Introduction to Traffic Signal Operations
March 2000

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Modules
1. Case study
2. Tour of Moscow signal system
3. Overview of tools and issues
4. Queuing model
5. Estimating performance measures at signalized intersections
6. Phasing plans
7. Estimating capacity of permitted left turns at signalized intersections
8. Cycle length
9. Green split
10. Clearance time
11. Pedestrian crossing times
12. Case study
1.1 Overview
The City of Moscow is studying the intersection of State Highway 95 and Styner Avenue, in the south part of the city. The intersection is currently controlled by stop signs. Traffic has significantly increased at this intersection in recent years, particularly with the opening of the Arby’s restaurant and the Sunset Mini-Mart. New residential development to the west and east of the intersection have added to the use of this intersection. Through traffic on Highway 95 continues to increase, particularly as commercial vehicle traffic from Canada and the Lewiston Port becomes more important.

This photograph looks towards the west along Styner Avenue. Highway 95 runs from left to right across the photograph, with north toward the right. Two vehicles are shown traveling on Highway 95, one is traveling southbound while the other is turning to the east onto Styner.

The city is considering whether it is time to put a traffic signal at the intersection. This decision has important implications for the flow of traffic on State Highway 95 and for access to neighboring commercial and residential areas. Some of the questions that the city is considering include:
• Is there sufficient capacity to safely accommodate the flow of traffic today? In the future?
• How much delay should motorists tolerate at the intersection?

Transportation engineers are concerned with both engineering and management of the transportation system, including design, construction, operation, maintenance, and optimization. During the next week, you will learn about traffic signal operations analysis and how it can be applied to very common problems faced by transportation engineers. Specifically, you will learn what the City of Moscow staff must consider as it studies the intersection of State Highway 95 and Styner Avenue. When you have completed this material, you will be able to:

• Determine whether signal control is needed.
• Evaluate the performance of a signalized intersection, given traffic flow, traffic control, and geometric conditions.
• Understand the basics of traffic signal systems and controllers.
• Determine signal timing parameters.
1.2 Signal Design Elements
What are the key elements of signal design?

- What kind of controller?
  - Fixed time
  - Actuated control

- Does it operate independently or as part of a system?
  - Isolated
  - Coordinated

- What is the phasing?
  - Two phase
  - Three phase
  - Four phase
  - Eight phase

- What are the timing elements?
  - Cycle length
  - Green splits
  - Pedestrian phase lengths
  - Offsets

- What is the intersection geometry and how is lane usage assigned?
  - Exclusive left turn lanes
  - Shared left turn/through lanes

- Is special left turn protection needed?
  - Exclusive left turn lanes
  - Protected left turn phasing

- What kind of vehicle detection is needed?
  - Loop detectors
  - Video detectors
1.3 Discussion Questions

Why do we use signal control?

What information does the City of Moscow staff need to know to determine whether the intersection of SH95 and Styner/Lauder should be signalized?

What considerations should be given to the adjacent signalized intersections? (Sweet Avenue? SH8?)

What are the pros and cons of fixed time vs actuated control at this intersection?
### 2.1 Overview

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<tr>
<th>Location</th>
<th>Type</th>
<th>Detection</th>
<th>Isolated/Coordinated?</th>
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<td><strong>Downtown System</strong></td>
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<td>6th/Main</td>
<td>Fixed time</td>
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<td><strong>State Highway 8 system</strong></td>
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<td>Warbonnet Ave</td>
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<td>Loops</td>
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<td>Farm Road</td>
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<td>Line St</td>
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<td><strong>University area</strong></td>
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<td>6th/Deakin</td>
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<td>SH8/Sweet Ave</td>
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<td>Video cameras</td>
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<td><strong>Outlying areas</strong></td>
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<td>SH95/D St</td>
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<tr>
<td>SH8/Blaine St</td>
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<td>Loops</td>
<td>Isolated</td>
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2.2 Downtown System
2.3 State Highway 8 System (Farm Road)
2.4 Highway 95/Sweet Avenue
2.5 SH8/Blaine
2.6 Summary

What kinds of controllers are used in Moscow?

What kinds of detection are used?

Why is isolated control used in some cases and coordinated control in others?
MODULE 3 – TOPICS AND ISSUES

3.1 Tools and Models
We need to develop several tools or models to help us analyze various aspects of a signalized intersection:

- Queuing model to represent the arrivals and departures of vehicles at the intersection.
- The sequencing of traffic movements, or phasing of the traffic signal
- Specification of various signal timing parameters including the cycle length, the green splits, and the pedestrian phase length.
3.2 Terms and Concepts
We need to define some terms and concepts

- What is the flow rate?

- What is the headway between vehicles?

- What is the saturation headway?

- What is the capacity or maximum flow rate that can be achieved?

- What are the key signal timing parameters?

- What is the green ratio?
MODULE 4 – QUEUING MODEL

4.1 Observing Traffic Flow In The Field
Consider what you observe at an intersection, standing at the stop line, at a signalized intersection. What is the nature of the traffic flow? What patterns do you observe? The photographs on this page and the following pages illustrate three sequences at the intersection of 3rd Street and Jackson Street in downtown Moscow. The view is looking toward the west on 3rd Street. Vehicles flowing toward you are traveling eastbound. Jackson Street runs southbound toward the left in the photographs.

In the photographs on this page, vehicles are arriving and departing during green with no delay.
In the photographs on this page, we see a queue of vehicles build up during red and then depart when the signal changes to green. Follow the sequence from left to right in the first row, then left to right in the second row.
Here, we also see the queue grow during red (again left to right, first row then second row) ... ... and then depart with short headways during green. The short headway between vehicles that we observe during the time that the queue is clearing is called the saturation headway.
4.2 Vehicle Trajectories
We will now look at a time-space diagram, a graph that shows the trajectory of one or more vehicles traveling along a roadway. This graph shows two vehicles traveling along a roadway, each is traveling at a different speed. The faster trailing vehicle eventually catches up with the slower leading vehicle.
Here is a time space diagram that shows the trajectories of a set of vehicles arriving at a signalized intersection during the red phase, waiting, and then departing once the signal changes to green. What can we learn about traffic flow from this plot?
4.3 Patterns of Arrival and Departure

**Flow Profiles**
Now let's consider this same pattern of vehicle trajectories but this time from a different perspective. Here is a plot of the flow rates of vehicles arriving at and departing from the intersection during the period of one signal cycle.
**Cumulative vehicle plot**
Here is a plot of the same traffic flow pattern. This time the plot shows the cumulative number of vehicles that arrive at and depart from the intersection over time. Consider the following questions:
- what is the delay for \( i^{th} \) vehicle?
- what is the queue length at time \( t \)?
Queue Accumulation Polygons
Another way of presenting this information is to use the queue accumulation polygon. This chart shows the variation of the queue length over the length of the cycle. What is the delay experienced by all vehicles arriving at the intersection? How can we estimate this delay?
4.4 Questions to consider

- What is the saturation flow rate?

- What is the saturation headway?

- What does the queue accumulation polygon show?

- What are the three primary departure flow rates at a signalized intersection?
MODULE 5. ESTIMATING PERFORMANCE MEASURES AT SIGNALIZED INTERSECTIONS

5.1 Queue Clearance Time

Computing queue clearance time
We’ll now construct the queue accumulation polygon again, showing the evolution of the queue during one signal cycle. How long does it take for the queue that accumulated during red to clear once the green phase begins?
Computing queue clearance time
Sample calculation:
5.2 Delay

**Computing average delay per vehicle**
We’ll now use the queue accumulation polygon to compute the average delay per vehicle during one signal cycle.
Computing average delay per vehicle
Sample calculation:
Effect of cycle length on delay
Inspection of the delay equation:

- How does an increase in the volume on the intersection approach affect the average delay?
- How does an increase in the cycle length affect average delay?
- How does an increase in the green ratio (g/C) affect average delay?
- What happens when vehicles do not arrive in a uniform pattern?
Sample calculation using the delay equation: how does delay vary with cycle length?
Assume that the saturation flow rate is 1800 vehicles per hour of green, the approach volume is 700 vehicles per hour, the green ratio (g/C) is 0.5, and the cycle length varies from 40 seconds to 160 seconds.
5.3 Capacity

**Computing approach capacity (sufficiency of capacity)**
Capacity is equal to the product of the green ratio ($g/C$) and the saturation flow rate ($s$). Sample calculation:
5.4 Summary

Questions to consider

• What is the queue clearance time?

• What is uniform traffic flow?

• What is uniform delay?

• Does delay increase or decrease as cycle length increases?

• What is the green ratio?

• What happens to delay when most vehicles arrive during the green phase? During the red phase?
MODULE 6. PHASING PLANS

6.1 Overview
Definition: Signal phasing is the sequence by which the various movements of both vehicles and pedestrians are being served at a signalized intersection.

Objective: Minimization of the potential hazards arising from the conflicts of vehicular and pedestrian movements, while maintaining the efficiency of flow through the intersection.

Two-phase:

Three-phase:
Eight-phase:

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6.2 Phasing considerations for case study
MODULE 7. ESTIMATING CAPACITY OF PERMITTED LEFT TURNS AT SIGNALIZED INTERSECTIONS

7.1 Permitted left turns from exclusive left turn lane
We found earlier that the capacity of a through lane at a signalized intersection is given by the product of the saturation flow rate (s) and the green ratio (g/C). Typical values for the saturation flow rate for a through lane range from 1800 to 1900 vehicles per hour of green.

How do we determine the capacity of a left turn lane, when the traffic in that lane must wait for suitable gaps in the opposing traffic? Let’s now consider the capacity of an exclusive left turn lane. When a left turn movement must wait for opposing traffic, this is called a permitted movement (if the left turn movement has a green arrow, this is called a protected movement).
We can determine the capacity of the permitted left turn movement from an exclusive lane by dividing the signal cycle into three parts, and considering the capacity of the left turn movement during each of these parts.

- what is the left turn flow during red?
- what is the left turn flow during the time that the opposing queue is clearing, at the beginning of the green phase?
- what is the left turn flow during the remainder of the green phase, after the opposing queue has cleared?
7.2 Capacity analysis
Sample problem: Consider the intersection shown in the figure on the left. The cycle length is 60 seconds, the green time for the north-south phase is 30 seconds, and the saturation flow rate for the through movement is 1800 vehicles per hour of green. For the northbound left turn movement, the critical gap $t_c$ is 5.0 seconds, while the follow up time $t_f$ is 2.1 seconds.

- what is the capacity of the southbound through movement?
- what is the time required for the southbound queue to clear after the beginning of the green phase?
- what is the maximum flow for the northbound approach during the remaining green time after the opposing southbound queue has cleared?
- what is the capacity of the northbound approach?

$v_s = 600 \text{ vph}$
$v_N = 100 \text{ vph}$
7.3 Questions to consider

- What is a permitted movement?

- What are three parts of the signal cycle that are of interest when computing the capacity of a permitted left turn movement?
MODULE 8. CYCLE LENGTH

8.1 Optimizing Cycle Length (Webster’s Method)
8.2 Example Problem
MODULE 9. GREEN SPLITS

Definition: Allocation of cycle length to each movement according to the relative traffic volumes of each movement.

Example calculation:
MODULE 10. CLEARANCE TIMES

Concept: Dilemma Zone: Providing the proper clearance time (yellow plus all red) such that a driver has sufficient time to stop safely or safely clear the intersection.

Example Calculation:
MODULE 11. PEDESTRIAN CROSSING TIMES

Basic concept: Phase times must be sufficiently long to accommodate safe pedestrian crossing.

Walking speed: What is typical walking speed?

Crossing time sample calculation:
We will consider a simplified version of the intersection of State Highway 95 and Styner Avenue. While it is not exactly like the actual case, it will give you the opportunity to apply the tools that you have now learned to answer the same kinds of questions that the City of Moscow is now considering:

Questions to consider:
- What assumptions should we make about the intersection operation?
- Should the controller be fixed time or actuated?
- Should the intersection be isolated or connected to adjacent signalized intersections?
- What is the appropriate phasing plan?
- How long should the cycle be?
- What are the appropriate green splits?
- What are the appropriate clearance intervals?
- How long should the pedestrian clearance times be?
- Is there sufficient capacity to handle the projected traffic flow?
- What is the delay that will be experienced by motorists?
- What other factors should be considered?