CEE518 ITS Guest Lecture
ITS and Traffic Flow Fundamentals

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The main objective of these two lectures is to establish the connection between Intelligent Transportation Systems (ITS) and traffic flow fundamentals. Introduction of traffic flow fundamentals has appeared on virtually every ITS book and the reader is very curious about why should an ITS book talk about traffic flow fundamentals. Unfortunately, a connection between these two subjects is typically missing, or at least vague, in these ITS books. This motivates these two lectures. In Lecture 1, a qualitative introduction is presented to walk the reader step by step from ITS to traffic flow fundamentals without involving any math. In Lecture 2, a quantitative introduction is given by using a concrete example to show how traffic flow fundamentals help solve real-world ITS problems. Questions and comments should be directed to Dr. Daiheng Ni.

Lecture 1: Qualitative Introduction

Why ITS?
- Congestion, better use of roads, wise trip making, peace in mind, etc.

What does ITS do?
- ATIS - travel times, queues, delays
- ATMS – throughput, bottlenecks, control strategies, etc.

Underlying methodology?
- "Watch" – Sensor technologies
  - Mobile sensors
  - Point sensors
  - Space sensors
- "Control" – Traffic flow analysis
  - Where are bottlenecks?
  - How long will a queue build up?
  - How long does it take for the queue to dissipate?
  - How much delay will be encountered?
  - In case of an accident, what's the best cleanup strategy, full closure or partial closures?

Traffic flow fundamentals
- How does traffic look like – flow, speed, density, and their relationships
  - Traffic stream characteristics
    - 3 basic char – q, k, u
    - Other char – throughput, queue, delay, travel time – built on q, k, u
  - Equilibrium traffic flow models
    - See q-k-u observations and fitting.doc
- How will traffic evolution – traffic flow models and simulation
  - Dynamic traffic flow models
    - Simple models
    - Complex models
  - Manual calculation
  - Traffic simulation

Flow-speed-density:
- Time-space domain: sensor technologies and traffic flow characteristics
- Fundamental relationship

Equilibrium traffic flow model – pair-wise relationship between speed and density

Field observations

Greenshields: $u = u_f - \left(\frac{u_f}{k_j}\right)k$

Greenberg: $u = u_m \ln\frac{k_j}{k}$

Underwood: $u = u_f e^{-k/k_m}$

Northwestern: $u = u_f e^{-\frac{1}{2}\left(\frac{k}{k_o}\right)^2}$

Generalized: $u = u_f\left(1 - \left(\frac{k}{k_j}\right)^n\right)$

Fundamental diagrams:

Speed-density: mainly used in research
Flow-density: highway traffic control
Speed-flow: highway capacity analysis and LOS

Dynamic traffic flow models

Equilibrium traffic flow models are just a summary of observations over time and space, so these models alone won't answer questions regarding traffic evolution, i.e. traffic conditions at any time-space point (x, t).

Considering that flow, speed, and density all vary over time and space, these traffic stream characteristics are functions of time and space. Therefore, the independent variables here are time t and space x and the dependent variables here are q(x, t), u(x, t), and k(x, t). Any formulation that describes the relationship between these time- and space-dependent variables is called a dynamic traffic flow model.

Derivation of conservation law – equation of continuity

LWR model – a system of two equations

The equation of continuity has one equation but contains two unknown variables. Need to supply an additional equation in order to solve for the unknown variables.

Equilibrium traffic flow model comes into play. Therefore,

$$\begin{cases} \frac{\partial k(x,t)}{\partial t} + \frac{\partial q(x,t)}{\partial x} = 0 \\ q = f(k) \end{cases}$$

If we can solve the LWR model with certain boundary and initial conditions, then we know q(x,t), k(x,t), and u(x,t) for everywhere in the time-space domain, and various MOEs can be calculated such as queues, delays, travel times, etc.

How to solve LWR model?

Shock waves – Starting from boundary and initial conditions in time-space domain, draw shock waves which will divide the time-space domain into regions and each region contains the same traffic conditions.

Questions: what are shock waves and how to draw them?

Shock waves

Shock waves are lines in time-space domain delineating regions of different traffic conditions.
Example:

shock wave at a highway bottleneck.
shock wave at an intersection

Lecture 2: Quantitative Introduction

Shock waves

How to determine shock wave speeds?

How does this relate to the fundamental diagram?

How can this relation help solve LWR model?

How to apply LWR model?

An example ITS problem

An example ITS problem:

On Wednesday 9:00 AM, there is an accident on northbound Interstate-91. The traffic operation center (TOC) has to decide how to cleanup the accident. After collecting information and communicate with highway patrol and emergency operator, the TOC determines that there are two alternative:

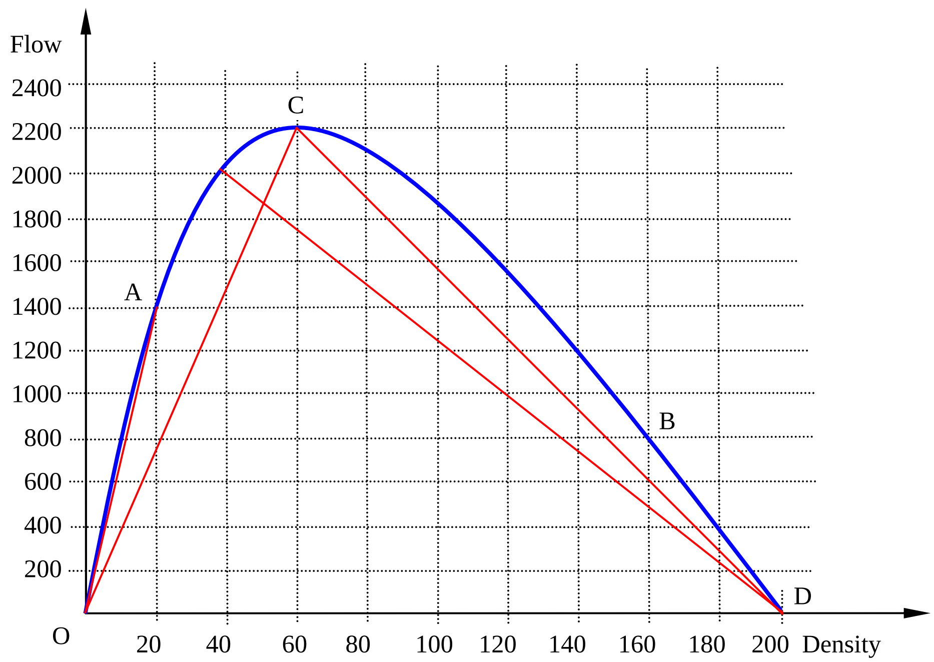
1. Completely shut the interstate off for 10 minutes, do cleanup, and then reopen the Interstate for normal operation, or
2. Partially open the Interstate at reduced capacity, but the cleanup requires longer time – about 30 minutes – before normal operation can be resumed.

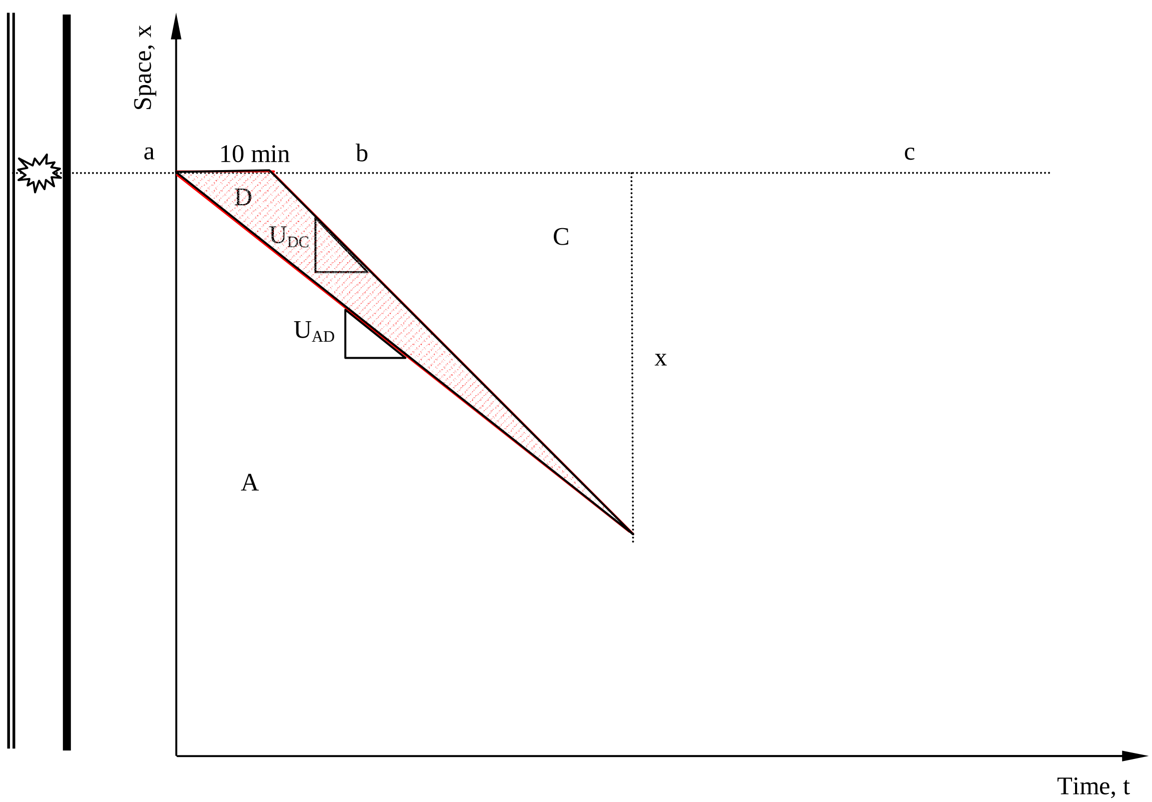
One of the concerns at the TOC is how long the queue will grow because the queue on the Interstate will overflow via ramps and further block upstream surface streets.

As a transportation engineering student in UMass Amherst, you are asked to offer you knowledge to help the TOC make the decision.

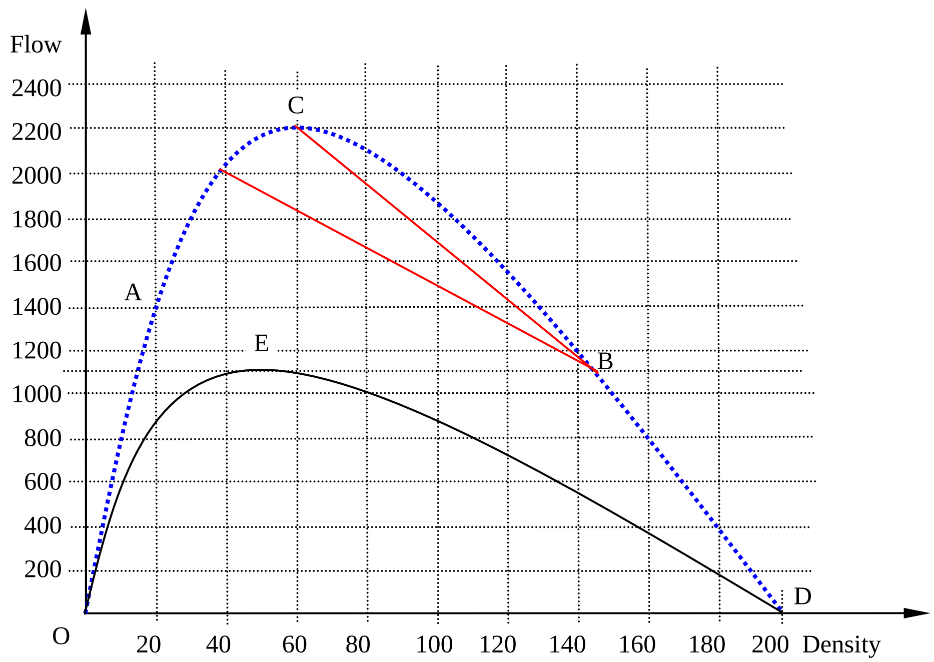
More details:
Arrival flow (condition A): q = 2000 veh/hr, k = 40 veh/mi, u = 50 mi/hr
Queued flow (condition D): q = 0 veh/hr, k = 200 veh/mi, u = 0 mi/hr
Capacity flow (condition C): q = 2200 veh/hr, k = 60 veh/mi, u = 36.7 mi/hr
Reduced capacity flow (condition E): q = 1100 veh/hr, k = 50 veh/mi, u = 22 mi/hr

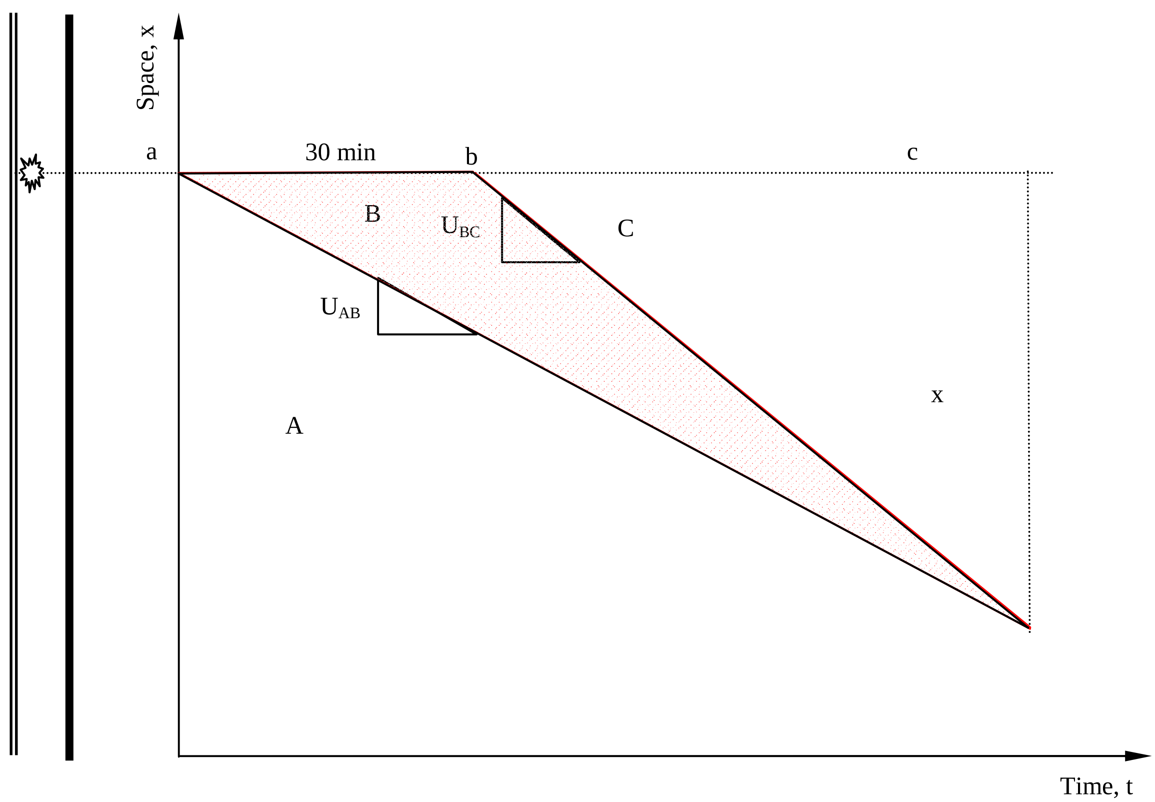
Find: which alternative creates longer queue?



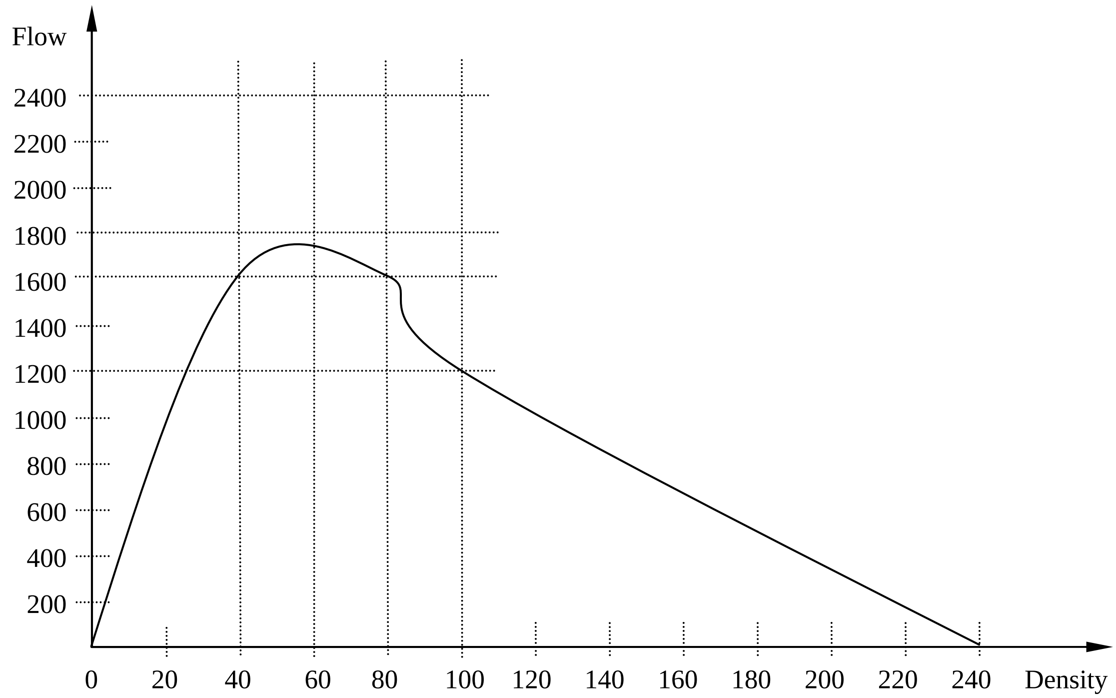


U_{AD} = (0-2000) / (200-40) = - 2000 / 160 = - 12.5 mph = x / ac
ac = x / 12.5
U_{DC} = (0-2200) / (200-60) = - 2200 / 140 = - 15.7 mph = x / bc
bc = x / 15.7
10 min = 1/6 hour = ac – bc = x / 12.5 – (x / 15.7) = 0.016 x
x = 1 / (6 * 0.016) = 10.2 mi





U_{AB} = (1100-2000) / (145-40) = - 900 / 105 = - 8.57 mph = x / ac
ac = x / 8.57
U_{BC} = (1100-2200) / (145-60) = - 1100 / 140 = - 12.94 mph = x / bc
bc = x / 12.94
30 min = 1/2 hour = ac – bc = x / 8.57 – (x / 12.94) = 0.039 x
x = 1 / (2 * 0.039) = 12.7 mi



This graph shows how the example in the ITS text book is ill-posed. The main reason is that the q-k relationship is not convex for the congested regime.