Tradeoffs in the Design of Route Guidance Systems

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What is Route Guidance?

• The term “route guidance” is used in the literature to mean different things
  – Prescriptive messages on VMSs are sometimes considered route guidance
  – In-vehicle systems that provide static routes might also be called route guidance

• For this discussion to be constructive, we will narrow the topic somewhat

• In this presentation, we will assume that by “route guidance” we mean the provision of routes to individual drivers. Drivers communicate with the route guidance system while *en route*. Prescribed guidance is dynamic and considers the current network state
Introduction

• Route guidance is a challenging problem!
• The goal of this presentation is not to present a single perfect solution, but to illustrate the trade-offs and options that exist in designing a route guidance system
• We will formulate some answers to the following questions:
  – What are the desirable attributes of a route guidance system?
  – What are the constraints of the problem?
  – What methods can we use?
The Goal of Route Guidance

• The goal of route guidance is to get travelers from A to B better
  – *What makes a route “better?”*
    • Lower travel time?
    • Lower cost (including congestion pricing and gas)?
    • Higher average speed?
    • A combination of the above?
• When we generate route guidance, we do so with some objective in mind
Some notes on Objectives:

- At some level, most route guidance systems use some type of “shortest” path algorithm or heuristic to generate guidance.
  - Later, we will discuss where these methods fit into route guidance systems
  - For now, let’s just discuss the implications of our choice of objective
- Our choice of objective influences our choice of algorithm
  - For example, in time-dependent networks, generating a least time path is different than generating a least cost path
Some notes on Shortest Paths

- The field of shortest paths algorithms is very extensive. Algorithms exist for many many variants of the problem. These variants consider different:
  - Objective functions
  - Representations of Time (Discrete, Continuous)
  - Rules (for example, whether waiting is allowed at nodes)
  - Quantities of paths generated (A best path? All best paths? The k-best paths?)
  - Qualities of solution (Exact? Approximate?)
System Optimal or User Optimal?

• Let’s get back to thinking about the objectives of route guidance

• Who are we optimizing for?
  – System optimal route guidance maximizes the total objective for all drivers
    • All equipped drivers?
    • All drivers?
  – User optimal route guidance maximizes each individual driver’s objective
    – *What is the problem with providing system optimal route guidance? User optimal?*
Tradeoffs in Objectives

• The problem with system optimal route guidance is that it can disadvantage some drivers in favor of others.
• The problem with user optimal route guidance is that there is no guarantee that it will improve the efficiency of the network.
• What questions should we ask when deciding between system optimal and user optimal?
  • Who is providing the system?
    – A public agency has some incentive to optimize for all users; a private entity has incentive to optimize for its customers.
  • Is there a cost for using the system?
    – If people pay for guidance, it is expected that it will benefit them.
  • Are we concerned about user trust and loyalty?
    – Yes! If users detect that they are being disadvantaged by the system, they will stop using it.
Sensing

• Assume we’ve selected an objective. Now what?
• We need data to evaluate the current state of the traffic network. Where should we get this data?
  – Sensors in the network (cameras, loop detectors, etc)?
  – Sensors on vehicles (to detect speed, following distance, etc)?
• *What are the advantages of each?*
Sensing: Tradeoffs

Stationary Sensors:
• Dependable: we know the locations and update frequency of our data sources
• Sense all vehicles: not just equipped vehicles
• Better at estimating traffic flow rates

Vehicle-Based Sensors:
• Require less infrastructure and less cooperation with public agencies; sensing cost borne by users
• Vehicles already sense their own speed everywhere they go…we should use this data
• More ubiquitous
A Centralized or Decentralized System?

• Assume we have data. What do we do with it? Where do we send it? How do we use it? What is the architecture of the system?
• Route guidance systems are typically thought of as centralized or decentralized
• In a centralized system, sensed data is communicated to a single central computational unit where route guidance is generated for the whole network
• In a decentralized system, sensed data is communicated to many smaller computational units (possibly with some overlap) that work on local problems
• What are the pros and cons of centralized and decentralized structures?
Centralized vs. Decentralized: Tradeoffs

• It is hard to generalize about centralized and decentralized architectures
• Generally, decentralized systems do not have full sharing of data, and thus tend to be poorer at prediction
• Centralized systems may be difficult to scale and less robust
• Decentralized systems are often envisioned as reactive, while centralized systems are usually predictive
• *What is the difference between predictive and reactive systems and is the above pairing merited?*
Reaction vs. Prediction

• Once we have collected our data and sent it around the system, should we:
  – react to it immediately, or
  – use it to generate predictions and act upon these predictions?

• What are the strengths and weaknesses of either approach?
Reaction vs. Prediction: Tradeoffs

Reaction:
- Low computational burden, responds quickly to changing conditions
- Easy to implement in a decentralized system

Prediction:
- Can generate better guidance, in terms of solution quality and consistency
A Note on Consistency…

• The concept of consistency is often not well understood, but is very important to predictive route guidance.

• A route guidance system is consistent if the predicted conditions are actually encountered by drivers:
  – Giving a weather forecast does not change the weather, but giving travel time predictions changes experienced travel times!

• To generate consistent route guidance, one can iteratively execute routines which:
  – Predict the future network state (including the expected effect of guidance)
  – Generate guidance according to predicted future network state

• This iterative routine is an application of Dynamic Traffic Assignment (DTA) models.
A Note on DTA…

• DTA is an iterative process with two primary components:
  – Given the time-dependent network state, generate paths
  – Assuming vehicles travel on the generated paths, estimate the resulting time-dependent network state

• DTA can be performed using several types of models:
  – Simulators (micro-, meso- or macro-scopic)
  – Analytical Models (a system of solvable equations)
Centralized vs. Decentralized and Predictive vs. Reactive

• Going back to the tradeoff between centralized and decentralized systems…
  – Why is there often a pairing between (centralized and predictive) and (decentralized and reactive)?
  – Are there reasons to look beyond this pairing?
Hybrid Centralized/Decentralized Architectures

• Hybrid architectures have been proposed recently to achieve the benefits of both centralized and decentralized route guidance.
• One approach (Chiu and Mahmassani) is to formulate a bi-level linear program where:
  – The upper level generates centralized guidance and the lower level generates decentralized guidance.
  – The interactions between the two levels are a Stackelberg game.
• Hybrid route guidance is a new and active area of research.
Who should deploy a route guidance system?

• Several of the tradeoffs we have outlined are really institutional/policy questions
  – Should public agencies provide route guidance? Why? How?
  – Should private companies provide route guidance? Why? How?
You are the head of a public agency and are considering funding a route guidance initiative. What kind of system appeals to you?
You are a car manufacturer looking to provide a dynamic route guidance system in your vehicles. What type of system appeals to you?
Readings

• Watling and van Vuren – focuses on the modeling of route guidance systems, but also gives a great overview of the issues in route guidance

The other readings focus on several systems that occupy three different positions on the centralization axis.

• MIT ITS Program document – outlines the basic structure of a centralized route guidance system (when reading, focus on DynaMIT, not DynaMIT-P)

• Hawas and Mahmassani – contains a logic for decentralized route guidance and comparative study of centralized vs. decentralized route guidance

• Chiu and Mahmassani – newer work which proposes a scheme for hybrid route guidance
Some Opinions on Route Guidance