Macroscopic multi-class simulation models for the evaluation of freight policies in urban area

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VREF workshop

ASSIGNMENT MODELS

SIMULATE DEMAND-SUPPLY INTERACTIONS, RESULTING FLOWS AND PERFORMANCES ON NETWORK ELEMENTS.

[Diagram showing the flow between demand model, path flows, demand-supply interaction model, path costs, and supply model]
ASSIGNMENT MODELS

Not congested network

Demands Model
OD demand flows
Path/Departure time choice model
Path flows (h)
Path cost (g)
Path Performances Model
Network Flow Propagation Model
Link flows (f)
Link costs (c)
Link Performances Model

Supplies Model

Congested network – Equilibrium models

Demands Model
OD demand flows
Path/Departure time choice model
Path flows (h)
Path cost (g)
Path Performances Model
Network Flow Propagation Model
Link flows (f)
Link costs (c)
Link Performances Model

Supplies Model

Within-day Dynamic Systems
MULTI-CLASS ASSIGNMENT MODELS

Users/goods fall into a number of distinct classes. Users/goods of a given class share all the behavioral characteristics such as specification, parameters and attributes of the relevant demand models, including path choice. All these features may be different from those of other classes.

For example, in urban systems, classes may be identified on the basis of
- trip purpose (delivering, procurement / work, shopping)
- vehicle type (auto, light and heavy commercial vehicles),
- commodity types (e.g. perishable, oil, raw materials)
- activity duration (e.g. parking duration)
- cost functions (e.g. different travel costs and time values)

SUPPLY MODEL
- \( g_{od,i} = \Delta_{od,i}^T c^i \quad \forall \ od \ \forall \ i \)
- \( c^i = c(f^1, \ldots, f^i, \ldots) = c(f) = c(S_i f^i) \quad \forall \ i \)
- \( f^i = S_{od} \Delta_{od,i} h_{od,i} \quad \forall \ i \)

DEMAND MODEL
- \( h_{od,i} = d_{od,i} p_{od,i} (-g_{od,i}) \quad \forall \ od \ \forall \ i \)

Hypothesis:
- fixed demand
- single mode assignment
- fully pre-trip path choice behavior
- non-additive cost not considered

were:
- \( \Delta_{od,i} \) be the link-path incidence matrix for the O-D pair \( od \) and class \( i \)
- \( d_{od,i} \) be the demand flow for the O-D pair \( od \) and class \( i \) (for a given mode and time band);
- \( f^i \) be the link flow vector for class \( i \),
- \( c^i \) be the link cost vector for class \( i \),
- \( g_{od,i} \) be the additive path cost vector for O-D pair \( od \) and class \( i \)
- \( h_{od,i} \) be the path flow vector for O-D pair \( od \) and class \( i \)
- \( p_{od,i} = p_{od,i} (-g_{od,i}) \) be the path choice probabilities vector for O-D pair \( od \) and class \( i \)
MULTI-CLASS ASSIGNMENT MODELS

CLASSIFICATION

Link congestion function of each class is:

- a linear transformation of a common congestion function (undifferentiated congestion)
- different between classes (differentiated congestion)

Undifferentiated congestion

link cost function becomes:

\[ c^i_a = c^i_a(f) = \gamma_i \bar{c}_a(f) + c^i_{0,a} \quad \forall i \]

where:
- \( \bar{c}_a = \bar{c}_a(f) \) is the reference cost function of link \( a \);
- \( \gamma_i \geq 0 \) is the ratio (assumed independent of the link) between the link cost for class \( i \) and the reference cost; if \( \gamma_i = 0 \) the class \( i \) costs are uncongested;
- \( c^i_{0,a} \) is the cost of link \( a \) specific to class \( i \), assumed independent of congestion

Undifferentiated congestion equilibrium multi-class assignment models

\[ f^i = \sum_{od,i} \Delta_{od,i} p_{od,i} (\gamma_i \bar{c}_a(f) - \gamma_i \Delta_{od,i}^T \bar{c}_a(f) - \gamma_i \Delta_{od,i}^T c^i_{0}) \quad \forall i \]
MULTI-CLASS ASSIGNMENT MODELS

Differentiated congestion

Differentiated congestion multi-class assignment models can be formulated with respect to the path or link flows of each class. These must be consistent with the corresponding costs experienced by each class. In the case of congested network assignment, cost functions generally differ for each class, and depend on the total flow of all classes.

Differentiated congestion multi-class equilibrium assignment models

\[ f^i = \sum_{od} \Delta_{od,i} p_{od,i} \left( \frac{- (\Delta_{od,i} \cdot c_i(f)))}{\forall i} \right) \]

Mutually consistent flows and costs

DEMAND MODELS

A travel demand model can be defined as a mathematical relationship between travel demand flows and their characteristics on the one hand, and given activity and transportation supply systems and their characteristics on the other.

\[ d[K_1, K_2, ...] = d(SE, T, \beta) \]

A demand flow is an aggregation of individual trips, and each trip is the result of multiple choices made by the transportation system users, i.e. an individual traveler in the case of passenger transportation or an operator (manufacturer, shipper and carrier) for freight transportation.

<table>
<thead>
<tr>
<th>TYPE OF CHOICE</th>
<th>Mobility or context models</th>
</tr>
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<tbody>
<tr>
<td>SEQUENCE OF CHOICES</td>
<td>Trip-based demand models</td>
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<tr>
<td></td>
<td>Trip chaining models</td>
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<tr>
<td>LEVEL OF DETAIL</td>
<td>Activity-based models</td>
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<tr>
<td>BASIC ASSUMPTIONS</td>
<td>Behavioral models</td>
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<td></td>
<td>Descriptive models</td>
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</tbody>
</table>
DEMAND MODELS

EXAMPLE:

Four-level trip-based travel demand model system

\[ d_{o,d}^{s,h,m,k} = d_{o,d}^{s,h} \cdot p^1(d/osh)(SE,T) \cdot p^2(m/oshd)(SE,T) \cdot p^3(k/oshdm)(SE,T) \]

- SOCIOECONOMIC ATTRIBUTES SE
- PERFORMANCE ATTRIBUTES T

conditional to

taking into account

input variables

EXAMPLE:

Structure of a trip chaining model system

\[ d_{o,d}^{s_1,s_2,m_1,m_2,h_1,h_2} \]

JOURNEY FREQUENCY MODEL FOR PRIMARY PURPOSE

TIME PERIOD DISTRIBUTION FOR PRIMARY TRIP

PRIMARY DESTINATION CHOICE MODEL

TRIP TYPE CHOICE MODEL

SECONDARY DESTINATION CHOICE MODEL

TIME PERIOD DISTRIBUTION FOR SECONDARY TRIP

TIME PERIOD DISTRIBUTION FOR RETURN HOME

TRIP CHAIN MODE CHOICE MODEL

ROUND TRIP MODE CHOICE MODEL

NUMBER OF USERS IN ZONE o of o

EMISSION OR FREQUENCY MODEL

DISTRIBUTION MODEL

MODE CHOICE OR MODAL SPLIT MODEL

PATH CHOICE MODEL

OD DEMAND BY MODE PURPOSE, TIME PERIOD AND PATH

- SOCIOECONOMIC ATTRIBUTES SE
- PERFORMANCES ATTRIBUTES T
ESTIMATION OF O-D DEMAND FLOWS USING TRAFFIC COUNTS

Aggregate data
- Traffic counts for each class \( i \) and time interval \( (f) \)
- OD flows for each class \( i \) and time interval \( (d) \)

Source
- Survey (SP vs RS)
- cameras, sensors, GPS, Bluetooth, ... (ITS technology)

O-D estimation
\[ d^* = \arg\min_{x \geq 0} [z_1(x, \hat{d}) + z_2(r(x), \hat{f})] \]

CHANGES IN OD FLOWS

Model elasticity for transportation policies

Policy for a class \( i \) (the right mix of interventions) → Transport simulation model (passenger and freight) → Impact estimation
- into the class \( i \)
- among all the classes
SOME REFERENCES


NAPLES SIMULATION MODEL

Passenger and environmental

Freight
- Cartenì, A. and Russo, F. (2009); A tour-based model for the simulation of a distributive freight system; in The Expanding Sphere of Travel Behaviour Research; selected papers from the 11th International Conference Travel Behaviour Research; Ryuichi Kitamura, T. Yoshii (Eds.). Emerald Group Publishing Limited: UK.