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1st Annual Training Seminar on SmaLog issues

Urban Goods Flow Modelling 1

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Reading materials

✓ Papers:

➢ **International Journal of Urban Sciences**

Agostino Nuzzolo, Antonio Comi & Luca Rosati: **City logistics long-term planning: simulation of shopping mobility and goods restocking and related support systems.** Published online: 25 Jul 2014

➢ ELSEVIER

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

TRANSPORTATION RESEARCH

Urban freight demand forecasting: A mixed quantity/delivery/vehicle-based model

CrossMark

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Lecturer references

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Contents

Urban Goods Flow Modelling
1 - Introduction

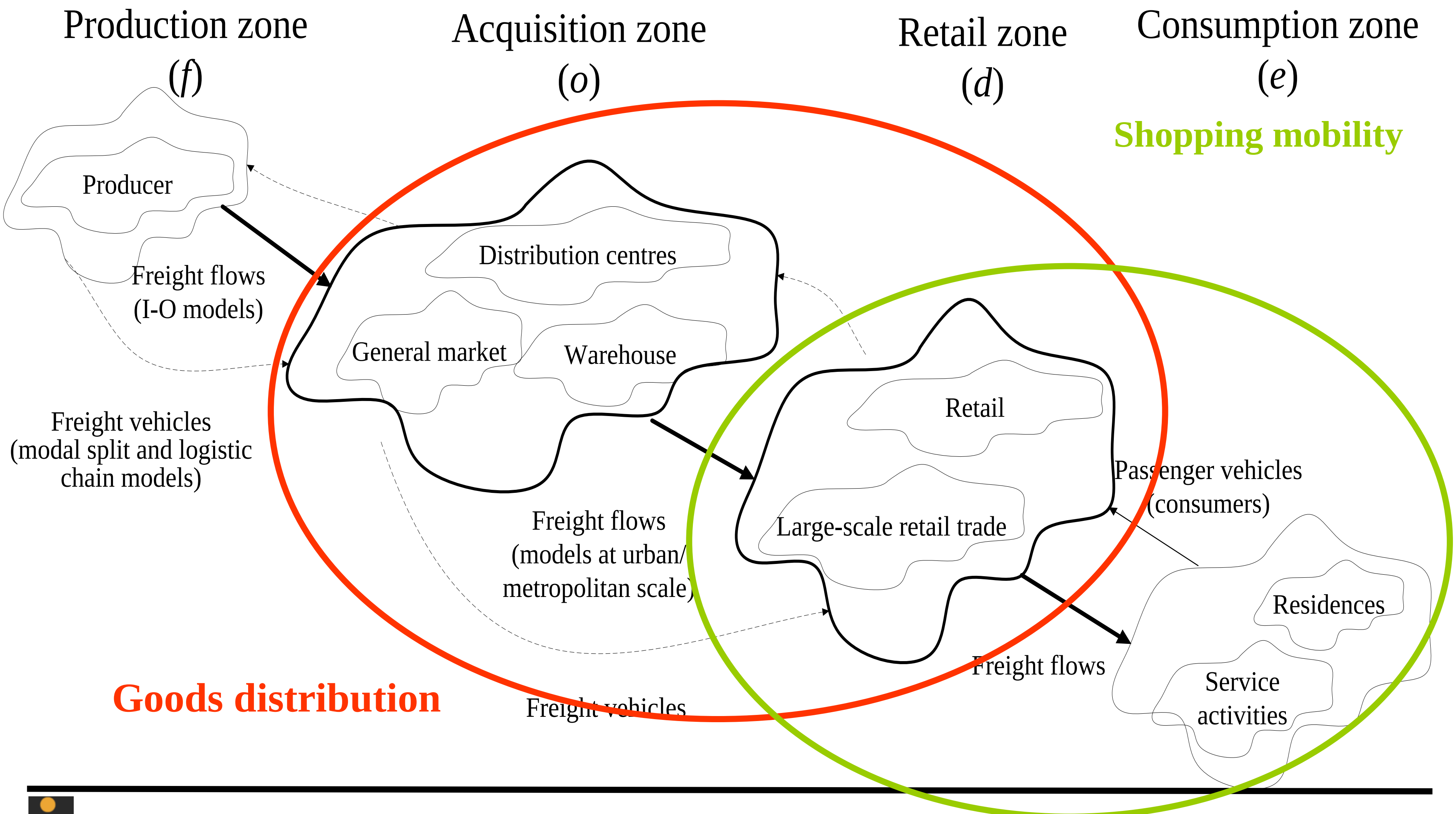
Agostino Nuzzolo - Antonio Comi

Contents

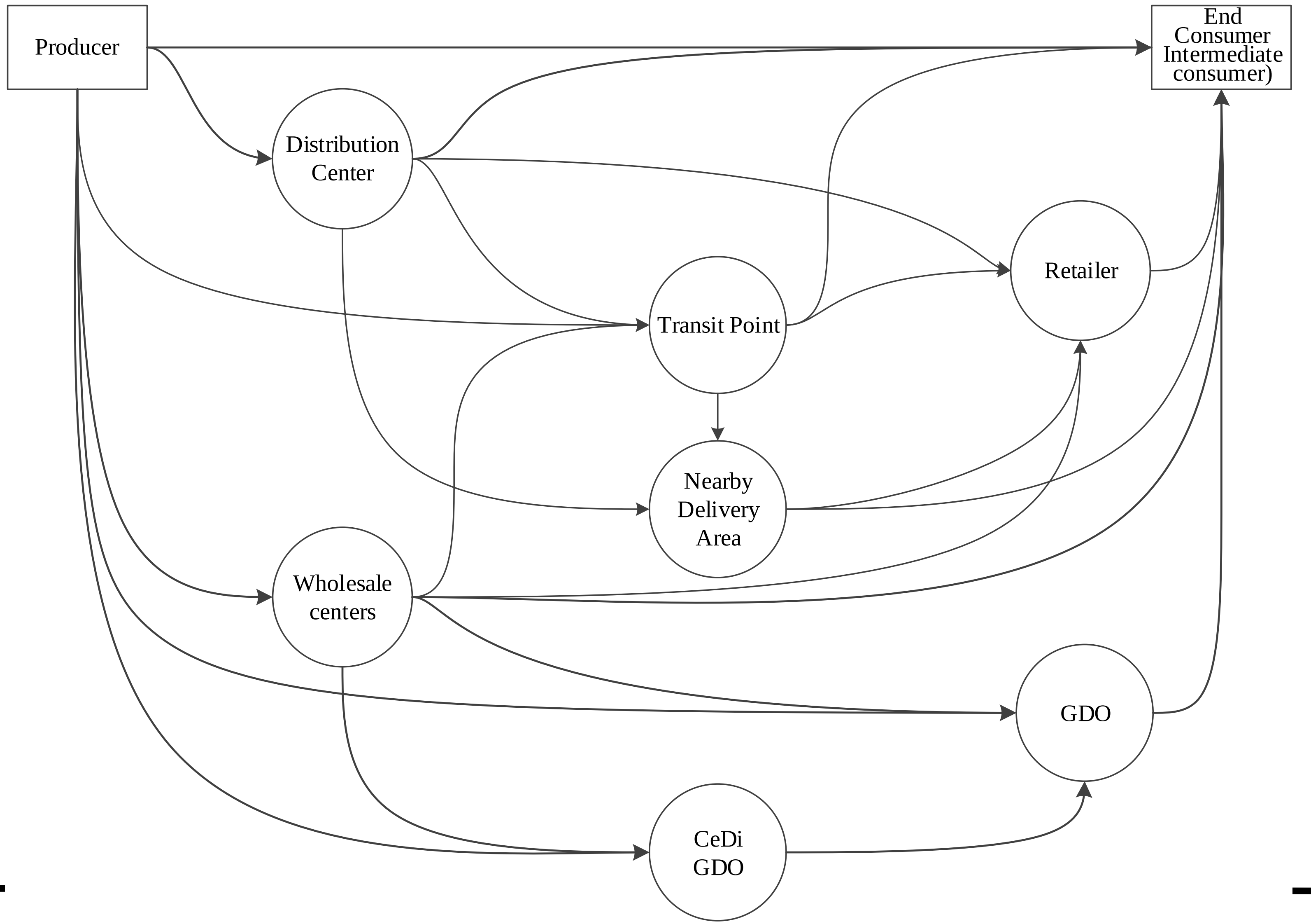
- ✓ Urban goods logistics and transport
- ✓ Actors of urban supply chain
- ✓ Urban goods mobility, internal end external costs
- ✓ Sistems of urban freight demand models

Urban goods logistics and transport

Urban supply chain - USC



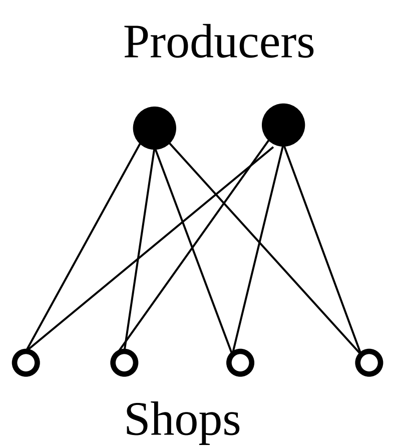
Distribution networks



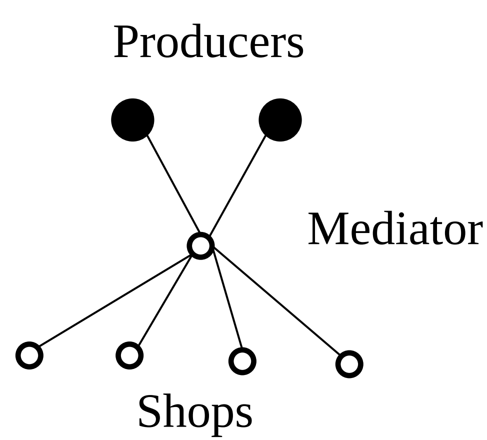
Urban distribution nodes

✓ Activities:

- Connect national distribution with regional and urban
- De-consolidation/ consolidation
- Storage and warehousing
- Urban distribution
- Additional logistic services
- Sale and public exercise



Number of transaction = 2 x 4 = 8



Number of transaction = 2 x0,5+ 4x0,5 = 3

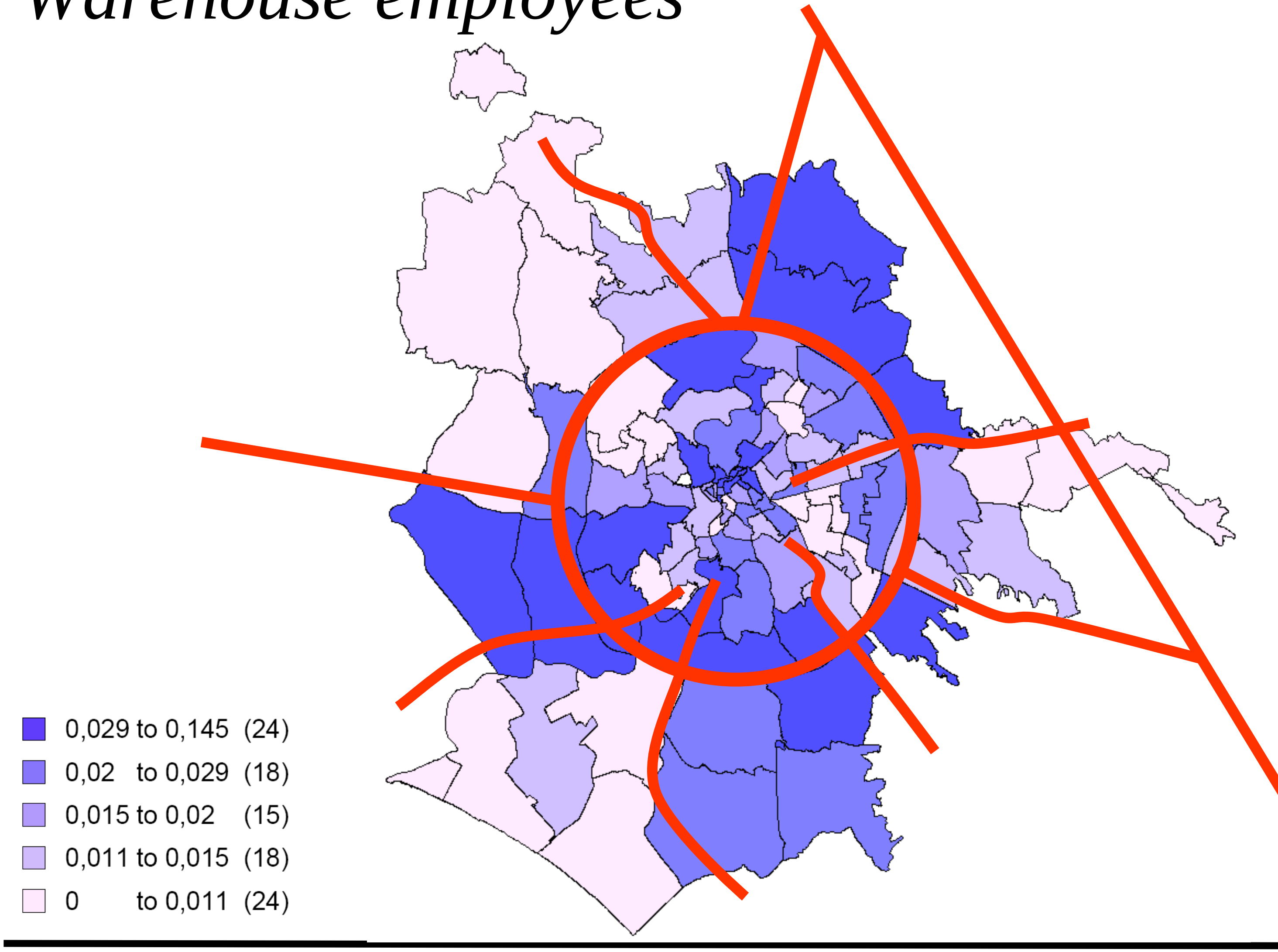
Fonte: Maggi, 2007

Urban distribution nodes

- ✓ Classification and functions:
  - ✓ 1° level nodes:
    - Distribution Center (DC): reception, storage, distribution
    - Wholesales Centres (including fruit markets, flowers, fish, ...): reception, storage, sale
    - Whareouses: storage

Municipality of Rome

Warehouse employees



Urban distribution nodes

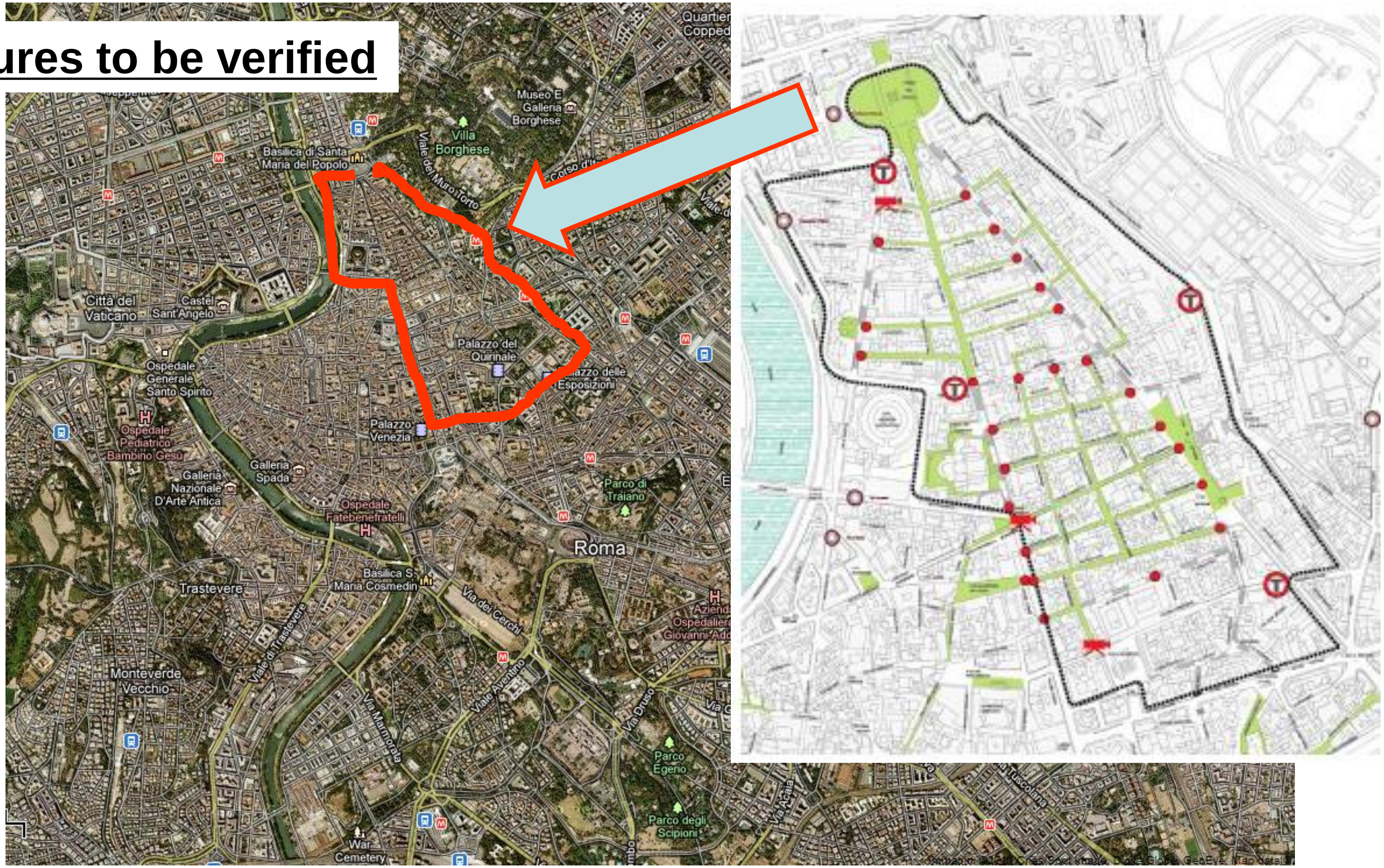
- ✓ Classification and functions:
  - ✓ 2° level nodes:
    - Distribution centers (DI.CE): reception, storage, distribution for GDO, franchising, ….
    - Local warehouses: storage
    - Transit Points: de-consolidation and consolidation
    - Nearby Delivery Area: local vehicle transhipment

City logistics policies in Rome

2/3

Regulation after 2011: Nearby Delivery Area

<u>Measures to be verified</u>

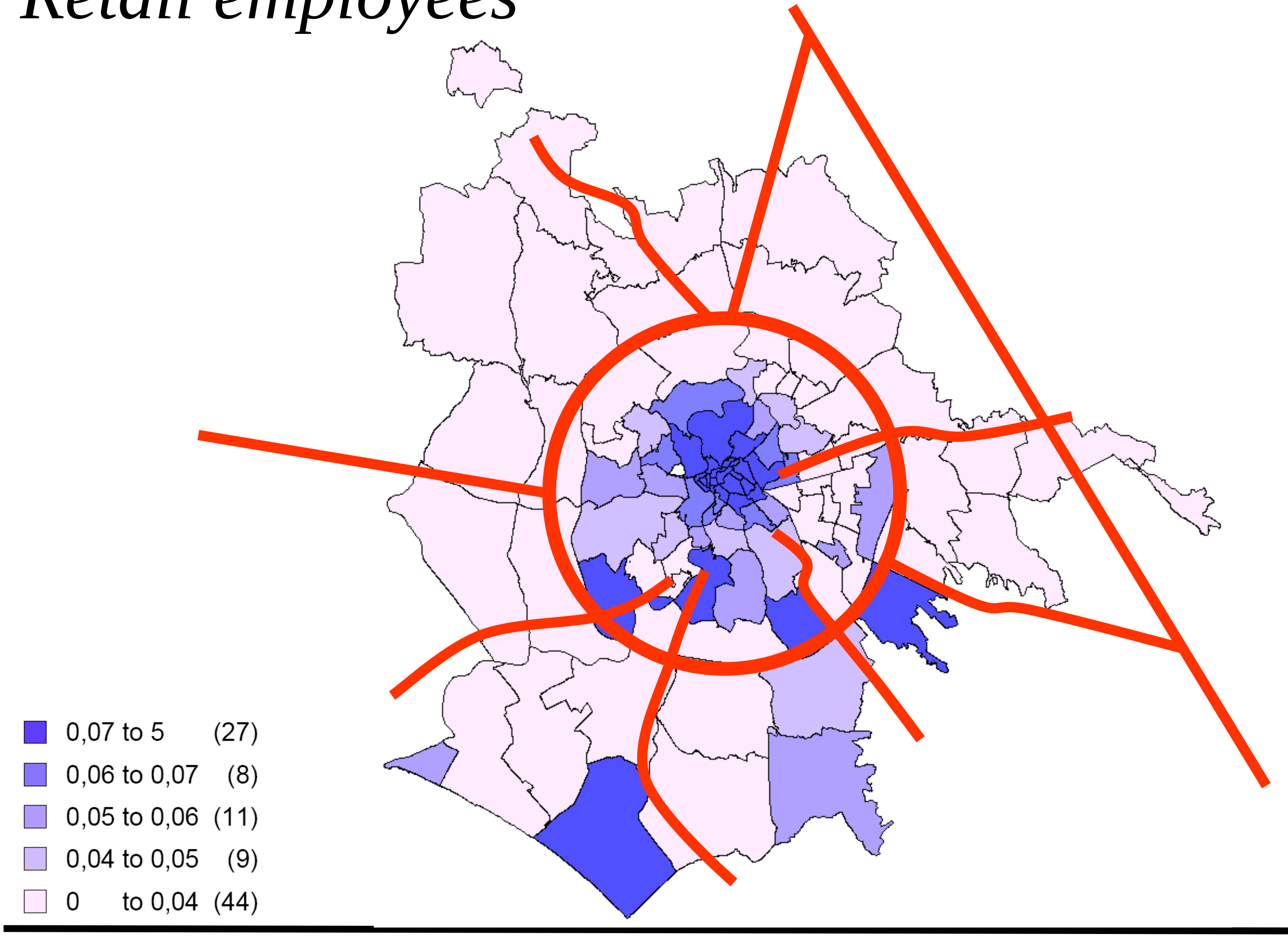


Urban distribution nodes

- ✓ 3° level nodes
  - Sale spaces and public exercises:
    - Retail
      - Neighborhood
      - Local market
      - Neighborhood natural mall
      - Large area natural mall (es. via Condotti)
      - Suburban/extraurban mall (es. Romanina, Valmontone)
    - Franchising (small, medium, big)
    - Organized Large Distribution
      - Supermarket
      - Hipermarket
    - Public exercises/Ho.re.ca (hotel, restaurant, catering)

Municipality of Rome

Retail employees



Operators of Urban Supply Chain

- ✓ Activities of supply chain (auto-production and/or outsourcing):
  - ➢ Planning of distribution network (number, localization, depot dimension, transit point)
  - ➢ Planning and management of storage
  - ➢ Depot pick-up (picking), transport and delivering

2) The USC main objective is to coordinate USC activities and the relative actors in a way that meets customer requirements (**effectivness)** at minimum cost **(efficiency)**

Actors (agents) of USC

- *Wholesaler/Distributor*

  they buy large quantities of products from manufacturers and, then, sell them to retailers

- *Logistic and transport operators*

  They provide integrated logistics services, storage services, manage logistic infrastructures

- *Carriers and couriers*

  They provide transport services

Other actors of Urban Goods Mobility

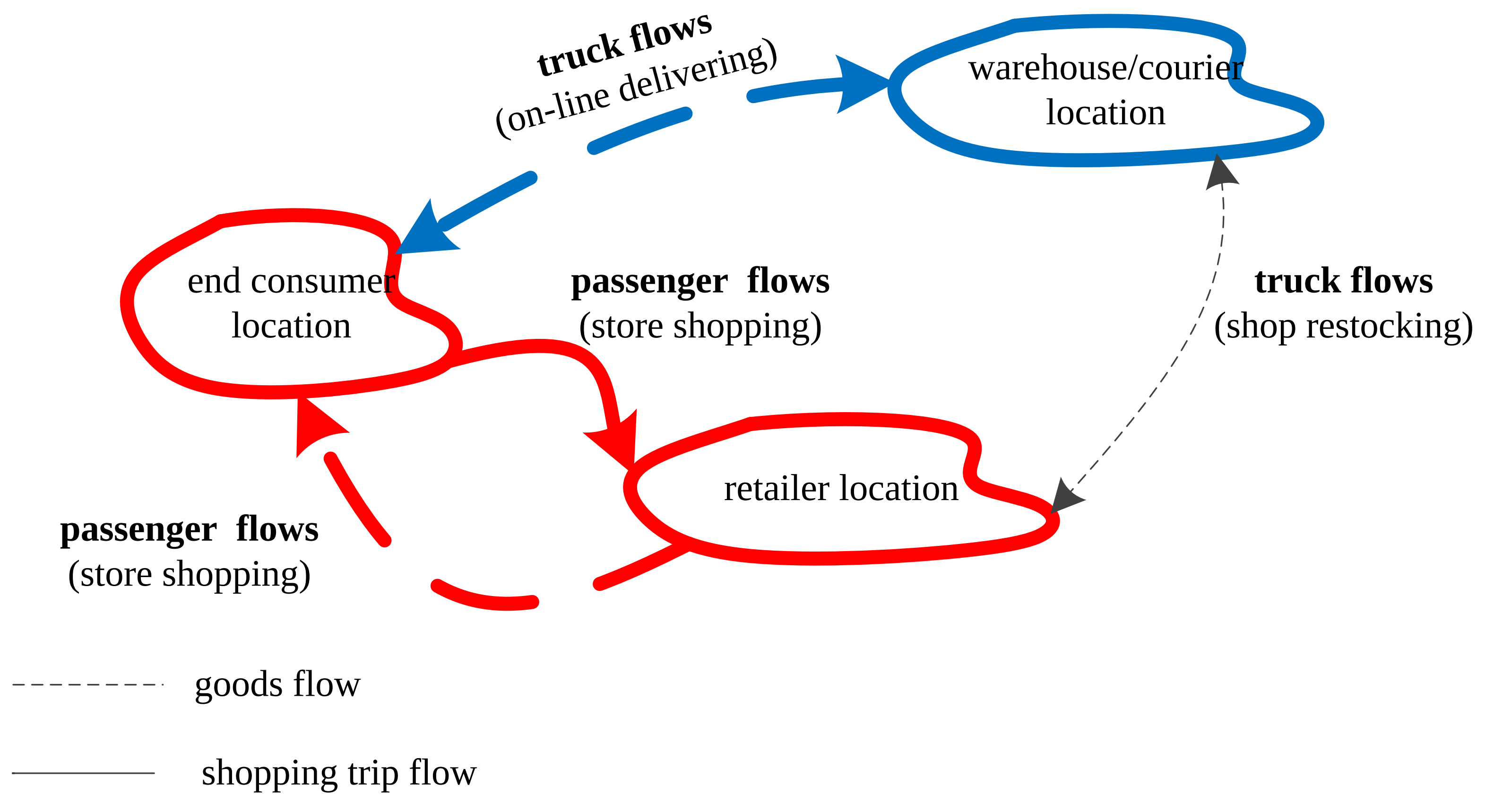
- ***End-consumers*** *(*Inhabitants, City users, Service activities)

  They buy goods through **shopping trips** or **e-shopping** or **other goods consumption activities** (hotels, restaurants, …)

- ***Retailers***

  they sell to end-consumers and have to be restocked

Urban goods-related mobility-UGM



Urban goods mobility - UGM

- ✓ *shopping mobility* refers to the trips undertaken by consumers (residents, tourists, city users) to shop;

- ✓ *shop restocking mobility* refers to the trips undertaken by commercial vehicles to restock the outlet activities (i.e. retailers) where consumers go to buy the products they need;

- ✓ *e-purchase delivering mobility* refers to the trips undertaken by commercial vehicles for the delivery of on-line purchases.

Urban goods flows modelling

Modelling approaches:

Agent-based simulation

Aggregate goods flow models

Agent- based simulation

- Reproduces the interactions among the actors (and stakeholders) of urban logistics and transport

Aggregate goods flow models

- Allow to obtain the **Origin-Destination Matrices of goods quantities** among the traffic zones of the study area.

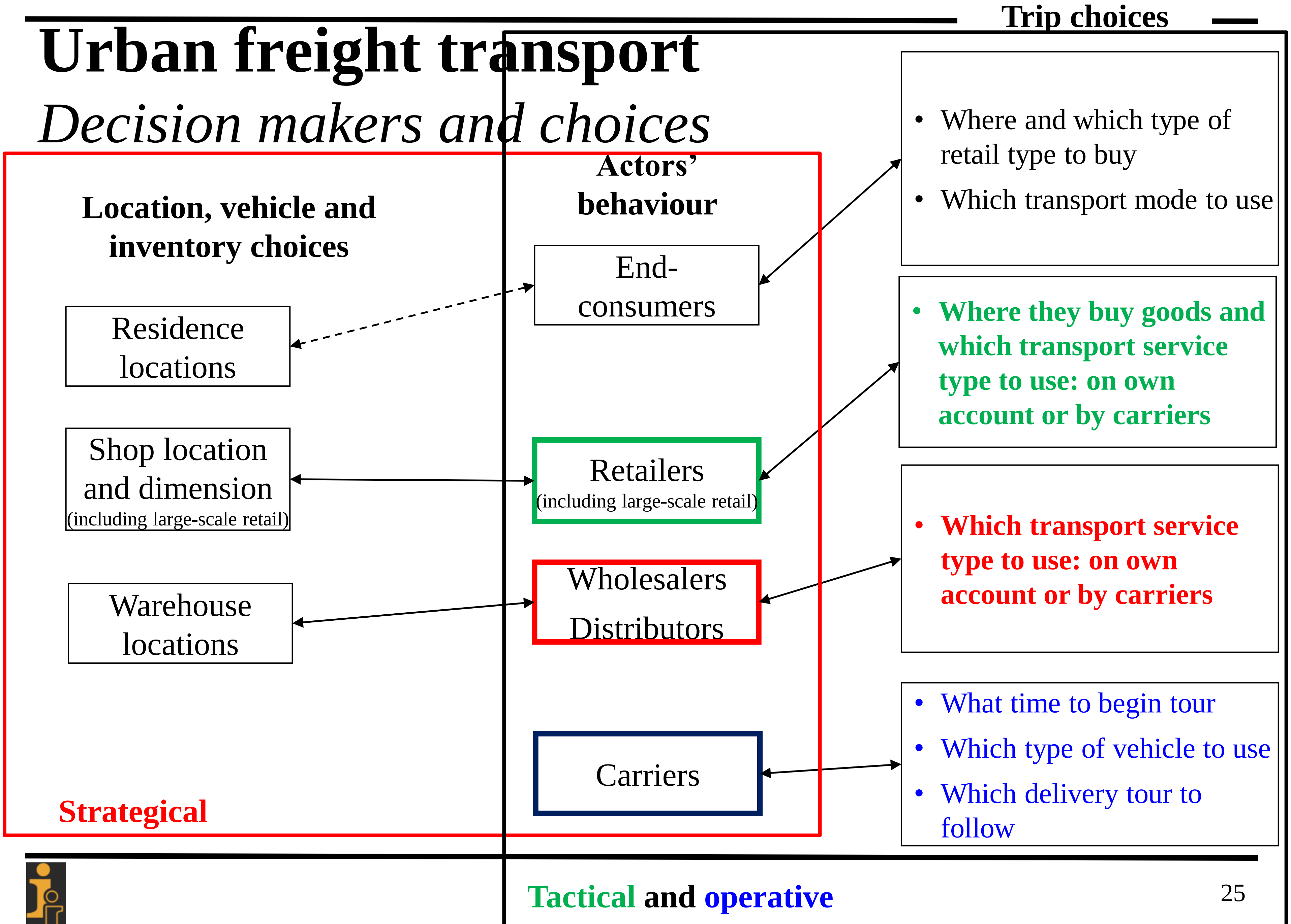
- These matrices of goods quantities are then trasformed in **matrices of freight vehicle flows**, which are **assigned** to the road network to obtain the **freight vehicle flows** of the **network links**

Setting up an urban freight model system

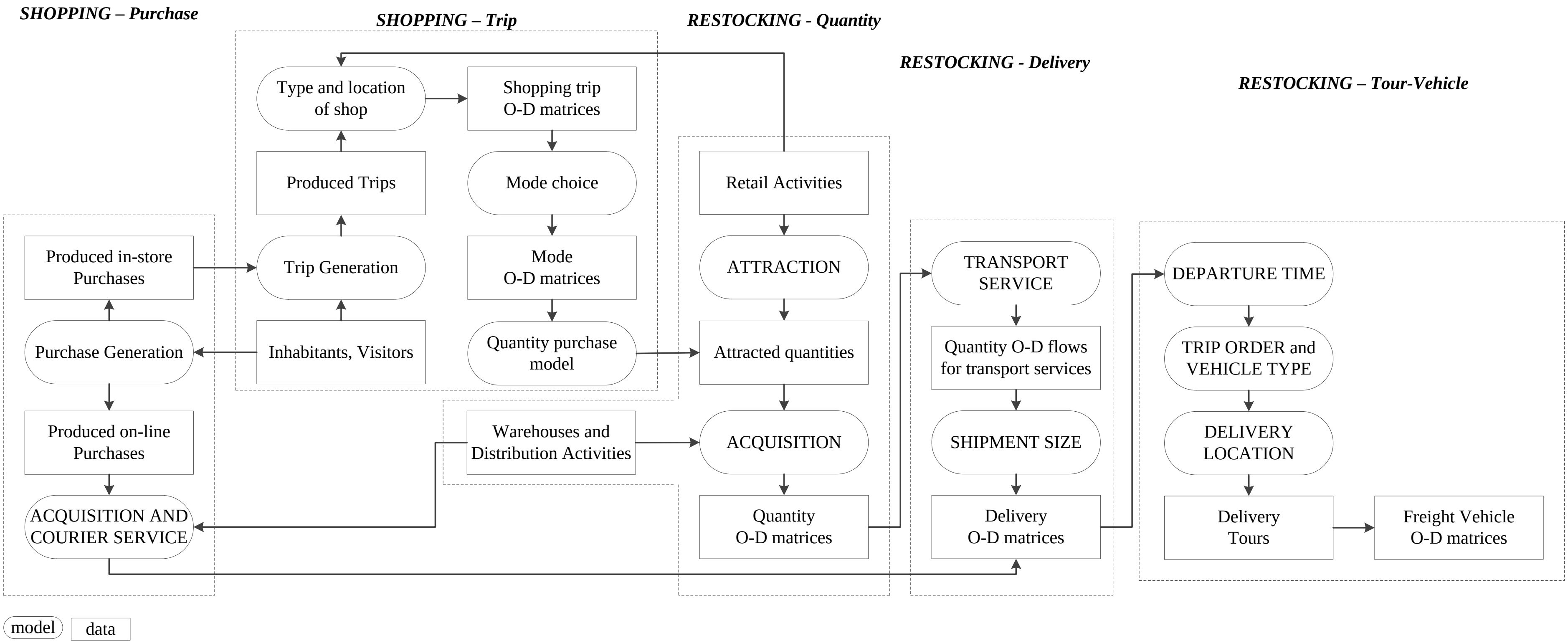
- ✓ In order to set up a suitable model system we have to analyze
  - ➢ the structures of urban freight distribution for freight type (done)
  - ➢ the decision-makers involved in the process (done)
  - ➢ the choice dimensions of each decision-maker: in the following

Urban freight transport

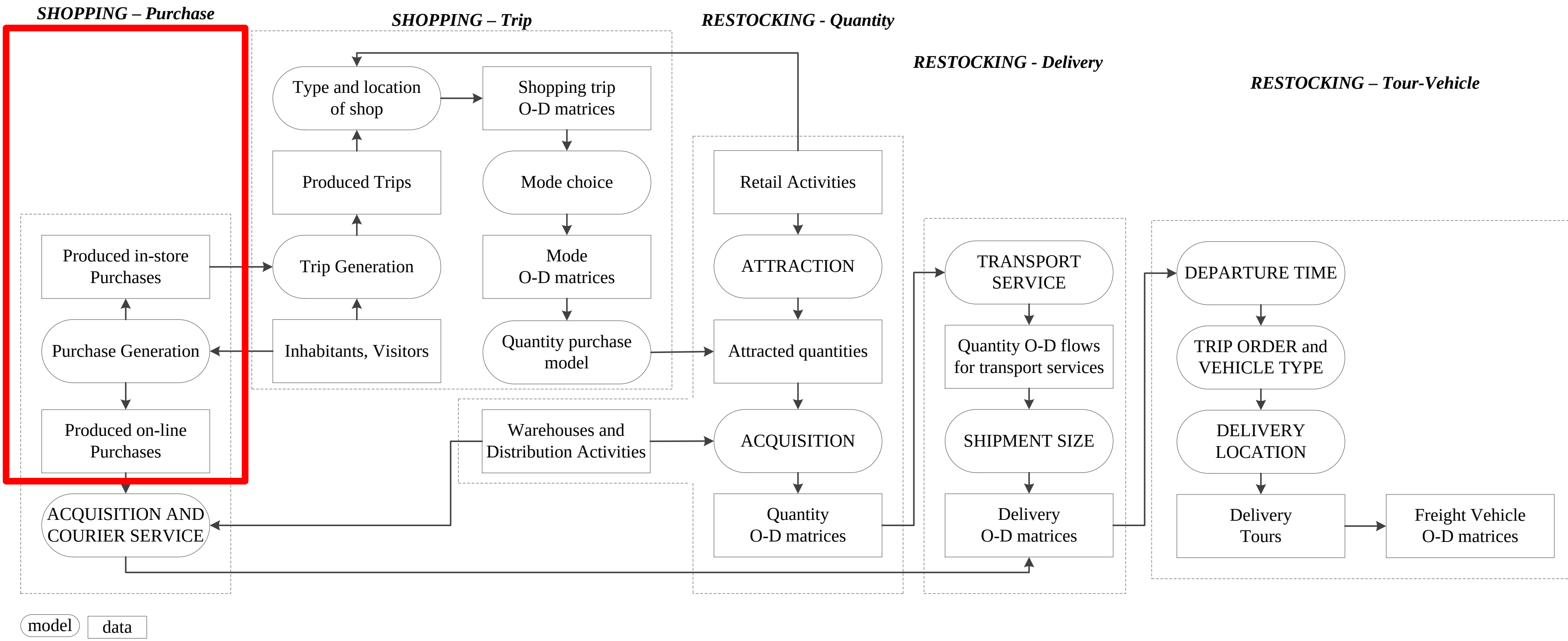
Decision makers and choices



Aggregate demand model framework

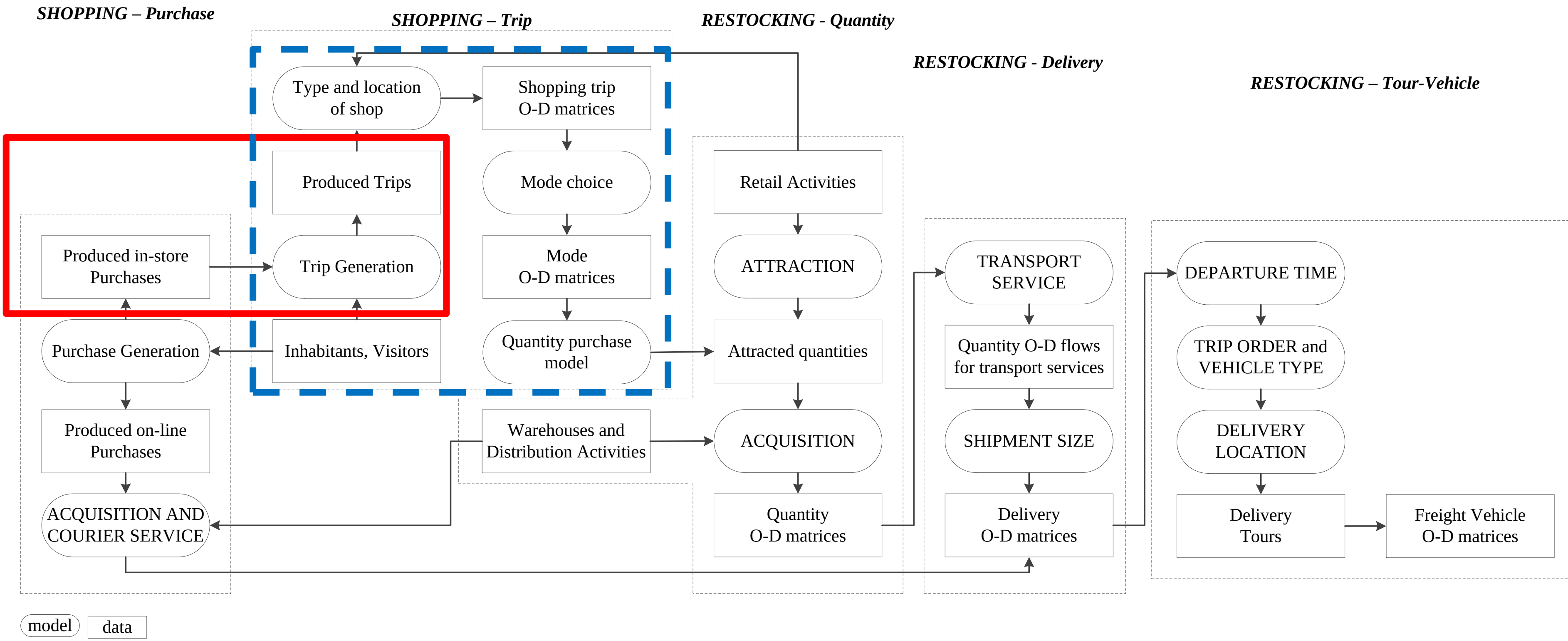


Urban freight modelling framework:
Shopping: purchase modelling

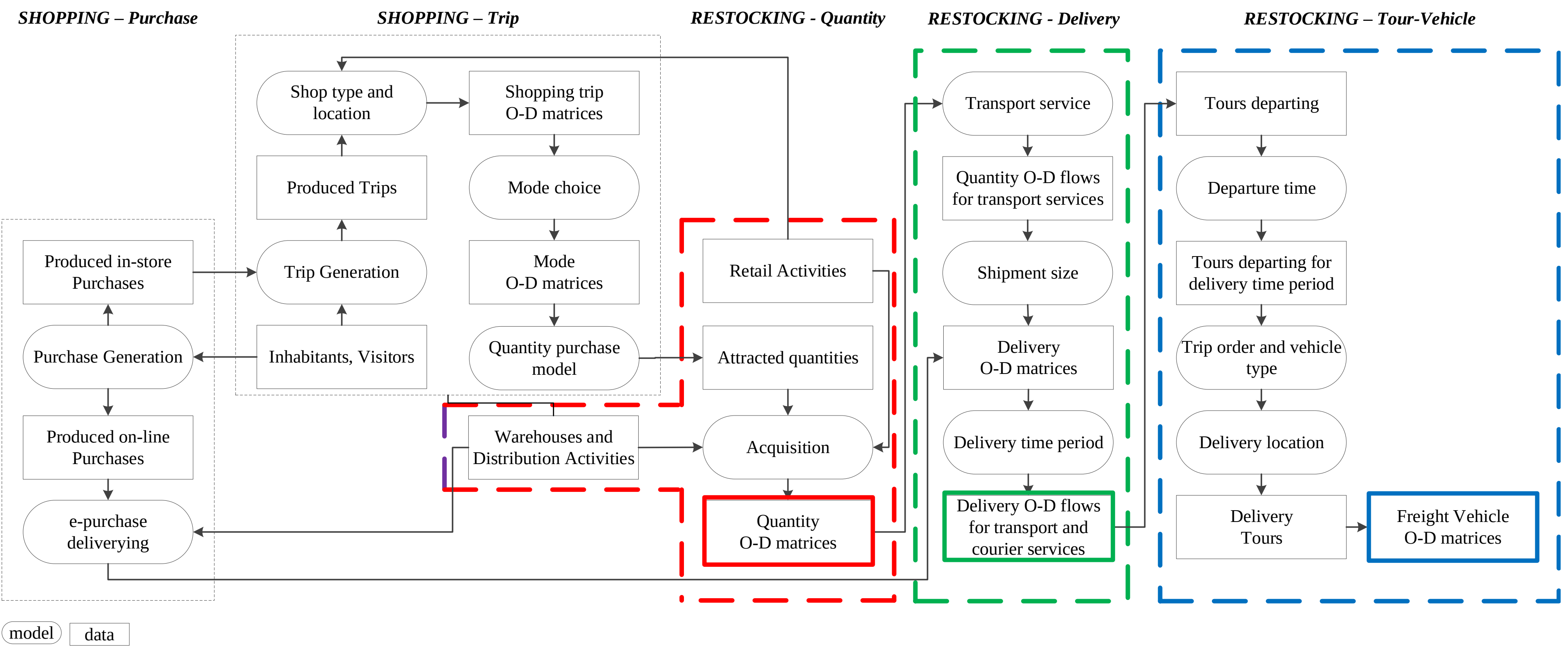


Urban freight modelling framework

Shopping trip models



Restocking models ⇒ O-D Matrices



Quantity

allows to capture the mechanisms underlying the freight demand generation

Delivery

allows to follow the decisional and logistic process of restocking

Vehicle

Input for assignment and performance models

Urban freight transport modelling:

Quantity and delivery O/D matrices

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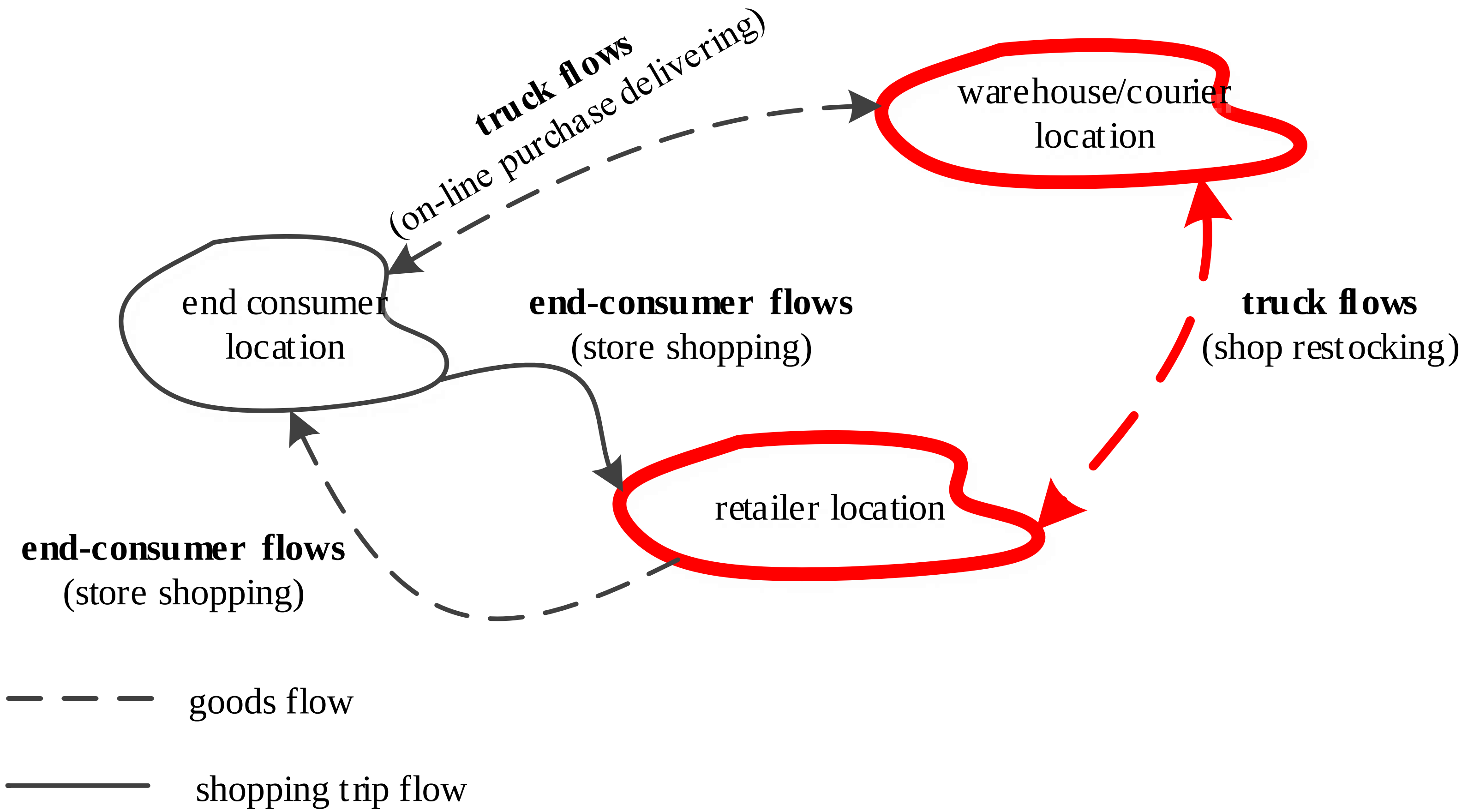
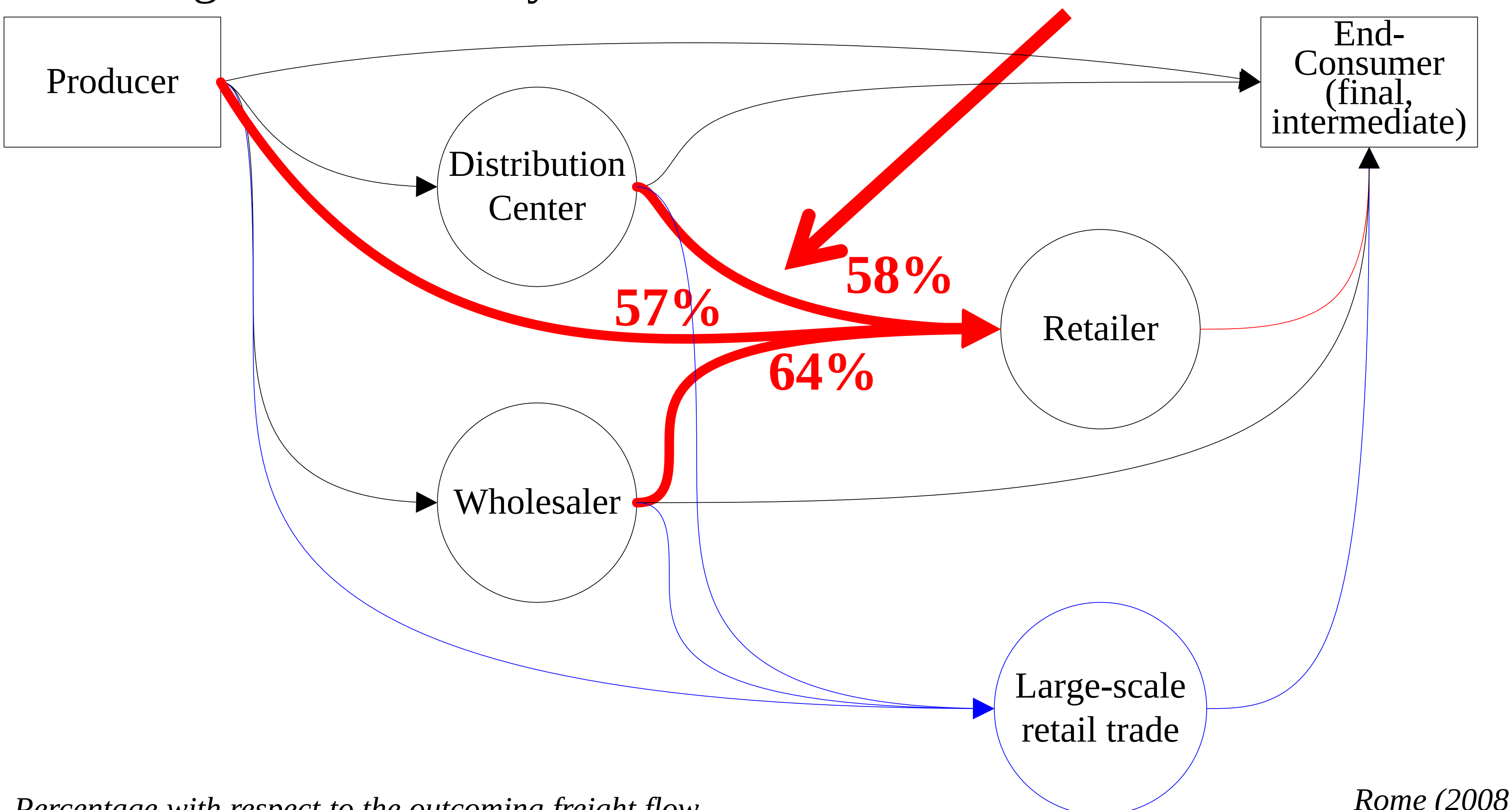
Urban freight trips considered



Distribution process (distributive logistics)

Esemplificative hypothesis

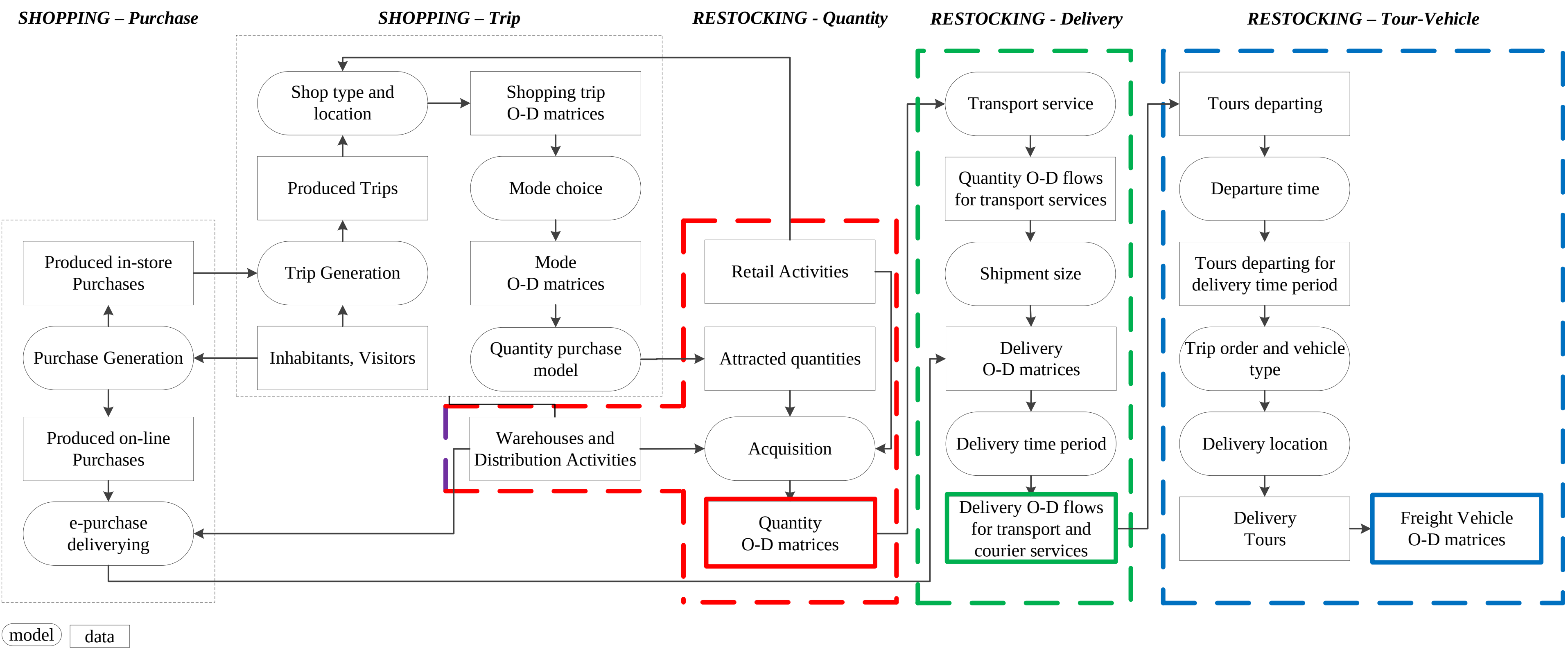
Restocking of retail activity



Percentage with respect to the outcoming freight flow

Rome (2008)

Demand model ⇒ O-D Matrices



Quantity

allows to capture the mechanisms underlying the freight demand generation

Delivery

allows to follow the decisional and logistic process of restocking

Vehicle

Input for assignment and performance models

Demand model ⇒ O-D Matrices

Structure

Quantity (tons/kgs) **O-D matrices**

↓

Delivery (number) **O-D matrices**

↓

Vehicle (number) **O-D matrices**

Demand model $\Rightarrow$ Quantity O-D Matrices

Quantity (tons/kgs) **O-D matrices**

Quantity *O-D* Matrices

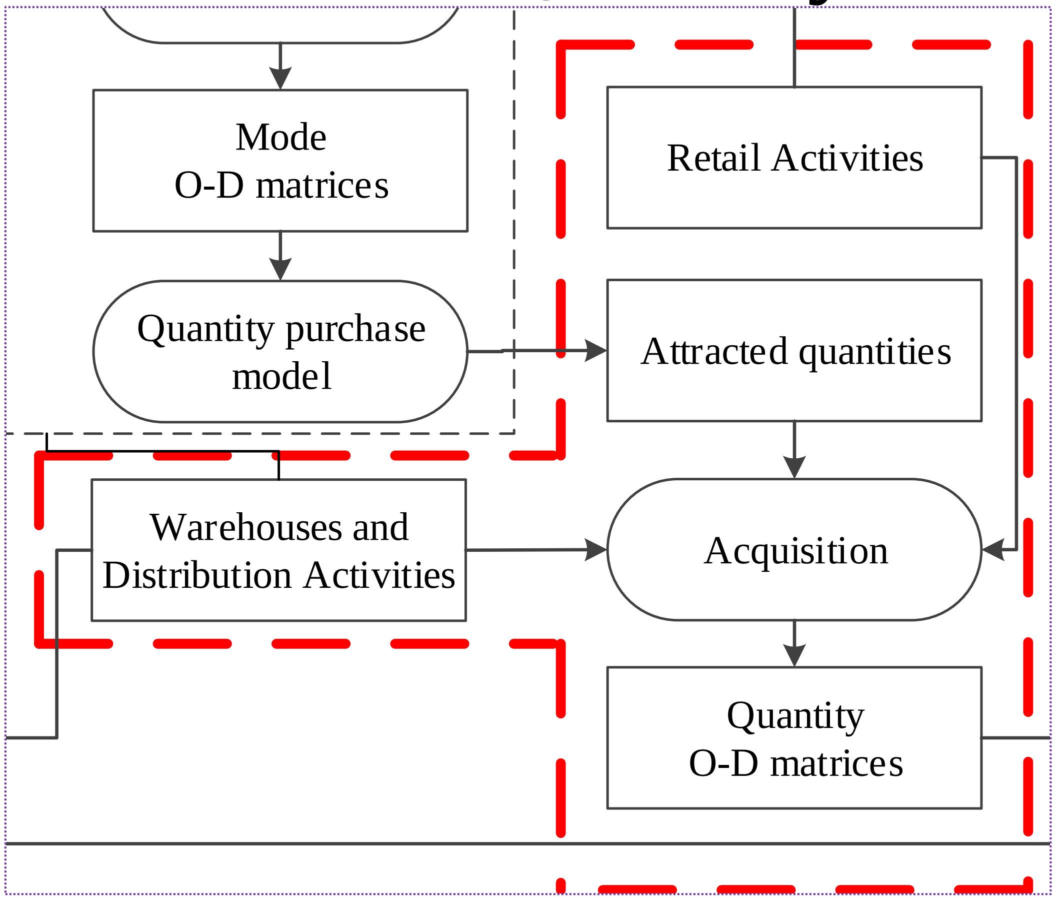
They give the average quantity flow

$$Q_{od}^{sh}$$

of type *s* freight, between a zone *o* and a zone *d* in a time period *h*.
Type of freight strongly influence supply chains, in particular:

- Perishability
  - Fresh food
  - Dry food, beverages
- Cold chain
- Value Freight
- High volume and/or weight

Demand model ⇒ Quantity O-D Matrices



Quantity
allows to capture the mechanisms underlying the freight demand generation

Delivery
allows to follow the decisional and logistic process of restocking

Vehicle
Input for assignment and performance models

Quantity O-D matrices

$$Q_{od} = Q_{.d} \cdot p\left[o/d\right]$$

- ✓ Q_{od} is the average quantity flow of freight attracted by zone *d* and coming from zone *o*;
- ✓ $Q_{.d}$ is the average quantity of freight attracted by zone *d* obtained by an **attraction model**;
- ✓ $p\left[o/d\right]$ is the share or the probability that freight attracted by zone *d* comes from zone *o* (e.g. production place/firm, distribution centre, warehouse, etc.); it represents the acquisition share (probability) obtained by an **acquisition model**.

Attraction model

Example of Category regression model (Rome)

$$Q_{.d} = \beta_{AD} \cdot AD_d + \beta_{ASA} \cdot ASA_d \quad [\text{t/day}]$$

- ✓ $Q_{.d}$ is the average quantity of freight attracted by zone 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 0.35 (35%).

	Foodstuffs	*Home accessories*
β_{AD}	0.06	1.6
(t-student)	*(1.89)*	*(2.52)*
β_{ASA}	599.7	240.7
(t-student)	*(5.96)*	*(2.53)*
R^2	**0.91**	**0.79**

Rome (2008)

Acquisition model

$$p[o/d]$$

p[o/d] is the probability that freight attracted by zone *d* comes from zone *o* (production place, distribution center, warehouse); it can be expressed by a logit model:

$$p\,[o/d] = \frac{\exp(\alpha V_o)}{\sum_{o'} \exp(\alpha V_{o'})}$$

$$V_o = \Sigma_j\, \beta_j A_{jo} + \Sigma_t\, \beta_t C_{od}$$
$$\beta_j > 0 \quad \beta_t < 0$$

A_{jo} is the j-th "*emission*" attribute of zone o
(e.g. wholesale employees of freight type *foodstuffs*)

$C_{t,od}$ is the t-th "*cost*" attribute for transporting freight from zone o to zone d
(e.g. generalized cost of transport to go from zone o to zone d)

Acquisition model

Example

$$p[o/d] = \left(AI_o\right)^{\beta_1} \cdot C_{od}^{\beta_2} \Big/ \sum_{o'} \left(AI_{o'}\right)^{\beta_1} \cdot C_{o'd}^{\beta_2}$$

- ✓ AI_o is number of warehouse employees of zone *o*;
- ✓ C_{od} is the length of travel trip between *o* and *d*.

	Foodstuffs	*Home accessories*
	2.1	0.13
(t-student)	*(1.94)*	*(2.63)*
	-0.05	-0.08
(t-student)	*(1.85)*	*(2.80)*
$\boldsymbol{\rho^2}$	**0.45**	**0.52**

Rome (2008)

Demand model ⇒ Delivery O-D Matrices

Quantity *O-D* matrices

Delivery *O-D* matrices
per transport service type

Delivery *O-D* Matrices

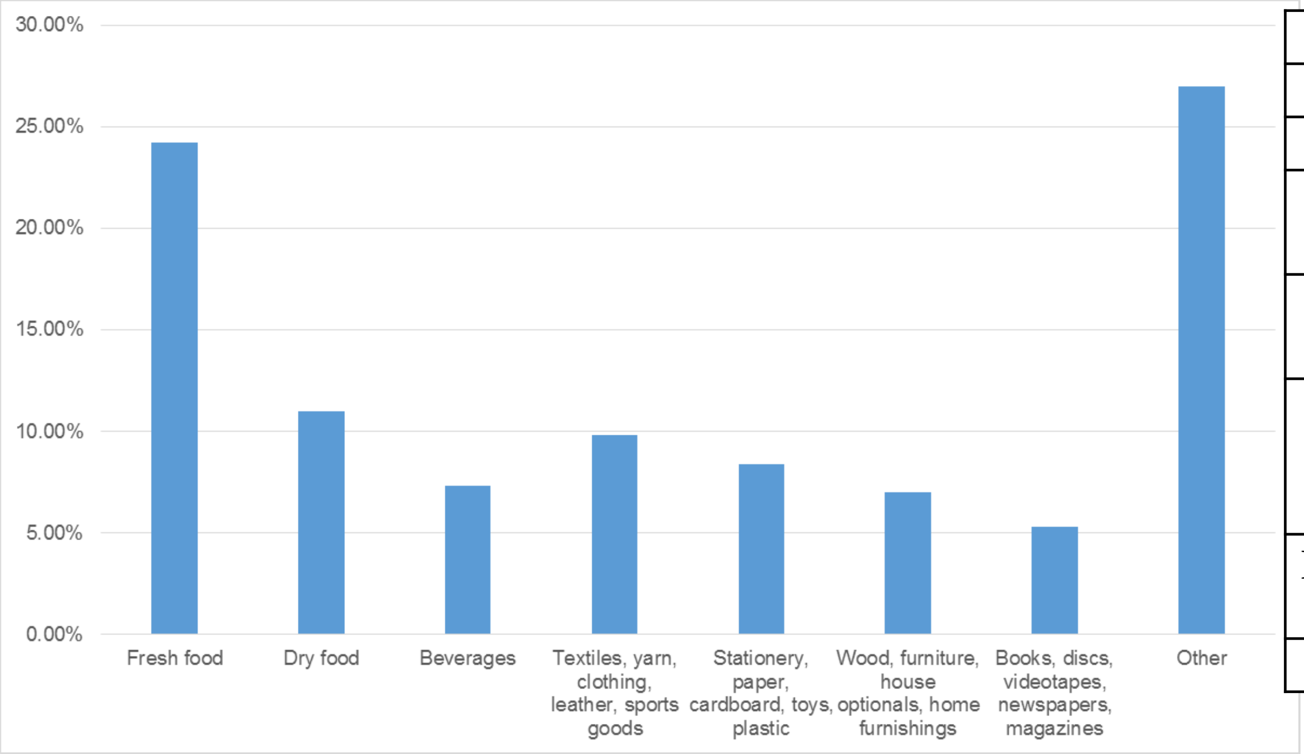
They give the average delivery flow, *ND*, of freight type *s* between the zone *o* and the zone *d* in a time period *h* characterised by:

- ✓ transport service type (*r*)
  - ➢ Receiver account (e.g. retailer)
    - Own account
    - Third party: carrier or courier
  - ➢ Sender account (e.g. wholesaler)
    - Own account
    - Third party: carrier or courier
  - ➢ Delivery time period

For simplicity of notation, the class index *s* (freight type) and *h* (time period) will be taken as understood unless otherwise stated $\Rightarrow$

$$ND_{od}\left[r\right]$$

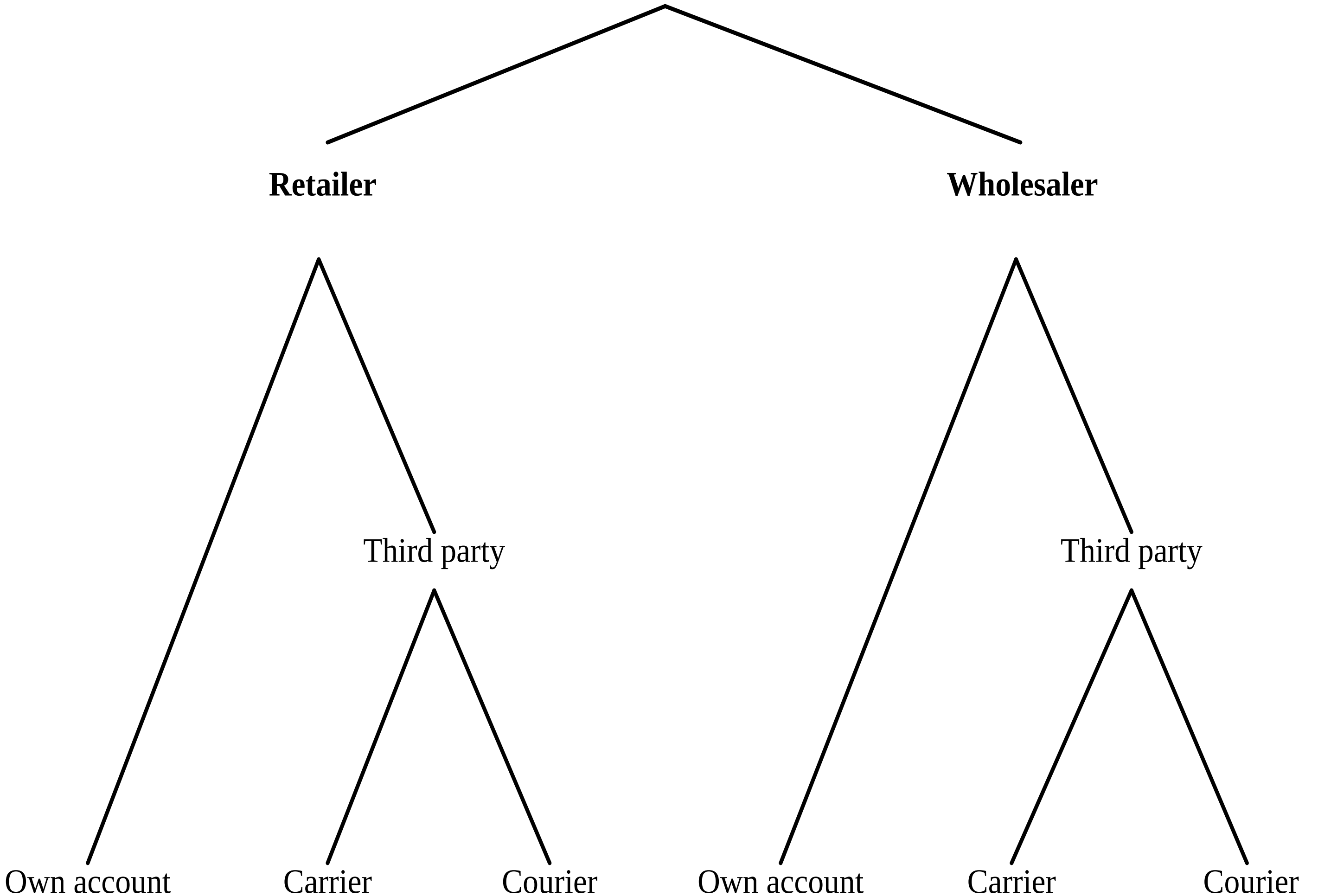
Deliveries - FLTZ Rome



Fresh food	24.2%
Dry food	11.0%
Beverages	7.3%
Textiles, yarn, clothing, leather, sports goods	9.8%
Stationery, paper, cardboard, toys, plastic	8.4%
Wood, furniture, house optional, home furnishings	7.0%
Books, discs, videotapes, newspapers, magazines	5.3%
Other	27.0%

Distribution process

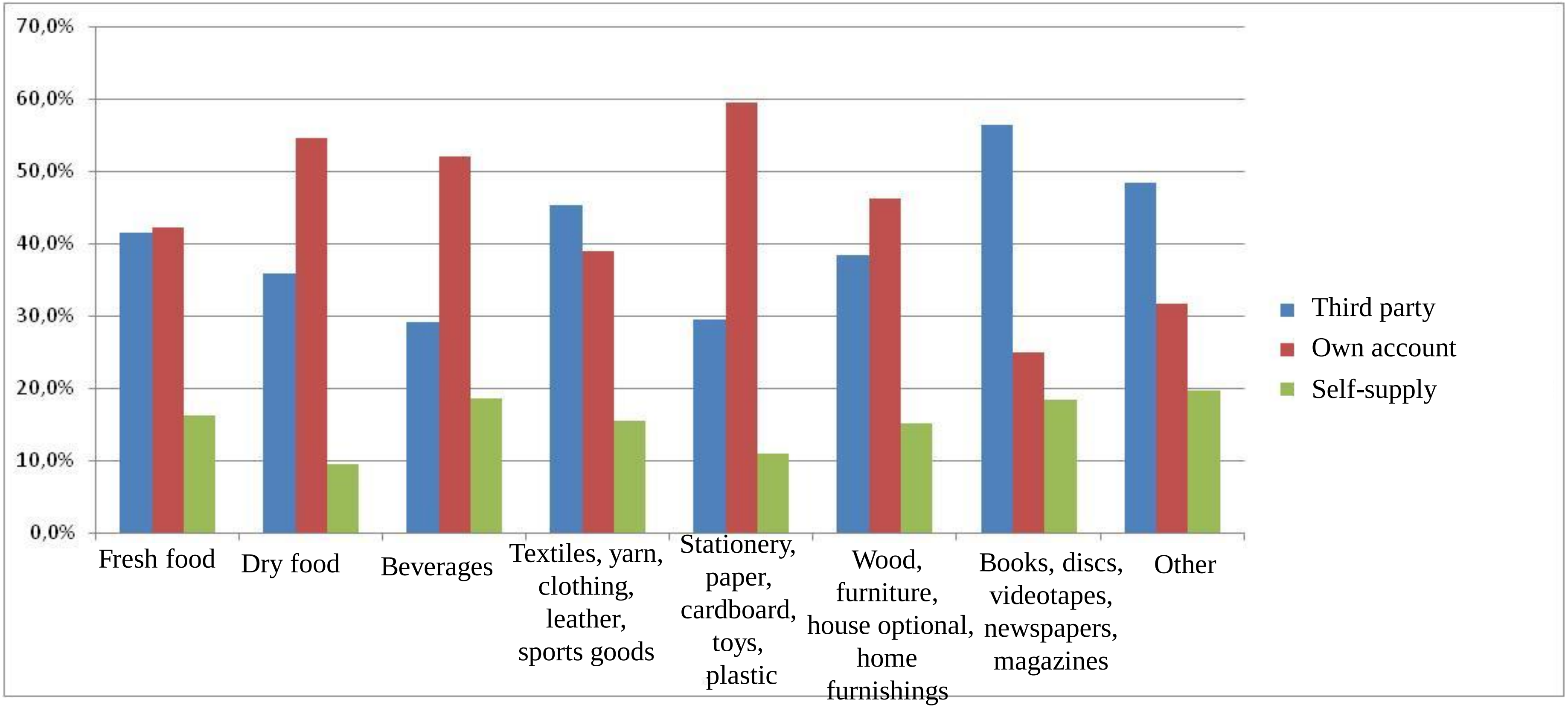
Transport services



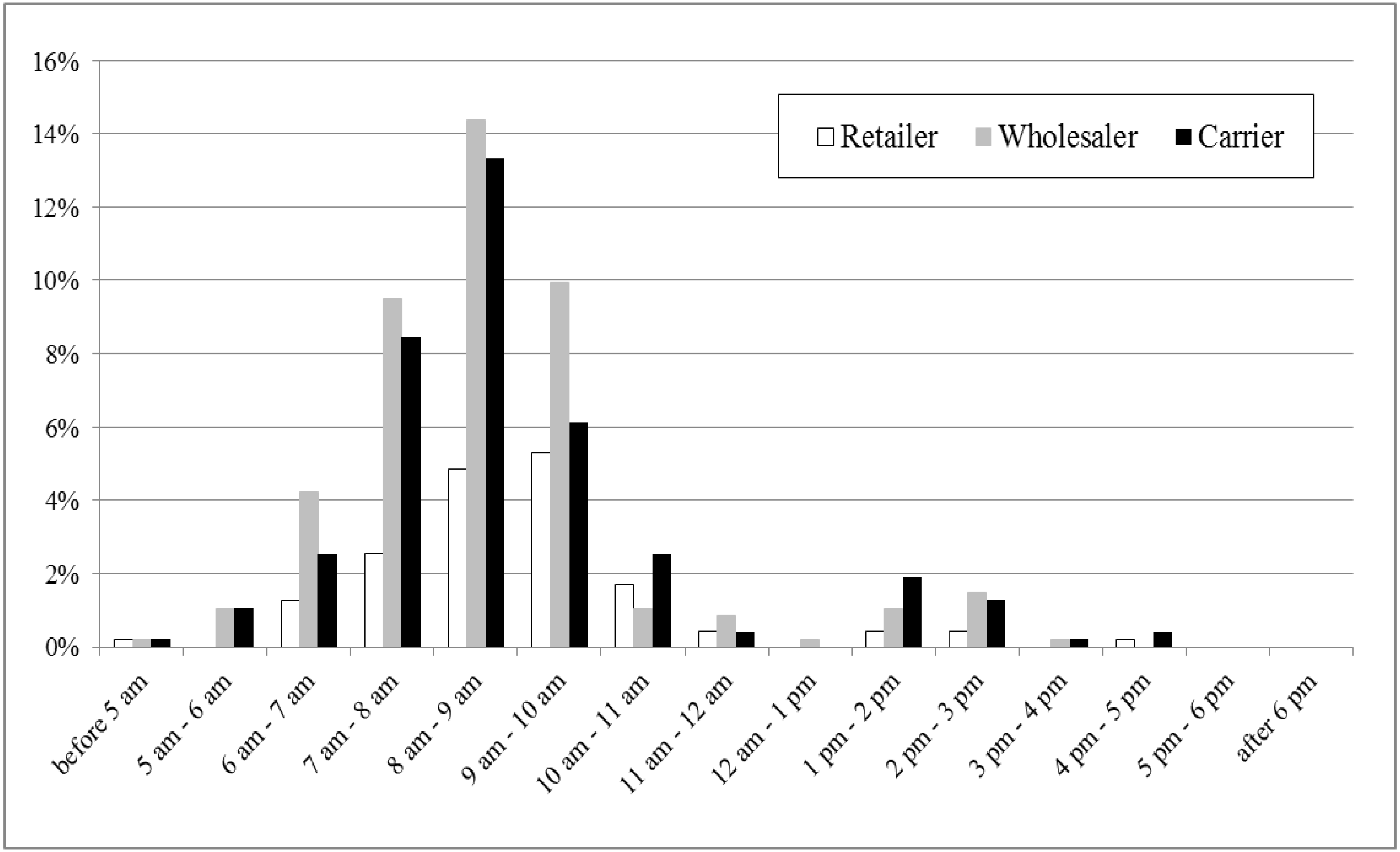
Deliveries split in Own Account and Third Party

SENDER – RECIPIENT	Bar, restaurant, hotel			Retail			End Consumer (Residents, Service company)			Average		
	CT	CP m	AUTO	CT	CP m	AUTO	CT	CP m	AUTO	CT	CP m	AUTO
Wholesaler	**41.5%**	32.9%	25.6%	31.9%	**54.6%**	13.5%	32.7%	**50.4%**	16.9%	**32.7%**	**47.7%**	**19.6%**
Warehouse. depot	24.6%	51.7%	23.7%	**61.3%**	38.7%	0%	35.5%	**55.8%**	8.8%	**43.3%**	**45%**	**11.7%**
Productive unit	**62.7%**	23.5%	13.8%	**60.9%**	30.3%	8.8%	36.3%	**44.6%**	19.1%	**50.7%**	**36.1%**	**13.2%**
Average	**43.3%**	**37.4%**	**19.3%**	**52.2%**	**41.1%**	**6.7%**	**37.8%**	**42.3%**	**19.9%**	**41.8%**	**42%**	**16.2%**

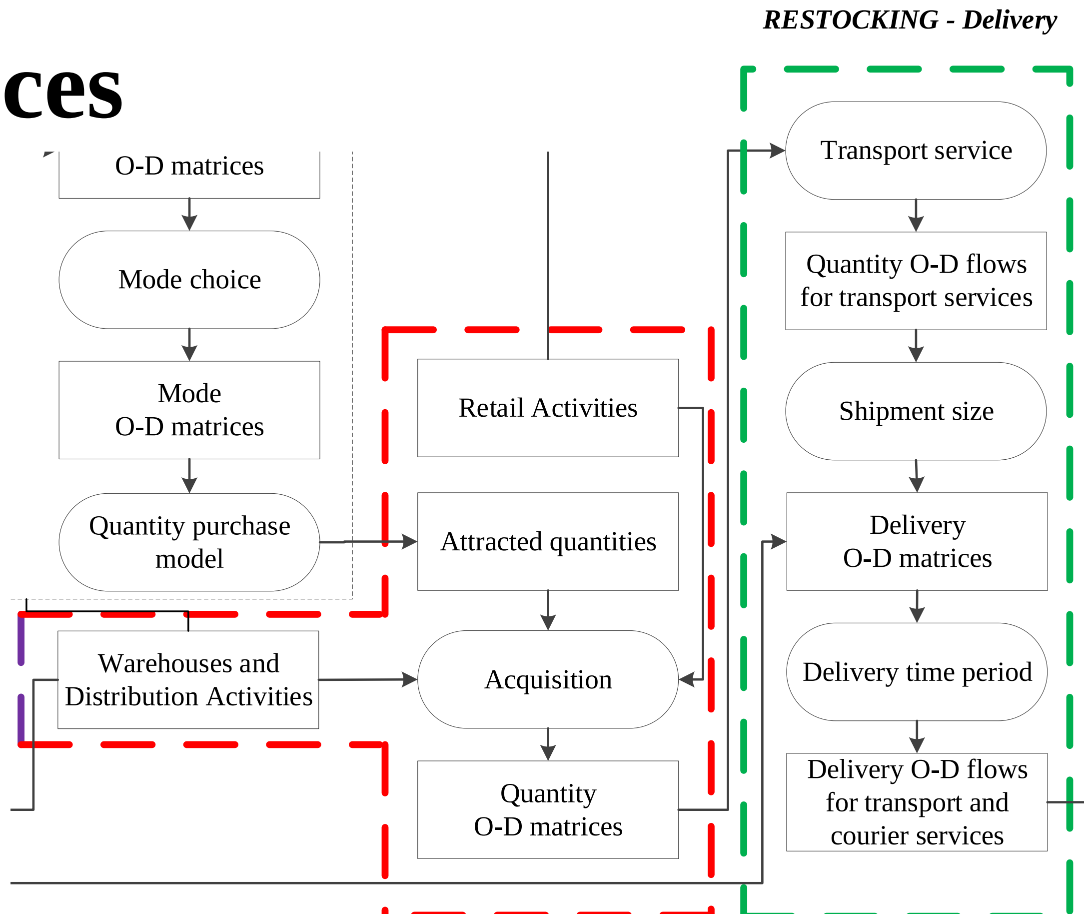
Deliveries split Own Account/Third Party



Delivery time period (slice)



Demand model ⇒ Delivery O-D Matrices



Quantity
allows to capture mechanisms underlying the freight demand generation

Delivery
allows to follow the decisional and logistic process of restocking

Vehicle
Input for assignment and performance models

Delivery *O-D* matrices

$$ND_{od}\left[r\right] = \frac{Q_{od}}{q\left[r\right]} \cdot p\left[r / d\right] \cdot p\left[\tau / rod\right] \; \left[deliveries / time \ slice\right]$$

- ✓ $ND_{od}\left[r\right]$ is the number of deliveries carried out by transport service type *r* on *od* pair;
- ✓ Q_{od} is the average freight quantity flow on *od* pair;
- ✓ $q\left[r\right]$ is the average freight quantity delivered with service type *r* (**shipment size model**).
- ✓ $p\left[r / d\right]$ is the share or the probability of having deliveries by service type *r* (**transport service model**);
- ✓ *p[τ/rod]* is the share or the probability to delivery at time τ (**delivery time period/slice model**).

Transport service type model

Revealed shares

$$p\left[r\,/\,od\right]$$

	Foodstuffs	*Home accessories*
Retailer on own account	15%	31%
Wholesaler on own account	61%	46%
Third party *(transport company and courier)*	24%	23%
Total	**100%**	**100%**

Rome (2008)

Transport service type model

$$p\left[r/od\right]$$

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

$$\mathrm{p}\left[\mathrm{r}/\mathrm{od}\right] = \frac{\exp(\alpha \mathrm{V}_{\mathrm{r}})}{\sum_{\mathrm{r}'} \exp(\alpha \mathrm{V}_{\mathrm{r}'})} \qquad V_r = \Sigma_j \, \beta_j \, X_{jr}$$

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

Transport service type model

Retailers: logit model

$$V_{c_{oa}} = \underset{(1.6)}{0.032} \cdot PC + \underset{(3.4)}{1.008}$$

ρ² = 0.21

$$V_{c_{tp}} = \underset{(6.3)}{1.97} \cdot PROD + \underset{(7.8)}{2.56} \cdot CD + \underset{(6.4)}{1.82} \cdot WH + \underset{(1.5)}{0.023} \cdot EM + \underset{(1.3)}{0.6} \cdot q$$

- V_{coa} is the systematic utility for transport **in own account**,
- V_{ctp} is the systematic utility for transport **by carrier**,
- *PROD* is a dummy variable equal to *1* if the restocked freight arrives from a *producer*,
- *CD* is a dummy variable equal to *1* if the restocked freight arrives from a *distribution center*,
- *WH* is a dummy variable equal to *1* if the restocked freight arrives from a *wholesaler*,
- *PC* is a dummy variable equal to *1* if the restocked shop is a *public concern* (e.g. bar, restaurant),
- *EM* is the number of employees at shop to be restocked,
- *q* is the average *shipment size*, expressed in tons.

Transport service type model

Retailers: logit model

Public concerns **prefer** restocking in **own account**

ρ^2 = 0.21

$$V_{c_{oa}} = \underset{(1.6)}{0.032} \cdot PC + \underset{(3.4)}{1.008}$$

$$V_{c_{tp}} = \underset{(6.3)}{1.97} \cdot PROD + \underset{(7.8)}{2.56} \cdot CD + \underset{(6.4)}{1.82} \cdot WH + \underset{(1.5)}{0.023} \cdot EM + \underset{(1.3)}{0.6} \cdot q$$

- V_{coa} is the systematic utility for transport **in own account**,
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- *WH* is a dummy variable equal to *1* if the restocked freight arrives from a *wholesaler*,
- ...ked shop is a *public concern* (e.g. bar, restaurant),
- ...estocked
- *q* is the average *shipment size*, expressed in tons.

Probability to be **restocked by carriers is related to the type of origin centre: producer**, **distribution centre** and **warehouse**

Probability to be **restocked by carriers increases** with increasing **shipment size** and number of employees (**shop dimension**)

Shipment size

$$q[r]$$

Shipment size: revealed delivery quantity [t/delivery]

	Foodstuffs	*Home accessories*
Retailer on own account	0.389	1.197
Wholesaler on own account	0.367	0.982
Third party *(transport company and courier)*	0.232	0.611
Average	**0.320**	**0.902**

Average no. of deliveries	**2.4**	**1.8**

Rome (2008)

Shipment size model for retailers 1/2

$$q^i = \underset{(5.3)}{5.83} \cdot EM^i + \underset{(3.84)}{95.17} \cdot STORE + \underset{(1.6)}{32.71} \cdot PC + \underset{(5.2)}{130.63} \cdot MR \qquad [kg / delivery]$$

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;

Shipment size model for retailers

2/2

$$q^i = \underset{(5.3)}{5.83} \cdot EM^i + \underset{(3.84)}{95.17} \cdot STORE + \underset{(1.6)}{32.71} \cdot PC + \underset{(5.2)}{130.63} \cdot MR \qquad [kg\,/\,delivery]$$

R^2=0.56

Shipment size increases with the presence of depot and number of employees

Larger shipment size for public concerns

during the **morning** the delivered quantity is **larger** than in the afternoon

- ✓ …ed quantity at shop *I*, expressed in kg;
- ✓ …nployees at shop *i*;
- ✓ …iable equal to *1* if there is a depot, *0* otherwise;
- ✓ …e equal to *1* if the restocke… …*ern* (e.g. bar, restaurant), *0* otherwise;
- ✓ *MR* is a dummy vari… …ock… (i.e. in the morning), *0* otherwi…

Delivery time period (slice) model

Revealed shares

$$p[\tau/rod]$$

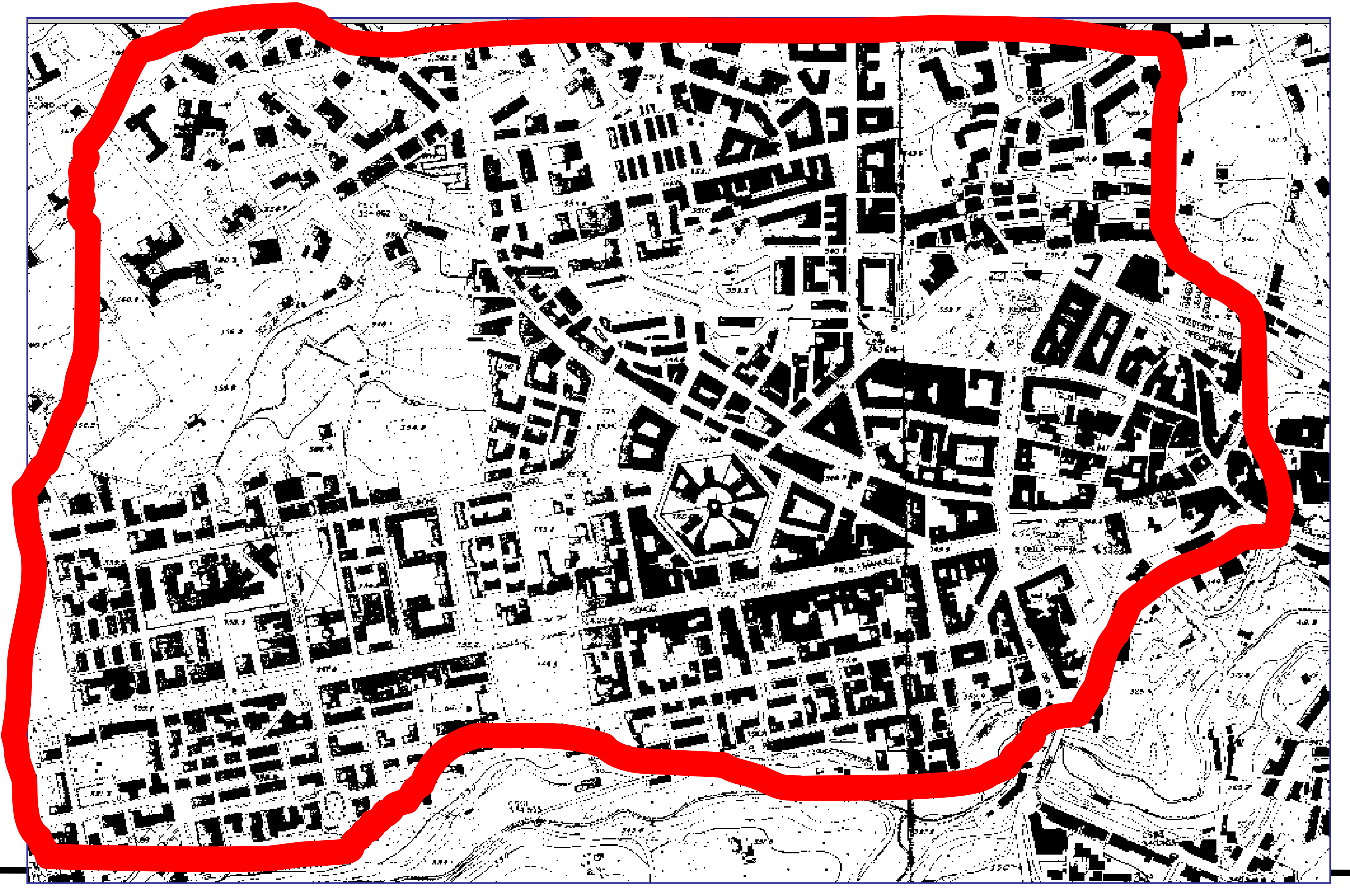
is the share or the probability to delivery at time τ

	Foodstuffs
Before 12:00	76%
Between 12:00 – 15:00	13%
After 15:00	11%

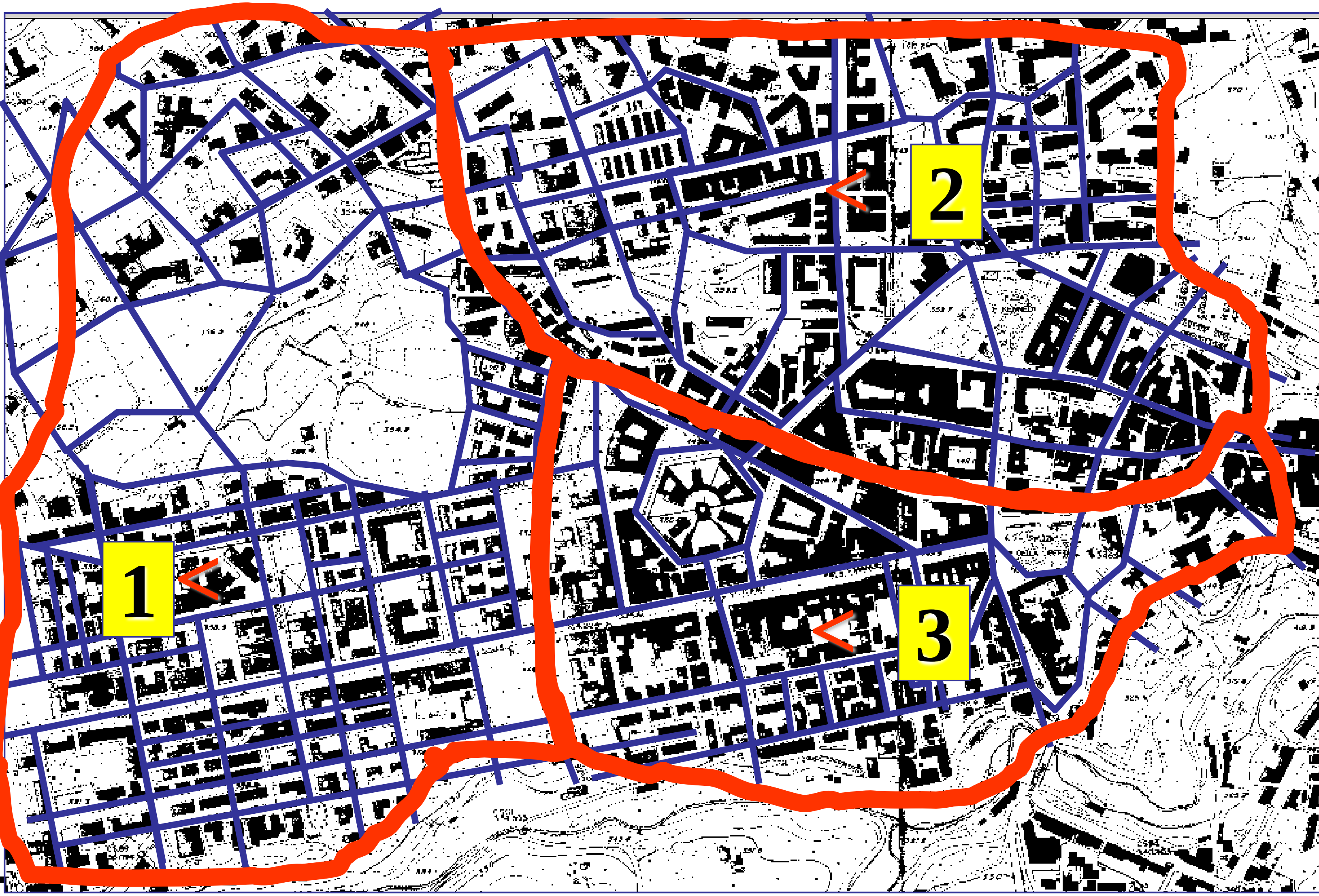
Appendix

✓ **Model application example**

Study area



Traffic zones



Socio-economic data

Traffic zones	*Freight type*	*Retail employees*	*Warehouse employees*	*% of retail employees on residents*
1	Foodstuffs	152	50	5%
2	Foodstuffs	2,149	150	40%
3	Foodstuffs	1,550	90	26%

Attracted quantity

$$Q_{.d} = \beta_{AD} \cdot AD_d + \beta_{ASA} \cdot ASA_d \quad [\text{t/day}]$$

- ✓ **Zone 1**
  - ➢ Foodstuffs $Q_{.d} = 0.06 \cdot AD_d + 599.7 \cdot ASA_d \quad [\text{t/day}]$

	Foodstuffs
Zone 1	9.1
Zone 2	728.6
Zone 3	93.0

Quantity O-D matrices (1/2)

$$Q_{od} = Q_{.d} \cdot p[o/d] \qquad [\text{t/day}]$$

$$p[o/d] = \left(AI_o\right)^{\beta_1} \cdot C_{od}^{\beta_2} \Big/ \sum_{o'} \left(AI_{o'}\right)^{\beta_1} \cdot C_{o'd}^{\beta_2}$$

C_{od}	*Zone 1*	*Zone 2*	*Zone 3*
Zone 1	5.0	12.0	10.0
Zone 2	12.0	4.5	7.2
Zone 3	10.0	7.2	4.0

✓ **Foodstuffs**

$$p[o/d] = \left(AI_o\right)^{2.1} \cdot C_{od}^{-0.05} \Big/ \sum_{o'} \left(AI_{o'}\right)^{2.1} \cdot C_{o'd}^{-0.05}$$

$p[o/d]$	*Zone 1*	*Zone 2*	*Zone 3*
Zone 1	7.2%	6.6%	6.8%
Zone 2	69.0%	70.0%	69.0%
Zone 3	23.8%	23.4%	24.2%
Total	**100.0%**	**100.0%**	**100.0%**

Quantity O-D matrices

$$Q_{od} = Q_{.d} \cdot p[o/d] \qquad [\text{t/day}]$$

Foodstuffs

Q_{od}	*Zone 1*	*Zone 2*	*Zone 3*	**Total**
Zone 1	0.7	48.3	6.3	**55.3**
Zone 2	6.3	509.9	64.1	**580.3**
Zone 3	2.2	170.4	22.6	**195.1**
Total	**9.1**	**728.6**	**93.0**	**830.8**

Quantity O-D per transport service type

$$Q_{od}[r] = Q_{.d} \cdot p[o/d] \cdot p[r] \quad [\text{t/day}]$$

	Foodstuffs
RETAILER in own account	15%
OTHER transport services (e.g. wholesaler in own account + carrier)	85%
Total	**100%**

Retailer own account

	Zone 1	*Zone 2*	*Zone 3*	**Total**
Zone 1	0.1	7.3	0.9	**8.3**
Zone 2	0.9	76.5	9.6	**87.1**
Zone 3	0.3	25.6	3.4	**29.3**
Total	**1.4**	**109.3**	**14.0**	**124.6**

Other

	Zone 1	*Zone 2*	*Zone 3*	**Total**
Zone 1	0.6	41.1	5.3	**47.0**
Zone 2	5.3	433.4	54.5	**493.3**
Zone 3	1.8	144.8	19.2	**165.9**
Total	**7.8**	**619.3**	**79.1**	**706.1**

Delivery O-D matrices

$$ND_{od}\left[r\right] = Q_{od}\left[r\right]/q\left[r\right] \qquad \left[deliveries\ /\ day\right]$$

	q= average shipment *[t]*
RETAILER in own account	0.389
OTHER transport services (e.g. wholesaler in own account + carrier)	0.300

Retailer own account

	Zone 1	*Zone 2*	*Zone 3*	**Total**
Zona 1	0.3	18.6	2.4	**21.3**
Zona 2	2.4	196.6	24.7	**223.8**
Zona 3	0.8	65.7	8.7	**75.2**
Totale	**3.5**	**281.0**	**35.9**	**320.3**

Other

	Zone 1	*Zone 2*	*Zone 3*	**Total**
Zona 1	1.9	136.9	17.8	**156.6**
Zona 2	17.8	1,444.8	181.7	**1,644.3**
Zona 3	6.2	482.7	64.0	**552.9**
Totale	**25.8**	**2,064.5**	**263.5**	**2,353.8**

Delivery O-D matrices per time slice

$$ND_{od}\left[\tau r\right] = Q_{od}\left[r\right] / q\left[r\right] \cdot p\left[\tau / d\right] \quad \left[deliveries / time\ slice\right]$$

	$p[\tau/d]$
Before 11:00 am	0.70
After 11:00 am	0.30

Delivery O-D matrices per time slice

Retailer own accownt before 11:00 am

	Zone 1	*Zone 2*	*Zone 3*	**Total**
Zone 1	0.2	13.0	1.7	**14.9**
Zone 2	1.7	137.6	17.3	**156.6**
Zone 3	0.6	46.0	6.1	**52.7**
Total	**2.5**	**196.7**	**25.1**	**224.2**

Other before 11:00 am

	Zone 1	*Zone 2*	*Zone 3*	**Total**
Zone 1	1.3	95.9	12.5	**109.6**
Zone 2	12.5	1,011.4	127.2	**1,151.0**
Zone 3	4.3	337.9	44.8	**387.0**
Total	**18.1**	**1,445.1**	**184.5**	**1,647.7**

Retailer own accownt after 11:00 am

	Zone 1	*Zone 2*	*Zone 3*	**Total**
Zone 1	0.1	5.6	0.7	**6.4**
Zone 2	0.7	59.0	7.4	**67.1**
Zone 3	0.3	19.7	2.6	**22.6**
Total	**1.1**	**84.3**	**10.8**	**96.1**

Other after 11:00 am

	Zone 1	*Zone 2*	*Zone 3*	**Total**
Zone 1	0.6	41.1	5.3	**47.0**
Zone 2	5.3	433.4	54.5	**493.3**
Zone 3	1.8	144.8	19.2	**165.9**
Total	**7.8**	**619.3**	**79.1**	**706.1**