1.225J (ESD 205) Transportation Flow Systems

Lecture 7

Freeway Traffic Control:
Pre-timed, Coordinated Ramp Metering

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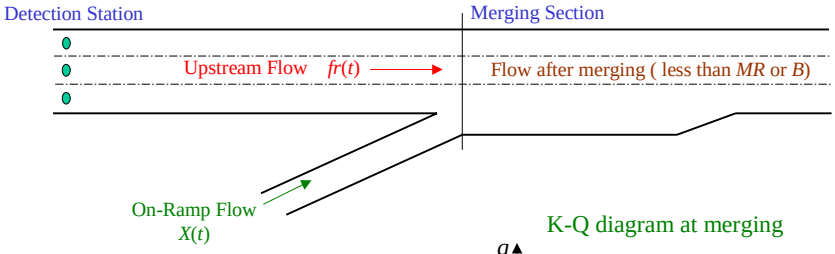
Lecture 7 Outline

- Introduction:
  - Freeway traffic control
  - Ramp metering
- Pre-timed, coordinated ramp metering (R11, R13)
  - Example
  - LP formulation for the example
  - General LP formulation
- Summary

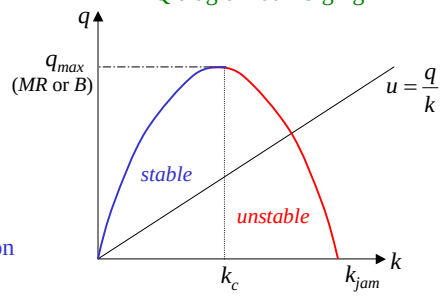
Freeway Traffic Control

- Lane control:
  - Variable speed limit signs
  - Keep-lane signs
  - Congestion and incident warnings
  - Environmental condition warnings, such as fog, ice, rain and snow
- Freeway network control:
  - Variable Message Signs (VMS) for driving information and/or guidance
  - Individual route guidance
- Two types of freeways: Urban freeways and Intercity freeways
- Ramp metering is applicable to urban freeways due to:
  - Large number of on and off ramps
  - Many ramp-to-ramp trips
  - Recurrent as well as non-recurrent (usually dynamic) congestion

The Ramp Metering Concept



K-Q diagram at merging



- Find $X(t)$ such that:
  - $X(t) \le MR - fr(t)$
  - This results in a stable flow immediately upstream and downstream of the merging section

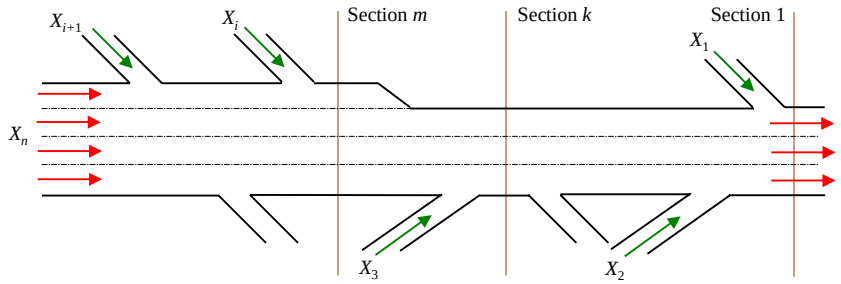
Ramp Metering: General Aspects

- Examples of objectives:
  - Preserve freeway capacity
  - Maximize total vehicles served
  - Reduce duration and extent of recurrent congestion
  - React to non-recurrent congestion
- Implementation: Traffic lights (one car at a time or traffic cycles)
- Main geographical areas of applications:
  - Europe
  - Asia
  - California and Texas
- Controllability limitations:
  - Amount of controlled ramps
  - Minimum ramp volumes
  - Ramp length

Types of Ramp Metering Methods

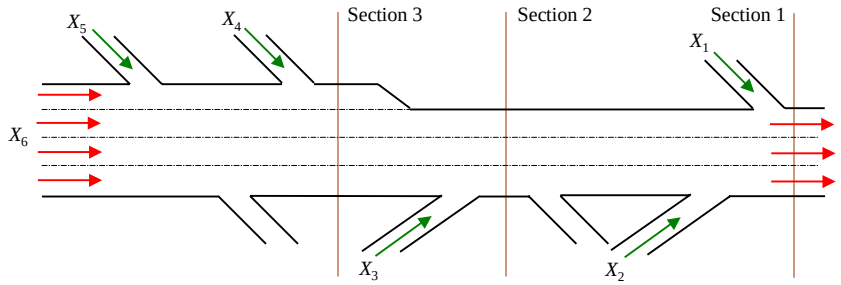
- Types of ramp metering methods:
  - *Isolated* vs. *Coordinated*
  - *Pre-timed* (*time-of-day*) vs. *Traffic responsive*
- Pre-timed (also called fixed-time) ramp metering:
  - Does not need real-time measurements
  - Calculations are done off-line and are based on historic demands
  - Assumes no dynamics, which is valid for sufficiently long roads and time periods only
- Focus of this lecture: *Pre-timed*, *Coordinated* ramp metering

LP Formulation: Notations



- Notations
  - X_j : input volumes to the freeway system ($j = 1,2,...,n$)
  - A_{kj} : decimal fraction of vehicles entering at input j which pass through section k ($k = 1,2,...,m$; $j = 1,2,...,n$)
  - B_k : capacity of freeway section k ($k = 1,2,...,m$)
  - D_j : hourly demand at input ramp j

Pretimed, Coordinated Ramp Metering: Example



- Input data (6 ramps (n=6), 3 sections (m=3))

A_{jk}		j					
		1	2	3	4	5	6
k	1	1.000	1.000	0.949	0.933	0.842	0.519
	2			1.000	1.000	0.922	0.619
	3				1.000	0.969	0.777

k	B_k
1	5900
2	6000
3	6450

j	1	2	3	4	5	6
D_j	600	475	450	500	825	6800

LP Formulation and Solution: Example

- Maximize total vehicles served:

$$\max \; X_1 + X_2 + X_3 + X_4 + X_5 + X_6$$

$$\begin{aligned}
\text{s.t.} \quad & X_1 + X_2 + 0.949X_3 + 0.933X_4 + 0.824X_5 + 0.519X_6 \le 5900 \quad (S_1)\\
& X_3 + X_4 + 0.922X_5 + 0.619X_6 \le 6000 \quad (S_2)\\
& X_4 + 0.969X_5 + 0.777X_6 \le 6450 \quad (S_3)\\
& X_1 \le 600 \quad (S_4)\\
& X_2 \le 475 \quad (S_5)\\
& X_3 \le 450 \quad (S_6)\\
& X_4 \le 500 \quad (S_7)\\
& X_5 \le 825 \quad (S_8)\\
& X_6 \le 6800 \quad (S_9)
\end{aligned}$$

$$X_j \ge 0, \quad j = 1,2,3,4,5,6$$

- An optimal solution: $X_1 = 447,\ X_2 = 475,\ X_3 = 450,\ X_4 = 367,\ X_5 = 825,\ X_6 = 6800$
- Objective function value = 9364 (maximum flow)
- Slack variables: $S_1 = 0,\ S_2 = 213,\ S_3 = 0,\ S_4 = 153,\ S_5 = 0,\ S_6 = 0,\ S_7 = 133,\ S_8 = 0,\ S_9 = 0$

General LP Formulation

- Problem: $\max \sum_{j=1}^{n} X_j$

$$\begin{aligned}
\text{s.t.} \quad & \sum_{j=1}^{n} A_{kj} X_j \le B_k, \quad k = 1,2,\ldots,m \quad \text{(section capacity constraints)}\\
& X_j \le D_j, \quad j = 1,2,\ldots,n \quad \text{(on-ramp demand constraints)}\\
& X_j \ge 0, \quad j = 1,2,\ldots,n \quad \text{(non-negativity constraints)}
\end{aligned}$$

- Solution method:
  - The above LP can be solved by the Simplex method
  - There are numerous software solvers for LPs (XPRESS-MP, LINDO, CPLEX, EXCEL)
  - The Excel LP Solver may be used for problems of moderate size only

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