Predictive Route Guidance

*An Interesting ITS Application*

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Introduction
Goals of presentation

- Provide an overview of predictive route guidance
Goals of presentation

- Provide an overview of predictive route guidance
- Give a sense of what's known
Goals of presentation

- Provide an overview of predictive route guidance
- Give a sense of what's known
- Give a sense of what's *not* known
Goals of presentation

- Provide an overview of predictive route guidance
- Give a sense of what's known
- Give a sense of what's *not* known
- Identify some of the major issues
Why travel information?

People have an imperfect knowledge of the network
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  - Possible 10% savings from better knowledge of paths (Autoguide)
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  - 40-50% of delays on major U.S. roadways are incident-related (TTI)
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  - Individuals make better travel decisions (probably)
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- By providing better travel information
  - Individuals make better travel decisions (probably)
  - Network conditions improve overall (maybe)
What is travel information?

- Some means of communicating with travelers . . .
What is travel information?

Some means of communicating with travelers ...  
- Before they begin trip ("pre-trip")
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  - In the past ("historical" guidance)
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  - In the past ("historical" guidance)
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Based on network conditions
- In the past ("historical" guidance)
- In the present ("current" guidance)
- In the future ("predictive" guidance)
Responses to travel information

- Psychological responses
Psychological responses

- Feel better knowing what’s happening
Responses to travel information

- Psychological responses
  - Feel better knowing what’s happening

- Activity-related responses
Responses to travel information

- Psychological responses
  - Feel better knowing what’s happening

- Activity-related responses
  - Call ahead to destination
Responses to travel information

- Psychological responses
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- Activity-related responses
  - Call ahead to destination
  - Rearrange activity schedule
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  - Cancel trip
Responses to travel information

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- Trip-related responses
  - Cancel trip
  - Pre-trip: Change departure time, route, mode
Responses to travel information

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  - Cancel trip
  - Pre-trip: Change departure time, route, mode
  - En route: Change route, mode
Route guidance
Let’s think about:
Guidance issues

Let’s think about:

◆ What data are needed
Guidance issues

Let’s think about:
- What data are needed
- How they’re collected
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- How network reacts
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  - How messages are communicated
  - How network reacts
  - How guidance system reacts
Historical guidance

- Data needed:
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- Data needed:
  - Travel conditions (link, subpath, path, O-D) over time
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- How guidance system reacts:
  - Update travel condition database
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Data needed:
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- How guidance system reacts:
  - Update condition estimation algorithms, database
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Predictive guidance

- Data needed:
  - Network model
  - Prevailing travel conditions
  - Historical demand information

- How collected:
  - Vehicle tracking technologies
  - Image processing; ILD, cell phone signatures

- How processed:
  - Forecast future demand, conditions
  - Generate guidance
  - Reconcile as necessary

- How communicated:
  - Like current guidance

- How network reacts:
  - Depends on quality of predictions, guidance

- How guidance system reacts:
  - Track discrepancies between predictions, reality
  - Update algorithms, databases
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  - Track discrepancies between predictions, reality
  - Update algorithms, databases
Predictive route guidance
Suppose we have a great network prediction model
The key issue - Part I

- Suppose we have a great network prediction model
- Suppose we can tell drivers our predictions
The key issue - Part I

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- Suppose we can tell drivers our predictions
- Drivers listen to us and do what they do:
The key issue - Part I

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- Suppose we can tell drivers our predictions
- Drivers listen to us and do what they do:
  - Some ignore us completely
Suppose we have a great network prediction model
Suppose we can tell drivers our predictions
Drivers listen to us and do what they do:
  - Some ignore us completely
  - Some factor what we say into their routing decisions
The key issue - Part I

Suppose we have a great network prediction model
Suppose we can tell drivers our predictions
Drivers listen to us and do what they do:
  - Some ignore us completely
  - Some factor what we say into their routing decisions
  - Some do the opposite to "avoid the crowd"
The key issue - Part I

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- Drivers listen to us and do what they do:
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  - Some do the *opposite* to "avoid the crowd"

- If a significant number of drivers change their decisions in some way
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- If a significant number of drivers change their decisions in some way
- The effects of their decisions on network conditions
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- The effects of their decisions on network conditions
- Will invalidate our predictions!
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- The effects of their decisions on network conditions
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- The Self-Defeating Prophecy!!
Example of a self-defeating prophecy
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Suppose we predict congestion on one of two parallel routes
Example of a self-defeating prophecy

- Suppose we predict congestion on one of two parallel routes
- We tell drivers about it
Example of a self-defeating prophecy
- Suppose we predict congestion on one of two parallel routes
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- If enough of them listen to us and shift to the other route
Example of a self-defeating prophecy
- Suppose we predict congestion on one of two parallel routes
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- If enough of them listen to us and shift to the other route
- It may congest worse than what we predicted for the original
Example of a self-defeating prophecy
- Suppose we predict congestion on one of two parallel routes
- We tell drivers about it
- If enough of them listen to us and shift to the other route
- It may congest worse than what we predicted for the original
- And leave the original route free-flowing
The key issue - Part II

- Example of a self-defeating prophecy
  - Suppose we predict congestion on one of two parallel routes
  - We tell drivers about it
  - If enough of them listen to us and shift to the other route
  - It may congest worse than what we predicted for the original
  - And leave the original route free-flowing

- Another possibility:
The key issue - Part II

- Example of a self-defeating prophecy
  - Suppose we predict congestion on one of two parallel routes
  - We tell drivers about it
  - If enough of them listen to us and shift to the other route
  - It may congest worse than what we predicted for the original
  - And leave the original route free-flowing

- Another possibility:
  - Congestion oscillates from one route to the other
Example of a self-defeating prophecy

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- If enough of them listen to us and shift to the other route
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In all these cases, guidance was based on wrong predictions
The key issue - Part II

- Example of a self-defeating prophecy
  - Suppose we predict congestion on one of two parallel routes
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- In all these cases, guidance was based on wrong predictions
  - We’ve probably made network conditions worse
Example of a self-defeating prophecy

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Another possibility:

- Congestion oscillates from one route to the other

In all these cases, guidance was based on wrong predictions

- We’ve probably made network conditions worse
- And people will eventually stop listening to us
Guidance is "consistent"
The key issue - Part III

- Guidance is "consistent"
- When the network condition predictions
The key issue - Part III

- Guidance is "consistent"
- When the network condition predictions
- On which our guidance messages are based
The key issue - Part III

- Guidance is "consistent"
- When the network condition predictions
- On which our guidance messages are based
- Turn out to be true (within limits of model accuracy)
The key issue - Part III

- Guidance is "consistent"
- When the network condition predictions
- On which our guidance messages are based
- Turn out to be true (within limits of model accuracy)
- After drivers receive the messages and react to them
Guidance is "consistent"
When the network condition predictions
On which our guidance messages are based
Turn out to be true (within limits of model accuracy)
After drivers receive the messages and react to them

How do we compute consistent guidance?
If only a small fraction of drivers receive predictive guidance
If only a small fraction of drivers receive predictive guidance

Or react to the guidance messages
If only a small fraction of drivers receive predictive guidance
Or react to the guidance messages
Their reactions will not affect network conditions –
Side points

- If only a small fraction of drivers receive predictive guidance
- Or react to the guidance messages
- Their reactions will not affect network conditions –
- The consistency problem does not arise
If only a small fraction of drivers receive predictive guidance
- Or react to the guidance messages
- Their reactions will not affect network conditions –
  - The consistency problem does not arise
- The individual drivers may benefit
- If only a small fraction of drivers receive predictive guidance
- Or react to the guidance messages
- Their reactions will not affect network conditions –
- The consistency problem does not arise
  - The individual drivers may benefit
  - But network conditions are unchanged
Side points

- If only a small fraction of drivers receive predictive guidance
- Or react to the guidance messages
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- It’s possible to make predictions by extrapolation:
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  - Use current conditions, historical trends, other info
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It’s possible to make predictions by extrapolation:
- Use current conditions, historical trends, other info
- At least one company currently does this
- Difficult to factor driver response into extrapolations
- Won’t consider further
System approach
Rolling horizon approach
Rolling horizon approach

- Consider a *guidance horizon*
Rolling horizon approach

- Consider a guidance horizon
- Say 1-2 hours into the future
Major steps

- Rolling horizon approach
  - Consider a *guidance horizon*
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- Generate guidance for each *guidance interval* within guidance horizon
Major steps

- Rolling horizon approach
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- Generate guidance for each guidance interval within guidance horizon
  - Guidance remains fixed over guidance interval
Rolling horizon approach
   - Consider a *guidance horizon*
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Generate guidance for each *guidance interval* within guidance horizon
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- Generate guidance for each *guidance interval* within guidance horizon
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  - Say 5-10 minutes
  - *Affects stability of network conditions*
- **Rolling horizon approach**
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- **Generate guidance for each *guidance interval* within guidance horizon**
  - Guidance remains fixed over guidance interval
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- **Generation uses network model over guidance horizon**
Major steps

- Rolling horizon approach
  - Consider a guidance horizon
  - Say 1-2 hours into the future
- Generate guidance for each guidance interval within guidance horizon
  - Guidance remains fixed over guidance interval
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  - Affects stability of network conditions
- Generation uses network model over guidance horizon
- Network model uses continuously collected data inputs
Rolling horizon approach
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Generate guidance for each guidance interval within guidance horizon
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Generation uses network model over guidance horizon

Network model uses continuously collected data inputs

Each update interval guidance is re-computed
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- Network model uses continuously collected data inputs
- Each update interval guidance is re-computed
  - Each update, the process is rolled forward by one period
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Major steps

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  - Depends on data processing, communication times
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  - Update interval might be one/several guidance intervals
  - Depends on data processing, communication times
- If an incident is detected, reset
A network model for guidance
Conventional network models

- These network models assume drivers have perfect information
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  - If this were true, no need for route guidance!
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- Picture!
Conventional analysis of DTA models is based on the equilibrium as a fixed point.
Equilibrium as a fixed point

- Conventional analysis of DTA models is based on
- Infinite-dimensional variational inequalities
Equilibrium as a fixed point

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- Turns out to be difficult to generalize to guidance problem
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Fixed point approach more applicable
Equilibrium as a fixed point

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- Fixed point approach more applicable

- Fixed point definition
  for $T : X \mapsto X$, $X \subseteq \mathbb{R}^n$ (or $X$ more general)
  find $x^* \in X$ such that $x^* = T(x^*)$
Equilibrium as a fixed point

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Fixed point definition

\[ T : X \mapsto X, \quad X \subseteq \mathbb{R}^n \quad \text{(or } X \text{ more general)} \]
\[ \text{find } x^* \in X \text{ such that } x^* = T(x^*) \]

Fixed point expresses an equilibrium condition

\[ S \circ D(T) = T \]
\[ D \circ S(F) = F \]
Guidance network models

- Need to account for new aspects of problem
Guidance network models

- Need to account for new aspects of problem
  - Guidance messages ($M$)
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- Key variables are:
Guidance network models

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- Key variables are:
  - Time-dependent path, subpath splits ($P$)
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Consistency as a fixed point

Fixed point expresses a consistency condition

\[
G \circ S \circ D(M) = M
\]
\[
D \circ G \circ S(P) = P
\]
\[
S \circ D \circ G(T) = T
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- There are heuristic algorithms for solving these, but they are very slow
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  - the method of successive averages (MSA)
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  - the method of successive averages (MSA)
  - iterate averaging methods (Polyak averaging)
- My doctoral research was on this
Research needs
Basic models and components
Basic models and components
  - Real-time dynamic O-D matrix estimation
What needs doing

- Basic models and components
  - Real-time dynamic O-D matrix estimation
  - Models of driver response to guidance
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- Basic models and components
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- Algorithms and computational methods
  - Improved fixed point solution methods
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- System architecture and design
What needs doing

- Basic models and components
  - Real-time dynamic O-D matrix estimation
  - Models of driver response to guidance
- Algorithms and computational methods
  - Improved fixed point solution methods
  - Approximate solution methods
- System architecture and design
  - Designs for an operational system
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- New ideas
What needs doing

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- New ideas
  - Adaptive guidance in presence of uncertainty (Gao 2004)
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  - Adaptive guidance in presence of uncertainty (Gao 2004)
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  - Multi-regional issues
- New ideas
  - Adaptive guidance in presence of uncertainty (Gao 2004)
  - Vehicle-centric guidance
  - Hybrid centralized/vehicle-centric systems (Farver 2005)
Thank you! – Questions?