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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 environments. An in-depth 8-month survey of commercial vehicle tours leaving from an Urban Distribution Centre (UDC) located on the outskirts of the city of Parma (Italy), was carried out, merging information from a GPS-based dataset and a wider operation dataset. Tours were classified according to UDC–customer distances in order to prove the clear correlation between the efficiency of the distribution process and the size (and the network characteristics) of the area being served. When such area covers the city center, available data highlighted how vehicle routing is affected by constraints which strongly prevent the optimization of routes and occupancy rate.

Through continuous approximation models, the relative impact of the time-dependent parameters of the delivery process, particularly maximum tour travel times and preferred time slots for deliveries, was analyzed along with the effects of traffic congestion on commercial vehicle tours. The resulting scenario analysis allowed to assess a significant increase in the number of tours needed (+34,3%) and the total distance travelled (+9%), to serve a given set of customers in the city center, when travel time variability and tour duration constraint become stricter.

1. 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 increased environmental pollution, energy consumption and congestion of urban road networks. In Europe, commercial vehicle movements account for 10–15% of vehicle equivalent miles traveled in city streets, which represent 3–5% of urban land dedicated to freight transport and logistics (Dablanc, 2010) and they are the cause of over 20% of traffic congestion (Schoemaker et al., 2008). The growing proportion of commercial Vehicle Kilometers Traveled (VKT) in urban areas is due to stores' inventory stocks being reduced and businesses restocking more frequently in line with a "just-in-time" concept (Browne et al., 2012). According to the results of a survey undertaken in 2001 in Milan, more frequent replenishments have reduced the number of deliveries per vehicle daily from 30 to 17–18 (Da Rios & Gattuso, 2003).

This paper focuses on the efficiency of one-to-many distribution processes in urban environments (with a typical depot located on the outskirts of the service area supplying several retailers or customers), how these processes apply in a city with a built-up environment of historical interest (Parma, Italy with its maze of narrow streets and numerous landmarks), and on the relation between typical features, i.e. the urban environment, typical end-user behavior, operational issues and road traffic congestion. The one-to-many configuration was chosen because a number of studies have shown that deliveries from a warehouse have a very large impact on VKT in urban areas (CITYPORTS, 2005; Outwater et al., 2005; STA, 2000); moreover, this is in line with the many examples of Urban Distribution Centres (UDC) successfully operating in Europe. In this paper, approximations of the distance traveled by a fleet of commercial vehicles in a service area are based on simple formulae derived from continuous approximation models and applied to the Parma UDC case study. The assumptions, regarding the properties and binding constraints of commercial delivery tours in urban areas based on real-world data analyses, were taken as a starting point in order to analytically model the trip chain structure using the proposed methodology, and to assess the relevance of specific time constraints for the overall management of operations.

2. Methodology

Estimations of the average length of Traveling Salesman Problems (TSPs) and Vehicle Routing Problems (VRPs) based on continuous approximation models, were successfully applied to the existing literature in order to undertake strategic analyses of delivery operations and assess their performances. For problems where a distribution center serves an area in which demand varies, the average distances traveled

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are estimated as a function of the number of customers to be served and the number of tours needed to meet their requests. In fact, the distance traveled is a key parameter both in assessing the efficiency of the process from the logistic operator's perspective and in solving problems of facility location, fleet size and network design.

Figliozzi (2007) contributed significantly to the analysis of the effects of routing constraints (vehicle capacity, length of the working day, service-level targets, etc) on the number and characteristics of the tours that carriers may use to meet customer demands. Figliozzi advocated that tours can be classified according to supply chain characteristics and route constraints and, using a model based on Daganzo (1991) of routing problems, his analysis concluded that both VKT and Vehicle Hours Traveled (VHT) could be strongly influenced by the tour type. Sankaran and Wood (2007) presented continuous approximation models which sought to identify the relative impact on distribution costs of consignee behavior, particularly Just-in-time (JIT) replenishment, the length of the working day and traffic congestion. They indicated that congestion-related costs increase with the average number of tours per day and decrease with the work day duration. Figliozzi (2010) analyzed the impact of congestion on commercial vehicle tours through simple and intuitive formulae, once again based on Daganzo's approximation routing problems. Analysis based on a real-world situation (the service area represents the industrial district of Bankstown in the city of Sydney, Australia) and tour data described in the literature showed that long distances between the depot and the customer(s) exacerbate the negative impact of congestion; moreover, travel time variability is not a significant variable when the travel time between the depot and customer is short in relation to the maximum tour duration and when tours are not highly constrained.

The research question is whether it is possible to extend the analytical approaches mentioned above in more complex service areas, such that of Parma (further described), to assess how the efficiency of the distribution process is strictly related to the size and the characteristic of the area to be served. To do this, this paper focuses on a system with one depot and n customers to be served. A tour is defined as the path that a truck follows from the depot to one or more customers in a sequence before returning to the depot during a single driver's shift. In this research, the mathematical expression used to approximate the distance traveled (l) to serve the customers (n) located in the service area, taking into consideration the number of customers, the proximity of the customers to each other and the proximity of the storage facility to the customers, is:

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

where z is the number of tours needed to serve n customers, a is the size of the service area and k_z, k_l and k_b are parameters, estimated by a regression exercise, that depend mainly on the depot location, routing constraints, and spatial distribution of customers. The expression (1) can be interpreted as follows: the first term represents the distance from the UDC to the service area, the second term the local tour distance traveled in the Traveling Salesman Tour (TST) to reach the end-consumers and the last term the bridging distance between them. The expression (1) was formulated by Figliozzi (2008), again using Daganzo's continuous approximation models applied to routing and distributing problems, and it has proven to be a more robust approximation in predicting the distances involved in VRPs in real urban networks and in randomly generated problems.

In this study, the expression (1) has been modified assuming the term (n − z)/n to approximate the length of the local tour, as follows:

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

The properties of this term, in adjusting the accuracy of the tour length estimation as a function of n and z, have already been tested (Figliozzi, 2008); moreover more accurate predictions have been obtained by applying the expression (2) to the Parma 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 tour length and the estimated one, as a percentage of the actual distance traveled, and the MPE shows if the estimated tour length is longer or shorter than the actual one.

Assuming expression (2) as an approximation of the distances traveled to reach n customers, the numbers of retailers served per tour can increase or decrease according to the routing constraints (vehicle capacity, drivers' working time, time slots preferred for deliveries), and because of possible exogenous factors, typically travel times variability due to congestion. A common assumption when continuous approximations are utilized is that routes are balanced, i.e. routes have a similar number of customers (Daganzo, 1991). Assuming balanced routes, the binding constraint for each route with an average of n/z customers can be expressed as:

$$\frac{1}{\bar{s}} \left(k_z + \frac{k_l}{z} \frac{n-z}{n} \sqrt{an} + \frac{k_b}{z} \sqrt{\frac{a}{n}} \right) + \frac{n}{z} t_c \leq w \tag{3}$$

where:

$\bar{s}$ average travel speed on the network
t_c the service time when stopping at the retailer (end-consumer);
w the drivers' real working time;

An increase in average travel time can be expressed by the congestion increase coefficient $\alpha \geq 1$ which reflects the increase in average travel times on the road network compared to free-flow condition, as follows:

$$\bar{s} = \frac{\overline{s^f}}{\alpha}. \tag{4}$$

If the travel times are not constant, the buffer $\sigma_r^* \zeta$ must be added to the right-hand term of the expression (3) in order to guarantee the customer service level, where σ_r is the route travel time standard deviation and ζ is the coefficient related to the probability of completing the tour within the time allotted, assuming normally distributed travel times.

By using the coefficients described above, the expression (3) becomes:

$$\frac{\alpha}{\overline{s^f}} \left(k_z + \frac{k_l}{z} \frac{n-z}{n} \sqrt{an} + \frac{k_b}{z} \sqrt{\frac{a}{n}} \right) + \frac{n}{z} t_c \leq \rho w - \sigma_r \zeta \tag{5}$$

where ρ is the time window factor, i.e. the ratio between the time window length for delivery and the working shift length (w).

Increased congestion will reduce the average travel speed and affect the travel time variability; consequently, if a tour exceeds the time allotted, the average number of stops per tour will have to be reduced and the number of tours increased, and in order to satisfy the customers' requests. The impact on efficiency is significant, since the binding time constraint not only reduces the time available to accomplish the average delivery tour but also decreases the number of customers per tour.

3. The Parma case study

The pre-requisite for studying one-to-many distribution processes in urban areas is the availability of selected data on the operations of a given distribution company or local platform in charge of last-mile delivery operations. This is a critical problem caused by operators being reluctant to provide information; furthermore, it explains why,