INTELLIGENT TRANSPORTATION SYSTEMS

Lecture 9:
Traffic Assignment & Calibration

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Last two weeks:
- Laws of traffic modeling and simulation at the macro level and micro level

This session:
- Principals of trip distribution and calibration models
Demand Forms

- In-flow and turning proportions at intersection and exit sections
- The traffic demand input is defined in terms of origin-destination matrices
What is Traffic Assignment?

- The process of allocating a given set of trip interchanges to the specified transportation system.

**OD-Matrix (set of trips)** → **Set of routes**
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Why?
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OD-Matrix (set of trips) \rightarrow \text{Set of routes}

Why?

- The fundamental aim of the traffic assignment process is to reproduce the pattern of vehicular movements when the travel demand represented by the trip matrix is assigned.
Example.

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If the $q_{12} = 12$ (flow), what is the flow on each link?
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Transportation systems involve interactions among multiple agents. The basic facts are:

- Although travel choices are made individually, they impact others as well (congestion).
- The impacts of others’ travel choices are important as you make your choices.

“It’s the evening peak period, so the freeway will probably be congested. I’ll take another route.”
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- In traffic assignment, each traveler is an agent choosing a route; the joint actions of all travelers result in congestion patterns throughout the network, which determines the travel time each traveler faces.
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- In traffic assignment, each traveler is an agent choosing a route; the joint actions of all travelers result in congestion patterns throughout the network, which determines the travel time each traveler faces.

At the equilibrium solution, no traveler can reduce their travel time by switching to another route.
Wardrop's first principle of route choice, also known as "user equilibrium"

The journey times in all routes actually used are equal and less than those that would be experienced by a single vehicle on any unused route.

John Glen Wardrop
(1922–1989)
Example.

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If the 100 cars agreed that 50 travel via ABD and the other 50 through ACD, then travel time for any single car would actually be 3.5, which is less than 3.75.
Dietrich Braess (1968): Adding one or more roads to a road network can slow down overall traffic flow through it
Induced demand by Braess's paradox

General framework of DTA

The principle of dynamic user equilibrium is the following:

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**General framework of DTA**

**Equilibrium = Fixed point**
Simulation-based Traffic Assignment (in SUMO)

1. Initialize the process by computing the fastest route through the empty network for each vehicle.
   - Add this route to the list of routes known by this vehicle.
   - The probability of using this route by this vehicle is set to 1.

2. Perform the simulation using the currently chosen routes to obtain the edges’ travel times over simulation time.

3. Compare the mean travel times against those obtained in the previous run.
   - Quit if the algorithm converges, i.e., the mean travel time reduction falls below a given threshold.

4. Compute new routes for all vehicles using the network’s current travel times.
   - If a new route for a vehicle was found, add it to the list of routes known by the vehicle.
   - Update all known routes’ estimated travel times and their probabilities to be chosen.
   - Choose one route for this vehicle, taking into account the route choice probabilities
   - Continue with step 2
Traveler Model

Disaggregate the time-dependent OD-matrix into a set of drivers with a fixed departure time. Each driver $d$ is described by the following variables:

1. An origin $O_d$, a destination $D_d$ and a departure time $t_d$,
2. A set $R_d$ of routes from $O_d$ to $D_d$,
3. A probability distribution $p_d : R_d \rightarrow \mathbb{R}^+$ with $\sum_{r \in R_d} p_d(r) = 1$,
4. "Learned travel times" $\tau_d : R_d \rightarrow \mathbb{R}^+$. 
Problem with Enumerating All Routes

- Precalculate a ‘feasible’ set of routes, for example, the $k$ disjoint shortest paths.
- Start with only a single route for each driver, i.e., the shortest path. After each iteration of the algorithm, check if the portion of each driver's travel time spent in queues exceeds some limit. If so, calculate the shortest path according to the time-dependent link cost functions generated by the last simulation run and add this route to $R_d$. 
Update Rules: Travel times

A driver $d$ chooses a route $r \in R_d$ according to the probability distribution $p_d$. After the simulation, the travel times $\tau_d(r)$ are updated according to

$$
\tau'_d(r) = \tau_s(r)
$$

$$
\tau'_d(u) = \beta \tau_g(u) + (1 - \beta) \tau_d(u) \quad \forall u \in R_d - r
$$

- $\tau_s(r)$ is the travel time of route $r$ measured in the simulation
- $\tau_g(u)$ is the travel time of route $u$ calculated from the time-dependent link costs generated by the simulation
- The second update is to prevent drivers from ‘remembering’ the travel times of routes they have not used for a long time.
Update Rules: Probabilities

\[ p'_d(r) = \frac{p_d(r)(p_d(r)+p_d(u)) \exp\left(\frac{\alpha \delta_{ru}}{1-\delta_{ru}^2}\right)}{p_d(r) \exp\left(\frac{\alpha \delta_{ru}}{1-\delta_{ru}^2}\right)+p_d(u)} \]

- \( p_d(r) \) is the prior probability to use route \( r \) by driver \( d \);
- \( p'_d(r) \) is the new probability to use route \( r \) by driver \( d \);
- \( r \) is the route used in the last simulation run;
- \( u \) is another route from the list of known routes;
- \( \delta_{ru} \) is the relative cost differences between routes \( r \) and \( u \), computed as

\[ \delta_{ru} = \frac{\tau_d(u) - \tau_d(r)}{\tau_d(u) + \tau_d(r)} \]

The probability to use the route which was already used in the last iteration step is updated by

\[ p'_d(u) = p_d(r) + p_d(u) - p'_d(r) \]
Remarks

- DTA models are not the universal cure that can cost-effectively address all types of problems at hand.
- Most existing DTA models focus on route choice, and relatively few are implemented for departure time or arrival time choice.
- The existing simulation-assignment paradigm is vehicle-based instead of person-based, and travelers are generally considered homogeneous in many choice dimensions.
- Normally, travel times for edges are collected and aggregated into intervals of 15 min during the simulation’s runs.
- To get usable assignments, often more than 20 iterations are necessary.
https://traffic-simulation.de/
Is the simulation model an accurate representation of the real world?

Simulation can be seen as a sampling experiment on a dynamic real system through a computer model formally representing it.
Validation is an iterative process consists of:

- collecting the simulated data
- comparing it to the system’s measured data based on statistical analysis methods
- determine whether the observed and simulated data samples are significantly close enough.
Data inputs to traffic models can be classified into two categories:

1. Directly observable data, i.e., measurements of traffic variables affected by errors (flows, speeds, occupancies, travel times, etc.), which are based on available technologies.

2. Data not directly observable, such as transport demand modeled by time-dependent origin-destination matrices.
Validation of the model is an iterative process that calibrates the model parameters, compares the model to the actual system behavior, and uses the discrepancies between the two and the insight gained, to improve the model until the accuracy is judged to be acceptable.

Calibration process aims to find the values of these parameters that will produce a valid model. Calibration is the process of obtaining such values from field data in a particular setting.
Field Validation

Manual counting is sometimes unavoidable :)

Supilinn, Tartu
Do People Use the Shortest Path?

Wardrop's first principle:
The journey times in all routes actually used are equal and less than those that would be experienced by a single vehicle on any unused route.
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Travelers differ in

- attributes (value of time (VOT), willingness to pay, time budgets, etc.),
- behavioral preferences (e.g. willingness to take risks, willingness to switch routes with potential savings),
- experience, and knowledge about travel, all of which could lead to significant heterogeneity in route choice behavior.
Case study:
3 weeks, random vehicles equipped with GPS devices, Minneapolis, St. Paul metropolitan area.

- The results show that about two-thirds of the subjects do not use the shortest travel time path.
- No subjects followed the shortest distance path unless it also coincided with the shortest travel time path.
- Travelers clearly have other preferences when making their route choices. Therefore, a better understanding of people’s route preferences could also inform the development of choice set generation algorithms.

Transportation infrastructure lasts for decades. Therefore, effective planning must predict the impact of projects and policies decades into the future.

On the other hand, human beings can behave in ways that are impossible to predict.
Conclusions

- We focus on models that include a clear set of rules describing the behavior of drivers, vehicles and/or traffic flows.
- These models are usually relatively easy to understand and are shaped by a set of mathematical equations, that can often be solved analytically for (very) simple problems.
- However, human behavior in traffic is often much more complex than can be described by these models.
- Novel methods such as artificial intelligence models have been developed to describe traffic flow using, for example, fuzzy logic or neural networks.