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YEAR XVI, NUMBER 46, December 2010

Special issue on: Freight Transport Modeling

European Transport \ Trasporti Europei n. 46 (2010): 1-2

Special issue on Freight Transport Modeling

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1. Special issue introduction

This special issue of the European Transport/Trasporti Europei Journal on "Freight Transport Modeling" publishes a selection of the papers presented at the XIII Euro Working Group on Transportation Meeting "Advances in Transportation Systems Analysis", held in Padova, Italy, on September 23 - 25, 2009.

The Euro Working Group on Urban Traffic and Transportation was founded in July, 1991 in Cetraro (Italy) during the 7th Euro Summer Institute on Urban Traffic Management. The name was changed during the Meeting in Glasgow in July, 1994 to "Transportation", in order to enlarge the topics to be addressed and to involve more people in the participation. Until now thirteen meetings have been hosted by several Universities in Europe having a great success.

The main targets of the Group are providing a forum to share information and experiences of research activities on the field of transportation, encouraging joint researches and the development of both theoretical methods and applications, and promoting the cooperation among different institutions and organizations, leaders at national level in the field of traffic and transportation systems. In this sense EWGT promotes Workshops and international Conferences where researchers exchange knowledge and experiences in the field of transportation systems analysis and modeling.

The Euro Working Group on Transportation Meeting is an annual international scientific conference that provides a high quality forum for the presentation of methods and models and case studies, and for the exchange of ideas and scientific discussions on advanced applications and technologies in transportation. The EWGT2009 Meeting took place in Padova, Italy, on September 23 - 25, 2009. Scientists from all around the world met at this conference to present the state-of-the-art of their research in the fields of operational research, management science, computer science, and mathematical modeling applied to transportation problems.

The high standards of the conference are ensured by a wide and competent scientific committee and by a selective review process. The reviewing of the manuscripts submitted for possible publication in the special issue "Freight Transport Modeling" started in October 2009 with at least 2 reviewers per paper with further revision by the guest editors. The revision and selection process has been completed in September 2010. Among the 8 contributions selected for publication, advances in the state-of-the-art related to several fields of freight transportation are illustrated and discussed.

We would like to thank the participants to the EWGT2009 Meeting for submitting high quality papers, allowing us to edit this special issue of the European Transport \Trasporti Europei journal. A special thanks to all the reviewers for a professional work carried out.

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Demand and routing models for urban goods movement simulation

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Abstract

This paper presents a macro-architecture for simulating goods movements in an urban area. Urban goods supply is analysed when the retailer is the decision-maker and chooses to supply his/her shop. Two components are considered: demand in terms of goods supply and vehicle routing with constraints to simulate goods movements.

To analyse demand we consider a multi-step model, while to analyse goods movements a Vehicle Routing Problem with Time Windows (VRPTW) is formalized. We examine the distribution process for a VRPTW in which the optimum paths between all the customers are combined to determine the best vehicle trip chain. As regard optimum path search, a multipath approach is proposed that entails the generation of more than one path between two delivery points. Some procedures (traffic assignment, real time system measurement, reverse assignment) to estimate system performance are also proposed.

Finally, heuristics to solve the proposed problem are reported and their results are compared with those exact.

Keywords: City Logistics; Goods movement; Vehicle routing problem.

1. Introduction

In this paper a macro-architecture to simulate goods movements in urban/metropolitan areas is presented. Two components are considered: demand in terms of goods supply and vehicle routing with constraints (time windows, fleet size, load factor …) to simulate goods movements.

We consider a multi-step model, which on two different levels, gives as output: 1) commodity flows, 2) vehicle flows. The first level is a commodity-based demand model that simulates goods movements in terms of quantity: here we recall briefly a commodity-based model, which simulates the quantity of goods purchased by a retailer. The second simulates path choice made by the retailer. In this paper we report in detail the Vehicle Routing Problem with Time Windows (VRPTW).

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For the first level there are various models and methods to analyse urban goods movements: the main classifications concern the output considered and the structure. As regards the latter, some models have a structure similar to that used for passengers (multi-step models), while others are based on the macro-economic approach (spatial price equilibrium models) (Harker, 1985). In terms of output, while some models estimate the commodity quantities transported, others estimate the vehicle number involved in goods transport in urban areas (Ogden, 1992).

For the second level, as regards the Vehicle Routing Problem (VRP, it is a combinatorial optimization problem)*, there is no single universally accepted definition due to the diversity of constraints encountered in practice* (Laporte, 2007).

In this paper, we consider the follow definition of the VRP: the problem consists in determining a set of *m* vehicle routes starting and ending at the origin, and such that each customer is visited by exactly one vehicle, the total demand of any route does not exceed the vehicle capacity, and the total routing cost (time) is minimized (Laporte, 2007).

The VRP was introduced by Dantzig and Ramser (1959) so as to optimize the movements of a fleet of gasoline delivery trucks. Since then research in this field has greatly developed (recent works alone include Baker and Ayechew, 2003; Taniguchi *et al*., 2007; Almeida *et al*., 2008; Wang an Lu, 2009; Jozefowiez *et al*., 2009).These studies propose a formulation of the VRP (in an attempt to consider all the aspect of the problem) and solution procedures (exact, heuristics). There are several types of VRP: for example, referring to the customer may be termed a Dynamic VRP (DVRP), in which the number of customers is a problem variable (Montemanni *et al*., 2005; Hanshar and Ombuki-Berman, 2007); reference to the cost function can be termed the Time-Dependent VRP (TDVRP) in which cost (travel time) is a function of travel day (Malandraki and Daskin, 1992); referring to time constraints can be called the VRP with Time Windows (VRPTW) in which deliveries can be made within a set time interval (Hu *et al*., 2007; Ando and Taniguchi, 2006), and so on.

Several procedures have been proposed to solve the vehicle routing problems, both exact (branch and bound, branch and cut) and heuristic procedures (tabù search, genetic algorithms). For the exact approach, reference may be made to Fisher (1994), Toth and Vigo (2002), and Baldacci et *al*. (2008). For the heuristic approach we may cite Laporte (2007), Montemanni et *al*. (2005), Hanshar and Ombuki-Berman (2007), Laporte et *al*. (2000), and Jones et *al*. (2002). Exact approaches have limitations in terms of computing times and the size of the problems that can be solved. An extended review concerning the VRP, several variants and solution approaches is reported in (Laporte, 2007; Gendreau *et al*., 2008).

The VRPTW proposed in this paper is treated as a combinatorial problem in which the optimum paths between all the customers (Ben Akiva *et al*., 1984; Antonisse *et al*., 1985; Cascetta *et al*., 1996; Russo and Vitetta, 2003) are combined to determine the best vehicle trip chain.

In this paper a macro-architecture for goods movements is proposed (Russo and Comi, 2010). The macro-architecture allows us to analyse the restocking process starting from the delivery quantity and ending with the distribution process. In particular, we analyse the distribution process for a VRPTW in which the optimum paths between all the customers are combined to determine the best vehicle trip chain. As regards the optimum path search, a multipath approach is proposed that concerns the generation of more than one path between two delivery points. Moreover, some procedures (traffic assignment, real time system measurement, reverse assignment) to estimate system performance are proposed. Finally, some heuristics to solve the proposed problem are reported and their results are compared with those exact.

The paper is organized as follows. In section 2 the macro-architecture is reported and some aspects are developed in detail. In section 3 and 4 the routing models and the algorithms are proposed. In section 5, the proposed algorithms are applied to some test cases and a comparison between the results is reported. Finally, some conclusions are drawn and future developments are outlined.

2. Macro-architecture methodology

The general macro-architecture of reference is that reported in the literature (Russo and Comi, 2010; Russo and Comi, 2006; Russo *et al.*, 2007). For the purposes of this paper, analysis of the macro-architecture has four successive *zooms*, in which goods movements are analysed from upper macro-levels (commodity and vehicle level) to the path choice model (figure 1).

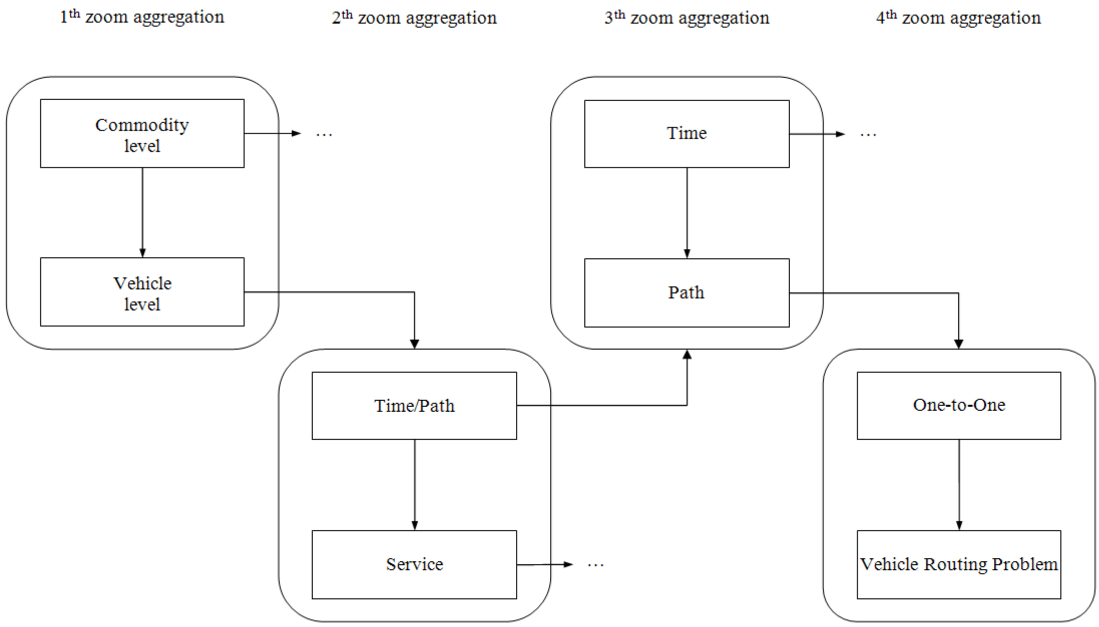

Figure 1: Macro-architecture of goods movements.

At the first zoom the goods quantity purchased in a zone by a retailer can be analysed on two levels (Russo *et al.*, 2007):

- *commodity level*, consisting of two macro-models:
  - attraction macro-model for end-consumer quantities;
  - acquisition macro-model for logistics trips from the retailer's shop;
- *vehicle level*, which consists of two macro-models:
  - service macro-model;
  - path macro-model.

At the second zoom, we focus on the *vehicle* level. We obtain the *service* and the *time/path* macro-models:

- the first (*service*) concerns the goods quantity delivered at each consignment and the vehicles needed for restocking; in this model the distribution channels are investigated (by *distribution channel* we mean how a product is physically transferred or distributed from the production site to the point at which it is made available to the customers), as is the service macro-model when the retailer can be considered the decision-maker;
- the second concerns the *time/path* choice for each goods movement; the *time/path* choice model simulates the time and path choice when the retailer moves from his/her shop to one or more delivery points (the location of a wholesaler, a producer, and so on).

At the third zoom, focusing on the *time/path* model, we find the *time choice* and *path choice* models:

- the first simulates the *time* in which the goods must reach the retail shop; with this model the departure time from the retail shop to reach the delivery points at an established time window can also be simulated;
- the second concerns the path choice made by the retailer; this model can be stochastic or deterministic (whether or not the costs are a random variable), dynamic or static (whether or not the cost depends on time).

At the fourth zoom the *One-to-One Problem* (OOP) and the *Vehicle Routing Problem* (VRP) are specified. Both problems can be tackled with a deterministic or probabilistic approach, static or dynamic approach, depending on the approach to the path choice:

- the OOP concerns the case in which the retailer chooses to pick up goods at only one delivery point;
- the VRP concerns the case in which restocking is done at various warehouse points; we note that this problem is similar to the case in which a carrier restocks several retailers from one warehouse.

In this paper we focus on the fourth zoom aggregation, with particular attention to the VRP. The VRP is a combinatorial optimization problem: the minimum paths between all possible pairs of delivery points are combined to find the best trip chains, where a trip chain is a combination of several paths.

3. Routing models

The path choice model allows us to estimate the path choice probability/possibility for the retailers in urban and metropolitan areas. As regards the problem of path simulation and design for retail vehicles, two classes of individual users could be considered:

- private users (motorists and so on), i.e. those travelling for several reasons (work, shopping, etc.) and following the path of maximum perceived utility;
- retailers, i.e. those travelling to restock their shops, who can be further distinguished into:

- Non-Controlled (NC) retailers, i.e. those assumed to follow the path of maximum perceived utility in the same way as private users (in accordance with User Equilibrium-UE hypothesis);
- Controlled (C) retailers, i.e. those obtaining indications supplied by an external (or internal) authority regarding optimal paths (that satisfy specific criteria, e.g. time minimization) to follow, who are assumed, rather than to maximize their own utility, to cooperate in minimizing total internal costs (in accordance with system optimum-SO hypothesis).

Moreover, it is assumed that the number of C-retailers is smaller than the sum of private users and NC-retailers. In a city, the number of private users is at least 100 times greater than that of the retailers present. In such conditions the C-retailer's path choice behaviour does not affect system performance (i.e. link/path costs). The behaviour of independent users and NC-retailers can be simulated in accordance with UE hypothesis to obtain the costs on the network (possibly as a function of flows, assuming that the network is congested and that the system is dynamic). Taking account of network costs, the optimal path according to SO hypothesis for C-retailers can be designed considering the network costs derived from UE.

The proposed procedure can be summarized in three steps.

STEP 1 - *System performance estimation*. In this step, the transport system is analysed in order to estimate system performance (i.e. in terms of travel time or travel cost). This objective can be achieved through static or dynamic Traffic Assignment (TA), Real-time System Monitoring (RSM) or Reverse Assignment (RA) (Russo and Vitetta, 2005).

STEP 2 - *One-to-One Problem* (OOP) solution. In this step, the shortest path between each delivery point pair is calculated, taking account of the costs obtained by step 1; the mono–path and multi–path approach (MOOP) can be considered:

- in the mono-path case, with a deterministic approach, just one path (equal to the shortest path) with maximum choice probability (equal to 1) is generated; this approach, extensively used in the literature, is not very realistic due to the fact that it does not take into account the uncertainty related to the simulation of user perception of the alternative and the variability of the system states in time, hence its dynamic nature;
- in the multi-path case (Multi-path OOP, MOOP), with a probabilistic approach, a set of possible paths is generated, each of which has a choice possibility/probability that depends on the user perception of the alternative and the possibility/probability of there being a specific system state that influences the choice process.

STEP 3 - *VRP* solution. To solve the VRP, the OOP solution obtained at step 2 is considered. The objective is to calculate the best combination of shortest paths in order to visit a succession of customers in the least time/cost possible whilst respecting some constraints. If the one-to-one problem is solved using a multi-path approach, we have a multi-path VRP (MVRP).

In figure 2 we report the three simulation steps for the case in which the multi-path approach is used. In step 1 the data input are the supply and demand. Using TA, RSM and/or RA it is possible to obtain cost and flow for each link. In the general case (dynamic case) the cost and flow are time-dependent. The costs and flows found at step 1 are the input for step 2 which, in a multi-path approach, give the probability of choosing paths belonging to a set of possible paths. The path choice probability is the input for step 3, where the VRP is solved (using an appropriate procedure) to obtain the trip chains.

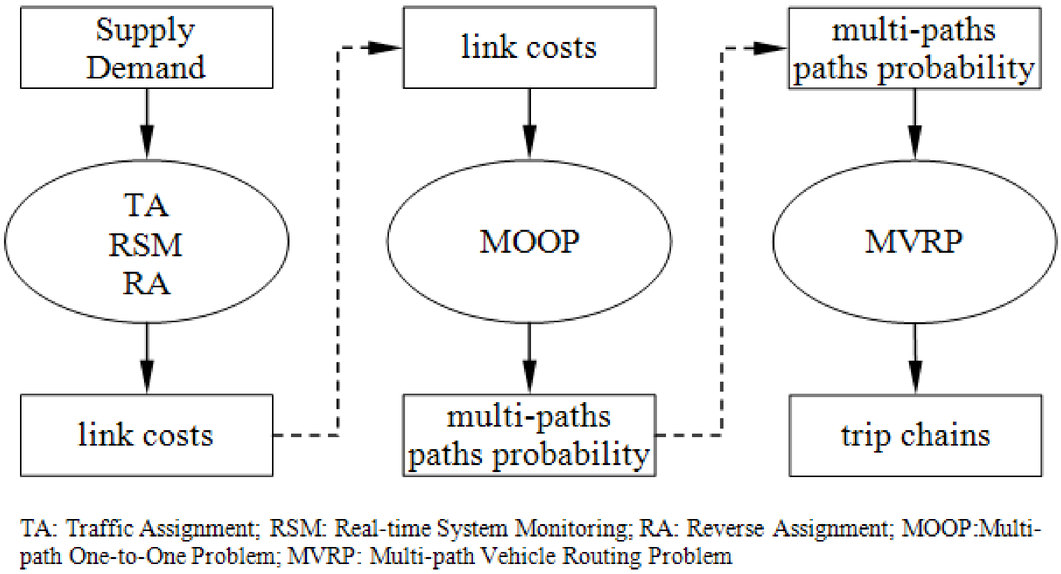

Figure 2: Solving the restocking problem.

Below (sub-sections 3.1, 3.2 and 3.3) steps 1, 2 and 3 are itemized.
The following notations are used:
$\mathbf{N} = \{1, 2, \ldots, n\}$, node set;
$\mathbf{L} = \{a : a = (i,j)\ \forall\ i, j \in \mathrm{N}\}$, link set;
$\mathbf{Z} = \{1, 2, \ldots, m\}$, $\mathbf{Z} \subset \mathbf{N}$ nodes must be visited;
f link flow vector with component f_a on link $a \in L$;
h path flow vector with component h_k on path k;
c link cost vector with component c_a on link a;
g path cost vector with component g_k on path k;
$\mathbf{g}^{ADD}$ is the additive path cost vector; an element g_k^{ADD} is defined as the sum of the links belonging to path k;
$\mathbf{g}^{NA}$ is the non-additive path cost vector;
u is the retailer's shop;
$\mathbf{NV} = \{1, 2, \ldots, NVmax\}$, set of goods vehicles;
b_j vehicle capacity, $j=1, 2, \ldots, NVmax$;
Q_j vehicle load, $j=1, 2, \ldots, NVmax$;
r_i demand on node i;
$BT_{l,k}$ penalty before time at client (node) l using path k;

$AT_{l,k}$ penalty after time at client (node) *l* using path *k*;
$OT_{l,k}$ operation time at client (node) *l* using path *k*;
y_{iv} variable that is equal to *1* if node *i* has already been visited by vehicle *v*, *zero* otherwise;
x_{kv} variable that is equal to *1* if path *k* is used by vehicle *v*, *zero* otherwise;
$\mathbf{P}$ path choice probabilities matrix;
$\mathbf{f}_t$ time–dependent link flow vector;
$\mathbf{c}_t$ time–dependent link cost vector;
$\mathbf{d}$ demand vector;
$\mathbf{h}^*$ equilibrium path flow vector;
$\mathbf{\Delta}$, links-paths incidence matrix with component δ_{ak} for link a and path k;

3.1. System performance estimation

In this section, the transport system simulation is analysed to evaluate its performance. The input consists in demand and supply; the output comprises the link flows and costs. To calculate the link flows and costs, three methods could be used: TA, RSM or RA.

The TA simulates the demand-supply interaction to determine system performance (flows and costs). Two approaches are possible: User Equilibrium (UE) or Dynamic Process (DP) (Wardrop, 1952; Beckman *et al.*, 1956; Sheffi, 1985; ben Akiva *et al.*, 1998; Cascetta, 2009). The TA input was:

- a supply model simulating network characteristics;
- a demand model simulating user behaviour;

which give as output:

- link flows;
- link costs.

The models for traffic assignment to the transportation network simulate demand-supply interaction and allow us to determine network performance. Below, we recall the supply and demand models.

A *supply model* can be defined as a model simulating performance and the flows resulting from user demand and the technical and organizational aspects of physical transportation supply (Cascetta, 2009). The supply model can be formulated as follows:

$$\mathbf{g} = \mathbf{g}^{ADD} + \mathbf{g}^{NA} = \mathbf{\Delta}^T\mathbf{c} + \mathbf{g}^{NA}$$

In the case of congested networks, the cost depends on link flow:

$$\mathbf{c} = \boldsymbol{c}(\mathbf{f})$$

Assuming the relation between link flow and path flow is:

$$\mathbf{f} = \mathbf{\Delta}\,\mathbf{h}$$

the supply model can be expressed as:

$$\mathbf{g} = \mathbf{\Delta}^T\boldsymbol{c}(\mathbf{\Delta}\,\mathbf{h}) + \mathbf{g}^{NA}$$

A *demand model* can be defined as a mathematical relationship between demand flows and the transportation supply system (Cascetta, 2009). The demand model may be formulated as follows:

$$\mathbf{h} = \boldsymbol{P}(-\mathbf{g})\,\mathbf{d}$$

The TA model is obtained by combining the supply model and demand model. The TA can be solved with a static or dynamic approach; static assignment models simulate a transportation system in stationary conditions, reproducing the condition in which link flows and link costs are mutually consistent. The output is the link flow vector **f** and the link cost vector $\boldsymbol{c}(\mathbf{f})$. To calculate the link flow a Stochastic User Equilibrium (SUE) is considered; the SUE requires an algorithm to solve the fixed point model: the applied algorithm is based on the Method of Successive Averages (MSA).

Equilibrium link flows (deterministic or stochastic) can be expressed as the solution of a fixed-point model (Cascetta, 2009):

$$\mathbf{f}^{*}= \boldsymbol{\Delta}\,\boldsymbol{P}(-\boldsymbol{\Delta}^{T}\boldsymbol{c}(\boldsymbol{\Delta}\mathbf{h}^{*}) - \mathbf{g}^{NA})\,\mathbf{d}$$

Dynamic traffic assignment models remove the assumptions of static models, allowing transportation system evolution to be represented. Dynamic traffic assignment models can be analysed in relation to the characteristics of the link model adopted. In particular, link flow representation can be continuous or discrete, and cost functions can be aggregate or disaggregate. The output is the link flow vector for each time t, $\mathbf{f}_t$, and the link cost vector, $\boldsymbol{c}_t(\mathbf{f}_t)$.

The RSM allows us to obtain the traffic flow data using monitoring techniques and can be obtained with:

- measurement at fixed points in the network with traditional measurement systems like loop detectors and image processing (Hoose, 1991);
- floating cars (Torday and Dumont, 2004) in the network (individual cars, taxis, transit system vehicles).

RSM costs and flows are usually made for a subset $\mathbf{S} \subseteq \mathbf{L}$ of the network links. For each link $a \in \mathbf{S}$ RSM provides the link flow vector $\mathbf{f}_{RSM}$ and the link cost vector $\mathbf{c}_{RSM}$ and/or the link flow vector for each time t $\mathbf{f}_{t,RSM}$ and the link cost vector $\mathbf{c}_{t,RSM}$. Because the values are available only in a subset of links, RSM has to be used together with TA, giving RA models.

RA models (Russo and Vitetta, 2005) have the following input:

- link flows;
- link performance in terms of costs;

and give as output

- the link cost parameters of the cost-flow functions used in the supply model;
- the value (number of trips) and/or the model parameters of the demand model.

RA models, starting from observed costs and flows (i.e. provided by RSM), provide the demand value and/or parameter and/or the link cost parameters of the cost-flow functions used in the supply model. Hence, RA can be formulated as an optimum problem which, starting from **d**, $\mathbf{f}_{RSM}$ and $\mathbf{c}_{RSM}$, provides $\mathbf{f}^{*}_{RSM}$ and $\mathbf{c}^{*}_{RSM}$ in the whole network. In the time-dependent problem the outputs are $\mathbf{f}^*_{t,RSM}$ and $\mathbf{c}^*_{t,RSM}$ (Russo and Vitetta, 2005).

3.2. One-to-One Problem

As input the OOP has costs and flows and, as output, it supplies the optimal paths; the users involved are C-retailers. In this paper, we consider C-retailer path choice using two approaches:

- the mono-path approach;
- the multi-path approach, which can be mono-criterion or multi-criteria.

The mono-path concerns the generation of only one path between an origin and a destination. This approach, widely used in the literature, is deterministic and the path generated is assumed the best path. Hence, the output is a path set $\mathbf{\Gamma}$. An element $k \in \mathbf{\Gamma}$ is associated to each origin/destination pair.

The MOOP concerns the generation of more than one path between an origin and a destination. This approach is probabilistic; the link cost is a random variable, which means:

- each path has a probability to come;
- the retailer is ill-informed on the system state.

For each retailer *n* the output consists of some path sets $\mathbf{\Gamma}_i^n$; each path $k \in \mathbf{\Gamma}_i^n$ has a probability $p^n(k)$; an element $k \in \mathbf{\Gamma}_i^n$ is associated to each pair of delivery points.

In the literature, only the mono-path approach is used, but it is plain that in reality the multi-path approach should be used since it takes into account the uncertainty related to simulating the user perception of the alternative and system state variability over time, hence its dynamic nature (Russo and Vitetta, 2006).

In the MOOP a choice set is generated; in this phase we distinguish:

- formation, concerning the structure of the potential analytical path set/sets;
- extraction, concerning the extraction of the choice set.

In this paper, to solve the OOP, a probabilistic approach is adopted. In this approach, having established a criterion to define the cost (e.g. minimum travel time), the link cost, and hence the path cost, is a random variable resulting from the retailer's perception of the possible alternatives (paths). The probability $p_n(k)$ can be calculated as the sum, on all the sub-sets $\mathbf{\Gamma}_i$ which contain the alternative k, of the product between the probability $p^n(\mathbf{\Gamma}_i^n)$ of the sub-set $\mathbf{\Gamma}_i^n$ and the conditional probability $p_n(k/\mathbf{\Gamma}_i^n)$ of choosing path k given the choice set $\mathbf{\Gamma}_i^n$ (Manski, 1977):

$$p^n(k) = \Sigma_i \, p^n(\mathbf{\Gamma}_i^n) \, p_n(k/\mathbf{\Gamma}_i^n)$$

To calculate the paths, a modification of the Dijkstra algorithm is used in order to evaluate more than one path between an origin and a destination (Russo and Vitetta, 2006).

3.3. Vehicle Routing Problem

The vehicle routing problem is introduced to simulate the restocking approach when the retailer chooses to restock in some delivery points: the problem can be described as the design of optimal trip chains from the retail shop to a set of delivery points (warehouses, producers,…); each point can be reached exactly once. The constraints are economic (travel cost, operation costs …) and operational (vehicle capacity, time windows,…). The objective is to purchase whilst respecting the constraints and minimizing the total cost.

As input, the VRP has paths generated by the OOP. As output, it supplies the optimal trip chains that join the delivery points (a trip chain is a combination of several paths).

If the OOP is tackled with the mono-path approach the solution is a set $\mathbf{\Psi}$ of trip chains. If the OOP is tackled with the multi-path approach, it is possible to formulate an MVRP. For each retailer *n*, the output consists of trip chain sets $\mathbf{\Psi}_i^n$; each trip chain $\kappa \in \mathbf{\Gamma}_i^n$ may be linked to a probability $p^n(\kappa)$. Moreover, the MVRP can be static or dynamic: in the first case we have $\boldsymbol{c}(\mathbf{f})$ as input variable, in the second case $\boldsymbol{c}_t(\mathbf{f}_t)$.

The problem constraints are as follows:

- a delivery point can be reached exactly once;
- vehicle capacity;
- time windows.

In this paper the problem proposed is a VRP with Time Windows (VRPTW), applied to the case in which the retailer restocks his/her shop on his/her own account. The origin and destination point is the shop; the intermediate points are some delivery points (wholesaler, producer, and so on). The problem solution is a sequence of delivery points.

The case of a congested network is also considered, and the VRPTW is expressed with an optimum problem:

$$\text{minimizing } \Sigma_k(g_k(\mathbf{f}) \cdot x_{kv}) \qquad (1)$$

subject to:

$$\sum_{v=1\ldots NV_{max}} y_{iv} = 1 \qquad \forall\, i \in \mathbf{Z},\ i \neq u \qquad (2)$$

$$\sum_{v=1\ldots NV_{max}} y_{uv} = NV_{max} \qquad (3)$$

$$\sum_{i\in Z} r_i \cdot y_{iv} \leq b_v \qquad \forall\, v \in \mathbf{NV} \qquad (4)$$

$$x_{kv} \in \{0,1\} \qquad \forall\, k \qquad (5)$$

$$y_{iv} \in \{0,1\} \qquad \forall\, v \qquad (6)$$

$$g_k(\mathbf{f}) = \Sigma_a \delta_{ak} \cdot c_a(\mathbf{f}) + g_k^{NA} \qquad \forall\, k \qquad (7)$$

Constraint 2 indicates that a node can be visited exactly once, constraint 3 that all vehicles go back to the shop. In the case in which we have a single_vehicle, constraints 2 and 3 degenerate into:

$y_i = 1 \qquad\qquad \forall\ i \in \mathbf{Z},\ i \neq u$

$y_u = 1$

Constraint 4 is a capacity constraint. In the case of a single vehicle:

$$\sum_{i \in Z} r_i \cdot y_i \leq b$$

Constraint 5 indicates that the problem variable can only take the value zero or one, in the case of a single vehicle:

$x_k \in \{0,1\} \qquad\qquad \forall\ k$

In constraint 7, the term $g_k(\mathbf{f})$ is the path cost between an origin/destination pair (shop – delivery point, delivery point – delivery point, delivery point – shop). The path cost is the sum of two elements: additive costs, which depend on link and flow characteristics, and non-additive costs. The first element is obtained by solving an OOP, using a shortest path search procedure. Assuming that the travel time on the path is the path cost, a cost matrix may be defined, in which the generic element is the travel time between an origin/destination pair. The second element consists of three components: the before-time ($BT_{l,k}$), after-time ($AT_{l,k}$) and operation time ($OT_{l,k}$) for client *l* visited by path *k*. These components are calculated for each client reached by the vehicle *v* that follows the path considered.

Before-time indicates the time penalty for advance arrival at the node. It is assumed that before-time is a linear function of arrival time. *After-time* indicates the time penalty for delayed arrival at the node. It is assumed that if the vehicle arrives late the penalty is a fixed value. *Operation time* indicates the time for unloading operations. Operation time is a function of goods quantity delivered at the delivery point *l*:

$OT_l = m \cdot q_l$

in which
m is the proportionality factor;
ql is the quantity of goods delivered to delivery point *l*.

The non-additive path cost can then be formalized as:

$$g_k^{NA} = \sum_l \left(BT_{l,k} + AT_{l,k} + OT_{l,k}\right)$$

Finally, x_{kv} is the problem variable. It is a binary variable that is equal to *one* if path *k* is used by vehicle *v*, *zero* otherwise. Note that the proposed formulation is independent of vehicle type and that the time penalties (before-time and after time) allow us to obtain a solution that respects the time windows.

To solve the problem expressed by equation (1) exact (e.g. Branch and Bound), heuristic procedures (i.e. simulated annealing, genetic algorithms, other heuristic) or hybrid procedures can be used. In this paper a greedy procedure and a genetic algorithm are proposed; the results obtained are compared with those exact. In the next section the above algorithms are itemized.

4. Routing algorithms

A retailer who restocks his/her shop on his/her own account in most cases makes a small number of stops. In this case it is acceptable to use an exact algorithm to solve the problem (for example Branch and Bound or an exhaustive evaluation approach). However, if the node number increases the computing times, it is necessary to use a heuristic procedure.

In this section we report:

- a greedy algorithm (called Iterated Nearest Insertion, INI);
- a Genetic Algorithm (GA).

4.1. Iterated Nearest Insertion Algorithm

The Iterated Nearest Insertion (INI) algorithm is a greedy algorithm that consists in an insertion of nodes (delivery points) to minimize the travel time. At each successive insertion the delivery point nearest the previous one is inserted into the solution. When a solution is found, the procedure is repeated *l* times, with *l* greater than 1 and less than the number of delivery points. A single iteration of the algorithm is schematized as follows.

STEP 0 Initialize. The node list *W* comprises the delivery points and the point where the retailer is located. The *current node* is the point where the retailer is located.
STEP 1 List. The *current node* is deleted from *W*.
STEP 2 Path. The shortest paths between the *current node* and the delivery points in *W* are calculated.
STEP 3 Update. The nearest *delivery point* is the new *current node*.
STEP 4 Repeat. Go to step 1 while $W \neq \emptyset$.

4.2. Genetic Algorithm

In this paper, we also propose a genetic algorithm (GA) to solve the problem (1). Problem solution is a node sequence (delivery points) associated to individual vehicles. The following definitions are adopted:

- trip chain: an ordered sequence of delivery points associated to one vehicle κ_j=(u…, i, …u) $\forall$ i $\in$ Z. Each trip chain has the depot *u* as the initial and final node;
- solution: a set of trip chains $\mathbf{\Psi}=\{(\kappa_1,\kappa_2,\ldots,\kappa_j,\ldots)\ j=1,2,\ldots, NV_{max}\}$. A solution has as many trip chains as there are vehicles.

If we have a single vehicle, the solution coincides with the trip chain. The genetic algorithm proposed is reported in figure 3 and its steps are analysed below. Note that the procedure is applicable whether we have a single vehicle or we have more than one.

The *initial population* consists of a fixed number of solutions (population size). To each solution a cost value is associated.

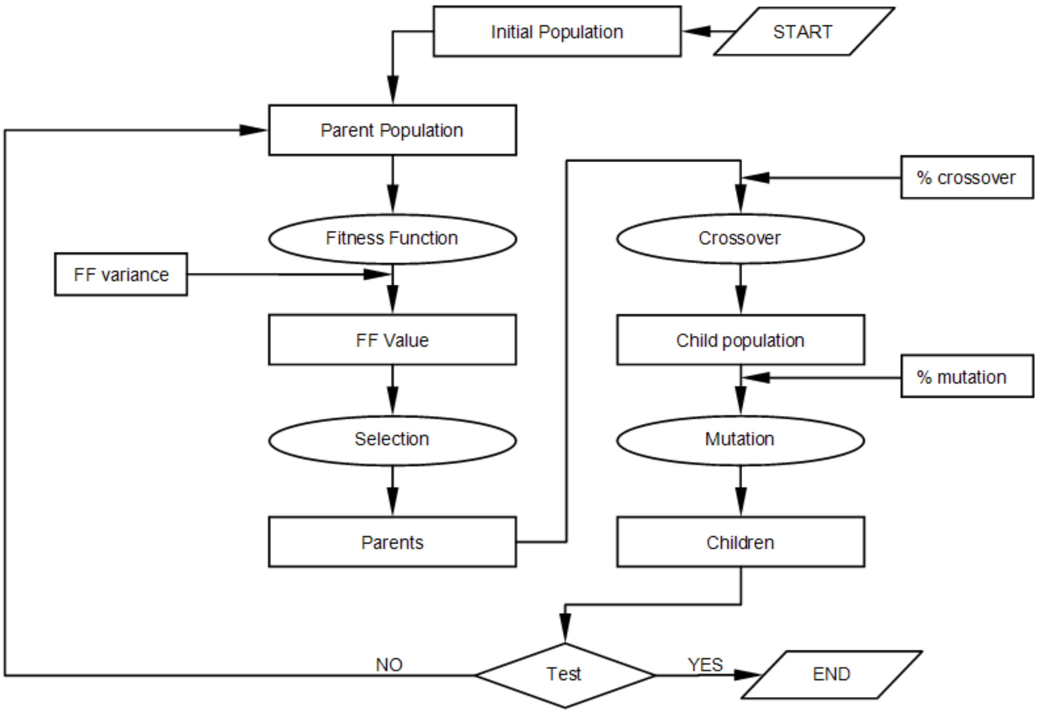

Figure 3: Genetic algorithm.

In the first step the *initial population* is determined; the procedure used being a heuristic insertion procedure in which the trip chain is built with the iterative insertion of nodes, respecting vehicle capacity. The procedure is formulated as follows:

Maximizing $Q_v = \sum_{i\in Z} \delta_i q_{i,v}$

subject to:

$Q_v \leq b$

in which

δ_i is a binary variable that is equal to *1* if node *i* can be added to the trip chain associated to vehicle *v*, *zero* otherwise;

$q_{i,v}$ is the goods quantity at node *i* delivered by vehicle *v*.

For each trip chain belonging to a solution, the first node is inserted randomly; the trip chain is completed by random insertion of nodes, maximizing function Q_v. At the first iteration, the *parent population* and *initial population* coincide.

A fitness value is associated to each element of the parent population. The fitness measures the reproductive capacity of an element. The formulation proposed for the *fitness function* is an exponential function of the objective function:

$$FF_i = \alpha \exp(-\alpha OF_i)$$

where

α is a fitness function parameter and OF_i is the objective function associated to solution i.

The *selection* operator depends on the fitness value. Indeed, the selection probability is the ratio between the selection probability of element i and the sum of fitness of all elements of the population:

$$pr_i = \frac{FF_i}{\sum_j FF_j} = \frac{\exp(-\alpha OF_i)}{\sum_j \exp(-\alpha OF_j)}$$

The proposed fitness function formulation allows the selection probability to be calculated with a Logit model. The selection operator is applied to the parent population to select the fittest parents. In the proposed algorithm, a random selection procedure is defined: the population is represented by a roulette plate; part of the roulette plate, proportional to the selection probability, is associated to each parent, and a number of random extractions (equal to population size) are made.

The *parents* set is the output of the selection operator: in this set the solutions for the *crossover* will be chosen.

In general, the crossover operator allows us to cross the solutions and obtain a new solution. In this paper two crossovers are defined:

- an endo-crossover in which two trip chains of the same solution are crossed;
- an eso-crossover in which two solution are crossed.

The *endo-crossover* refers to any one element of the population chosen randomly; in this element two trip chains to cross are selected.

For each trip chain a cut point (figure 4) is identified which defines the node sequence that will be crossed.

In figure 4 the endo-crossover operator is shown: the cut points are randomly selected and the node sequences identified are swapped in the two trip chains. This produces two new trip chains that generally have a different node number. Moreover, given that a goods quantity is associated to each node, the goods quantity associated to a trip chain is also changed (that is, the goods delivered by the vehicle). A capacity test is thus required to ascertain whether the goods quantity is less than or equal to vehicle capacity. If the test is verified, the crossover is stopped, or else the cut points are shifted one position until the constraints are satisfied. If shifting the cut points does not allow an admissible solution to be obtained, two new trip chains are selected and the procedure is repeated. If the solution coincides with a trip chain (as is the case where we have a single vehicle) the endo-crossover degenerates into a mutation operator.

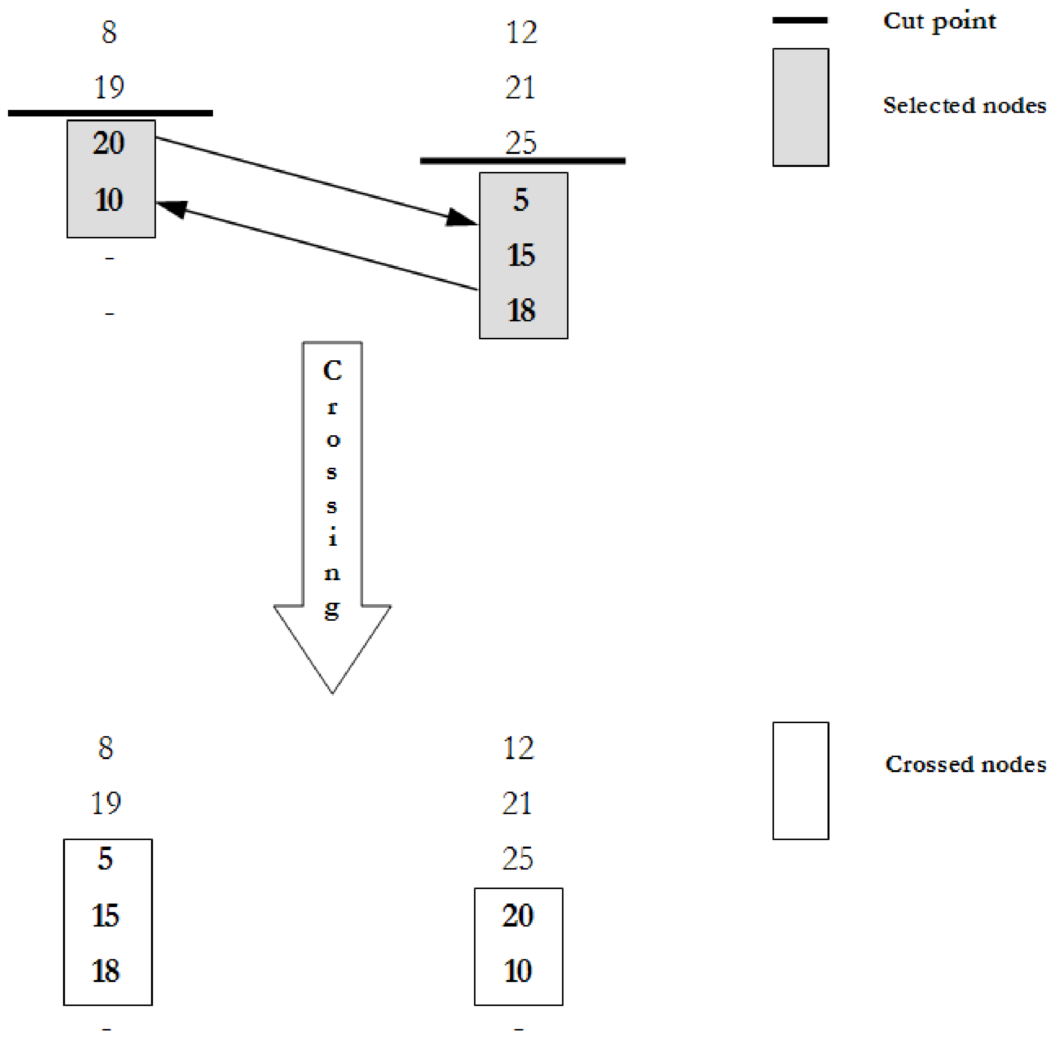

Figure 4: Endo-crossover: selection and crossing.

Eso-crossover refers to two solutions (parents) selected randomly, that are crossed. The first step of the procedure is the selection of two trip chains (figure 5). The nodes (clients) in the trip chains will be swapped as for the endo-crossover, obtaining two new trip chains with a new sequence of nodes. However, the solution is temporary: two tests are necessary to verify the solution. The first is an admissibility test: in general, in the temporary solution there are some nodes repeated that must be eliminated. A search procedure allows repeated nodes to be identified and eliminated. The second test is the capacity test previously described for the endo-crossover.

The procedure is applied a number of times determined by the *crossover rate*. The output is *child population*; some of the children are selected (according to the *mutation rate*) and the *mutation* operator is applied. The mutation used considers, in a trip chain, the swapping of two nodes. An example of mutation is shown in figure 6.

The output of the mutation is the *child set*. In this set we select the solution which has the maximum fitness (and hence minimum cost), the fitness value being compared with that of the previous solution: if the comparison satisfies the test for the last k iteration, the procedure ends, or else it is iterated. In this case, the actual child set is the parent set for the next generation.

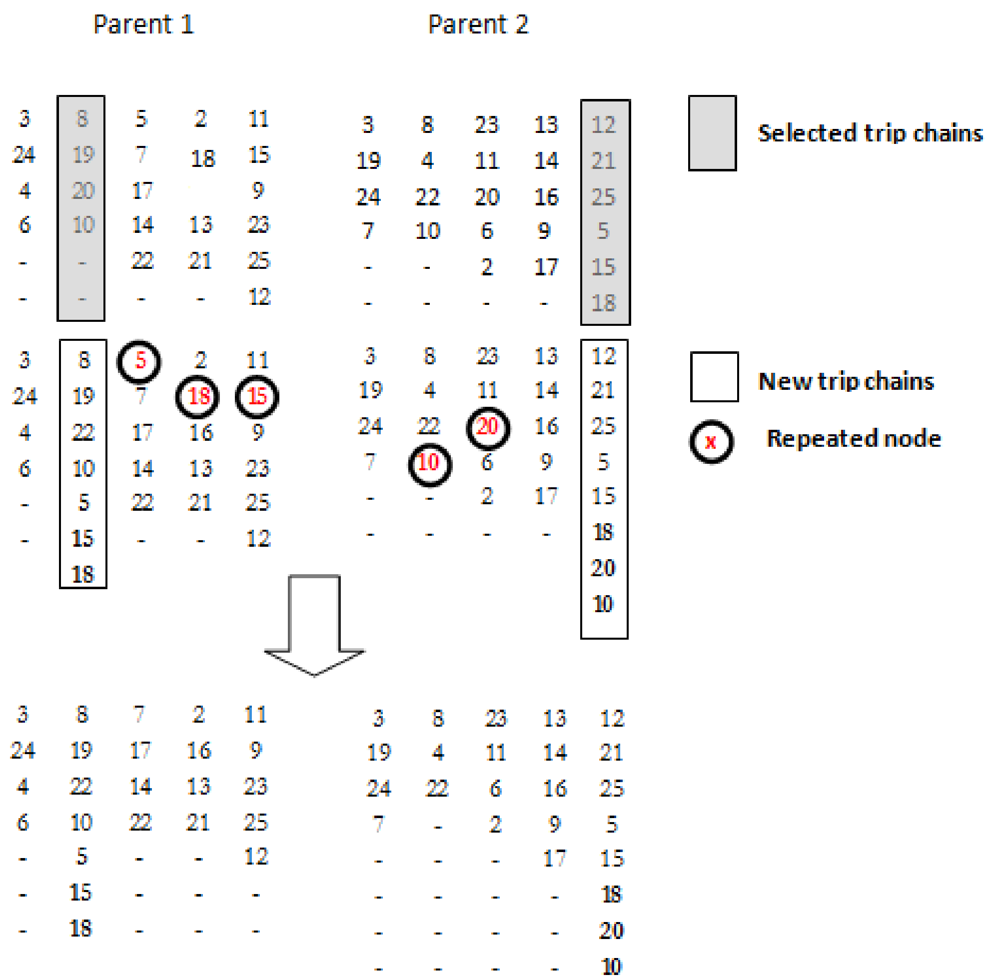

Figure 5: Eso-crossover: selection, crossing and elimination.

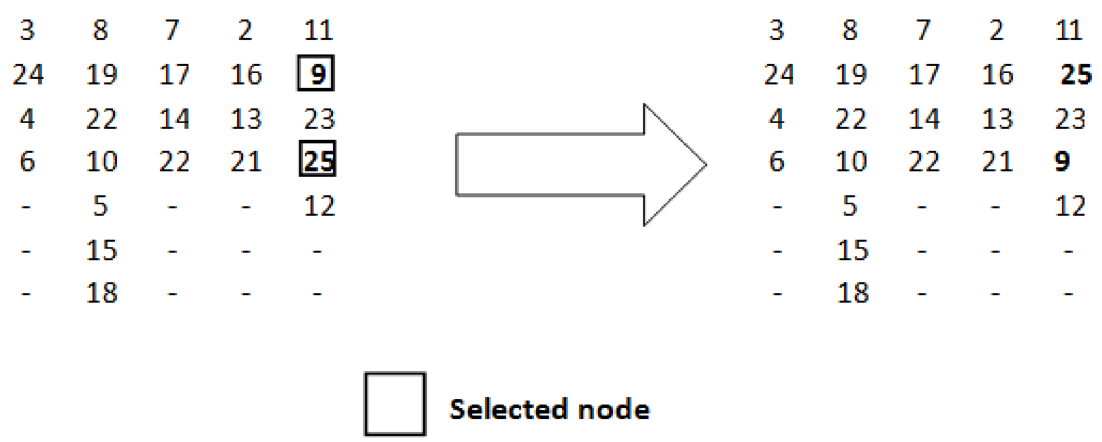

Figure 6: Mutation: selection and swapping.

5. Application

This section is divided into two parts: in the first, some test cases are proposed to evaluate performance and compare the solution provided by the algorithms proposed in the previous section; in the second we report a study in a real case.

5.1. Test cases

Test cases differ in the number of delivery points, which vary from 3 to 14. To create a test case the procedure described in sections 2 and 3 is simplified: the delivery point positions are random generated and hence also the link cost. This is sufficient for a test problem, but in a real case (section 5.2) it is necessary to apply the procedure reported in section 3 (steps 1, 2 and 3) because user behaviour has to be simulated. Under this simplifying assumption, the path cost is given and it is possible to apply a procedure to combine the generated paths and solve the vehicle routing problem.

The exact approach provides the solution to be compared with those provided by the heuristic algorithms. The solution provided by the iterated nearest insertion algorithm in 18% of cases coincides with the exact; in the other cases (82%) the variation in the solutions varies from 2.5% to 24%.

The genetic algorithm was implemented using the following best calibrated parameters:

FF variance = 0.00025
%crossover = 0.8
%mutation = 0.2
population size = 30

The results demonstrate that the solution is exact until 10 delivery points. In this case the genetic algorithm provides the exact solution whereas the solution provided by iterated nearest insertion is, on average, 7.00% greater than the exact. For a number of delivery points between 10 and 14, the genetic algorithm provides a solution greater than the exact (12.50% on average). If we consider some additional tests (i.e. with 15, 20 and 30 delivery points) the GA provides solutions worse than those provided by the INI.

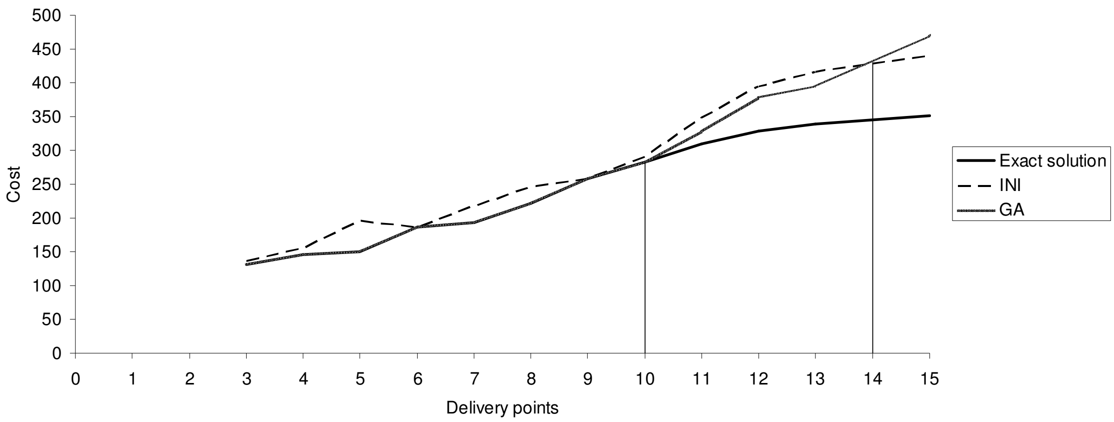

Figure 7: Results comparison.

Figure 7 reports the trend of the solutions found for each test. In addition, it also highlights the points where:

- the GA deviates from the exact solution;
- the GA provides worse solutions than those provided by the INI.

An alternative procedure is the combination between the GA and INI to improve solution goodness. In particular, the solution provided by the INI algorithm is inserted in the population, replacing the worse element after a number of fixed iterations. The tests demonstrate that, in some conditions, combined use of the genetic algorithm and iterated nearest insertion gives a better solution than that found by using the algorithms on their own (figure 8).

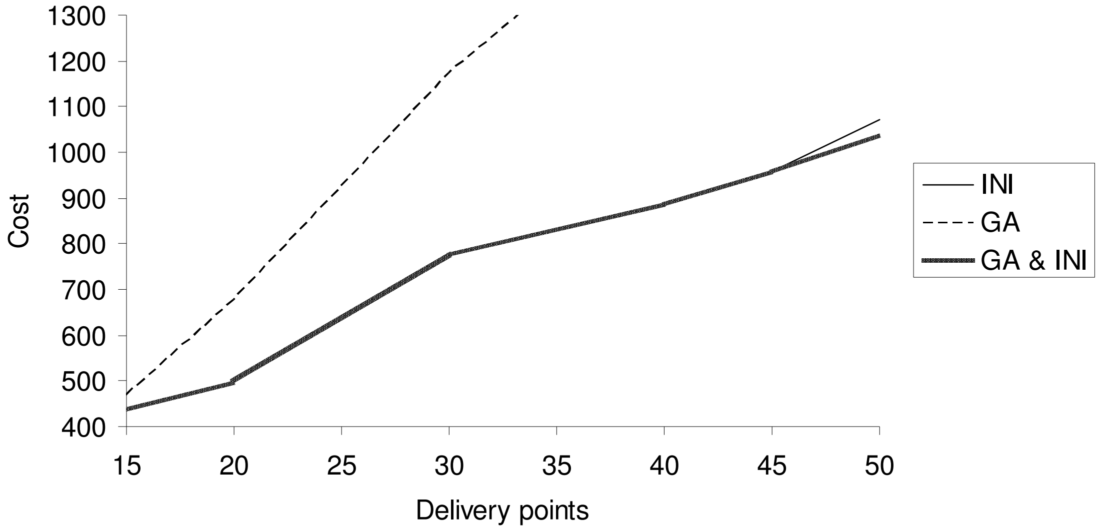

Figure 8: Combination of algorithms.

5.2. Real case

The application focuses on a real case of goods distribution in an urban area. The database concerns a sample of 1862 retailers and information collected during a survey on supply and goods distribution in the city of Palermo (CSST, 1998). Analysis showed that 17% of the retailers supply their shops on their own. Of these, 75% choose the delivery points inside the city. Focusing attention on the latter, some retailers go to the fish market and the fruit and vegetable market: these retailers have time windows to respect (market opening/closing); others go to various delivery points (food, stationery and so on). We assume that operation time is a function of the goods quantity delivered.

In relation to the framework proposed in the previous sections (figure 1) the application refers to the vehicle level, in particular to the path choice (third zoom aggregation) and to VRP (fourth zoom aggregation). Note that the VRP is addressed as the search of a paths combination that minimizes the total cost. Moreover, the goods quantity (first zoom aggregation) is that observed.

We consider two cases:

A) a retailer who supplies his shop using a single vehicle,

B) a carrier who supplies retailers using more than one vehicle.

In both cases, the approach adopted is that described in section 2. In the first step, through traffic assignment, the travel time for each element of the network is determined. In the second step, the one-to-one problem is solved by considering the travel time found in the first step. In the case (A), known the retailer shop position and the delivery points' position, the shortest paths between all possible origin-destination pairs (shop-delivery point, delivery point- delivery point, delivery point- shop) can be determined. In the case (B) the carrier depot position and the shop positions are knew; the procedure used is similar of case (A). In the third step the shortest paths are combined to find the best routes. The shortest paths combination allows to determinate a path sequence which: case A) start from the shop and go back in it, visiting the delivery points in a certain order; case B) start from the carrier depot and go back in it, visiting the shops in a certain order.

In the case (A) we have a retailer that visit four delivery points. The solution procedure applied (exact algorithm, GA, INI algorithm and GA & INI combination) give the same solution.

In case (B) we applied the GA, the INI algorithm and the GA & INI combination. Two versions of the GA are also applied (see section 4.2): GA with single crossover (GA1) and GA with double crossover (GA2). In this case, the carrier does the deliveries using a fleet of four vehicles. The results are shown in figure 9.

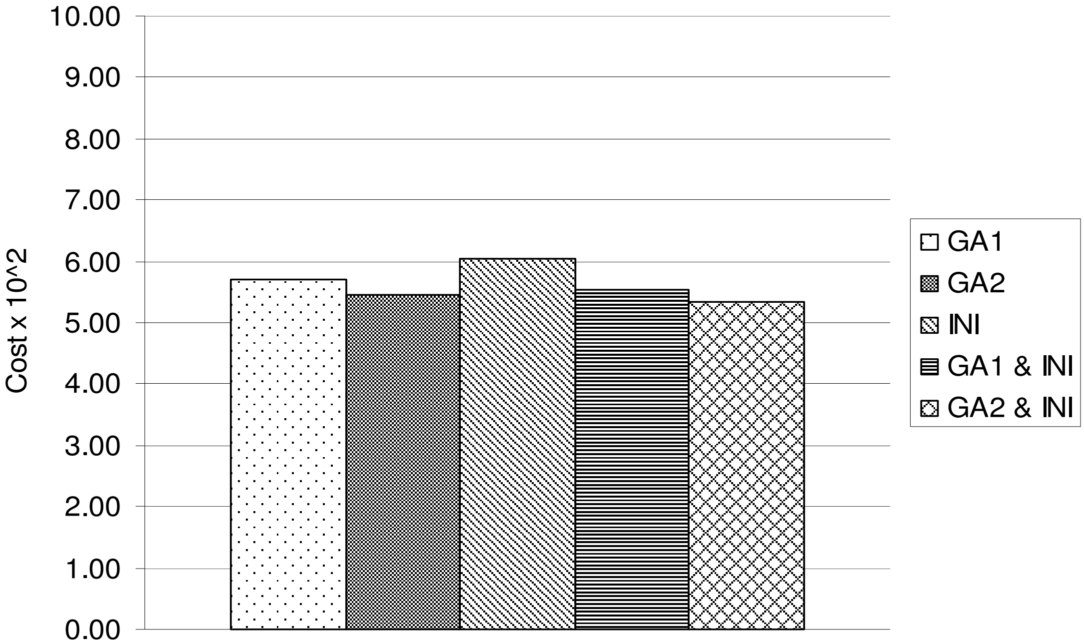

Figure 9: Case B): results comparison.

6. Conclusion

In this paper, a method to study the retailer's delivery approach is presented. A macro-architecture is reported for a model system to simulate goods movements in an urban area when the retailer is the decision-maker. In the macro-architecture four subsequent zooms are distinguished in which goods movements are analysed from the upper macro-levels (commodity and vehicle level) to path choice. Path choice is analysed by considering two problems: the one-to-one problem and the vehicle routing problem. The one-to-one problem is tackled in two cases: the mono-path case with a deterministic approach and the multi-path case with a probabilistic approach. The vehicle routing problem is formulated as a combinatorial problem whose objective is to determine the best combination of one-to-one paths in order to visit a certain number of nodes in succession: a multi-path vehicle routing problem is considered. Calculation of the shortest path requires analysis of the transport system and definition of the flow and cost vectors: to this end some methods (traffic assignment; real time cost measurement; reverse assignment) are reported.

The vehicle routing formulation involved definition of some cost terms – *travel time, operation time* and *penalty time* – to allow for various aspects of the problem – *travel, operations* and *delay/advance*.

To solve the problem we propose an exact procedure (explicit enumeration of all solutions), a greedy algorithm and a genetic algorithm; the results obtained have been compared. It emerges that for a small number of delivery points (<10) the genetic algorithm provides the exact solution whereas the solution provided by iterated nearest insertion is, on average, 7.00% greater than the exact. For a number of delivery points between 10 and 14, both the genetic algorithm and the iterated nearest insertion provide a solution greater than the exact (12.50% and 15.50% respectively).

For a number of delivery points greater than 14, the genetic algorithm provides a solution greater than that provided by iterated nearest insertion. This suggests that for a high node number it is advisable to combine the two algorithms into a hybrid algorithm to assist convergence. A first test from combining the genetic algorithm and iterated nearest insertion is proposed. Future calibration of the demand model is scheduled and application to a larger, real case will be studied. Implementation of a hybrid algorithm (genetic and nearest insertion) is also scheduled.

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European Transport \ Trasporti Europei n. 46 (2010): 24-35

Data allocation and application for time-dependent vehicle routing in city logistics

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Abstract

In city logistics, service providers have to consider dynamics within logistics processes in order to achieve higher schedule reliability and delivery flexibility. To this end, city logistics routing demands for time-dependent travel time estimates and time-dependent optimization models. We consider the process of allocation and application of empirical traffic data for time-dependent vehicle routing in city logistics with respect to its usage. Telematics based traffic data collection and the conversion from raw empirical traffic data into information models are discussed. A city logistics scenario points out the applicability of the information models provided, which are based on huge amounts of real traffic data (FCD). Thus, the benefits of time-dependent planning in contrast to common static planning methods can be demonstrated.

Keywords: City Logistics; Time-dependent; Data analysis; Data mining; Vehicle routing.

1. Introduction

City logistics is about logistics in urban areas. The focus is on concepts for fast and reliable transportation of goods in terms of cost-efficient and environmentally acceptable pickup and delivery routes. Nowadays, service providers have to consider dynamics within logistics processes, e.g. shorter delivery times, higher schedule reliability and delivery flexibility (Windt and Hülsmann (2007)). Furthermore, city logistics service providers compete against other road users for the scarce traffic space of inner cities. In conurbations, traffic infrastructure is often used to capacity.

In wide area networks, vehicle routing is usually based on distances. However, vehicle routing in city logistics networks demands for time-dependent travel time estimates for every route section. Vehicle routing based on actual travel time estimates requires empirical traffic data as a key input. Up to now, empirical traffic data has not

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been available to a sufficient extent due to prohibitive census costs. Recently, such data arises from modern vehicular communication networks.

In order to benefit from telematics based data collection, time-dependent travel time estimates have to be integrated into time-dependent vehicle routing frameworks. Whereas static approaches are well studied, time-dependent vehicle routing forms a field of potential research. Especially the preparation and the integration of time-dependent data into vehicle routing approaches is rarely focused:

- For city logistics, Fleischmann et al. (2004) design a traffic information system. Flow and speed data are collected in a field test with stationary measurement facilities and specially equipped vehicles in the metropolitan area of Berlin, Germany. The data is then aggregated and utilized in savings and insertion route construction methods. Here, the data collection methods used have surpassed by progress in technology.
- Eglese et al. (2006) refer to Floating Car Data (FCD) for time-dependent routing in a supra-regional road network in the UK. The FCD originate from a communication network consisting of trucks and coaches. Data is transmitted via text messages (SMS) and stored as a "road timetable" in a central database. In city logistics context, text messages are not appropriate for data collection due to high communication costs. The complexity of urban traffic and its variety of influences require a very thorough data collection method.
- Van Woensel et al. (2008) consider queuing theory to provide time-dependent travel time estimates. They refer to a tabu search approach to solve the time-dependent capacitated vehicle routing problem. Donati et al. (2008) focus on ant colonies to heuristically solve time-dependent vehicle routing problems. Both publications are more focused on large area networks.

In this paper, the process of allocation and application of empirical traffic data for time-dependent vehicle routing in city logistics is considered with respect to its usage. We discuss data collection and the conversion from raw empirical traffic data into information models (Section 2). An application example compares several information models based on real traffic data regarding its benefits for time-dependent route planning (Section 3). Then, the integration of information models into time-dependent vehicle routing frameworks is discussed (Section 4). Finally, the paper is concluded (Section 5).

2. From data to information models

The starting point for the estimation of time-dependent travel times for city logistics is the collection of traffic data. Reliable decisions must be derived from this raw data. Therefore, empirical traffic data has to be transformed into time-dependent information models. We shortly sketch the phases of the corresponding data chain and focus on the two main steps in terms of first and second level aggregation.

2.1. Data chain

Varying traffic flows require time-dependent routing decisions in cities. GPS based traffic data may be the source for the derivation of such decisions. The data chain ranging from GPS based collection of raw traffic data to time-dependent routing decisions is shown in Figure 1. Efficient decisions are enforced by the transformation of raw data into first level aggregated data into second level aggregated data. In particular, the elements involved are as follows:

- data collection: Taxi-FCD is a recent GPS based data collection method that provides raw traffic data in urban areas (cf. Section 2.2). Taxi-FCD result in a large data volume of city-wide traffic data, mainly based on the use of taxis as moving data sources.
- data cleaning: Erroneous data records are removed. E.g. obviously unrealistic speed observations due to GPS shadowing effects are filtered. Data cleaning is the precondition for reasonable data mining.
- data integration: The collected single Taxi-FCD records (empirical traffic data) are amended by a common digital roadmap (infrastructure data). The data is integrated into one database and aggregated for analysis purposes (first level aggregation, cf. Section 2.3).

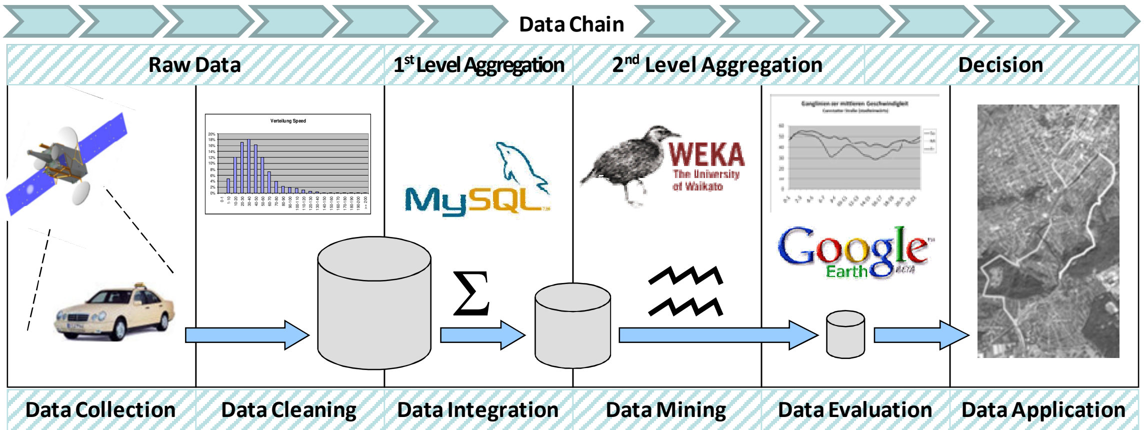


Figure 1: Data allocation and application in the context of GPS based data collection and time-dependent vehicle routing in city logistics (Ehmke et al., 2009).

- data mining: Aggregated Taxi-FCD are analyzed by means of cluster analysis. Cluster analysis is used for the allocation of time-dependent travel time estimates (second level aggregation, cf. Section 2.4). Widely-used algorithms are available in software packages like WEKA (Witten and Frank (2005)), also being used for this research.
- data evaluation: The travel time estimates are subject to evaluation and presentation because routing algorithms require realistic travel time estimates. To this end, the travel time estimates are visualized in daily courses in order to be compared with typical traffic patterns. Furthermore, geographical information systems like Google Earth (Google Earth KML 2.0) are involved. In this paper, we refer to a computational routing experiment in order to evaluate the information models from first and second level aggregation in contrast to travel time estimates based on a common digital roadmap (cf. Section 3).
- data application: The final step comprises the integration of time-dependent travel time estimates in time-dependent optimization frameworks (cf. Section 4).

2.2. Raw data

In order to derive travel time estimates for city logistics, city-wide data collection is necessary. To this end, conventional data collection methods are of limited use because they require a tremendous amount of effort (Gühnemann et al. (2004)). Typically, for vast parts of the city road network no data samples are available.

Traffic data can be collected by using telematics systems in terms of FCD. Recently, GPS have been propagated and are widely used for routing purposes. The Taxi-FCD project run by the German Aerospace Center (DLR) implements the idea of using taxis as mobile data sources for the collection of FCD. Here, a fleet of taxis characterized by typically high mileage is the basis of the system. The taxis are already equipped with GPS based navigation systems used for taxi disposition, hence causing no further costs for data transmission. Taxis transmit their current positions approximately every minute via digital radio trunking. A more detailed description of the data collection method can be found in Brockfeld et al. (2007). DLR has developed several map-matching and data handling algorithms. For the processing of the raw data, a general overview on Taxi-FCD and applications see Lorkowski et al. (2004) and Lorkowski et al. (2005). The structure of a resulting FCD record serving as input for the determination of time-dependent travel time estimates is shown in Table 1.

Table 1: Structure of Floating Car Data records.

TIME	*LINK*	*SPEED*
time of positioning	road segment ID	determined speed [km/h]
2003-08-01 07:01:22	54362718	50.73

2.3. First level aggregation

The raw Taxi-FCD records are filtered, integrated into a single database and then precalculated in terms of time-dependent aggregation. Here, raw traffic data evolve into planning data (first level aggregation). FCD speed averages are calculated for each link $\boldsymbol{l}$ according to the harmonic mean of the single measurements $v_{lw} = n / \sum_{i=1}^{n} \frac{1}{v_{lwi}}$, with $\boldsymbol{n}$ being the number of speed measurements for $\boldsymbol{l}$ within time interval $\boldsymbol{w}$ and $\boldsymbol{v_{lwi}}$ being the single vehicle speed. The result is a mean FCD speed $\boldsymbol{v_{lw}}$ for each link $\boldsymbol{l}$ and time interval $\boldsymbol{w}$, being the fundament for the derivation of time-dependent travel time estimates. If the data coverage is rather low, the median can be taken as a robust representation of $\boldsymbol{v_{lw}}$, alternatively.

The total number $\boldsymbol{W}$ of time intervals must be determined according to the requirements of the city logistic application. In the literature, several selections of $\boldsymbol{W}$ have been defined. E.g., Eglese et al. (2006) refer to 15 time intervals of different length per day ($\boldsymbol{W}$ = 15 x 7), whereas Ichoua et al. (2003) use 3 time intervals after "careful observation" of real traffic data.

Corresponding to common analysis methods from the area of traffic research (e.g. Pinkofsky (2006)), we refer to FCD by establishing 24 time intervals per day ($\boldsymbol{W}$ = 24 x 7). The resulting speed averages are referenced to as "FCD hourly average" (FH) (see Table 2). FH is supposed to cover expected fluctuations in travel times during 24 hours of the day and 7 days of the week.

Table 2: FCD hourly averages (FH) example for a link [km/h].

Time	*0-1*	*1-2*	…	*3-4*	…	*8-9*	…	*16-17*	…	*22-23*	*23-24*
Sun	47	52	…	55	…	50	…	42	…	47	50
Fri	47	52	…	52	…	33	…	31	…	44	46

For interpretation and analysis purposes, FH data can be transformed by normalization procedures in the following two ways. A min-max normalization into the interval [0,1] can be interpreted as daily course of speed variation for every link with focus on relative minimum and maximum speed. On the contrary, a normalization based on means describes daily courses of speed variation with focus on average speeds.

FH based planning algorithms for vehicle routing must cope with a huge amount of travel time estimates. However, limited memory capacities, complex vehicle routing algorithms and the desire for fast and reliable routing decisions require the reduction of the volume of input data without a significant decrease of reliability. The following cluster analysis approach responds to these requirements by providing weighted FCD averages in terms of second level aggregation.

2.4. Second level aggregation

In this section, we introduce data mining as important component of the data chain. We focus on weekday dependent clustering of FH data for the efficient allocation of time-dependent travel time estimates. The resulting clusters are supposed to characterize included links with similar speed variations. Thus, the data input for vehicle routing algorithms can be reduced by data mining (second level aggregation).

Table 3: Normalized FCD hourly averages example for a link.

Time	*0-1*	*1-2*	…	*3-4*	…	*8-9*	…	*16-17*	…	*22-23*	*23-24*
Sun	0.4	0.8	…	1.0	…	0.7	…	0.1	…	0.4	0.6
Fri	0.8	1.0	…	1.0	…	0.2	…	0.1	…	0.6	0.7

Normalized FH data (cf. Table 3) are clustered by the use of a $\boldsymbol{k}$-means algorithm (MacQueen (1967)). The $\boldsymbol{k}$-means algorithm is a partition-based clustering algorithm, requiring the number $\boldsymbol{k}$ of desired clusters and a distance function as input. The algorithm then iteratively minimizes the error sum of the data objects' distances to the cluster centers.

We parameterize the $\boldsymbol{k}$-means algorithm by a Euclidean distance function. In order to achieve a meaningful estimation of $\boldsymbol{k}$, we propose the determination of internal indices evaluating the quality of a clustering. The idea is to repeat a clustering with ascending size of $\boldsymbol{k}$, and then compare the results of the index (Tan et al. (2006), Jain and Dubes (1988)), e.g. the error amount of squares in partitioning clustering approaches. The general trade-off is as follows: On the one hand, $\boldsymbol{k}$ must be large enough to give a good approximation of the actual link travel time variations. On the other hand, $\boldsymbol{k}$ should be kept as small as possible in order to minimize the input data for routing algorithms.

Clustering of normalized FH data leads to a compact representation of time-dependent travel time estimates in terms of discount factors. The discount factors represent typical speed variations for the derivation of time-dependent travel time estimates. The main idea is to look up a link's discount factor and then weight a robust speed figure (e.g. average speed or maximum speed). Thus, the resulting information model is referenced as "Floating Car Data Weighted Averages" (FW).

Table 4: From the cluster analysis resulting discount factors (example with k = 4).

Cluster	*0-1*	*1-2*	*…*	*3-4*	*…*	*8-9*	*…*	*16-17*	*…*	*22-23*	*23-24*
1	0.71	0.76	...	0.79	...	0.25	...	0.23	...	0.59	0.65
2	0.64	0.65	...	0.63	...	0.52	...	0.53	...	0.64	0.64
3	0.43	0.46	...	0.55	...	0.30	...	0.27	...	0.38	0.41
4	0.78	0.76	...	0.77	...	0.48	...	0.45	...	0.71	0.75

An example result of clustering is given in Table 4. Each cluster represents a group of links. Each link is associated with its groups' representative vector of 24 discount factors. Thus, time-of-the-day specific link speeds can be derived by using the time-of-the-day specific discount factor and weighting it by its link's mean speed. This leads to enormous savings regarding input data for vehicle routing.

Table 5: Comparison of required volume of input data regarding different information models.

Information model	digital road map	FCD hourly average (FH)	weighted FCD average (FW)
Input data	n	t x d x n	n + (t x d x k)
Input data Stuttgart (t = 24, d = 7, n = 100 000, k = 4)	100,000	16,800 000	100,672
Input data Stuttgart per link	1	168	1.01

Notes: n = number of links, t = number of time intervals, d = number of days, k = number of clusters.

In Table 5, the resulting information models are compared in terms of the volume of input data for routing algorithms. Therefore, the resulting volume of input data is described formally and instantiated with specific figures from empirical FCD of Stuttgart, Germany (cf. Section 3). For a comparison of the information models from an algorithmic point of view, we point out the resulting amount of input data per link. Whereas a common digital roadmap would result in 100,000 travel time estimates or one travel time estimate per link, the FH information model amounts up to 16,8 millions travel time estimates to be considered. The FW approach results in 100,672 travel time estimates, indicating an upper bound of data reduction for the Stuttgart example from 168 travel time values (FA) to only 1.01 travel time values (FW) per link.

3. Example city logistics application

In this section, we provide time-dependent information models and evaluate its benefits in a city logistics context. The advantages of time-dependent planning for the reliability and the robustness of planned routes are demonstrated, contrasting disadvantages of common static planning methods. Therefore, a huge amount of FCD from the area of Stuttgart, Germany from the years 2003-2005 is processed as described before. All in all, about 230 million data sets are analyzed and aggregated in terms of first and second level aggregation, leading to FH and FW information models.

3.1. Experimental setting

The experimental setting comprises a fictitious city logistics application for the area of Stuttgart, Germany, as well as the usage of several information models and several traffic scenarios. We plan and simulate itineraries that are affected by a high fluctuation of travel times, thus requiring the consideration of time-dependency. The following questions are discussed:

- Which information model leads to the realization of the time-shortest itinerary?
- Which information model results in the most reliable travel time prediction?

To this end, several kinds of travel time estimates are used for route planning. We compare the resulting itineraries with respect to the realization of the fastest route and the most reliable travel time estimation. The itineraries' realization is done by simulation of the planned routes. Here, simulation means the recalculation of planned routes based on "true" travel times for specific days and time slots. The required "true" travel times have its seeds in a travel time database provided by the DLR, resulting from calendar date specific FCD of about 40 Mondays. Itinieraries are calculated using *Dijkstra's algorithm* (Dijkstra (1959)). Each route is denoted by its anticipated duration and its network links used.

The following *information models* provide travel time estimates for route planning:

- Digital Roadmap (DR): Travel time estimates associated with the links of the digital roadmap of Stuttgart serve as a static benchmark for the following FCD based travel times.
- FCD hourly averages (FH): Travel time estimates resulting from first level aggregation, depending on day of the week and time of the day.
- FCD weighted averages (FW): Travel time estimates resulting from second level aggregation, depending on day of the week and time of the day.

The following *representative traffic network scenarios* are considered for route planning. They have been identified by the observation of typical traffic states in urban areas (Ehmke et al. (2008)):

- "free flow network" (Monday 3-4 am),
- "early rush hour" (Monday 8-9 am),
- "average traffic" (Monday 11-12 am) and
- "late rush hour" (Monday 4-5 pm).

Itineraries are calculated for each combination of traffic network scenario and information model. Thus, the influence of time-dependency on planning quality can be demonstrated.

3.2. Example itinerary: airport – main station

Planning results for one interesting example itinerary are presented in Table 6. The given itineraries comprise routes between the outskirts of the city (airport) and Stuttgart main station (downtown). Generally, these routes are heavily frequented. Hence, a high fluctuation of the travel time is to be expected, enforcing the consideration of time-dependency in route planning.

Table 6: Extract from computational results for one route (airport – main station).

	DR: digital roadmap					*FH: FCD hourly averages*					*FW: Weighted FCD averages*				
	anticipated	simulated	diff	diff	std-dev	**anticipated**	simulated	diff	diff	std-dev	**anticipated**	simulated	diff	diff	std-dev
	(min)	(min)	(min)	(%)	(min)	**(min)**	(min)	(min)	(%)	(min)	**(min)**	(min)	(min)	(%)	(min)
3-4 am	**11.4**	14.8	3.4	29 %	1.89	**14.4**	14.2	0.9	6%	0.89	**14.1**	14.1	1.0	7%	0.95
8-9 am		22.2	10.8	95%	2.75	**19.7**	18.9	1.5	8%	1.31	**20.9**	23.2	3.4	16%	3.34
11-12 am		17.3	5.9	51%	2.27	**17.5**	17.2	1.2	7%	1.04	**18.4**	17.7	1.9	10%	2.06
4-5 pm		23.5	12.1	106%	3.17	**18.1**	18.1	1.4	8%	1.54	**20.6**	18.4	2.7	13%	1.37

In the digital roadmap case (DR), there is only one anticipated duration resulting from only one static travel time estimate per link, whereas FH and FW data allow for time-dependent travel time anticipations (cf. columns "anticipated"). The use of DR data for route planning leads to a time-independent travel time anticipation of 11.4 minutes and an average simulated route duration of e.g. 22.2 minutes (cf. "simulated", based on FCD "true" travel time) in the early rush-hour (8-9 am). The simulated route durations differ 10.8 minutes (or 95%, cf. "diff") from the anticipated route duration and are characterized by a standard deviation (cf. "std-dev") of 2.75 minutes. In contrast, FH based planning leads to a time-dependent travel time anticipation of 19.7 minutes and a simulated route duration of 18.9 minutes in average, which represents a significant decrease in differences and an increase in planning reliability (8-9 am). Differences are higher in the FW case (e.g. 16% in the early rush-hour), which is reasoned by a loss of accuracy due to the aggregation by cluster analysis.

Altogether, FH data leads to itineraries characterized by short durations and high planning reliability throughout all traffic scenarios. FW information models lead to slightly higher differences than in the FH case, but much lower than in the DR case. Static information models like the common digital roadmap can hardly reflect fluctuations in travel times.

3.3. Overall results

An aggregated overview on all computational results is given in Table 7. Experiments are based on 48 city logistics scenarios and about 4000 route simulations. Here, the information models are compared in terms of overall quality (cf. "mean difference") and reliability (cf. "mean std-dev"). The columns "mean difference" and "mean std-dev" denote the average difference from "true" travel times as a figure for planning quality and the mean standard deviation within this difference as a figure for planning reliability, respectively.

Table 7: Comparison of several information models.

	mean difference	mean std-dev	duration		difference		standard deviation	
			count	%	count	%	count	%
DR	72%	3.10	5	10%	0	0%	2	4%
FH	8%	1.47	48	100%	48	100%	47	98%
DR	72%	3.10	11	23%	1	2%	6	13%
FW	13%	2.08	42	88%	47	98%	42	88%
FH	8%	1.47	43	90%	44	92%	37	77%
FW	13%	2.08	15	31%	4	8%	11	23%

The DR information model features relatively high differences (72%) between anticipated and simulated routes in comparison with FH (8%) and FW (13%) information models. Thus, planning quality is relatively higher in the FH and FW case. The same is valid for the "mean standard-deviation", which is the smallest in FH case (1.47 min) and the highest in the DR case (3.10 min).

In the remaining six columns, the information models are compared to each other pair-wisely with respect to the provision of the number of actually fastest routes ("duration"), actually smallest differences ("difference") and actually smallest standard deviation ("standard deviation"). E.g. DR based planning results in the actual fastest route in only 5 cases (or 10 %), whereas FH based planning provides the relatively fastest route in all cases. The main conclusion is that FH as a comprehensive information model leads to relatively reliable and short routes. However, the cluster analysis based FW approach is useful for time-dependent planning, resulting in much more reliable and shorter routes (88 %) than in the static DR case and reducing effort for planning algorithms.

4. Integration of information models for time-dependent vehicle routing

As subsequent step to data analysis, this section provides an overview on the characteristics of time-dependent problem formulations. The main goal is to integrate the information models presented into a time-dependent optimization framework. In "static" city logistics networks, customers are usually represented by vertices. Vertices are connected by edges which represent shortest paths between customers in terms of distances or static travel time estimates. Each edge is associated with its static cost, duration or travel time.

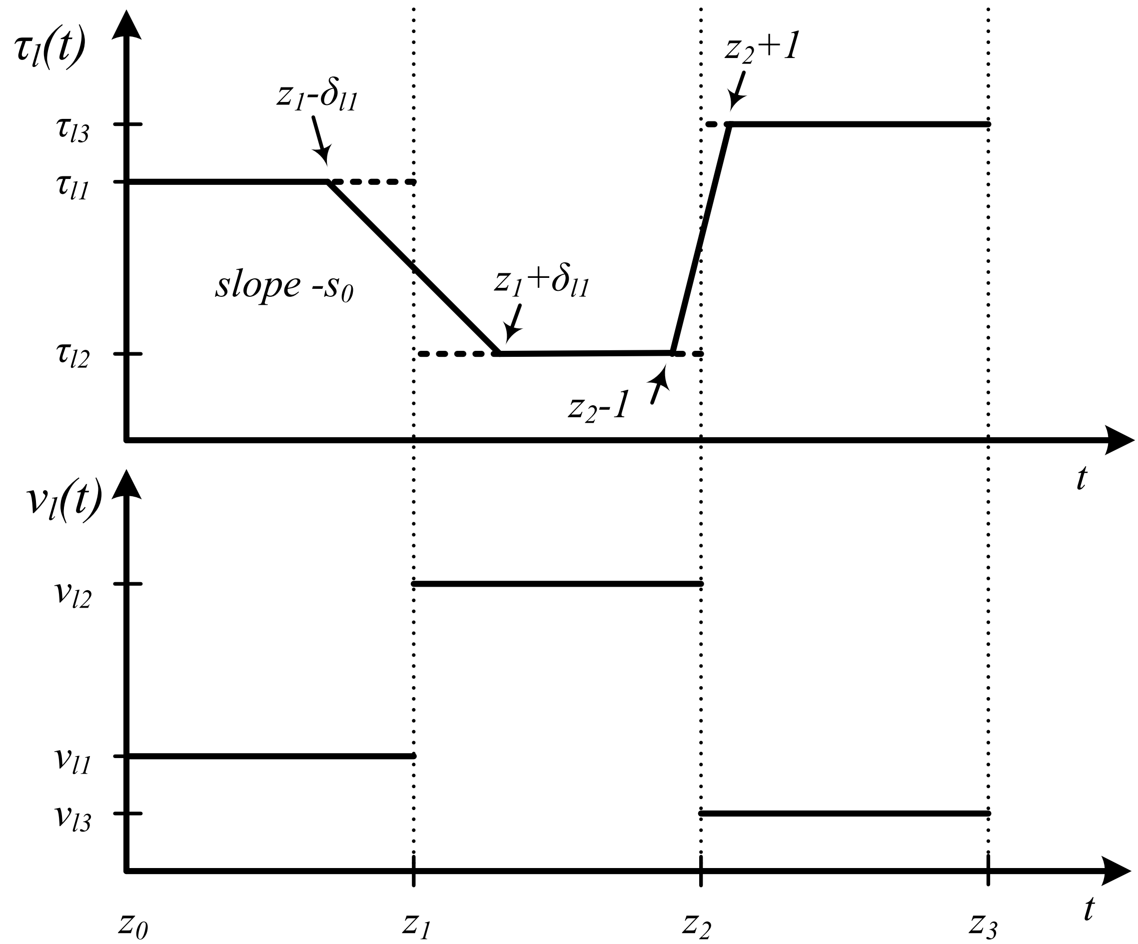
In contrast to static networks, time-dependent networks have to consider varying travel time estimates for each edge. Thus, the travel time is modeled as a function of departure time, which is to be determined in advance. Travel time functions are distinguished into integer and real valued functions, also known as discrete and continuous modeling (Dean (1999)).

In a discrete setting, time-dependent travel time estimates are usually approximated by piecewise-linear functions. Therefore, the time horizon considered has to be partitioned into an appropriate number of time intervals $\boldsymbol{W}$. In the continuous case, travel time functions are estimated based on e.g. empirical traffic data.

Travel time estimation based on empirical traffic data does not guarantee FIFO behavior. In FIFO networks, vehicles do not "pass" each other, i.e. vehicles arrive in the order they commence an edge ("non-passing condition", Kaufman and Smith (1993), Ichoua et al. (2003)). FIFO networks allow for time-dependent shortest path calculation in terms of a trivially-modified variant of any label-setting or label-correcting static shortest path algorithm like Dijkstra's algorithm (cf. Dijkstra (1959)). This is due to the following properties, resulting in reduced complexity of time-dependent vehicle routing (Dean (1999)):

- In FIFO networks, waiting at nodes delays arrival.
- In FIFO networks, one always finds shortest paths which are acyclic.
- In FIFO networks, one always finds shortest paths whose subpaths are also shortest paths.

Figure 2: Construction of the piecewise linear travel time function, including linearization at jumps z_1 and z_2.



The information models presented lead to piecewise-linear travel time functions, ignoring the FIFO property. Thus, the travel time function jumps between two time intervals, and passing may occur if the travel time decreases. Fleischmann et al. (2004) solve this problem by introducing a “smoothed” travel time function that transforms non-FIFO into FIFO networks. Therefore, the jump between two intervals is linearized.

In Figure 2, the derivation of travel times τ_{li} from average speeds v_{li} is illustrated for an example link l. The travel time function τ_l(t) results from the FH or FW information model and features several jumps at z_i. E.g. at z_1, the average speed changes from relative low to relative high speed, inducing a rather long or rather short travel time, respectively. This change is not FIFO valid; a vehicle starting shortly before z_1 would be overtaken by a vehicle starting shortly after z_1. Fleischmann et al. (2004) handle these jumps by linearizing the travel time function in the range $[z_i - \delta_{li}; z_i + \delta_{li}]$. The corresponding slope $-s_0$ is not allowed to become larger than s = 1, assuring the FIFO property. In the case of increasing travel times, the slope can be chosen freely.

More on basic concepts of time-dependent shortest paths can be found in a survey paper by Dean (1999). Pallottino and Scutella (1997) give an application driven overview on shortest path algorithms. A recent overview on algorithms for both the discrete and continuous case as well as a performance comparison is provided by Ding et al. (2008). Furthermore, Dell’Amico et al. (2008) introduce an approach for non-FIFO time-dependent networks.

5. Conclusions

This paper considers the allocation and application of travel time estimates for time-dependent vehicle routing in city logistics. Here, telematics based traffic data is converted into time-dependent planning data. An approach for sophisticated data analysis including data clustering and reduction of memory requirements for routing algorithms is introduced. The resulting information models are compared regarding usefulness for time-dependent route planning in terms of a fictitious city logistics example, based on real traffic data. The time-dependent calculation of shortest paths is identified as important part of an efficient and realistic representation of the road network typology for time-dependent planning problems.

The experiments underline the superiority of time-dependent information models (FH, FW) over common static data sets. FCD based time-dependent travel time estimates lead to more reliable routing results compared to route planning based on common digital roadmaps. The data mining approach presented provides time-dependent travel times in a memory efficient way without a significant reduction of the itineraries' reliability and robustness.

This paper focused data collection and application dependent provision of time-dependent travel time estimates. Based on this contribution, time-dependent optimization frameworks can be built, which integrate time-dependent information models and time-dependent optimization models. Thus, reliable delivery services can be provided.

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A community of agents as a tool to optimize industrial districts logistics

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Abstract

The aim of this paper is to find an optimal solution to operational planning of freight transportation in an industrial district. We propose a system architecture that drives agents – the industrial district firms - to cooperate in logistic field, to minimize transport and environmental costs. The idea is to achieve logistics optimization setting up a community made of district enterprises, preserving a satisfactory level of system efficiency and fairness. We address the situation in which a virtual coordinator helps the agents to reach an agreement. The objectives are: maximizing customers satisfaction, and minimizing the number of trucks needed. A fuzzy clustering (FCM), two Fuzzy Inference System (FIS) combined with a Genetic Algorithm (GA), and a greedy algorithm are thus proposed to achieve these objectives, and eventually an algorithm to solve the Travelling Salesman Problem is also used. The proposed framework can be used to provide real time solutions to logistics management problems, and negative environmental impacts.

Keywords: Logistics optimization; Industrial districts logistics; Inter-firms relationship; Fuzzy multi-agents systems.

1. Introduction

Pyke and Sengenberger (1992) describe the main characteristic of an Industrial District as "the existence of strong networks of (chiefly) small firms". This "togetherness" implies a cultural homogeneity that gives rise to an atmosphere of cooperative and trusting behaviour in which economic action is regulated by implicit and explicit rules. Marshall (1925), the author of the original concept of the Industrial District, identified also a class of external economies obtained by individual firms from the increased pooling of common factors that include skilled human resources, specialized suppliers, and technological spillovers. Different models have been proposed to investigate inter-firm relationships in Industrial Districts, such as constellations of firms, flexible specialisation model, milieux innovateurs, firm networks, and clusters. Each model emphasises different and complementary aspects of

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Industrial Districts, yet all of them focus on the features of inter-firm relationships (Carbonara, et al. - 2002). These models show that cooperation among Industrial District firms could represent a way to improve their competitiveness. According to this, in this paper we assert that Districts Firms should operate in a cooperative way, in order to optimize logistics performance.

Today, logistic chain has been playing an increasing role in industrial system. The key issue to its optimization is to deliver the goods on time, in order to assure customer satisfaction and, at the same time, to minimize the costs. Many efforts have been endeavouring to improve the logistic performance to achieve high agility without increasing costs.

For the logistic system, the optimization problem is a multi-objective problem. In fact, conflicting variables like, for example, the difference between proposed and desired delivery dates, and the number of trucks used have to be optimized. Although an optimal combination of criteria is highly desirable, this combination is very difficult in practice. With the increase of agents' expectations in terms of low costs and high quality of services, the logistic planning projects are involving trade - offs among different incompatible goals.

This research proposes a method to combine these criteria using the Fuzzy Logic. The work focuses on optimization of freight transportation demand expressed by firms in an Industrial District. The aim is to find an optimal solution, or rather the nearest one to the optimum, in solving logistic problems. The paper also offers evidence that firms working in a cooperative way show a higher performance.

The paper is developed as follows. In the following section there is a short outline of logistics' district management, and the relationships among the industrial district firms. The second section shows an application that achieves the creation of a Logistics Community among district agents. The last section presents a case of study, some final remarks and suggests future developments of the research.

2. The logistic in Industrial Districts

2.1 Logistic problems

Industrial Districts are territorial agglomerations of small-medium firms located into a specific geographic area, and integrated through a complex network of inter-firms relationships. According to Carbonara et al. (2002), Industrial Districts have three different evolution stages: Formation, Development and Maturity. During the first stage, the dimension of an Industrial District is set up as the local area, characterised by craftsman-like firms, in which two main processes can take place: (1) decentralisation of production, carried out by large firms internal or external to the area, or (2) agglomeration of a craftsman-like entrepreneurial system within that area. This stage of the district's evolution process (Formation) is characterized by rare or absent relationships among firms. In fact, each of them tries to get its target by competing with others, increasing the complexity of the system. In Industrial Districts there is frequently a lack of inter-firm relationships: companies don't know each other, so they behave like individual agents. Therefore, "coordination" and "interaction" could represent a chance to solve logistics optimization problems, taking advantage of possible external economies.

Small firms – as is usual in Industrial Districts - could deal with more problems than big companies in logistics. Usually, small district firms contact one by one transportation services providers, just when they need to deliver their products. In other words, small and medium firms generally require "on demand" transportation services. However, vehicles used for transportation are frequently not filled up, since production of a single company could be not enough to fill a truck. As a consequence, transportation costs and external diseconomies such as accidents, pollution and traffic congestion increase.

3. An approach to logistic optimization in an Industrial District

The advantages to be an Industrial District firm are represented by the external economies that the District produces when firms work together. Organizations frequently require decisions to be made by a cooperative group. A decision may involve optimization of multiple conflicting objectives that should be considered simultaneously. The final decision is then selected from a set of "good" alternative solutions using a set of selection criteria. Consequently, the aim in making group decisions with multiple objectives is to obtain a satisfactory solution that is the most acceptable for the group of individuals as a whole over the set of optimal solutions (Bui, 1989; Korhonen and Wallenius, 1990; Lu and Quaddus, 2001).

Our proposed system takes into account conflicts and aggregation situations among group members. The final decision is expected to be the most acceptable by the group of individuals as a whole.

3.1 Proposed solution: Creation of an Agent's Community

In this paper, we propose the creation of a network among logistics services customers, in the following called "agents". The proposed network allows a set of agents improving logistics through information exchange and negotiation, and reaching a mutual agreement about goals or plans. We assumed that negotiation is more efficient if information is available to all parties. However, this approach requires all parties to surrender part of their privacy, that is to reveal their shipment demand attributes. Since they are basically unwilling to disclose private information during a negotiation (Heiskanen et al., 2001), the system minimizes the amount of information that agents reveal about their preferences. In the presented framework, agents are aware of the existence of other similar agents. However, they do not have an explicit view of the information about the shipment demand provided by other agents. The information match is done by the Virtual Coordinator, as explained in the following sections.

We have considered both vertical and horizontal relationships power in supply chains. Although logistics cooperation often have a vertical perspective (e.g., buyer-supplier), horizontal cooperation is considered an interesting approach to decrease costs, improve service, or protect market positions among others. This, despite the competitive element in horizontal cooperation increases the threat of opportunism, and lowers the level of trust. In fact, a participant may use information to improve its market position at the expense of other participants (Dullaert et al., 2007). Some examples of horizontal cooperation in logistics are - as defined by the European Union (2001) - manufacturers consolidation centers (MCCs), joint route planning, and buyers groups.

The proposed tool facilitates contacts and negotiation processes among agents that start acting, in this way, like a community of agents in the district. In fact, they can set up groups of agents agreeing on delivery dates, so that more agents can share the same vehicle, reducing consequently the number of vehicles used for shipment. Of course, the filling rate of vehicles increases.

The attractiveness of being a community is related to the increase of utility perceived by agents. In this case, the expected pay-off is made up of rationalization of material flows within the Industrial District.

3.2 Methodology

In decision-making practice, individual preferences are often expressed through linguistic terms, which reflect imprecise values. Thus, precise mathematical models could be not able to easily tackle such situations. Instead, Fuzzy Logic can deal with problems having approximate or uncertain data. Indeed, to build a customer's coalition frequently we need to handle imprecise or lacking information about agents preferences. Therefore, in this paper we have proposed a fuzzy approach.

The Fuzzy Logic was introduced by Zadeh (1965). More recently, approaches for aggregating fuzzy opinions in multiple criteria decision-making were investigated (Kacprzyk, 1992). The basic principle is grounded on the degree of membership (Md) of an element x to a set A. In classical crisp logic, the membership function can takes only two values: if x is a member of A, then Md is 1; otherwise, Md is 0. Instead, in Fuzzy Logic an element x can be "partially" included into a set A, so the value of its Membership Function belongs to interval [0,1].

In this paper we use the Fuzzy C-mean for the cluster creation, and the Fuzzy Inference Systems (FIS) for evaluating the agent's satisfaction, and the "goodness" of solution, as explained in the following paragraphs.

3.3 Fuzzy C – mean : Clusters formation

We have used the Fuzzy C-mean to find a possible coalition among district's agents, comparing their different demands and finding similarity among them. The similarity concept could involve imprecise evaluations: for example, in case of goods transportation, similarity of two different demands could be measured through the distance between their shipment dates. This distance could be defined using linguistic statements such as: "far" or "close". In this case, the closer the dates, the more similar are the demands. Fuzzy C-means (FCM) algorithm is thus useful to handle these imprecise values, to find similarity among different demands, and consequently to find possible coalitions.

Let n be the number of transportation demands submitted by agents. These demands are clustered into C clusters ($2 \leq C \leq n$), homogenous with respect to a suitable similarity measure. The goal is dividing shipment demands in such a way that demands assigned to the same cluster should be as similar as possible, whereas two objects belonging to different clusters should as dissimilar as possible. However, fuzzy clustering algorithms usually require that the number of clusters be previously defined by the user (Höppner et al., 1999). This is quite restrictive in practice, since the number of clusters in a data set is generally unknown, especially in real-world data involving overlapping clusters. In order to get around this difficulty, in our case the system makes clusters from 2 to n.

In other words, when the agents' shipment demands n = 5, the Fuzzy C-mean clusters them into 2, 3, 4, and 5 clusters, according to the similarity of demands. The value of Md indicates the degree of membership to Ci cluster for each agent.

In the following Table 1 the relevant pseudo-code is shown:

Table 1: The Fuzzy C-Mean pseudo-code.

1. Initialize $U = \left[\mu_{ij}\right]$ matrix,
2. Calculate the cluster centers :

$$c_j = \frac{\sum_{i=1}^{N} \mu_{ij}^{m} \cdot x_i}{\sum_{i=1}^{N} \mu_{ij}^{m}}$$

3. Compute distances:

$$d_{ij}^2 = \left(x_j - c_i\right)^T \left(x_j - c_i\right)$$

4. Update partition matrix:

$$\mu_{ij} = \frac{1}{\sum_{k=1}^{c} \left(d_{ij} / d_{kj} \right)^{2/(m-1)}}$$

5. $\left\| U^{(k+1)} - U^{k} \right\| < \varepsilon$ then STOP; otherwise return to step 2

The algorithm starts choosing just one arbitrary partition P, calculates the cluster centres c_j, and updates partition matrix U. This process goes on iteratively until partitions are "near enough" each other.

In the following, we show an example of matrix U when the shipment demands are 5.

Table 2: U similarity matrix.

$$U_2 = \begin{bmatrix} 0.9 & 0.06 \\ 0.9 & 0.05 \\ 0.5 & 0.4 \\ 0.01 & 0.9 \\ 0.8 & 0.1 \end{bmatrix} \qquad U_3 = \begin{bmatrix} 0.8 & 0.07 & 0.02 \\ 0.9 & 0.06 & 0.02 \\ 0.01 & 0.9 & 0.01 \\ 0.0001 & 0.0001 & 0.9 \\ 0.45 & 0.44 & 0.09 \end{bmatrix}$$

$$U_4 = \begin{bmatrix} 0.8 & 0.08 & 0.03 & 0.01 \\ 0.7 & 0.2 & 0.05 & 0.02 \\ 0 & 0.0001 & 0.9 & 0 \\ 0 & 0 & 0 & 1 \\ 0.002 & 0.9 & 0.002 & 0.0007 \end{bmatrix} \qquad U_5 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The number of rows is equal to the total number of demands, and the number of columns is equal to the number of clusters considered.

3.4 Fuzzy Inference System : The evaluation of agents satisfaction, and the "goodness" of solution

The finding of the best clustering solution requires efficient criteria to quantitatively measure the quality of the solutions (Milligan, M.C. Cooper, 1985). Several criteria for fuzzy clustering assessment have been proposed in literature (see for example Halkidi, et al., 2001).

This paper proposes a new "cluster validity measure" as a criterion to help the decision making process for managing logistic district problems. We evaluate the solution on the basis of the results made by two Fuzzy Inference Systems (FIS).

The first one measures the agents satisfaction for the solution proposed by the algorithm. The degree of satisfaction of each solution is calculated using a set of fuzzy rules. The input variable in our system is the favourite day for the delivery, along with a range of dates. The closer the delivery date proposed by the system to the favourite date, the higher the satisfaction. The input can be divided in the three Fuzzy set, as illustrated in Figure 1. Note that in this figure the variable "date" is normalized, that is its values have been rescaled in the range [0,1], taking into account minimum and maximum values, in order to make the system adaptable for all possible intervals and to simplify the modeling process.

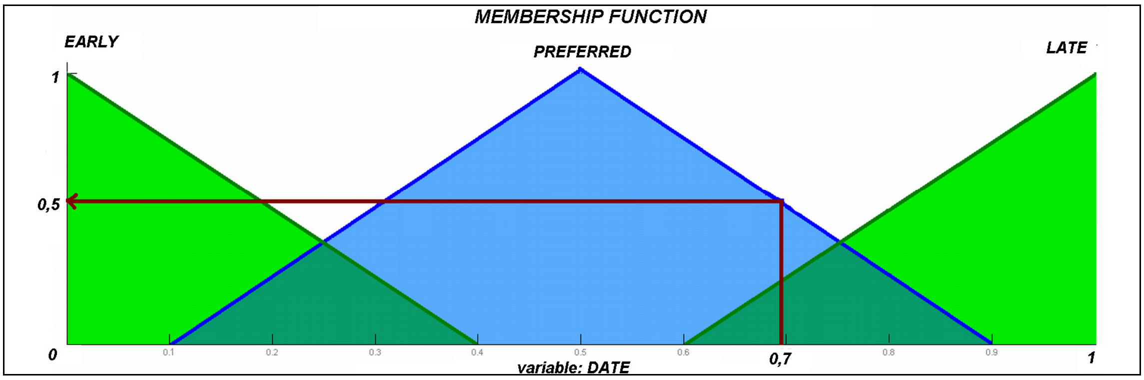


Figure 1: Membership functions.

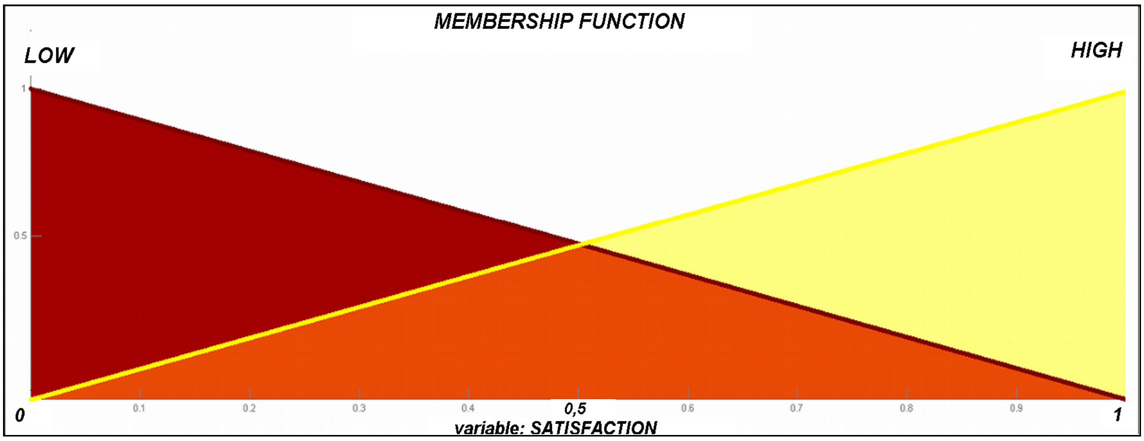


Figure 2: Membership functions.

In order to set the satisfaction for the delivery date, proposed by system after the optimization, we also have to define the output “satisfaction” which includes two attributes, *low* and *high*, as shown in Figure 2.
We can calculate the degree of satisfaction, using the following set of fuzzy rules:

If date is early then satisfaction is low
If date is late then satisfaction is low
If date is preferred then satisfaction is high

The satisfaction level is one of the input variables for the second FIS, which measures the “goodness of the solution”. The second input is the number of trucks, which has two fuzzy values: many and few. Then, the goodness of solution is calculated through the following set of rules:

If trucks are many then solution is bad
If trucks are few then solution is good
If satisfaction is low then solution is bad
If satisfaction is high then solution is good

3.5 The framework

In this paper we assume that a kind of Virtual Coordinator helps the district agents to find an agreement about their shipment demand, to achieve the logistics optimization. The Virtual Coordinator creates the agents’ community, but doesn’t provides transportation services, it is not a forwarder. It collects shipment demands, submitted by the agents, and creates clusters on the basis of the destination’s similarity. In other words, the Virtual Coordinator is a “place” that allows agent to communicate and negotiate among themselves, for example about shipment date. Therefore agents, after negotiation phase, could ask "together" transport services to a forwarder, optimizing monetary and environmental costs.
Figure 3 illustrates this process that will be explained, step by step, in the following sections:

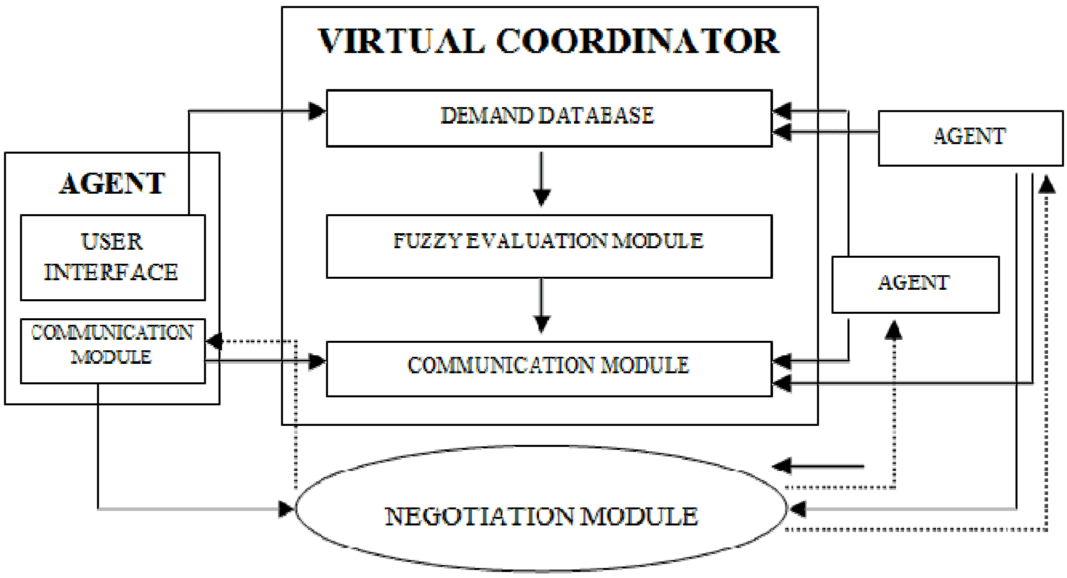


Figure 3: The Virtual Coordinator.

The proposed process can be divided in four steps:

1. submission of demands by the district agents;
2. clustering formation through the Fuzzy C-mean algorithm;
3. calculation of number of Shipment Unit needed;
4. finding possible solutions and choice of a "good solution" through the Fuzzy Inference System.

3.6 First step: The Demand database

The district agents log in the system through the web. They iteratively submit to the coordinator the attributes of shipment demands, and give, through the user interface, the following data:

- destinations;
- quantity of product to deliver;
- a favourite day to deliver and a range of dates in which the agent considers acceptable the delivery;

The Virtual Coordinator stores these data into a "Demand database" (Figure 3), and undertakes the initiative of forming the coalition among interested agents. It helps the agents to reach an agreement, preserving a satisfactory level of system efficiency and fairness.

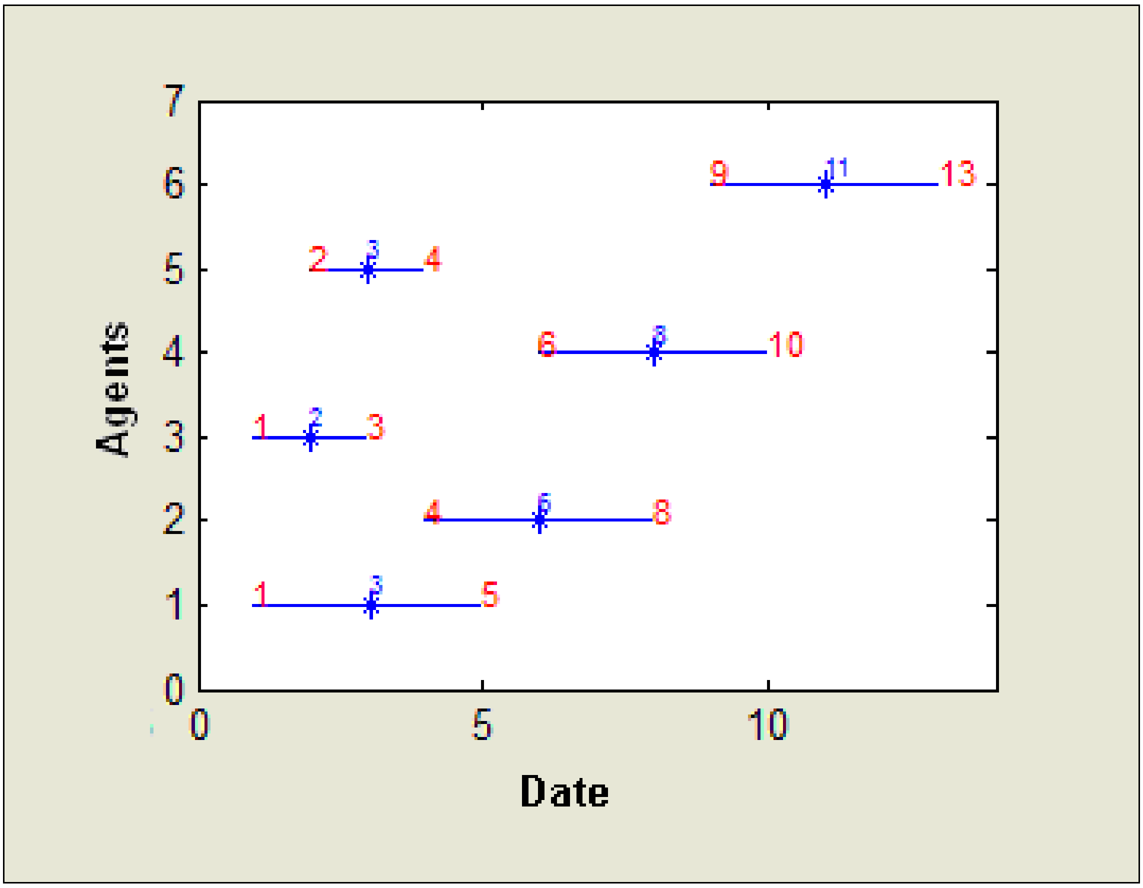


Figure 4: An example of time ranges and "favourite day"(*).

In the Demand Database:
- destinations are defined by their latitude and longitude;
- quantities of products to deliver are in tonnes;
- delivery date is entered by clients as a favourite day, and a tolerance interval for dates for delivery.

As for shipment demand attributes, we need to remark that:
- since districts are formed on the basis of homogeneity of the products, in this paper we did not take into account their type. In other words, we assumed that firms are producing similar products,
- we have considered only the delivery date (d_d), since the departure day and time are calculated as a function of d_d,

the system accepts only symmetric ranges, therefore the favourite day should be the centre value of the range, which must be at least one day after and one before the "favourite day" (Figure 4).

The system puts all data into a matrix called "U".

3.7 Second step: Forming the clusters of demands through the Fuzzy C-Mean algorithm.

At first, the Virtual Coordinator browses the database, and picks out from the Fuzzy Evaluation Module (Figure 3) "similar" demands and clusters them on the basis of closeness of destinations and similarity of range of delivery dates entered by agents.

The algorithm shows partitions starting from agents' shipment demands. The system stops creating clusters when each cluster is made of only one agent.

3.8 Third step: number of Shipment Units needed.

Once number and elements of clusters have been set up, the system calculates the number of Shipment Units (*SU*) needed to satisfy shipment demands. *SU* could be, without distinction from the point of view of the algorithm, containers or trucks for bulk goods. In fact, they represent the bottleneck even in case of multi-modal transport, like for example truck+train. Of course, the operational cost changes case by case. For sake of simplicity, in the following we have considered an uni-modal transport, with trucks as *SU*.

For the i-th cluster, the system splits the loads into trucks, on the basis of the weight of loads and capacity of the considered trucks. The minimum number of trucks needed for this cluster is given by the equation (1):

$$SU_i = \text{minimum integer} \geq \Sigma_k Q_{ki}/C \quad (1)$$

in which Q_{ki} is the weight of the k-th shipment demand in the cluster i, and C is the capacity of the average *SU*.

Of course, when the number of clusters increases, the agents satisfaction increases as well, but also the number of SU needed to fulfil the transportation demand increases.

3.9 Fourth step: The Fuzzy/Genetic Algorithm.

After the Fuzzy C-mean clustering, a Fuzzy/Genetic algorithm (FA/GA) has been used. GAs have been widely used in the optimization field. In our logistic optimization problem we chose to use a GA because it presents the following advantages:

- no need to know a lot about the function being optimized while searching for its maximum;
- possibility to find the solution after examining surprisingly a small number of states;
- possibility to obtain better results repeating the evolution, since many operations are carried out randomly.

There are three main aspects to take into account to implement the algorithm on an optimization problem: (i) the encoding of the solution; (ii) the definition of the fitness function, and (iii) the implementation of the basic genetic operations (selection, crossover and mutation) within the problem. Through selection, crossover and mutation among cluster members, the algorithm finds the nearest optimal solution. In this application to logistic systems, the population has been initialized as random binary strings. Selection of individuals to be replaced is done according to “elitism method” in which worst individuals are replaced by the best individual. Mutation and crossover process starts from a situation in which all the individuals are the same. The procedure restarts iteratively, until the best value of fitness function is found, or the number of iterations exceeds a fixed threshold. In Table 3 the relevant pseudo-code is reported.

Table 3: The Fuzzy/genetic algorithm pseudo-code.

```
 BEGIN
      Create initial population
      Calculate individual fitness
      WHILE NOT finished DO BEGIN
             BEGIN
                    Select new population (elitism)
                    Crossover between two individuals
                    Mutation of single individuals
                    Calculate the descendants' fitness
             END
             IF stop condition is satisfied THEN
                    finished:= TRUE
             END
      END
END
```

Genetic algorithm creates few combinations. They give the optimal solution based on fitness calculation (Tab. 3). In this paper, a combination of GA and FA is used. It allows to add the advantages of the GA, analyzing and finding several different solutions/combinations of population/shipment demands, to the advantages of FIS, which estimates the fitness (satisfaction) of the agents. This process evolves the population (shipment demands) until a solution is found. The FA/GA algorithm generates more solutions and evaluates each solution according to its fitness.

The “best” solution is found by two Fuzzy Inference Systems (FIS). The first FIS finds the agents’ satisfaction, on the basis of the closeness of proposed solution to the favourite day entered by the agent.

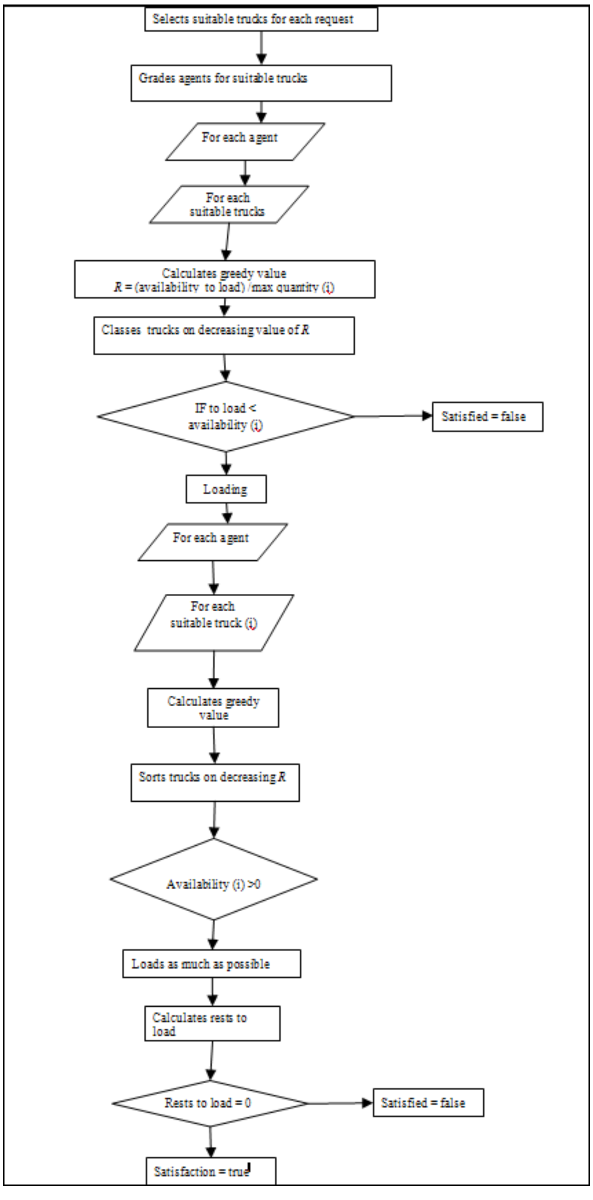
The second FIS calculates the "goodness" of solution, based on the maximization of agents' satisfaction, and minimization of the number of trucks needed. This system has two inputs: the "satisfaction" calculated through the first Fuzzy Inference System, and the "number of truck" needed to fulfil the shipments demands. Afterwards, the system optimizes truck loading through a greedy algorithm. The greedy value is given by:

$r = (d_1 - a_1) / c_{max}$

where:
d_1= availability to load
a_1= weight of goods to load
c_{max}= capacity of a truck

In the table below (Table 4) the relevant pseudo - code is illustrated.

Table 4: The Greedy algorithm pseudo-code.



The algorithm loads trucks so that the load split for each agent is as small as possible. Finally, the proposed system solves a Travelling Salesman Problem to minimize the delivery route.

3.10 Results

The system finds out the possible members of the coalition among agents with similar transportation demands. The Virtual Coordinator submits to agents the set of clusters having the best performance in terms both of number of trucks needed and agents' satisfaction. On their turn, agents can accept the proposed solution or, through a negotiation module (Figure 3), can change the demand attributes. The system shows to agents the negotiation changes (Figure 3), and any agent could decide individually to change his tolerance about delivery date, fulfilling a not completely full truck and thus reducing the shipment costs. Otherwise, they could reduce or increase the load amount, and thus agree with another cluster member having same shipment destinations, to takes advantage in using a truck completely full. In this case, the procedure restarts with formation of new clusters.

4. A practical example

In our case of study we have hypothesized an industrial district located around the city of Taranto, in Apulia region, Southern Italy, formed by seven agents. The agents submit their shipment demands to the Virtual Coordinator.

4.1 The demand database

The district agents enter their shipment demands attributes, as shown in the following Table 5.

Table 5: Case of study: shipment demands database.

Agent	*Destination*	*Destination Latitude*	*Destination Longitude*	*Quantity (t)*	*Date to deliver*	*Tolerance Interval (dates)*
A	Bari, Italy	41° 8' 0"	16° 51' 0"	25	9	7-11
B	Naples, Italy	40° 50' 0"	14° 15' 0"	30	7	5-9
C	Venice, Italy	45° 26' 19"	12° 19' 36"	12	12	9-15
D	Milan, Italy	45° 28' 0"	9° 12' 0"	6	21	19-23
E	Genoa, Italy	44° 25' 0"	8° 57' 0"	50	24	22-26
F	Paris, France	48° 52' 0"	2° 20' 0"	4	24	23-25
G	Berlin, Germany	52° 31' 0"	13° 24' 0"	23	17	14-20

4.2 Clustering shipment demands

Afterwards, the Virtual Coordinator creates the agents community. In the Fuzzy Evaluation Module, the Fuzzy C-mean algorithm collects the seven shipment demands and clusters them on the basis of the "similarity" of the destinations, and the range of dates for delivery. In our case, the algorithm shows partitions in two, three, four, five, six, and seven clusters. In Figure 5 the clusters resulting from these data, as listed in Table 5, are presented. Each cluster is represented by a different colour.

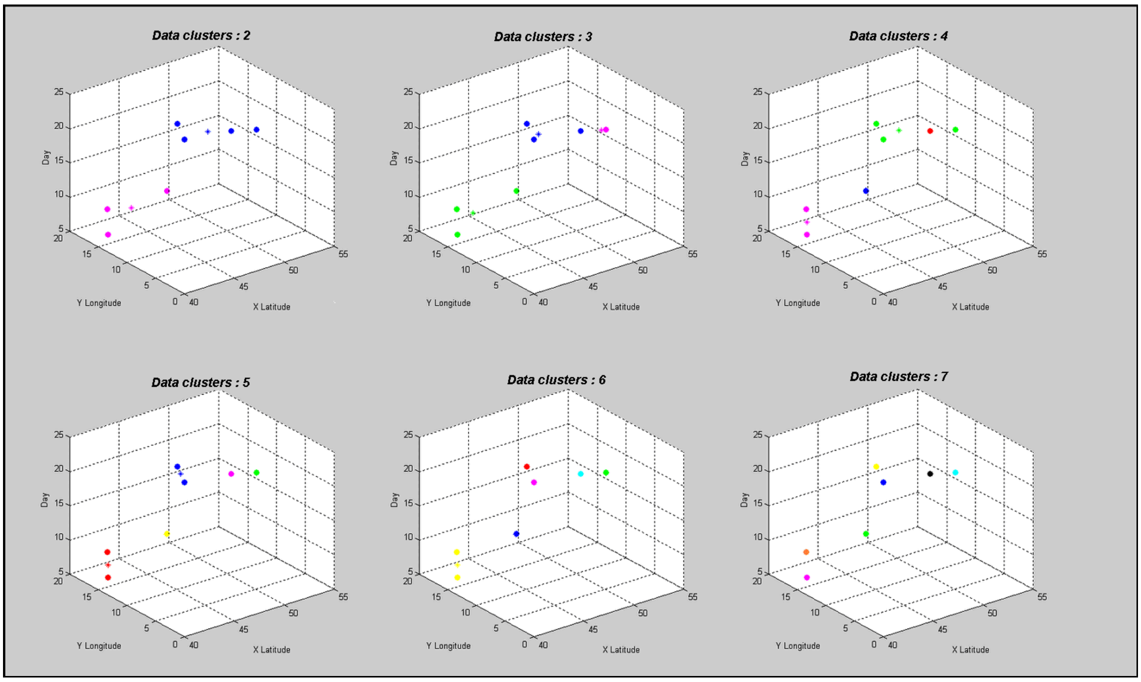


Figure 5: Case of study: clustering procedure.

4.3 Calculation of the number of trucks

For sake of simplicity we consider an average truck having capacity of 25 tonnes. The number of trucks for each cluster calculated by the system is reported in the following. In Figure 6, an example of result window for three partition is represented.

for partition into 2 clusters: SU1 = 3, SU2 = 4
for partition into 3 clusters: SU1 = 3, SU2 = 4, SU3 = 1
for partition into 4 clusters: SU1 = 3, SU2 = 1, SU3 = 3, SU4= 1
for partition into 5 clusters: SU1 = 1, SU2 = 3, SU3 = 1, SU4= 3, SU5= 1
for partition into 6 clusters: $SU_1 = 1$, $SU_2 = 1$, $SU_3 = 1$, $SU_4 = 2$, $SU_5 = 3$, $SU_6 = 1$
for partition into 7 clusters: $SU_1 = 1$, $SU_2 = 2$, $SU_3 = 1$, $SU_4 = 1$, $SU_5 = 2$, $SU_6 = 1$, $SU_7 = 1$

4.4 The proposed solutions and their evaluation

The possible solutions are found through the fuzzy/genetic algorithm, which select the best solutions, for each cluster, through two FIS.

Figure 6 shows an example of results given by the algorithm in case of three partitions.

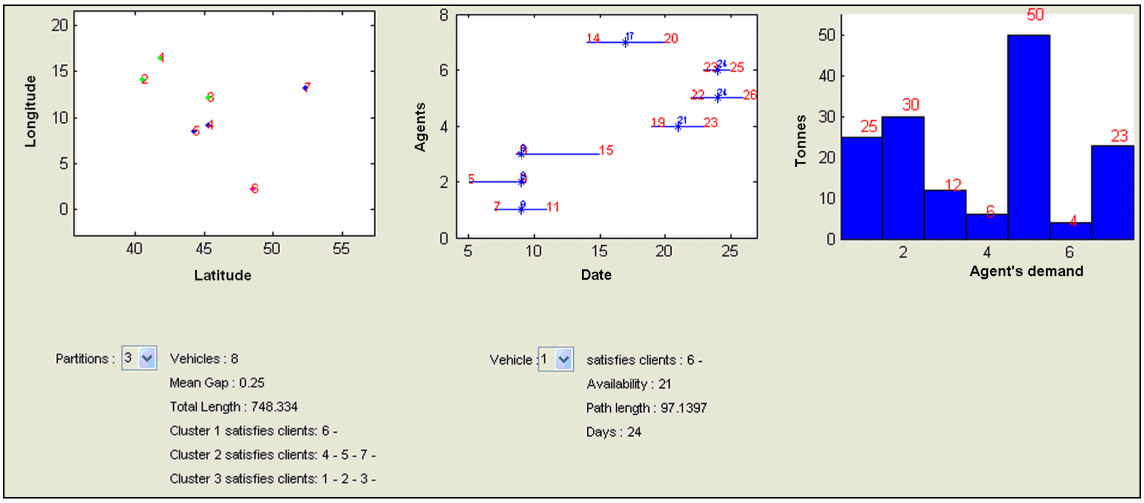


Figure 6: An example of proposed solution for three partition. Window A.

Through the window represented in Figure 6, one can actually select the number of partitions (from 2 to n). In the example, three partitions have been selected, and the figure shows that the total load is divided into eight trucks. Also, agents belonging to each cluster are indicated. In the right side of the figure, one of the eight trucks needed can be selected. For the selected truck, the system shows the clients satisfied, the availability (21 tonnes in this case), and the date for the delivery (day 24).

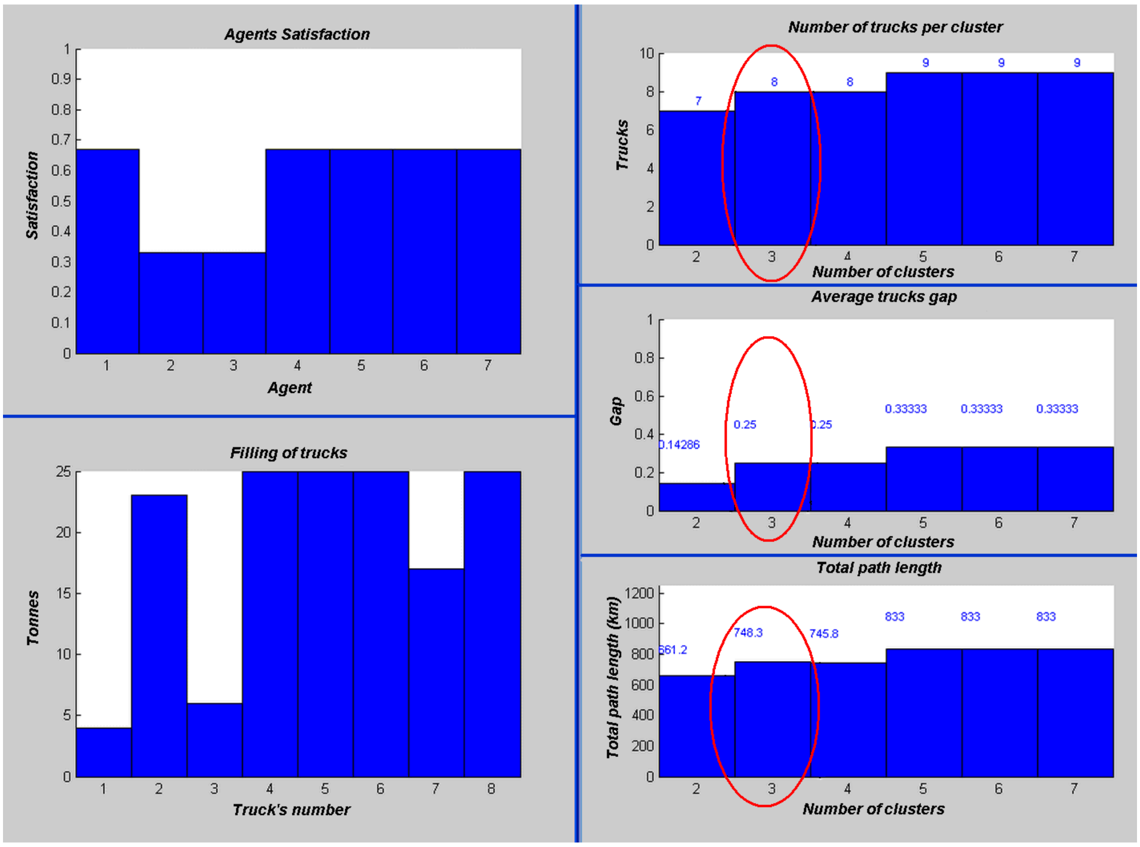


Figure 7: An example of proposed solution for three partitions. Window B.

In another window (Figure 7) are illustrated: in the left side, the satisfaction of each agent, and the filling rate of each truck for partition into three clusters; in the right side, the number of trucks needed for each cluster, the average capacity of trucks not filled up (average trucks gap), and the path length for each cluster are highlighted for partition into three clusters.

These information are important in negotiation phase, because each agent involved in it could decide whether to accept the proposed solution or, and possibly how, change its shipment demand.

5. Conclusion and future developments

In this paper we have proposed a framework that could be useful to streamline the flow of goods in Industrial Districts. Industrial Districts represent a particular context in which cooperation advantages are more evident. In the proposed case, the agents can achieve an economical benefit because can put tougher their goods, and share the cost of shipments.

The proposed system is able to create an e-community, where agents can meet each other, exchange information and knowledge, and possibly negotiate a compromise among them about products shipment. In fact, in this context e-negotiation may produce several benefits on the logistic performance, due to cooperation among firms belonging to the same industrial district.

A Fuzzy Logic-based model for making trade-offs in negotiations in an e-marketplace is also presented. Conflicting objectives are simultaneously considered through a fuzzy optimization algorithm. Behaviour of agents when making trade-offs are explicitly formulated through fuzzy inference systems.

It appears that this framework can be used to provide real time solutions to complex practical logistics and environmental problems. The proposed architecture makes easier the cooperation among district firms in the shipment of their products, reducing the number of vehicles used.

Future research will focus on the negotiation phase and carry out an application of the proposed e-negotiation system on a real case.

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European Transport \ Trasporti Europei n. 46 (2010): 52-71

Analysis and modeling of container handling equipment activities

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Abstract

Although the technical literature contains numerous efforts to simulate container terminal performance, little attention has been paid to setting up, calibrating and validating models for handling equipment activities. This paper presents results from the estimation of activity duration concerning three different types of handling equipment: mobile harbor cranes, gantry cranes and reach stackers. Two estimation approaches (sample means vs random variables) were investigated with respect to different hypotheses with regard to activity aggregation and container type (undifferentiated, 20', 40', full or empty). A concise but exhaustive state of art is proposed, an in-depth descriptive analysis of experimental data is carried out, several probability distribution functions were tested and more than 60 statistical models are proposed. The results can be easily implemented in any terminal simulation model.

Keywords: Container terminal; Handling equipment; Time duration; Random variable estimation.

1. Introduction

The overall task of a container terminal is to manage vessel berthing, inbound container unloading, outbound container loading and storage yards as efficiently as possible. Such a goal can be obtained by coordinating the berthing time of vessels, the resources needed for handling the workload, the waiting time of customer trucks and, at the same time, by reducing congestion on the roads, at the storage blocks and docks. Each of these activities significantly influences port efficiency with consequences on the local and global economy of the freight transport system. In order to manage a container terminal, it is necessary to develop decision support systems able to analyze the system situation, identify system inadequacies or critical points and/or to verify one or more alternative design scenarios.

Although the field of container terminal simulation has been widely tackled in the literature through optimization or simulation approaches, little attention has so far been paid to handling equipment models set-up, calibration and validation. Container

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terminal models have chiefly been on the application and/or comparison of design scenarios, while estimation of handling activity performances appear to be largely overlooked in most of the applications found in the literature. While many contributions present no information on handling equipment models used, the remaining contributions carry out very simple approaches (deterministic) and/or give scant information on the estimation approach pursued, the experimental data used, the parameters estimated and the parameter values.

Given such shortcomings in the existing literature, this paper proposes a concise but exhaustive analysis of the state of the art on handling equipment models and aims to integrate the state of the art itself with respect to the following handling equipments: mobile harbor cranes, gantry cranes and reach stackers. In particular, random variable estimation was compared to sample mean estimation, and different estimation methodologies and different distribution functions were investigated. Moreover, different models were estimated with respect to container type and hypothesizing different level of activity aggregation for each handling equipment. The paper is divided into four sections. The state of the art is reported in section two, calibration of handling equipment models is treated in depth in section three, model validation is described in section four, and the main conclusions are summarised in section five.

2. Handling equipment models: state of the art

As stated in the introduction, to implement a simulation model effectively, estimation of handling performance should be one of the main areas addressed, which does not appear to be the case in most existing applications. Half the papers that give information on the handling equipment models used adopt a stochastic approach and show estimated parameter values. Most of the contributions deal with vessel loading/unloading operations. There is substantial heterogeneity regarding the level of aggregation of activities involved and how such activities are aggregated in a single macro-activity: El Sheikh et al. (1987), Choi and Yun (2000), Kia et al. (2002) and Shabayek and Yeung (2002) analyse the entire time to load (unload) a vessel (vessel cycle time); Koh et al. (1994) and Bugaric and Petrovic (2007) investigate the crane cycle time (time needed to: lock onto the container, hoist and traverse, lower and locate, unlock and return); crane loading time to/from a vessel is analysed by Tugcu (1983), Thiers and Janssens (1998), Yun and Choi (1999), Merkuryeva et al. (2000), KMI (2000), Parola and Sciomachen (2005), Bielli et al. (2006), and Lee and Cho (2007).

As regards vessel cycle time, a stochastic approach is unanimously proposed. In particular, El Sheikh (1987), Kia et al. (2002) and Shabayek and Yeung (2002) suggest using Erlang random variables whereas Choi and Yun (2000) proposes normal random variables for two crane types (quay, yard). As regards crane cycle time, Koh et al. (1994) advise the use of a Weibull random variable; Bugaric and Petrovic (2007), for a bulk cargo terminal, propose normal random variables and report the estimated parameters.

Table 1: Survey of handling models: Gantry crane (GC).

Operation/ activity	*Handling equipment*	*Reference*	*Handling model proposed*	
Crane operation time	Quay GC	Yun and Choi (1999)	Exponential	Mean = 0.50 (min)
		Lee and Cho (2007)		Mean = 1.00 (min)
		Merkuryeva et al. (2000)	Uniform	Min.=2.00 (min.) Max=4.00 (min.)
		Bielli et al. (2006)	Deterministic	Mean = 1.50 (min)
	Yard GC	Yun and Choi (1999)	Exponential	Mean = 1.00 (min)
		Merkuryeva et al. (2000)	Triangular	40' loading : Mean = 6.00 (min) 40' unloading : Mean = 4.00 (min) S.d. = 0.41 (min)
		Lee and Cho (2007)		Mean = 1.55 (min) s.d. = 0.08 (min)
		Bielli et al. (2006)	Deterministic	Mean = 1.50 (min)
	n.s.*	Parola and Schiomachen (2005)	Normal	Not reported
		Tugcu (1983)	Deterministic	Not reported
		Thiers and Janssens (1998)	Deterministic	Not reported
		KMI (2000)	Deterministic	Not reported
Crane cycle time	n.s.*	Koh et al. (1994)	Weibull	Not reported
	Bulk cargo	Bugaric and Petrovic (2007)	Normal	Mean = 5.00 (min) s.d. = 0.26 (min)
Vessel cycle time	Quay GC	Choi and Yun (2000)	Normal	Mean = 112.80 (min) s.d. = 5.60 (min)
	Yard GC	Choi and Yun (2000)	Normal	Mean = 87.00 (min) s.d. = 13.89 (min)
	Entire loading operation	El Sheikh (1987)	Erlang	Mean = 4.20 (day) K = 4.33
	Entire unloading operation	El Sheikh (1987)	Erlang	Mean = 7.57 (day) K = 10.77
	n.s.*	Kia et al. (2002)	Erlang	Mean = 37.85 (hour) K = 4.00
		Shabayek and Yeung (2002)	Erlang	Mean $\in$ [9.6, 16.3] (hour) K = 117
Crane speed	Quay Gantry crane	Yun, Choi (1999)	Deterministic	45 (metres/min.)
		Legato et al. (2008)	Deterministic	45 (metres/min.)
		KMI (2000)	Deterministic	45 (metres/min.)
	Hoist with Full load	KMI (2000)	Deterministic	55 (metres/min.)
	Hoist without Load			130 (metres/min.)
	Ship trolley			180 (metres/min.)
	Store trolley			75 (metres/min.
	Yard Gantry crane	Choi and Yun (2000)	Deterministic	134 (metres/min.)
	n.s.*	Tugcu (1983)	Deterministic	Not reported
		Koh et al. (1994)	Deterministic	Not reported
		Thiers and Janssens (1998)	Deterministic	Not reported

Note: * n.s. = handling equipment type or the type of activity are not specified.

With regard to crane loading/unloading time, Tugcu (1983), Thiers and Janssens (1998), KMI (2000) and Bielli et al. (2006) follow a deterministic approach, contrasting with the stochastic approach adopted by Yun and Choi (1999), Merkuryeva et al. (2000), Lee and Cho (2007), and Parola and Sciomachen (2005). Yun and Choi (1999) propose the exponential distribution function both for quay cranes and yard cranes; Merkuryeva et al. (2000) propose the uniform distribution function for quay cranes and a triangular distribution function for yard gantry cranes; Lee and Cho (2007) suggest the exponential distribution function for quay crane and a triangular distribution function for yard gantry crane operation time. Parola and Sciomachen (2005) estimated a normal random variable but do not report parameter values. With respect to crane speed, all propose deterministic and aggregate models while only Yun and Choi (1999), Choi and Yun (2000), KMI (2000) and Legato et al. (2008) report the estimated mean values.

With respect to other handling equipment, not much can be found in the literature: Sgouridis and Angelides (2002) use deterministic values for a straddle carrier, whereas Merkuryeva et al. (2000) propose a triangular distribution function for the forklift. As regards shuttle performances (speed, travel time, waiting time …), the few models existing are hard to transfer to different case studies (due to the influence of path length, path winding, vehicle congestion inside the terminal and so on).

A synopsis of the above analysis is presented in tables 1, 2 and 3. For each type of handling equipment and for each activity simulated, probability distribution and corresponding parameters are reported.

Table 2: Survey of handling models: Straddle carrier (SC).

<table>
<tr><th>Operation/activity</th><th>Handling equipment</th><th>Reference</th><th colspan="2">Handling model proposed</th></tr>
<tr><td>Speed</td><td rowspan="5">Straddle carrier</td><td rowspan="5">Sgouridis and Angelides (2002)</td><td>Deterministic</td><td>Inside yard: 110(met./min.)
Outside yard: 250 (met./min.)</td></tr>
<tr><td>Shuttle loading/ Unloading time</td><td>Deterministic</td><td>0.60 (min.)</td></tr>
<tr><td rowspan="2">Spreader movement Turning</td><td>Deterministic</td><td>0.30 (min.)</td></tr>
<tr><td>Deterministic</td><td>0.02 (min.)</td></tr>
<tr><td>Container spotting</td><td>Deterministic</td><td>1.00 (min.)</td></tr>
</table>

Table 3: Survey of handling models: Forklift (FL).

<table>
<tr><th>Operation /activity</th><th>Handling equipment</th><th>Reference</th><th colspan="2">Handling model proposed</th></tr>
<tr><td rowspan="2">Loading/ Unloading time</td><td rowspan="2">Forklift</td><td rowspan="2">Merkuryeva et al. (2000)</td><td rowspan="2">Triangular</td><td>20’ loading
Mean = 4.00 (min.)
St. Dev. = 0.41 (min.)</td></tr>
<tr><td>20’ unloading
Mean = 3.00 (min.)
St. Dev. = 0.41 (min.)</td></tr>
</table>

3. Handling equipment models calibration

3.1 Methodology and case study

In this section, handling equipment times are estimated. Sample means and estimations of random variables are explored for each elementary handling activity of each type of handling equipment. Two different estimation methodologies and different distribution functions were tested on experimental data taken from a survey carried out between January 2003 and July 2005 inside the Salerno Container Terminal (SCT).

Whilst being one of the major private container terminals in the south of Italy, SCT is also a small and very efficient terminal, reaching 0.4 million TEUs in 2007, or 40,000 TEUs/ha. The terminal operates five ship-to-shore cranes, all equipped with twin-lift spreaders (3 post panamax with a 17-row out-reach and 2 panamax with max 15 rows out-reach), in an area of approximately 120,000 m2, used for the storage of full and empty containers. Container berths making up a total quay length of 890 metres are available, supplemented by 1,120 meters of quay length for additional requirements. RTGs, reachstackers, top-loaders and a substantial fleet of dockside handling equipment including multi-trailer-trains for transporting containers from operational to stacking areas, ensure a high level of productivity and fast despatch.

From January 2003 to July 2005 the whole container terminal was monitored (more than 1,000 vessels were monitored). The data acquired were used for analysis of the vessel, gate and yard macro-areas, and particularly for estimation of the berth-side/land-side demand (per container type and time period) at the container terminal.

Jointly with these data, an integrative survey was carried out during the first six months of 2005. In particular, all the berth macro-area activities involving more than 3,000 containers were monitored (equal to 20% of the containers loaded/unloaded per month and 1% of the containers loaded/unloaded per year), each of which was traced from its origin to its final destination. Each trip was subdivided into homogeneous activities (see table 4) and for each activity the time duration was measured and the resulting data were classified according to the following classes: 20’ (full and/or empty), 40’ (full and/or empty), 2 x 20’ (full). Finally, four different handling models were estimated:

- *sample mean* as estimation of activity time duration;
  - Sample Mean Undifferentiated (SMU) model, where no differentiation was made among containers type;
  - Sample Mean Container Type (SMCT), where the following container types were taken into account (20’ full and/or empty; 40’ full and/or empty; 2 x 20’ full);
- *random variable* as representative of activity time duration;
  - Random Variable Undifferentiated (RVU) model (see above);
  - Random Variable Container Type (RVCT) models (see above).

Table 4: Activities analyzed for each handling equipment.

Mobile harbour crane (MHC)	*Gantry crane (GC)*	*Reach stacker (RS)*
Loading from dock to vessel	Unloading to shuttle/truck	Unloading from shuttle/truck
Loading from shuttle to vessel	Loading from shuttle/truck	Loading to shuttle/truck
Unloading from vessel to dock	Unloading to stack	Stacking to tier
Unloading from vessel to shuttle	Loading from stack	
	Trolley movement with container	
	Free trolley movement	
	Crane movement	

The analyses are divided into preliminary descriptive analysis of experimental data and statistical analysis. In the descriptive analysis, the mean values and corresponding standard deviations are estimated. Such values are useful to develop/implement a decision support models based on sample mean variables, and allow the need for a stochastic approach to be appreciated.

By contrast, statistical analysis aims to estimate the theoretical continuous cumulative distribution function $F_X(\underline{x};\ \mu, \sigma)$ that best fits the sample distribution function $F^{sample}(\underline{x};\ n)$. Given a sample $\underline{x} = (x_1, \ldots, x_n)$, with mean $\overline{x}$ and variance s^2, *Kolmogorov-Smirnov* statistic was used to evaluate the quality of the estimation methodology and the random variable tested:

$$D_n = sup \mid F^{sample}(\underline{x};\ n) - F_X(\underline{x};\ \mu, \sigma) \mid = D_{n,X(\mu,\sigma)}(\underline{x})$$

For large values of n, Smirnov (1948) gives the limiting distribution of $D_n{\cdot}n^{1/2}$; it is thus possible to compute the critical values $d_{n,\alpha}$ (the thresholds) for large samples (n>35):

$$d_{n,\alpha} = 1.3581 / n^{1/2} \text{ for } \alpha = 0.05$$
$$d_{n,\alpha} = 1.6276 / n^{1/2} \text{ for } \alpha = 0.01$$

For smaller sample sizes the critical values are estimated in Miller (1956).

The *Kolmogorov-Smirnov* statistic with respect to two sample distributions is the statistic used to evaluate whether two sample distributions are the same from a statistical point of view. This statistic was used to evaluate whether sample distributions related to similar activities are equal (for example whether the sample distribution related to the 20' full container loading time is same as the sample distribution for the 20' empty container loading time).

Two estimation methods were compared: moment estimation and maximum likelihood (M-L) estimation. Several variables (exponential, log normal …) were tested for each activity introduced in table 4 and for different container types.

The estimation results show differences in terms of parameter value variables between 0.5% and 12%. From a statistical point of view, M-L estimations show the best results. Furthermore, sometimes the moment D_n values are greater than the corresponding thresholds $d_{n,\alpha}$. These results suggest we should prefer M-L model estimation.

Comparison among different models (random variables) shows that only Normal, Gamma and Weibull random variables were statistically significant. The three random variables produce D_n values below the thresholds; however, D_n values related to the Gamma random variable may often be below the others. It can be concluded that, while the three random variables could all be used to represent the time duration of the main container terminal handling activities, the Gamma random variable produces the best results. In the following, the main results are shown for both analyses.

3.2 Calibration results

3.2.1 Mobile harbour cranes (MHCs)

The MHCs operating in the Salerno Container Terminal are three Gottwald HMK 260 mounted on rubber tyres; these are particularly popular in ports and terminals frequented by feeders and other vessels with widths of up to 25 metres. This equipment is also suitable for twin-lift (2 x 20' full) cargo containers. MHC activities are mainly devoted to loading/unloading containers to/from berthed vessels.

The analyses carried out concern loading activities from shuttle to vessel or from dock to vessel, and unloading activities from vessel to dock. The following container types were considered: undifferentiated containers, 20', 40' and 2x20'. Since most Salerno Container Terminal loading/unloading activities concern full containers, the analysis mainly focused on these. Some results on empty containers are proposed only for activities that systematically involve such containers.

As regards undifferentiated containers, the results reported in table 5 show an average MHC unloading time of 0.871 minutes and a corresponding standard deviation of 0.263 minutes, 30% less than the average. For loading activities the standard deviation (0.657 min) is 46% below the average (1.426 min). Such results show that loading activities such as container alignment in the hold are more subject to unexpected events (e.g. problems with the spreader and poor visibility during stowing). Distinguishing *loading from dock* to vessel and *from shuttle* to vessel, it is worth noting that average loading time from dock is almost equal to the average loading time from shuttle; while standard deviations are quite different (17%) and turn out to be more than 50% less than the average value.

The same analysis carried out for container type (20', 40' and 2x20') shows that MHC performance changes as the container size changes. For *loading from dock*, loading time is 1.316 minutes for 20' full containers and 1.494 minutes for 40' full containers (14% greater). Standard deviations differ from zero and are about 60% lower than the corresponding averages, appreciably varying with container type: 0.485 minutes for 20' full containers and 0.632 minutes for 40' full containers (30% greater). Such results confirm that container types should be taken into account and the need for a stochastic approach.

As regards *loading time from shuttle,* no significant differences can be observed between 20' full and 40' full, standard deviations differ from zero and are about 60% less than the average values. Comparing *loading time from dock* and *from shuttle*, it should be pointed out that *loading from dock* needs more time (≈ +17%) both for 20' full and 40' full, and show higher dispersions: +20% for 20' full containers, +40% for 40' full containers.

Finally, since MHCs can move two 20' containers at the same time (2x20'), the loading time for 2x20' full containers was estimated. Estimates show an average loading time of 2.214 minutes and a standard deviation of 0.926 minutes. Interestingly, the loading time is 8% less than the time required to load two 20' full containers in succession, and the standard deviation is 60% greater than the standard deviation of loading time of a 20' full container.

There is essentially one activity that involves empty containers: *loading from shuttle*. It is worth noting that standard deviation is similar to those estimated for 20' full and 40' full, while the average loading time is 13% less than 40' full and only 6% less than 20' full.

Similar analyses were carried out for vessel unloading activities. In this case we refer only to the unloading time from vessel to dock, since activities from vessel to shuttle are not frequent in the Salerno Container Terminal.

The estimates (see also table 5) show similar average unloading time and standard deviations for both 20' full containers and 40' full container, in particular standard deviations differ from zero and, for all types, are 30% less than the corresponding averages. Unloading time of 2x20' containers is not substantially different (+12%) from the unloading time of a single container; in this case, moving two containers at the same time is much more effective. Finally, unloading times for 20' empty containers were estimated. While the average unloading time is 11% less than the time to unload a 20' full or a 40' full, the standard deviation (0.216 minutes) is 2% smaller than the corresponding standard deviations of both 20' full or a 40' full.

Table 5: Mobile harbour crane (MHC) empirical results.

Activity Time (minutes)	*Undifferentiated*		*20'*				*40'*				*2 x 20'*	
			Empty		*Full*		*Empty*		*Full*		*Full*	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Loading	1.426	0.657	1.102	0.385	1.257	0.444	1.121	0.386	1.332	0.476	2.214	0.926
Unloading	0.871	0.263	0.768	0.216	0.856	0.221	n.p.	n.p.	0.867	0.230	0.971	0.366
Loading from dock	1.398	0.562	n.p.	n.p.	1.316	0.485	n.p.	n.p.	1.494	0.632	n.p.	n.p.
Loading from shuttle	1.435	0.678	1.102	0.385	1.193	0.387	1.121	0.386	1.272	0.389	2.214	0.926
Unloading to dock	0.871	0.263	0.768	0.216	0.856	0.221	n.p.	n.p.	0.867	0.230	0.971	0.366

Notes: n.p. = not present / n.a. = not available.

Statistical analysis for undifferentiated containers shows that the Gamma distribution function is always statistically significant, while Normal and Weibull distribution functions do not always verify the K-S test. The same random variable seems to be the best approximation for loading and unloading activities that involve 20' and 40' (full or empty) containers. In table 6 means and standard deviations are reported for each activity (related to M-L estimation and Gamma distribution). Values are consistent with those introduced in the descriptive analysis and may be interpreted in the manner discussed above.

Table 6: Mobile harbour crane (MHC) statistical results: parameters of the Gamma distribution function (M-L estimation).

Activity Time (minutes)	*Undifferentiated*		*20'*				*40'*				*2 x 20'*	
			Empty		*Full*		*Empty*		*Full*		*Full*	
	μ	*σ*	*μ*	*σ*	*μ*	*σ*	*μ*	*σ*	*μ*	*σ*	*μ*	*σ*
Loading	1.366	0.514	1.084	0.387	1.238	0.405	1.101	0.340	1.288	0.402	2.083	0.690
Unloading	0.862	0.214	0.664	0.139	0.825	0.183	N.p.	N.p.	0.835	0.188	0.933	0.326
Loading from dock	1.389	0.441	n.p.	n.p.	1.252	0.407	n.p.	n.p.	1.372	0.485	n.p.	n.p.
Loading from shuttle	1.350	0.549	1.084	0.387	1.227	0.405	1.101	0.340	1.244	0.375	2.083	0.690
Unloading to dock	0.862	0.214	0.664	0.139	0.825	0.183	n.p.	n.p.	0.835	0.188	0.933	0.326

Notes: n.p. = not present / n.a. = not available.

As stated before, *Kolmogorov-Smirnov* validation test was used. With respect to the M-L estimation, in table 7 the D_n values and thresholds $d_{n,\alpha}$ (with $\alpha = 0.05$) are reported. As we can see, the D_n values are always lower than the correspondent $d_{n,\alpha}$ thresholds.

Table 7: Mobile harbour crane (MHC) statistical results: validation test outputs (M-L estimation).

Activity Time (minutes)	*Undifferentiated*		*20'*				*40'*				*2 x 20'*	
			Empty		*Full*		*Empty*		*Full*		*Full*	
	Dn	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*
Loading	0.049	0.050	0.050	0.115	0.049	0.112	0.048	0.109	0.050	0.112	0.053	0.118
Unloading	0.048	0.050	0.056	0.101	0.062	0.102	n.p.	n.p.	0.037	0.100	0.064	0.101
Loading from dock	0.069	0.071	n.p.	n.p.	0.096	0.134	n.p.	n.p.	0.067	0.150	n.p.	n.p.
Loading from shuttle	0.068	0.071	0.062	0.136	0.059	0.136	0.060	0.136	0.032	0.087	0.059	0.133
Unloading to dock	0.048	0.050	0.090	0.160	0.045	0.074	n.p.	n.p.	0.053	0.094	0.098	0.155

Notes: n.p. = not present / n.a. = not available.

3.2.2 Gantry cranes (GCs)

The GCs operating in the Salerno Container Terminal are four rubber-tyred gantry cranes used both for movement/storage of containers and for loading of shuttles/trucks. This crane type usually consists of three separate movements for container transportation. The first movement is performed by the hoist, which raises and lowers the container. The second is the trolley gear, which allows the hoist to be positioned directly above the container for placement. The third is the gantry, which allows the entire crane to be moved along the working area.

The analyses carried out concern loading and unloading to the shuttle/truck, and loading and unloading to the stack (sometimes called pile). Each activity was analyzed distinguishing undifferentiated containers from 20' and 40' containers. Moreover, loading time from stack was analyzed, further distinguishing the tier. The analysis focused on full containers, since these activities are the most frequent in the Salerno Container Terminal.

As regards loading time of undifferentiated containers (see table 8), the differences between loading time from shuttle and from stack (all tiers) are smaller. Average loading time from shuttle (0.888 min) is 13% greater than the loading time from stack, while loading time from shuttle standard deviation (0.352 min) is 10% smaller than loading time from stack standard deviation. In terms of loading time from stack for each tier, it can be pointed out that the mean decreases as the tier number increases. In particular, a significant difference (>30%) can be observed for the standard deviations between the 1st and 2nd tiers, whereas from the 2nd to 5th tiers, the standard deviation increase can be considered negligible.

Only for loading time from stack are data available for container type. As for undifferentiated containers, average loading time from stack decreases as the tier number increases. This trend holds both for 20' full and 40' full containers. Comparing the averages for each tier number, small differences (about 1% or 2%) can be observed among container type. More appreciable differences exist among the different tiers. With respect to tier 1, loading time increases more than 30% for tier 2, more than 34% for tier 3 and more than 40% for tiers 4 and 5; differences among tiers from 2 to 5 are negligible. As regards the standard deviations, considerable differences can be observed between container type and between the different tiers. With respect to 40' full containers, 20' full container standard deviation is 46% less for tier 1, 81% less for tier 2, and more than 100% less for tiers 3, 4 and 5. With respect to undifferentiated containers, smaller standard deviations can be observed for 20' full containers (-20% for tier 1, -30% for tier 2, -40% for tier 3), whereas greater standard deviations can be observed for 40' full containers (+20% for tier 1, +26% for tier 2, +24% for tier 3).

As regards unloading of undifferentiated containers, the results (see table 8) show an average unloading time to shuttle (equal to 1.331 min) which is 40% greater than the unloading time to stack (average on all tiers). For both activities the standard deviations differ from zero and are about 30% smaller than the corresponding average values.

In particular, the unloading time to shuttle shows a 30% greater standard deviation (0.434 min) than the standard deviation of unloading time to stack (0.309 min). These results confirm that unloading to a shuttle/truck or stack should be analyzed through a stochastic approach; furthermore, unloading to a shuttle/truck requires more time than loading due to the time required to align the container to the shuttle, and shows higher dispersion due to the greater number of unexpected events that may occur in such operations (e.g. problems with container blocks on the shuttle or poor visibility during unloading). Carrying out the same analyses for 20' and 40' full containers, the estimation results show small differences (≈5%) for average values, but more appreciable for standard deviations (13%).

As regards unloading time to stack, no differences were observed among container types and the analyses were carried out distinguishing the unloading activities with respect to the tier number. The results show that average unloading time, as expected, decreases as the tier number increases, and there are no significant differences from tier 3 to tier 5, while the differences between tiers 1 and 2 (46%) and tiers 1 and 3 (58%) are significant. Unlike average values, standard deviations increase between tiers 1 and 2 while they decrease among tiers greater than 2.

Table 8: Gantry crane (GC) empirical results (minutes).

Activity Time (minutes)	*Undifferentiated*		*20' Full*		*40' Full*	
	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
Loading (from shuttle)	0.888	0.352	n.a.	n.a.	n.a.	n.a.
Unloading (to shuttle)	1.331	0.434	1.303	0.460	1.367	0.402
Loading (from stack)	0.769	0.380	0.758	0.283	0.774	0.422
Unloading (to stack)	0.760	0.309	N.a.	N.a.	N.a.	N.a.
Loading (from stack) - tier 1	1.025	0.431	1.019	0.348	1.031	0.509
Loading (from stack) - tier 2	0.713	0.270	0.706	0.188	0.721	0.340
Loading (from stack) - tier 3	0.672	0.290	0.658	0.169	0.683	0.361
Loading (from stack) - tier 4	0.625	0.374	0.618	0.236	0.636	0.401
Loading (from stack) - tier 5	0.614	0.376	0.605	0.261	0.623	0.415
Unloading (to stack) - tier 1	1.101	0.236	No significant differences with respect to undifferentiated containers			
Unloading (to stack) - tier 2	0.753	0.339				
Unloading (to stack) - tier 3	0.699	0.312				
Unloading (to stack) - tier 4	0.647	0.309				
Unloading (to stack) - tier 5	0.640	0.307				

Notes: n.p. = not present / n.a. = not available.

Finally, averages and standard deviations were estimated for trolley speed and crane speed. As reported in table 9, the average full trolley speed (trolley with a container) is equal to 13 metres/minute (with a standard deviation of more than 6 m/minute) and it is 74% lower than the free trolley speed (50 m/minute, with a standard deviation of more than 30 m/minute). With respect to crane speed, the estimation results show an average speed of about 13 m/minute (with a standard deviation of about 6 m/minute). Distinguishing by container type, the difference between average trolley speed averages is negligible (≈ 6%), the differences between standard deviations (≈ 65%) point to the need for a stochastic approach.

For all the described activities and for each container type, in-depth analysis was developed to find the statistical distribution which best fitted the data. Three distribution functions were statistically significant: Gamma, Normal and Weibull. As regards undifferentiated containers, the Gamma distribution function proved the best solution for all analysed activities. Similar results were achieved on analyzing activities for each container type and each tier number. In tables 10 and 11 means and standard deviations are reported for each activity (related to M-L estimation and Gamma distribution). Values are consistent with those introduced in the descriptive analysis and may be interpreted in the manner discussed above.

Table 9: Gantry crane (GC) empirical results (m/min).

Activity Speed (meters/ minutes)	*Undifferentiated*		*20' Full*		*40' Full*	
	$\bar{x}$	*s*	$\bar{x}$	*s*	$\bar{x}$	*s*
Trolley speed (with container)	12.663	6.416	13.243	4.142	12.508	6.902
Free trolley speed	49.076	30.202	-	-	-	-
Crane speed	12.916	5.515	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

Table 10: Gantry crane (GC) statistical results: parameters of the Gamma distribution function (M-L estimation).

Activity Time (minutes)	*Undifferentiated*		*20' Full*		*40' Full*	
	μ	*σ*	*μ*	*σ*	*μ*	*σ*
Loading (from stack)	0.752	0.406	0.741	0.311	0.769	0.457
Unloading (to stack)	0.766	0.352	n.a.	n.a.	n.a.	n.a.
Loading (from stack) - tier 1	1.022	0.449	1.011	0.353	1.060	0.561
Loading (from stack) - tier 2	0.687	0.250	0.658	0.222	0.712	0.256
Loading (from stack) - tier 3	0.668	0.323	0.659	0.246	0.673	0.383
Loading (from stack) - tier 4	0.592	0.325	0.583	0.261	0.606	0.390
Loading (from stack) - tier 5	0.571	0.355	0.560	0.280	0.584	0.399
Unloading (to stack) - tier 1	1.097	0.231	No significant differences With respect to Undifferentiated containers			
Unloading (to stack) - tier 2	0.703	0.308				
Unloading (to stack) - tier 3	0.671	0.256				
Unloading (to stack) - tier 4	0.638	0.245				
Unloading (to stack) - tier 5	0.613	0.240				

Notes: n.p. = not present / n.a. = not available.

Table 11: Gantry crane (GC) statistical results: parameters of the Gamma distribution function (M-L estimation).

Activity Speed (meters/ minutes)	*Undifferentiated*		*20' Full*		*40' Full*	
	μ	*σ*	*μ*	*σ*	*μ*	*σ*
Trolley speed (with container)	11.653	4.597	12.740	4.275	11.203	4.530
Free trolley speed	46.609	29.892	-	-	-	-
Crane speed	11.498	4.586	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

In table 12 and 13, D_n values and $d_{n,\alpha}$ thresholds (with $\alpha = 0.05$) are reported. As we can see, the D_n values are always lower than the correspondent $d_{n,\alpha}$ thresholds.

Table 12: Gantry crane (GC) statistical results: validation test outputs (M-L estimation).

Activity	*Undifferentiated*		*20' Full*		*40' Full*	
	Dn	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*
Loading (from stack)	0.065	0.100	0.092	0.142	0.088	0.142
Unloading (to stack)	0.045	0.130	0.064	0.184	0.065	0.184
Loading (from stack) - tier 1	0.062	0.196	0.062	0.269	0.101	0.269
Loading (from stack) - tier 2	0.084	0.202	0.101	0.275	0.143	0.294
Loading (from stack) - tier 3	0.055	0.185	0.077	0.269	0.106	0.242
Loading (from stack) - tier 4	0.101	0.250	0.147	0.363	0.143	0.363
Loading (from stack) - tier 5	0.097	0.264	0.141	0.384	0.151	0.384
Unloading (to stack) - tier 1	0.094	0.238	No significant differences With respect to Undifferentiated containers			
Unloading (to stack) - tier 2	0.075	0.238				
Unloading (to stack) - tier 3	0.063	0.238				
Unloading (to stack) - tier 4	0.095	0.327				
Unloading (to stack) - tier 5	0.095	0.327				

Note: n.p. = not present.

Table 13: Gantry crane (GC) statistical results: validation test outputs (M-L estimation).

Activity	*Undifferentiated*		*20' Full*		*40' Full*	
	Dn	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*
Trolley speed (with container)	0.069	0.100	0.105	0.217	0.086	0.112
Free trolley speed	0.066	0.144	-	-	-	-
Crane speed	0.094	0.248	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

3.2.3 Reach stackers (RSs)

Eleven RSs operate in the Salerno Container Terminal, equipped with a twin-lift spreader able to move two full 20' containers. They are used both to transport containers very quickly over short distances and to pile/stow them in various rows.

The analyses concern: loading to shuttle/truck, unloading from shuttle/truck and stacking. Each activity was analyzed distinguishing undifferentiated containers from 20' and 40' containers. Moreover, stacking was analyzed distinguishing the tier number. The analysis focused on full containers since the main activities in Salerno Container Terminal concern full containers.

As regards undifferentiated containers (table 14), reach stacker unloading activities show an average unloading time from shuttle/truck of 0.215 minutes and a standard deviation of 0.114. With respect to stacking time, the estimation results show an average (calculated with respect to tier, up to five, in which a container is stacked) stacking time of 0.288 minutes and a standard deviation of 0.157 minutes. For all the activities, the standard deviation values confirm the need of a stochastic approach.

Interesting results can be observed on distinguishing between container types. With regard to loading, an average time of 0.365 minutes was observed for the 40’ full container (with a standard deviation of 0.272 minutes) and 0.344 minutes for the 20’ full container (with a standard deviation of 0.205 minutes). It can be concluded that the averages and corresponding standard deviations are similar and independent of container type.

As regards unloading, the average time for a 20’ full container is 0.153 minutes (with a standard deviation of 0.055 minutes), whereas it is double for the 40’ full container in terms of average (0.236 minutes) and standard deviation (0.119 minutes). For this activity, average values and standard deviations differ considerably (almost 50%) from undifferentiated values and, along with the high number of activities in which RSs are involved, show that different hypotheses on aggregation levels may lead to very different results and that such an issue should be carefully weighed up in the micro-simulation of a terminal container.

For stacking time, the time duration for each tier (up to five) was computed, but it was not possible to distinguish container type. With respect to tier 1, the average estimated stacking time is 0.201 minutes (with a standard deviation of 0.062 minutes), 0.186 minutes for tier 2 (with a standard deviation of 0.077 minutes), 0.238 minutes (with a standard deviation equal to 0.098 minutes) for tier 3, 0.355 minutes (with a standard deviation of 0.148 minutes) for tier 4 and 0.542 minutes (with a standard deviation of 0.164 minutes) for tier 5. Activity duration increases as the tier increases except for tier 2 which shows the lowest time duration since the arm of the RS is positioned at the same height as tier 2. The standard deviations are independent of the tier in which a container is stacked.

Starting from the same data, several random variables were tested. For RS loading and unloading, only Gamma and Weibull variables met the statistical significance tests: the Gamma random variable fits the data better due to better values in the validation test. In table 15, the results are shown and comments may be made similar to those proposed before for empirical analysis.

Table 14: Reach stacker (RS) empirical results.

Activity Time (minutes)	*Undifferentiated*		*20’*		*40’*	
			Full		*Full*	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Loading to shuttle/truck	0.357	0.250	0.344	0.205	0.365	0.272
Unloading from shuttle/truck	0.215	0.114	0.153	0.055	0.236	0.119
Stacking time	0.288	0.157	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 1	0.201	0.062	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 2	0.186	0.077	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 3	0.238	0.098	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 4	0.355	0.148	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 5	0.542	0.164	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

Table 15: Reach stacker (RS) statistical results: parameters of the Gamma distribution function (M-L estimation).

Activity Time (minutes)	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	μ	σ	μ	σ	μ	σ
Loading to shuttle/truck	0.307	0.170	0.304	0.155	0.311	0.188
Unloading from shuttle/truck	0.186	0.074	0.144	0.056	0.200	0.087
Stacking time	0.260	0.146	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 1	0.185	0.056	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 2	0.167	0.071	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 3	0.212	0.086	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 4	0.334	0.118	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 5	0.542	0.140	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

As regards RS speed, the authors suggest estimating the time duration of these activities directly. In this case, statistical models are not easily transferable since they depend on peculiarities of the container terminal: geometrical characteristics (path winding, …..), traffic congestion, etc..

In table 16 D_n validation test values and $d_{n,\alpha}$ thresholds (with $\alpha = 0.05$) are reported. As we can see, also for the reach stacker models, the D_n values are always lower than the correspondent $d_{n,\alpha}$ thresholds.

Table 16: Reach stacker (RS) statistical results: validation test outputs (M-L estimation).

Activity	*Undifferentiated*		*20'*		*40'*	
			Full		*Full*	
	Dn	*dn,α*	*Dn*	*dn,α*	*Dn*	*dn,α*
Loading to shuttle/truck	0.072	0.085	0.081	0.166	0.104	0.120
Unloading from shuttle/truck	0.090	0.103	0.075	0.215	0.175	0.287
Stacking time	0.095	0.110	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 1	0.084	0.231	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 2	0.149	0.223	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 3	0.117	0.246	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 4	0.104	0.246	n.a.	n.a.	n.a.	n.a.
Stacking time - tier 5	0.232	0.269	n.a.	n.a.	n.a.	n.a.

Notes: n.p. = not present / n.a. = not available.

4. Handling equipment models validation and comparison

The aim of this section is to validate the handling models proposed in section 3 (SMU, SMCT, RVU and RVCT) and to compare the effectiveness of the proposed approaches (sample mean estimation vs random variable estimation; container type differentiation vs no differentiation).

The handling model outputs were compared with the data surveyed in 2003 in the container terminal in order to ascertain the suitability of the model for representing real conditions. Model validation was carried out, estimating goodness of fit for each of the proposed models with respect to:

- single container movement time. This allows measurement of the model's ability to simulate single container movement. Such validation could be insightful in the event of the need to implement a short-term/real-time planning strategy, where simulation of single container movements should be as realistic as possible.
- Handling equipment operation time. This allows measurement of the model's ability to simulate handling equipment operation time. Such validation could be useful to understand which handling equipment is most affected by different modelling hypotheses and could be insightful for implementing short/medium term planning strategies.

As regards single container terminal time, with respect to a set of monitored terminal operations container movement times were estimated and compared with observed times. Absolute percentage error was estimated for each container and a global measure was obtained by summing each percentage error.

As regards handling equipment operation time, for each elementary activity and for the containers involved, the sum of estimated and observed container movement time was calculated, and the percentage error variation was estimated with respect to the sum of observed container movement time. Handling activities taken into account were: vessel loading and/or unloading time; quay/yard crane idle time; shuttle waiting time; shuttle transfer time; reach stacker stacking time; reach stacker idle time; gate in/out waiting time. Such an analysis could be insightful for understanding if the modelling approach may depend on the specific handling equipment. In other words, a simpler modelling approach (e.g. sample mean) might turn out to be effective enough to simulate reach stackers activity time, but not to simulate cranes activity time.

Starting from the previous estimated values, an aggregate indicator was estimated by calculating the average error of each type of handling equipment weighted with respect to the number of activities in which the handling equipment is involved.

Since the output of a random variable model may be considered a realization of a stochastic process (the time associated to each single activity is the realization of a random variable), the values used for calibration are obtained by determining the average of 25 simulations (see Law and Kelton, 2000, about the "replication/deletion approach" for calculating the number of simulations required to obtain an estimate of the sampling average with a fixed interval of reliability).

The results in terms of average absolute percentage estimation error are reported in table 17. The use of sample mean handling models does not produce good results in terms of single container movement time estimation. Average percentage estimation error is greater than 29%, and differentiation among container type does not seem to improve models goodness of fit.

Better results were obtained in terms of handling equipment activity time estimation. Aggregating all the equipments, average percentage estimation errors exceed 11%; analyzing single equipment, average percentage estimation errors vary substantially from 13% for mobile harbor crane to 10% for gantry cranes, and to 5% for reach stackers. The differentiation among container type reduces estimation errors, and seems to be more effective for mobile harbor cranes and for gantry cranes.

Results obtained using random variable handling models are much more significant.

As regards single container movement time estimation, only using the RVCT handling models the absolute percentage estimation error is acceptable (>11%); in all other cases the estimation errors are about 30%.

As regards handling equipment activity time estimation, average absolute percentage error significantly decreases down to 6% with the RVU handling model, and down to about 3% with random variable container type (RVCT) handling models. Analyzing single equipment, average percentage errors shows the same trend of the aggregate indicator. For the mobile harbor crane and for the gantry crane RVU models results show an average errors of 6%-8%; while for reach stacker the estimation error is about 3%. Noteworthy results are obtained differentiating container type.

Table 17: Average absolute percentage estimation error: estimation sample.

Handling model	*Absolute percentage estimation error*				
	Container	*Handling equipment*			
		Mobile harbor crane	*Gantry crane*	*Reach stacker*	*All*
Sample Mean Undifferentiated (SMU)	30.8%	15.8%	12.6%	5.9%	13.2%
Sample Mean Container Type (SMCT)	29.3%	13.3%	10.6%	4.9%	11.0%
Random Variable Undifferentiated (RVU)	28.5%	7.8%	6.2%	2.9%	6.5%
Random Variable Container Type (RVCT)	11.2%	3.6%	2.9%	1.4%	3.0%

In conclusion, if the aim is to simulate handling equipment performances it can be deduced that cranes should be better simulated through random variable models and differentiation among container type is advisable, whereas reach stackers activity time can be effectively estimated through sample mean model, even without differentiating container type. If the aim is to simulate container movement time, there is no alternative to random variable modeling approach and differentiation among containers is mandatory.

In figure 1 cumulative absolute percentage estimation error variation is reported. Regarding the handling equipment indicator, the great variability of the phenomenon observed produces absolute estimation errors for sample mean models lower than 10% only for 25% of the handling equipment simulated, while for random variable models the absolute estimation error is always lower than 10% and for the RVCT this value is lower than 5% for 75% of the handling equipment simulated. If the aim of the simulation is to estimate container movement, the only suitable handling model is the RVCT one: only for this model is the absolute estimation error of the container operation time lower than 10% for 45% of the observations, and lower than 15% for over 60% of the observations. By contrast, for over 80% of the observations the absolute estimation error is lower than 30%. As can be seen in figure 1, the other models (SMU, SMCT and RVU) produce unacceptable absolute estimation errors for the purposes of the simulation.

From the model validation results we may obtain the following application guidelines. Results differ according to the handling models used; sample mean models could be used for estimating handling equipment indicator, with absolute percentage errors of 11%-13%; on using random variable handling models for estimating handling equipment indicator, absolute percentage errors decrease to 3%-6%. To estimate container movement performance (container indicator) only the RVCT handling models can be used (average absolute percentage estimation error more than 11%).

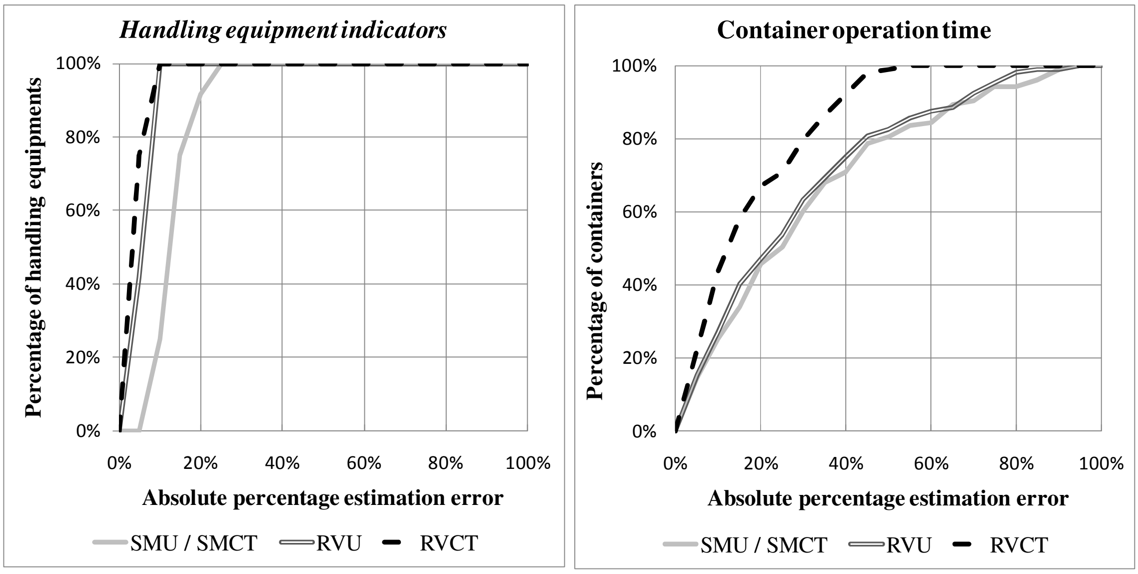

Figure 1: Cumulate absolute percentage estimation error variation.

5. Conclusions

In this paper container terminal handling equipments were modeled, with three main issues being addressed:

a. estimation of mean and standard deviation of activity time duration for different handling equipment and for different container types;
b. estimation of models for three handling equipment types (mobile harbor cranes, gantry cranes, reach stackers) and for different container types (undifferentiated, 20 feet, 40 feet, empty, full….);
c. effects on simulation of different hypotheses regarding (i) the approach to estimating handling time duration (sample mean vs random variable estimation), (ii) the level of aggregation of handling activities (e.g. vessel loading vs explicit simulation of elementary activities sequence), (iii) the segmentation of container type.

As regards point (a), our results allow the differences between activity time duration to be determined if different aggregation hypotheses are made for handling activity and/or container type. For instance, whether and to what extent an activity can be subdivided into several elementary activities, whether and how to distinguish container type. Sample mean values and standard deviations show that non-negligible differences can be observed and bear out the need for modeling handling activities through random variables. Particular care should be paid to container type, to the correct identification of elementary activities involved, and to those activities which stack containers in different tiers.

As regards point (b), calibration results enrich the existent state of art, give some insights on the best calibration approach (moment, maximum likelihood), highlight a family of suitable distribution functions to simulate handling equipment time duration and define the best-performing distribution functions for each handling equipment and each container type. >From a statistical point of view, the maximum likelihood estimation approach appears to perform best, while Normal, Gamma and Weibull distribution functions proved statistically significant to interpret handling activity time duration. In particular, the Gamma random variable leads to better goodness of fit for all handling activities and for all container types involved. The whole set of distribution functions (and of their parameters) allows different simulation models to be implemented with changes in activity aggregation and container type.

As regards point (c), some application guidelines may be drawn, with results differing according to what we want to simulate. If the focus is to simulate handling equipment time duration, both sample mean and random variable estimation can be pursued. Although sample mean models could be used for estimating handling equipment indicator, greater average absolute percentage errors must be accepted (11% to 13%) with respect to random variable handling models that have absolute percentage errors varying from 3% to 6%.If single container trip time (container indicator) is to be simulated, only *Random Variable Container Type* handling models should be used. In this case, average absolute percentage estimation error is about 11%, while about 30% for the other approaches.

Finally, the obtained results can be easily implemented in any terminal simulation model.

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European Transport \ Trasporti Europei n. 46 (2010): 72-85

Models of intermodal node representation

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Abstract

This paper analyses three different approaches of supply representation for intermodal nodes and proposes some functional and topological models for the representation of ports and Freight Villages. Besides in the paper functional and topological representation of container port and freight village are proposed.

Further research is directed to the specification and calibration of cost functions, useful for cost estimation for different components of node network, with a view to facilitate the analyses of freight mobility on multimodal large networks.

Keywords: Intermodal node; Supply representation; Functional representation; Graph; Cost functions.

1. Introduction

Intermodal nodes, which are different in structure and functions, are essential elements of the transport network and their functionality considerably affects the overall efficiency of the intermodal chain.

A basic element for the implementation of procedures to optimize the global processes of intermodal logistic node management is supply representation.

In particular, intermodal terminals can be represented following three different approaches: functional, topological (graph theory) and analytical (cost functions).

This paper analyses the three different approaches of supply representation for intermodal nodes and proposes certain functional and topological models for the representation of ports and of the Freight Villages.

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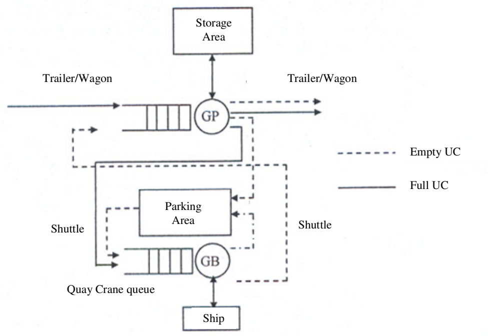
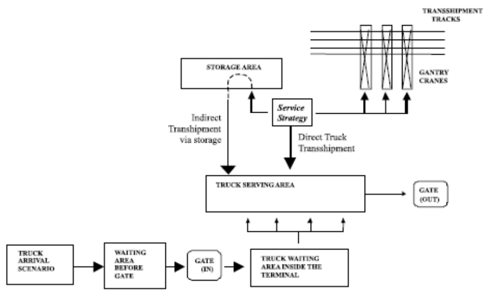
2. Functional representation

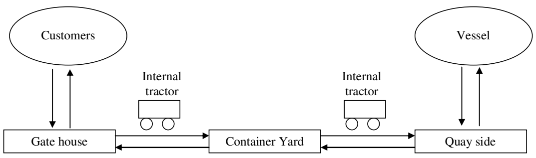
Node functional representation aims to show the terminal functional components as well as their existing relations. It can meet various requirements, such as analyses and assessments of the node spatial, organizational and relational structure. The functional representation is carried out through the use of block diagrams which show the typical utilities of the terminal and the connections between the different areas composing the node. This kind of representation allows to describe the different operations by means of flow charts, where the various phases of goods handling and the conditions to observe are represented by model symbols, called building blocks and connected with each other by arrows.



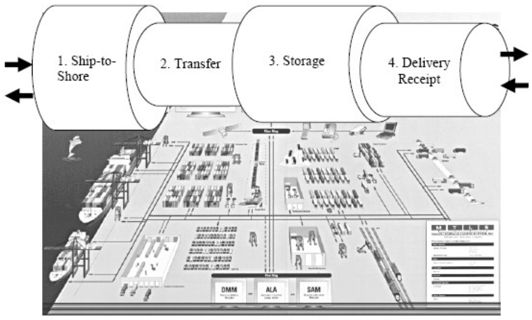
Container Port (Gambardella et al., 1998)



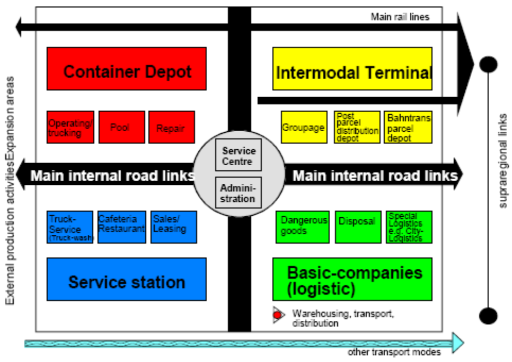
Rail/Road Terminal (Ballis and Golias, 2002)



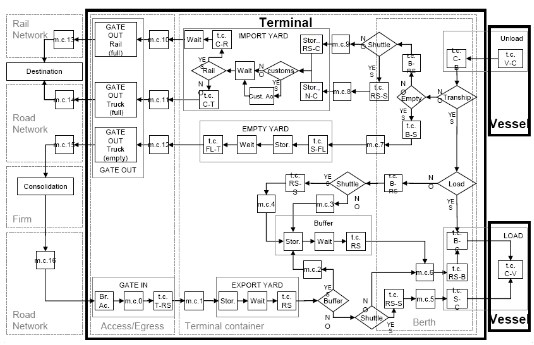
Container Port (Cheung et al., 2002)



Container Port (Henesey, 2004)



Freight Village (SUTRANET Project, 2007)



Container Port (Cantarella et al., 2007)

Figure 1: Models of functional representation of intermodal nodes.

Sector literature includes several examples of functional representation for intermodal nodes (Gambardella et al., 1998; Ballis and Goulias, 2002; Cheung et al., 2002;

Henesey, 2004; Cantarella et al., 2007; SUTRANET, 2007). Figure 1 shows a synthesis of certain functional representations found in sector literature and specifies the represented type of node. Besides goods flows, the so-called "immaterial flows" have also become more and more significant, particularly information exchanges between the subjects within the node and between them and the outside (Gattuso et al., 2005). Figure 2 shows a model of representation of information flows within a port area.

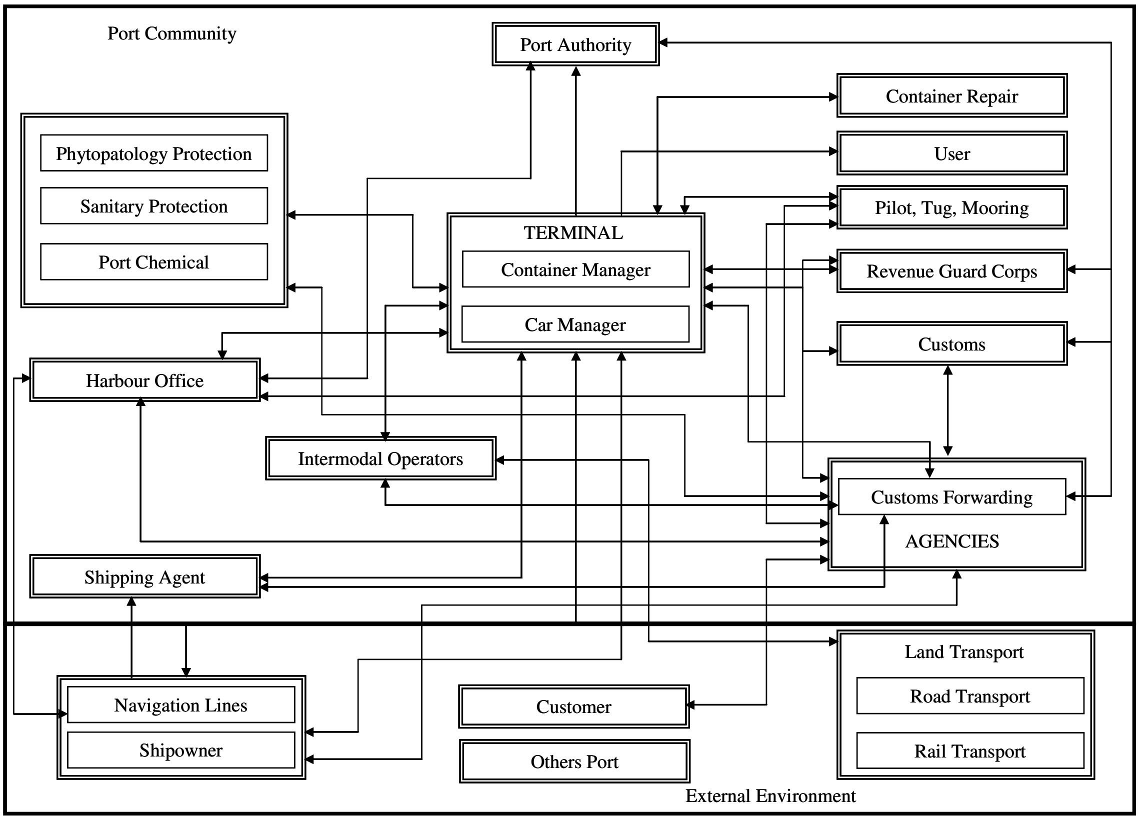


Figure 2: Information flows in the port of Gioia Tauro (Gattuso et al., 2005).

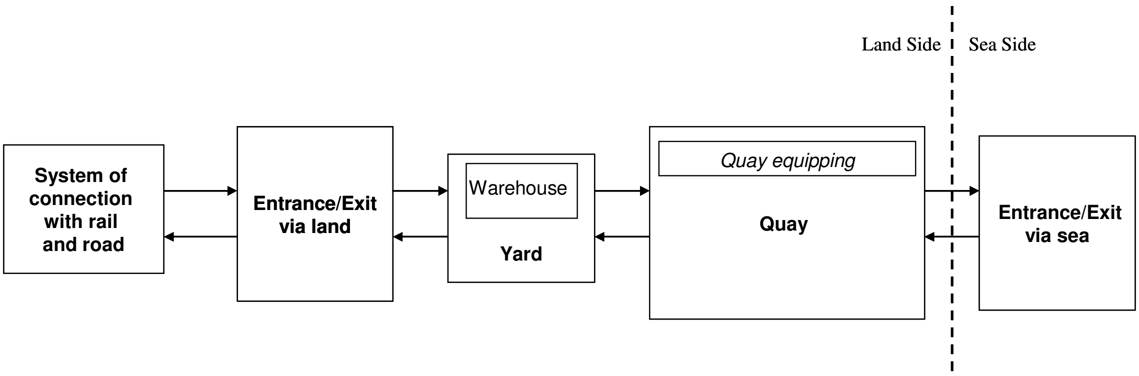


Figure 3: Functional representation of a port.

Ports are intermodal nodes where the waterway transport network is connected with the land transport network. Generally, the port structure can be divided into two macro-blocks: the first identifying sea side activities, the second including land side operations; it is possible to distinguish five functional blocks where different activities are carried out (Figure 3): an entrance via sea; one or several mooring docks; equipment for goods load/unload operations; a yard for goods handling and/or storage with possible sheltered warehouses/depots; an exit gate via land; a system of connection with land transport systems (road and rail).

The functional scheme can be organised depending on the demanded level of detail and on the type of port to represent. Figure 4 shows a proposal of functional representation of a container port. Symbols belong to an international standard language and have specific meanings.

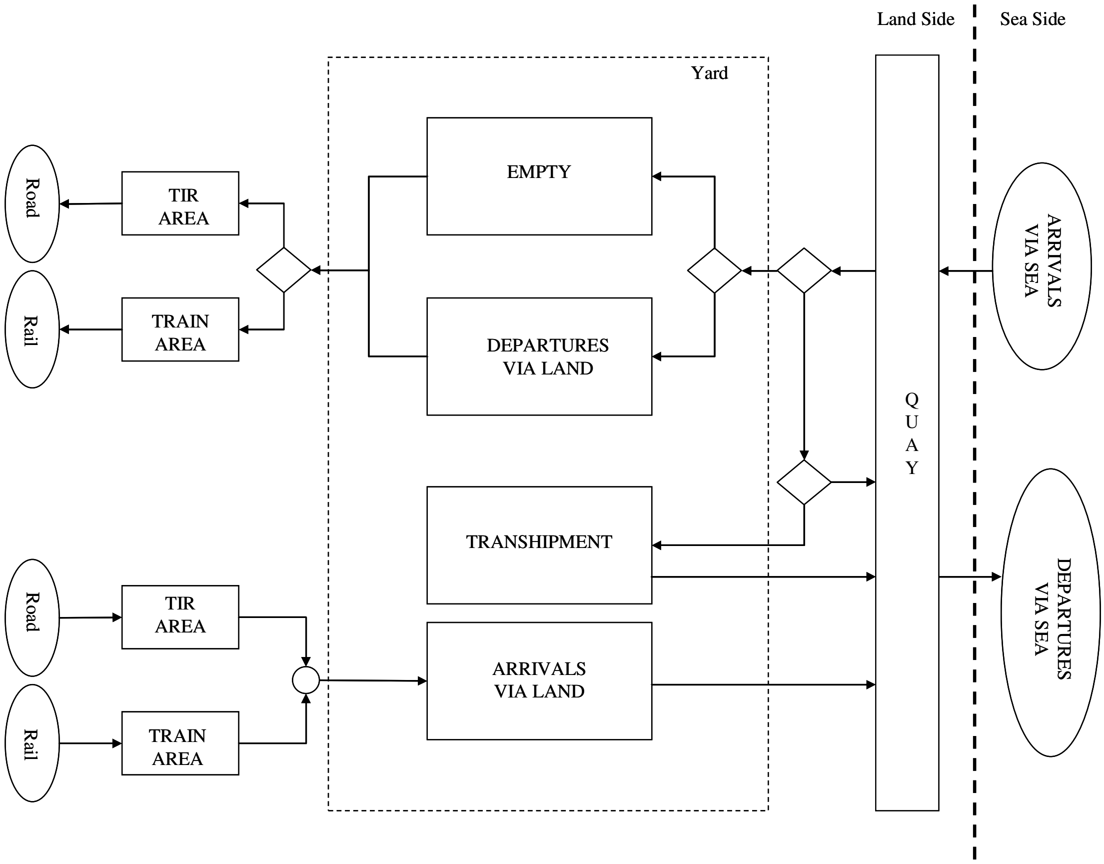


Figure 4: Functional representation of a container port.

The Freight Village is a well organised set of structures and integrated services for the exchange of goods between the different transport modes, which includes, however, a railway station that can form or receive complete trains and is connected with ports, airports and highways (Italian Law n. 240/90).

A Freight Village is a typical infrastructure destined to:

- host transport and logistics companies, as well as product processing businesses;
- integrate the different modes of transport, both in a structural way and through information exchange;
- provide services to the hosted businesses, to goods and people, with a view to enhance the intermodal transport and the storage of products, as well as to assure the control of common areas, the Freight Village entrance and exit, the regular functioning of the technological plants.

On the basis of the above-mentioned functions, as a general rule, it is possible to define 5 functional macro-areas within a Freight Village:

- *the intermodal terminal*: it is the heart of the Freight Village, the place where shunting, change between the different modes of transport (usually road-rail) and load/unload handling occur; it includes a railway station and special warehouses for the temporary storage of goods,
- *the logistic area*: where industrial and productive facilities are located; in this area products are processed/manipulated to gain added value, goods are consolidated/deconsolidated, distributed and collected, or simply stored;
- *administrative area*: it has a central position which is easily accessible by visitors and includes the administrative offices of the Freight Village, of customs and of the fire brigade;
- *commercial area and services to personnel*: it offers tertiary and commercial services to the personnel (restaurant, hotel, bank, post office, etc.);
- *services to vehicles*: where there are parking facilities, assistance to vehicles and repair shops for transport units and unit loads.

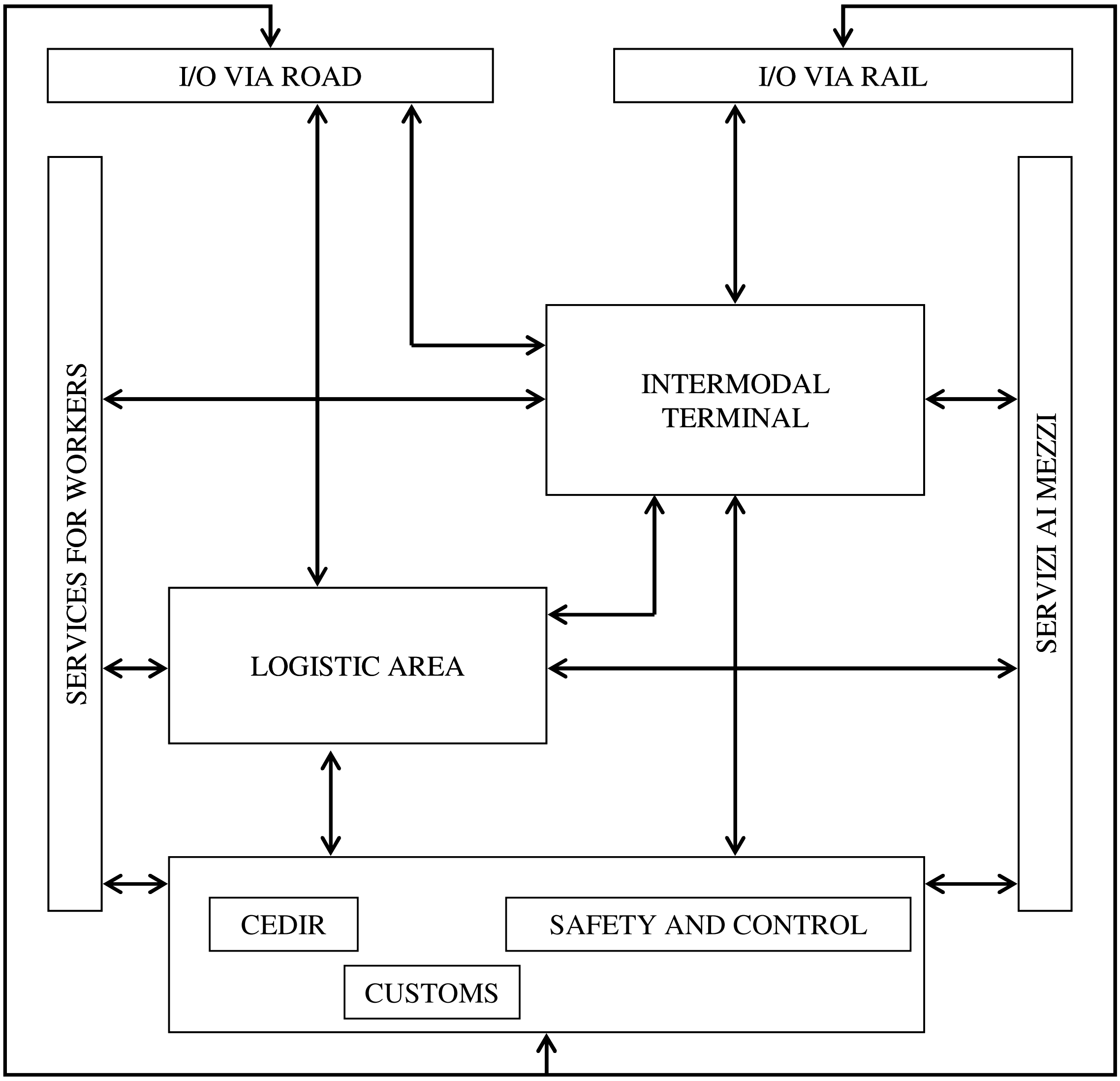


Figure 5: Relations between the areas of Freight Village.

Besides the above-mentioned areas, it is worth mentioning the presence of the road and rail input/output gates. Figure 5 shows the relations between the different functional areas of a Freight Village, while figure 6 proposes a functional representation of the Freight Village node constructed according to the rules of the flow chart theory and taking into account the access/egress functional areas, the intermodal terminal and the logistic area.

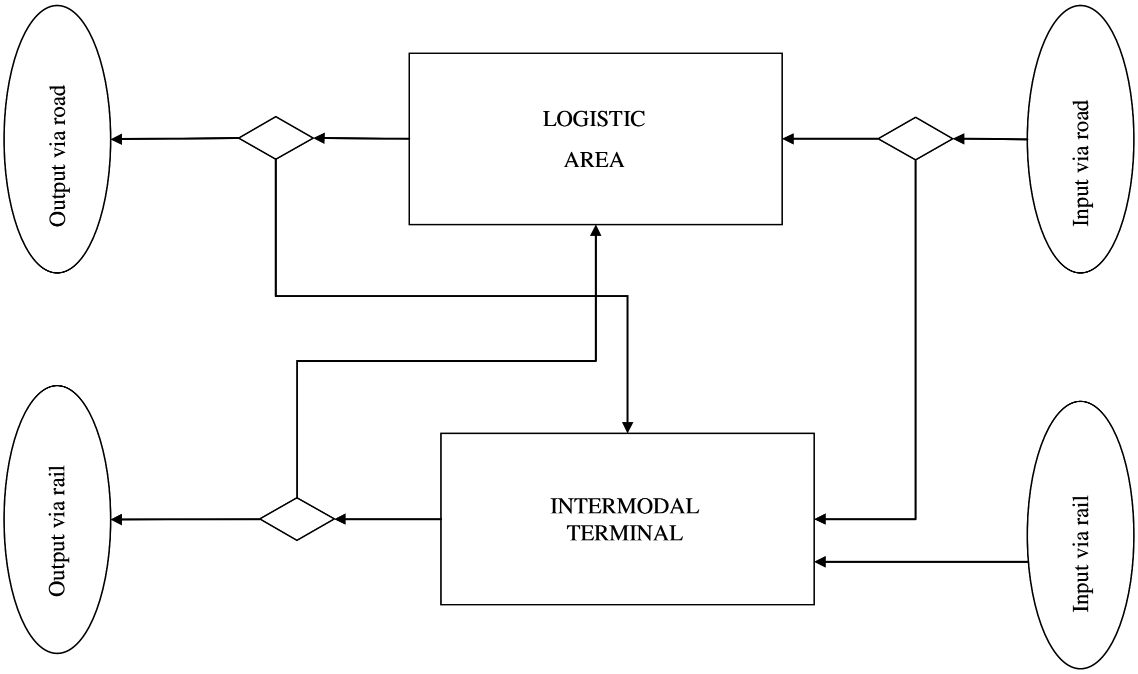


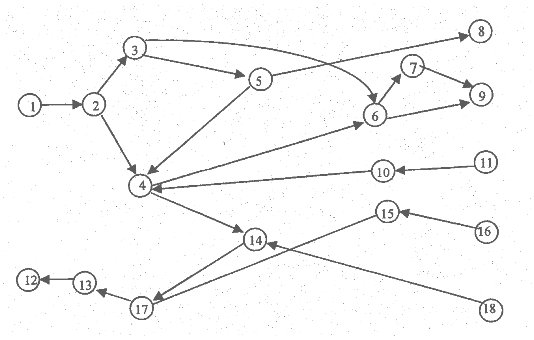
Figure6: Functional representation of a part of Freight Village.

3. Topological representation

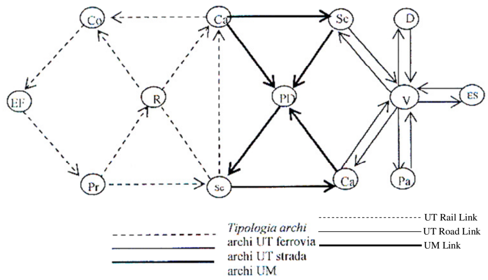
The topological representation of the intermodal logistic node is made through the construction of a graph which allows the precise schematization of its activities. In general, graph nodes represent physical and/or temporal points where an elementary operation, which is part of the transport cycle of goods and of their possible manipulation/processing, starts or finishes; on the contrary, line segments represent goods handling and/or processing operations. After a brief state of the art of the models of topological representation, an alternative network model for a port and a Freight Village is proposed below.

3.1 Literature models

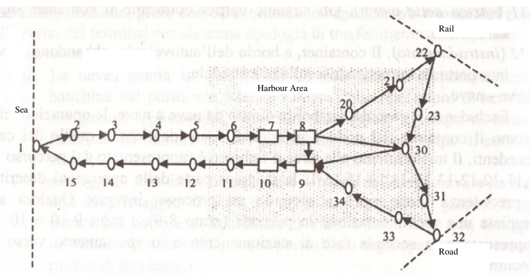
In sector literature there exist several examples of topological representation of intermodal nodes (Pratelli, 2000; Russo, 2000; Gattuso and Musolino, 2002; Gattuso and Chindemi, 2002; Russo and Cartisano, 2005; Gattuso et al., 2008). Figure 7 shows a synthesis of certain topological representations found in Italian sector literature and specifies the represented type of node.



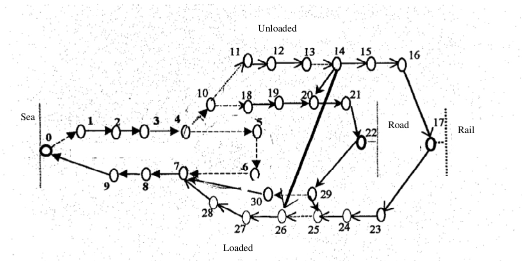
Port (Frankel, 1987)



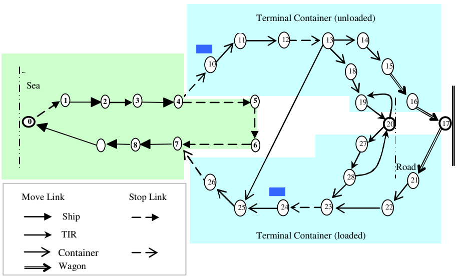
Rail/Road Terminal (Russo, 2000)



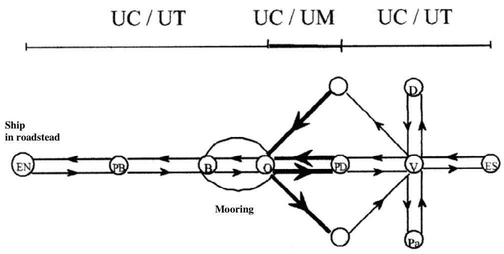
Container Port (Gattuso and Musolino, 2002)



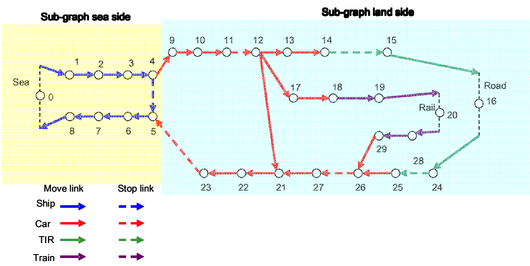
Ro-Ro Port (Gattuso and Chindemi, 2002)



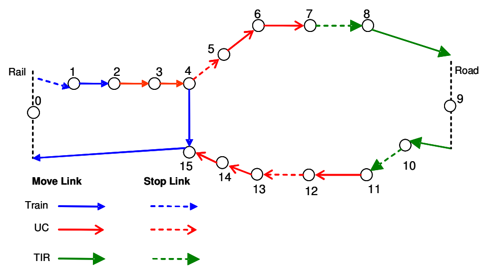
Container Port (Gattuso and Chindemi, 2002)



Ro-Ro Port (Russo and Cartisano, 2005)



Ro-Ro Port (Gattuso et al., 2008)



Rail/Road Terminal (Gattuso et al., 2008)

Figure 7: Models of topological representation of intermodal nodes.

Generally, the schematization of the port functional organization includes the functional relations between dock, goods storage areas (distinguished into import and export areas), intermodal sites, port entrance and exit points. Operations are carried out in the nodes corresponding to exchange relations between different spatial components. The graph can be constructed starting from the hypothesis that the elements, which make up a freight integrated system, can be aggregated into three categories (Russo, 2001): unit loads (UL), handling units (HU) and transport units (TU).

Depending on such elements the port can be divided into three sub-systems: sections where ULs are transported by sea TUs (UL/TU); sections where ULs are transported by HUs within the port (UL/HU); sections where ULs are transported by road TUs (UL/TU). The road-rail intermodal terminal can also be schematised through three sub-graphs: sub-graph of the ULs transported by rail TUs; sub-graph of the ULs transported by road TUs; sub-graph of the ULs transported by HUs. The representation proposed by Gattuso et al. (2002 - 2008) concerns the activities taking place in a Ro-Ro terminal and in a container port. A part of the graph represents seaward operations, the other represents landward handling activities, which are different depending on whether the unit load is a vehicle (lorry, road train or articulated lorry) or a nonmotorised unit (container or semi-trailer).

3.2 Proposed models

An alternative graph for the representation of the various phases of goods handling in a container port terminal and in a Freight Village is proposed below. The previously described models of node representation have been taken into account as points of reference, yet certain further elements have been added. In accordance with the proposed functional representation, the node supply of a container port terminal can be represented by means of a graph divided into two sub-graphs:

- *Sea Side sub-graph*, which schematises the entrance/exit operations via sea, from the entrance of the vessel in the roadstead up to its dock hauling and viceversa;
- *Land Side sub-graph*, which schematises the vessel load/unload operations, handling and storage activities in the yard, goods routing on land transport networks.

Figure 8 shows the schematised graph of the port; in particular, it is possible to distinguish the two sub-graphs, the entrance/exit paths followed by the vessel, by articulated lorries and by trains within the node, the movements of the unit loads (TEUs), the waiting and handling arcs. Besides, in relation on proposed functional representation, it is possible to distinguish start and finish areas of the activity, processing area of the goods, decision and collection point.

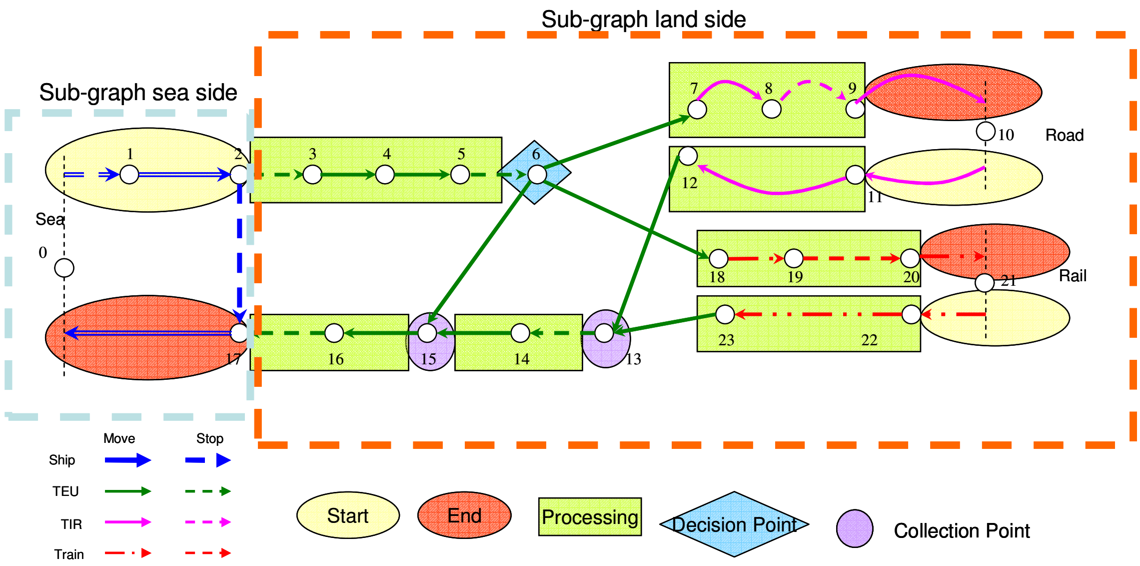


Figure 8: Proposed graph for a container port.

Table 1 shows each arc of the graph with the activity it represents. It is worth noticing that the graph has been constructed considering that the activities of tug and dock mooring are carried out at the same time as pilot activities (from a technical point of view, tug shadows pilot and mooring shadows tug) and that there is no direct ship-ship transhipment.

Table 1: Arcs of the graph of the container port terminal.

Link	*Operation*	*Link*	*Operation*
0-1	Wait in roadstead	12-13	Positioning container in storage area
1-2	Pilot, Tug, Mooring	13-14	Stop container in storage area
2-17	Wait ship for loading/unloading	6-18	Moving container towards train area
2-3	Wait container on the ship	18-19	Loading container on wagon
3-4	Drawing container, positioning in crane buffer	19-20	Formation train
4-5	Positioning container in storage area	20-21	Routing train via rail
5-6	Stop container in storage area	21-22	Entry train to port
6-7	Moving container towards TIR area	22-23	Unloading container to train
7-8	Loading container on TIR	23-13	Positioning container in storage area
8-9	Wait TIR for practices	6-15	Movin container towards quay
9-10	Routing TIR via road	15-16	Loading container on ship
10-11	Entry TIR to port	16-17	Finishing loaded operations
11-12	Unloading Container to TIR	17-0	Unmooring, Pilot, Tug

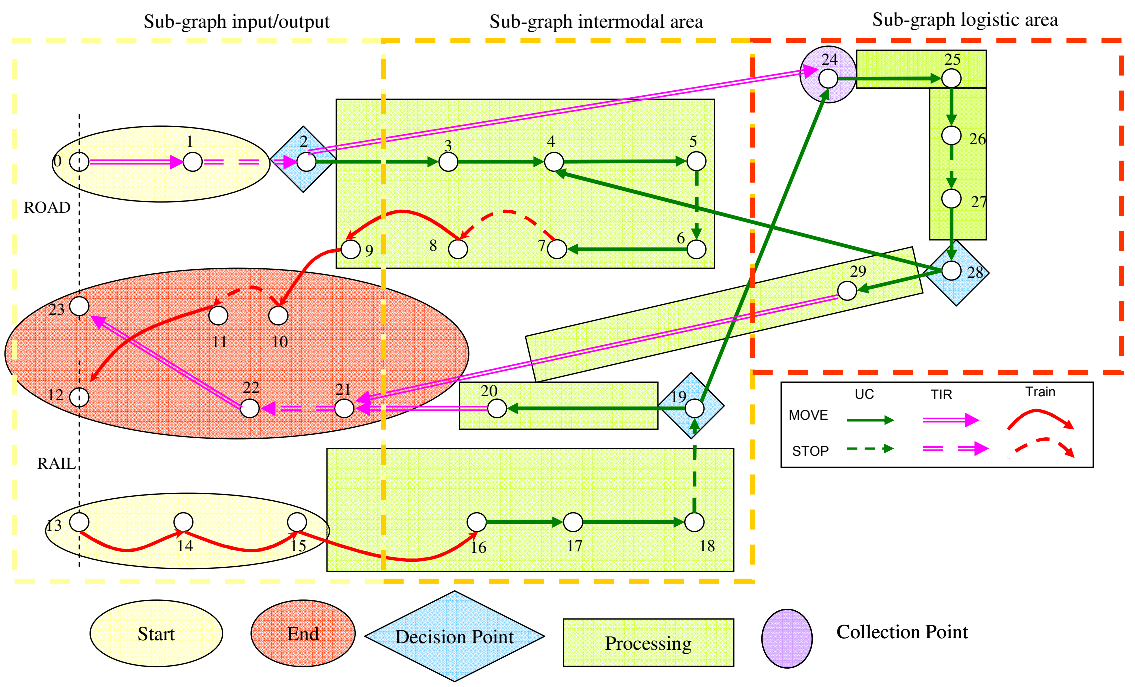


Figure 9: Example of a graph for Freight Village.

In the case of a Freight Village, since its core activities and functions are carried out in the intermodal terminal and in the logistic area, the graph can be divided into 3 sub-graphs:

- *Access/egress sub-graph*, which represents the activities performed at the terminal input/output gates;
- *Intermodal area sub-graph*, which represents the transhipment operations which are carried out in the road-rail intermodal terminal;
- *Logistic area sub-graph*, which represents activities taking place within this area.

Figure 9 proposes an example of graph of a Freight Village where the intermodal terminal is served by transtainer and the length of the operating tracks can assure the handling of a train without sectioning it. Besides, in relation on proposed functional representation, it is possible to distinguish start and finish areas of the activity, processing area of the goods, decision and collection point. Table 2 shows a description of the arcs which form the graph.

Table 2: Arcs of the graph of the Freight Village intermodal terminal.

Link	*Operation*	*Link*	*Operation*
0-1	Entry TIR to freight village	27-28	Loaded preparation
1-2	Check-in operations	28-29	Loading on TIR
2-3	Start TIR towards intermodal terminal	29-21	Start towards exit road gate
2-24	Start TIR towards logistic area	28-4	Start towards intermodal terminal
3-4	Unloading UC to TIR	13-14	Entry train to freight village
4-5	Positioning UC in storage area	14-15	Replacment locomotive
5-6	Wait in storage area	15-16	Start train towards operative railway
6-7	Loading UC on train	16-17	Unloading UC to train
7-8	Finishing train loaded operations	17-18	Positioning UC in storage area
8-9	Start train towards tacking/delivery railway	18-19	Storage
9-10	Replacment locomotive	19-20	Loading UC on TIR
10-11	Wait train	20-21	Start towards exit road gate
11-12	Routine train on railway	21-22	Check-out operations
24-25	Unloading TIRin logistic area	22-23	Introduction on road network
25-26	Treatment, manipulation, manufacturing	19-24	Start UC towards logistic area
26-27	Storage		

4. Analytical representation

To analytically represent an intermodal node means to identify cost functions which allow to evaluate the costs (times) related to the goods transit through that node.

Cost evaluation in intermodal nodes is crucial; in fact, such costs are an important component of the total transport cost. They are costs varying according to the "involved" modes of transport and to the possible storage and processing of the goods in transit.

As a general rule, a cost function can be defined as a function that associates to input and output prices the minimum cost to bear for their production. Formally:

$$C(p,q) = \min_x \{p' x : x \in L(q)\}$$

where x is the input vector, p is the vector of the relative prices, q is the vector of productions and $L(q)$ is the input requirement set of the vector of productions q, that is, the set of input combinations which allow the production of q.

From the point of view of a Multimodal Transport Operator (MTO), the monetary cost Cp , associated to the goods transit in the node, can be evaluated as a function of the quantity Q of handled goods through the following expression:

$$C_n = \delta \cdot Q$$

where δ is a unit cost parameter (€/t) which has different values depending on the type of node (Table 3).

Table 3: Values of parameter δ.

Source	*Node*	*δ (€/t)*
SCENES (2000)	Container port	5,6
UIC (2006)	Railway terminal in Europe	3,4
UIC (2006)	Railway terminal in East Europe	6,6

It is possible to evaluate the cost of the transit through the node as a function of the number N of the handled ULs:

$$C_n = \alpha \cdot N$$

where α is expressed in €/UL and varies depending on the type of node and performed operation (Table 4).

Table 4:Values of parameter α (RECORDIT, 2003).

Node	*Operation*	*α (€/UC)*
Railway terminal	Road-Rail Transhipment	32,50
	Rail-Rail Transhipment	27,40
Port	Road-Sea Transhipment	24,00
	Sea-Rail Transhipment	40,00

The cost in the node can be more precisely evaluated as the sum of the costs of the UL entrance/exit operations through the gates ($C_{i/u}$), of the storage in the terminal (C_s), of the transhipment on train or lorry (C_t), of the expenses related to goods delivery and customs operations (C_v), of the expenses of possible manipulation/processing (C_l):

$$C_n = C_{i/u} + C_s + C_t + C_v + C_l \, .$$

Specifically referring to an intermodal port, it is suitable to underline that the entrance/exit cost is generally included in the fare the MTO pays to the shipping company for the sea transport service. If a vessel is taken into account as a transport unit, for a shipping company such a cost is given by the sum of the pilot, tug and mooring costs (Figure 10).

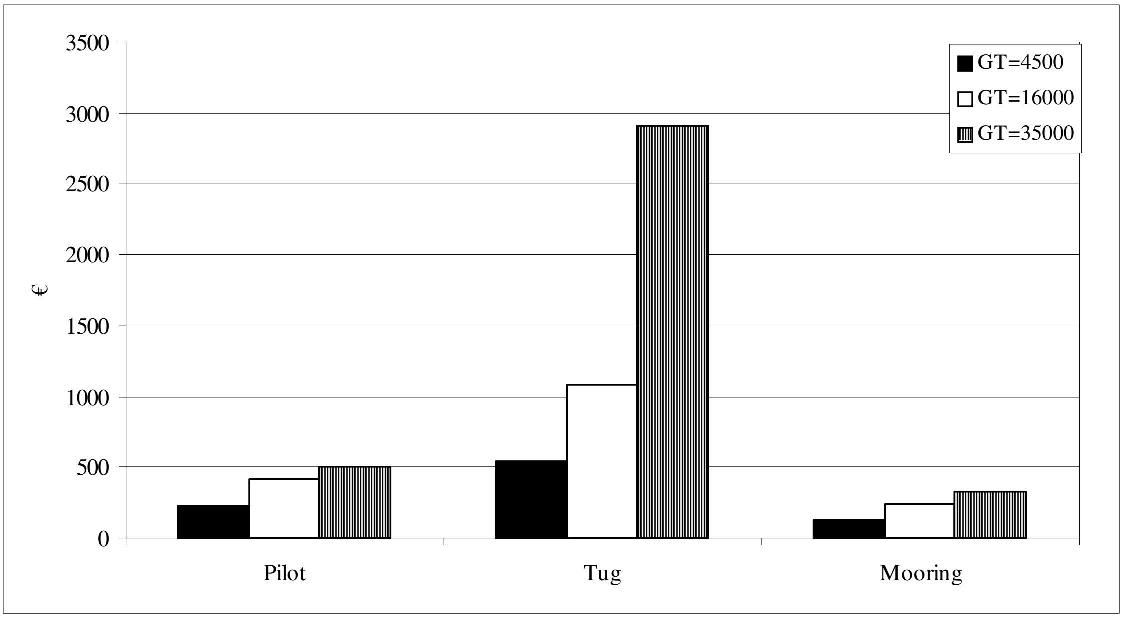


Figure 10: Average cost of port entrance/exit for a vessel.

It can be observed that the vessel entrance/exit cost increases in proportion to the vessel gross tonnage (GT); the tug cost is the most significant. On the contrary, the costs of storage, transhipment, customs and possible processing/manipulation depend on the quantity of goods, that is, on the number of unit loads handled on the land side of the port. Such costs significantly change according to the goods dwell time in the node, to the quantity of goods, to the involved modes of transport.

The temporal cost (T_n) associated to the goods transit through the node can be evaluated as the sum of the node entrance/exit time ($T_{i/u}$), of the time of UL load/unload from the transport unit ($T_{c/s}$), of the UL waiting time and downtime in the node (T_{att}), of the handling time for the transfer of the UL from an area of the node to another (T_{mov}):

$$T_n = T_{i/u} + T_{c/s} + T_{att} + T_{mov}$$

In the case of a port, entrance/exit times depend on the type of port and on its physical characteristics; table 5 shows certain estimations of entrance/exit times for different types of port (Ro-Ro and Lo-Lo).

Table 5: Entrance/exit times.

Source	*Port*	T_{entry} *(h)*	T_{exit} *(h)*
Russo and Cartisano, 2005	Ro-Ro	0,47	0,41
	Lo-Lo	0,40	0,37
Marino S. (2000)	Ro-Ro	0,50	0,50

The time necessary to carry out load/unload operations is a function of the number and type of unit loads to handle, of the type and number of the used handling units and of their net productivity.

In the case of a Ro-Ro port, where semi-trailers are handled, such a time can be evaluated as (Russo e Cartisano, 2005):

$$T_{c/s} = \beta_1 \cdot NT + \beta_2 \cdot NS / NT$$

where *NT* is the number of trailers used for handling, *NS* is the number of handled semi-trailers, β_1 and β_2 are model parameters (Table 6) which can vary depending on whether a load or unload operation is being carried out.

Table 6: Values of parameters β_1 and β_2 (Russo and Cartisano, 2005).

Operation	β_1	β_2
Loading	0,18	0,12
Unloading	0,17	0,16

In the case of a container port, load/unload time can be evaluated as (Russo e Cartisano, 2005):

$$T_{c/s} = \beta \cdot N$$

where N is the number of loaded/unloaded containers and β is the model parameter equal to 0.08, if the unload phase is considered, and to 0.07, if the load phase is considered. Table 7 shows certain values relative to the waiting and handling times in a container port according to the modal transfer.

Table 7: Average waiting and handling times in a container port (Gattuso and Musolino, 2002).

	S-S	*S-T*	*T-S*	*S-C*	*C-S*
T_w (h)	146	12	36	12	24
T_{mov} (h)	0,42	0,36	0,71	0,55	0,83

Notes: S= Ship; T= Train; C=Truck.

5. Conclusions

The supply representation for the intermodal node is a fundamental element for the definition of procedures to optimise the performances of the node and of a logistic chain. The functional representation allows analyses of the spatial and organizational structure of the node. The topological representation provides a precise schematization of the activities, which are carried out in the node, through the construction of graphs. The analytical representation allows to evaluate the cost components, related to the goods transit through the node, in temporal and monetary terms.

This paper proposes certain functional and topological representations for intermodal ports and Freight Villages, highlighting the relations existing between the different functional parts of the two terminal systems.

Further research is directed to the specification and calibration of cost functions for the estimation of the costs related to the goods transit through ports and Freight Villages, with a view to facilitate the analyses of goods mobility on multimodal networks.

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European Transport \ Trasporti Europei n. 46 (2010): 86-99

Intermodal terminal simulation for operations management

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Abstract

A freight terminal is a key node in a transportation network and the transit time of containers through this terminal represents one of the most relevant bottleneck in logistic chains.

The system performance reduction and the corresponding increase of transit time is often due to the increase of the freight flow without a corresponding increase of stacking and handling capacity.

For this purpose it was decided to approach the problem by a discrete event simulation model, in order to reproduce the activities carried out inside an intermodal terminal, to calculate the total transit time and to identify the bottlenecks.

The transit time of a cargo unit in a terminal is the summation of times required for the development of each phase of the process (waiting time + operational time).

Therefore, the first step was the identification of the main activities and the analysis of waiting and operational phases, in order to quantify the times of each phase.

For modelling the software Planimate® was used. Planimate® allows the simulation of a process as a set of discrete events, in series or in parallel, through the use of hierarchical networks.

In order to optimise handling operations on containers, different scenarios were simulated with various fleets of trailers and front cranes to investigate the corresponding variations of performance indicators.

For the application of the model an Italian case study was chosen: the container terminal inside the harbour of Livorno (Darsena Toscana Terminal).

Keywords: Intermodal terminal; Simulation; Freight; Logistic; Management.

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1. Introduction

Railway freight terminals play a key role within multimodal transport and the transit time through these terminals represents one of the most relevant bottlenecks in logistic chains.

A freight terminal is a basic node in a transportation network, where thousands of daily decisions are taken to manage relevant flows of containers.

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To predict the traffic evolution inside and nearby a terminal is, moreover, important in order to manage the required flows and the available areas.

One of the main causes of the reduction of system performance is, in fact, the increase of the freight flow, without a corresponding increase of stacking and handling capacity. The consequences are the congestion of terminal flows and the corresponding increase of transit time.

In the research a decision support system for the management of an intermodal container terminal is presented and a simulation tool has been developed.

In the last years the role of simulation has become of high relevance in managing and planning such terminal's activities. For this purpose it was decided to approach the problem by a simulation model capable of reproducing the activities carried out inside an intermodal terminal.

A discrete event simulation tool has been implemented with the aim to calculate the total transit time and to identify the bottlenecks. It allows to reduce the probability of system performances reduction through optimisation of container unloading and handling operations. The simulation has been applied to Darsena Toscana Terminal in Livorno harbour.

This work is the follow-up of the activities developed by the research team devoted to the functional analysis and the modelling of intermodal terminals.

2. Intermodal terminal operation

An important parameter for performance evaluation of an intermodal terminal is the transit time of a cargo unit, calculated as the lapse between the arrival of a single transport unit at the terminal, from an outside transport infrastructure, and the departure towards a different transport system.

The transit time of a cargo unit in a terminal is the summation of times required for the development of each phase of the process, in which a phase is normally composed by a waiting time and an operational time.

For the modelling of handling times, the activities related to the transfer of cargo units from the ship to the stacking area are analysed.

The first step was the identification of the main activities and the analysis of waiting and operational phases, in order to formalise the times of each phase:

- check-in operations on ship arrival;
- waiting for 1st transfer (transhipment – stocking area);
- 1st transfer (transhipment – stocking area).

A simulation model reproduced ship arrival and the related check-in operations:

a) unloading and loading of container by port crane from ship to trailer;
b) transfer of loaded trailer (from transhipment area to stocking area);
c) downloading of trailer by reach stacker and drop off on stocking area.

Two different assumptions were made for trailer movement:

1) planning of routes to send the trailer where its service is required (port-crane without trailer queue): if a trailer arrives under a busy crane it is sent to the first free crane;

2) no operational traffic rules: the trailer is moving under the port crane and stops only where a queue is not present only, otherwise it moves to the next port-crane and so on.

One more assumptions was made about container distribution on the different areas of the ship (bow, central and stern):

1) fixed container distribution (equally splitted);
2) random container distribution.

The assumptions of random distribution of containers reproduces the real conditions of possible different load configurations.

3. Model structure description

The software Planimate® was used to build the model. Planimate® allows the simulation of a process as a set of discrete events, in series or in parallel, by means of hierarchical networks.

The model for container handling in a maritime terminal is organised in two completely separate networks ("Intermodal terminal layout" and "Stocking area"). "Stocking area" is actually a subnet of "Intermodal terminal layout". It is treated differently from the other subnets due to the complexity of the operations performed within the stocking area.

The top level network ("Intermodal terminal layout") reproduces the system layout (Figure 1), including the hierarchical structure of the model, the stocking areas (the "Stocking area" subnet) and the quays. The paths followed by the handling vehicles (trailers) are also reproduced. It is described in 3.1. The "Stocking area" subnet is described in 3.2.

3.1 Intermodal terminal layout

A number of main phases were identified in order to simulate transfer activities. Each phase corresponds to a subnet. They are shown here in sequence:

1) ship arrival;
2) check-in;
3) trailer arrival;
4) port-crane activities;
5) trailer handling (to stocking area);
6) stocking area operation (including reach stacker operation);
7) exit of unloaded trailer from stocking area and trip back to crane.

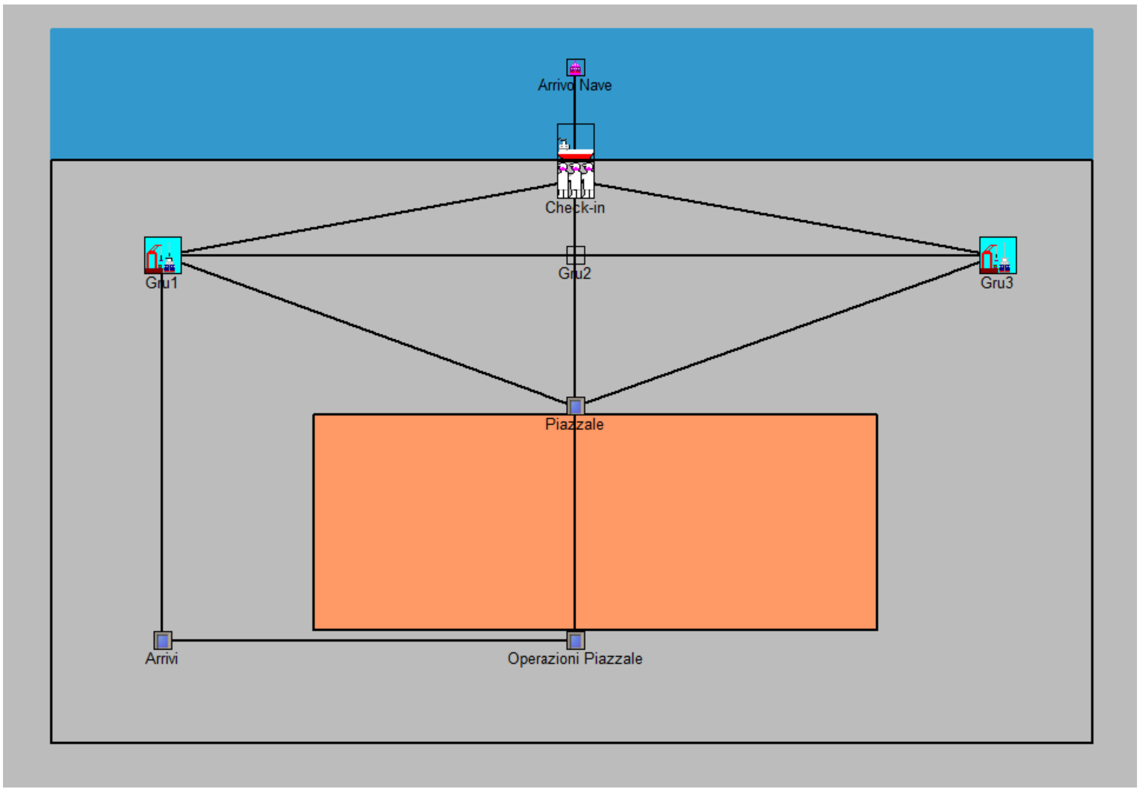

Figure 1: Terminal Layout.

A subnet was designed for each main phase. Each subnet reproduces the sequence of operations required for the implementation of the specific transhipment activity.

The general flowchart of the sequence of phases from ship arrival to storage of containers into the stocking area is shown in Figure 2.

The flowchart, in Figure 2, also shows the main assumptions and choices on the different variables and operational requirements considered for the development of the model. These assumptions regard:

- ship arrival timetable;
- ship load distribution (e.g. bow, central and stern);
- operational behaviour of the crane when the trailer is not under it;
- operational traffic rules of the trailers;
- trailer arrival frequency under the cranes;
- crane operational time;
- trailer handling time to the stocking area;
- travelling time of the trailer to the meeting point with the reach stackers;
- travelling time of the reach stackers to the meeting point with the loaded trailer.

The main operations of the subnets are detailed hereafter.

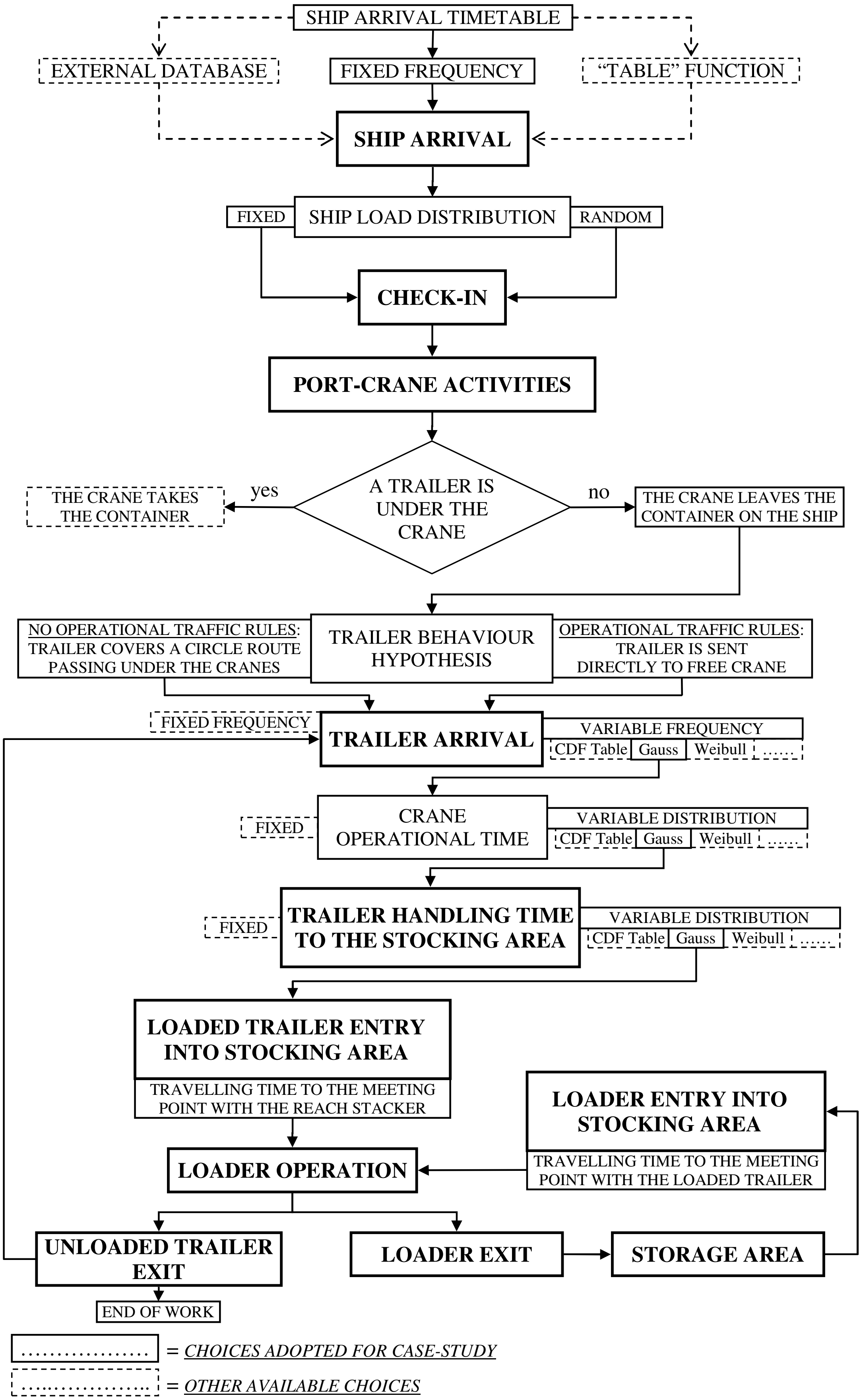

Figure 2: Sequence of main phases.

3.1.1 Ship arrival

The "ship arrival" subnet reproduces the operations concerning the phases of:

- approach of the ship to the port mouth;
- access into channel;
- evolution;
- quay approach;
- anchorage.

In particular, the time each phase takes is calculated considering movement and rotation (evolution phase) speed of the ship and the distance travelled, using the attributes of ship object and the characteristics of its route from the mouth approach phase to the anchorage phase.

Moreover Planimate® allows to specify a timetable both as linked to an external database or with the "table" function inside the structure of the program.

3.1.2 Check-in

The "check-in" subnet (Figure 3) reproduces check-in operations and the load conditions of the ship. This subnet reproduces the different possible distributions of ship load by identifying the number of containers located in different areas of the ship (e.g. bow, central and stern). It is possible to choose a fixed or variable distribution of ship load. Generally the load partitioning is different from ship to ship and therefore the assumption of a random distribution is the more suitable. It is assumed that an unloading crane is available in each of three ship areas.

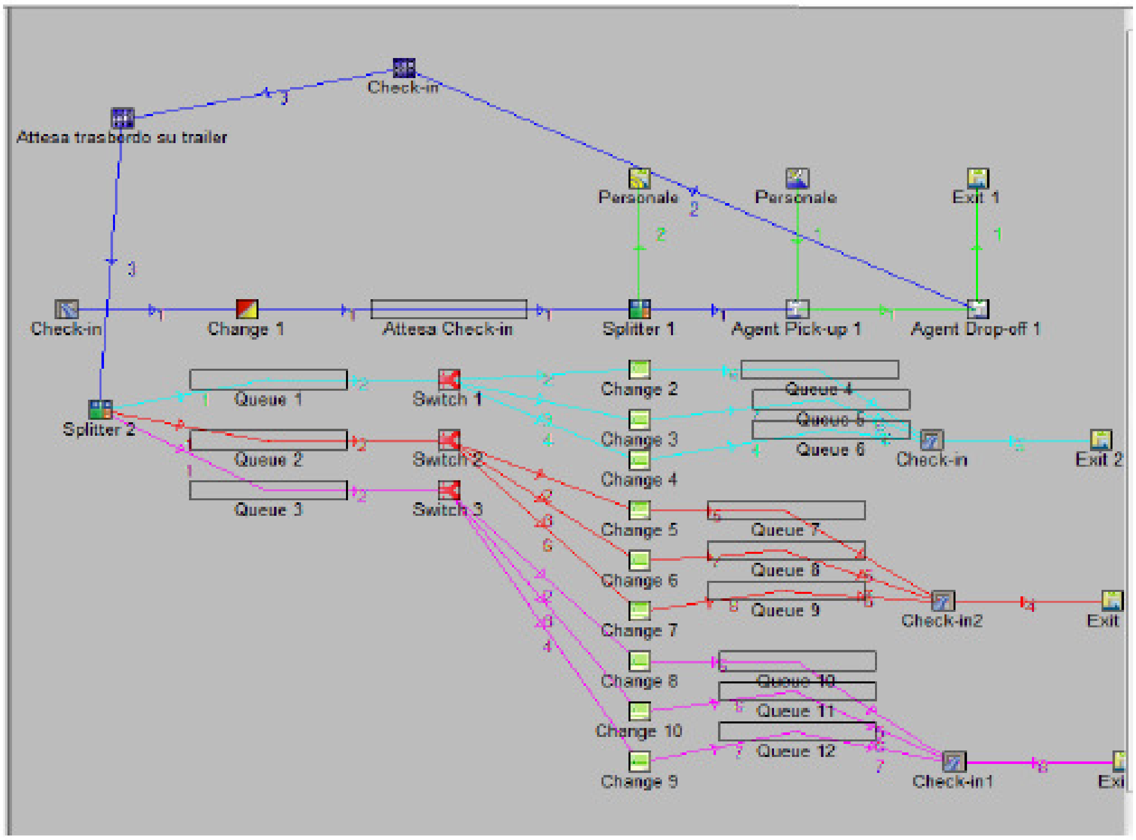

Figure 3: Check-in subnet.

3.1.3 Trailer arrivals

The subnet "trailer arrivals" simulates the apportionment, under the cranes, of the trailers for the transfer of containers from the quay to the stocking area, with a periodic frequency governed by variable or constant distributions.

In the case study a Gaussian distribution was used.

3.1.4 Port-crane activities

In "port-crane activities" subnets, the unloading operations of containers from the ship by the crane, the arrival of the trailer and the transfer of the containers from cranes to the trailer leaving the stocking area are simulated.

It was established that, if the trailer is not present under the crane, the container is waiting on the ship.

The subnet is structured in such a way that when a crane has completed the unloading of containers of its area, the trailers are sent to the crane still requiring transfer of containers.

In this subnet it is possible to account for two different trailer behaviours:

- the trailer covers a circle route passing under the first, second and third crane and stopping when it finds a free crane;
- the trailer is sent directly to a free crane.

The handling of the trailer from crane to stocking area is also reproduced.

The operational times of cranes and trailers are assigned a probabilistic distribution (Gaussian).

3.2 Stocking area

The “Stocking area” subnet is also a subnet of the top level network (“Intermodal terminal layout”, see 3.1). It represents the stocking area, with the assumptions that the handling operations take place in a central area and are guaranteed by 5 subnets (figure 4):

1) loaded trailer entry;
2) loader entry;
3) loader operation;
4) unloaded trailer exit;
5) loader exit.

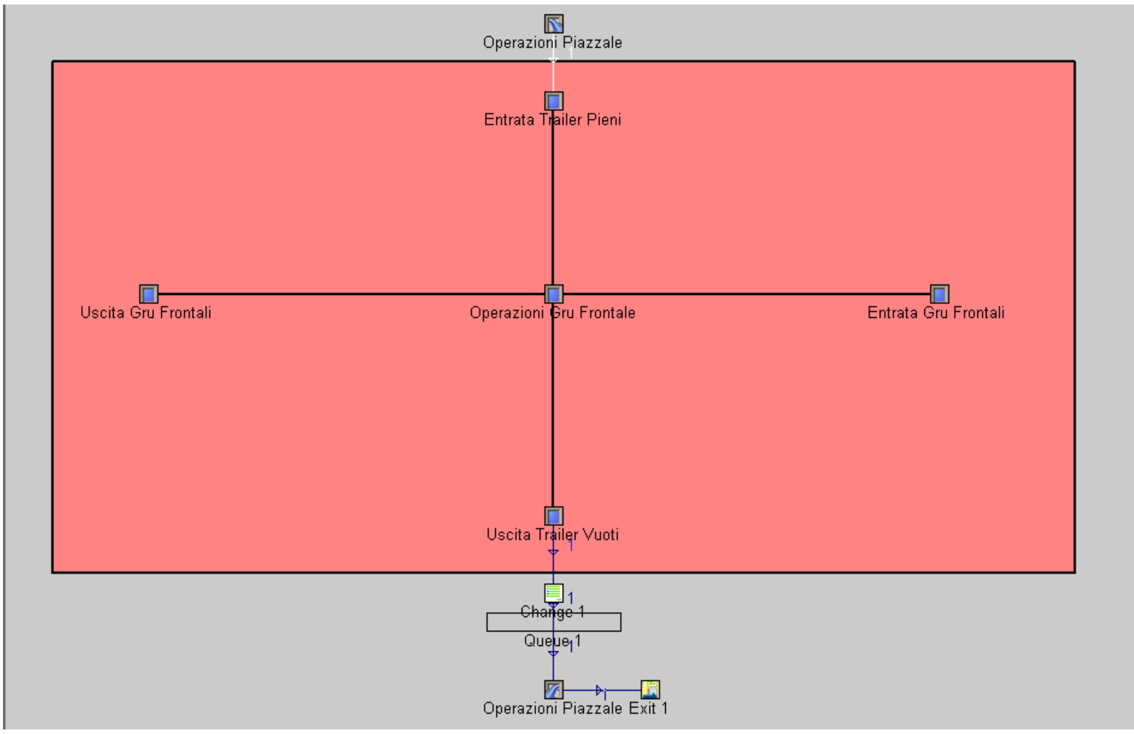

Figure 4: Stocking area layout.

This subnet represents the operations performed by the trailers and the reach stackers inside the stocking area.

The reach stackers pick up the container from the trailer, unload it on the stocking area and run back to a starting position, while the unloaded trailer leaves the stocking area following a path towards the ship crane.

A critical factor for simulated operations is the stocking area size, important for the calculation of travelling time of trailers and reach stackers inside this area.

3.2.1 Loaded trailer entry

The subnet "loaded trailer entry" simulates the entry in the stocking area of loaded trailers and the approach to the meeting point with the reach stackers (represented by the subnet "loader operation") situated in the centre of the stocking area.

The mean value of travelling time is calculated once the average speed of longitudinal movement of the trailer (about 20 km/h) and its average position in the middle of the stocking area are known.

3.2.2 Front crane entry

Similarly, in the "front crane entry" subnet the entry in the stocking area of the reach stackers and their approach to the meeting point with the trailers is reproduced.

3.2.3 Loader operation

The "loader operation" net (Figure 5) simulates the activities within the stocking area: it includes the interactions between the loaded trailer and the reach stacker.

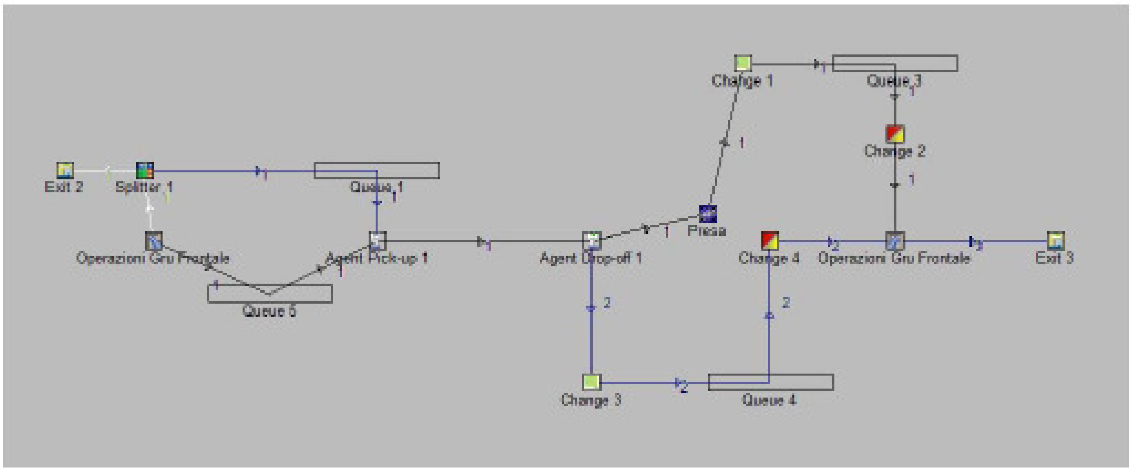

Figure 5: Loader operation subnet.

The loaded trailer waits within the stocking area for the arrival of the reach stacker assigned to it. Once unloaded the trailer moves towards the exit of the stocking area.

3.2.4 Unloaded trailer exit

In the "unloaded trailer exit" subnet the unloaded trailers are driven outside the stocking area and sent to the "trailer arrivals" subnet (terminal layout), so that the total number of working trailers is fixed.

3.2.5 Loader exit

Finally the "loader exit" subnet reproduces the unloading of the container by reach stackers, highlighted by the change of the icon from load to unload, and the link to the "loaders entry" for movements simulations.

The containers in the stocking areas will wait to be moved again towards their destination by a second transport system.

3.3 Simulated scenario

To improve the knowledge of the potential of the model and to optimise container unloading and handling operations three types of scenarios were simulated.

Scenario 1 – TRY & FDC: with operational traffic rules and fixed distribution of containers on the ship and quay cranes;

Scenario 2 - TRN & RDC: without operational traffic rules and random distribution of containers on the ship and quay cranes;

Scenario 3 – TRY & RDC: with operational traffic rules and random distribution of containers on the ship and quay cranes.

Moreover, for each scenario, the number of trailers and front cranes were changed to investigate the corresponding performances variations.

4. Case study description and results

The container terminal located in the Italian harbour of Livorno (Darsena Toscana Terminal) (Figure 6) was chosen, as a case study, for the application of the model. It is a multipurpose terminal capable of handling all types of cargo ships and passenger traffic. Livorno harbour's basin extends over 1.600.000 square meters, while the surface on land is equal to 2.500.000 square meters, 800.000 inside the customs gates. It offers about 12.000 meters of quay with 90 dockings, with a depth of up to - 13 meters. The extension of the stocking area is 272.000 square meters, and the terminal is equipped with a total of 36 trailers, 16 loaders and 8 port cranes.

In addition to warehouses and equipped stocking areas, there are three rail yards inside the harbour with 60 km of tracks.

Figure 6: Darsena Toscana Terminal.

Livorno was selected due to its foreseen relevant increase of freight traffic and the continuous evolution of its harbour, with the creation of a new basin that will triple the current terminal activities, providing the opportunity to host last-generation ships.

The simulated unloading times are reported in Table 1, evaluated assuming the use of operational traffic rules and fixed distribution of containers on the ship. The columns indicate the values of time obtained with different simulations for variable fleets of trailers and reach stackers. In the last column the calculated average unloading time is shown.

A first analysis of the values obtained through the simulations (Table 1) shows that with the increase of the reach-stacker fleet, the variation of the unloading time allows to identify a dimension of the reach-stacker fleet (in our case 8 units) beyond with the decrease of the total unloading time becomes negligible.

In fact for a fixed number of 25 trailers, with the operation of 6 reach stackers the average unloading time is 11:27 hours, in comparison to 9:56 hours calculated with 8 reach stackers, with a reduction of 1:31 hours (-13%). The corresponding time reduction from 8 to 12 reach stackers is only 9 minutes (-1,5%).

Table 1: Unloading time with the operational traffic rules and fixed distribution of containers.

Trailers	Reach stackers	Unloading time [hours]						
		#1	#2	#3	#4	#5	#6	Average
25	6	11:29	11:35	11:20	11:29	11:26	11:26	11:27
	8	10:06	9:49	9:52	9:45	10:03	10:04	9:56
	12	9:50	9:40	10:00	10:03	9:35	9:36	9:47
15	6	11:36	11:12	11:37	11:25	11:41	11:40	11:31
	8	10:30	10:40	11:05	10:45	11:10	11:11	10:53
	12	10:50	10:40	10:48	10:45	11:01	11:00	10:50

Moreover Table 1 shows that the increase of trailer numbers, for a fixed number of reach stackers, produces a reduction of total unloading time of containers higher than the case in which the number of reach stackers is increased.

The simulation was also implemented with and without operational traffic rules and random distribution of containers.

The results are reported in Tables 2 and 3.

Table 2: Unloading time without operational traffic rules and random distribution of containers.

Trailers	Reach stackers	Unloading time [hours]						
		#1	#2	#3	#4	#5	#6	Average
25	6	11:41	11:33	11:37	11:35	11:39	11:40	11:37
	8	10:25	10:20	10:26	10:23	10:28	10:30	10:25
	12	10:15	10:22	10:20	10:19	10:18	10:18	10:18
15	6	11:51	11:44	11:49	11:47	11:46	11:46	11:47
	8	10:40	10:45	10:44	10:43	10:43	10:43	10:43
	12	10:29	10:40	10:39	10:33	10:32	10:32	10:34

Table 3: Unloading time with operational traffic rules and random distribution of containers.

Trailers	Reach stackers	Unloading time [hours]						
		#1	#2	#3	#4	#5	#6	Average
25	6	11:13	11:20	11:18	11:16	11:16	11:16	11:16
	8	10:15	10:18	10:17	10:12	10:12	10:12	10:14
	12	10:11	10:00	10:07	10:04	10:04	10:04	10:05
15	6	11:35	11:28	11:39	11:26	11:31	11:30	11:31
	8	10:39	10:32	10:36	10:30	10:35	10:34	10:34
	12	10:32	10:29	10:21	10:24	10:28	10:27	10:26

The results of the simulations represented in Tables 1, 2 and 3 confirm that the use of operational traffic rules provides benefits especially when the number of trailers is high.

The corresponding average unloading times are represented in Figure 7 and 8 respectively with 25 and 15 trailers.

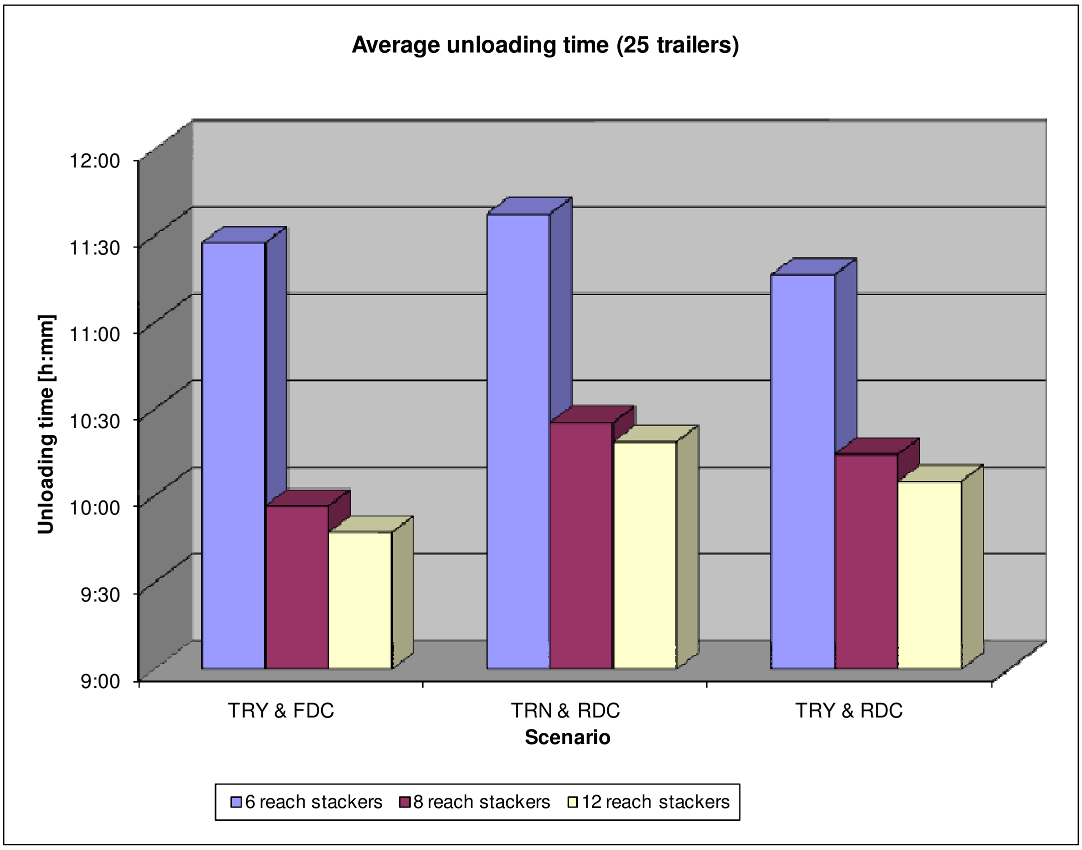

Figure 7: Average unloading time with 25 trailers.

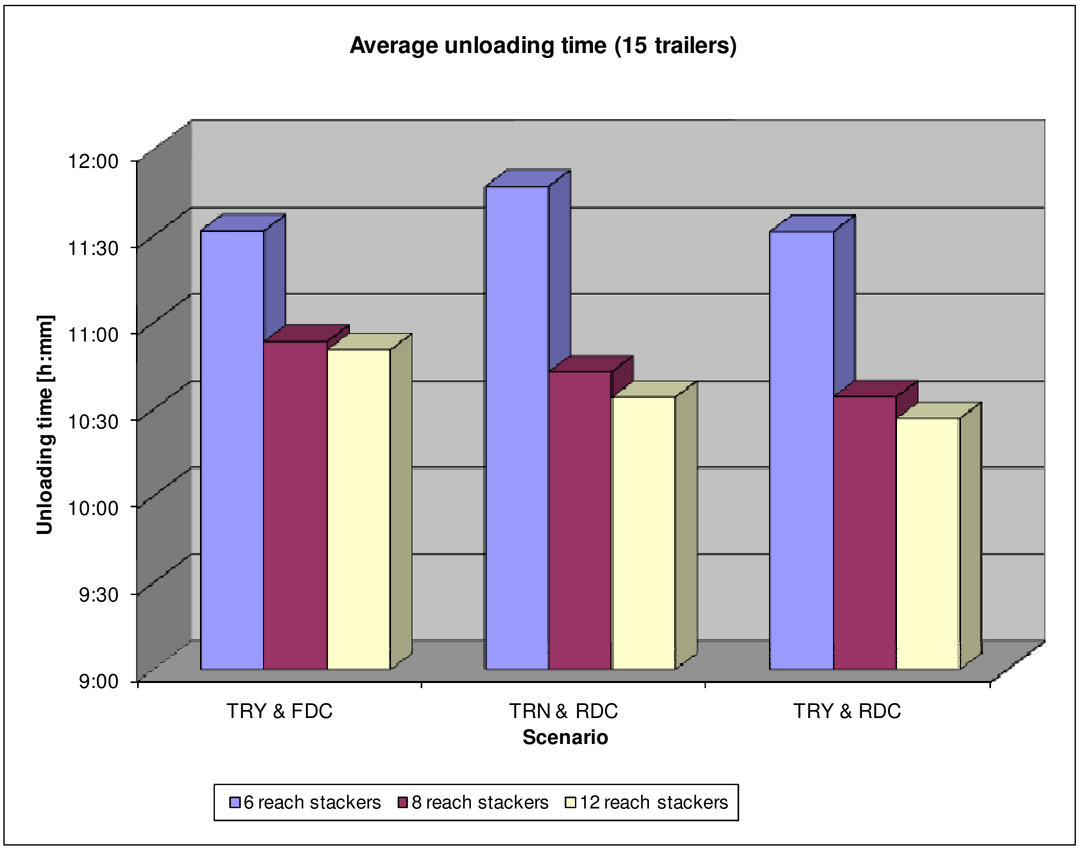

Figure 8: Average unloading time with 15 trailers.

5. Validation

The simulation results were compared for validation with data provided by the Port Authority of Livorno and with data obtained with an analytical model (Marinacci C., Quattrini A., Ricci S. - 2008).

Results of the comparison are shown in Table 4.

Table 4: Comparison results.

	CONTAINERS [n°]	PORT-CRANES [n°]	TRAILERS [n°]	REACH STACKERS [n°]	TOTAL TIME [hh.mm]	AVERAGE UNIT TIME [min]
LIVORNO PORT AUTHORITY	566	8 (available)	36 (available)	16 (available)	17:17	110
ANALYTIC MODEL	566	2	included in the average handling time	included in the average handling time	16:22	104
SIMULATION MODEL	566	3	15	6	11.31 ÷ 11.47	73 ÷ 75
			15	8	10.34 ÷ 10.53	67 ÷ 69
			15	12	10.26 ÷ 10.50	66 ÷ 69
			25	6	11.16 ÷ 11.37	72 ÷ 74
			25	8	9.56 ÷ 10.25	63 ÷ 66
			25	12	9.47 ÷ 10.18	62 ÷ 65

The mean value of the total time for unloading and handling of containers, calculated on the basis of data provided by Livorno Port Authority, is 17:17h.

With the analytic model, in which 2 port-cranes are used, the result is 16:22h, while the value obtained with the simulation model, in which 3 port-cranes are used, is variable between 9:47h and 11:47h.

Also in this case the deviations are limited because the total availability includes the reserve units for maintenance and additional services.

Total time, and single unit average times are lower by about 30%, but it is well justified by the use of 2 instead 3 port-cranes in the daily operation.

Therefore these data confirm the global respondence of simulation model results.

The fleets dimensions are comparable with those managed by the Livorno Port Authority (the analytical model does not calculate these parameters).

6. Conclusions

In coherence with the initial objective it has been built up and partially validated a simulation model based on the Planimate® software.

For the analysed case study the most relevant results are that:

1) over a certain reach stackers fleet dimension the decrease of the container unloading times becomes negligible;
2) the system is more sensible to the amount of working trailers than to the amount of reach stackers.

Moreover, the results of simulations confirm that the use of operational traffic rules provides benefits especially when are increased the number of trailers.

Further developments of the research will be devoted to identify the most effective application fields for the various model typologies.

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European Transport \ Trasporti Europei n. 46 (2010): 100-113

A metamodelling approach for performance evaluation of intermodal transportation networks

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Abstract

The paper proposes a metamodelling procedure devoted to provide a reference model to be used by decision makers in the performance evaluation of Intermodal Transportation Network (ITN). In order to obtain a generic model describing a nonspecific ITN from the structural and behavioural point of view, the metamodelling approach consists in applying a top down and modular procedure. The model is specified by the well known Unified Modelling Language (UML), a graphic and textual modelling formalism intended to describe systems from structural and dynamics viewpoints. Hence, the paper models a generic ITN starting from the network description and shows by a case study the metamodel of one of the most important nodes that compose it: the port subsystem. Moreover, the case study model is translated in a simulation software and the performance measures obtained by the simulation results are shown.

Keywords: Intermodal transportation networks; Modeling; Discrete event simulation; UML; Performance evaluation.

1. Introduction

Intermodal Transportation Networks (ITN) are systems integrating different transportation modes (rail, ocean vessel, truck etc.) to move freight or people from origin to destination in a timely manner (Chen et al. 2006). The 21st century will see a renewed focus on ITN, driven by the necessity of moving ever growing quantities of goods and by the technological evolution of each transport mode has recently gone through (Ramstedt and Woxenius 2006, Woxenius 2007).

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To be efficient and competitive, an ITN needs to plan and synchronize the logistics operations and the information exchange among its stakeholders (Feng and Yuan 2006). Currently, ICT (Information and Communication Technologies) are being applied to ITN to better arrange shipments and use commercial vehicles (Feng and Yuan 2006, Giannopoulos 2004, Xu and Hancock 2004). Indeed, the implementation of advanced traveller information systems and traffic management systems can provide timely information for both pre-trip planning and en route decision making. However, ITN decision making is a very complex process, due to the dynamical and large scale nature of ITN, as well as the randomness of various inputs and operations. In order to operate such choices, there is a need of dynamic models able to track the state changes of the various system components and to determine operation indices such as utilization, traffic indicators and delivery delays (Yun and Choi 1999, Arnäs 2007).

In the domain of ITN models, and in particular at the operational level, we recall the class of discrete event system models (Fisher and Kemper 2000, Di Febbraro et al. 2006, Dotoli et al. 2010) and of the simulation models (Xu et al. 2004, Yun et al. 1999). On the one hand, discrete event models are widely used to describe decision making and operational processes in logistics systems. ITN systems can be successfully modelled as discrete event systems, whose dynamics depends on the interaction of discrete events, such as demands, departures and arrivals of means of transportation at terminals and acquisitions and releases of resources by vehicles. Moreover, in the related literature simulation has represented an effective and useful instrument to analyze transport logistics and evaluate the impacts of the proposed solutions. However, the cited models are primarily designed to describe a particular ITN and do not fully depict a generic system by taking into account the multiplicity of elements that can influence the ITN dynamics and the related information structure. An effort in such a direction is performed in the work by Arnäs (2007) that analyzes the control problems of generic transport systems characterized by complexity and uncertainties that are produced by heterogeneous goods. Nevertheless, the author does not deal with a systematic modelling approach devoted to describe an intermodal transportation network.

The motivation of the present work is providing a methodology to build a generic, systematic and accurate ITN model for use by decision makers in the performance evaluation of such systems at the operational level. In order to obtain a generic model describing a nonspecific ITN, the paper proposes a metamodelling technique that applies to models and provides an accurate description of the construct and rules needed to obtain semantic models. In addition, the metamodel encapsulates all concepts necessary to describe the structure and the behaviour of a particular system (Ghazel et al. 2004). The obtained model has a general and modular structure and is characterized by information integration. To allow ITN performance evaluation at the operational level, the model describes in adequate detail the structure and the dynamic evolution of the ITN and can be updated on the basis of data exchanged by the players in the chain and of information obtained by using modern ICT techniques (Ikkai et al. 2003).

The proposed metamodelling approach is based on a top-down procedure using Unified Modelling Language (UML) (Miles and Hamilton 2006), a graphic and textual modelling formalism suitable to understand and describe systems from various viewpoints. Indeed, UML reflects various views of a system and enables us to describe the structure and the behaviour of a generic ITN. In particular, starting from the description of the network, UML characterizes the most important entities that compose it, called classes, and their corresponding activities. Moreover, UML unifies the formalism by using appropriate and effective diagrams that can be easily translated into any simulation software (Teilans et al. 2008) in an object oriented approach. Comparing the proposed metamodelling approach with the object oriented modelling approach proposed in (Arnäs 2007), we point out that we propose a generic framework able to describe systematically a generic intermodal transportation network including the information and management modules. On the contrary, the model presented in (Arnäs 2007) employs UML tools to describe road and ferry transport systems able to manage different types of goods. Hence, the presented metamodelling approach overcomes the object oriented solution proposed in (Arnäs 2007) to obtain a generic and detailed description strategy devoted to specifying suitable decision support systems for managing and supervising real transportation systems.

To illustrate the metamodelling procedure for ITN operational performance evaluation, a real case study representing the port of Trieste (Italy) and the inland terminal of Gorizia (Italy) is considered. We first describe the structure of a generic ITN by UML package diagrams and we subsequently propose the model of a case study composed of a port and an intermodal terminal using UML class diagrams. Moreover, we employ UML activity diagrams to specify some basic port activities, such as the unloading procedures in the port and in the inland terminal. A simulation study points out the two objectives of the paper: i) proposing an effective tool that can be easily translated into a simulation software for ITN operational performance evaluation; ii) building a reference model that reproduces the ITN evolution and can be employed to supply the management modules with the knowledge base for decisions at the operational level. In particular, using the metamodelling technique, we show how simulation enables the detection of anomalies and bottlenecks, so that alternative solutions can be determined and tested on the basis of the estimation of suitable performance indices. In addition, the presented metamodelling technique can be the basis for the construction of a decision support system for taking operational decisions in large and complex ITN that may rely on information based services.

The paper is organized as follows. Section 2 presents the main steps of the metamodelling approach to describe the ITN structure. Subsequently, Section 3 models the behaviour of the case study by the UML formalism and Section 4 reports the case study performance evaluation. The last section summarizes the conclusions.

2. The Metamodel of the Intermodal Transportation Network structure

To describe a generic ITN at the operational level for performance evaluation, the model has to be broad, systematic, modular and easy to update. Hence, we apply metamodelling, a technique that applies to models (Ghazel et al 2004) and provides an accurate description of the construct and the rules needed to obtain semantic models while encapsulating all concepts necessary to describe the structure and the behaviour of a particular system.

The metamodelling approach presented in this paper follows a top-down methodology that decomposes the system in sub-systems. The technique is based on the UML formalism, a visual language for specifying, constructing, and documenting the artefacts of systems (Miles and Hamilton 2006). In the sequel, after recalling the basics of UML, we devise a procedure addressing ITN structural models, by employing the UML package and class diagrams.

2.1 Basics of UML

From the structural point of view, a system is made up of a collection of pieces often referred to as objects and described in UML by classes. Each class is represented by a rectangular box divided into compartments. The first compartment holds the class name, the second holds attributes and the last holds operations. More precisely, attributes are qualities that characterize the class and operations are features that specify the class behaviour. Moreover, classes can exhibit relationships that are represented by different graphic connections: association (solid line), aggregation (solid line with a clear diamond at one end), composition (solid line with a filled diamond at one end), inheritance or generalization (solid line with a clear triangle at one end), realization (dashed line with a clear triangle at one end) and dependency (dashed line with an arrow at one end).

From the behavioural point of view, a system can by described in UML by activity diagrams that provide an overview of the system dynamics. The main elements of these diagrams are: the initial activity (denoted by a solid circle); the final activity (denoted by a bull's eye symbol); other activities, represented by a rectangle with rounded edges; arcs, representing flows, connecting activities; forks and joins, depicted by a horizontal split, used for representing concurrent activities and actions respectively beginning and ending at the same time; decisions, representing alternative flows and depicted by a diamond, with options written on either sides of the arrows emerging from the diamond; signals representing activities sending or receiving a message, which can be of two types: input signals (message receiving activities), shown by a concave polygon, and output signals (message sending activities), shown by a convex polygon. Moreover, activities may involve different participants in a system. Hence, partitions or swim lanes are used to show which actor is responsible for which actions and divide the diagram into columns or swim lanes.

Class and activity diagrams can be collected into logically related groups that in UML are modelled with packages that may communicate with each other. Hence, arrows show the cases in which a class in one package needs to use a class in another package and causes a dependency between packages.

In this section we present the top-down procedure that addresses the ITN structural model by using the UML package diagrams and class diagrams to specify the sub-system structure. In a subsequent section, the ITN behavioural models are described with reference to the case study by the UML activity diagrams.

2.2 The Package Diagram

The first step of the metamodelling approach consists in identifying the main subsystems that compose an ITN. More precisely, the ITN can be divided into structural subsystems (i.e., ports, airports, railway stations, intermodal terminals, ground, sea and air connections), and the information and management system. However, such subsystems are complex nodes that can be viewed as composed of other generic objects (or classes). Hence, we represent the overall ITN by the UML package diagram shown in Figure 1.

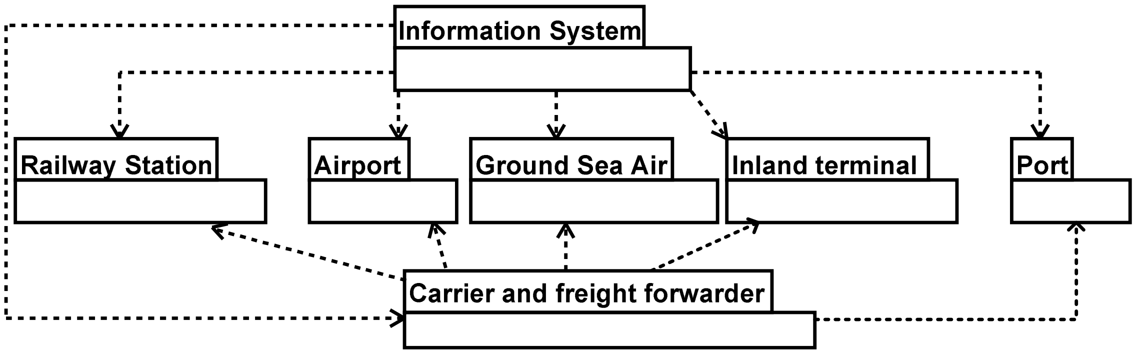

Figure 1: The package diagram of the ITN: the arrows show dependence among packages.

In particular, Figure 1 identifies the following seven packages that form the ITN: the railway station, the airport, the ground, sea and air connection, the intermodal terminal, the port, Information System and the Carrier and Freight Forwarder. Each package is composed of different classes representing structural basic objects interconnected with each other. The arrows in Figure1 show the cases in which a class in one package needs to use a class in another package. This causes a dependency between packages: for example, the information system is updated on the basis of data obtained in real time by using modern ICT techniques. We assume that each package includes an information class representing the informative structure devoted to manage the classes included in the package. However, we consider also a centralized information system that can manage different packages. For example, the package "Port" contains an information class that manages the flow of trucks, trains, cranes, etc. On the other hand, the external and higher level information system can control the interactions between the port and the infrastructures, by receiving data from the port area and the ground, sea, rail and air connections.

2.3 The Class Diagrams

The subsequent step of the structural metamodelling technique consists in setting up the class diagrams, specifying the configuration of the various packages defined in the previously discussed package diagram.

For the sake of conciseness, in this paper we describe the port class diagram and the inland terminal class diagram shown in Figures 2 and 3, respectively. The main classes included in the diagram in Figure 2 are the following: i) Intermodal_Transport_System; ii) Management_System; iii) Costs_manager. In particular, the Intermodal_Transport_System class models the resources present in the port, the queues that involve the flows of material, and the authorities. Resources are distinguished in two types: those belonging to the port area (i.e., the parking, quay, discharge and warehouse areas) and the transportation means (i.e. ships, cranes, trucks). Moreover, the transportation resources are represented by the trucks, trains and ships that are associated with containers and packages. Other basic classes are the queues associated with trucks, ships and gates. Analogously, the diagram of Figure 3 depicts the resources of the inland terminal that includes the warehouse and different areas such as enter, delivering, unloading, parking, exit, preparing, labelling and customs areas. Other relevant classes are the queues of transportation resources in input to and in output from the terminal.

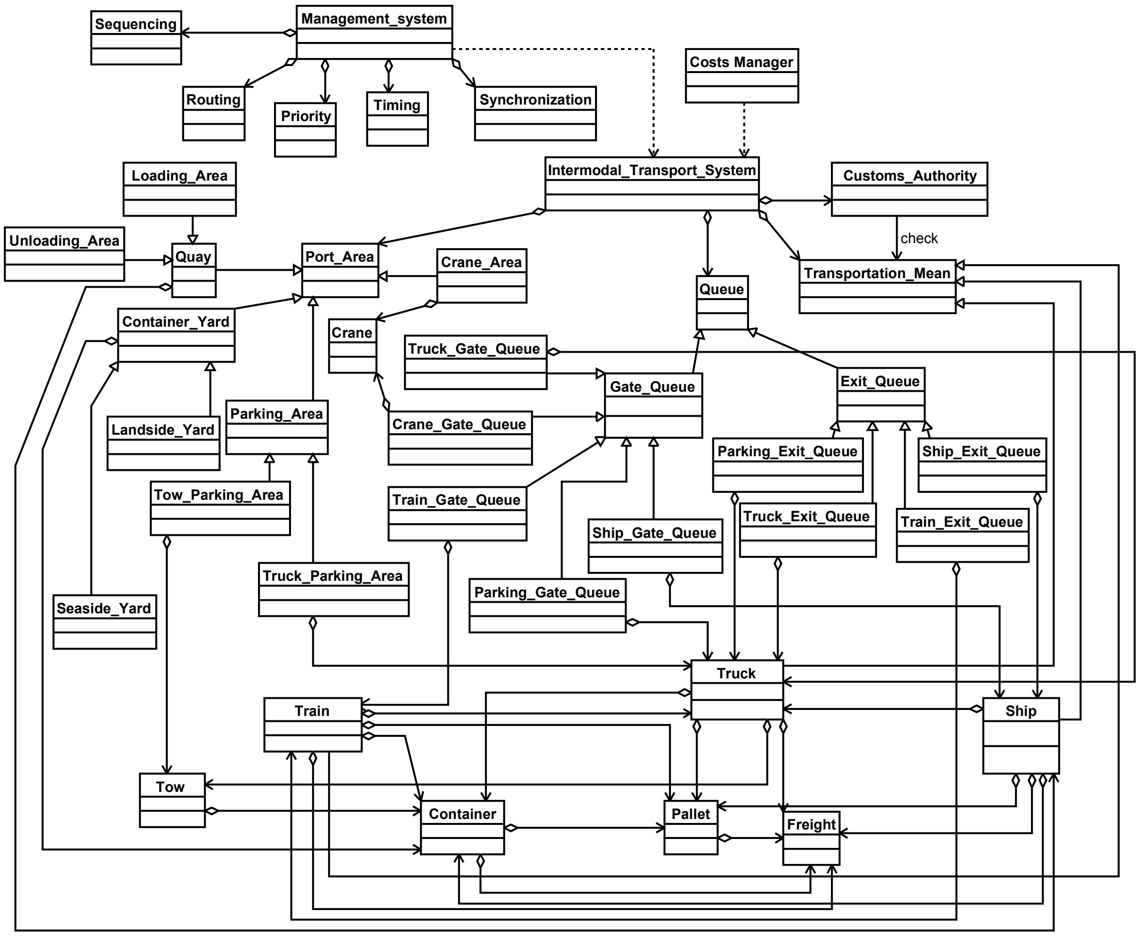

Figure 2: The port class diagram.

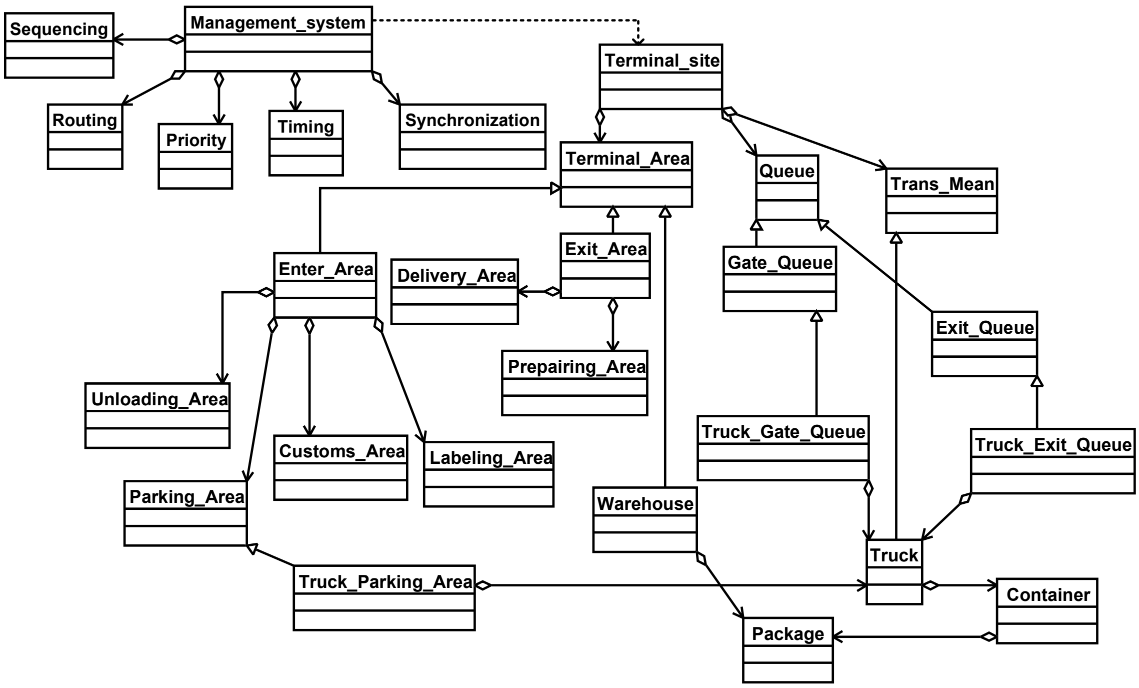

Figure 3: The inland terminal class diagram.

Table 1: Attributes and Operations of the Intermodal Transport System class.

Class Attributes	*Class Operations*
1) Dynamic lists of ships, trains and trucks that are currently in the terminal	1) Registration of ships, trains and trucks entering the terminal
2) Dynamic lists of ships, trains and trucks already served by the operators in the terminal or by the quay cranes and waiting for permission to exit from the terminal	2) Extraction from the list of ships, trains and trucks waiting for service
3) Dynamic lists of ships, trains and trucks that are queued and wait for service	3) Extraction from the list of available cranes
4) Dynamic lists of ships, trains and trucks currently being served	4) Assignment of a crane to a specific task of freight loading/unloading
5) Dynamic lists of ships, trains and trucks currently leaving the terminal	5) Crane activation
6) Lists of occupied quay cranes and available ones	6) Extraction from the list of ships, trains and trucks leaving the terminal
	7) Update of the list of served ships, trains and trucks
	8) Update of the list of waiting ships, trains and trucks
	9) Update of the list of ships, trains and trucks exiting the terminal
	10) Update of the list of available cranes

Moreover, the class diagrams of Figures 2 and 3 show the different types of relationships among the classes of the port and of the inland terminal packages. For the sake of clarity, the figures do not depict the attributes and operations of each class and a more detailed description of the remaining classes can be found in (Boschian et al. 2009). However, as an example, Table 1 reports the attributes and the operations of the "Intermodal transport system" class in Figure 2.

We remark that the system dynamics is described by the evolution of the class attributes that can change at each event occurrence. Hence, the state provided by the model is described by the attributes of the classes composing the system.

3. The case study description

This section considers a simple ITN composed of a port, the port of Trieste (Italy), the inland terminal of Gorizia (SDAG, Italy) and the ground connection between them. In particular, we analyze the flow of glass sheets used to produce solar panels arriving from the China port to the port of Trieste. Figure 4 shows the schematic flows of goods and information starting from the China port up to the Trieste port and to the Terminal of Gorizia.

In order to model the case study and evaluate the operational performance indices, we consider the class diagrams of the port and of the terminal as described in Section 2. Moreover, the case study focuses on two activities: the freight transportation and the ship unloading procedures. The following sections describe in detail these two processes and build the corresponding activity diagrams.

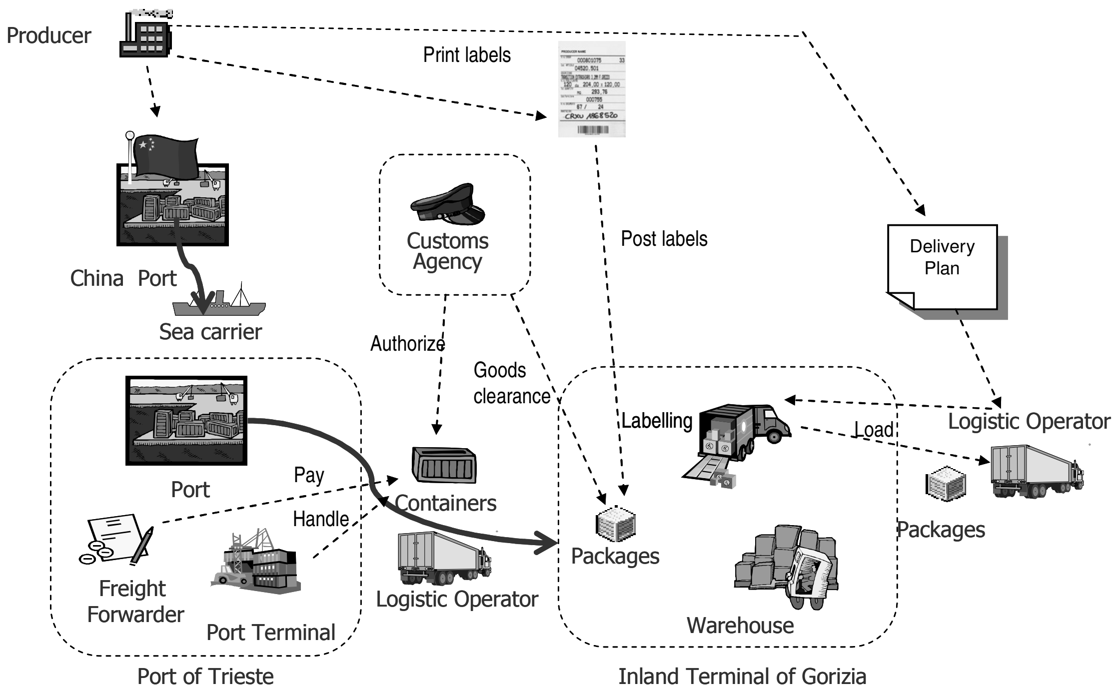

Figure 4: The schematic flow of goods and information for the case study.

3.1 The intermodal freight transportation and ship unloading procedures

The considered flow of goods and information regarding a subset of freight arriving to the Trieste port is described by the following phases.

1) Shipping phase: the freight is transported by the shipping company. During this phase, a set of documents is prepared, e.g., a packing list for loading, called "manifest". This document is transferred to Customs and contains information about all the freight in the ship.
2) Unloading phase in port: after the shipment, the load arrives to the port of Trieste, where it is unloaded by the port area staff.
3) Payment phase: the freight forwarder receives the information regarding containers and packages inside them. When a container is released by the terminal operator, shipping tariffs are paid in relation to the quality and quantity of the transported goods.
4) Authorization phase: the freight forwarder and the Customs authority prepare the transportation documents to authorize the exit of containers from the port area.
5) Transportation phase: after the payment and the authorization phases, goods are loaded on trucks and transported by the carrier to the Gorizia truck terminal.
6) Unloading phase in SDAG: containers arrive to Gorizia, where they are unloaded to wait for the authorization to enter in SDAG.
7) Customs clearance phase: depending on the quality and quantity of goods, different Customs tariffs are paid. Customs clearance operations are currently quite slow in execution and they are carried out by the freight forwarder, who prepares the Customs duties bill containing a Customs code, the origin of freight, its value and profit after the operations carried out in the port of Trieste.

8) Warehousing phase: goods are managed by SDAG. Operations regard opening containers, warehousing and labelling packages. The SDAG staff sticks labels on packages. Such labels are prepared and posted by an agency in Italy before the goods arrival.
9) Loading phase in SDAG: the carrier communicates to SDAG the delivery plan and SDAG loads the goods on trucks depending on the packing list. Finally, SDAG communicates that the load is ready to the carrier, who has the responsibility to deliver goods to their final destination.

3.2 The activity diagrams

In this section we present UML activity diagrams of the case study to describe the management processes concerning the flow of goods and the ship unloading procedures.

Figures 5 (a) and 5 (b) respectively show the activity diagrams that specify the ship unloading procedure in the port and the freight transportation and unloading in the SDAG terminal. More precisely, Figure 5 (a) represents the logic flows that are associated to the ship unloading operations described in section 3.1. The ship enters the port and the freight forwarder (belonging to the carrier and forwarder class) prepares the documents to unload vehicles and goods. After the unloading phase performed by the port staff, a fork in the diagram shows that the freight forwarder pays the shipping tariffs and the Customs authority prepares the transportation documents to authorize the exit of the containers from the port area. When these activities go to an end (as the join of Figure 5 (a) shows), the goods are loaded on trucks and transported by the carrier to the Gorizia truck terminal. Successively, the activity diagram of Figure 5 (b) shows that the carrier transports goods to SDAG: the freight forwarder requires the authorization to enter and when the authorization is available the clearance phase begins. After the payment of Customs duties and the execution of Customs operations, the SDAG staff starts the unloading and warehousing. Hence, the carrier plans the delivery, the SDAG staff loads the containers on the trucks and the carrier performs the delivery.

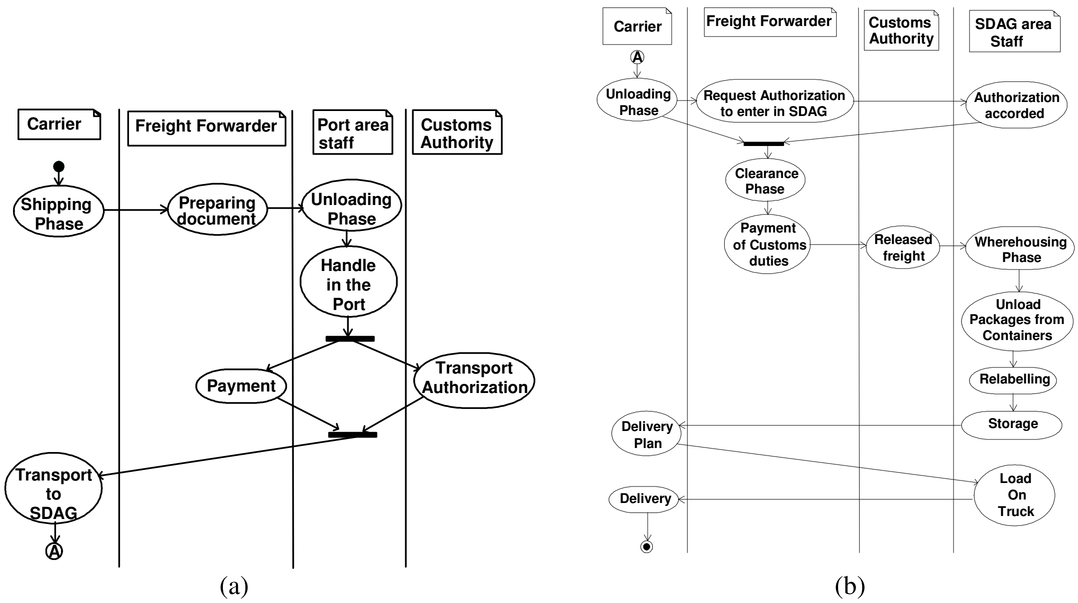

Figure 5: The activity diagram of the ship unloading procedure in the port (a) and of the freight transportation and unloading at the SDAG terminal (b).

4. The case study performance evaluation

This section describes the simulation of the considered ITN in order to evaluate the system performance in terms of the flow of goods during the significant phases of the freight transportation. Hence, the simulation starts from the beginning of phase 1 (shipping phase) and ends with phase 9 (loading phase in SDAG). The UML model of the system is realized in the Arena Rockwell environment, a software particularly suitable to deal with large-scale systems (Kelton et al. 1998). Indeed, the activity diagrams described in section 3 can be easily used to generate the Arena simulation model that can be straightforwardly implemented by the following three steps (Teilans 2008):

1) the Arena modules are associated to the UML activity diagram elements, by establishing a kind of mapping between each Arena module and the UML graphical element of the activity diagrams;
2) the simulation parameters are included in the Arena environment: i.e., the activity times, the process probabilities, the resource capacities, the average input rates are assigned. These specifications can be modified in every simulation and enable the choice of the scenarios in the case study implementation and management;
3) the simulation run of the experiments is singled out and the performance indices are determined and evaluated with suitable statistics.

The port of Trieste handles about 336.000 twenty-foot equivalent units (TEU) of containers per year. However, the case study simulation considers only the flow of containers that are managed by a specific freight forwarder (managing the flow of glass sheets from China to Italy as described in Section 3) equal to 1600 TEU/month in input to the system. Hence, the arrival time instants of containers are simulated by an exponential distribution of mean 54 time units (t.u.), where we consider the minute as t.u. Note that the exponential distribution is selected since it is often used to model inter-event times in random arrival processes (Kelton et al. 1998). In addition, the processing times of the phases described in section 3.1 are assigned a triangular distribution. Indeed, while the exponential distribution is generally inappropriate for modelling process delay times, the triangular distribution is commonly used in situations in which the exact form of the distribution is not known, but estimates (or guesses) for the minimum, maximum, and most likely values are available (Kelton et al. 1998).

Table 2 shows the data of the triangular distribution of processing times and number of necessary operators. In particular, the second column of Table 2 reports the modal values δ of such distributions, the third and forth columns show the maximum and minimum values of the range in which the processing time varies, denoted respectively by D_δ and d_δ. Moreover, the last column of Table 2 reports the number of infrastructure operators, denoted by *Op* that are necessary to perform the corresponding operation.

The case study performance evaluation focuses on the interactions among carriers, authorities and infrastructure operators and we investigate on how the relations between Customs and freight forwarder affect the system behaviour. Using the metamodelling technique, simulation enables the detection of the system anomalies and bottlenecks, so that alternative solutions can be determined and tested on the basis of the estimation of suitable performance indices. Hence, three different scenarios S1, S2 and S3 are considered, with different numbers of operators devoted to the activities specified in

Figure 5 (see Table 3): forwarders in SDAG, port area staff, Customs staff in port, SDAG area staff, Customs staff in SDAG and forwarders in port.

Table 2: The triangular distribution of processing times and number of necessary operators.

Operation	δ (t.u.)	D_δ	d_δ	*Op*
Unloading phase 1	30	180	25	2
Handle in the port	20	22	18	1
Payment	15	30	12	1
Transport authorization	15	120	12	1
Transport to SDAG	120	144	96	1
Unloading phase 2	30	120	25	2
Request authorization	10	60	8	1
According	30	120	25	1
Clearance phase	15	30	12	1
Payment duties	15	30	12	1
Released freight	30	180	25	1
Unload packages	30	120	25	2
Re-labelling	30	40	24	1
Storing	120	144	96	1

Table 3: Number of operators for each scenario.

Resources\Scenarios	S1	S2	S3
Forwarders in SDAG	1	1	3
Customs staff in port	1	2	2
Port area staff	4	4	4
Customs staff in SDAG	1	2	2
Area staff in SDAG	8	8	8
Forwarders in port	3	3	6

To analyze the system behaviour, the following basic performance indices are selected (Viswanadham 1999):

- the system throughput T, i.e., the average number of containers delivered per t.u. by SDAG;
- the lead time $LT1$, i.e., the average time interval elapsed from the unloading phases in the port (phase 2) till the authorization phases (phase 4);
- the lead time $LT2$, i.e., the average time interval elapsed from the unloading phases in SDAG (phase 6) till the warehousing phases (phase 8);
- the total lead time LT , i.e., the average time spent by the goods from the unloading phases in the port (phase 2) till the warehousing phases (phase 8);
- the average percentage utilization of the resources.

All the indices are evaluated by a simulation run of 540000 t.u. (equal to 12 months and 15 days, if we associate one minute to one t.u.) with a transient period of 21600 t.u. In particular, the estimates of the performance indices are deduced by 50 independent replications with a 95% confidence interval. Besides, we evaluate the half width of confidence interval equal to 1.5% of the average value in order to assess the accuracy of the indices estimation. Considering that the average CPU time for a simulation run is about 120 seconds on a PC equipped with a 1.83 GHz processor and 1 GB RAM, it is apparent that the presented metamodelling approach can be applied to large and complex systems.

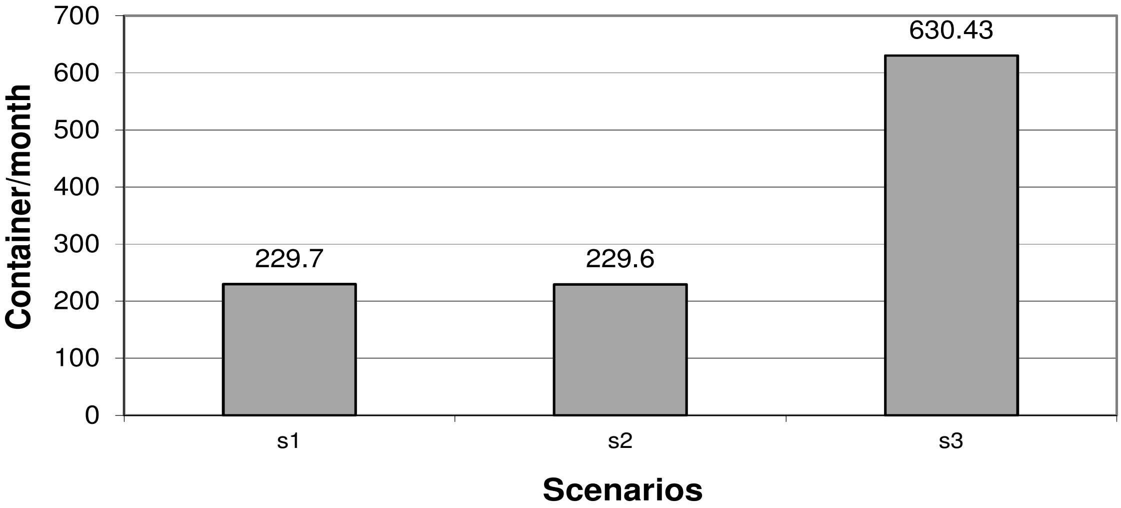

Figure 6: The average system throughput for each scenario.

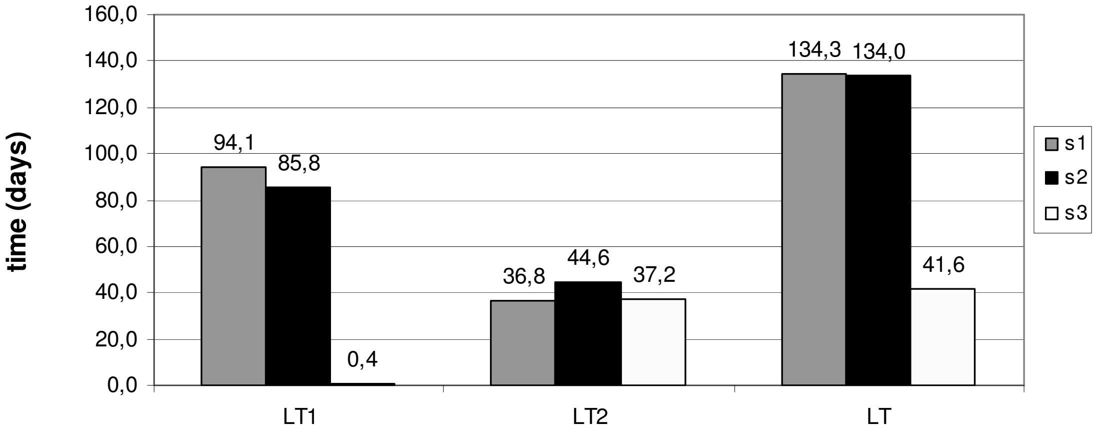

Figure 7: The average lead times for each scenario.

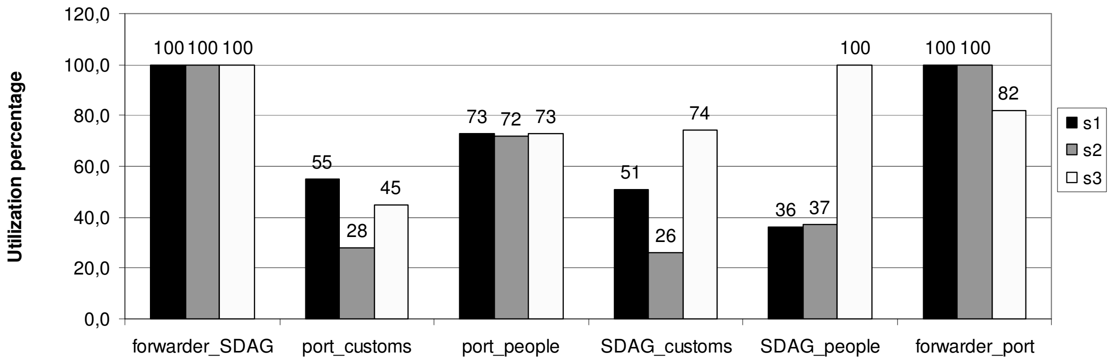

Figure 8: The average utilization of resources for each scenario.

The simulation results are depicted in Figures 6, 7 and 8, respectively reporting the throughput, the lead time values, and the average percentage utilization of the ITN operators. The simulation results show that the throughput in scenario S3, where forwarders are tripled in SDAG and doubled in the port with respect to S1 (see Table 3), is more than doubled with respect to S1 and S2 (see Figure. 6). On the contrary, in S2, despite the doubling of Customs staff both in port and SDAG, the ITN throughput is practically unchanged with respect to S1 (see Figure 6). In addition, increasing the forwarder resources in S3 leads to a noteworthy decrease of the total average lead time (see Figure 7). Hence, the simulations enlighten that the ITN bottleneck is represented by the forwarder operators in the port as well as in SDAG. Furthermore, Figure 8 shows that under S3 the resource utilizations remarkably increase with respect to Customs staff both in port and SDAG, with a basically unchanged utilization for the other operators in the ITN. Consequently, implementing the metamodelling technique by a discrete event simulation model, we evaluate the operational performance of the ITN. We conclude that enhancing the resources used by the freight forwarder allows a better utilization of the whole ITN while increasing the system productivity and responsiveness. On the other hand, increasing the Customs staff does not improve the system throughput. Summing up, simulation points out that the role of the forwarder has a crucial importance in the management of the freight transportation and suggests the potential effectiveness of ICT integration and enhancement in the ITN.

5. Conclusions

The paper presents a metamodelling approach to describe the structure and behaviour of Intermodal Transportation Networks (ITN). The aim is providing a reference model for the performance evaluation at the operational level of ITN by decision makers. The proposed metamodelling procedure is based on the Unified Modelling Language (UML), a graphic and textual language able to describe systems from structural and dynamics viewpoints. In order to illustrate the metamodelling procedure, the paper focuses on an ITN case study composed of the port of Trieste (Italy) and the intermodal terminal of Gorizia (Italy). The detailed descriptions of the main system components and of two basic processes of the port show how UML tools can effectively represent the structure and activities of such complex and large systems. Hence, the proposed metamodelling approach and the used UML formalism provide a reference model at the operational level that simulates the evolution of the ITN and may be employed to supply the management with the knowledge base necessary for performance evaluation and consequent decisions in real time.

Future research will address the detailed metamodel of all the ITN nodes. In addition, the presented metamodelling approach will be the foundation for the construction of a decision support system for taking operational decisions in large and complex ITN that may rely on information based services.

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European Transport \ Trasporti Europei n. 46 (2010): 114-146

Urban freight policies and distribution channels

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Abstract

Urban areas are vital centers of economic activity and innovation generating large economies of density and proximity. Yet, procuring and distributing goods in an urban context is fraught with difficulties because of infrastructure congestion, external costs, conflicting objectives among stakeholders, and asymmetric information.

In order to improve the performance of the urban goods transport system many policies have been proposed, including goods vehicle time windows, vehicle-type restrictions, loading\unloading policies, fiscal policies, the promotion urban transhipment and consolidation centres. Unfortunately, not much is known concerning how these policies affect the existing distribution practices. It is quite likely that the impact is differentiated by type of product and distribution channel. The aim of this paper is to explore this issue. Drawing on the existing literature and on the empirical evidence from some Italian cities, the paper identifies and discusses the relationship between each of the above-mentioned policies and the distribution channels of some goods (fresh food sold in retail stores, food distributed by Hotels, Restaurants and Catering (Ho.Re.Ca.), pharmaceutical products and clothing&footwear) which are commonly distributed in Italian urban centers. It is found that the distribution of pharmaceutical products is unaffected by these policies, whereas the distribution of fresh food is negatively affected especially by access time regulation and loading\unloading policies. The Ho.Re.Ca. and the clothing&footwear channels are likely to be impacted the most by fiscal policies and by the promotion of urban transhipment and consolidation centres.

Keywords: City Logistics; Goods movement; Vehicle routing problem.

1. Introduction

Urban areas are vital centers of economic activity and innovation generating large economies of density and proximity (Camagni, 2007). Yet, procuring and distributing goods in an urban context is fraught with difficulties because of several reasons.

Urban good distribution takes place in a context characterised by severe conflicts over the use of the urban space (between transport, recreational and economic uses, and

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between passenger traffic, freight traffic and parking) and over the use of scarce public goods such as air quality, noise, severance, safety. Such conflicts are regulated by city administrators and subject to continuous debate and negotiation among stakeholders. As a result the urban context is highly unstable.

Many actors are involved in the production and distribution chains: the producer, the wholesaler, the carrier (transport operator), the retailer and the consumer. Each has his own profit or welfare function[1]. Hence, there are multiple decision makers and the information is distributed among spatially dispersed individuals. As a result urban goods distribution is often characterized by high transaction costs and asymmetric information.

Congestion, generated by limited infrastructure availability, and environmental impacts of transport are well-known sources of external costs inducing suboptimal private decisions.

Because of instability in the regulatory setting, high transaction costs, asymmetric information and external costs, urban goods distribution may fail to achieve, efficiently and effectively, its goals. Examples of such failures are suboptimal traffic congestion, excessive noise and air pollution, visual intrusion, insufficient safety, irregular parking, and good distribution inefficiencies.

The urban goods distribution issue has been extensively analysed by researchers. The concept of *city logistics* - defined as "the process of totally optimizing the logistics and transport activities by private companies with support of advanced information systems in urban areas considering the traffic environment, the traffic congestion, the traffic safety and the energy savings within the framework of a market economy." – has been proposed by Taniguchi et *al*. (2001) as a paradigm to approach the issue[2].

Many policies have been proposed to improve the existing urban good distribution system: regulatory policies, fiscal measures, land-use and planning measures, technological innovations, investment and practice innovations ((Visser et . al., 1999; Maggi, 2007). In this paper we focus on five types of policies, frequently implemented by local authorities: goods vehicle time-access regulation, vehicle type restrictions, loading\unloading regulation, fiscal policies and the promotion of urban transhipment and consolidation centres. Their effect on the behaviour and on the decisions of private operators (shippers, carriers, and retailers) and, consequently, their impact both on the private logistic costs and on the social benefits are not easy to predict and, in our opinion, have not been sufficiently studied.

The purpose of this paper is, therefore, to contribute to the literature focusing on the impact of such policies on the distribution channels through which a good is made available at the retail point located in the urban area.

A distribution channel is a component of a supply chain. In general terms, a supply chain includes all firms that engage in activities that are necessary to convert raw materials into a good or service. A supply chain can be subdivided into a supplier

[1] For a theoretical analysis of the interaction among the main actors (seller, transporter, receiver) see Friesz et. al. (2008).

[2] Logistics as a business problem is defined as "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods and related information from point of origin to point of consumption for the purpose of conforming to customer requirements" (Ballou, 1999). It is acknowledged that solving the logistic problem at a single firm level is not an easy task, since a firm is often made up by more than one person or department which need to share goals, motivations, abilities and information. At a supply chain level, involving more than one firm, the task is ever more difficult.

network and a distribution channel. There can exist multiple channels through which a good can be distributed to the consumers[3].

An analysis of the data available for some Italian cities, reported in the next section, allows us to identify some goods whose distribution channels are of particular relevance. They are: fresh food sold in retail stores, food distributed by Ho.Re.Ca., pharmaceutical products and clothing&footwear. Hence, the paper is restricted to the illustration of the distribution channels for these goods, although several other goods, and distribution channels, can be found in an urban area.

The paper is hence organised as follows: Section 2 introduces the concept of a distribution channel and illustrates the main features of the distribution channels of the above-identified types of goods, with reference to the Italian case; Section 3 presents and discusses the potential of five types of frequently used urban freight policies; and, finally, Section 4 discusses the likely impact of each policy on each distribution channel. Section 5 draws some conclusions and proposes some lines of research.

2. Distribution channels in Italian cities

The supply chain of a product comprises all firms engaged in the activities necessary both to convert raw materials into goods, and to sell the products to consumers. Indeed, a supply chain can be subdivided into two parts: an upstream network including the firms that supply raw materials, components, parts, information, finances, and expertise to create the product, and a downstream network, called marketing or distribution channel, including the firms that make the product available for use to business users and\or consumers. Each member of the distribution channel adds value by bridging the time, place, and possession gaps that separate the producers of goods and services from their users. A supply chain might have multiple distribution channels (multichannel), a strategy generally used to reach different customer segments.

There can be many types of distribution channels, as illustrated in Figure 1. Short, or direct, distribution channels (n° 1 in the Figure), where producers sell goods or services directly to retailers or consumers. Long channels, characterized by intermediation activities performed by distribution centers owned by producers (n° 2), or by wholesalers (n° 3) (e.g. general wholesalers, single-line wholesalers, specialty lines wholesalers, drop-shippers wholesalers, truck wholesalers, cash and carry) or by agents and brokers (n° 5). If the production of the good is fragmented among many small firms, the producers can enhance bargaining power and increase logistics efficiency by joining in associations (or cooperatives) aimed at collecting and selling the product to the retailers (n° 4). Similarly, if the retail system is fragmented in many small firms, the

[3] The need to analyse policy impacts differentiating by supply chains and distribution channels is supported by the literature (e.g. Maggi, 2007). Recently, Hensher and Puckett (2005), focusing on congestion charging, recognize that "A key element of the intersection between freight transport and traffic congestion is the role that agents in the supply chain can play in cooperating to change freight distribution activity. This involves a re-consideration of existing distribution networks (Chopra 2003) and ways in which we can design and activate collaborative process networks (Holmstrom *et al.*2003).". Holguin-Veras (2006) underlies that the commodity type affects the decisions made by carriers and retailers in the contest of the choice between day and night deliveries. Similarly, Quak and de Koster (2006, 2007) and Browne *et al.* (2005) focus on how different supply chains are affected by time-access regulations.

retailers may join in associations or cooperatives (n° 6). Indeed, the complexity of the channels increases as the number of actors interacting along the distribution chain raises, implying, if channel members adopt mark-up strategies, higher management costs for producers and higher prices for consumers. However, a large number of intermediaries allows the producers to reach many target markets and the consumers to chose among broader assortments of products.

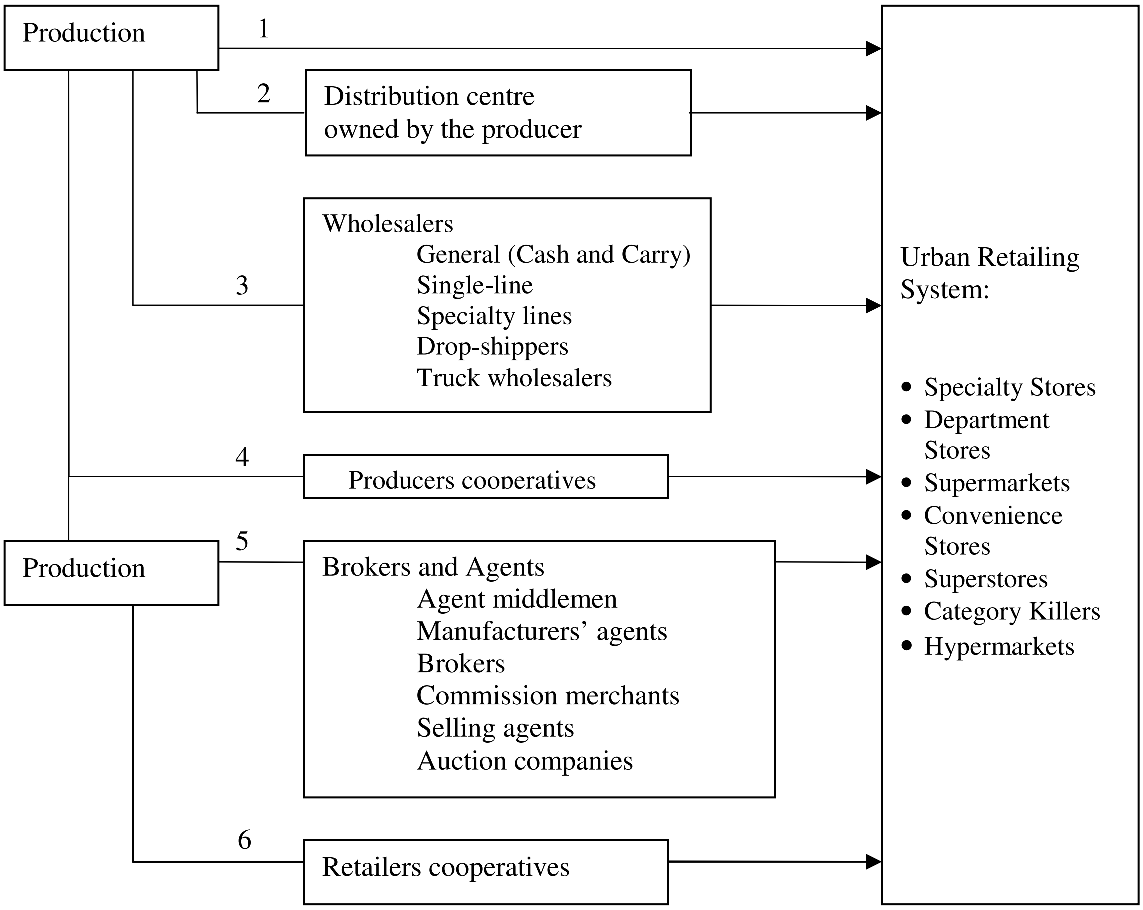

Figure 1: Distribution channels of a generic supply chain.
Source: Authors adaptation from Kotler and Armstrong (1999).

Boone and Kurtz (2001) show that the length of the distribution channel is influenced by several factors. An initial factor is the size and type of the market: if the end consumer is a firm that is geographically concentrated, buying large quantities of a product characterized by extensive technical knowledge and requiring regular service, such firm will be most likely supplied via a short channel. On the contrary, if the end consumer is a private individual, geographically dispersed, buying small quantities, incorporating little technical knowledge, and no extra service, that consumer will be supplied via a longer distribution channel. A second important factor is the type of product: if the product is perishable, complex or expensive, it is distributed via short channels, while if it is standardized, durable and inexpensive, it is delivered via longer channels. A third relevant factor is related to the characteristics of the producer and of its competitive strategy. If the manufacturer has adequate resources to perform promotion and delivery functions over broad product lines whose demand is significantly influenced by the quality and quantity of promotion and marketing activities, the distribution channel will be short, and vice versa[4].

A further important factor characterizing a distribution channel is represented by the transport and logistics activities that are performed by its members in order to transfer the products along the supply chain. The characterization of the transport and logistics activities is quite complex. It involves the description of at least the following features: a) the number of deliveries and collections at urban establishments; b) the pattern of goods vehicles activity at urban establishment by time of day, day of week and month of year; c) the vehicle type used to make deliveries; e) the vehicle dwell time; f) the loading/unloading process; g) the vehicle rounds and h) the percentage of own-account versus third-party operators[5] (Allen et *al*., 2008).

2.1 Urban distribution channels. Evidence from Italian cities

What are the most important distribution channels in a city, and what are their main features? In the following sections, we provide an answer to these questions at least with reference to the Italian cities.

In Italy, there are only a few studies mapping both the distribution channels at urban level and their transport organization. A study conducted in 2004 in Mestre, a typical medium-sized Italian city located near Venice in the Veneto Region, reported that the most frequent retail activities in the central area are: Ho.Re.Ca. (30.3%), small specialized traditional stores (27.7%), clothing&footwear stores (13.8%), food stores (11.6%), home furnishing and electronics stores (7.7%), stationary and tobacco stores (5.4%), pharmacies (3.3%) and large retail organizations (0,2%) (Comune di Venezia, 2004). The retail system of the central area of Bologna, a larger-sized city located in the Emilia Romagna region, shows a similar structure since, according to a study performed in 2004 within the Cityport project (Regione Emilia Romagna, Assessorato Mobilità e Trasporti, 2005), the most common activities are: traditional stores specialized in products other than food (35.3%), Ho.Re.Ca. (30.3%), clothing&footwear stores (19.9%), and food stores (fresh, 10.6%; grocery 3.4%; frozen 0.5%).

In the city centre of Bologna the average size of these activities differs substantially by product type: it is small for fruit and vegetable stores (about 50 m^2), intermediate for grocery stores (101 m^2) and traditional stores specialized in products other than food (103 m^2), and larger for HO.RE.CA. (116 m^2), clothing&footwear stores (139 m^2) and frozen food stores (196 m^2). Most of the times, the inventory storing capability of these shops is quite small determining the dependence from frequent consignments.

Most of the distribution channels of Bologna have origin within the region (48%) or within the province (34%). The percentage of regional suppliers is very differentiated among retail segments, being as high as 95% for Ho.Re.Ca., and as low as 28% for traditional stores specialized in products other than food. On average, in Bologna, 63% of the suppliers of the retail system are producers, and 31% are wholesalers.

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[4] Sabbadini and Mungo (2009) acknowledge the importance of the last factor reporting on the propensity of the biggest Italian retail organizations to shorten their supply chains, thereby by-passing the existing intermediaries, using voluntary chains, corporate chains, retailer cooperatives, merchandising conglomerates, and franchise organizations.

[5] This last feature is quite relevant since own-account services generally appear to have a lower loading factor, to perform suboptimal routing and to use more polluting vehicles than third-party services.

Freight transport represents an important share of total traffic. The percentage of vehicles transporting goods compared to the total number of vehicles entering in 1999 the Mura Aureliane of Rome between 7 a.m. ad 6 p.m. was equal to 12%. Such percentage is estimated as high as 67% during the morning peak hours (ISFORT, 2003).

In terms of percentage of consignments, in 2004 in Bologna, traditional stores specialized in products other than food have the largest share (42%), followed by Ho.Re.Ca. (18%), food stores (15%), and clothing&footwear stores (1%). Concerning the consignments frequency, in Mestre it was found that pharmaceutical products were delivered either once a day (60%), or more than once a day (40%), Ho.Re.Ca was supplied mostly on a weekly (60%) or daily (38%) basis, food stores were supplied mainly daily (68%) or more-than-once per day (16%), while clothing&footwear stores were supplied weekly (48%), on a daily bases (19%) or occasionally (14%).

The relative share of own-account vs. third-party transport is as follows: it is equal to 63% in the central area of Milan (Vaghi, 2009) and it was reported as high as 78% in other Italian cities. In Mestre the percentage of retailers owning a vehicle to transport the goods from the producers or the wholesalers to their premises is equal to 42%. More specifically, it is as high as 71% for Ho.Re.Ca., 58% for home furnishing and electronics stores, and 47% for food stores, while it is equal to 33% for clothing&footwear stores , and to 20% for pharmacies (Comune di Venezia, 2004). In Bologna the percentage of products transported into the central area via vehicles owned by the producers is equal to 82% for Ho.Re.ca, 77% for food stores, 57% other then food products, 11% for pharmaceutical products.

Own-account transport, hence, represents, at least in Italy, an important segment of urban goods distribution to which, as we will see, policy makers devote a fair share of attention. Such attention appears to be motivated since own-account proved to be far less efficient than third-party per unit of vehicle used. For instance, it is measured that the number of own-account vehicles entering the central area in Bologna is approximately equal to the number of vehicles owned by third-party operators, but the former makes half the consignments made by the latter.

Given the above information, we decided to focus our attention on the distribution channels of fresh food sold in retail stores, food distributed by Ho.Re.Ca., pharmaceutical products and clothing&footwear since they appear to be important traffic generators in Italian cities[6]. In the following sections we will describe their organization structure and their performance level. Our analysis will be based on a selection of indicators developed by Quak and de Koster (2006) integrated by some indicators that we propose. We will focus on: the type of distribution channels used by each supply chain to service the urban retail system, which actor along the supply chain acts as the logistic coordinator, the distance between the stores and the distribution centre, the percentage of stores located in central areas, the competitive strategy chosen by the retailers, the assortment of products offered by the retailers, the product value, the product volume, the consignment size, the delivery frequency, likely self-implied time windows[7], the number of time windows, the degree of transport activities performed via own account, the type of routing chosen by the carrier, potential transport activities requiring special vehicles.

[6] Similar results are reported by Dufour and Patier (1999) for Bordeaux.

[7] A self-implied time window is the time window required by the retailer given staff availability or to separate the shopping public from the supplying activities.

2.2 Fresh food

2.2.1 Citrus, fruit and vegetables

In Italy there are four main distribution channels for citrus (Aguglia, 2008):

a) *A short channel*: the producer sells its products directly to the consumers. It is typically used by small producers having no or limited logistic organization and directly taking care of promotion and delivery activities.
b) *A long channel*: the producer sells its products to a wholesaler who trades them with large retail chains or corporations, small specialty stores, or final consumers. The wholesaler coordinates the entire distribution channel frequently providing also the transport service.
c) *An integrated channel*: the producer sells its products directly to the retailer, no intermediation is performed by wholesalers, and the coordination of the distribution activities is performed by the producer or by the retailer according to their size and their logistic organization.
d) *A logistic platform channel*: the retailers coordinate their supplying activities via purchasing groups, retailers' cooperatives or associations, and voluntary chains, who buy the products directly from the producers or from the wholesalers. The product is then collected in a logistic platform and transported by third parties operators.

The distance between the distribution centres and the retailers can be either short, as for distribution channel (a) and (c), or medium as in channel (b) and (d).

In Italy citrus represents 24% of the total sales of fruit. 45% is distributed by medium or large retail organizations (LRO, such as supermarkets, hypermarkets and hard discounts). The remaining is distributed via small specialty stores (25%) and fruit and vegetable stalls (23%). A significant proportion of the citrus bought by large retail organizations is sold to Ho.Re.Ca..

The distribution channels of fruit and vegetables in Italy are very similar to those already described for citrus. Large retail organizations hold 30-40% of the market share, while small specialized retailers and itinerant vendors have diminishing market shares over time.

The percentage of stores located in central urban areas is low (large retail chains or groups are generally sited in the peripheries of large urban areas), or medium (small specialty stores and itinerant vendors). While large retail organizations base their competitive strategy on product differentiation, low prices and quick response, small specialty stores and itinerant vendors are more quality and brand-oriented. The assortment type of large retail organizations is much more complex than the one characterizing small specialty stores and itinerant vendors (AGCM, 2007).

The product volume is generally small or medium, while the drop size depends on the retailer size. It is typically large for retail organizations or corporations, both because the turnover is much higher than for smaller stores and because their stocking facilities are larger, while it is medium for specialty stores.

The delivery frequency is high and the consignments are performed early in the mornings. The number of the delivery time windows is not flexible and the self-implied time windows are narrow.

The transport activities are performed by third-party operators for large retail organizations, generally via multi-dropping routing if the consignment for each store of the network is less-than-truck (LTL) load. Special refrigerated trucks are used for the transport activities especially if the distance between the distribution centre and the stores is long. Small specialty stores and itinerant vendors, instead, perform transport activities using their own vehicles because they prefer to personally check the assortment type and quality of the products offered by the wholesalers and they want to negotiate on the products' price.

2.2.2 Fresh fish and meat

The fish market is composed of two segments: the industrial fish segment (Figure 2) and the non-industrial (artisan) one (Figure 3). In the industrial fish segment, selling 390,000 tons annually, there are several distribution channels:

- a direct channel from the producer to Ho.Re.Ca., trading 5% of the total product;
- a producer-wholesaler-Ho.Re.Ca. channel, trading 31% of the total product;
- a producer-wholesaler-fish market-Ho.Re.Ca. channel, trading 5% of the total product;
- a producer-wholesaler-specialty store-consumer channel and a producer-wholesaler-fish market-specialty store-consumer channel, trading 26% of the total product;
- a producer-wholesaler-LRO-consumer channel and a producer-LRO-consumer channel, trading 26% of the total product.

Hence, the distribution channels of the industrial segment are multilevel and quite complex, and generally coordinated by the wholesalers. The distance between the distribution centers and the stores is medium or long.

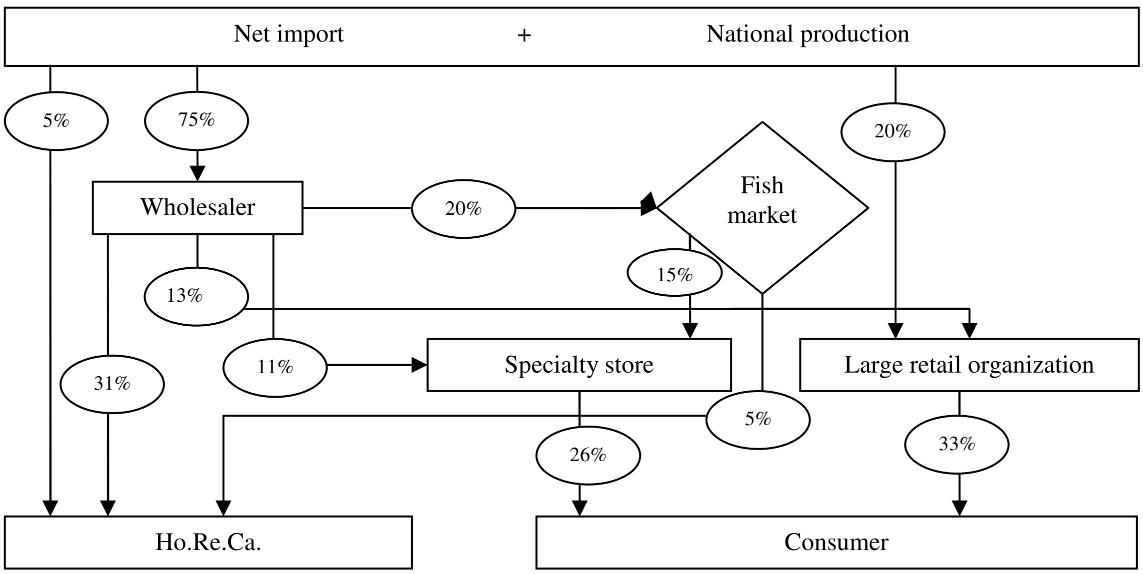

Figure 2: Distribution channels of the industrial segment of the fishing industry in Italy.
Source: INDIS and Osservatorio Nazionale del Commercio (2006, p. 16).

Within the artisan fish segment, selling 100,000 tons annually, there are also several distribution channels:

- a direct channel from the producer to Ho.Re.Ca., trading 4% of the total product;
- a producer-wholesaler-Ho.Re.Ca. channel, trading 21% of the total product;
- a producer-wholesaler-fish market-Ho.Re.Ca. channel, trading 4% of the total product;
- a producer-wholesaler-specialty store-consumer channel, a producer-wholesaler-fish market-specialty store-consumer channel, and producer-specialty store-consumer channel trading 66% of the total product;
- a producer-consumer channel, trading 5% of the total product.

The main differences between the industrial and the non-industrial channel are that a) the coordination role is played both by the wholesalers and by traditional markets, b) the LRO plays no role since it does not find economically convenient to deal with very many small producers, and c) the short distribution channel is quite relevant (24%), being the sum of direct and intermediated by specialty stores only sales. The distance between the distribution centers and the stores is typically short.

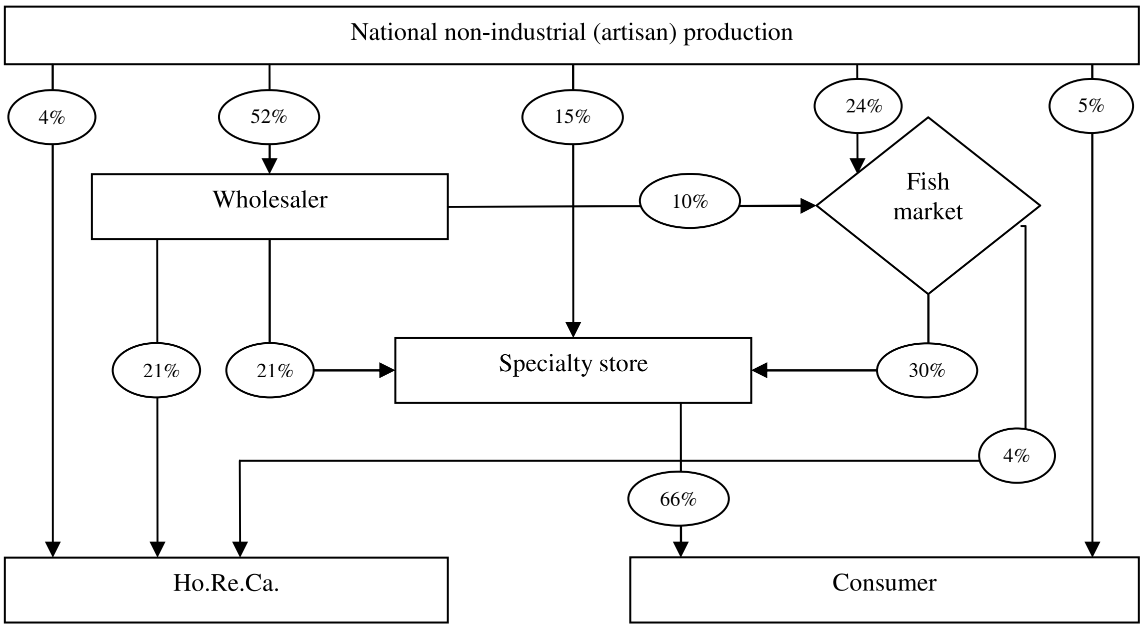

Figure 3: Distribution channels of the artisan segment of the fishing industry in Italy.
Source: INDIS and Osservatorio Nazionale del Commercio (2006, p. 17).

In Italy 114,500 tons of cattle and 450,000 tons of pork are traded annually in the meat industry.

The cattle distribution channel is quite complex. Compared with the previous ones it adds the following characteristics:

- wholesalers play a role also in procuring the product (7%);
- the slaughtering industry is the most important coordinator, selling directly to the food industry (15%), Ho.Re.Ca. (9%), the LRO (32%) and the specialty stores (25%) and indirectly via wholesalers (19%).

In the pork distribution channel, since the supply is more dispersed, wholesalers are the main suppliers of the slaughtering industry (63%). The slaughtering industry sells a large quantity to the food industry (45%) and, again, to the wholesalers (27%). Then specialty stores and LRO distribute the product to the final consumer and Ho.Re.Ca.

The complexity of the distribution channels of this sector is due to the high number and the small size of all the actors involved (INDIS and Osservatorio Nazionale del Commercio, 2006).

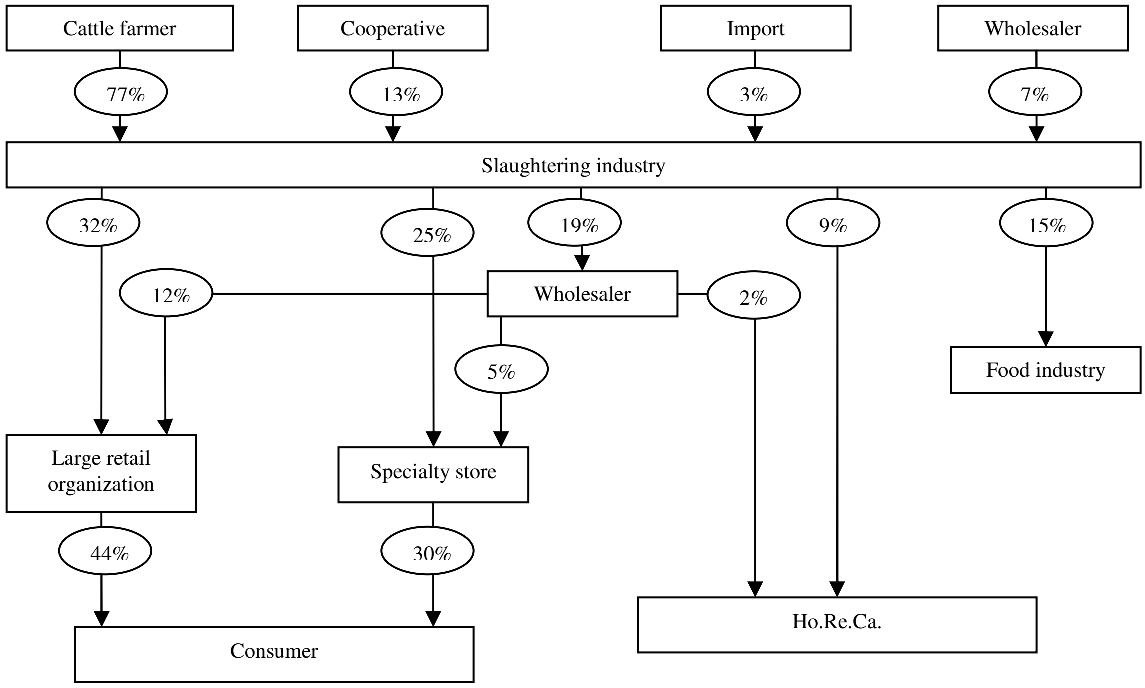

Figure 4 Cattle distribution channels in Italy.
Source: INDIS and Osservatorio Nazionale del Commercio (2006, p. 34).

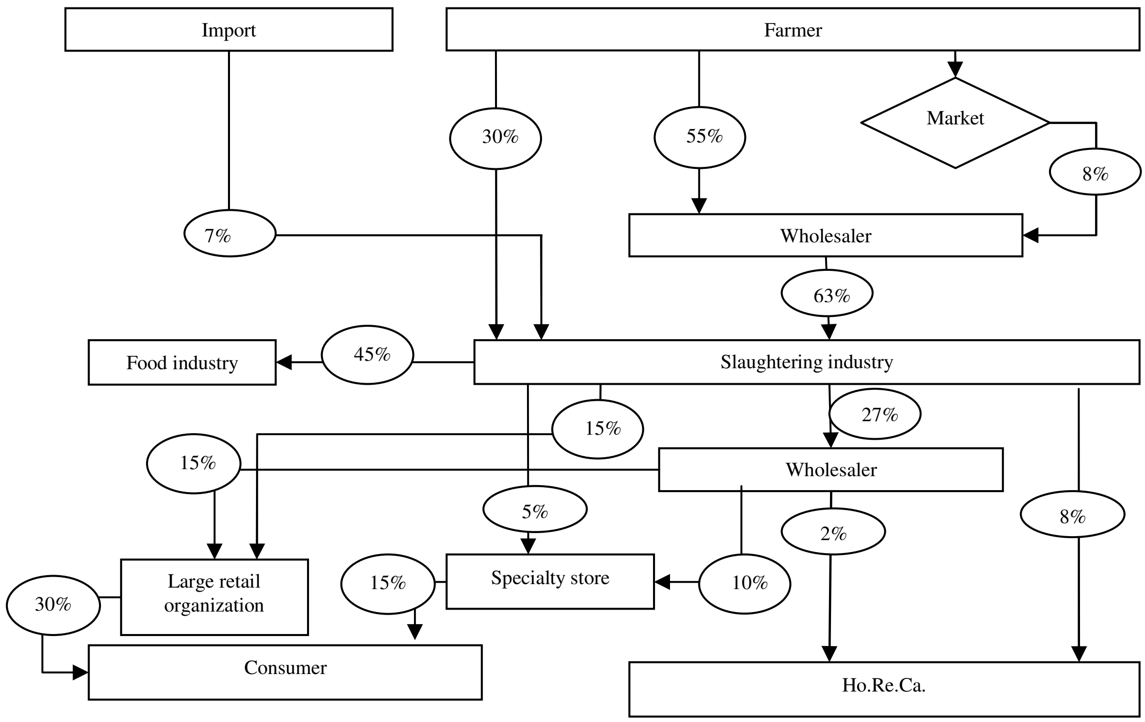

Figure 5 Pork distribution channels in Italy.
Source: INDIS and Osservatorio Nazionale del Commercio (2006, p. 38).

The distribution channels of the fresh fish industry and of the meat industry are coordinated, respectively, by the wholesalers and by the slaughter industry. In both cases their main functions are to group the small quantities of product offered by each producer and to ensure a broad assortment to final consumers, small specialized retailers, large retail organizations, Ho.Re.Ca., and the manufacturing industry.

The percentage of stores localized within the urban center is medium. The competitive strategy of the retailers is based on the origin and the quality of the product for small traditional stores, while it is cost-oriented and aimed at ensuring a standardized assortment level for large retail organizations. The assortment type is simpler for small specialized stores than for large retail organizations.

The product volume and the drop size is medium with high delivery frequency. The self-implied time windows are very narrow for small specialty stores, while they are wider for large retail organizations, although in both cases the consignments should to be done early in the morning.

The transport activities are performed using refrigerated trucks by third parties hired by wholesalers or via own account.

2.2.3 Dairy products

In Italy there are almost 46,000 firms producing milk and dairy products, although most of them are localized in the northern part of the country. Milk is transported and collected in centralized facilities (Centrali del Latte) generally owned by cooperatives of producers and localized near large urban areas. Here milk undergoes the pasteurization and the packaging process. It is then distributed to the urban retail system (Direzione Generale Agricoltura della Regione Lombardia, 2007).

Dairy products are distributed mainly via large retail organizations (59%) and only a marginal percentage is sold by traditional (13%) or specialty (6%) food stores, by hard discounts (5%), or by Ho.Re.Ca. (8%). The distance between the distribution centers and the stores is short or medium depending on the assortment type of the products sold by the retailers.

The percentage of stores localized in central urban areas is low (large retail organizations) or medium (small traditional stores) according to the retailer typology considered. The competitive strategy pursued by the retailers is based on product differentiation and quick response for large retail organizations, while it is brand-based for small traditional stores. The assortment type is complex for large retail organization, and it is simple for small traditional stores.

The product volume and the drop size is medium. The product is delivered on a daily bases during the mornings within narrow self-implied time windows.

The transport activities are organized via multi-drop consignments and are performed using refrigerated trucks generally owned by the producers' organizations (*Centrali del Latte*) or by the large retail organizations.

2.3 Hotels, restaurants, catering

The segment of hotels, restaurants, and catering (Ho.Re.Ca.) is generally described as an homogenous retail segment. However, its commercial activities present very different logistics and organizational constrains according to the specific service offered to the final consumers.

In Milan, most Ho.Re.Ca. is supplied by wholesalers, servicing 53% of the bars and 43% of the restaurants, or directly by the producer, supplying 21% of the bars and 15% of the restaurants (Cermes Bocconi, 2006). The so called cash&carry represents the preferred distribution channel for 13% of the bars and for 20% of the restaurants, while traditional food stores and local markets supply, respectively, 5% and 3% of the bars and 10% and 9% of the restaurants. The distribution channels chosen by Ho.Re.Ca. are extremely heterogeneous according to the product type. Own-account (cash and carry) is particularly relevant for liquors (45%), flour, sugar and salt (41%), preserved food (40%), cooked meals (35%), soft drinks (27%), that is for products whose replenishment can be planned in advance and that can be easily stored. The short distribution channel, instead, is preferred for coffee (68%), wine (43%), ice-cream (34%), and confectionery (31%). Bread (55%), pastry (33%), meat (28%), fruit and vegetables (22%), fish (22%), and dairy food (19%) are among the products more frequently purchased from specialty stores. Wholesalers are preferred when frequency, timing, and freight vehicle characteristics are critical issues characterizing the logistic activities, producer and specialty stores, instead, are chosen when quality is judged as more important, while cash&carry prevails if price and variety is particularly relevant.

The percentage of Ho.Re.Ca. activities are localized within central urban areas is quite high. Their competitive strategy is very heterogeneous and is based on differentiation, response or price according to the market segment they are focused on. The assortment type is simple and the product value is low.

The product volume and the drop size are small or medium. The self-implied time windows for the consignment operations are narrow, and restaurants and bar specialized in breakfast and lunches need to receive the supplies early in the morning.

When the supply channels are specialty stores or cash&carry the transport activities are performed by the retailer using his own vehicles, while they are performed by third-party operators or by agents of the producers when the suppliers are wholesalers or producers. Special refrigerated trucks are used for fresh or frozen food.

2.4 Pharmaceutical products

In Italy there is one main distribution channel for pharmaceutical products. It is founded on 230 pharmaceutical firms stocking their product in 150 distribution centres, delivering them via 138 wholesalers and almost 17,000 pharmacies (Figure 6, Dallari, 2006).

The distribution channels of the pharmaceutical products are four:

- a direct channel from the producer to the pharmacies (6%);
- a producer-distribution centre- logistic provider-wholesaler-pharmacy channel (78%);
- a producer-distribution centre- logistic provider- hospital (14%);
- a producer-distribution centre- logistic provider-wholesaler- hospital (2%).

The distribution channels are mainly coordinated by logistics providers and wholesalers. The distance between the pharmacies and the distribution centers are generally short, as each pharmacy is supplied by the nearest regional centre carrying the required product.

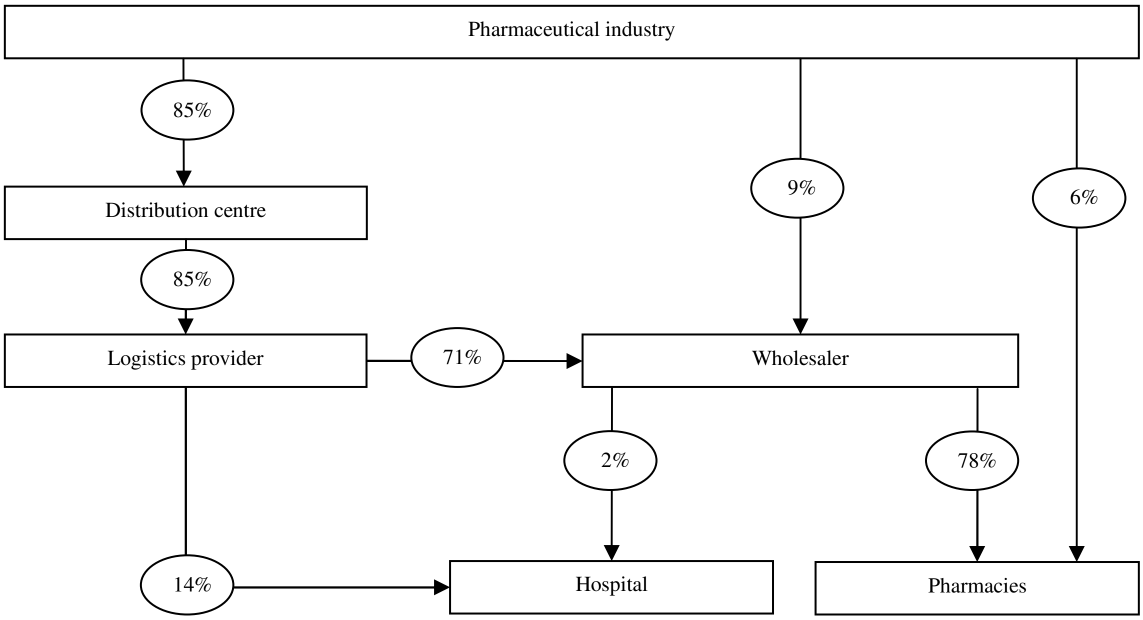

Figure 6 Pharmaceutical distribution channels in Italy.
Source: Dallari (2006, pp.8-9).

This distribution system is very effective because all the actors involved share the same electronic database with real-time listings of the quantity of products required by each pharmacy, and the availability of products stored by the wholesalers localized in their proximities. 80% of the information transmitted through this supply chain is sent on line via EDI (electronic data interchange) and Internet.

As the Italian regulation of this industrial sector requires a maximum of one pharmacy every 5,000 inhabitants for municipalities up to 12,500 inhabitants, and a maximum of one pharmacy every 4,000 inhabitants for larger municipalities, the percentage of pharmacies localized in central urban areas is quite small. The competitive strategy pursued by each pharmacy is based on responsiveness (the Italian regulation requires pharmacies to have a lead time under 12 hours), and product assortment. The externalization of the stocking activities to wholesalers and distribution centres allows the producers and the pharmacies to substantially reduce their costs, while the size of their intermediaries are rapidly increasing, allowing to better exploit economies of scale and to further reduce supply chain costs.

The complexity of the assortment type is such that, although the product volume is typically small, the quantities stored per product type are small and the delivery frequency is very high, up to 4 times a day, with an average lead time of 4 hours. The drop size is small and the delivery operations are performed on-street.

The transport activities are performed by third parties hired and paid directly by the wholesalers. They use refrigerated trucks and organize the deliveries via multi-drop routing supplying all the pharmacies within the city boundaries.

2.5 Clothing&footwear

In Italy there are four main distribution channels of clothing&footwear and differ according to the retailer type: 1) small traditional stores, which account for 51% of the turnover, and are particularly relevant for menswear and shoes; 2) itinerant vendors, which produce 15% of the turnover, and are quite popular especially for underwear; 3) retail chains and corporations (17% of the turnover) and 4) franchising stores (17% of the turnover). The latter two are increasing their market share specializing their activities in sportswear, and in female and child clothing, respectively (Osservatorio Nazionale del Commercio, 2006).

These distribution channels differ substantially in terms of logistical organization. Indeed, while retail chains, corporations and franchising stores have a centralized logistic coordination supplying all the stores included in the network and based on centralized distribution centers, traditional stores and itinerant vendors lack any sort of logistic coordination, except for the transport service generally provided by the wholesalers during the replenishment period at the beginning of the winter and summer season and supplying more than one store during the same trip. The distance between the distribution centers and the stores can be quite long, especially for big retail chains or corporations or for highly geographically concentrated franchising organizations.

The comparison of the Italian retail system with those of other European countries (Germany, Spain, France and UK) shows that the Italian one is much more fragmented. Indeed, in 2002 in Italy there were 15 small clothes stores for every 10,000 inhabitants, while the proportion was equal to 3 in Germany and to 2 in UK. Similarly, in Italy there were almost 4 small footwear stores every 10,000 residents, while the proportion was equal to 1 in Germany and to 0.7 in UK (Osservatorio Nazionale del Commercio, 2006).

The percentage of stores localized in central urban areas is typically high. The competitive strategy of the retailers can differ substantially among the four distribution channels described at the beginning of this sections since it is typically cost-oriented for itinerant vendors and retail chains and corporations, brand-oriented for franchising stores, and differentiation-oriented for traditional small stores. The product assortment is generally complex and the product value ranges from low to medium according to the product type and brand sold by the retailer.

The product volume is small or medium, while the consignment size is large for seasonal orders concentrated during September/November and March/May, while it is small for stock replenishment.

The delivery frequency is low as the turnover of the stocked products is generally low. The retailers do not have stringent self-implied time windows, although they prefer to receive the deliveries during the mornings rather than during the afternoons, and are quite flexible in terms of number of time windows.

The transport activities are generally performed by third parties (express companies performing multi-drop or single-drop routing according to the size of the delivery and the location of the stores to be supplied) especially for the seasonal orders and when they transport hanging clothes using specially equipped vehicles. When the retailers are small, instead, the stock replenishment products are transported directly by the agent of the wholesaler or via own account.

2.6 Distribution channels in Italian cities: a comparative summary

In Table 1 we have summarized some characteristics of the types of products that, in our view, are among the most critical generators of transport and logistic activities in Italian urban centres.

The distribution channels used by each type of product are quite heterogeneous and range from the homogeneous, highly efficient one used for pharmaceutical products coordinated by a logistics provider, to the less efficient, multichannel systems used for the other products. Not at all distribution channels have a logistics coordinator. There appears to be a lack of coordination in some segments of the small commercial activities selling clothes or fresh food and part of Ho.Re.Ca.. The distance between stores and distribution centres is short for pharmaceutical products and Ho.Re.Ca., long for clothing&footwear and ranges from short to medium for fresh food.

Table 1: Characteristics of the distribution channels of four types of products.

	Fresh food	***Ho.Re.Ca.***	***Pharmaceutical products***	***Clothing & footwear***
Logistics coordinator	Wholesaler, slaughtering industry, milk factories, no coordination	Partly the wholesaler, no coordination	Logistics provider	Franchising firms, producers, no coordination
Distance between stores and DC	Short, medium	Short	Short	Long
% of stores in central areas	Low, medium	High	Low	High
Competitive strategy	Differentiation, cost, response, brand	Differentiation, cost, response	Response	Differentiation, cost, brand
Assortment type	Simple, complex	Simple	Complex	Complex
Product value	Low	Low	Low	Low, medium
Product volume	Small, medium	Small, medium	Small	Small, medium
Drop size	Medium, large	Medium	Small	Small, medium
Consignment size	Highly variable size due to product and retailer type	Small but variable due to receiver specificity	Small parcels, high frequency, quick response	Variable size due to seasonal orders versus stock replenishment
Delivery frequency	High	Medium	High	Low
Self-implied time windows	Narrow	Narrow	Wide	Medium
N° of time window	Not flexible	Flexible	3-4 a day predefined	Flexible
Own account	Yes: for Specialty Stores	Yes: for Specialty Stores, and C&C	No	Yes: for Small Stores
Routing	Both multi-drop and single-drop	Both multi-drop and single-drop	Multi-drop	Both multi-drop and single-drop
Special vehicle	Yes	Yes for perishable or frozen food	Yes	Yes for hanging cloths

At supply chain level, the number of stores localized within the urban centre over the overall number of stores localized in the urban area is higher for clothing&footwear and

Ho.Re.Ca., than for fresh food and pharmaceutical products. The competitive strategies pursued by pharmacies are based mainly on response, hence, requiring an efficient and highly integrated logistics organization. On the contrary, the competitive strategies of the other products are much more heterogeneous including differentiation, brand, and cost. This hinders their integration and efficiency levels.

The assortment type (i.e. the variety of goods distributed) is complex for pharmaceuticals products and clothing&footwear, whereas it is often simple for Ho.Re.Ca. and fresh food, although is depends on the type of retail activity considered. None of the analysed supply chains trade high value products, except for some clothing segments (boutiques). The product volume and the drop size are very small for pharmaceutical products, small or medium for clothing&footwear (could be large for the seasonal orders) and Ho.Re.Ca., and medium or large for fresh food (depending on the product type and on the retailer size).

The delivery frequency is very high for pharmaceutical products, high for fresh food, high or medium for Ho.Re.Ca. and low for clothing&footwear. The self-implied time windows are particularly narrow for fresh food and Ho.Re.Ca., while they are less stringent for pharmaceutical products and clothing&footwear. The number of self-imposed time windows is 3-4 a day for pharmaceutical products, variable for clothing&footwear and Ho.Re.Ca. (except for bars serving breakfast and lunches) and limited to the early mornings for fresh food.

Pharmaceutical products are supplied exclusively via third party operators, hence, with higher levels of efficiency, whereas the other products are distributed also via own-account transport. The latter is used for clothing&footwear in the case of the stock replenishment and for Ho.Re.Ca. for products bought from cash&carry or specialty stores. Own-account transport prevails in the acquisition of fresh food sold by small traditional stores.

Special refrigerated vehicles are used for pharmaceutical products, fresh food and Ho.Re.Ca., whereas clothing&footwear require special vehicles only when transporting hanging cloths.

3. Urban freight transport policies

In the following paragraphs five specific, frequently implemented, urban freight transport policies will be examined: goods vehicle time-access regulation, vehicle type restrictions, loading\unloading policies, fiscal policies and the promotion urban transhipment and consolidation centres.

Other relevant policies such as public-private partnerships, information and communication technology (ICT), Intelligent transportation systems (ITS) and land use planning will not be discussed in this paper not because they are not relevant but in order to limit the scope of the paper.

In the next subsections some information will be provided on how each of the five policies has been implemented and on what are their main effects.

3.1 Goods vehicle time-access regulation

Local authorities increasingly use time-access regulations. Quak and de Koster (2006, p. 6) quote a survey among the 278 largest municipalities in the Netherlands showing that the proportion of municipalities that use time-window regulations increased from 41% in 1998 to 53% in 2002.

The general aim is to improve social sustainability, such as the attractiveness of the city centre. More specifically time-access regulations aim at: a) improving the shopping climate by separating the shopping public from the suppliers; b) reducing the perceived impacts of trucks on congestion during certain periods of the day; c) increasing pedestrian safety or d) reducing the nuisance caused by urban freight transport especially during nighttime or the early morning hours.

The variety of aims leads, not surprisingly, to a variety of implementations. Browne et *al* (2007) find that "in London they are in many ways the reverse of those in Paris": London restricts night deliveries but does not regulate day restrictions, whereas Paris regulates day restrictions. In fact, in London "the objective of the scheme is to reduce noise nuisance at anti-social times by eliminating through heavy lorry traffic at night-time and weekends and minimizing the environmental intrusion of heavy lorries with business in London during the ban period." (Browne et *al*., 2007, p. 213)[8]. In Paris the regulation is under revision, however, it seems more focused on avoiding the intrusion and congestion caused by large vehicles on city livability and traffic[9].

Analyzing the application of the regulation in Italian cities, one also finds highly differentiated regulations. Some cities prefer to restrict access late in the morning and early in the afternoon to favor tourism (Ferrara, Parma, Siena, Ravenna, Vicenza); others prefer to restrict access during the morning peak (Piacenza, Parma, Rimini); others distribute restrictions all day long (Bologna, Roma, Firenze, Lucca); some cities differentiate access restriction between third-party and own-account vehicles (Rome, Florence, Bologna) (see Cityports, 2005; Maggi, 2007).

Not much is known about the actual effects and costs on these restrictions on the supply chain operations. Valuable exceptions are Quak and de Koster (2006, 2007), Browne et *al*. (2005), and Holguin Veras (2007a, 2008).

Quak and de Koster (2006) evaluate five different time-window schemes regulating access in Dutch cities and find that the current time-window scheme (5 hours 20 minutes in the afternoon) performs worst and show how a reformed, more harmonized, policy could decrease costs. The effect also seems to depend on the number of regulated cities. In fact, they conclude that "it appears that cost and emissions increases are moderate, when few cities are affected. However, as more cities are affected, costs and emissions increase considerably, particularly if time-window lengths become shorter. Time-windows harmonized between cities lead to fewer negative effects." Quak and de Koster (2007, p. 1103). This implies that central governments might have an important role in guiding regulation.

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[8] Browne *et al*. (2007, p. 214) report that "The LLCS aims to ease traffic noise in residential areas by restricting lorry movements (for goods vehicles over 18 tonnes gross weight) on designated roads during the night (21.00–07.00) and at weekends (13.00 on Saturdays through to 07.00 on Mondays)."

[9] Browne *et al*. (2007, p. 213) report that "Under the new scheme, goods vehicles up to $29m^2$ (i.e., rigid goods vehicles with gross weights of up to approximately 19 tonnes) are not allowed to enter the Paris area between 17.00–22.00 but can enter at all other times. Goods vehicles over $29m^2$ are only allowed to enter between 22.00–06.00."

Besides analysing what the likely impacts of time-access windows on a retailer's financial and environmental performance will be[10], Quak and de Koster (2007) discuss which dimensions related to a retailer's network structure and logistical planning will determine its sensitivity to time-windows. They focus on various retailer characteristics (product characteristics, network structure, logistical planning) and distribution performance (operational, financial, environmental). Since they use fourteen cases, the sample is too small to consider any statistical analysis. However, they conclude that the impact of increasing time-window pressure varies among different retailers. The retailers that supply more stores during the time-window hours - thanks to the short distance, short unloading time, and larger drop size – are affected the least. On the contrary, the retailers which use their vehicles most during a 24-h period in the current situation are affected the most by time-windows.

Browne et *al*. (2005) raise the question of whether the night-delivery curfews currently imposed by many local authorities are inappropriate or too severe. They argue that time restrictions will lead to a situation where more vehicles are required in the delivery, there is less productive output from drivers since they have to deliver when traffic levels are high, and lastly, more fuel will be used as consumption increases in more congested areas. On the contrary, a removal\relaxation of the policy could improve efficiency of operations and improve sales, allow faster and more reliable journey times with a potential reduction in social and environmental impacts of truck trips. However, it may also result in noise disturbance for the people living close to the point of delivery due to the engine and unloading noise. They analyse the relevant UK and European literature to produce estimates of the cost and freight activity reduction that would result from removal of the restrictions and support the view that there will be both costs and benefits. The challenge is to find an acceptable way to measure them and to identify in which instances there could be a positive benefit-cost ratio. It was also observed that the type and location of retail shops is diversified and that the policy is more appropriate for shops situated at the edge of urban areas than for urban or central shops located nearby residential areas.

In a series of papers Holguin Veras (2007a, 2008) analyze the potential for night delivery as a way to decouple passenger traffic peaks from freight traffic peaks using stated preference data and discrete choice modeling. Holguin Veras (2007, p. 294) finds that the retailer decides the time of the consignment and "that carrier centered policies, working in isolation, are of limited effectiveness to switch truck traffic to the off-peak hours. This is because: not all the carriers can pass the extra costs to receivers; and, more importantly, even when extra costs are passed they are of no consequence with respect to the marginal costs to receivers associated with accepting off-peak deliveries." Holguin Veras (2007) also studies the financial incentives that might induce retailers and carriers to shift to off peak periods. He finds that "receivers are sensitive to the financial incentives considered in this research. However, different industry segments were found to be more sensitive than others. Receivers of wood/lumber, alcohol, paper, medical supplies, food, printed materials and metal are found to be between two to eight times more sensitive than the rest of the population of receivers." (Holguin Veras, 2007, p. 294). The commodity type plays a significant role in shaping the attitude of companies towards off peak deliveries for carriers as well "only specific segments of

[10] Quak and de Koster (2006a,b,c, 2007) use the term retailer to identify retail chains with many stores in multiple cities. All retailers organise the entire logistics and manage directly or via contracted third party carriers the transportation operations.

the carrier industry are sensitive to the type of financial incentives considered…. only carriers transporting wood/lumber, food, textiles/clothing, petroleum/coal and computer/electronics are sensitive to toll savings or financial rewards." (Holguin Veras, 2008, p. 353). It remains to be assessed why different retailers and carries behave differently.

3.2 Vehicle restrictions

In order to curb congestion and pollution, cities often regulate vehicle access according either to their dimension, weight, loading factor, and emission factor or fuel type.

The limits of the truck dimension or the weight dimension are aimed at decreasing congestion, road occupancy and the large emissions of air pollutants that characterize large trucks.

As in the previous case, in real world applications one can find a high variability of restriction limits. For instance, Paris restricts access according to vehicle dimension (16 m^2 or 24 m^2) Amsterdam does not allow trucks heavier than 7.5 tons, London than 16 tons, Barcelona than 16.5 or 3.5 tons, Milan than 15 or 3.5 tons.

A potential side effect is the reduction of the consolidation possibilities. More small trucks can have the same or even more negative effects compared to fewer large trucks, as McKinnon (1999) has demonstrated in the context of the evaluation of the transshipment option. The same argument is put forward by Holguin-Veras (2006, p. 4-5).

An important element in judging the efficiency of road transport is the load factor[11] and the policies that induce its improvement. It is estimated that in the UK, for example, average load factors declined from 63% in 1990 to 60% in 1999. It is often argued that replenishing supplies on a just-in-time (JIT) basis corresponds to decreasing vehicle load factors[12], however one also observes that average payload weight actually increased. According to McKinnon (2000) improving vehicle loading can enhance energy and environmental efficiency of road transport. Increasing truck load factor is estimated to have larger energy saving effects than doubling rail freight traffic McKinnon (2000, fig. 2). This is true both for intercity and for urban traffic[13].

One of the policies which can enhance load factors is the relaxation of maximum vehicle weight limits, hence showing a potential contrast between the policies. Other policies include: redesigning of vehicles to permit greater load consolidation (e.g., by compartmentalization of trucks to allow different temperatures); using of more space-efficient handling systems and packaging; organizational improvements such as the adoption of more transport-efficient order cycles such as the adoption of the Nominated

[11] Measured as the ratio of the actual weight of goods carried to the maximum weight that could have been carried on a laden trip.

[12] McKinnon (2000) quoted numerous reasons for declining freight density: change in the nature of the products; increased packaging; greater use of unitized handling equipment; declining "stackability"; order-picking of palletized loads at an earlier stage in the supply chain; tightening health and safety regulations.

[13] As explained by McKinnon (2000) the load factor is only a partial measure of vehicle utilization. As an exclusively weight-based measure, it takes no account of the use of vehicle space or deck area, or the proportion of vehicle kilometers run empty. Many low-density products fill the available vehicle space (or "cube out") long before the maximum permitted weight is reached. In sectors characterized by low-density products, weight based load factors tend to underestimate the true level of utilization.

Day Delivery System[14] and abandoning the monthly payment cycle or by sharing vehicle capacity.

In the context of urban goods distribution some cities tried to introduce load factor requirement to enter the city centre. A recent example is Göteborg where a pilot project was initiated up, within the START European project, with the aim to develop the environmental zone with three new areas identified for load factor restriction implementation. The restrictions were implemented in parallel with a number of incentives developed in cooperation with the transport business. To access different parts of the centre the weight or volume load rate in the vehicles had to be over 65 % or the company had to have 50 customer deliveries. As incentives for increasing the load rate, the participating companies had access to 13 special loading zones and bus lanes in the city centre. The project was carried out according to plan but the results were not as expected. After one year many of the companies had left the project since they could not fulfill the load factor demands and/or reporting obligations. An independent evaluation showed that the compliance with the scheme was considered too complicated and too time consuming. This resulted in a termination of the pilot project in September 2007 (START, 2008, p. 27).

There is not much research on the effect of these restrictions on freight transport operations and costs. Exceptions are Allen et *al*. (2003) who found that the effect depends on the size of the fleet and the width of the serviced area. Quak and de Koster (2006b) also find that the use of the vehicle weight restriction results in decreased transport efficiency and, in almost all cases, in a considerable increase of pollutant CO2 emissions.

One likely effect on carriers is an incentive to fleet renewal. The effect is likely to vary depending on the lifespan of vehicles, the size of the fleet and the area to which the restriction applies relative to the serviced area.

An example of regulation based on emission factors is the one implemented in Milan with the Ecopass policy (Rotaris et *al*., 2009) where a truck is taxed according to its EURO emission standard. Similarly, cities can introduce low emission zones (LEZ). A survey carried out in London by Browne et *al*. (2005) prior to its introduction indicated[15] that there was some support among goods vehicle operators, depending on the precise scheme definition. Operators would generally try to comply with LEZ regulations, with most companies either using technical approaches to ensure that their London vehicle fleet complied with the required emission standard, or redeploying vehicles with the appropriate emission standard from other locations.

3.3 Loading\unloading policies

With a given number of parking spaces available there exists a competition between passenger and freight parking needs. It is not uncommon that loading\unloading (l\u) bays are used by a car, temporarily or for longer spells of time, as a solution for missing car parking spaces. In Paris survey work has demonstrated that l\u bays are occupied by illegally parked vehicles for 47% of the time, are empty for 47% of the time and are used by goods vehicles for collections and deliveries for only 6% of the time (Mairie de

[14] With the Nominated Day Delivery System the delivery day predetermined either by the seller or by the buyer.

[15] The LEZ operates in London 24 hours a day, seven days a week, including weekends and public holidays.

Paris 2006, quoted by Browne et *al*. 2007). In Bologna Dezi et *al*. (2008) find that 14% of the goods vehicles parked legally (2% in private l\u bays, 7% in public l\u bays and 5% on available parking spaces) and 86% illegally. L\u bays in Bologna are deemed insufficient. When goods vehicles drivers are asked why they did not make use of loading bays, 8% say because it was used by other goods vehicles, 6% because too far, 29% because not existing and 57% because occupied illegally by cars.

Signalling and enforcement is hence an important issue to solve. City authorities need to determine how many l\u bays to make available for freight distribution and where and how exactly in the road to position them. The German city of Düsseldorf has experimented with some success the introduction of differentiated bays for smaller and larger trucks, the use of special signals and road marks, and positioning the bay after a bus stop or just before a turning street (VCD, 2006).

The practice of regulating goods loading and unloading in Paris and London is discussed in detail by Browne et *al*. (2007). Loading bays need both to be protected and strictly regulated in theirs use. In London a Code of Practice has been jointly developed by a wide range of stakeholders that includes Transport for London, London boroughs, trade associations and companies 'to promote best practice amongst business, local authorities and parking enforcement contractors to find effective solutions where loading/unloading is an ongoing problem' (FTA 2006).

Although carriers are the more affected by the difficulties in l\u because of the longer l\u times, receivers are indirectly affected as well. Marcucci and Danielis (2008) estimated via a stated preference study that the distance from the l\u bay is a relevant factor in choosing the distribution technique. An increase in the l\u bay distance from the shop from 0 to 100 metres for own account users is estimated to have a large increase (from 25% to 75%) on the probability of using an urban distribution centre and having the good delivered by a third-party.

3.4 Fiscal policies

Fiscal policies comprise both taxes and subsidies. Taxes could be imposed as congestion charges or area licensing and can be defined accordingly to vehicle type (load factor, size, Euro emission standard), and/or to time window.

There are a few examples of congestion pricing in European cities (London, Stockholm, Milan) involving urban freight transport. In London a goods vehicle which enters the congestion charging areas pays a fee equal to £7. There has been a debated whether to ask goods vehicles to pay more or less than cars. Eventually, it was decided to make them pay the same amount.

In Milan, vehicles are charged according to their Euro emission standard. Goods vehicles Euro 0, 1 and 2 are charged €10 and diesel-fuelled goods vehicles Euro 3 are charged €5. Rotaris et. al. (2009) estimate that in Milan freight transport carries a large share of the tax burden ("13% of the vehicles pay 42% of the charge", p. 10). A cost-benefit analysis shows that freight transport is a net looser since the tax it pays is larger than the benefits it gets from congestion reduction.

In Italy, area licensing is quite differentiated among cities and according to fuel type and third-party versus own account transport, as reported in table 2.

Table 2: Regulation to enter the LTZ for goods distribution.

City	*Own-account*		*Third-party*	
	Patrol- or diesel fuelled vehicles	Low emission vehicles (electric, LPG, methane)	Patrol- or diesel fuelled vehicles	Low emission vehicles (electric, LPG, methane)
Reggio Emilia	309.87 €/year If parking in I\U bays in allowed times	Free-of-charge: electric vehicles	309.87 €/year If parking in I\U bays in allowed times	Free-of-charge: electric vehicles
Parma	30 €/month	Free-of-charge: electric vehicles	30 €/month	Free-of-charge: electric vehicles
Ferrara	100 €/year 2 hours a day	20 €/year 2 hours a day	50 €/year 7 hours a day	10 €/year 11 hours a day
Cesena	155 €/year Free during the time windows	Free-of-charge	155 €/year Free during the time windows	Free-of-charge
Rome	565 €/year Unless transporting: medicines, perishables, valuables, printed matter	Electric vehicles: 300 €/year methane, LPG: 432 €/year	565 €/year Unless transporting: medicines, perishables, valuables, printed matter Free during the time windows	Electric vehicles: 300 €/year methane, LPG: 432 €/year Free during the time windows
Florence	90 €/year, no time limits if located within the LTZ 65 €/year, if located within the LTZ limited to 2.5 hours a day	Free-of-charge: electric vehicles	90 €/year, no time limits	Free-of-charge: electric vehicles

Fonte: PROGETTO CITY PORTS Rapporto Intermedio (2005)

The rational for such a differentiation is not completely clear and it is probably based more on political compromise than on economic or efficiency improving reasons.

An important issue with fiscal policies is who bears the cost. The carriers who pay the charge or are they able to pass it on along the supply chain to the retailer\consumer or producer? McKinnon (2006) reports that according to a survey commissioned by the German government after the first 6 months of the German heavy goods vehicles tax (the Maut) the vast majority of hauliers had been able to pass on most of the toll to shippers. Many have had difficulty, however, recovering the tolls incurred on empty journeys, which in intercity freight transport represent, on average, 11% of autobahn truck trips. He also states that the hauliers' ability depends on whether the carriers carry less-than-truck load (LTL) or truck-load (TL).

Not much is yet known on the effects of charging. Tokyo Metropolitan Government conducted a survey to interview managers of trucking firms. It resulted that both small and large commercial trucks would reduce truck use. This would be achieved with more efficient fleet management and co-operative delivery system. It also resulted that road pricing would affect private (own account) trucks with relatively low loading factors more significantly. It implies that cargo would shift from private trucks to commercial (third-party) ones to some extent (Browne, 2004).

As it appears, affected the most by congestion are the supply chains with cross-dock policies, JIT arrangements (fresh products, pharmaceutical products), small inventory, lean production, booking-in systems. More efficient supply chains, hence, are more affected by congestion. According to Holguin-Veras (2006, p. 6), for-hire carriers are less sensitive to tolls because they have less flexibility to change time of delivery, hence, they cannot avoid to pay the toll.[16]

It is quite unlikely that fiscal policies could be the solution to freight management demand in urban areas, although it could be part of the solution. The key reason - according to Holguin-Veras (2006, p. 1) - is "that the price signal reaching the receivers is too weak to be effective" and that there exist "market imperfections of various kinds, contractual constraints, and, more importantly, interactions between agents that dampen the effectiveness of the price signals.".

3.5 Urban transhipment and consolidation centres

The introduction of urban transhipment and consolidation centres (UTCC) is an appealing policy aiming at changing the quantity and quality of deliveries. Many cities, mainly in continental Europe (Germany, The Netherlands, France, and more recently, Italy) have conducted studies, trials and experimented specific schemes. In 2008 the Italian government financed 4.8 million euro UTCC schemes in the Italian cities of 18 Italian cities. Yet, their results have been so far disappointing. Only in few cases the UTCCs survived financially without public subsidies or strong political commitment.

Woodburn, A. (2005) argues that UTCCs suffer from: a) lack of clarity of definition and scope, b) little overall analysis of factors contributing to success or failure, particularly from supply chain perspective, c) lack of evidence-based information about scheme viability which requires more evaluation in order to establish what actually works.

McKinnon (1999), examining the case of urban transshipment, finds that the term transshipment is rather vague. In fact, it can involve both disaggregation and consolidation of straight transfer of loads. He claims that the disaggregated/break-bulk form of transshipment would be costly and yield questionable environmental benefit, particularly if combined with tight vehicle size/weight restrictions. A much stronger economic and environmental case can be made for the consolidation of loads, even where this involves the use of larger/heavier vehicles. He also states that it would be difficult to justify investment in new transshipment depots, because (1) there are already in and around urban areas large amounts of distribution/warehouse space that could be more effectively used for break-bulk/consolidation operations and (2) it would be difficult for them to generate sufficient traffic to operate viably.

The more convincing success story is the Excel UTCC at Heathrow. It opened April 2001 with a 25000 square feet warehouse on the south east perimeter of the airport. It is characterized by multi-temperature operation, operational 24 hours per day, 7 days per week, 365 days of the year. It consists of 8 delivery areas (Landside and Airside in 4

[16] In a survey, Holguin-Veras (2006, p. 7) find that "72.3% of for-hire carriers cited cannot change schedule due to customer requirements while approximately 61% of private carriers reported the same reason. It was also found that a larger proportion of for-hire carriers (21.2%) transferred costs to their customers, compared to 16.3% for private carriers.".

terminals), a “Shuttle” based delivery schedule with fixed timetable, visiting each delivery area 4 times per day. Returns service is offered as part of the overall service. It includes cardboard collection and recycling service and delivery is made direct to store and unloaded into stockroom. According to (Foster, 2005), it is advantageous both for the British Airways Authority, for retailers, for suppliers and for the environment[17]. Financially, it turned out to be a success due to large volume that creates a critical mass for efficient operations and the old design of the airport which results in small space available. Furthermore British Airways Airport controls the airport area and it is therefore easy for them to impose the logistic scheme. With consolidated deliveries and pickups much less space and much less loading bays are needed (8 instead of 64). The cost is shared by three parties. Firstly, retailers make contribution to the construction. Secondly, retailers pay additional money for any special service they want. Thirdly, British Airways Airport got subsides from government. The cost is not the construction cost but also the management cost.

The relevant question is whether this success story can be transferred to ‘off-airport’ practices such as city center.

Dablanc (2005) discussing the French experience with UTCCs underlines that one of the difficulties is financial: UTCCs need high subsidies from municipalities. For instance, in La Rochelle the production costs are estimated to be 3.8€/parcel whereas price asked to UTCC users is 1.7€ (2001). Similarly, in Monaco the production costs is 3€ (2002) and the price asked to customers: 2.30 €/100 Kg, Monaco Logistique receiving 2.59 €/100 Kg as a subsidy.

Furthermore, according to Dablanc (2005) transport companies are reluctant to use them, their official reason is the fear of unequal competition, but they also consider UTCC prices too high (see example of Basel below) and prefer to continue to subcontract transport to small transport companies. This is also the results of the fact that municipalities do not enforce strict traffic/delivery regulations.

Other explanations to UTCCs failures listed by Dablanc (2005) are that: a) shipments to a city are extremely diverse (from small parcel to full load, from bulk to expensive manufactured goods), b) a delivery implies many more tasks and skills than a simple act of transport (administration, commercial, packaging, etc.), c) urban delivery is just one

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[17] According to Foster (2005), it enables British Airways Airport to meet its commitments regarding T5 with an expected reduction in delivery vehicles of 70% and it will provide improved security in the supply chain with pre-booked receipt from known suppliers and X-Ray Scanned deliveries to controlled areas. In-terminal operations will also benefit since there is greater control of airside vehicle movements, minimal delivery equipment left at stores or bays, and reduction in airside/landside security screening for deliveries.

Retailers gain because of the more reliable supply chain, improved staff planning and productivity, improved product availability, increased delivery frequency, drip feed manageable amounts rather than single bulk delivery, added value services, remote stock rooms (either self managed or Exel managed), pre-retailing of goods before delivery and collection of waste cardboard and plastic (processed for recycling by Exel at the Heathrow UTCC).

Suppliers gains since the CC enables a new approach to serving Heathrow, moving from multi drop, manual handling, vehicle size restrictions, airside security, delays at loading bays, delays waiting for store staff to single point of delivery, mechanized receipt, no vehicle restrictions, off airport delivery, delivery window at Heathrow UTCC, immediate off loading and checking.

The environment is also going to gain thanks to the reduction of vehicle movements in and around the airport, improved air quality, reduction of CO2 and effects on wider environment, reduction in NOX and PM10 affecting local environment, reduction in noise pollution, use of alternatively fuelled vehicles (LPG, CNG or Electric) and reduction in congestion levels due to easier access and maneuverability around airport for other users.

part of a global transport chain which has to be mastered at commercial, financial, and technical levels. Tracking from A to Z is an absolute requirement. As a result UTCCs may then be limited to some specific cities: 1) cities wanting to set an example (and ready to pay the price for it), such as La Rochelle's promotion of electric vehicles, 2) touristic cities or cities with a highly sensitive historic centre, 3) cities located apart from the main traffic flows and deprived of private transshipment facilities.

In Italy there are examples of active UTCCs in several Italian cities. Among these the one of Padua is particularly interesting because it is in operation since 2004 and has proven to be financially sustainable and successful in reducing adverse environmental emissions. The main factors determining its success are that it results from an agreement among the main local public authorities and business associations[18], it is hosted in a pre-existing intermodal infrastructure, the majority of transport operators accepted to use the UTCC to deliver their goods in the city center and its low emission vehicles are exempted from time window restrictions and can use reserved bus lanes.

A very relevant issue is which supply chain could take advantage of the services provided by a UTCC. The empirical evidence is scattered. A detailed feasibility study performed for the city of Mestre, Italy (near Venice) evaluating the possibility to adopt a UTCC scheme similar to Padua, concludes that they are likely to be clothing, specialised retails and dry food[19]. In the Bristol VIVALDI Project Experience in the UK it is found that the goods using the UTCC were of medium size, non-perishable, and not of high value[20] (Hapgood, 2005). In a stated-preference survey study performed in the Italian cities of Fano and Pescara, Marcucci and Danielis (2008) find that clothing and other specialised goods other than food are most likely to accept to use the UTCC, while Ho.Re.Ca is more unlikely to use it.

4. Impact of urban freight policies on distribution channels

In this section we will combine what we have learnt in the previous sections to derive some tentative conclusions about the likely impacts of urban distribution policies on the distribution channels localized within city centres. A summary of the main conclusions is reported in Table 3 where the policies, the main general impact, the relevant factors

[18] The founding members are: Commune of Padua, Chamber of Commerce, Interporto Spa, Province of Pausa, APS Holding Spa- Divisione Mobilità (www.cityporto.it).

[19] Translating from Italian to English, the study of the Comune di Venezia (2008a) concludes that: the largest part of "specialised" food (fruit and vegetable, fish, meet) retailers buy directly using own-account transport from the city markets (*mercati generali*); most Ho.Re.Ca retailers, particularly bars, buy directly from cash&carry shops; high-value product stores (jewellery and watches) would not use a UTCC for safety reasons; pharmacies have their own, fast and efficient distribution channel; tobacco stores are organized in a consortium; larger retail stores are supplied by regional warehouses with their own vehicles; furniture stores have size constraints.

[20] Retailers Involved in Bristol are: Lush –Cosmetics; Tie Rack –Men's Fashion; Accessorize –Fashion Accessories; Monsoon –Women's Fashion; Motaman–Car Accessories & Parts; Mastershoe x2 –Footwear ; Past Times –Gifts, household goods; Evolution –Gifts, household goods; Dulay –Men's & Women's Fashion; Kathies Comics –Comics, Magazines ; Paul Richards –Men's Fashion; Art –Art Work, Supplies; Virgin Megastore –Music & Entertainment goods; Virgin Express –Music & Entertainment goods; Carphone Warehouse x4 –Mobile Phones; Vodafone x2 –Mobile Phones

which determine the specific impact and the specific impacts on the distribution channels are summarized.

Access times restrictions, very frequently used in practice, aim at limiting the use of road space to trucks in favour of passenger traffic and the liveability of the city. Since this policy implies a reduction of the time available for delivery, it imposes an additional constraint in the search of a solution to the carriers' routing optimization problem. The impact of access time restrictions on own account carriers is likely to be marginal since they perform a single origin-destination trip (e.g., from the general fruit and vegetables market to their shop) often outside the restricted time windows. On the contrary, third party carriers have to solve a more difficult routing optimization problem, often with multiple origin-destination points, spread all along the working time and on geographically distant shops. Hence, an additional constraint is likely to impose large adjustment costs, generate suboptimal routing, decrease load factors and require larger fleets and a larger number of lorry drivers. Large retail organisation are an intermediate case between own-account and third-party operators. A further element to be taken into account when examining the impact of access times restrictions is the existence of self-implied times windows which depend on the nature of the product or the characteristics of the retail organization. Finally, the distance between shops determines the overall delivery times and costs.

Turning to the impacts on the above identified distribution channels, one observes that pharmaceutical products although distributed by third-party carriers using multi-drop routing are, in practice, exempted from this restriction, hence, they suffer no impact. With regard to fresh food, some products (especially meat and milk) are distributed by third-party carriers using multi-drop routing practices, whereas others (such as non-industrial fish, fruit&vegetables) are procured via own-account transport. If the former can not adjust to the time window regulation by developing an early schedule in non-restricted times because of self-implied time-window constraints, the impact is likely to be relevant. Some segments of Ho.Re.Ca. are impacted when supplied by third-party carriers or wholesalers. Lastly, clothing&footwear will bear only marginal effects since deliveries are less frequent and mostly single-drop. Both Ho.Re.Ca. and clothing&footwear might have self-implied time windows because of staff constraints.

Vehicle restrictions, either by weight, engine type or load factor, aim at containing the environmental and congestion externalities. They cause an increase in fleet size, and an accelerated fleet renewal rate. Larger companies are likely to be able to cope with this policy better than small firms or own-account carriers. The most affected distribution channels are those which require large quantities and frequent deliveries. Pharmaceutical products are delivered frequently but by small vehicles, since the size of the parcels is generally small. Moreover, they are typically exempted from this regulation, hence they are not affected. On the contrary, fresh food, being characterised both by large quantities and frequent deliveries are highly affected, especially when distributed via Large Retail Organization (LRO), because of the weight restrictions, and via own account, because of the engine type restrictions. Ho.Re.Ca. requires less frequent deliveries and small to medium quantities. Hence, it should suffer relatively less the impact of this policy, although procurement takes often place by own-account transport. Clothing&footwear involves unfrequent deliveries, seasonal large quantities and small replenishment deliveries. Hence, it is only marginally impacted. A potential side effect is on the size of the consignments, probably reduced in order to be transported with smaller vehicles.

Table 3: Urban freight policies and distribution channels: general impacts, relevant factors, specific impacts.

Policies	General Impacts	Relevant factors	Expected impacts on distribution channels (DC)
Access-time restrictions	- reduction of time available for delivery - more vehicles needed - more lorry drivers needed - suboptimal routing - decreased load factor	- third-party vs. own account - multi-drop vs. single drop - self-implied time windows - delivery frequency - distance from the shops	- no impact on pharmaceutical products DC since exempted - heavy impact on fresh food DC with the exception of fruit and vegetables stores with own-account procurement - impact on some segments of Ho.Re.Ca DC - marginal effects on clothing&footwear DC
Vehicle restrictions (weight, engine type)	- fleet size - fleet renewal rate	- third-party vs. own account - carrier size - delivery size	- no impact on pharmaceutical products DC since exempted - heavy impact on fresh food DC when distributed via large retail organizations (weight) or via own-account (engine type) - impact on Ho.Re.Ca DC when supplied via own-account - impact on the drop size of clothing&footwear DC
L\U policies	- consignment costs and times	- delivery frequency - delivery size - existence of l/u private facilities	- potential impact on pharmaceutical products DC since deliveries are frequent but require short l/u times - high impact on fresh food DC since deliveries are frequent and require medium/long l/u times - small impact on Ho.Re.Ca. DC since deliveries are less frequent with short/medium l/u times - small impact on clothing&footwear DC since deliveries are occasionally large with large l/u times, more frequently small with short l/u times
Fiscal policies	- consignment costs and times - multi-dropping routing - loading factors	- consignment frequency - third-party vs. own account - TL vs. LTL - goods value	- no impact on pharmaceutical products DC since exempted - small impact on fresh food DC since they require frequent deliveries - high impact on Ho.Re.Ca. DC and clothing&footwear DC especially for occasional deliveries performed via own-account
UTCC	- consignment costs and time - consignment consolidation - use of more environmentally friendly vehicles	- existing regulation - physical characteristics of the good - third-party vs. own account - logistics coordinator	- no impact on pharmaceutical products DC since it is not compatible - no impact on fresh food DC since it is not compatible - potential impact on clothing&footwear DC for occasional orders - potential impact on Ho.Re.Ca DC for non perishable products

Urban goods distribution needs proper spaces for l\u activities. Unless a shop has its own private, internal l\u bay, it relies on off-street or on- street parking spaces. This generates a conflict with the parking needs for passenger cars, highly requested in central areas. The aim of l\u policies is, hence, both to regulate the loading bay use among truck users and to prevent private cars to use the l\u bays. L\u policies affect substantially consignment costs and times. The actual practise of irregular on-street parking contains the carrier costs and times but generates high congestion costs. The provision of a larger number of l\u bays and their effective enforcement would probably leave unchanged or slightly increase the private costs and times, but certainly reduce social costs. Pharmaceutical products are frequently delivered but require short l\u times since the parcels are typically small, hence, the impact of a l\u regulation is likely to be modest. On the contrary, fresh food is highly impacted since it is frequently delivered, and requires medium\large l\u times. Most shops located in city centres do not have internal bays for l\u activities, with the exception of large retail organizations that generally have personnel dedicated to stock management activities. Ho.Re.Ca. products are less frequently supplied with medium l\u times, hence, the impact of a l\u regulation is likely to be small. Clothing&footwear stores are occasionally supplied in large quantities for seasonal orders and require large l\u times. More frequently, though, they are supplied in small quantities with short l\u times.

Fiscal policies, either in the form of congestion toll or, more frequently, area licensing fees, are used in some cities to regulate access to central areas. They aim to internalize congestion costs and to achieve an optimal congestion level. Fiscal policies should also induce an increase in load factors and multi-drop deliveries. As a result social efficiency of the overall transport system should be achieved. Congestion tolls affect negatively consignment costs, unless the value of the time saved is higher than the fare. This might happen when the value the goods transported is high. Area licensing fees are not proportional to the number of daily access entries, hence, the higher is the daily consignment frequency the lower will be the per-trip cost. The delivery costs of own-account carries are more impacted by fees than those of third-party carries since their load factors are lower. Finally, according to the literature (McKinnon, 2006), the cost of the fiscal policy can be more easily shifted from carriers to retailers when consignments are less-than-truck load.

Examining the impact of fiscal policies on distribution channels, one observes that, again, pharmaceutical products are generally exempted. With reference to fresh food, when a area licensing fee is applied, the impact on fresh food delivery costs is likely to be small since they are characterized by frequent deliveries of large quantities. On the contrary, the impact on the Ho.Re.Ca. and clothing&footwear delivery costs are likely to be relatively higher, since they have less frequent consignments made mostly via own-account. However, the final effect on goods prices paid by final consumers is uncertain, as well as the effect on land rents since they depend on the characteristics of the specific markets. As McKinnon stated (2006), fiscal policies produce most likely small effects, at least in the short run, on strategical and commercial decisions, while they might have some effect on the tactical and operational ones.

The development of a UTCC aims at optimizing the consolidation and routing patterns of the existing distribution channels and at using less polluting vehicles. Since it introduces an extra node in the distribution channel which imposes extra logistics costs, own account or third-party operators or the logistics coordinator of the distribution channel might not be willing to use it. The actual urban goods distribution regulation may obviously influence the decision favouring the use of UTCC vehicles against all other non- UTCC vehicles (see the case of Vicenza). Given the previous discussion we believe that pharmaceutical products and fresh food will not make use of a UTCC, since the specific characteristics of the goods distributed require dedicated and integrated channels and infrastructures, strong logistics coordination, and fast and frequent deliveries. On the contrary, clothing&footwear and Ho.Re.Ca, especially when supplied via own-account, might accept to use a UTCC: clothing&footwear for occasional replenishment orders, and Ho.Re.Ca for goods other-than-fresh food.

5. Conclusions and further research needs

Several researchers have argued that the impact of the commonly implemented urban distribution policies is likely to be differentiated by type of goods and distribution channels. However, so far, there is no clear understanding of how and why this happens, nor have these impacts been described in detail or measured empirically.

This paper has confronted this issue, firstly, by identifying the main features that chracterise a distribution channel. Then, it has selected four type of goods frequently distributed in Italian urban centres: fresh food, Ho.Re.Ca., pharmaceutical products, and clothing&footwear. For each type of good, the main features of their distribution channels have been quantified and described.

Based on the theoretical and empirical literature, five urban distribution policies (goods vehicle access-time and vehicle type restrictions, l\u policies, fiscal policies and the promotion of urban transhipment and consolidation centres) have been reviewed.

Finally, the likely effects of the policies on the distribution channels of the identified five types of goods have been discussed at a speculative level and on the basis of the evidence presented in the literature.

The statement that policies have differentiated impacts by type of goods and distribution channels is confirmed. It is found, in general terms, that the distribution of pharmaceutical products is little impacted by urban freight policies, whereas the other products are more impacted. Specifically, fresh food is mostly affected by access-time restrictions, vehicle restrictions and l\u policies, whereas Ho.Re.Ca and clothing&footwear are mostly affected by fiscal policies and by the promotion of urban transhipment and consolidation centres.

Moreover, the paper has stressed the role played by some crucial features of the distribution channels in determining the final impact. They are listed in the "Relevant factors" column of Table 3. They relate to the good (physical characteristics and monetary value), to the geographical location of the shops (distance between shops), to the institutional arrangement of the transport operations (third-party vs. own-account, and carrier size), to the transport and logistics organization (multi-drop vs. single-drop delivery, delivery frequency and size, TL vs LTL, existence of l/u private facilities, existence of a logistics coordinator), and to the existing regulation.

The above analyis can be useful in two respects: a) in policy modelling since it provides a list of the variables and factors which need to be taken into account in order to forecast or simulate the effect of policy measures, and b) in applied studies since it provides a set of hypothesis which can be further explored and tested with actual data.

The above discussion could also be used in the contest of the evaluation of the private and social benefits and costs of alternative policy measures.

In taking the analysis further, one should be aware that distribution channels evolve continuously: retailers re-localize from the city centres to more suburban areas reacting to consumers and traffic needs; space and transport intensive channels move to peripherical locations; large shopping centres are created outside the urban areas changing the competitive environment; and large retail organizations, characterized by highly efficient supply and distribution channels, substitute small traditional stores. Hence, in order to further explore the impacts of a policy, it is crucial to have a continuously updated map of the urban retailing system, of its distribution channels and of the resulting freight flows. Not enough information is available so far, at least in Italy.

Furthermore, distribution channels comprise many actors (producers, intermediaries, producer organizations, wholesalers, carriers, retailers' organizations, retailers, consumers) who play a very different role within a channel. The role played by each actor and the interaction among them should be better understood. For instance, it would be important to discover if and which actor plays the role of coordinator. Discrete choice models can be of help at this regard (Hensher and Puckett, 2005; Holguín-Veras, 2006, 2007, 2008; Marcucci et *al*., 2007).

Finally, there is the question of which policy or policies mix should be applied to improve urban distribution channels and the city transport and welfare. To answer this question a detailed, city-specific cost-benefit analysis, encompassing private and social costs and benefits in the short and long run, is needed. On the basis of this paper, there is no single catch-all policy but policies complement each other since they differently affect different distribution channels. In Italy, great hopes and public money are currently put in the promotion of UTCCs. On the basis of our analysis, such hopes are probably in excess of what the policy can actually deliver, whereas less attention is devoted to the potential of the other types of policies.

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