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Optimization of the FURBOT urban freight transport scheme

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Abstract

The paper refers to an innovative urban freight distribution scheme, aimed at reducing the externalities connected with the freight delivery process. Both packages destined to commercial activities and to end consumers (e-commerce) are taken into account. Each package is characterized by an address and dimensions. In the proposed transport system, freight is firstly delivered to the urban distribution centre on the border of urban areas through trucks or trains which perform the long distance transport. After, freight is reorganized and consolidated into special load units (FURBOT boxes), according to packages dimensions and to the addresses of receivers. Each box is addressed to a temporary unloading bay and it is delivered there by a smalllelectrically powered vehicle (FURBOT vehicle).
The paper concerns a methodology for optimizing this freight transport system's performances. The input data are the actual freight demand, the road network and the public policies. The methodology determines the best number of FURBOT boxes which minimizes the system cost. The overall cost is a sum of the users cost, which depends on the distance they have to walk for collecting their packages in the FURBOT box, and of the operator cost, which depends on the number of boxes, and the total distance travelled by the FURBOT vehicles. The minimization problem has been approached by a Simulated Annealing procedure. The methodology recalls two sub-problems: a first sub-problem to determine the optimum clustering of packages in the FURBOT boxes, and a second sub problem to determine the best routing of FURBOT vehicles. The methodology has been applied to the case study of Genoa city centre, Italy.

Keywords: Urban freight distribution; Optimization; Simulated Annealing; Clustering; Capacitated Vehicle Routing

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1. Introduction

This paper concerns freight distribution in urban areas. Freight is addressed to consumers and to commercial activities. The problems related to this issue are well known and regard pollution and traffic congestion due to high vehicular flows, low loading factors, empty return trips, and pollutant vehicles. Moreover often the freight addressed to consumers cannot be delivered because the receiver is not at home (or where the package is addressed) at the delivery time: this adds useless freight trips. An overview of the main problems related to urban freight distribution and of city logistics measures is provided in Dablanc (2007), Filippi et al. (2010), Russo and Comi (2010).

These problems related to urban freight distribution are going to increase in the future because: urbanization will bring more consumers in urban areas; and more freight will be addressed to consumers since e-commerce is quickly increasing and this growth trend is expected to continue.

Several projects on best practices of freight deliveries in urban areas have been already developed. These projects are mainly focused on studying policies, governance's measures and best practices rules, and on the impacts related to the application of them on the field. Some most important projects are: BESTUFS, BESTFACT, CEDM, BESTLOG, FREILOT, SUGAR, ENCLOSE, CIVITAS Caravel and MERCI. Several of these projects have also physically settled these facilities and measures on the field.

All these projects are based on the usage of the UDC (Urban Distribution Centre) where transhipment is performed from large trucks (or trains), which perform the long distance distribution, to small vans, which perform the last mile distribution. However, in practice often deliveries are performed directly from the production site to consumption sites, without the usage of the UDC, through medium sized vans. Or the major transport operators make use of their own logistic platform. This increases the number of useless freight trips. Therefore solutions aimed at increasing the usage of UDCs are desirable.

A new trend is the concentration of packages directed to customers into a few localizations, therefore: no empty trips occur, as receivers have a time window to collect their packages, and the number of delivery trips is reduced, thanks to the reduction of the capillarity of the demand. The disadvantage is related to the distance the receivers have to travel for collecting their packages. This idea has been applied by DHL in Germany (Pack stations) and has been improved by the CityLog European project (www.city-log.eu). The proposed transport system, developed within the FURBOT (Freight Urban RoBOTic vehicles) project funded in FP7, has been studied according to this idea.

The main characteristics of the proposed transport system are provided in section 2. The optimization methodology of the proposed transport system is described in section 3. The optimization methodology has been applied to the case study of Genoa historical city centre. Conclusions follow.

2. The FURBOT transport system

The proposed FURBOT transport system is an innovative freight delivery system for urban areas.

Freight is firstly delivered by large trucks, from the production/consolidation sites to UDCs on the border of urban areas, in the form of packages or pallets. Packages could be sacks, cases, boxes, envelopes and so on.

While pallets usually are addressed only to commercial activities, packages could be addressed to both consumers and commercial activities. Each pallet is characterized by the commercial activity's address and each package is characterized by its dimension and the receiver's address.

At the UDC, freight is reorganized and consolidated into the FURBOT boxes, according to packages dimensions and to the addresses of receivers.

The FURBOT boxes are innovative load units of two types: LBL box and FBL box. Both FBL and LBL FURBOT boxes have a standard dimension: the box footprint has the euro-pallet dimension (120 cm long and 80 cm wide), and the box is 180 cm high. A representation of a FURBOT LBL box is provided in figure 1.

A FBL box contains freight destined to only one receiver, while a LBL box contains freight destined to several receivers. A LBL box is divided in modular parcels and each parcel can accommodate packages addressed to a given receiver. A FBL box instead contains an euro ISO pallet addressed to a given commercial activity place.

At the UDC, an unloading bay is assigned to each box. In the case of a FBL box, the unloading bay is the commercial activity place the pallet is addressed to. In the case of a LBL box, the unloading bay is a function of the addresses of the packages contained in it.

At the UDC, FURBOT vehicles are consolidated and a route is assigned to each vehicle: each FURBOT vehicle is able to carry two boxes. Boxes are loaded on vehicles, according to their unloading bays. Consolidated vehicles then perform the freight distribution in the urban area.

The FURBOT vehicle is small in size, it is ecological and allows the automatic unloading of boxes. According to the time at disposal for completing the freight distribution, each vehicle could perform more than one delivery trip.

A virtual key and the actual address of the LBL box's unloading bay will be communicated to all the receivers. The receivers are then in charge of collecting their packages. We assume that a receiver has to travel from the address of their package (for instance their home address) to the unloading bay where the LBL box containing it has been unloaded.

The automatic unloading of boxes saves time and operative costs related to personnel. Since the unloading bay is occupied by the box only if there is freight addressed to its location, also the land occupation is minimized and the bay can be allocated to different uses, when not required. The high loading factor of the FURBOT box will lead to a decrease in the number of trips for freight distribution in urban areas and in its impact on pollution.

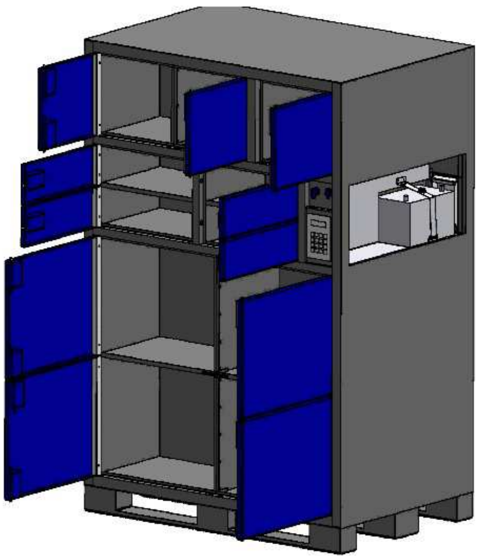

Fig. 1. A FURBOT LBL box.

3. The optimization of the FURBOT delivery system

The paper focuses on a methodology that allows to optimize the FURBOT delivery system in order to minimize the daily system cost.

Every day the proposed methodology allows to assess which are the number of LBL boxes (n_{LBL}^{*}), the fleet dimension n_v^{*}, the box consolidation and the vehicle routing that minimize the system cost, given the actual freight transport demand, the road network and the delivery time window (see figure 2).

Regarding the road network, we consider two networks: a footway network, and the FURBOT vehicles road network.

The footway network is constituted of: nodes representing the possible unloading bays and the receiver's addresses, and links connecting the receivers addresses to the unloading bays. A cost is associated to each link: it is proportional to the air line distance between the two nodes connected by the link. It therefore includes the paths travelled by receivers for collecting their packages.

The FURBOT road network consists on: the roads where FURBOT vehicles are allowed to travel, the localization of the UDC, the localization of the unloading bays. The road network is represented through a set of links and nodes. Each 100 meters long road section has been represented through a node. Nodes represent: the UDC, unloading bays and road intersections. Each portion of road comprised between two nodes is represented through a link. A cost is associated to each link, which is function of the slope, link length and average speed.

The freight transport demand is given by a matrix. The matrix rows refer to package dimensions and the columns refer to the road sections. Each element of the matrix represents the number of packages/pallets addressed to the destination road section the column refers to.

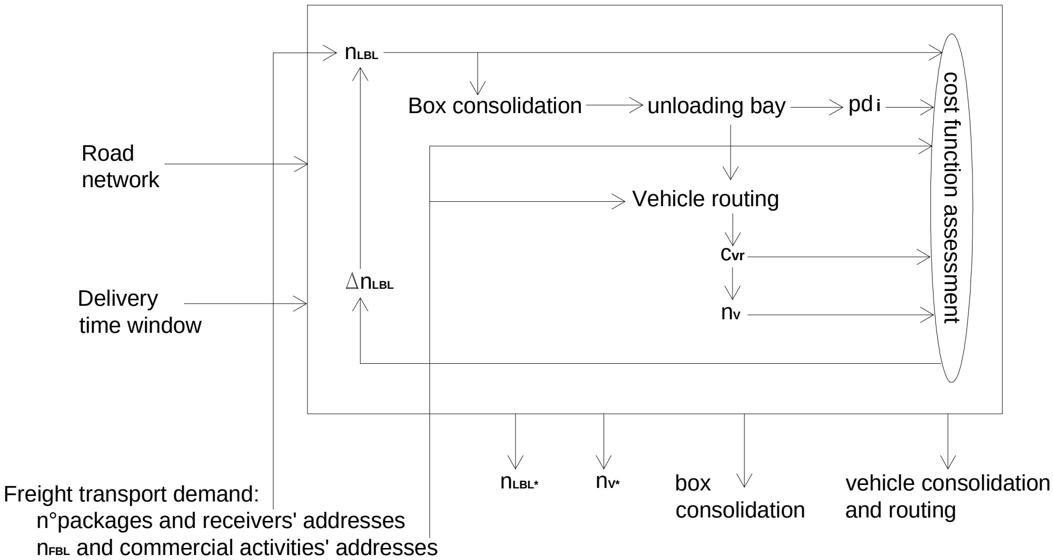

Fig. 2. The optimization methodology.

3.1. The cost function

The *daily system cost S* has two components: the user cost c_{user} and the operator cost $c_{operator}$:

$$S = \vartheta_{user} \cdot c_{user} + \vartheta_{operator} \cdot c_{operator} \tag{1}$$

where ϑ_{user} and $\vartheta_{operator}$ are weighting coefficients, to be calibrated. At this stage they have been assumed equal to 1.

The daily user cost c_{user} is a function of the overall distance travelled by receivers in a day to collect their packages at the unloading bays:

$$c_{user} = c_{pd} \cdot \sum_{i=1}^{d_{LBL}} pd_i \cdot v_{ped} \tag{2}$$

where:

- pd_i = walking distance covered by the i^{th} receiver: it depends on the position of the unloading bay where the package has been delivered, therefore on the number of LBL boxes (n_{LBL}) and on the box consolidation process;
- d_{LBL} = number of package receivers;
- v_{ped} = average pedestrian speed, equal to 1.1 m/s;
- c_{pd} = cost of an unit of walking time, assumed to be equal for all the receivers. It has been taken equal to that for public transport users, which, according to Shimamoto et al. (2010), is 0.36 €/min;

The daily operative cost $c_{operator}$ is a function of the overall distance travelled by FURBOT vehicles in a day, of the fleet dimension and of the number of LBL and FBL boxes. The daily operative cost has the following expression:

$$c_{operator} = c_{LBL} n_{LBL} + c_{FBL} n_{FBL} + c_v n_v + c_{km} q_{km} \tag{3}$$

where:

- c_{LBL} = daily operative cost of a LBL box;
- c_{FBL} = daily operative cost of a FBL box;
- n_{FBL} = number of FBL boxes: it equals the number of Euro ISO pallets that should be delivered in the simulated day;
- n_{LBL} = number of LBL boxes the system operator decides to use in the simulated day;
- c_v = daily cost of amortization of a FURBOT vehicle;
- n_v = number of required FURBOT vehicles: it depends on n_{LBL}, n_{FBL} and the time at disposal for completing the freight distribution;
- c_{km} = operative cost of running the fleet: it is function of the vehicle power consumption and therefore of the vehicle routing. The FURBOT vehicle consumes an average of 0.12 kWh for each km travelled; the average cost of the electricity in Italy is 0.17 €/kWh, which results in 0.021 €/km. Data about vehicles power consumption have been provided by Mazel Enginerios, the partners of the FURBOT project involved in the design of the power system of the FURBOT vehicle;
- q_{km} = the number of kilometers travelled by FURBOT vehicles each day.

As it concerns c_{LBL}, we assume that the purchase cost of each LBL box is equal to 800 € and the purchase cost of each FBL box is equal to 150 €. The LBL and FBL boxes lifetime is equal to 10 years. The cost of FURBOT vehicles has been assessed from an average cost of a similar electric van, which is around 25,000 €. The FURBOT vehicles lifetime has been assumed equal to 20 years.

All costs have been amortized according with the following formula:

$$C^{day} = n \cdot c \cdot \left[\frac{r(1+r)^{lt}}{(1+r)^{lt} - 1} \right] \frac{1}{365} \tag{4}$$

where:

- n is the number of elements (LBL boxes, FBL boxes, vehicles);
- c is each element purchase cost;
- r is the discount rate, equal to 8%;
- lt (number of years) is the element lifetime.

We chose a discount rate of 8% as it is an average rate of return for investments and thus reasonably represents the opportunity cost of the purchase.

The average fees of usage of the service do not appear in this formula, as they are contemporarily users costs and operator revenues, and therefore do not affect the daily system cost minimization.

3.2. The assessment of the cost function value

For a given n_{LBL}, the proposed methodology assesses the related system cost by sequentially *resolving two sub-problems* (as shown in figure 2).

The *first sub problem* optimizes the consolidation of freight in the FURBOT LBL boxes from which the users cost depends. Given a number *nLBL* of LBL boxes, the target is to find the sets of packages to load in each LBL box and to define the unloading bay for each box that minimizes the overall distance travelled by the receivers of the packages in the box. The problem constraints are: the capacity of the box, and the maximum distance that can be accepted by users. A fuzzy k-means clustering algorithm has been adopted. All details on this sub-problem, together with an application to a test network, are provided in Cepolina and Farina (2013).

The *second sub-problem* optimizes the delivery routes of FURBOT vehicles from which the operator cost depends. The FURBOT vehicle routing can be formalized as the Capacitated Vehicle Routing Problem (CVRP), with some modifications, and Genetic Algorithm is used to get the optimization solution. The output of the algorithm is the number of required FURBOT trips: for each FURBOT trip, the algorithm provides the identifications of the boxes that will be delivered in the trip, the travel time, the trip length and the energy consumption. Freight deliveries take place in a given time window: therefore the required FURBOT fleet dimension could be assessed given the travel times of the required FURBOT trips and the delivery time window. All details on this sub-problem are provided in Cepolina and Farina (2014).

According with the assessed value of the system cost, the proposed methodology explores the *search space, given by the* n_{LBL} *admissible values*, in order to minimize the daily system cost. The minimum admissible value of n_{LBL} is the minimum number of boxes capable to accommodate all packages. The maximum admissible value of n_{LBL} is determined in order to have an average load factor of LBL boxes greater than 0.3.

The overall *optimization output* is the number of LBL boxes that minimizes the daily system cost.

3.3. The exploration of the search space

The cost function independent variable is the scalar variable n_{LBL}. However, the cost function is composed of several terms, and each term has a different trend, therefore we cannot exclude to deal with a multi peak function. Moreover, the dependence of the system cost from the number of boxes is implicit, as it is calculated through the two optimization sub-problems. Therefore, a *Simulated Annealing* (SA) procedure has been chosen. Further details on the main characteristics of the SA scheme are provided in Cepolina and Farina (2012).

The main parameters of the SA algorithm are: the *cooling schedule*, and the *neighbor search* criterion.

The *cooling schedule* is defined by: the initial temperature, the law of its decrease and the final temperature. We fixed the cooling schedule in such a way to guarantee a good exploration of the search space. The starting temperature T_0 is determined according to Laarhoven and Aarts (1987), from an initial acceptance ratio p_0 of the worse solution equal to 0.5. The most commonly used temperature reduction function is geometric: $T_{k+1} = \alpha T_k$ where T_k and T_{k+1} are the temperatures in two consecutive iterations of the algorithm (Laarhoven and Aarts, 1987). α has been assumed equal to 0.9, according to Laarhoven and Aarts (1987).

Regarding the neighbor search, it has been chosen to adopt a *dynamic neighbor search*. Dynamic neighbourhood means that the neighbourhood dimension decreases step by step; the amount of this decrease is assessed as a functional relationship with the temperature's value at the current iteration of the algorithm (Yao, 1991). The most common functional dependencies are that the neighbourhood has either the dimension of the temperature or of the square root of the temperature. We chose a dynamic neighbor search because the overall procedure is very slow: dynamic neighbor search allows a wider exploration of the search space at the first iterations of the algorithm and faster convergence at a good solution at the last.

The proposed algorithm works as follows:

- *Starting solution*: the starting n_{LBL}, i.e. $n_{LBL,0}$, is assessed through a random extraction, in the range of the n_{LBL} admissible values.
- *First solution*: the i.e. $n_{LBL,1}$, is the midpoint of the widest between the two intervals: between $n_{LBL,0}$ and the minimum $n_{LBL}^{\min}$, between $n_{LBL,0}$ and the maximum $n_{LBL}^{\max}$. In this way on one hand we are sure of not exiting the admissible solution space, on the other hand we can ensure a good exploration of the search space.
- *Initialization of the algorithm*: given $n_{LBL,0}$ and $n_{LBL,1}$, we assess the initial temperature T_0. The dimension of the neighbourhood has been taken equal to the square root of the temperature.
- *Neighbour search*: At each step *k* of the algorithm the new solution is chosen in the following way:
  - given the current solution $n_{LBL,k}$, and the current temperature value T_k, the dimension of the move $\Delta n_{LBL,k}$ is taken equal to the square root of T_k;

   - the current solution $n_{LBL,k}$ is increased or decreased by $\Delta n_{LBL,k}$ with the probability of 50% if both moves are acceptable. Otherwise only the acceptable move is performed.
- *Stopping criterion*: The algorithm is stopped when no new solution is accepted for 100 consecutive steps. This criterion is a balance between the speed of convergence of the algorithm and the quality of the solution obtained.

4. Assumptions and limitations of the proposed approach

Three main assumptions have been made in the proposed approach.

The first assumption refers to the overall methodology: the optimization of the operative cost of the system is performed after the optimization of the users cost. More in detail, in our approach, at first the LBL boxes positions are determined according to the receivers addresses, in order to minimize the cost supported by them for collecting their freight. After, the FURBOT vehicle routing is optimized, according to the boxes positions determined at the previous step. This highly simplifies the problem but is quite a strong assumption, because the boxes positions determined according to the receivers addresses are not the optimum ones from the routing point of view.

The second assumption is that the reverse logistic is neglected. However, future work will be to consider the reverse logistic.

The third assumption refers to the battery discharge and recharge process of the FURBOT vehicle, which is not taken into account explicitly. It is assumed that the battery duration is sufficient for the vehicle to perform the most consuming delivery trip.

5. Application on the field

5.1. The procedure input data

The optimization procedure input data are:

- the freight transport demand;
- the Genoa road network:
   - position of the urban distribution centre;
   - the footways network;
   - number, localization and capacity of potential FURBOT unloading bays.
- the delivery time window.

The delivery time window is assumed: from 6 a.m. to 7:30 a.m, and from 9 a.m. to 12 a.m. It has been chosen not to perform deliveries in the morning peak period therefore: on one hand delivery trips do not increase their duration because of road congestion, on the other hand impedance to passenger cars because of FURBOT vehicles is avoided. Moreover, during the peak hour FURBOT vehicles can be put in charge.

Boxes can be placed only in correspondence of the FURBOT unloading bays and the number of boxes placed in each FURBOT bay must be below the bay capacity.

5.2. Genoa territory and the road network

The historical city centre of Genoa is the oldest part of the city and it is organized in several small roads of middle-aged origin. These roads are much narrow (they are often less than 2 metres wide) and steep, and are completely restricted to private traffic, except for only the residents. The extension of the area is only 1.2 km2, however, the population density is one of the highest in Europe: in the area live about 20000 inhabitants, subdivided in about 5000 buildings, and also the density of commercial activities is high: 2106 commercial activities are registered there. In this area, usually freight deliveries are performed through vans, but several retails are however not accessible by them. Therefore often vans are parked in some dedicated places and deliveries are completed through trolleys.

The urban distribution centre (UDC) has been placed besides the port, close to the highway gate, far about 1.5 km from the historical city centre and where the density of road infrastructures is high. A map of Genoa, together with the representation of the study area and the UDC localizations, is provided in figure 3.

FURBOT vehicles do not need any dedicated space for boxes unloading, since the operation is completely automatic and requires a very short time. Instead, unloading bays are needed to place the FURBOT boxes. On the whole, 33 places of Genoa historical city centre are suitable as potential FURBOT unloading bays, they are homogeneously distributed in the territory and are capable to accommodate on the whole 2800 FURBOT boxes. These places have been identified as potential unloading bays since they satisfy two requirements: can accommodate at least one box without disturbing pedestrian and/or vehicular flows and are accessible by the FURBOT vehicle.

Fig. 3. The Genoa area. The blue square provides the position of the UDC. The study area is contoured in red, the motorway exit is contoured through a blue circle

5.3. Genoa freight transport demand

The freight transport demand is not known but a reasonable estimation can be performed basing on local and national data bases. Target of the work is indeed to assess the performance of the transport system in the applicative case of study under different demand levels, therefore the input demand must be reasonable, but it does not have to be exactly determined. Both the demand directed to commercial activities and the demand directed to consumption zones (i.e. e-commerce) have been considered.

Data about the demand to commercial activities are reported in the section 5.3.1, and those about the demand to consumption zones (e-commerce) are reported in section 5.3.2.

5.3.1. The assessment of freight transport demand directed to commercial activities

Data are available from published case studies. According to CIVITAS Caravel, M.E.R.Ci. and Genova Eco, about 4700 deliveries per day are performed, and each delivery consists on the average on between 4.5 and 5 packages or pallets. 1303 freight vehicles enter each day in the historical city centre. The historical city centre is accessible from 12 controlled gates and 151 freight vehicles reserved areas are available (91 designed and 60 free).

According to a survey performed by the Assessorato Mobilità e Trasporti Emilia Romagna (2004), the mostly used package typologies are: pallet, box, case and sack. Their typical dimensions are:

- Pallet = 80 x 120 cm;
- Box = 80 x 120 x (120 or 200) cm;
- Case = 40 x 40 x 30 cm (these quantities are just indicative, cases dimension is extremely varied);
- Sack = 25 kg.

The table 1 shows their utilization in the different freight sectors.

Table 1. The typology of packages for each freight category. Data have been collected in the project CityPorts, for the case study of Bologna (Assessorato Mobilità e Trasporti Emilia Romagna, 2004).

Sector	pallet	heavy box	light box (case)	envelope	sack	looses
Fresh food	0%	37%	29%	22%	0%	12%
Dry food	0%	14%	45%	10%	25%	6%
Frozen food	0%	0%	33%	0%	33%	33%
Non food	15%	0%	47%	31%	3%	4%
Hanging garments	0%	0%	30%	21%	1%	48%
Catering	0%	6%	67%	10%	4%	14%
Total	4%	4%	41%	21%	5%	25%

5.3.2. The assessment of freight transport demand directed to consumption zones

Regarding e-commerce demand only a few data are available, which regard the whole Italian territory, and the related input freight transport demand has been extrapolated from them. The demand for e-commerce in Italy has been studied, from surveys performed by the Italian observatory for e-commerce of the Bocconi University of Milan (Osservatori.net). Data have been collected also from interviews to some important e-commerce operators, such as Privalia. We interviewed also the following shipping agencies that perform deliveries on national basis: TNT (ex Traco), GLS, Pagano, SDR, Poste Italiane (Italian Mail), Federal Express, BRT and DHL.

In year 2012, the Italian demand for e-commerce accounts for 17.6 million people older than 15 years; 8.2 millions habitually (i.e. at least once every three months) order goods on the internet, and 35.5 million orders have been performed on the web. Among them, 0.9 million orders regard grocery, 2.0 millions insurances, 4.5 millions electronics and computers, 5.5 millions clothes, 6.3 millions books and newspapers, and 16.3 millions tourism. The number of orders has grown by 15% from 2011, despite the economic crisis. In 2012, the average number of packages delivered in each order accounts for about 1.1 - 1.2, which results in an average of 76000 packages delivered each day (Source: Osservatori.net). Web shoppers are distributed in the Italian territory in these proportions: 33% north-west; 24.2 north-east; 22.1% central Italy; 12.4% south; 8.3% islands (year 2010 data, source: Osservatori.net).

Privalia has provided the following dimensions for their deliveries:

- Boxes (length x width x height):
  - 60x40x40 cm
  - 60x40x20 cm
  - 40x35x24.5 cm
  - 40x35x13 cm
  - 38x25x22 cm
  - 20x15x15 cm

- Plastic Bags (length x width x height): 37x47x5 cm

According to all these data we have estimated the demand for e-commerce in the scenario under study.

5.3.3. The total freight transport demand values and the optimization scenario

The total freight transport demand accounts for 22500 packages and 200 pallets, including sacks and heavy boxes. Packages could be classified in three classes (source: shipping companies websites) according to their dimensions: big packages have an average dimension of 0.0783 m^3, medium packages have an average dimension of 0.0426 m^3 and small packages have an average dimension of 0.0275 m^3. We assumed (source: shipping companies websites) that 40% of packages are big, 20% are medium and 40% are small. The total volume of the box is equal to 1.102 m^3. The optimization procedure has been applied with reference to a given day and the related freight demand. The demand has been randomly extracted: a dimension and an address for each package is randomly extracted according to a uniform distribution, whose average is coherent with the data collected.

In the following, we present the optimization results related to a given day. Boxes and packages addresses are shown in figure 4. The packages addresses related to the extracted transport demand for that day are marked as blue dots. Because of the high number of packages, only one dot is shown for each address, independently from the number of packages having that given address. FURBOT LBL boxes are represented in red. When several boxes are placed in the same FURBOT bay, only one red dot is shown. The width of the red dot is proportional to the number of boxes placed in the same FURBOT bay. In the x axis the longitude of points is reported, while in the y axis the latitude is shown. Both latitude and longitude are expressed in decimal degrees.

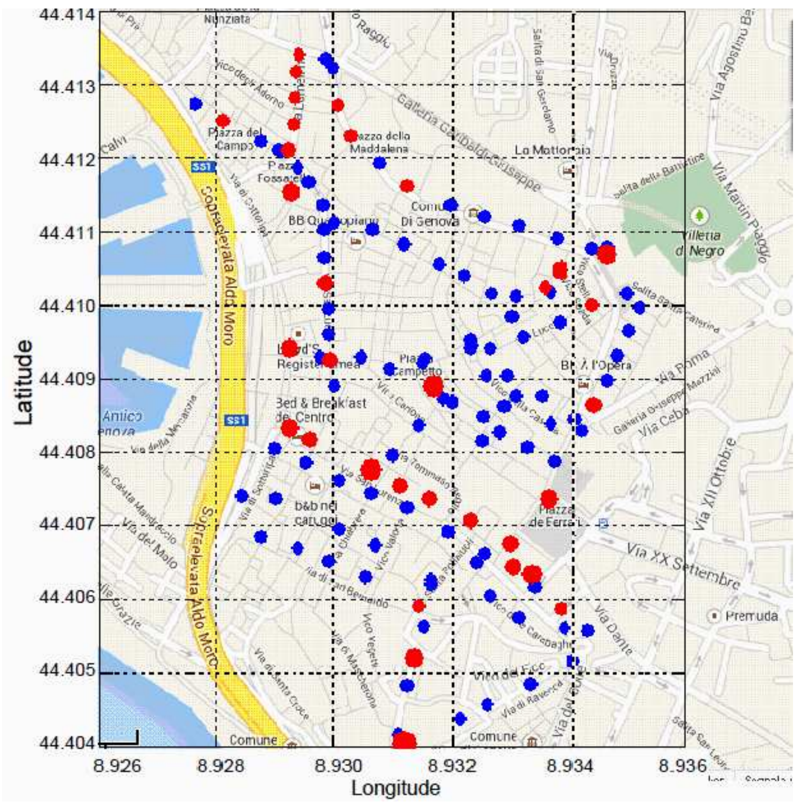

Fig. 4. Possible localization of FURBOT LBL and FBL boxes in the historical city centre of Genoa.

6. The optimization results and the performances of the FURBOT freight distribution

6.1. The results of the clustering

The optimization provides in output the final position of FURBOT boxes, the cluster of packages destined to each box, and the FURBOT system performances. The algorithm firstly provides an approximate position of each FBL box, and after corrects it by assigning the box to the closest available unloading bay. Actually each bay has a given capacity which is equal to the maximum number of boxes that can be accommodated there. If a bay is full, the remaining boxes assigned to this bay must be placed in the other neighbour bays. The final clustering of packages is performed by considering the boxes final positions.

On the whole, 1195 LBL boxes resulted the best number to satisfy the freight transport demand. These boxes are accommodated in 33 FURBOT unloading bays. All unloading bays have accommodated at least one FURBOT LBL box.

The system performances are expressed in terms of: the average load factor of LBL boxes, the maximum and the average distances walked by customers to collect their packages and the reduction in the number of trips necessary to perform the delivery operations.

The average load factor of FURBOT boxes is equal to 93%. Because the load factor of FURBOT vehicles is always equal to 1 as they always carry two boxes (despite obviously the last journey in which only the remaining box is carried), it is the boxes load factor that should be compared with that of vans currently performing freight distribution in Genoa city centre. According to Contursi (2004), these vans load factor is equal to 65%. As a result, the FURBOT system highly improves the freight delivery in the considered scenario, for the assessed freight demand.

The space occupancy of FURBOT boxes is also acceptable. Indeed, 1195 boxes must be accommodated. On the average, assuming that a freight vehicle dedicated space is about 5 m long and 2.5 m wide, each freight vehicles' unloading bay theoretically can accommodate 8 FURBOT boxes, leaving on the two sides of the box enough space to allow customers to collect their packages. Therefore, the space occupancy of all FURBOT boxes is theoretically the same as the space currently occupied by the existing 150 freight vehicle dedicated spaces. But, because of their small dimensions, FURBOT boxes can be placed also in several spaces, such as on footways or other narrow spaces, where parking freight vans is impossible. Moreover, no further space is needed for the unloading operation of FURBOT vehicles.

The maximum distance walked by customers is equal to 362 m, which is beyond the constraint (450 m); the average walking distance is equal to 24.72 m.

6.2. The results of the routing

The optimum number of delivery trips is 698. The total kilometers travelled each day are 4925.3 km. The maximum trip length is equal to 12 km and the average trip length is 7.0 km. The average trip duration is equal to 40 minutes. The trip duration comprises also the time required for loading and unloading the vehicle: it is fixed and equal to 2-3 minutes for each box.

The delivery time window is assumed: from 6 a.m. to 7:30 a.m, and from 9 a.m. to 12 a.m. It has been chosen not to perform deliveries in the morning peak period therefore: on one hand delivery trips do not increase their duration because of road congestion, on the other hand impedance to passenger cars because of FURBOT vehicles is avoided. Moreover, during the peak hour FURBOT vehicles can be put in charge at the UDC. Given the delivery time window, each vehicle should perform an average number of trips equal to 6.5. Therefore at least 108 FURBOT vehicles are required to perform the deliveries.

The number of trips performed by FURBOT vehicles is about half the number of trips currently performed by vans each day (data collected on the field in the projects MERCI and Genova Eco (Contursi, 2004; Merella, 2005)).

6.3. The cost function value

For the case of study the admissible values for n_{LBL} are between 1115 and 3715. 1115 is the n_{LBL} value which corresponds to 100% LBL boxes load factor; 3715 is the n_{LBL} value which corresponds to an average of 30% LBL boxes load factor. The optimum number of LBL boxes resulted equal to 1195. The related value of the cost function is 9539 €/day, where:

- The daily kilometers walked by the customers collecting their packages are 1141.9. Assuming an average value of pedestrian speed equal to 1.1 m/s, the total amount of time travelled by customers is equal to 288.4 hours. The total cost supported by users is therefore is 6228.5 €/day.
- The daily cost of a FBL box is equal to 0.13 €/day; the daily cost of a LBL box is equal to 0.80 €/day. Therefore the daily cost of FURBOT boxes is equal to 980 €/day.
- 108 FURBOT vehicles are necessary to perform the deliveries, therefore the daily cost of the fleet is 2230 €/day.
- The total distance travelled by vehicles in a day is equal to 4881 km therefore being 0.0204 the kilometric cost of a vehicle, the total operative cost of the fleet is equal to 99.6 €/day.

7. Conclusions and future work

A new freight delivery system for urban areas has been proposed. This system has been specifically designed for those places where, because of narrow roads, freight delivery through vans and medium-sized trucks is difficult or impossible. This system makes use of small vans, called FURBOT, which have been specifically designed to limit the space occupancy as much as possible. The vehicle is 2 m long and 1.7 m wide. The loading space is 1.2 m long and 1.6 metres wide, as it has been dimensioned to accommodate two Euro pallets.

The proposed system makes use of boxes, whose footprint is that of an Euro pallet, i.e. 120 cm long and 80 cm wide. These boxes store the packages directed to receivers, who could be both commercial activities and individual consumers. Boxes are consolidated at the urban distribution centre and are delivered through FURBOT vehicles to some specific temporary unloading bays, where boxes will be accessed by customers. The positions of potential FURBOT unloading bays, i.e. the areas where boxes can be placed, are fixed. FURBOT unloading bays are placed in areas easily accessible by FURBOT vehicles and where enough space is available to accommodate the boxes.

In the article a procedure for optimizing the FURBOT transport system performances is presented. Given a specific operative day, with specific values of freight demand, the procedure finds the number of LBL boxes, the clustering of packages into LBL boxes, the LBL boxes positions, and the FURBOT trips for delivering LBL and FBL boxes that minimizes a cost function.

The cost function takes into account the user cost and the operator cost. The user cost depends on the distance walked by receivers for collecting their packages in the LBL boxes. The operator cost depends on the FURBOT fleet dimension, on the number of FBL and LBL boxes, and on the overall distance travelled by FURBOT vehicles. The FURBOT fleet dimension is assessed given the total amount of time required to deliver the LBL and FBL boxes and the time at disposal to perform the deliveries.

In the proposed methodology, the freight transport demand is assumed fixed and therefore it is anelastic with respect to the fee the users have to pay for the transport service. This hypothesis is valid if the proposed transport system is offered by a public body. If the FURBOT system is managed by a private body, e.g. a consortium of freight transport operators, the target of the system manager is to maximize profits and the demand should be considered as a function of the fee for the service. In this last case, a new methodology can be proposed which deals with an elastic freight transport demand, and the elasticity of freight demand respect to the price of the FURBOT service can be studied.

Further research on this field will be therefore aimed: on one hand, at studying the reverse logistic; on the other hand, at modelizing the FURBOT system under the assumption of elastic demand.

The overall transport system has been applied to the scenario of Genoa city centre. The application results show that the system has a good performance. In fact, the load factor of LBL boxes is equal to 0.93. Furthermore, as FURBOT vehicles are electrically powered, the degree of pollution related to freight distribution is zero.

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