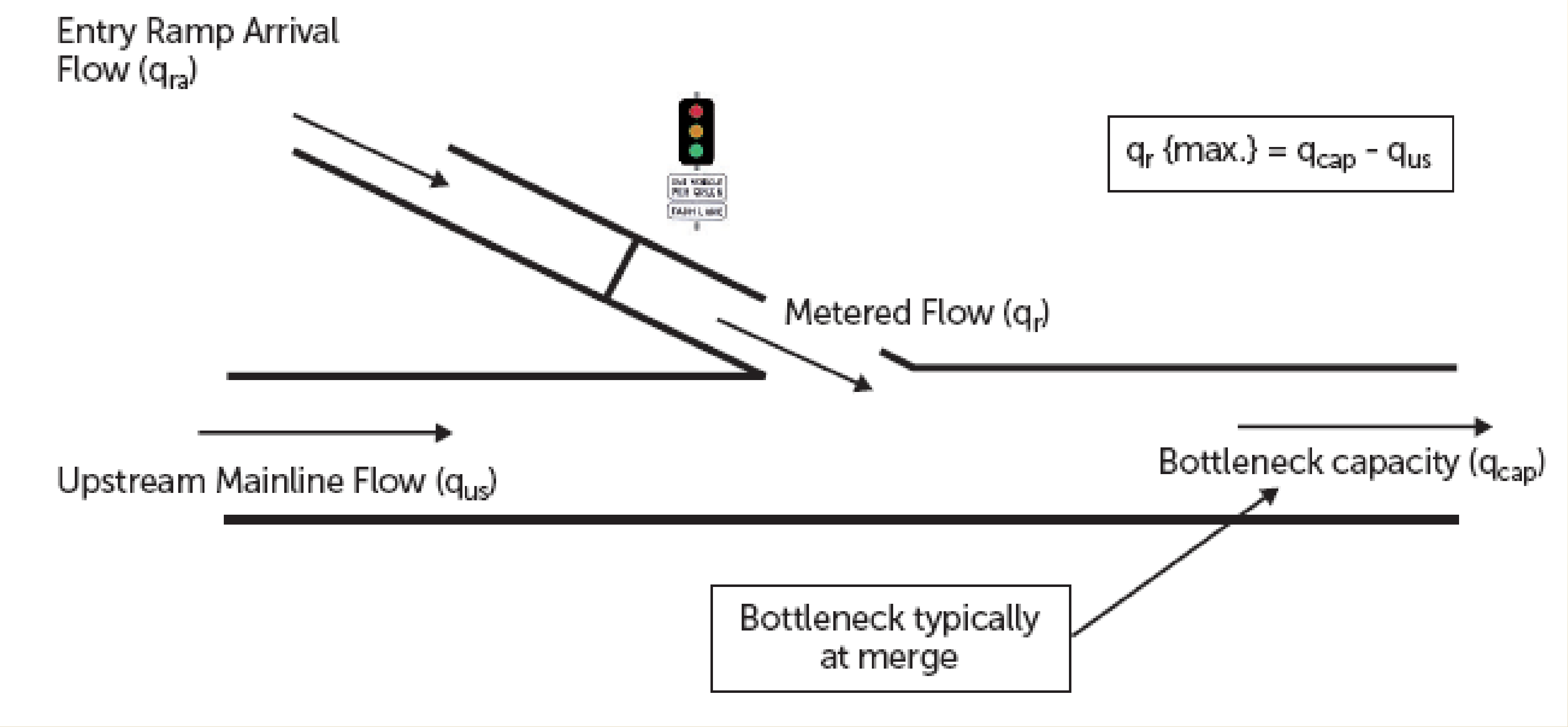
- Headway management of entering traffic.
- Managing the flow rate of entering vehicles at ramps.
- Maintaining mainline freeway volume within capacity at critical sections along the freeway.

Objectives of Freeway Ramp Metering

Objective 2: Improve safety.

- Reducing risk of incidents due to braking and stop- start flow during unstable conditions or when flow breaks down.
- Assisting merging.
- Minimizing lane changing, particularly in the vicinity of an entry ramp.
- Minimizing turbulence in areas of high weaving.

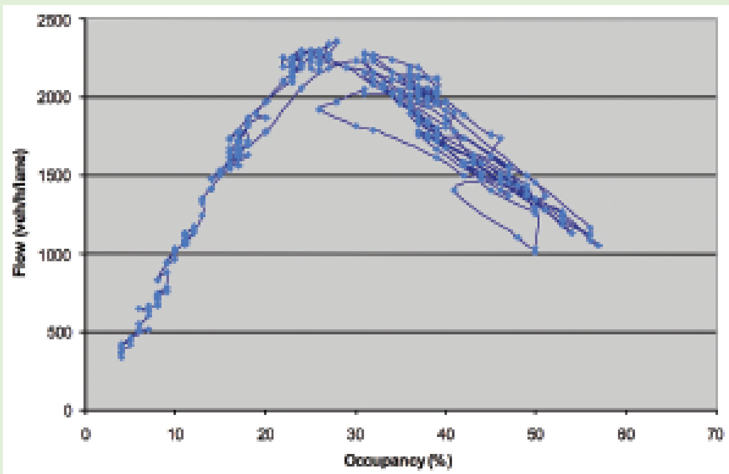
Metering traffic flow at merge bottleneck



Source: VicRoads – Freeway Handbook

Avoiding breakdown by ramp metering

Unmanaged Freeway

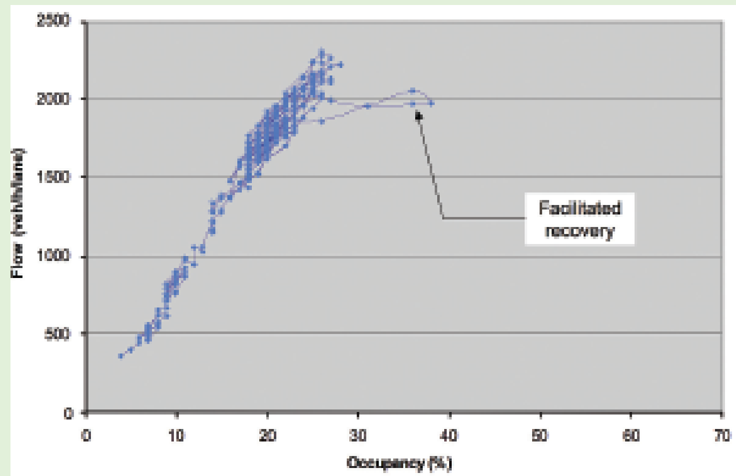


Flow Breakdown Occurs

Note:

- Reduced throughput
- Reduced speed
- Congestion
- Lost productivity.

Managed Freeway



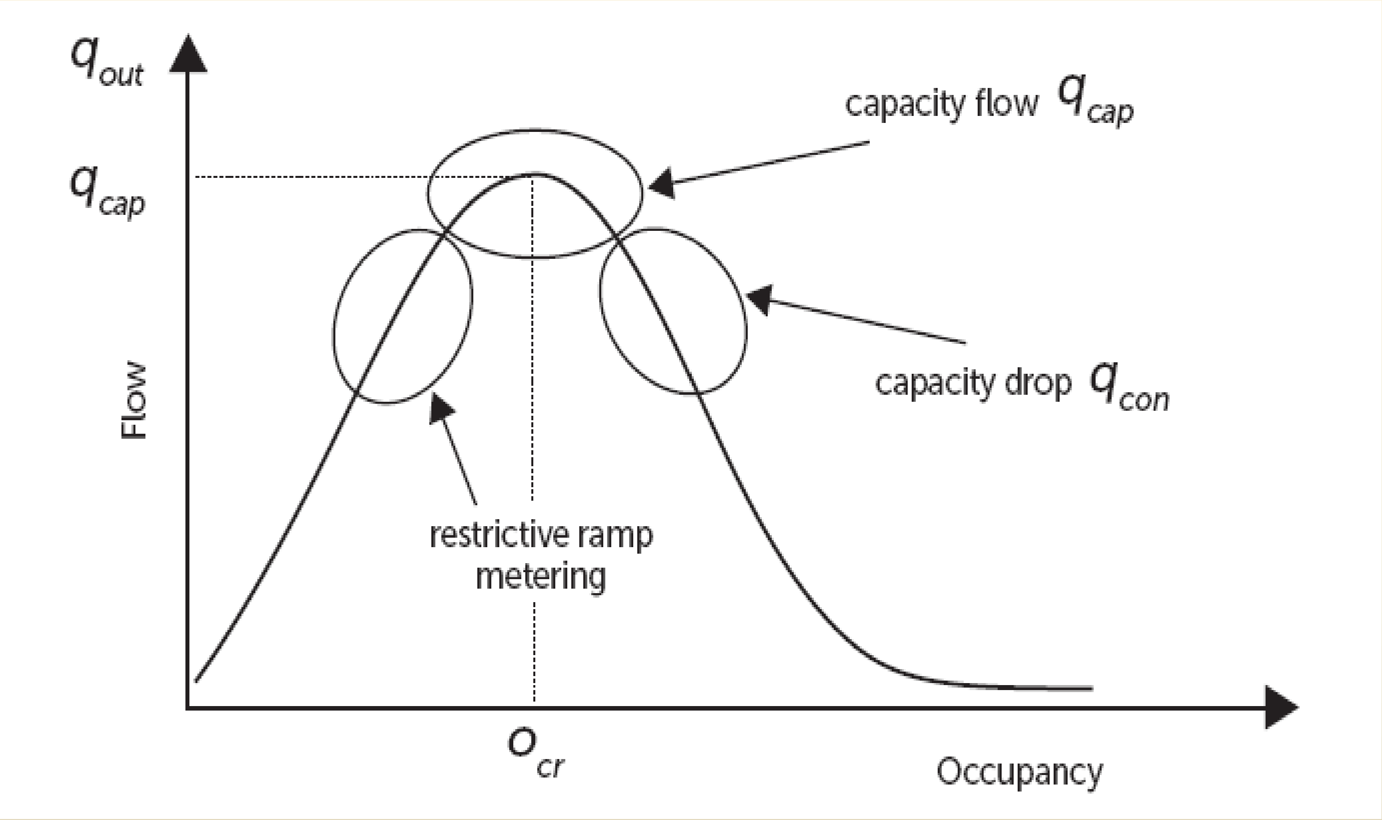
Flow Breakdown Avoided

Ramp signals with HERO control:

- Prevent flow breakdown
- Maintain optimum throughput
- Maintain optimum speed
- Facilitate flow recovery.

Source: VicRoads – Freeway Handbook

Fundamental diagram indicating importance of correct metering rate



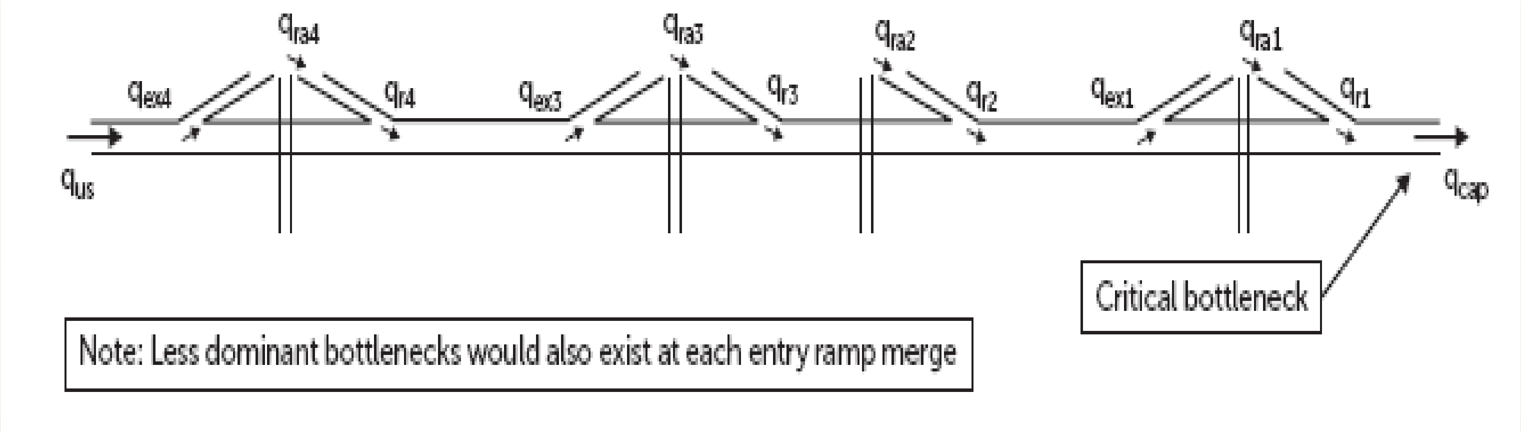
Source: VicRoads – Freeway Handbook

Coordinated Ramp Metering

Coordinated ramp metering has the following benefits:

- Reduces mainline demand at a downstream bottleneck when local control cannot manage flow.
- Provides equity by balancing of queues and delays between a number of ramps, i.e., shares the “pain.”
- Reduces the likelihood of queue overflow on short ramps by transferring delay to ramps with more storage.

Metering traffic with coordinated control

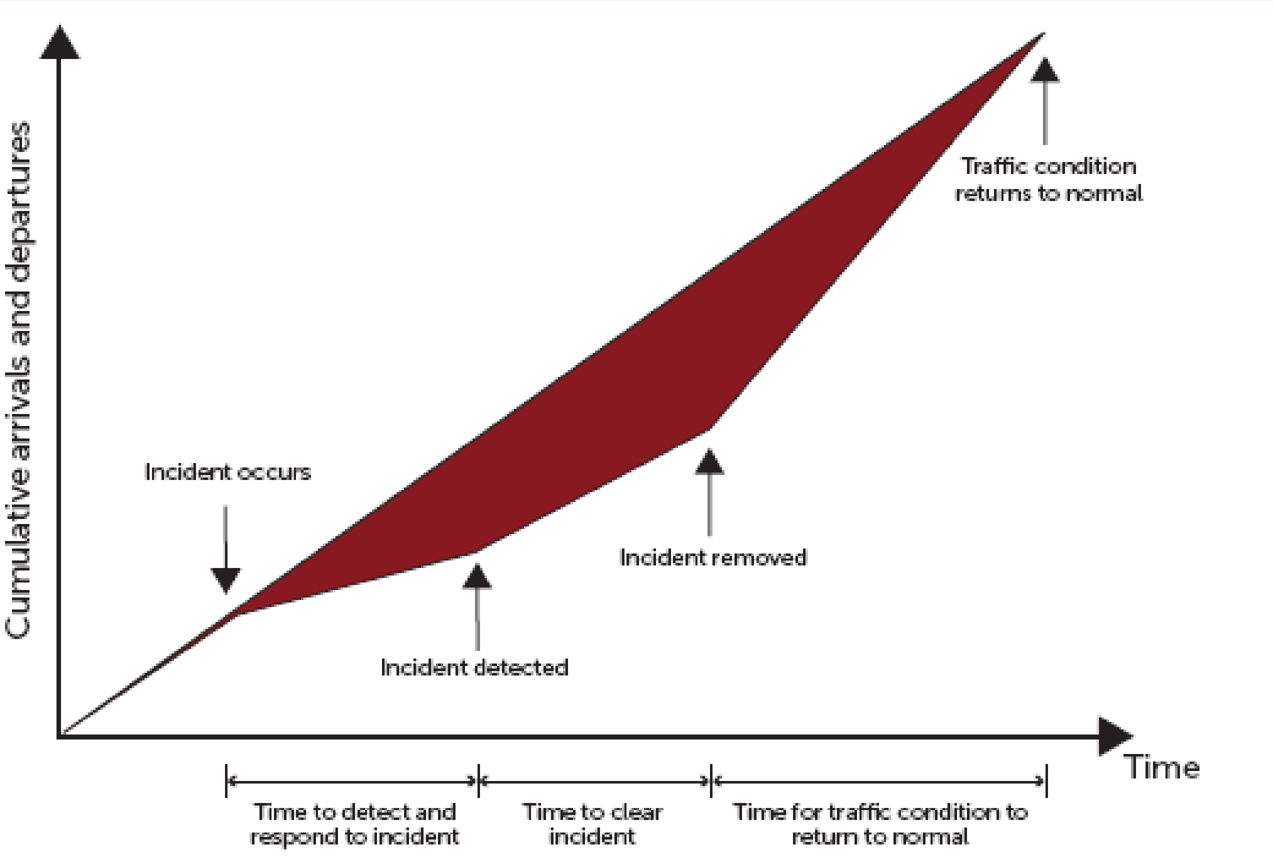


In this example:

$$\sum q_{rm}\{max\} = q_{cap} - q_{us} + \sum q_{ex}$$

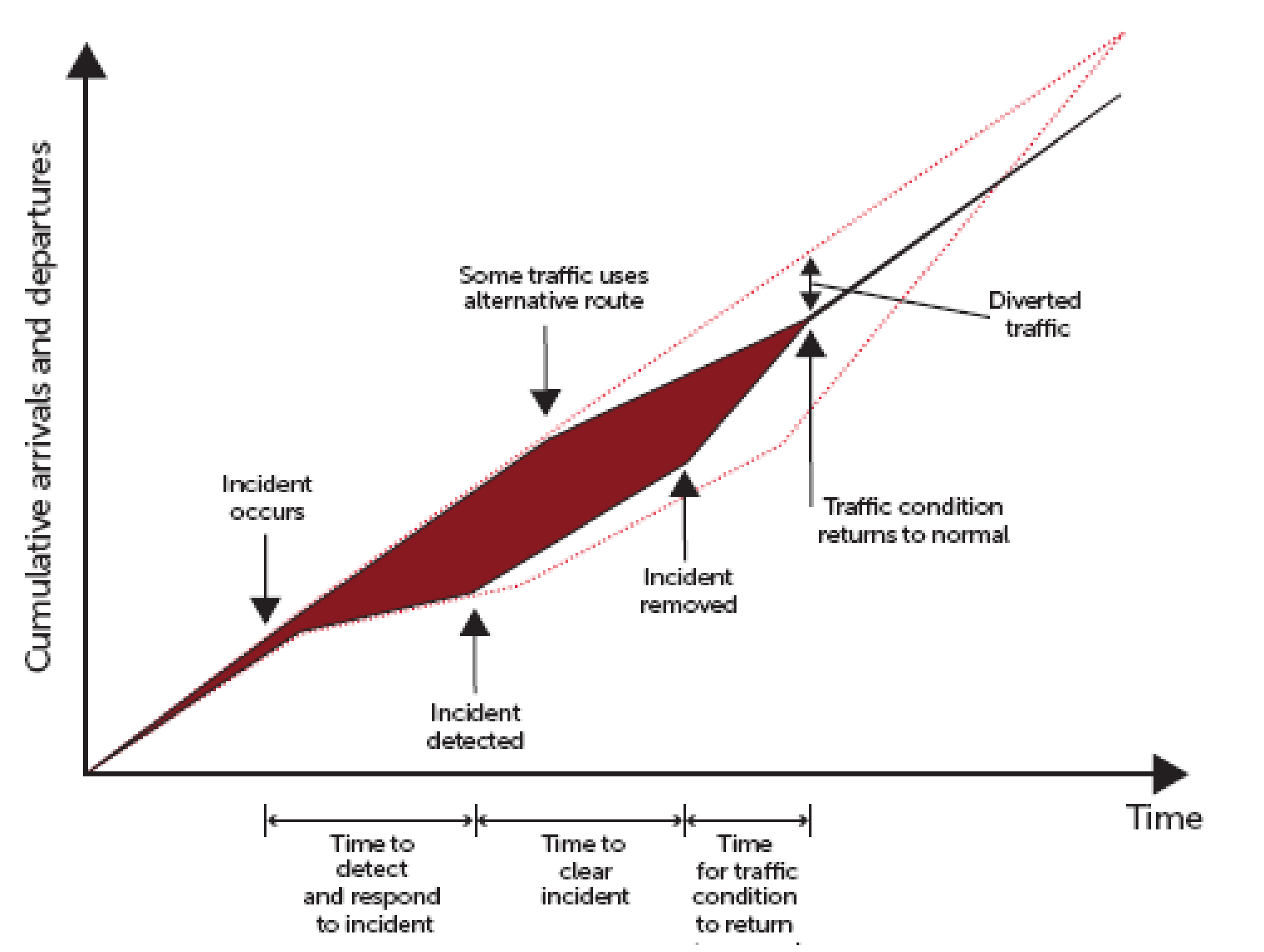
where q_{cap} is the bottleneck capacity.

Incident clearance without an incident management system



Source: VicRoads – Freeway Handbook

Incident clearance with an incident management system



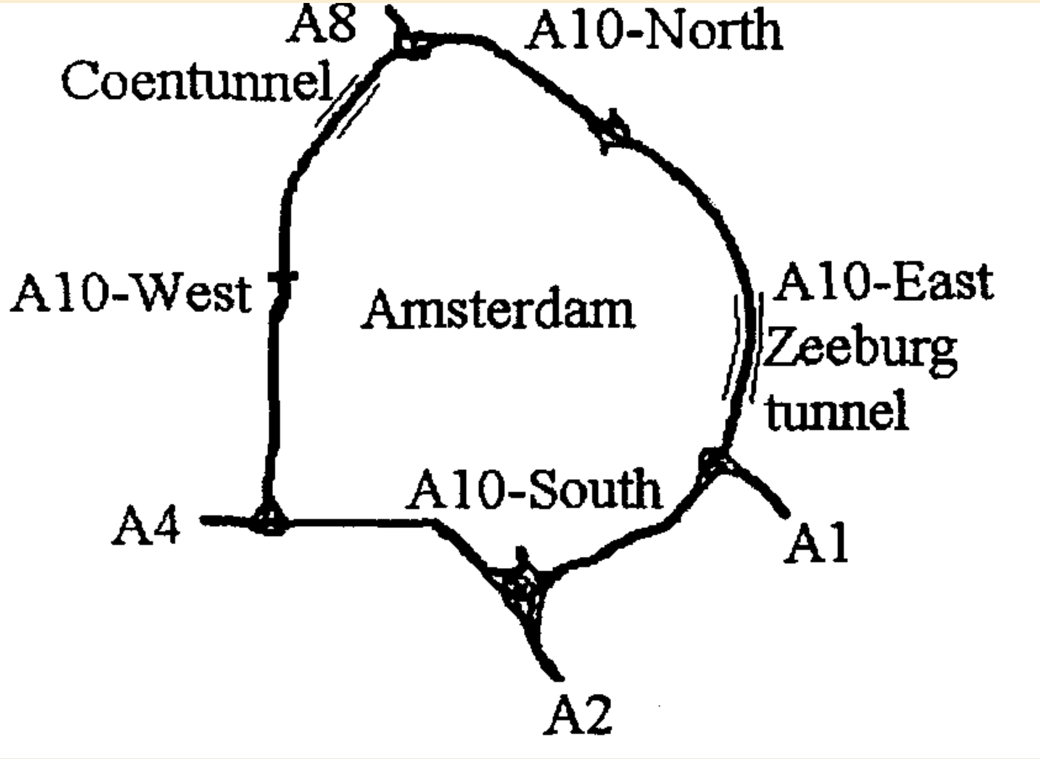
Source: VicRoads – Freeway Handbook

Incident Management System

Freeway ramp signals can be used to limit entry ramp flows upstream of the incident by implementing a high cycle time to minimize the entry flow rate.

This reduces the freeway flow at the incident site and also assists in diverting traffic, particularly if traveler information relating to travel time and incidents is provided.

Example - Ramp control on Amsterdam ring road



<u>Ref.:</u>
Freeway Ramp Metering: An Overview
M. Papageorgiou and A. Kotsialos
IEEE Procs., 2000

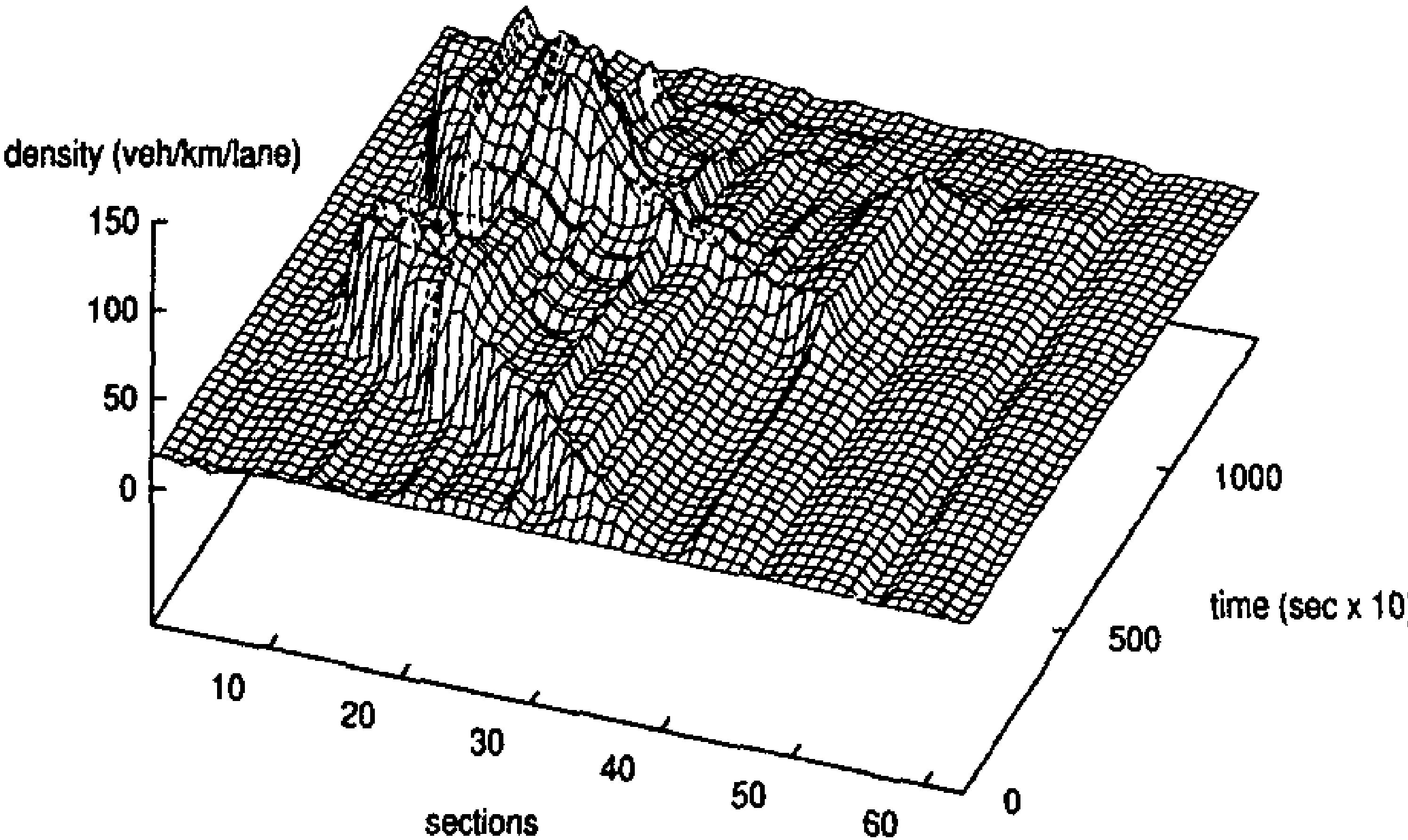


Figure 6. No control: Density.

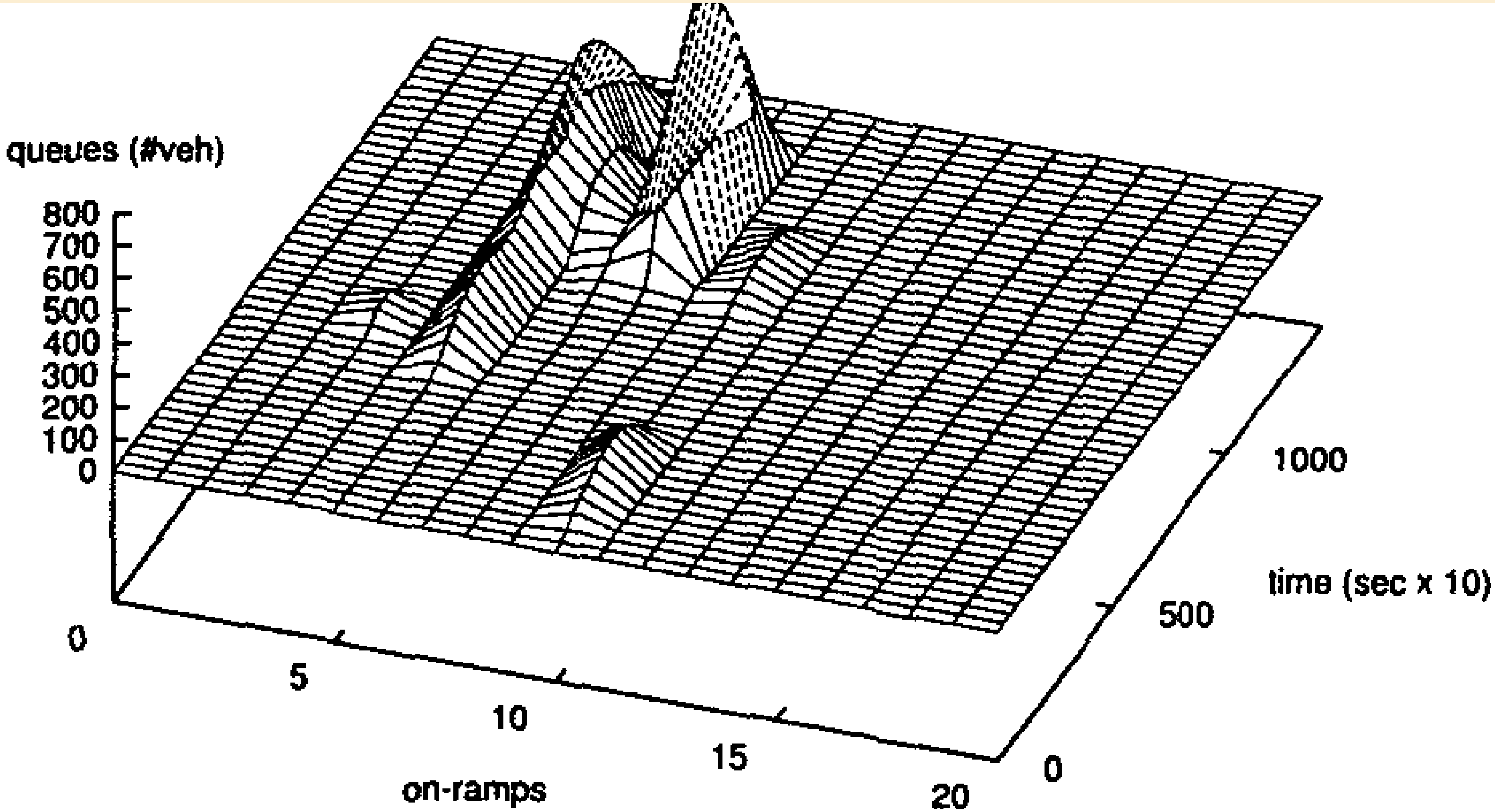


Figure 7. No control: Ramp queues.

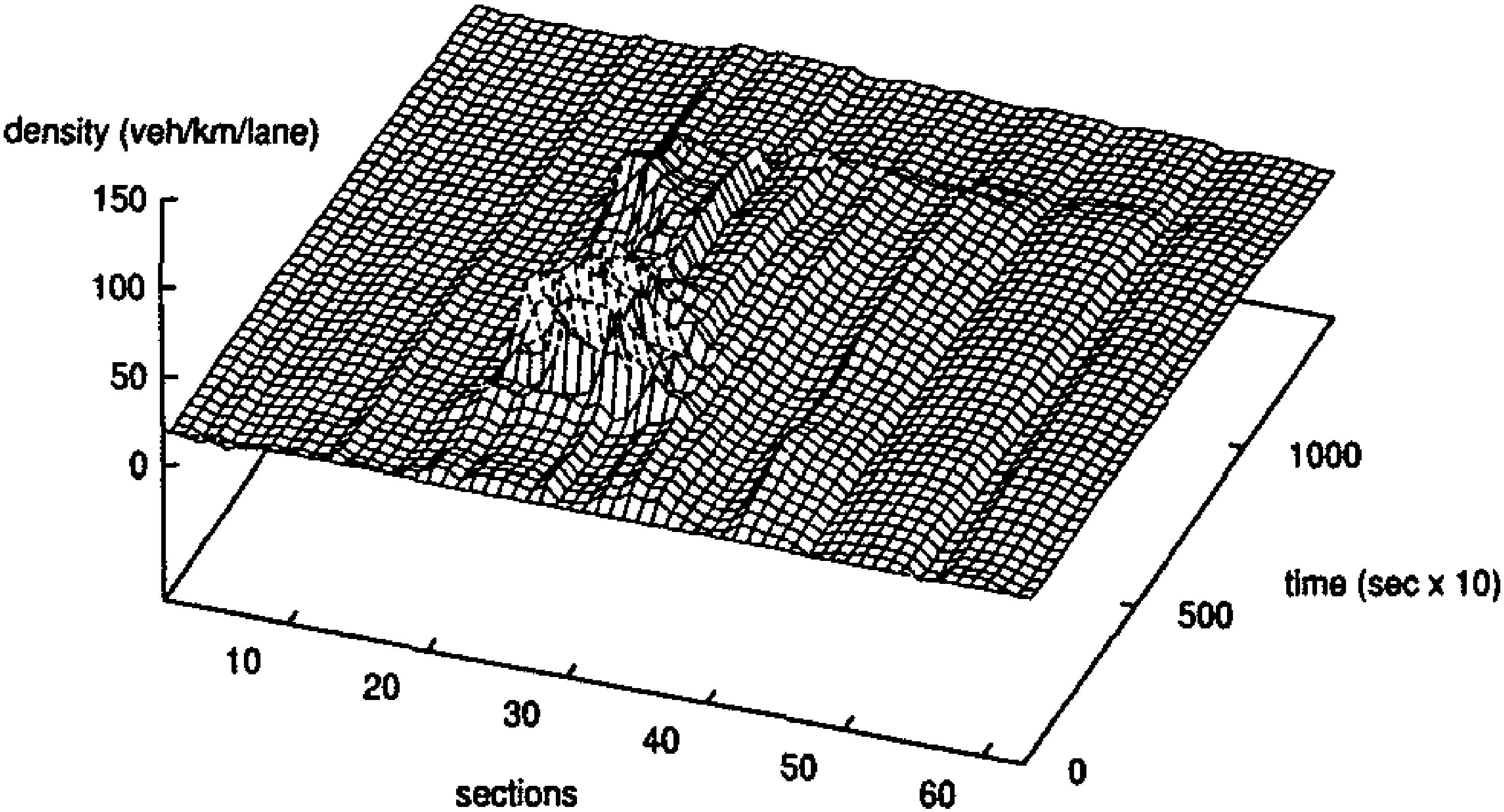


Figure 8. Optimal control: Density.

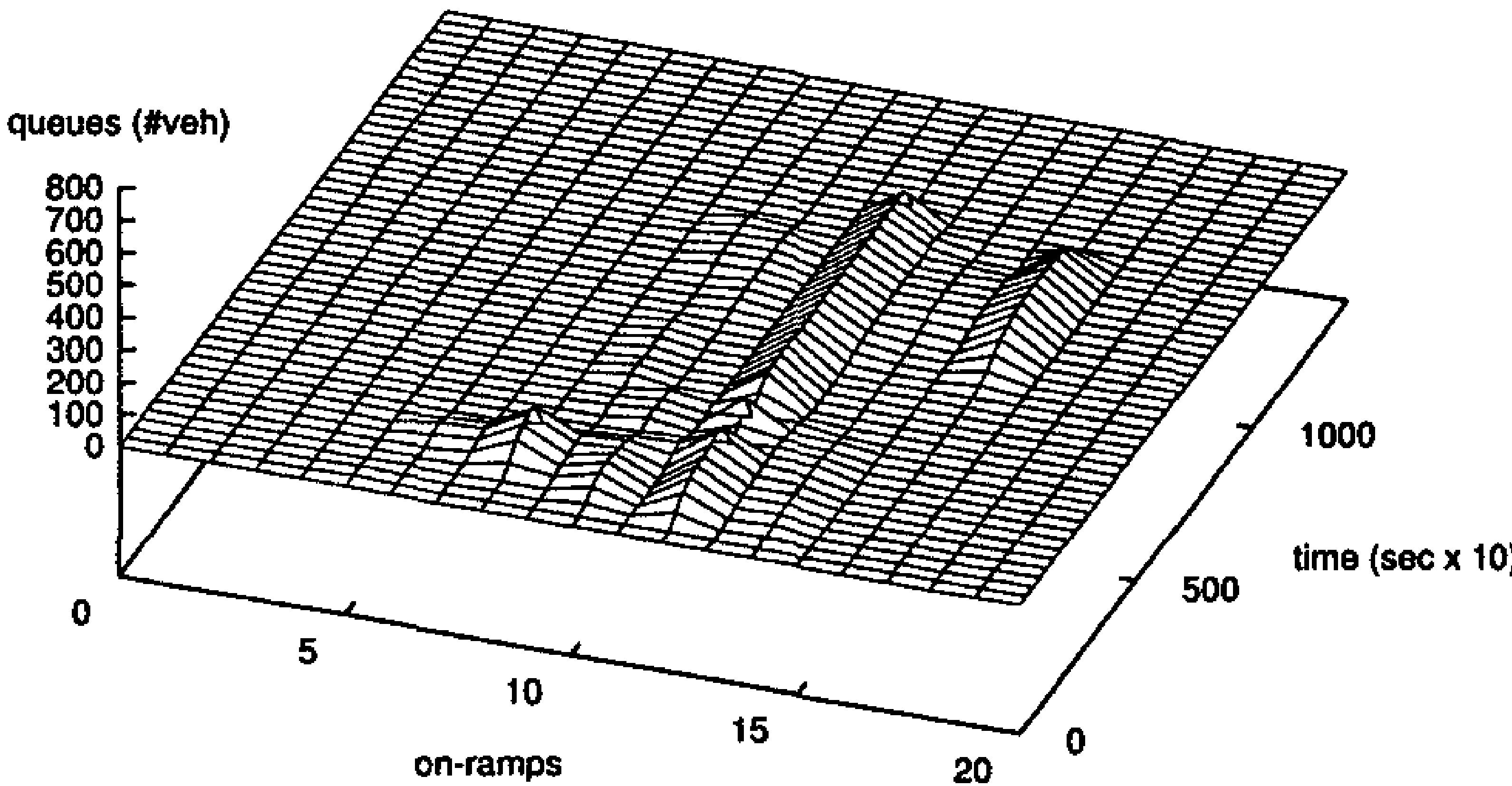


Figure 9. Optimal control: Ramp queues.

ISTTT20 Tutorials

Traffic Management
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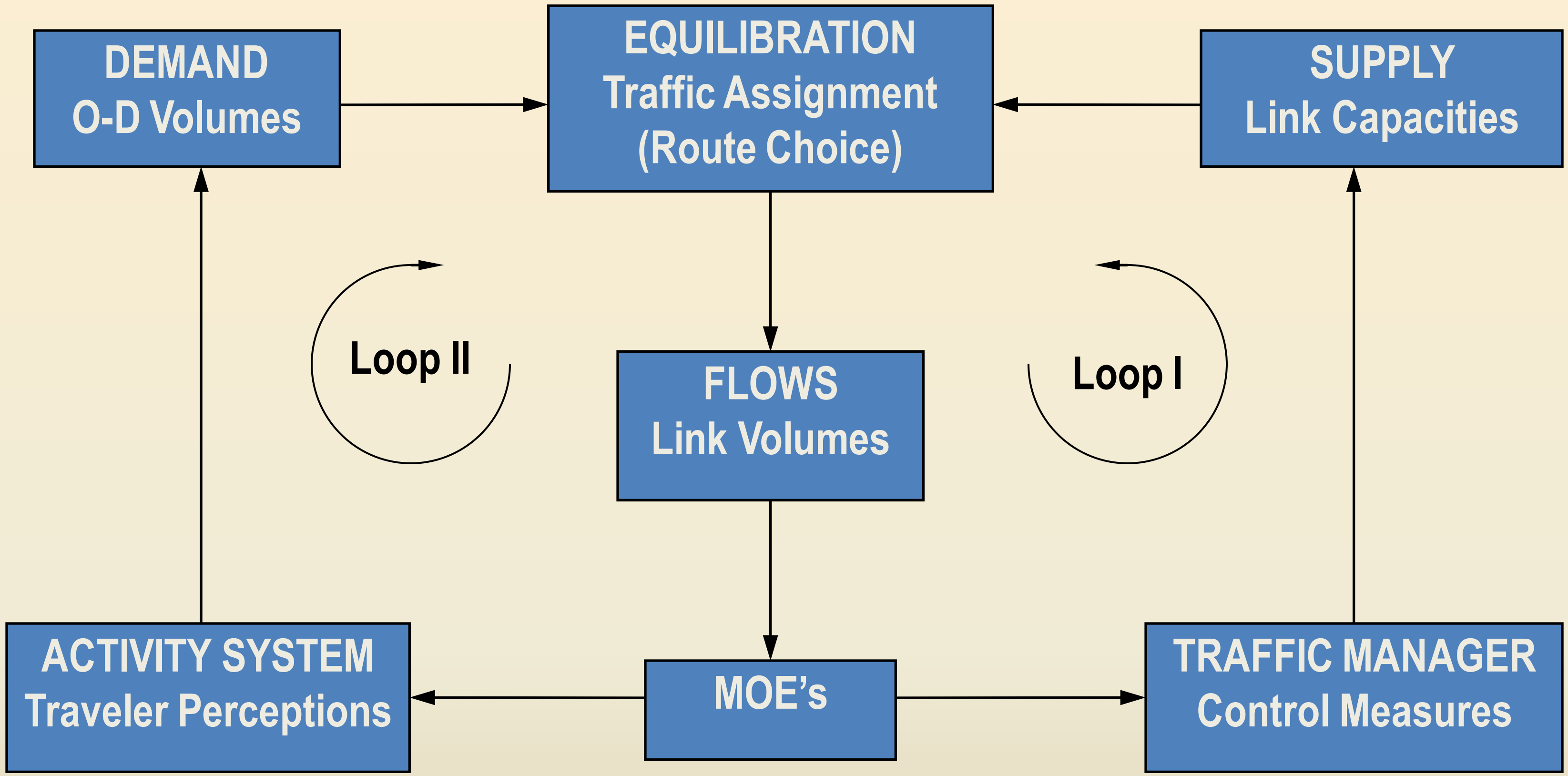
Control

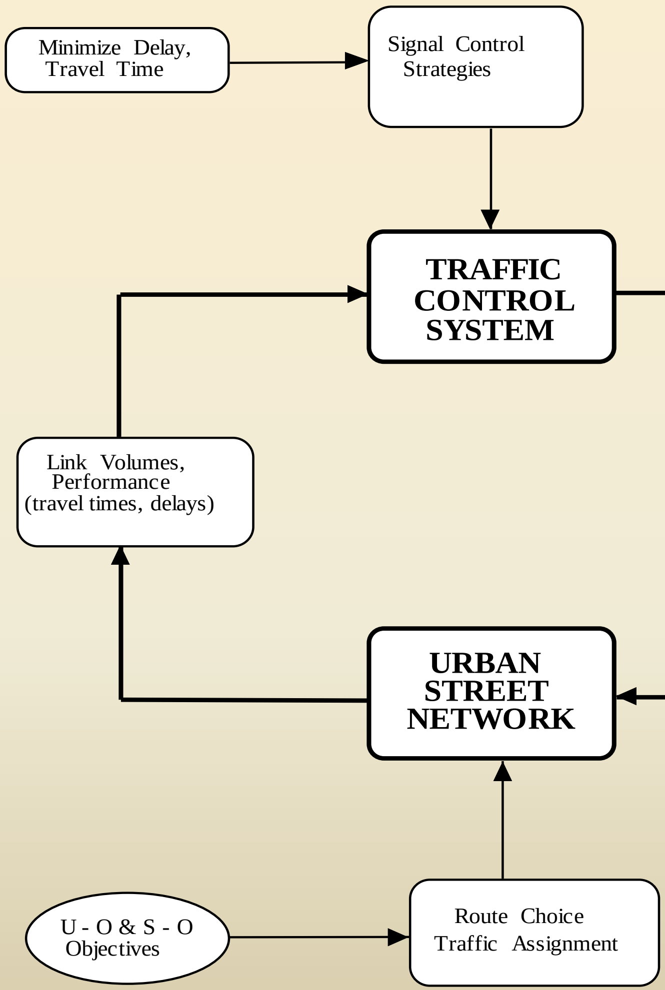
Network Interactions

Prof. Nathan H. Gartner
University of Massachusetts
Lowell, MA, USA

Mutual interaction between traffic manager and activity system



Mutual interaction between traffic signals and route choice



Ref:

Transportation Research Part C
Vol. 27 (2013) 205–218.

Robust controls for traffic networks:
The near-Bayes near-Minimax strategy,
by L.K. Jones et al.

Robust Optimization (RO)

An approach to optimization under uncertainty in which the uncertainty model is not stochastic, but rather deterministic and set-based.

Robust Optimization (RO)

Instead of seeking to immunize the solution in some probabilistic sense to stochastic uncertainty, the decision-maker constructs a solution which can cope best with all possible realizations of the uncertain data.

Robust Optimization (RO)

In general, a robust solution is not optimal for all realizations of the uncertain data, but performs well even for the worst case scenario.

Bertsimas et al, *SIAM Review* (2011).

Description

This paper addresses the problem of determining robust signal controls in a traffic network which:

(a) consider the interdependency of signal controls and flow patterns, and

(b) account for the variability or uncertainty in the origin-destination demands.

The *Bayes Solution*

We assume a probability density on y
and
on the possible OD matrices T

The minimum expected cost, c_B, is a function of the controls g:

$$\boldsymbol{c_B} = \min_{g} \boldsymbol{E_y} \left\{ \sum_{a} \boldsymbol{V_a}(\boldsymbol{\Pi}^*) \cdot \boldsymbol{c_a}(\boldsymbol{\Pi}^*) \right\}$$

The *Minimax* solution

applies to the most conservative case:

minimize the network cost for the worst OD conditions

$$\boldsymbol{c}_{M} = \min_{g}\left\{\max_{y}\sum_{a}\boldsymbol{V}_{a}(\boldsymbol{\Pi}^{*})\cdot\boldsymbol{c}_{a}(\boldsymbol{\Pi}^{*})\right\}$$

The *near-Bayes near-Minimax* (NBNM) strategy

The NBNM solution g^* provides controls that minimize the following as a function of g:

$$\max \left\{ \frac{E_y\{\sum_a V_a(\Pi^*) \cdot c_a(\Pi^*)\}}{c_B}, \frac{\max_y \sum_a V_a(\Pi^*) \cdot c_a(\Pi^*)}{c_M} \right\}$$

This is a combination of the *Bayes* and *Minimax* solutions.

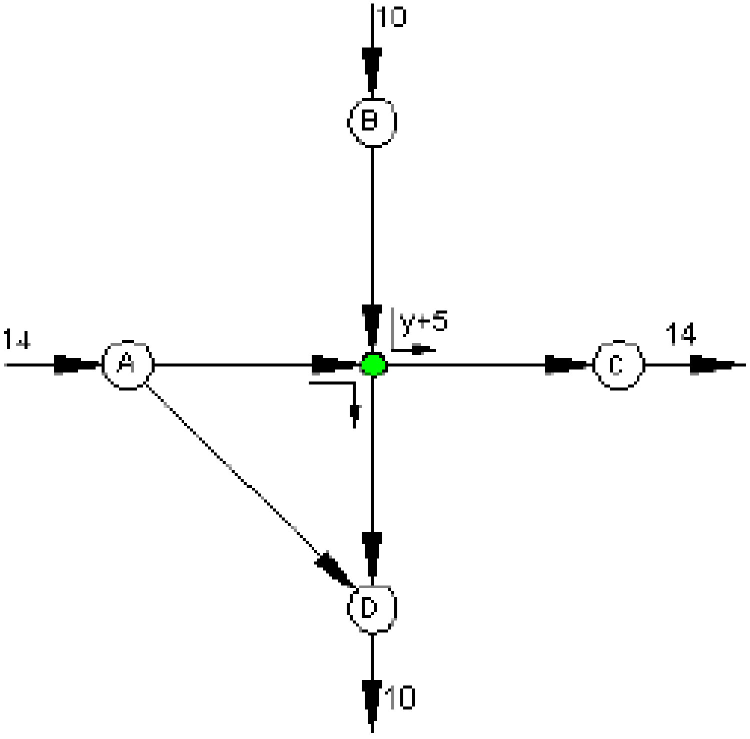
$T = T(y)$,

Example 1

OD matrix $T(y)$:

O\D	C	D
A	9.0-y	5.0+y
B	y+5.0	5.0-y

$0 \le y \le 5.0$



One-Point Bayes Case: Max Likelihood

	Expected Cost[1] (hv-hr/hr)	% above Bayes	Maximum Cost[2] (hv-hr/hr)	% above Minimax
System Optimization				
Bayes Solution	0.977	0	1.405	**10.7**
Minimax Solution	1.119	**14.5**	1.266	0
NBNM Solution	1.007	**3.09**	1.306	**3.09**
EC Optimization				
Bayes Solution	0.977	0	1.405	**10.9**
Minimax Solution	1.136	**16.3**	1.267	0
NBNM Solution	1.007	**3.10**	1.306	**3.10**

1. Expected cost under prior distribution.
2. Maximum cost over the space of OD matrices.

Twenty One-Point Bayes Case

	Expected Cost[1] (hv-hr/hr)	% above Bayes	Maximum Cost[2] (hv-hr/hr)	% above Minimax
System Optimization				
Bayes Solution	1.052	0	1.407	**11.2**
Minimax Solution	1.172	**11.4**	1.265	0
NBNM Solution	1.081	**2.8**	1.301	**2.8**
EC Optimization				
Bayes Solution	1.091	0	1.415	**11.7**
Minimax Solution	1.185	**8.6**	1.267	0
NBNM Solution	1.122	**2.7**	1.302	**2.7**

1. Expected cost under prior distribution.
2. Maximum cost over the space of OD matrices.

Discussion - 1

- Traffic network problems have to deal commonly with uncertainty or variability of demands due to unknown origin-destination matrices.

- Such problems are typically addressed by determining a “most likely” origin-destination matrix .

- Network design changes are analyzed assuming this matrix is immutable and is not affected by such changes.

Discussion - 2

- The approach taken in this study is to consider the uncertainty in the origin-destination demands concurrently with the design changes to produce a “best” control strategy that accounts for this uncertainty.

- The *near-Bayes near-Minimax* (NBNM) strategy provides performance that is close to the best that can be obtained under Bayes conditions, yet does not depart too far from the most beneficial controls under the worst expected conditions.

Discussion - 3

- The *near-Bayes near-Minimax* (NBNM) strategy is a conservative approach designed to provide robust controls that lead to stable and risk-averse performance.

- One pays a premium for the uncertainty in the demands by accepting a less than optimal solution for the Bayes strategy in return for assurance that very poor outcomes will be avoided.

ISTTT20 Tutorials

Traffic Management
and
Control

The Future

Prof. Nathan H. Gartner
University of Massachusetts
Lowell, MA, USA

Driverless cars could reshape the city of the future

AIM

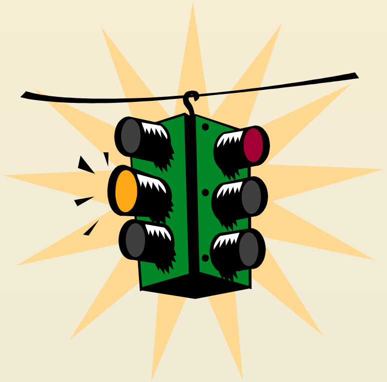
Autonomous Intersection Management Project

(University of Texas at Austin)

This project "AIM"s to create a scalable, safe, and efficient multiagent framework for managing autonomous vehicles at intersections.

http://www.youtube.com/watch?feature=player_embedded&v=4pbAI40dK0A#t=0s

Traffic Management
and
Control



End of Presentations