INTELLIGENT TRANSPORTATION SYSTEMS

Lecture 7 (20 Oct 2021)

Traffic Flow Modeling and Simulation

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Transportation planning is essential to ensure changes in infrastructure are made as effective as possible.

Engineers and researchers support this process by developing and running models which predict the impact of potential changes. Ex.

- what is the impact of adding a new lane to a major road on traffic and emission?
- the toll on a bridge is reduced?

Variety of measures of effectiveness can be considered: mobility, congestion, emissions, equity, toll revenue, transit ridership, infrastructure maintenance needs, or countless other metrics.
Transportation infrastructure lasts for decades. Therefore, effective planning must predict the impact of projects and policies **decades into the future.**

On the other hand, unlike trusses or beams, **human** beings can behave in ways that are **impossible to predict.**
What do we need?
Mathematical models :)
A **model** is a set of mathematical equations that tries to describe (or replicate) a physical process (ex. evolution of traffic congestion over time and space).

General pattern: start with a model which is simple, transparent, insightful... and also wrong. This simple model can then be improved in ways to make it more correct and useful.
How do we develop models?

- **Using physical laws**, such as conservation equations: the number of vehicles should conserve, and we cannot lose vehicles in an intersection.
- **Mixed approaches**; we can use some basic mathematical structure from physical considerations. Then, we can add some parameters to our models and estimate some values for these parameters (fundamental diagram).
Transportation Elements

Road Network

Traffic Flow

Signaling
How do we test our model?

- **Logical and mathematical consistency.**
- **Qualitative testing.** Does the model reproduce all the essential phenomena of the process? If I have a traffic network and some bottlenecks that create the congestion, my model should be able to reproduce this congestion and equivalently, my model should have no contradiction with the essential phenomenon of the physical process.
- **Quantitative accuracy.** Estimating the parameters and checking the sensitivity and transferability of the model.
- **Computational complexity.**
Optimal Parameter Estimation

$\rho^c_i$: critical density

$\rho_i$: jam density

$q_i$: Max flow

$\nu_i$: free-flow speed

$k$: discrete time index

$x$: state vector

$x^m$: real measurements

$u$: control inputs

$p$: vector of model parameters

d: demand

$J(p)$: difference between model and real data
Model Validation

\[ x = [\rho_1 v_1 \cdots \rho_N v_N]^T \]
\[ u = [r_1 \cdots r_N]^T \]
\[ d = [s_1 \cdots s_N v_0 q_0 \rho_{n+1}]^T \]
\[ p = [v_f \rho_{cr} \tau \nu \cdots]^T \]

Model: \( x^{m+1} = f[x^k, u^k, p], \quad x^0 = x_0 \)

Optimization problem: \( \min_p J(p) \)
Networks are a type of mathematical model which are very frequently used in the study of transportation: Static or Dynamic

A network consists of **links** and **nodes**.

- A link usually represents a means of travel from one point to another: a road segment between two intersections, a bus route between two stops, and so on.
- The nodes are the endpoints of the links.

<table>
<thead>
<tr>
<th>Network type</th>
<th>Nodes</th>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadway</td>
<td>Intersections</td>
<td>Street segments</td>
</tr>
<tr>
<td>Public transit</td>
<td>Bus or train stops</td>
<td>Route segments</td>
</tr>
<tr>
<td>Freight</td>
<td>Factories, warehouses, retailers</td>
<td>Shipping options</td>
</tr>
<tr>
<td>Air</td>
<td>Airports</td>
<td>Flights</td>
</tr>
<tr>
<td>Maritime</td>
<td>Ports</td>
<td>Shipping channels</td>
</tr>
</tbody>
</table>
Elements of Demand

Travels cause by people who need to perform activities at different geographic locations. Therefore highly differentiated by time of the day, day of the week, purpose, type of cargo, importance of duration of traveling, etc.

Demand is traditionally represented by aggregated “origin-destination-matrix” (OD matrix).

Classification of Traffic Flow Models

- **Microscopic** (mainly used for simulation)
  - models car following and lane changing behavior.
- **Mesoscopic**
  - captures vehicles with similar characteristics.
- **Macroscopic**
  - similar to fluid mechanics, variables like flow and density are used to describe the state of the network.

Microscopic Traffic Flow Models

- Car following and lane changing behavior are modeled.
- We get the detailed trajectories of vehicles following each other.
- Many software are available for microscopic simulation.


Macroscopic Traffic Flow Models

Given a road segment, space is discretized ($dx$). We have:

- **density** $\rho(x, t)$: number of vehicles per length unit (veh/km)
- **traffic volume** $q(x, t)$: number of vehicles per time unit (veh/h)
- **mean speed** $v(x, t)$ in km/h

This is a mathematical abstraction inspired by fluid mechanics. We assume in $dx$ space we have homogeneous conditions for density and speed.
Microscopic vs Macroscopic Modeling

- Macroscopic models are **analytical**, not just simulators. We can write down the analytical form of PDEs and use them to develop model-based control strategies.
- **Computation time**: Macroscopic models are much faster than microscopic ones. However, microscopic models contain details.
- Required **resolution**
- Traffic control **measures**
- Potential **accuracy vs validation** efforts
Software for Simulation of Traffic

SUMO

TRANSIMS

MATSIm

PTV VISSIM
"SUMO" for short, is an open-source, microscopic, multi-modal traffic simulation. It allows to simulate how a given traffic demand which consists of single vehicles, moves through a given road network.

SUMO is developed by the German Aerospace Center and community users. It has been freely available as open-source since 2001.
The major reason for the development of an open source, microscopic road traffic simulation was

- to support the traffic research community with a tool with the ability to implement and evaluate own algorithms.
- The tool has no need for regarding all the needed things for obtaining a complete traffic simulation such as implementing and/or setting up methods for dealing with road networks, demand, and traffic controls.
- By supplying such a tool, the DLR wanted to
  - i) make the implemented algorithms more comparable by using a common architecture and model base, and
  - ii) gain additional help from other contributors.
SUMO Features

- **Simulation**
  - Space-continuous and time-discrete vehicle movement
  - Different vehicle types
  - Multi-lane streets with lane changing
  - Different right-of-way rules, traffic lights
  - A fast OpenGL graphical user interface
  - Manages networks with several 10,000 edges (streets)
  - Fast execution speed (up to 100,000 vehicle updates/s on a 1GHz machine)
  - Interoperability with other applications at run-time
  - Network-wide, edge-based, vehicle-based, and detector-based outputs
  - Supports person-based inter-modal trips

- **Network Import**
  - Imports VISUM, Vissim, Shapefiles, OSM, RoboCup, MATsim, OpenDRIVE, and XML-Descriptions
  - Missing values are determined via heuristics

- **Routing**
  - Microscopic routes - each vehicle has an own one
  - Different Dynamic User Assignment algorithms

- **High portability**
  - Only standard C++ and portable libraries are used
  - Packages for Windows main Linux distributions exist

- **Open-source** (EPL 2.0)
### Some SUMO Applications

<table>
<thead>
<tr>
<th>Application Name</th>
<th>Short Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>sumo</td>
<td>The microscopic simulation with no visualization; command line application</td>
</tr>
<tr>
<td>sumo-gui</td>
<td>The microscopic simulation with a graphical user interface</td>
</tr>
<tr>
<td>netconvert</td>
<td>Network importer and generator; reads road networks from different formats and converts them into the SUMO-format</td>
</tr>
<tr>
<td>netedit</td>
<td>A graphical network editor.</td>
</tr>
<tr>
<td>netgenerate</td>
<td>Generates abstract networks for the SUMO-simulation</td>
</tr>
<tr>
<td>duarouter</td>
<td>Computes the fastest routes through the network, importing different types of demand description. Performs the DUA</td>
</tr>
<tr>
<td>jtrrouter</td>
<td>Computes routes using junction turning percentages</td>
</tr>
<tr>
<td>dfrouter</td>
<td>Computes routes from induction loop measurements</td>
</tr>
<tr>
<td>marouter</td>
<td>Performs macroscopic assignment</td>
</tr>
<tr>
<td>od2trips</td>
<td>Decomposes O/D-matrices into single vehicle trips</td>
</tr>
<tr>
<td>polyconvert</td>
<td>Imports points of interest and polygons from different formats and translates them into a description that may be visualized by sumo-gui</td>
</tr>
<tr>
<td>activitygen</td>
<td>Generates a demand based on mobility wishes of a modeled population</td>
</tr>
<tr>
<td>emissionsMap</td>
<td>Generates an emission map</td>
</tr>
<tr>
<td>emissionsDriving-Cycle</td>
<td>Calculates emission values based on a given driving cycle</td>
</tr>
</tbody>
</table>
Building and Modifying Networks in SUMO

**netconvert**: Network importer and generator; reads road networks from different formats and converts them into the SUMO-format

**netedit**: A graphical network editor.

**netgenerate**: Generates abstract networks for the SUMO-simulation
Demand Modeling in SUMO

- Real (physical) measures are done at induction loops
  - induction-loop measures
  - DFROUTER
  - SUMO-routes

- Counts at junctions may provide flows and turning ratios
  - turning ratios
  - JTRROUTER
  - SUMO-routes

- Traffic scientists estimate demands on district level
  - OD-matrix
  - OD2TRIPS
  - trips
  - DUAROUTER
  - SUMO-routes
References:

- Intro to Traffic Flow Modeling and Intelligent Transport Systems (EPFL)
- SUMO
- Transportation Network Analysis
- Intelligent Transportation Systems 2020/21 fall - UT