A DEMAND MODELLING SYSTEM FOR FORECASTING URBAN GOODS MOVEMENTS

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Overview

✓ Introduction

✓ The general structure of the proposed modeling system
  ➢ Demand sub-system
  ➢ Restocking tour sub-system

✓ Specification and calibration of the proposed modeling system
  ➢ The dataset
  ➢ Demand sub-system
  ➢ Restocking tour sub-system

✓ Conclusions and further developments
Introduction

✓ Significant impacts in road congestion, greenhouse gas and pollutant emissions and pavement wear

✓ City logistics measures should be implemented in order to alleviate these negative effects

✓ Methods and models need to analyze measures before implementing for an ex-ante assessment of impacts
Introduction

Actors

☑ Goods movement in urban and metropolitan areas is the result of a set of choices made by

- **Inhabitants/customers**, that decide where and how much to buy, as well as the mode of transport to use;
- **retailers** decide the shop location and where to bring the freight sold in the shop;
- **wholesalers, logistics operators** and **distributors** choose their location and how to restock retailers;
- **carriers** decide the delivery process.

Finally, **city administrations** try to **govern** the **overall process** aiming to **minimize** the global cost of the system made of distribution inner costs, inhabitants transportation costs for shopping, congestion costs and external ones (pollution and road safety),.
Introduction

Actors

- Wholesalers/Logistics operators/Distributors
- Carriers
- Retailers
- Inhabitants/customers

City administrators

City sustainability
City logistics measures

✓ **Infrastructures**
  - Urban Distribution/Consolidation Center (UDC)/Transit point

✓ **Governance**
  - Time windows
  - Weight constraints
  - Emission constraints
  - Incentives for Low Emission Vehicle (LEV)
  - Road/parking pricing
  - Incentives for third parties (3P)

✓ **Intelligent Transportation Systems (ITS)**
  - Freight transport management systems (e.g. tracking and tracing)
  - Traffic management systems (e.g. access control, traffic info, …)
## City logistics measures

### Choice dimensions, decision-makers and measures

<table>
<thead>
<tr>
<th>Choice dimension</th>
<th>Demand</th>
<th>Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>From where?</td>
<td>How?</td>
</tr>
<tr>
<td><strong>Decision-maker</strong></td>
<td></td>
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<tr>
<td>Retailer</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Wholesaler</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Carrier</td>
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</tbody>
</table>

### Measures/Policies

| Urban Distribution | x | x | x | x | x |
| Centre/transit point | x | x | x | x | x |
| Time windows       | x | x |   | x |   |
| Weight constraints | x |   | x |   | x |
| Emission constraints | x |   |   |   | x |
| Road/parking pricing | x |   |   |   | x |
| Incentives for LEV | x |   |   |   | x |
| Incentives for 3P | x |   |   |   | x |
| ITS                |   |   |   |   | x |
Models for urban freight transport demand

Integration of two classes of models:

- models which simulate the **level** and **spatial distribution** of commodity exchanged within the study area

- models which simulate the **restocking process** and allow us to obtain the link flows
Models for urban freight transport demand

O-D matrices

**REFERENCE UNIT**

- **Commodity/Quantity**: It allows to capture the mechanisms underlying the freight demand generation (e.g. Ogden, 1992; Oppenheim, 1994; Russo and Comi, 2010)

- **Delivery**: It allows to follow the decisional and logistic process of restocking (e.g. Routhier et al., 2007; Nuzzolo et al., 2010)

- **Vehicle**: Input for assignment model (e.g. Ogden, 1994; Hunt and Stefan, 2007; Wang and Holguin-Veras, 2009)
Models for urban freight transport demand

Integration of two classes of models:

- models which simulate the **level** and **spatial distribution** of commodity exchanged within the study area

- models which simulate the **restocking process** and allow us to obtain the link flows

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*Quantity/Delivery O-D matrices*

*Freight vehicle O-D matrices*
Freight vehicle O-D matrices

Problem definition

The general structure of the proposed modeling system – The restocking sub-system

<table>
<thead>
<tr>
<th>O-D</th>
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<th>d₁</th>
<th>d₂</th>
<th>d₃</th>
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</tbody>
</table>

- Restocker jointly chooses the **number** and the **location** of deliveries for each restocking tour
- Each restocker defines his tours trying to **reduce his costs** (e.g. using routing algorithm)
- The O-D matrices are the **sum** of single restocker **behaviours**
Freight vehicle O-D matrices

State-of-the-art

✓ from quantities/deliveries to freight vehicles

Aggregate models

Disaggregate models
(e.g. microsimulation or agent-based models)

Incremental growth approach
(Raothanachonkun et al., 2007; Hunt and Stefan, 2007; Wang and Holguin-Veras, 2008)

Two steps approach
(Nuzzolo et al, 2009, 2011)
The general structure of the proposed modeling system

✓ Distribution process (distributive logistics)
Models for urban freight transport simulation developed at “Tor Vergata” University of Rome

Demand sub-system

- Quantity O-D matrices

Delivery O-D matrices

Freight vehicle O-D matrices

Restocking tour sub-system
O-D estimation

Example of “Tor Vergata” demand modelling system

- Socio-economic data
- Restocking/Transport service attributes
  - Attraction
  - Attracted freight
  - Acquisition
  - Quantity O-D matrices
  - Transport service type (own account, third party)
  - Quantity O-D matrices per transp. service type

- LoS attributes
  - Shipment size
  - Delivery time
  - Vehicle type
  - Vehicle characteristics

- Demand sub-system
  - Restocking tour sub-system
  - Deliveries O-D matrices per transp. service type
  - Deliveries O-D matrices per time slice
  - Deliveries O-D matrices per vehicle type

- Trip chain order
  - Deliveries O-D matrices per n-th trip order
  - Delivery location
  - Freight vehicle O-D matrices

Restocking tour sub-system
The general structure of the proposed modeling system

Demand sub-system model

Quantity O-D matrices

Average quantity flow, $Q$, of freight type $s$ between the zone $o$ and the zone $d$ in a time period $h$ characterized by:

- service type $(r)$, defined by the possible transport service type:
  - own account by receiver (e.g. retailer)
  - own account by sender (e.g. wholesaler, distributor, producer)
  - third party by transport company
  - third party by courier (express company)

$$Q_{od}^{sh}[r]$$

For simplicity of notation, the class index $s$ (freight type) and $h$ (time period) will be taken as understood unless otherwise stated ⇒ $Q_{od}[r]$
Quantity O-D Matrices

\[ Q_{od}[r] = Q_d \cdot p[o/d] \cdot p[r/od] \]

- \( Q_{od}[r] \) is the average quantity flow of freight attracted by zone \( d \) and coming from zone \( o \) with transport service type \( r \);
- \( Q_d \) is the average quantity of freight attracted by zone \( d \) (attraction model);
- \( p[o/d] \) is the probability that freight attracted by zone \( d \) comes from zone \( o \) (e.g. production place/firm, distribution centre, warehouse, etc. - acquisition model);
- \( p[r/od] \) is the probability to be restocked by transport service type \( r \) (transport service type model).
Demand sub-system model

Delivery O-D matrices

Average delivery flow, \( ND \), of freight type \( s \) between the zone \( o \) and the zone \( d \) in a time period \( h \) characterised by:

- service type (\( r \))
- time slice (\( \tau \))
- vehicle type (\( v \))

For simplicity of notation, the class index \( s \) (freight type) and \( h \) (time period) will be taken as understood unless otherwise stated \( \Rightarrow ND_{od}[v \tau r] \)
Delivery O-D matrices

\[ ND_{od}[v \tau r] = \frac{Q_{od}[r]}{q[r]} \cdot p[\tau / d] \cdot p[v / \tau rod] \]

- \( ND_{od}[v \tau r] \) is the number of deliveries carried out by service type \( r \) and vehicle type \( v \) on \( od \) pair in time slice \( \tau \);
- \( Q_{od}[r] \) is the average freight quantity flow on \( od \) pair by service type \( r \);
- \( q[r] \) is the average freight quantity delivered with service type \( r \) (shipment size).
- \( p[\tau / d] \) is the probability of having deliveries in time slice \( \tau \) (delivery time model);
- \( p[v / \tau rod] \) is the probability that deliveries are carried out by vehicle type \( v \) (vehicle type model).
The general structure of the proposed modeling system

The restocking sub-system model

Freight vehicle O-D matrices

Average freight vehicle flow, \( VC \), transporting freight type \( s \) between the zone \( o \) and the zone \( d \) in a time period \( h \) characterized by:

- service type \( (r) \)
- time slice \( (\tau) \)
- vehicle type \( (v) \)

\[
VC_{od}^{sh} [v\tau r]
\]

For simplicity of notation, the class index \( s \) (freight type) and \( h \) (time period) will be taken as understood unless otherwise stated ⇒ \( VC_{od} [v\tau r] \)
The general structure of the proposed modeling system

The restocking tour sub-system model

- Trip chain order distribution

- Delivery location choice model

**Input:** delivery O-D matrices

- Trip chain order distribution

- Deliveries O-D matrices per n-th trip order

- Delivery location

- Freight vehicle O-D matrices

*Nuzzolo A, Cirsalli U, Comi A
A demand modelling system for forecasting urban goods movements*
Specification and calibration of the proposed modeling system

The dataset
City of Rome

✓ 99 traffic zones

Inner area (freight LTZ)
✓ 16 Districts
✓ 51,413 inhabitants
✓ 24,401 trade employees
Specification and calibration of the proposed modeling system

*The dataset*

  period of observation: 14 hours (from 7:00 to 21:00)

- **Retailer interviews** “Freight LTZ”
  (575 interviews)

- **Driver interviews** “Freight LTZ” on stops within study area
  (502 interviews)
Revealed freight flows

Revealed vehicle flows (car + truck)

Total freight vehicle flow 5.7%

256.965 veh/day

37.875 veh/day

59.185 veh/day

223.524 veh/day

Nuzzolo A, Cirsalli U, Comi A
A demand modelling system for forecasting urban goods movements
Specification and calibration of the proposed modeling system

O-D matrices in quantities

**Attraction model**

\[ Q_d = \beta_{AD} \cdot AD_d + \beta_{ASA} \cdot ASA_d \]  

- \( AD_d \) is the total number of retail employees in zone \( d \);
- \( ASA_d \) is a dummy variable introduced in order to measure the different power of selling in zone \( d \) with high shop density; it is equal to 1 if ratio between retailer employees and resident in the zone \( d \) is higher than 35%.

**e.g. Stationery**

\[ Q_d = 2.9 \cdot AD_d + 311.3 \cdot ASA_d \]  

\( R^2 = 0.89 \)
Specification and calibration of the proposed modeling system

O-D matrices in quantities

Acquisition models

\[
p[ o / d ] = \left( A_{l_o} \right)^{\beta_1} \cdot C_{o'd}^{\beta_2} / \sum_{o'} \left( A_{l_{o'}} \right)^{\beta_1} \cdot C_{o'd}^{\beta_2}
\]

- \( A_{l_o} \) is number of warehouse employees of zone \( o \);
- \( C_{o'd} \) is the length of travel trip between \( o \) and \( d \).

\[ R^2 = 0.52 \]

\[ p[ o / d ] = \left( A_{l_o} \right)^{0.13} \cdot C_{od}^{-0.08} / \sum_{o'} \left( A_{l_{o'}} \right)^{0.13} \cdot C_{o'd}^{-0.08} \]

\textit{e.g. All freight types different from foodstuffs}
Specification and calibration of the proposed modeling system

Quantity O-D matrices

Revealed vs estimated quantity

Attracted Quantity

Quantity O-D flows (Other goods)

Quantity O-D flows (Foodstuffs)
Specification and calibration of the proposed modeling system

Quantiy O-D matrices

Transport service type model

$p[r / od]\]

$p[r/od]$ is the probability to be restocked by transport service $r$, it can be expressed by a logit model:

$$p[r / od] = \frac{\exp(\alpha V_r)}{\sum_{r'} \exp(\alpha V_{r'})}$$

$$V_r = \sum_j \beta_j X_{jr}$$

$X_{jr}$ is the $j$-th attribute related to transport service type $r$. 

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A demand modelling system for forecasting urban goods movements
Transport service type model

First results

\[ V_{coa} = 0.032 \cdot PC + 1.008 \]

\[ V_{ctp} = 1.97 \cdot PROD + 2.56 \cdot CD + 1.82 \cdot WH + 0.023 \cdot EM + 0.6 \cdot q \]

- \( V_{coa} \) is the systematic utility for transport service type \( c_{oa} \) (i.e. retailer in own account),
- \( V_{ctp} \) is the systematic utility for transport service type \( c_{tp} \) (i.e. restocking by other transport service types),
- \( PROD \) is a dummy variable equal to 1 if the restocked freight arrives directly from the producer, 0 otherwise,
- \( CD \) is a dummy variable equal to 1 if the restocked freight arrives directly from a distribution center, 0 otherwise,
- \( WH \) is a dummy variable equal to 1 if the restocked freight arrives directly from a wholesaler, 0 otherwise,
- \( PC \) is a dummy variable equal to 1 if the restocked shops is a public concern (e.g. bar, restaurant), 0 otherwise,
- \( EM \) is the number of employees at shop to be restocked,
- \( q \) is the average shipment size, expressed in tons.

\[ \rho^2 = 0.21 \]
Transport service type model

First results

\[ V_{c_{oa}} = 0.032 \cdot PC + 1.008 \]  
\[ V_{c_{tp}} = 1.97 \cdot PROD + 2.56 \cdot CD + 1.82 \cdot WH + 0.023 \cdot EM + 0.6 \cdot q \]

- \( V_{c_{oa}} \) is the systematic utility for transport service type \( c_{oa} \) (i.e. retailer in own account),
- \( V_{c_{tp}} \) is the systematic utility for transport service type \( c_{tp} \) (i.e. restocking by other transport service types),
- \( PROD \) is a dummy variable equal to 1 if the restocked freight arrives directly from the producer, 0 otherwise,
- \( CD \) is a dummy variable equal to 1 if the restocked freight arrives directly from a distribution center, 0 otherwise,
- Probability to be restocked by other transport service types increases for shipments comes from producer, distribution center and warehouse
- \( EM \) is the number of employees at shop to be restocked
- \( q \) is the average shipment size, expressed in tons.

\( \rho^2 = 0.21 \)

Public concerns prefer restocking in own account

Probability to be restocked by other transport service types increases with increasing shipment size and number of employees (shop dimension)
Delivery O-D matrices

Shipment size

✓ Retailer

\[ q^i = 5.83 \cdot EM^i + 95.17 \cdot STORE + 32.71 \cdot PC + 130.63 \cdot MR \]

\[(5.3) \quad (3.84) \quad (1.6) \quad (5.2)\]

\[ [kg / delivery] \]

\[ R^2 = 0.56 \]

✓ \( q^i \) is the average delivered quantity at shop \( I \), expressed in kg;
✓ \( EM^i \) is the number of employees at shop \( i \);
✓ \( STORE \) is a dummy variable equal to 1 if there is a depot, 0 otherwise;
✓ \( PC \) is a dummy variable equal to 1 if the restocked shops is a public concern (e.g. bar, restaurant), 0 otherwise;
✓ \( MR \) is a dummy variable equal to 1 if the restocking happens before noon (i.e. in the morning), 0 otherwise;
Specification and calibration of the proposed modeling system

Delivery O-D matrices

Shipment size

✓ Retailer

\[ q^i = 5.83 \cdot EM^i + 95.17 \cdot STORE + 32.71 \cdot PC + 130.63 \cdot MR \]  
\[ (5.3) \quad (3.84) \quad (1.6) \quad (5.2) \]

\[ [\text{kg / delivery}] \]

\[ R^2=0.56 \]

✓ \( q^i \) is the average delivered quantity at shop \( I \), expressed in kg;
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✓ \( STORE \) is a dummy variable equal to 1 if there is a depot, 0 otherwise;
✓ \( PC \) is a dummy variable equal to 1 if the restocked shop is a public concern (e.g. bar, restaurant), 0 otherwise;
✓ \( MR \) is a dummy variable equal to 1 if the restocking happens before noon (i.e. during the morning), 0 otherwise;

during the **morning** the delivered quantity is **larger** than in the **afternoon**
Specification and calibration of the proposed modeling system

Delivery O-D matrices

Revealed vs estimated quantity

Attracted delivery flows (Foodstuffs)

Attracted delivery flows (Other goods)

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A demand modelling system for forecasting urban goods movements
Specification and calibration of the proposed modeling system

Delivery O-D matrices

Delivery time models

\[ p[\tau / d] \]

\( p[\tau/d] \) is the probability to restock in time slice \( \tau \) (e.g. 7:00 – 09:00); it can be expressed by a logit model:

\[
p[\tau / d] = \frac{\exp(\alpha V_\tau)}{\sum_{\tau'} \exp(\alpha V_{\tau'})}
\]

\[
V_\tau = \Sigma_j \beta_j X_{j\tau}
\]

\( X_{j\tau} \) is the \( j \)-th attribute related to restock in time slice \( \tau \).

time is constrained by governance regulations

Generally, statistic-descriptive model
Specification and calibration of the proposed modeling system – Delivery O-D matrices

Delivery time model

Example – revealed shares

\[ p[\tau / d] \]

<table>
<thead>
<tr>
<th></th>
<th>Foodstuffs</th>
<th>Home accessories</th>
<th>Stationery</th>
<th>Clothing</th>
<th>Household and personal hygiene</th>
<th>Building material</th>
<th>Other goods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 9:00</td>
<td>30%</td>
<td>30%</td>
<td>34%</td>
<td>23%</td>
<td>47%</td>
<td>38%</td>
<td>27%</td>
</tr>
<tr>
<td>9:00-11:00</td>
<td>40%</td>
<td>37%</td>
<td>50%</td>
<td>51%</td>
<td>32%</td>
<td>42%</td>
<td>31%</td>
</tr>
<tr>
<td>11:00-13:00</td>
<td>24%</td>
<td>17%</td>
<td>9%</td>
<td>15%</td>
<td>19%</td>
<td>10%</td>
<td>21%</td>
</tr>
<tr>
<td>13:00-16:00</td>
<td>6%</td>
<td>13%</td>
<td>6%</td>
<td>11%</td>
<td>2%</td>
<td>4%</td>
<td>20%</td>
</tr>
<tr>
<td>After 16:00</td>
<td>0%</td>
<td>3%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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</tbody>
</table>
Delivery O-D matrices

**Vehicle type model**

\[ p[v / \tau_{rod}] \]

\( p[v/\tau_{rod}] \) is the probability to restock by vehicle type \( v \); it can be expressed by a logit model:

\[ p[v / \tau_{rod}] = \frac{\exp(\alpha V_v)}{\sum_v \exp(\alpha V_v)} \quad V_v = \sum_j \beta_j X_{jv} \]

\( X_{jv} \) is the \( j \)-th attribute related to vehicle type \( v \).
Vehicle type model

First results – retailer in own account

\[ V_{\text{car}} = 1.01 \]  
\[ V_{\text{lgv}} = 0.003 \cdot EM + 0.50 \cdot q + 0.05 \]  
\[ V_{\text{mgv}} = 0.004 \cdot EM + 3.00 \cdot q + 0.006 \cdot \text{STORE} \]

where

- \( V_{\text{car}} \) is the systematic utility for using the car (e.g. SUV, station-wagon),
- \( V_{\text{lgv}} \) is the systematic utility for using the Light Goods Vehicle,
- \( V_{\text{mgv}} \) is the systematic utility for using the Medium Goods Vehicle,
- \( \text{STORE} \) is the surface of store, expressed in m\(^2\),
- \( EM \) is the number of employees at shop to be restocked,
- \( q \) is the average shipment size, expressed in tons.

\[ \rho^2 = 0.38 \]
**Vehicle type model**

*First results – retailer in own account*

\[ V_{\text{car}} = 1.01 \]
\[ V_{\text{lgv}} = 0.003 \cdot EM + 0.50 \cdot q + 0.05 \]
\[ V_{\text{mgv}} = 0.004 \cdot EM + 3.00 \cdot q + 0.006 \cdot \text{STORE} \]

where

- \( V_{\text{car}} \) is the systematic utility for using the *car*,
- \( V_{\text{lgv}} \) is the systematic utility for using the *Light Goods Vehicle*,
- \( V_{\text{mgv}} \) is the systematic utility for using the *Medium Goods Vehicle*,
- \( \text{STORE} \) is the surface of store, expressed in m\(^2\),
- \( EM \) is the number of employees at shop to be restocked,
- \( q \) is the average *shipment size*, expressed in tons.

\[ \rho^2 = 0.38 \]

Retailer tends to use light vehicles for small shops with few employees and a small depot.
Specification and calibration of the proposed modeling system

Freight vehicle O-D matrices

Trip chain order distribution

\[ p[n / o] = \frac{\exp(V_n)}{\sum_{n'} \exp(V_{n'})} \quad n \in I = \{ \text{number of stops / deliveries} \} \]

\( V_n \) is the systematic utility for a tour with \( n \) deliveries departing from zone \( o \).

Different models have been calibrated according to three transport service types:

- retailer in own account,
- wholesaler in own account,
- carrier.
Trip chain order distribution

Wholesaler in own account

\[ p[ n / o ] = \exp(V_n) / \sum_{n'} \exp(V_{n'}) \quad n \in I = \{1 \text{stop, 2 stops, 3 stops, > 3 stops}\} \]

\[ V_1 = 2.430 + 0.252 \cdot VEH \quad (2.5, 1.6) \]

\[ V_2 = -0.399 \cdot VEH - 0.075 \cdot \ln(IAA_o) - 0.151 \cdot q + 0.965 \cdot FGT + 2.429 \quad (-1.1, -2.1, -1.7, 2.1, 2.6) \]

\[ V_3 = -0.042 \cdot \ln(IAA_o) + 1.381 \cdot FGT + 1.788 \quad (-1.1, 2.7, 1.8) \]

\[ V_{>3} = -0.799 \cdot VEH - 0.082 \cdot \ln(IAA_o) - 0.195 \cdot q + 2.512 \cdot FGT \quad (-1.5, -1.4, -1.5, 3.1) \]
The systemic utility, $V_n$, has been specified as linear combination of the following attributes:

- **VEH**, dummy variable equal to 1 if the used vehicle is a Light Goods Vehicle, 0 otherwise;
- $q$, average quantity of freight delivered at each stop (i.e. delivery point) along the journey, expressed in tons;
- **FGT**, dummy variable equal to 1 if the delivered freight belongs to the *foodstuffs* class, 0 otherwise;
- **IAA$_o$**, *retailer* accessibility index of zone $o$, from which the tour departs (e.g. warehouse location):

$$IAA_o = \frac{AA_o - \min_z (AA_z)}{\min_z (AA_z) - \min_z (AA_z)}$$

where $AA_x$ is the accessibility of zone $x$ estimated as:

$$AA_x = \sum_j (UL_j)^{6.334} \cdot \exp[-3.913 \cdot dist_{xj}]$$

- $UL_j$ the number of retail establishments of zone $j$ to be restocked,
- $dist_{xj}$ the distance between zone $x$ and $j$,
- $\alpha_1$ and $\alpha_2$ calibration parameters,
Trip chain order distribution

Wholesaler in own account

\[ p[n / o] = \exp(V_n) / \sum_{n'} \exp(V_{n'}) \quad n \in I = \{1 \text{stop}, 2 \text{stops}, 3 \text{stops}, > 3 \text{stops} \} \]

\[ V_1 = 2.430 + 0.252 \cdot VEH \]

\[ V_2 = -0.399 \cdot VEH - 0.075 \cdot \ln(IAA_o) - 0.151 \cdot q + 0.965 \cdot FGT + 2.429 \]

\[ V_3 = -0.042 \cdot \ln(IAA_o) + 1.381 \cdot FGT + 1.788 \]

\[ V_{>3} = -0.799 \cdot VEH - 0.082 \cdot \ln(IAA_o) - 0.195 \cdot q + 2.512 \cdot FGT \]

- light goods vehicles have tours with few stops/deliveries
- increasing the accessibility of restocking zone, the number of stops/deliveries decreases
- more stops/deliveries per tour for small delivered quantity
- no. of stops/deliveries increases for foodstuffs

\[ \rho^2 = 0.18 \]
Delivery location choice model

\[
p\left[ d_{j+1}^k / d_i^k \mid n_0 \right] = \frac{\exp(V_{d_j^{k+1}})}{\sum_{d'} \exp(V_{d'}^{k+1})}
\]

\(V_{d_j^{k+1}}\) is the systematic utility of delivering in zone \(d_j\) the delivery \((k+1)\) conditioned to have previously delivered in zone \(d_i\) the delivery \(k\) within a tour with \(n\) deliveries that departs from zone \(o\).

The survey has revealed that different behaviors could be followed by a restocker in the choice of first destination within a tour and the following ones:

- **Choice of first delivery location,**
- **Choice of following delivery locations**
Delivery location choice model

✓ Wholesaler and retailer in own account: 

\[ V_{d_j} = 0.213 \cdot \ln\left(AD_{d_j}\right) - 0.028 \cdot dist_{od_j} + 2.03 \cdot DS_{od_j} + 7.84 \cdot IAA_{d_j} \]

- \(AD_{d_j}\) is the number of retail employees in zone \(d_j\);
- \(dist_{od_j}\) is the distance between zone \(o\) and \(d_j\), expressed in km;
- \(DS_{od_j}\) is the share of deliveries on \(od_j\) pair respect to all deliveries departing from zone \(o\);
- \(IAA_{d_j}\) is the retailer accessibility of zone \(d_j\).

\[ \rho^2 = 0.33 \]
Delivery location choice model

✓ Wholesaler and retailer in own account: 
*first delivery location*

\[
V_{d_j} = 0.213 \cdot \ln(AD_{d_j}) - 0.028 \cdot \text{dist}_{{od_j}} + 2.03 \cdot DS_{{od_j}} + 7.84 \cdot IAA_{d_j}
\]

- \(AD_{d_j}\) is the number of retail employees in zone \(d_j\);
- \(\text{dist}_{{od_j}}\) is the distance between zone \(o\) and \(d_j\), expressed in km;
- \(DS_{{od_j}}\) is the share of deliveries on \(od_j\) pair respect to all deliveries departing from zone \(o\);
- \(IAA_{d_j}\) is the retailer accessibility of zone \(d_j\).

\(\rho^2 = 0.33\)

Close destinations

tour planner uses to choose for the first location a zone where there are many deliveries to be performed

tour planner uses to choose for the first location a zone that allows better to reach the following destinations

Nuzzolo A, Cirsalli U, Comi A
A demand modelling system for forecasting urban goods movements
Delivery location choice model

✓ Wholesaler and retailer in own account: next delivery locations

\[ V_{d_j^{k+1}} = 0.291 \cdot \ln\left( AD_{d_j^{k+1}} \right) + 8.408 \cdot DS_{od_j^{k+1}} - 0.325 \cdot dist_{d_i^{k}d_j^{k+1}} + \\
-1.655 \cdot \ln\left( HT_{d_j^{k+1}} \right) + 1.064 \cdot ASA_{d_j^{k+1}=d_i^{k}} \]

- \( AD_{d_j} \) is the number of retail employees in zone \( d_j \);  
- \( dist_{didj} \) is the distance between zone \( o \) and \( d_j \), expressed in km;  
- \( DS_{odj} \) is the share of deliveries on \( od_j \) pair respect to all deliveries departing from zone \( o \);  
- \( HT_{dj} \) is the ratio between the distance to be covered to reach the next delivery location and the current covered distance.
Delivery location choice model

✓ Wholesaler and retailer in own account: next delivery locations

\[ V_{d_j^{k+1}} = 0.291 \cdot \ln (AD_{d_j^{k+1}}) + 8.408 \cdot DS_{od_j^{k+1}} - 0.325 \cdot dist_{d_i^k d_j^{k+1}} + 
\]
\[ -1.655 \cdot \ln (HT_{d_j^{k+1}}) + 1.064 \cdot ASA_{d_j^{k+1}=d_i^k} \]

- \( AD_{d_j} \) is the number of retail employees in zone \( d_j \);
- \( dist_{didj} \) is the distance between zone \( o \) and \( d_j \), expressed in km;
- \( DS_{odj} \) is the share of deliveries on \( od_j \) pair respect to all deliveries departing from zone \( o \);
- \( HT_{d_j} \) is the ratio between the distance to be covered to reach the next delivery location and the current covered distance.

Many deliveries to be performed

close destinations are preferred

\( \rho^2 = 0.25 \)
Conclusions and further developments

✓ Further developments

➢ demand sub-system model,

☐ development of probabilistic-behavioral models for simulate the *attraction* and *acquisition* considering other socio-economic variables, e.g. economic level of study area;

☐ development of probabilistic-behavioral models that allow us to consider the *other transport service types*, and to investigate how city logistics policies can influence the delivery target time, the delivery size and the vehicle type choice,
Conclusions and further developments

- restocking tour sub-system model,
  - development of probabilistic-behavioral models in order to investigate how other attributes could influence the definition of trip-chain order or the choice of delivery location;
  - development of delivery choice location models for retailer;
  - modeling of choice set generation within the delivery location choice model.

- DSS (Decision Support System) development
A DEMAND MODELLING SYSTEM
FOR FORECASTING URBAN GOODS MOVEMENTS

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O-D matrices in freight vehicles

1/2

The vehicle O-D matrices are made of elements, \( VC_{didj}[n] \), that represent the average freight vehicle flow on the \( d_i d_j \) pair for tours of \( n \) stops/deliveries

\[
VC_{odj}[n] = VC_{oi}[n] \cdot p\left[\frac{d_j}{no}\right]
\]

\[
...\]

\[
VC_{d_i d_j}^{k+1}[n] = VC_{d_i d_j}^{k-1}[n] \cdot p\left[\frac{d_j^{k+1}}{d_i^k no}\right]
\]

\[
n = \{1,2,...\}; \ k = \{0,1,2,...\}; \ i,j = \{1,2,...,z\}; z = \text{number of traffic zones}
\]
O-D matrices in freight vehicles

Subject to

\[ VC_{o} [n] = \sum_{d} ND_{od} [n] / n \]

\[ VC_{dj} [n] = ND_{odj} [n] \]

\[ ND_{od} [n] = \text{number of deliveries performed in zone } d \text{ by tours with } n \text{ deliveries departing from zone } o \]