

# URBAN GOODS MOVEMENTS IN A SENSITIVE CONTEXT: THE CASE OF PARMA

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## ABSTRACT

This paper focuses on the efficiency of one-to-many distribution processes in urban environment. An in-depth 8-month survey of commercial vehicle tours leaving from an urban distribution centre (UDC), located in the outskirts of the city of Parma (Italy), has been performed, merging information between a GPS-based databank and a wider operations databank. Through continuous approximation models, the relative impact of time-dependent parameters of the delivery process, particularly delivery frequency and favourite time slots for deliveries, has been analysed along with the effects due to traffic congestion on commercial vehicle tours.

Tours have been classified according to UDC-customer mutual distances to prove that the efficiency of the distribution process has a clear correlation with the size (and the network characteristics) of the area to serve. The resulting magnitude of the multiplicative impact of tour duration constraints and traffic congestion on the road network, dealing with increased travel times and uncertainty due to travel time variability, is analytically elaborated.

*Keywords: City logistics, Commercial vehicle tours, Time-sensitive replenishment activities, Traffic congestion.*

## INTRODUCTION

Urban freight transportation plays a critical role in ensuring the competitiveness and development of urban economies, but at the same time it is responsible for the increase in environmental pollution, energy consumption and congestion of urban road networks. In Europe, commercial vehicles movements represent 10 to 15% of vehicle equivalent miles travelled in city streets, which account for 3 to 5% of urban land dedicated to freight transport and logistics (Dablanc, 2010) and contribute for more than 20% in terms of traffic congestion (Schoemaker et al., 2006).

Even if congestion levels rise, recent trends in transportation service requirements, such as just-in-time systems, contribute to an increasing proportion of commercial Vehicle Kilometres Travelled (VKT) in urban areas. The necessary high frequency of replenishment operations,

along with the reluctance of end-users (retailers, private customers, etc.) to receive shipments outside given time-windows, make the distribution operations less efficient.

Starting from the definition of recurring tours types in urban operations, the paper focuses on a one-to-many distribution scheme and its application on a city with a typical premium built environment: Parma, Italy, with a maze of narrow streets and plenty of landmarks (Figure 1, with poorly accessible areas in red, according to the average speed values estimated on the observed UDC-customers routes), and the mutual interrelation among typical features: the urban environment, end-users typical behaviours, operational issues, and road traffic congestion.

An in-depth analysis of several months of detailed truck activity records from an urban public distribution center located in the outskirts of the city of Parma, allowed identifying both a series of relevant binding constraints imposed by commercial activities and operational requirements on urban vehicle routing. All of the above lead to analytically model trip chain structure using continuous approximations and assess how the multiplicative impact of temporal binding constraints, such as tour length and favourite time slots for deliveries, along with travel time variability due to congestion, can affect the distribution process efficiency.



Figure 1 – The study area

## **THE TEMPORAL DIMENSION OF URBAN FREIGH TRANSPORT**

Urban freight transport is capable of generating “temporal-related utility” in the urban economy by providing the goods required by the end-users (retailers, private customers, etc.) at the right time in the right place. Major changes occurred in the last decade in cities of developed countries, makes this aim more challenging.

The size of stores’ inventory stocks has reduced and businesses have increased their restocking activity frequency based on the just-in-time concept (Browne et al., 2012). According to the results of a survey undertaken in 2001 in Milan, the higher replenishment frequency has reduced the daily number of deliveries per vehicle from 30 to 17-18 (Da Rios, Gattuso, 2003). The number of products sold has considerably increased, and stocks change

several times a year (Dablanc, 2010). Measures typically implemented by local administrations, to reduce negative impacts of commercial vehicle movements in urban areas, are mostly based on traffic management policies, such as tight access time windows and vehicle access restrictions.

All of the above have made urban economies more dependent on logistics and, at the same time, the necessary replenishment process of end-users located in urban areas more dependent on the time sensitivity of the activity itself. The unavailability of a given product at a given time can produce two combined effects: the intrinsic value of the product decreases, or becomes zero in the provision of fresh products, and the operation of a retailer is disrupted by the late delivery.

If the level of service (related to the replenishment activity) provided by the logistic operator and requested by the end-user is strongly constrained by its time sensitivity, traffic congestion has to be considered at the same time an external cost related to the VKT in urban area by commercial vehicles and a crucial factor affecting the efficiency of the delivery process through increased travel times and uncertainty due to travel time variability.

## **THE CASE STUDY**

The pre-requisite for studying one-to-many distribution processes in urban areas is the availability of disaggregated data on operations run by a given distribution company and a local platform in charge of last-mile pick-up and delivery operations. This is a critical issue due to the operators' well-known reluctance to provide information and it also explains why analyses of the properties of urban freight tours, in relation to their efficiency and contribution to VKT, do not abound in the scientific literature. This is not the case of this study, which relied on the data supplied by the local Urban Distribution Center (UDC), operating across the Parma urban area since April, 2008. UDC is located in the city outskirts, 2km-far from the ring road which surrounds the city centre: a 2.6 sqkm area with about 21,000 inhabitants. Parma UDC is part of a more ambitious plan for the reorganization of the local logistics processes called *Ecologistics*, which envisages the use of low-emission vehicles for delivery operations and the enforcement of restriction policies to regulate the access of commercial vehicles to the city central area. The need to manage the access to the central area comes from the sensitiveness due to its built environment, mostly developed between the XIV-XVII centuries; this called, since the 1990's, for a specific preservation policy which turned the area into a "Zone of High Urban Relevance": a non-motorized realm (being bicycles since ever one of the most popular mode), with an access restriction for private vehicles.

Moreover, the Parma UDC serves as a case in point of one-to-many distribution schemes: a typical facility located in the outskirts of the operation area where a good amount of retailers or customers (i.e. the end users) are located. This configuration has been also chosen because a number of studies from Europe and United States have shown that deliveries from facilities similar to the Parma one have a very large impact on VKT in urban areas (Outwater et al., 2005; STA, 2000, CITYPORTS, 2005); this is also in line with the several examples of Urban Distributions Centres successfully operated in Europe.

## The databanks

The study relied on two different databanks:

- the so-called *Shipments Database* (where data concerning each single shipment, including origin and destination, shipment size and number of parcels, operated by UDC are stored);
- the so-called *Tour Database* (where data concerning tour operations are stored, thanks to the availability of GPS-based data collected directly on-board);

To avoid data overlaps or misinterpretations, a dedicated database has been developed merging information from each database, in order to have each shipment listed both per single trip (as the journey in between two deliveries) and per single tour (as the whole journey, from the moment the vehicle egress the UDC to the one the vehicle access it, at the end of the planned operations). An example of the spreadsheet with data coming from the Tour Database is reported in Figure 2.

	address	time (h:m)	trip distance (km)	trip travel time (min)	average speed (km/hr)	stop time (min)	number of parcels (n.°)	shipment size (100 kg)
departure from the depot	Strada del Taglio,5	07:49						
1° customer	Strada Garibaldi, 2	8:00 - 8:14	4.2	11	22.91	14	4	0.434
2° customer	Via Mazzolari, 30	8:24 - 8:34	4.6	10	27.6	10	2	0.196
3° customer	Via Guercino, 5	8:41 - 9:01	1.2	7	10.29	20	27	2.918
4° customer	Borgo Bernabei, 7	9:18 - 9:33	3.4	17	12.0	15	13	1.324
arrival at the depot	Strada del Taglio,5	09:43	3.0	10	18.0			

Figure 2 – An example of the spreadsheet of the Tour Database

## Parameters to study the distribution operations

Each tour operated to reach the  $n$ -customers, located in the “service area”, has been disaggregated into three consecutive phases, each corresponding to travelled kilometers for:

1. Reaching the first customer from the UDC;
2. Reaching the remaining  $n-1$  customers within the service area;
3. Reaching back the UDC;

For each phase information concerning the origin and destination as well as the departure and arrival times are available.

Phase 2, on its turn, is divided into the  $n-1$  trips travelled, for which origin and destination as well as the departure and arrival times are available, as well.

After having analyzed all of the above for a given tour, it is possible to assess some parameters typical of the urban logistics process, more specifically:

- The average speed per single trip (both within and outside the service area)
- The percentage of driving and stop times
- The journey back to the UDC and the related travel time
- The occupancy rate per tour.

### **General considerations on the case study**

The analysis was focused on a sample of 2,595 tours, corresponding to 22,700 trips and 19,582 deliveries, operated from January to August 2011, across an area wider than the municipal one; the localization of many customers beyond the municipal borders is due to the fact that the UDC belongs to a major facility, the Centro Agro Alimentare and Logistic of Parma (C.A.L.) which concentrates the main business of the local fruit and vegetable markets. As a result, values of many of the parameters above mentioned may markedly vary, especially in terms of travel times and travelled kilometres (Table 1)

Table 1 – Example of general characteristics of the tours

	Average Value	St. Deviation	Value Min.	Value Max
Tour length (km)	56.70	61.56	6.0	219.00
Tour travel time (h)	3.30	3.29	0.40	10.90
Deliveries per tour (unit)	5.6	4.4	1.0	23.0
Trip length (km)	12.34	17.13	1.00	82.6
Trip travel time (h)	0.36	0.38	0.06	6.35

Useful insights regarding the efficiency of commercial delivery tours in urban areas can be obtained considering the correlation between the percentage of driving time per tour and the average distance travelled per customer (Figliozzi, 2010). Since the percentage of driving time is not directly related to the total tour duration or the total distance travelled, such a parameter can be usefully applied to the Parma case study to provide a general tour analysis, because of the above mentioned variability (Figure 3).

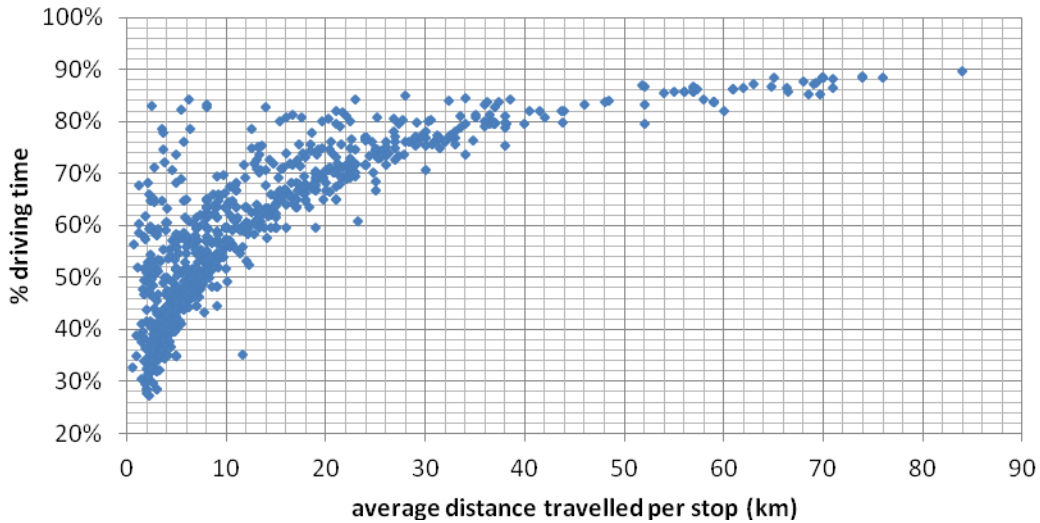


Figure 3 – Tour analysis by percentage of driving time and distance travelled per stop

Tours reported on the lower left section of the graph seem to be extremely efficient from the logistic operator’s perspective as they serve, on average, many customers located nearby the UDC and close to each others; consequently a low percentage of the tour duration is spent driving on the road. On the upper right section of the graph, tours have fewer stops and customers are, on average, located further away from the UDC; as a result, a high percentage of the tour time is spent to reach, from the facility, the area where the customers are located.

Moreover, the application of this analysis to the case study led to outline a concentration of short-distance tours (Figure 4), which calls for an analysis of the tours frequency, according to their length: actually, the majority of the tours are on short distances, if compared to the size of the served area, since 44.8% are less than 10 km long and 54.6% less than 20 km long. Although the UDC is part of a major facility (the C.A.L.) serving a larger area than the municipal one, it seems that its “vocation” is to operate across a more restricted area.

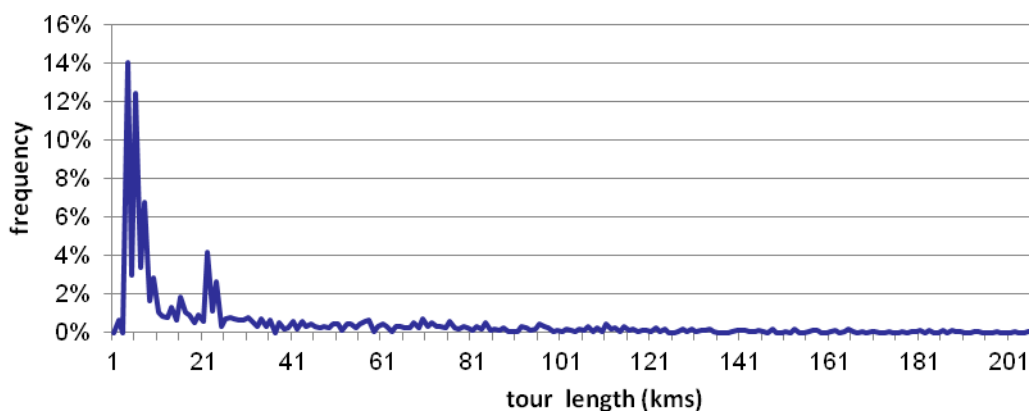


Figure 4 – Tour length distribution

## MAIN CHARACTERISTICS OF THE DISTRIBUTION OPERATIONS

The analysis above described suggests to interpret the characteristic of the local distribution operations in terms of UDC-customer distances; as a matter of fact, the analyzed tours can be divided into three classes, according to the surveyed distance between the facility and each customer to serve and the size of the whole urban area:

- Class I: tours with UDC-customer distance  $\leq 10$  km, also called *Urban Tours*
- Class II: tours with UDC-customer distance between 10 and 20 km
- Class III: tours with UDC-customer distance  $> 20$  km

Consequently, each Class can be characterized by the average values of the parameters reported in Table 2, and the main features of the Urban Tours can be highlighted.

The average value of the travelled kms per delivery (or stop) for Class I is virtually four times lower than that of Class III. Since it is generally acknowledged that the longer the distance, the higher the costs of operations and therefore the more time spent per single delivery, in this case such relationship highlights that Urban Tours (i.e. those of Class I) seem to be the most efficient, also if the modest variation of the amount of deliveries per tour among the three Classes is considered.

Table 2 – Characteristics of the tours classes

	Class I (distance <10 km)	Class II (distance >10 km and <20 km)	Class III (distance >20 km)
Distance travelled per delivery (km)	4.6	9.2	17.8
Deliveries per tour (unit)	4.5	4.8	5.5
Occupancy rate (%)	29.9	44.7	56.7
Direct deliveries/all deliveries (%)	23.5	27.8	10.5
Empty distance per tour (%)	38.5	39.2	22.5
<i>all average values</i>			

However, Urban Tours, although characterized by shorter distances, are affected by exogenous and endogenous constraints which prevent operators from optimizing occupancy and routes, as the Class I occupancy rate clearly demonstrates. This does not reach 30%, whereas those of Classes II and III are much higher, respectively 44.7% and 56.7%; Class I occupancy rate becomes even more significant if the relevance of the direct deliveries (i.e. no stops in between the UDC and end user) is considered: about one every four deliveries within a 10km distance is direct.

This means that, in this case, to the increase of the percentage of direct deliveries does not correspond an increase in the occupancy of the vehicles, as on the contrary it has to be expected if the overall efficiency of the distribution process is to be achieved.

The possibility to operate direct deliveries seems, therefore, not linked to occupancy constraints but to those of the levels of service: the typical end-user requires to be supplied by small amounts of parcels, rather frequently and, above all, within given time windows. Such requirements become stricter in urban areas, such as that of Parma, with very mixed land use and premium built environment, which often means both the sprawl across the whole central area of a high number of small size retail facilities, with even smaller or virtually no storage areas, and the increasing demand for the just-in-time management of supplies.

## **A Focus on Urban Tours**

The sensitiveness of the central area along with the high percentage of operations within a 10 km distance called for a specific focus on Urban Tours.

As a matter of fact, Urban Tours (or Class I Tours) accounted for about 40% of the 2,595 tours surveyed over the 8-month period, serving 607 end users, for a total of 3,456 trips operated by a fleet of 11 commercial vehicles (respectively: 6, 1.6 ton methane-fuelled and 5, 2.2 ton gasoil-fuelled). Each end-user served by an Urban Tour received, in average, 5 parcels per delivery (corresponding to 49 kg), a small amount if compared to the average of the three Classes (13 parcels per delivery, corresponding to 161 kg); a result consistent with the sensitiveness of the area, above mentioned.

The survey stressed the relevance of temporal constraints in the overall operations management, which was synthesized according to three main parameters: frequency of replenishment; temporal distribution of deliveries (and deliveries time slots); and travel speed variability.

### *The frequency of replenishment*

The overall analysis of the frequency of replenishment, based on the monthly distribution of operations in terms of minimum and maximum interval between two consecutive deliveries, pointed out a very clear behaviour (Figure 5): only about 7% of end-users have goods delivered several times per day, but about 24% of them concentrate the deliveries strictly on one day and the next and for about 44% of them the minimum interval between two consecutive deliveries is less than 3 days; at the same time, about one end users every four (24%) receive goods on a weekly basis at the latest.



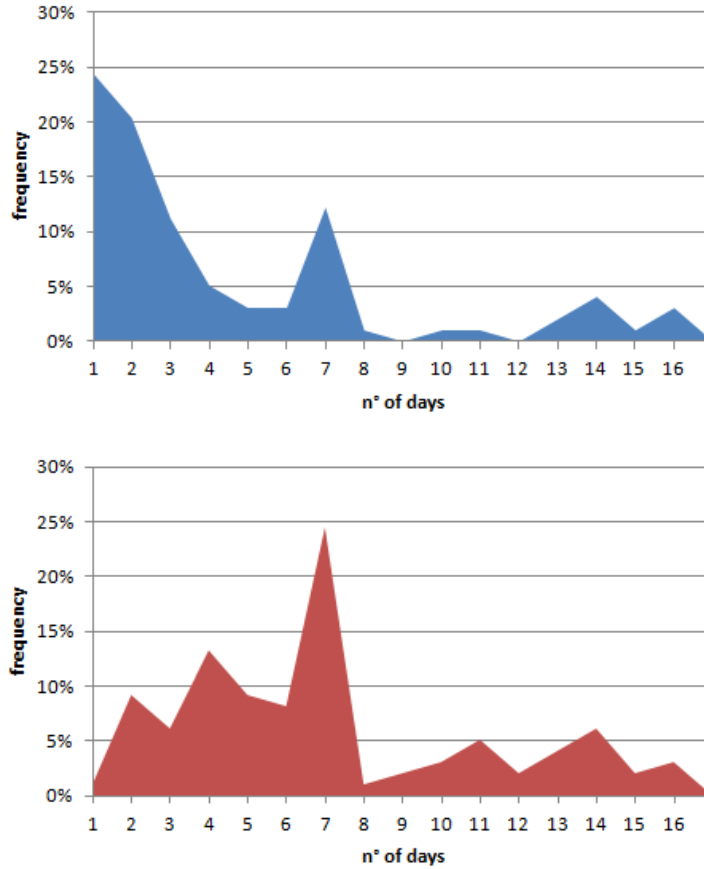


Figure 5 – Frequency of deliveries  
 (minimum - above - and maximum - below- interval between two consecutive deliveries)

*The temporal distribution of deliveries*

Needless to say, also in the case of Parma, the deliveries timeframe stressed strong peak phenomena, typical of urban areas (Figure 6). More specifically, about 46% of the surveyed deliveries occurred from 8 to 10 am, with a 31% peak between 8 and 9 am. Afternoon (2 - 7 pm) can be considered the off-peak time, with much smaller percentage of deliveries (between 3.8 and 5.8 %). To describe the peak time in other words, it suffices to say that 74% of retailers have goods delivered in the morning time.

It is also worth stressing that virtually no deliveries occur outside the business times (which is usually from 9 am to 1 pm and from 2 to 7 pm), being only 2.9% of deliveries recorded before 8 am and just 0.5% after 7 pm or during the lunch break. This is mainly due to the retailers' reluctance to afford extra business hours just to receive goods, although commercial vehicles are permitted to enter the central area from 6 am to 10 pm.

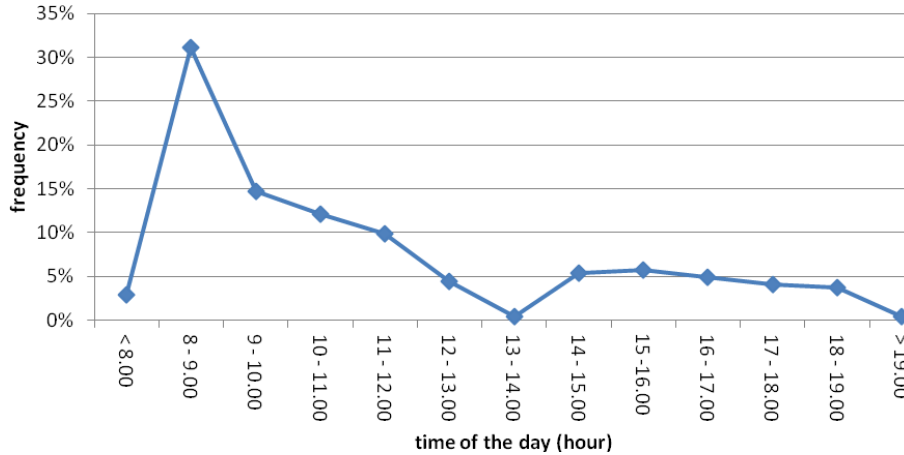


Figure 6 – Temporal distribution of deliveries

Time distribution of deliveries has been also analyzed according to the types of goods delivered/facility served (Figure 7).

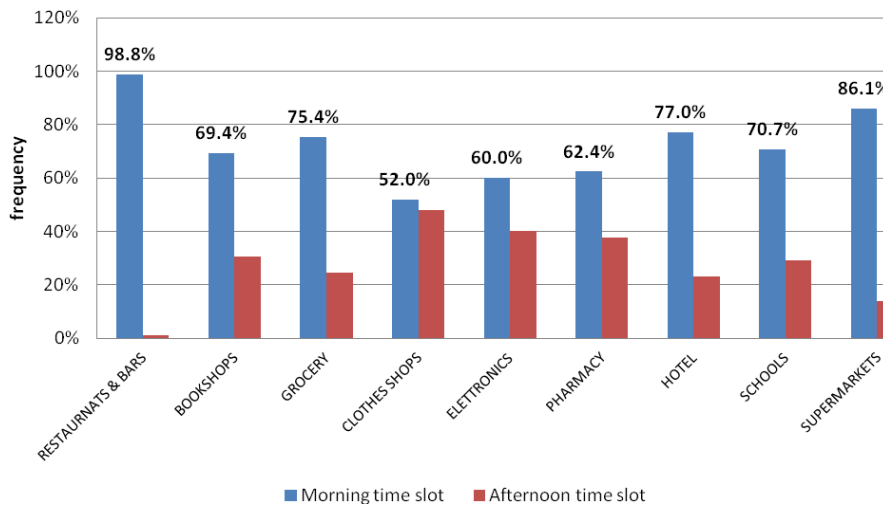


Figure 7 – Deliveries time slots distribution

The only category which is, virtually, equally served in both morning and afternoon slots is the clothing one (52% in the morning and 48 % in the afternoon); in this trend, although at a lower level, can be included pharmacies and electronics retail stores. On the contrary, the food delivery seems to be a morning-only business, as the percentages of restaurants/eateries/coffee shops and supermarkets demonstrate (respectively 98.8% and 86%); Ho.Re.Ca. seems to be a little more flexible (77%).

### *The travel speed variability*

A reciprocal relationship was observed between the variability of travel times and the traffic peak/off-peak phenomena for Urban Tours, even more significant if compared to that for tours of Class III (Table 3).

Table 3 –Speed Average, Standard Deviation and Coefficient of Variation per departure time and tour class

		<i>Departure time</i>						
		6.00 – 8.00	8.00 -10.00	10.00 – 12.00	12.00 – 14.00	14.00 – 16.00	16.00 – 18.00	18.00 – 20.00
<i>Class I</i>	<i>Average Speed (km/h)</i>	23.09	18.97	19.83	21.18	19.74	19.26	22.79
	<i>Speed Standard Deviation</i>	4.00	7.01	7.37	6.18	7.05	8.24	5.91
	<i>Speed Coefficient of Variation</i>	0.17	0.37	0,37	0,31	0,36	0,43	0,26
<i>Class III</i>	<i>Average Speed (km/h)</i>	30.01	31.73	32.92	32.83	32.88	33.92	29.98
	<i>Speed Standard Deviation</i>	6.74	9.46	8.11	7.46	7.67	9.40	7.06
	<i>Speed Coefficient of Variation</i>	0.22	0.30	0.25	0.23	0.23	0.28	0.23

The average speed for Urban Tours is the lowest: 20.7 km/h vs 32 km/h recorded for Class III tours, which is not surprising, for the majority of roads within the city center are local, with very narrow carriageways. The strongest speed reductions for Urban Tours occur during the morning (8 – 10 am) and afternoon (4 – 6 pm) peak hours, thus coinciding with the majority of home-to-work and home-to-school journeys within the central area; similarly, reductions for Class III are registered respectively earlier in the morning (6 – 8 am) and later in the afternoon (6 – 8 pm), thus coinciding with the major flows accessing and egressing the urban area. The Standard Deviation analysis stresses that the longest tours are also the most variable ones, probably reflecting the variety of the infrastructures (from the narrow alleyways of the city center to the more modern highways of the outskirts).

Finally, the coefficient of variation, ratio of the standard deviation to the average speed, shows higher average values for Urban Tours, which seem to be subject to more speed variation during the whole day.

## THE METHODOLOGY

Estimations of the average length of Traveling Salesman Problems (TSPs) and Vehicle Routing Problems (VRPs), based on continuous approximation models, have been successfully applied in the extant literature to provide strategic analyses of delivery operations and capture their performance (Figliozzi, 2008; Sankaran and Wood, 2007). In such problems, dealing with a distribution centre serving an area with variations in demand, average distances travelled are estimated as a function of the number of customers to be served and the number of tours needed to meet their requests. As a matter of fact, the

distance travelled is a key parameter to assess the process efficiency from the logistic operator's perspective and also to solve problems dealing with facility locations, fleets size and networks design (Figliozzi, 2008).

In this paper, approximations to the distance travelled by a fleet of commercial vehicles in a service area, based on simple formulas derived through continuous approximation models, are applied to the Parma UDC case study. All of the insights regarding the properties and binding constraints of commercial delivery tours in urban areas, derived from the above described real-world data analyses, have been assumed as a starting point to analytically model, through the proposed methodology, trip chain structure and estimate the relative impact of specific time-related parameters affecting the delivery process. Since tours of Class I have been proven to be *time constrained tours*, i.e. delivery processes with high time sensitivity and routing operation mostly constrained by temporal variables (typical end-user requires to be supplied by small amounts of parcels, rather frequently and, above all, within given time windows), the analysis is focused on this tour class.

### The tour model

A crucial requirement to analytically study urban freight tours is to select a mathematical expression that can assess the distance travelled to serve the customers located in the selected area, taking into consideration the number of stops per tour, the proximity among the customers and the proximity of the storage facility to the customers. The expression used in this research to approximate the length of a Vehicle Routing Problem (VRP) tour, starting and ending at the distribution centre, is:

$$(1) \quad l(n) = k_z z + k_l \sqrt{an} + k_b \sqrt{a/n}$$

where  $n$  is the number of stops,  $z$  is the number of tours,  $\bullet$  is the density of stops,  $a$  is the extent of the service area and  $k_z$ ,  $k_l$  and  $k_b$  are parameters that have been estimated by regression and mainly depending on the depot location, routing constraints, and spatial distribution of customers. The first term represents the connecting distance from the UDC to the service area, the second term accounts for the local tour distance travelled in the Travelling Salesman Tour for reaching the end-users and the last term can be assumed as the bridging distance between them. Expression (1) has been derived by Figliozzi (2008), using Daganzo's continuous approximation models applied to routing and distribution problems (1991), and it has proven to be a more robust approximation to predict the length of VRPs in real urban network and in randomly generated problems.

In this study, expression (1) has been modified assuming the term  $(n - z)/n$  to approximate the length of the local tour (expression 2).

$$(2) \quad l(n) = k_z z + k_l \frac{n-z}{n} \sqrt{an} + k_b \sqrt{a/n}$$

The theoretical and intuitive properties of this term, in adjusting the accuracy of the tour length estimation as a function of  $n$  and  $z$ , have been already tested (Figliozzi, 2008); moreover better performance in terms of prediction accuracy have been obtained applying expression (2) to the case study: the regression fit is high with a  $R^2 > 0,98$ , a Mean Absolute Percentage Error (MAPE) of less than 6,0%, and a Mean Percentage Error (MPE) of -1,0%. The MAPE represents the average deviation between the actual tours length and the estimated one, as a percentage of the actual distance traveled, and the MPE shows if the estimated tours length is higher or lower the actual one.

Table 4 – Tour model fit comparison

	$R^2$	MAPE (%)	MPE (%)
Tour model - expression 1	0,983	8,0	-1,2
Tour model – expression 2	0,989	6,0	-1,0

When not all customers can be served in the same tour, the temporal binding constraint for each tour with an average of  $n / z$  stops can be expressed as:

$$(3) \quad \frac{a}{s^f} \left( k_z + \frac{k_l}{z} \frac{n-z}{n} \sqrt{an} + \frac{k_b}{z} \sqrt{\frac{a}{n}} \right) + \frac{n}{z} t_c \leq rw - s_r z$$

let:

- $k_z$ : the congestion increase coefficient which reflects the increase in average travel times on the road network with respect to the free-flow condition;
- $s^f$ : the free-flow travel speed;
- $t_c$ : the service time when stopping at the retailer (end-user);
- $w$ : the effective drivers' working time;
- $r$ : the time windows factor, i.e. the ratio between the time window length for delivery and working shift length ( $w$ );
- $s_r$ : the route travel time standard deviation;
- $a$ : the coefficient related to the probability of completing the tour within the allowed tour duration, assuming normally distributed travel times.

It is worth pointing out that when the total length of the tours is estimated using continuous approximations, a common assumption is that routes are balanced, i.e. the number of stops is the same or similar across tours.

Within this basic structure, for a given set of end-users' requests, the transport service provider plans the delivery process in order to meet such requests according to both routing constraints, such as vehicle capacity, drivers' working time, favoured time windows for deliveries, and possible exogenous factors, typically travel time variability due to congestion. An increase in congestion will reduce the average travel speed and affect the travel time variability; as a consequence, if the tour duration constraint is violated, to restore feasibility the number of tours needed for satisfying the customers' requests must be increased and the average number of stops per tour must be decreased.

The impact on the efficiency of tours is significant, since the binding temporal constraint not only reduces the proportion of time available for accomplishing the average delivery tour but also decreases the density of customers per tour. It is well-known that between customers' density, i.e. number of customers to be served within the service area, and logistic costs exists an inverse mutual interrelation, as shown in Figure 8.

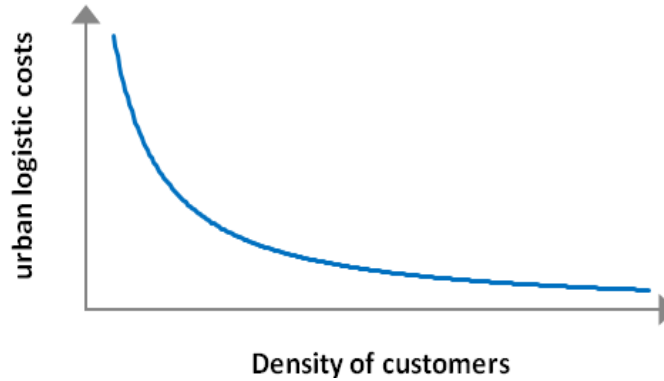


Figure 8 – Typical mutual interrelation between urban logistic costs and density of customers in the service area.

### The time-sensitivity analysis

The analytical approach above described has been applied to the UDC's truck activity records (stored in the Tour Database) as regard to Urban Tours, to provide a sensitivity analysis dealing with temporal-related parameters and assess how congestion and temporal routing constraints affect the tours efficiency from the distributor perspective.

Expression (3) has been used to assess how the interactive effect between temporal constraints affecting the tours maximum travel times along with an increase in travel time and travel time variability due to congestion can affect the tour optimisation. Since congestion reduces the ability to serve customers per working shift or favoured delivery time slot, the impact on travel time alone is not enough to describe the implications on the efficiency of logistics operations, and the distance travelled to serve a given set of end-users requests must also be considered

On a quality level, an increase in congestion would affect both the average time to complete the tour, through the effect of the congestion increase coefficient  $\bullet > 1$  – on the left-hand term of expression (3), and the tour duration constraint, through the buffer  $\bullet_r^*$  in the right-hand term of the same inequality, since the route travel time standard deviation can be expressed as:

$$(4) \quad s_r = n \text{ a } s_r^f = n \text{ a } \sqrt{\sum_{k \in L_r} (t_k^f)^2}$$

let:

- : the travel time coefficient of variation, assumed constant along the whole route  $L_r$  for the sake of simplicity;
- $^f_r$ : the free-flow standard deviation of the route travel time;

$t_k^f$ : the free-flow travel time in link  $k, \forall k \in L_r$

A tour starts at the UDC, visits 2, 5 or 8 customers and then returns to the facility. The sensitivity analysis assumes as relevant parameters the congestion increase coefficient ( $\bullet$ ), the travel time coefficient of variation ( $\bullet$ ) and the tour duration constraint ( $\bullet w$ ). The results are presented in Table 5 in terms of increase factor of the number of tours needed, compared to the no-variability scenario (i.e.  $\bullet = 0$ ). For example, by setting  $\bullet = 2$ ,  $\bullet = 0.2$  and  $\bullet w = 8h$  the number of 5-stop tours needed is 1.071 times higher than the number of the same type of tours needed when travel time variability is equal to 0; if, in addition, the tour duration constraint decreases from  $\bullet w = 8h$  to  $\bullet w = 6h$ , the number of 5-stop tours needed increases by a coefficient of 1.439. The reduction in travel speed with respect to free-flow condition is given by three different values of the congestion increase coefficient ( $\bullet = 1, 2$  and 3) resulting in the average travel speed values of 50, 25 and 16.6 km/h.

Table 5 – Increase factors of the number of tours needed

$\bullet = 1$				
		$\bullet w = 8h$	$\bullet w = 6h$	$\bullet w = 4h$
$\bullet = 0.2$	2-stop tours	1.028	1.373	2.064
	5-stop tours	1.034	1.383	2.088
	8-stop tours	1.069	1.433	2.178
$\bullet = 0.4$	2-stop tours	1.059	1.403	2.078
	5-stop tours	1.071	1.425	2.128
	8-stop tours	1.149	1.536	2.313
$\bullet = 2$				
		$\bullet w = 8h$	$\bullet w = 6h$	$\bullet w = 4h$
$\bullet = 0.2$	2-stop tours	1.059	1.416	2.134
	5-stop tours	1.071	1.439	2.188
	8-stop tours	1.152	1.557	2.393
$\bullet = 0.4$	2-stop tours	1.127	1.484	2.166
	5-stop tours	1.158	1.535	2.280
	8-stop tours	1.362	1.827	2.775
$\bullet = 3$				
		$\bullet w = 8h$	$\bullet w = 6h$	$\bullet w = 4h$
$\bullet = 0.2$	2-stop tours	1.096	1.467	2.218
	5-stop tours	1.117	1.506	2.308
	8-stop tours	1.258	1.712	2.681
$\bullet = 0.4$	2-stop tours	1.214	1.582	2.272
	5-stop tours	1.266	1.674	2.469
	8-stop tours	1.694	2.286	3.513

As expected, the time – sensitivity of the delivery processes is higher for tours reaching more customers per route (Figure 9), since travel time standard deviation grows with the number of stops per tour and affects the right-hand term of expression (3) along with the increase in travel time variability.

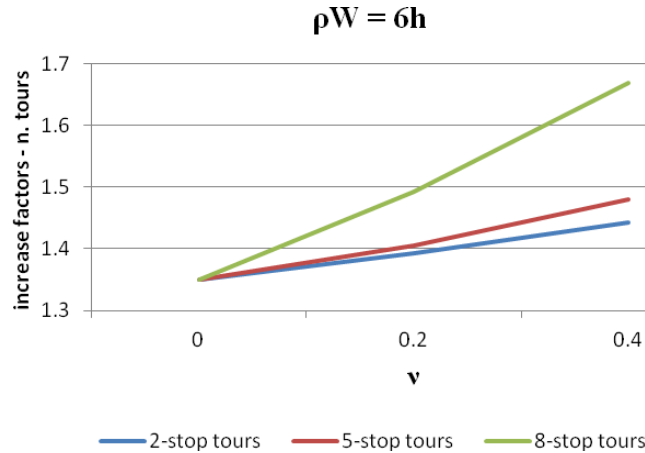


Figure 9 – Increase factors trends per travel time variability and type of tours

### A final remark

A last finding from the sensitivity analysis concerns the relationships among the increase factors of the number of tours and those of variations respectively of the travelled km and of the driving time, for the three considered types of tour.

If the following can be assumed, i.e.:

- The impact due to congestion, hypothesizing for each tour an average speed of a 25 km/h ( $\bullet = 2.0$ ) and a coefficient of variation of driving times ( $\bullet$ ) of 0.2 (according to what observed in the case study);
- The effect due to the concurrency of the temporal constraints affecting the tours maximum travel times along with the requirement of favoured time slots, hypothesizing for the latter a comparison between two options: a) deliveries can take place within a 8-hour working shift ( $\bullet w = 8h$ ); b) deliveries can take place within a 6-hour working shift ( $\bullet w = 6h$ );

then, it is possible to obtain the increase factors of the number of tours, travelled km and driving times reported in Table 6.

Table 6 – Increase factors of the number of tours needed, distance travelled and driving time

Increase factors		Tours	Travelled km	Driving time
$\frac{\Gamma_w = 6h}{\Gamma_w = 8h}$	2-stops Tour	1.337	1.079	2.160
	5-stops Tour	1.343	1.081	2.164
	8-stops Tour	1.351	1.085	2.170

As the temporal constraint ( $\bullet w$ ) becomes stricter, then operations are planned to have more travels, although shorter, in order to comply with such temporal constraint; moreover, since the UDC is very close to the area where the majority of deliveries takes place, to an increase of the amount of tours does not correspond a marked increase of connecting distances (i.e., the distance between the UDC and respectively the first and last customers to serve in each



tour). As a consequence, the amount of travelled km increases according to coefficients always minor than those of the number of tours.

On the contrary, driving time sensitivity, if compared to the other two terms, is higher, especially when congestion increases (thus assuming  $\alpha = 2$  and  $\beta = 0.2$ ), because speed progressively decreases and the compliance of the temporal constraint calls for tours with a higher amount of travelled km per single customer, with no variation of the replenishment times.

As a result, for a given set of customers' requests, the multiplicative impact of traffic congestion on the road network ( $\alpha = 2,0$  ;  $\beta = 0,2$ ) and the tour duration constraints (which decreases from 8 to 6 hours), result into a general increase of number of tours needed (+ 34,3%) and total distance travelled (+ 9%).

## **CONCLUSIONS**

The real-data analysis based on the Parma case study allowed to demonstrate the strict relationship existing between the efficiency of the distribution process originated from the local UDC and the size of the area to serve. More specifically, when such an area corresponds to the city centre, tours are affected by endogenous and exogenous constraints which prevent operators from optimizing aspects such as occupancy and routes. If Classes I and III are compared, this becomes evident when the effects of these constraints on tours efficiency simultaneously occur:

- the reduction of the occupancy rate up to 50%;
- the 100% (or higher) increase of the direct deliveries;
- the 40% increase of the empty tours.

If the focus is specifically on Urban Tours, to these a 35% reduction of the average speed must be added and the high variability of such parameter due to the built environment features (narrow carriageways, poor on-street parking availability, high density of intersections) has to be considered. Moreover, their planning is markedly affected by the end users' requirement to have deliveries at given time windows: 75% of end users located in the city centre receive goods either in the morning or in the afternoon time slot.

But the study case served also as a case in point to outline some high level considerations in the field of commercial vehicle tours analysis. The modelling approach above described demonstrated how the effect due to the simultaneous occurrence of temporal constraints and congestion forces operators to re-plan deliveries in order to have higher amounts of tours but shorter; this by increasing not only the driving time but also the travelled km. Such an effect increases according to the tours "complexity" (increasing number of stops and trips) and, unlike what usually reported in the scientific literature, this is also valid when the distance between the UDC and the area to serve is rather modest, as the case of Parma demonstrated. This also suggests that application of the modelling approach to a city with a valuable built environment, such as that of Parma, can be considered as a step forward compared to those examples applied to less complex urban patterns or where the travelled km parameter becomes dominant in the overall assessment of operations.

Finally, the study outlined relevant implications for data collection efforts: no realistic statements about the properties of urban freight tours in relation to their efficiency and contribution to VKT can be made unless there is disaggregated information on tour routing constraints, which suggests a revision of usual methods for truck trips generation based on commodity flows or land-use categories (Figliozzi, 2007). Moreover the analytical survey shows that the temporal dimension of the delivery process, mostly in terms of favoured time slots for delivery and traffic congestion impacts, has to be considered as a relevant parameter dealing with the types of tours that are likely to be originated from the depot.

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