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

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The Ramp Metering Concept

- Detection Station
- Merging Section

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

K-Q diagram at merging:

\[ q = \frac{q_{max}}{k} \]

\( u = \frac{q}{k} \)

\( k_c \) and \( k_{jam} \): Stable and unstable regions.
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 freeway input for section $j$

Pretimed, Coordinated Ramp Metering: Example

- **Input data (6 ramps (n=6), 3 sections (m=3))**
LP Formulation and Solution: Example

Maximize total vehicles served:
\[
\begin{align*}
\text{max} & \quad X_1 + X_2 + X_3 + X_4 + X_5 + X_6 \\
\text{s.t.} & \quad X_1 + X_2 + 0.949X_3 + 0.933X_4 + 0.824X_5 + 0.519X_6 \leq 5900 \quad (S_1) \\
& \quad X_1 + X_4 + 0.922X_1 + 0.619X_6 \leq 6000 \quad (S_2) \\
& \quad X_4 + 0.969X_4 + 0.777X_6 \leq 6450 \quad (S_3) \\
& \quad X_1 \leq 600 \quad (S_4) \\
& \quad X_2 \leq 475 \quad (S_5) \\
& \quad X_3 \leq 450 \quad (S_6) \\
& \quad X_4 \leq 500 \quad (S_7) \\
& \quad X_5 \leq 825 \quad (S_8) \\
& \quad X_6 \leq 6800 \quad (S_9) \\
\end{align*}
\]
\[X_j \geq 0, \quad j=1,2,3,4,5,6\]

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: \(\text{max} \sum_{j=1}^{n} X_j\)
\[\text{s.t.} \quad \sum_{j=1}^{n} A_{kj}X_j \leq B_k, \quad k=1,2,...,m \quad \text{(section capacity constraints)}\]
\[X_j \leq D_j, \quad j=1,2,...,n \quad \text{(on - ramp demand constraints)}\]
\[X_j \geq 0, \quad j=1,2,...,n \quad \text{(non - negativity constraints)}\]

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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