Modeling the Impact of Technological Changes on Urban Commercial Trips by Commercial Activity Routing Type

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ABSTRACT

An array of noteworthy developments in logistics practice has taken place without an equivalent and comprehensive development in urban freight transportation modeling. Part of the problem is the lack of deep understanding of the workings of distribution processes in relation to the generation of truck traffic. In this paper it is emphasized the role and importance that distribution network size, and information and communication technology have on the truck traffic flows that materializes as the supply chain that flows over the public infrastructure. This paper develops the concept of commercial activity routing types that characterize the interplay between transportation demand requests and routing characteristics. This research contributes to the field proposing a novel and detailed characterization of truck flows in a supply chain context. Using well-known yet simple models and formulas from vehicle routing, operations research, and management science literature, we derive behavioral insights about distributors and carriers' routing and order sizing decisions, as routing constraints and second order effects are important drivers of truck flows. The main contribution is to bring a new commercial activity-routing perspective and deeper level of operational decision-making analysis to cope with the intricacies of freight transportation modeling.

KEYWORDS: Freight Transportation, Urban Freight Demand, Carrier Behaviour, Shipper Behaviour, Vehicle Routing Problem, Commercial Vehicle Traffic, Urban Logistics, Commercial Freight Activities

1. Introduction

Despite the critical role played by freight transportation in economic development and most economic activities, freight transportation modeling is not yet a mature field. Undoubtedly, freight transportation traffic and demand models have received far less attention than passenger models. This underdevelopment has been widely recognized [1, 2]. The accelerated pace of change in logistics practices with the advent of the information and communication technology (ICT) revolution has not improved the status quo.

An array of noteworthy developments in logistics practice have taken place without an equivalent and comprehensive development in freight transportation modeling. A short list of such logistics developments includes EDI[1], bar coding and more recently RFID, JIT, VMI[2], cross docking, containerization, and electronic commerce. Despite the growing interest in considering and incorporating technological and behavioral elements into the freight transportation planning processes, the goal remains elusive [3]. The decision processes governing freight distribution and commercial truck traffic are not yet well understood.

This research proposes that part of the problem is the lack of deep understanding of the workings of distribution processes in relation to the generation of commercial truck traffic. It is widely accepted that the demand for freight transportation is a derived demand. This research accepts this assumption. However, in this paper it is emphasized the role and importance that distribution network size and technology may have on the truck traffic flows that "materialize" supply chain flows (demands) over the public infrastructure.

This paper develops the concept of commercial activity routing types that characterize the interplay between transportation demand requests and routing characteristics. The classification of commercial activity routing types is then used to model how technological changes may impact the generation of commercial truck flows. Having disaggregated commercial activity into significant routing types, it is possible to analyze how technological changes affect routing frequency, order size, and number of customers per route. From these route changes it is possible to infer how commercial activity truck flows may change. This paper focuses only on commercial commodity truck flows. The detailed study of commercial service truck flows is left as a future research topic.

The paper is organized as follows: section 2 reviews literature related to logistics trends and urban freight modeling approaches. Section 3 develops the concept of commercial activity routing type. Section 4 defines terminology and notation used in the paper. Section 5 studies how commodity truck flows are affected by changes in the distribution system. The paper ends with conclusions in section 6.

2. Literature Review

The changes and trends in shipper-carrier procurement strategies have received a great deal of attention in the transportation and logistics academic literature, mostly through published

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[1] EDI: Electronic Data Interchange

[2] RFID: Radio Frequency Identification, JIT: Just-in-Time (production system), VMI: Vendor Managed Inventory

survey results. For example, Crum and Allen [4] report how Just In Time (JIT) inventory and production systems and economic deregulation have impacted carrier-shipper relations. These authors use survey data to demonstrate trends indicating a reduction in the number of motor carriers utilized by individual shippers and a move towards long term contracting. A slightly different trend is reported by Lieb and Randall [5]. These authors report a trend, mainly among big companies, towards outsourcing transportation and logistics responsibilities to 3PLs. Crum and Allen [6], after comparing survey data taken in 1990 and 1996, conclude that the trend in carrier-shipper relationships continues to move away from a transactional framework to a relational one (from a cost based procurement to a collaboration based procurement)

Technology has also spurred changes and transformation of transportation-logistics procurement structures. Shortly after deregulation legislation was passed in the USA, Electronic Data Interchange (EDI) began to be available. Williams [7] studies and reports how EDI facilitates and fosters a seamless integration between a shipper and group of core carriers. Golob and Regan [8] studied how carriers adopting information technology tools and Ng et al. studies [9] the type of information that carriers and drivers would like to receive from traveler information services. A survey study about the adoption and usage of Internet procurement tools by shippers was conducted by Lin et al. [10]. That survey indicated that 60% of the shippers use the internet to procure transportation services (phone usage was tallied at 90%). Load matching and transportation auctions were used by 15% of the shippers that used some transportation online service (2001 data).

The references mentioned thus far provide insight into trends or changes in supply chain relationships, technology adoption, or procurement strategies. Unfortunately, they are not very useful from the freight modeler point of view since they provide little insight into how the knowledge acquired in the surveys can be translated into parameters of freight or urban transportation models. However, on the modeling side there are several efforts underway to capture complex logistics relationships that are completely ignored in traditional four stage approaches borrowed from the passenger modeling literature. Two innovative modeling approaches are in progress in the cities of Calgary [11] and Los Angeles [12].

A different approach, from a multidisciplinary/multiagent perspective, is being adopted by the relatively novel field of “city logistics”. Focusing in urban environments, city logistics aims at optimizing logistics operations in an urban environment taking into account benefits and costs for all stakeholders: shippers, freight operators, urban residents, and the governmental agencies. Taniguchi et al. [13] present a current review of the field and evaluate approaches that combine both optimization and simulation to predict the effect of policy measures. Hensher and Puckett [14] present a general framework to study how supply agents interact using stated choice experiments, with a focus on collaboration or partnership formation as a tool to reduce traffic congestion.

A few research works emphasize the importance that network production/distribution details and costs have in urban freight distribution flow patterns. Nemoto [15] presents a detailed traffic and cost analysis of a freight consolidation scheme aimed at reducing the negative impact of a high number of frequent and small sized shipments in the city of Fukuoka, Japan. Moinzadeh et al. [16] presents an analysis of how congestion created by small order sizes can negatively impact delivery times and inventory levels. The relation between lot sizes and traffic congestion on a common access road is studied by using an inventory-queuing model. More recently Sankaran et al. [17] performed a case study between congestion levels and replenishment order sizes in Auckland, New Zealand.

Another stream of research comes from the industrial/production engineering literature. Given that transportation can account for up to 50% of total logistics costs, different methods have been proposed to reduce logistics costs taking advantage of transportation price structures. This Industrial Engineering (IE) literature modifies the original economic order quantity (EOQ) model to incorporate different transportation pricing methods. Pricing may profoundly affect order size. Quantity discounts in the case of less-than-truck-load (LTL) and the number of truck-loads (TL) affect delivery cost per unit and the optimal order size from the shipper’s point of view [18]. A further generalization of Lee’s model is studied by Swenseth and Godfrey [19], where both vendor (warehouse) and buyer (retailer) are subject to a replenishment cost structure that includes a fixed cost plus a stepwise component. On the behavioral freight demand modeling, the trade-off between ordering/transport costs and inventory has also been widely studied after the seminal contribution of Baumol and Vinod [20].

This research differs from previous literature in two important aspects: a) it attempts to model truck flows as a function of commodity/activity routing pairs and b) it incorporates the transportation and distribution costs as a function of route and activities constraints. To the best of the author’s knowledge, there is no research work or analytical model that incorporates these aspects. Furthermore, no research work has modeled the impact of technological changes and congestion on distribution systems at the route level.

3. Commercial Activity Routing Types

The importance of routes and vehicle routing decisions stems from the fact that the assignment of trucks to the public network is ultimately determined by the distribution/service center solution to his or her vehicle routing problem. Routing is understood as the process that carriers use to “materialize” supply chain flows over the public infrastructure. The movement of a truck over a network generates the traffic flow associated with that truck in that network. Therefore, truck flows are the materialization needed to satisfy the spatial dimension of customer requests in a supply chain.

This section develops the concept of commercial activity routing type that characterizes the interplay between transportation demand requests and routing characteristics. Logistics strategies, including distribution, are designed to meet customer expectations (regarding the product/service required) in a cost efficient manner. The commercial activity type reflects how the scheduling and routing of commercial vehicles (trucks) and people (drivers, service/repair personnel) materialize in the urban network. The relative importance of distribution/routing costs on the product/service offered has a decisive influence on the design and materialization of the distribution system.

The objectives and constraints utilized for the routing/distribution problem are determined by the commercial activity type; which determines the type of vehicle routing problem used. The conjunction of a vehicle routing problem and a specific set of demands or requests materialize or objectify a supply/service chain activity into an observable set of parameters: number of customers per route, sequencing, time of service, vehicle used, distance, links traveled, etc.

The provision of a product or service is denoted herein as a commercial activity or simply an activity. Two fundamental dimensions are used to discriminate the effects of activities on routing: 1) the time sensitivity of the activity, and 2) the value of the activity itself. In the case of products, value is an important determinant of production, inventory, and distribution strategies. In general, the value of activities is an important factor that determines how the logistics system design provides flexibility to meet the demand for speed, quick response, and consistency in deliveries.

Time sensitive activities can originate in two ways a) the value of the activity itself decreases over time, or b) not having the activity at a given time disrupts the operation of a system or company. An example of the former is the provision of fresh vegetables or fresh bakery products; as the products get stale their intrinsic value decreases considerably or even becomes zero (must be discarded). An example of the latter is the provision of a Just In Time (JIT) supply; the value of the supply product itself may not be too high (e.g. an LTL shipment of bolts for a specific car) but stopping the production line due to a late delivery carries a very high penalty for the consignee.

A simple classification of the activities according to their time sensitivity and value (1) is presented in Table 1. The transportation decisions associated with low value, low time sensitive products (1), are driven by trade-offs between inventory and transport/order costs. Examples of these kinds of products include the urban distribution of food products to supermarkets and fuel to service stations. Deliveries are made with TL (truckload) or LTL (less-than-truckload) deliveries. It is the typical made to stock environment. Production, stocking, and distribution are done in anticipation of a future demand. Routes tend to be planned in advance, The distribution center influence area is divided into service areas (clusters) that can be attended by a route [21]. Capacity or route length constraints limit the number of customers that can be served in a given route.

The transportation decisions associated with low value - high time sensitive products (2), are driven by the necessary replenishment frequency. This frequency can be determined by organizational issues (personnel assigned to receive orders on a given time/day), commercial activity (retailer limited shelf space), or product characteristics (perishable). Examples of this kind of activities include the urban distribution of newspapers, miscellaneous products to convenience stores, fresh baked bread, garbage collection services, replenishment of vendor machines, regular repair crews, etc. Deliveries are typically made with LTL (less-than-truckload) deliveries since the frequent delivery reduces the amount of the average order size. Routes tend to be planned in advanced and zoning or driver territory is also an important issue: Golden and Wasil report the importance of clustering in the soft drink industry [22]; Erkut et al. reports how Canada's largest publicly owned electric utility company redesigned its service-delivery network clustering facilities into call pools [23]. Route time length constraints usually limit the number of customers that can be served in a given route.

The transportation decisions associated with high value - high time sensitive products (3), are the most demanding activities in terms of transport service requirements. For products, order sizes are small and the most frequent delivery mode is package or direct delivery (courier) services. A Make to Order-JIT production fits in this category (e.g. Dell Computers) as well as emergency repair work. In many cases routes cannot be planned in advance and delivery points change constantly. Unlike the two previous cases, there may be exclusive service trips – one stop/customer only. The penalties for late deliveries are high. Lieb and Miller found that companies that implement JIT production systems place a great emphasis on evaluating carrier responsiveness to unexpected service requests as well as on time delivery performance [24]. Speed and reliability are the key routing constraints.

The first two routing types, (1) and (2), are static and allow the dispatcher to plan ahead. In contrast, vehicle routing problems in the third type (3) are dynamic, with requests that cannot be always foreseen. Part or all of the request information becomes available only during the day of operation.

The classification of commercial activity routing types is then used to model how technological changes may impact the generation of commercial truck flows. Having disaggregated commercial activity into significant routing types, it is possible to analyze how technological changes affect routing frequency, order size, and number of customers per route. From these route changes it is possible to infer how commercial activity truck flows may change. This paper focuses only on commercial commodity truck flows. The detailed study of commercial service truck flows is left as a future research topic.

4. Modeling Framework, Assumptions, and Notation

This paper focuses on one type of structure: a distribution or service center that provides to several retailers or customers. Within this basic distribution structure the number of retailers/customers in a given route can increase or decrease due to economical or technological reasons. This configuration has been chosen because recent studies in urban areas in the United States have shown that deliveries from distribution canters (DC) or warehouses have one of the largest impacts on vehicle miles traveled (VMT) in urban areas [25]. On the service side, the commercial vehicles with the largest impact on VMT are business and personal service vehicles, rental cars, and public service vehicles [25] which mostly operate from a central depot. The one to many model is not only ubiquitous but also represents distribution activities of hypermarkets, distribution centers, producers, and repair service centers while keeping analytical complexity at a tractable level.

Since carriers' operational aspects and behavior have been mostly neglected in the freight modeling literature, this work emphasizes the role and importance of routing. Therefore, cost, capacity, and time elements that condition and constrain carriers' routing decisions are explicitly incorporated in the model. It is assumed that retailers, customers, or specific business settings define the characteristics of the service such as order size, frequency, or time windows (the demand for freight transportation is a derived demand). Accordingly, routes are delineated in order to satisfy these requests by the central distribution or service center.

Given one vehicle and a set of costumers, the routing problem where one vehicle must visit each and every costumer exactly once is denoted as the traveling salesman problem (TSP). This problem is notoriously difficult to solve optimally, i.e. to find the best sequence to visit customers in order to minimize costs. However, if only the total distance traveled is needed (not the sequence information), fairly good approximations can be obtained with a simple formula. Several approximations have been proposed in the operations research (OR) literature ([26],[27],[28]). Assuming that a set $\mathrm{R} = \{req_1, req_2, ..., req_n\}$ of requests is randomly and independently dispersed over an area A and denoting the optimum traveling salesman tour length as $L(\mathrm{R}, A)$, for a reasonably compact and convex area, the following approximation formula is proposed by Larson and Odoni [27]:

$$E[L(R, A)] \approx k\sqrt{nA} \qquad (1)$$

where $k \approx 0.765$ and $n = |R|$.

As long as feasibility is satisfied, economies of density are achieved because route length grows slower than the number of customer requests served. The same type of expression but with a different value of k can be obtained for Manhatan or L1 metric. More constrained problems have equal or larger solution costs as shown by Haimovich and Kan [29] for the capacitated vehicle routing. Simulations performed by Chien [30] show that expression (1) is a robust and accurate approximation to the length of a TSP.

Without feasibility constraints, the cost of routing customer requests as expressed in expression (1) is sub-additive. This is reasonable because, all things being equal and without feasibility constraints, routing costs per customer tend to decrease on average as more customers can be included in a given route and area. Expression (1) is used in this research as a continuous approximation of the length of TSP tours in order to analytically determine how technological changes and trade-offs between transport and inventory costs affect the demand for transport. A similar modeling approach has been used to solve and gain insight into numerous logistics problems. A detailed compilation of such models is presented by Daganzo [31] who also presents an extensive analysis of approximation formulas for TSP.

Summarizing, the following assumptions are made in this research:

- The cost formulation is for a generic multi-stop tour, delivering shipments from a single distribution/service centre to several retailers/customers;
- Route distance is approximated with a routing cost expression similar to (1);
- A single product or service is distributed;
- Delivery or service areas are fixed;
- Route and delivery/service frequency f is determined by the type of commodity or activity;
- The distributor/service center owns/operates the fleet (private carrier);
- A cluster first, route second method is used to divide distribution/service center influence area A into m delivery regions $\{A_1,...,A_m\}$ where $\mathrm{A} = (A_1 \cup A_2 \cup ... \cup A_m)$ -- the delivery regions similar size and customer density
- Customers/retailers are identical; and
- Truck deliveries are randomly scattered over the delivery region served.

Notation

$A =$ Area of a generic area $A \in \mathrm{A}$ that has a set of costumers R and a delivery route with $n = |\mathrm{R}|$ stops, each customer has a demand d and an order size q.

$m =$ Number of areas.

$f =$ delivery/service frequency for area A.

$r =$ Line-haul distance from the distribution centre to A or the vicinity of the stops.

$\overline{r} = \dfrac{\sum_m r_m}{m} =$ Average line-haul.

$\sum_n d_i = D =$ Total demand in area $A \in \mathrm{A}$.

$\sum_{n} q_i = Q =$ Total order size in area $A \in$ A .

V $= \{v_1, v_2, ..., v_L\} =$ Ordered set of possible vehicle sizes.
$c(v_l) =$ Truck capacity for type v_l, with $c(v_k) < c(v_l)$ for any $v_k < v_l$.
$s(v_l) = s =$ Average truck speed for any type of truck v_l.

t = Time available for truck operations (i.e. driver maximum working hours per day minus lunch or mandatory breaks).
t^{TW} = Time available given by the time window length, in general time windows are more restrictive than working hours: $t^{TW} < t$.
t_l = Time to load a unit of product into the truck.
t_u = Time to unload a unit of product from the truck (loading/unloading times are highly dependent on the loading/unloading equipment used -- manual, forklift, conveyor, etc -- and the distance to/from the truck to the receiving area).
t_{or} = Fixed time needed for order receiving when stopping at the retailers (this time includes order receiving, order checking/inspection, paperwork and documentation, etc).

$c_d^d(v_l) =$ Cost/distance when using truck type v_l, this cost includes variable costs like fuel, maintenance or tires, with $c_d^d(v_k) < c_d^d(v_l)$ for any $v_k < v_l$.
c_t^d = Cost/time on the route, this time includes driver's time cost mostly. Inventory in transit cost is not considered due to the short journeys of urban deliveries.
c_o^d = Distributor order preparation cost, this cost includes preparation of route and shipping documents, notify driver, etc.
c_{ol}^d = Distributor loading cost per unit of cargo, this cost includes packing and loading truck costs during time t_l .

c_u = Product unit cost for the distributor and retailer (assumed in the same company).
c_f^r = Freight cost per order/stop, paid by the retailer (transportation cost only).
c_{fu}^r = Freight cost per unit of product delivered, paid by the retailer (transportation cost only).
c_o^r = Fixed cost per order placed paid by the retailer, this cost includes employee time for clerical and administrative tasks plus the cost of order submission (phone, fax, EDI, email, etc).
c_{ou}^r = Cost per unloading, handling, and storing each unit of product during time t_u .
c_{or}^r = Fixed cost per order receiving which includes employee time (t_{or}) per order receiving, checking/inspection, paperwork and documentation.
$h = h_i^r = h^d$ = Inventory holding costs at retailer i or central distributor .

Basic Relationships

$T = m\, f =$ Total number of trips per unit time

$f = \dfrac{d}{q} =$ Frequency for commodity based cases (frequency is given externally for services).

Using equation (1), the distance per route per unit time is the following:

$z = \dfrac{d}{q} 2r + \dfrac{d}{q} k\sqrt{nA} =$ total distance per unit time area $A \in \mathrm{A}$.

$Z = \sum_m z_m = \dfrac{md}{q} 2\bar{r} + \dfrac{md}{q} k\sqrt{nA} =$ total system distance.

The distance per unit of time per retailer is equal to:

$$\frac{Z}{mn} = \frac{md}{mnq} 2\bar{r} + \frac{md}{mnq} k\sqrt{nA} = \frac{d}{nq} 2\bar{r} + \frac{d}{q} k\sqrt{\frac{A}{n}} \qquad (2)$$

This is a measure of the efficiency of the distribution system. As the number of customers per route n increases, the distance per unit of time per customer decreases (economies of scope). As the order size q increases the distance per unit time per customer decreases (economies of scale). Therefore, as n and q increase the negative impact of the distribution center on urban traffic *decreases* ceteris paribus. Conversely, as n and q decrease the negative impact of the distribution center on urban traffic *increases* ceteris paribus.

As mentioned in the previous section, a route can be constrained or unconstrained. In the former case, typical constraints present in urban operations are capacity and route length constraints. Using previous notation these constraints can be expressed as:

$$\sum_n q_i = Q \le c(v_l) \qquad (3)$$

$$\frac{1}{s}(2r + k\sqrt{nA}) + nt_{or} + t_u Q \le t \qquad (4)$$

Total costs per full truck type v_l, per route, for the n customers in the area A can be expressed as $C_d(v_l, c(v_l))$ or simply as $C_d(v_l)$:

$$C_d(v_l) = c_d^d(v_l)(2r + k\sqrt{nA}) + c_t^d\left(\frac{1}{s}(2r + k\sqrt{nA}) + nt_{or} + t_u c(v_l)\right) \qquad (5)$$

Expression (5) includes all distributors' costs since the truck is loaded and leaves the DC fully loaded until it comes back empty after serving *n* customers. For a variable cargo size $Q < c(v_l)$, per route, for the *n* customers in the area *A* is:

$$C_d(v_l, Q) = [\, c_d^d(v_l)(2r + k\sqrt{nA}) + c_t^d\,(\frac{1}{s}(2r + k\sqrt{nA}) + nt_{or} + t_u Q)\,] \qquad (6)$$

The cost per stop or customer is:

$$\frac{1}{n}C_d(v_l, Q) = [\, c_d^d(v_l)(\frac{2r}{n} + k\sqrt{\frac{A}{n}}) + c_t^d\,(\frac{1}{s}(\frac{2r}{n} + k\sqrt{\frac{A}{n}}) + t_{or} + t_u q)\,]$$

$$= \frac{1}{n}C_d(v_l) \ + \ c_t^d\, t_u(q - c(v_l)/n) \qquad (7)$$

$$\approx \frac{1}{n}C_d(v_l) \qquad (7')$$

The expressions (7) and (7') are identical for a full truck load, which is a good approximation for high load factors. When this is the case, the value of q is close to $c(v_l)/n$. The only term in (7) that depends on the order size is that which relates to unloading costs. The cost per unit per costumer also shows economies of scale (8). Hence, if constraint (3) is satisfied, economies of scale can be achieved in expression (8) for all three terms: distance, time, and order costs.

$$\frac{1}{qn}C_d(v_l, Q) = \frac{1}{q}[\, c_d^d(v_l)(\frac{2r}{n} + k\sqrt{\frac{A}{n}}) + c_t^d\,(\frac{1}{s}(\frac{2r}{n} + k\sqrt{\frac{A}{n}}) + t_{or} + t_u q)\,] \qquad (8)$$

5. Commercial Commodity Flows

This section studies how logistics technology may affect commodity based truck flows. The study is undergone comparing two different technological scenarios for each of the three basic activity routing types described in section three.

The two technological scenarios are: a) providing a set of retailers without ASN[3] [32] and RFID and b) providing a set of retailers with ASN, RFID, and VMI central inventory control. Retailers and distributors are assumed to belong to the same company, however in scenario a) retailers determine order sizes independently (i.e. only analyzing their own inventory

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[3] Advance Shipping Notification: "Advanced shipment notifications are used to notify a customer of a shipment. ASNs will often include purchase order (PO) numbers, stock-keeping unit (SKU) numbers, lot numbers, quantity, pallet or container number, and carton number. ASNs may be paper based, however electronic notification is preferred. Advanced shipment notification systems are usually combined with bar coded compliance labeling that allows the customer to receive the shipment into inventory through the use of bar code scanners and automated data collection systems" (Piasecki, 2003, Glossary)

transport trade-off). In scenario b) the central distributor determines the order size of the retailer taking into account system wide inventory.

Low Value – Low Time Sensitivity (1)

a) Independent Retailers without ASN, RFID

In this scenario, each retailer and the distributor are different profit maximizing agents. Retailers' quantity and frequency (of orders) is set to minimize their purchase, inventory holding, and ordering costs. The costs incurred by retailer *i* per unit time can be expressed as the sum of purchase, holding, and ordering costs:

$$d(c_u + c_{fu}^r + c_{ou}^r) + \frac{qc_u h}{2} + \frac{d}{q}(c_o^r + c_f^r + c_{or}^r) =$$

$$d(c_u + c_t^d t_u + c_{ou}^r) + \frac{qc_u h}{2} + \frac{d}{q}(c_o^r + C_d(v_l)/n + c_{or}^r) \qquad (9)$$

where $c_f^r = \frac{1}{n} C_d(v_l)$, $c_{fu}^r = c_t^d t_u q$ from expression (7'). Minimizing costs (9) over q:

$$q_{1a}^2 = \frac{2d_i(c_o^r + C_d(v_l)/n + c_{or}^r)}{hc_u} \qquad (10)$$

The optimal order size is in this case is denoted q_{1a}. Truck flows decrease as the order size increases. Higher truck flows are expected as products become more expensive or when distribution and ordering costs are relatively inexpensive.

b) Under VMI – centralized ordering – with ASN, RFID

Up to this point changes that can be brought about by technology have been ignored. Information and communication technologies (ICT) have a major impact on processes or transactions that can be accelerated or performed automatically. It also allows for efficient and economical transmission of information and centralized decision making. In this context, it is possible to set an ordering policy that take into account the distributor and retailer echelons simultaneously. If the distributor owns the retailers, the distributor tries to minimize total system distribution and inventory holding costs. Furthermore, under VMI policies the distributor or manufacturer is responsible for inventory decisions at the retailer level, therefore retailer ordering costs are eliminated.

If the distributor tries to minimize total system costs, it must take into account the amount of inventory held at the distribution center too. This inventory is accounted for using a multiplicative coefficient $a \geq 1$ and accounts for the inventory held at the distributor due to the lack of coordination between inbound/outbound shipments that are arriving (leaving) to (from) the distribution center. With perfect coordination (efficient cross-docking for example) the value of $a = 1$. However, for other settings such as: a) the distributor holds inventory (e.g. inbound order size higher than outbound sizes), b) inbound/outbound schedules are uncoordinated, or c) the distributor is also a producer of the product, a value of $a \geq 2$ is possible as indicated by Burns et al. [33].

Tasks that mostly require data manipulations, verification, or updating are those tasks which fall in a position to greatly benefit from ICT advances. In these kinds of tasks, denoted *data oriented*, human processing can be eliminated or greatly reduced thus dramatically lowering execution times. On the other hand, for tasks that mostly depend on physical manipulation of the cargo or products, the benefits of ICT are obtained indirectly through better system coordination or incremental improvements in handling processing techniques or equipment. The latter kinds of tasks are denoted as *physical tasks.*

Using EDI or a web based system a retailer can place an electronic order directly into the distributor's system. The distributor's system electronically confirms the order and transmits information about the order to the distributor's shipping and accounting departments as well as to the carrier. The carrier's system electronically confirms the pickup and provides the distributor and retailer with pickup and delivery information respectively (information includes date, time, and other details of the upcoming pickup/delivery). Close to pickup/delivery time an updated ASN is placed and the shipping/receiving departments can prepare to ship/receive the order (assign docking area, equipment, personnel, etc.). All these information processing and transmission tasks can be achieved without any significant human intervention. When the carrier arrives, using RFID (or at least scanning) the order received is matched against the purchase order and invoice reference, thus saving inspection and document processing time. Once the system is in place and working, the marginal costs of order processing can become negligible. The data oriented costs that can be significantly reduced using VMI, EDI, ASN, and RFID are: c_o^d (distributor order preparation cost), c_o^r (retailer ordering cost), c_{or}^r (retailer order receiving cost). Once the systems are installed and fully operational, the ordering operating costs are assumed negligible. The time per stop is also reduced by eliminating the paperwork, therefore the contribution of time t_{or} to the route costs are discounted. Systems costs can be expressed as:

$$n[d(c_u + c_{fu}^r + c_{ou}^r) + \frac{a\,qc_u h}{2} + \frac{d}{q}(C_d(v_l)/n - c_t^d\, t_{or})]$$

The order quantity that minimizes systems costs is:

$$q_{1b}^2 = \frac{2d\,(C_d(v_l)/n - c_t^d\, t_{or})}{a\,hc_u} \qquad (11)$$

Order size $q_{1b}^2 < q_{1a}^2$ always; the numerator of expression (10) is larger than the numerator of (11) and the denominator of expression (10) is smaller than the denominator of (11).Therefore, truck traffic flows will increase when ordering/receiving tasks are performed automatically.

Second order technological effects

The technological improvement described in part b) will not only bring cost reductions but also important savings in time. The fixed time for order receiving (t_{or}) can be significantly reduced with ASN and RFID technologies. In urban deliveries this is an important item since the number of stops can easily be in the dozens ($n \geq 25$) depending on the type of commercial activity. The vehicle routing literature report that $n \approx 25$ is the median number of daily delivery services such as soft drink industry [34]. In order to get a sense of the savings, 5' savings per stop in a route with 25 customers represent 26% of an 8 hours driver working day.

For the sake of simplicity, it will be assumed that the fixed time due to order receiving can be eliminated as in expression (11), however, the variable time and cost associated with the physical unloading of the cargo remains. Reducing delivery times reduces delivery costs; which in turn results in smaller order sizes and more truck traffic. Technological improvements (VMI, EDI, ASN, and RFID) have led to a simultaneous reduction in order size, costs, and route time length. However, neither the fleet, nor route, nor customers have changed.

Ex-ante (before introducing technological improvements), a rational distributor/carrier has chosen the truck type that minimizes costs with order size nq_{1a} per route. Ex-post (after introducing technological improvements), a rational distributor/carrier will reconsider routes and truck sizes. Since the cost of routing additional customer requests is sub-additive, for any given truck size, costs are minimized while including as many customers as possible per route. Hence, for any truck type, the carrier will add as many customers per route as possible until either constraint (3) or (4) is binding. Two situations may arise: the original route was bounded by the capacity constraint (3), or the original route was bounded by route time length constraint (4). These second order effects are analyzed next.

Relaxing capacity or route length constraints

If the original route was initially bounded by capacity constraints, after the introduction of technological improvements the capacity constraint is no longer binding. If the original route was at first bounded by time length, after the introduction of technological improvements the length constraint is no longer binding. In this case, the carrier can serve more customers along the route until the constraint is binding.

The carrier has two distinct options:

- Leave the routes intact and decrease the truck size of the fleet until a constraint is binding again; since $c_d^d(v_k) < c_d^d(v_l)$ for any $v_k < v_l$, smaller trucks will decrease operational costs and transportation cost per customer.
- Leave the original trucks but increase the number of customers served per route (if possible) until a constraint is binding again; due to its sub-additive property transportation costs per customer are going to decrease if more customers are added to the route.

In either case the decrease in transportation costs will lead to a decrease in order sizes and to a new constraint relaxation and so on until convergence is reached (ultimately, the spiral down effect will be limited by available truck sizes, or constant cost/distance elements such as r).The maximum number of extra customers $x^* = \min(x_T^*, x_Q^*)$ that *can be added* to the route is determined by:

$$x_q^* \in \underset{x \in \mathbb{N}^+}{\arg\max}\; n\, q_{1b}(1+x) \leq c\,(v_l) \qquad (12)$$

$$x_T^* \in \arg\max \frac{1}{s}(2r + k\sqrt{(n+x)A(1+x/n)} + t_u q_{1b}(n+x) \le t \qquad (13)$$

$$x \in \mathrm{N}^+$$

Low Value – High Time Sensitivity (2)

In this type of activity replenishment frequency is given by the commercial activity itself. With frequent replenishment, time length constraints are expected to be binding. The analysis is similar as the one already performed for activity type (1).

Ex-ante (before introducing technological improvements), a rational distributor/carrier has chosen the truck type that minimizes costs and can serve as many customers as possible for the demanded frequency of delivery f . Ex-post (after introducing technological improvements), a rational distributor/carrier will have reconsidered routes and try to take advantage of the additional time. Since the cost of routing additional customer requests is sub-additive, for any given truck size, costs are minimized while including as many customers as possible per route. Hence, for any truck type, the carrier will tend to add as many customers per route as possible until constraint (4) is binding.

If n increases then the distance per unit time per retailer decreases as indicated by expression (2). This is a noteworthy outcome since the impact of technological changes has the *opposite sign* on the generation of truck flows.

It follows that the same technological changes have a beneficial or detrimental impact on the generation of truck flows *depending on the activity routing type*. As in the previous analysis, the magnitude of the change in truck flows will be influenced by the number of existing stops and the amount of time that can be saved with the introduction of new technologies. It still holds that for routes with $n \approx 25$ a savings of five minutes per stop represents a total time savings of approximately 26% of an eight hour driver working day. This saved time can be used to add more customers per route.

Relaxing capacity or route length constraints

If the original route was at first bounded by time length, after the introduction of technological improvements the length constraint is no longer binding. In this case, the carrier can serve more customers along the route until the constraint is binding again.

If the original route was initially bounded by capacity constraints, the introduction of technological improvements alone will not lead to a higher number of customers per route. If capacity is binding, the carrier has two distinct options:

- Leave the routes intact, or
- Increase the truck size of the fleet until a constraint is binding again. This is based on the fact that $c_d^d(v_k) < c_d^d(v_l)$ for any $v_k < v_l$, larger trucks will increase operational costs while more customers per route will decrease the distance traveled per unit time and customer (due to the sub-additive property).

The trade-off between higher truck operating costs and savings due to decreased distance per customer determines if larger trucks are cost-effective (this is only relevant when capacity is binding in low value – high time sensitivity activity-routing)

As in low value – low time sensitivity activity routing, the technological improvements may also bring about a reduction in distribution costs. However, the reduction is expected to be more significant when the binding constraint is only route length; more customers can be added without a required increase in truck size. Expressions (12) and (13) still apply but with the addition of the trade-off between trucks operating costs and distance if the capacity constraint is binding. It follows that the same technological changes can have a different impact on truck flow generation *depending not only on the activity routing type* but also on the kind of constraint that is binding.

High Value – High Time Sensitivity (3)

In this type of activity, routing is not constrained by capacity or route time length; rather they are constrained by tight time windows. Customer requests or delivery locations are not regularly scheduled but rather appear dynamically as carrier operations unfold (not all customers are visited in a regular basis or at regular times). Routes are changed or planned on a day-to-day basis or several times per day. The carrier's focus is on short delivery times or satisfying on-time delivery performance. Typical examples of this kind of activity are express package service, parcel pick-ups or delivery problems. For example, next day express *deliveries* usually require a time window determined by: a) the ending of hub sorting activities or earliest business (consignee) operating hours (whichever is the latest) and b) latest delivery time (usually before midday). Conversely, time windows for *pick-up* operations are determined by: a) either the drop box, agent cut-off receiving time (usually around 5pm) or shipper pick-up location (whichever is most constraining) and b) latest delivery time that will not delay hub sorting activities or inter-hub departing flights [35].

In general, time windows for high value - high time sensitivity activities are more restrictive than working hours: $t^{TW} < t$. Two consequences of this higher level of temporal restrictions are: a) the usually binding constraint is time windows rather than capacity and b) the number of customers served per route tends to be smaller than in routes for activity routing types (2). The latter easily follows from the analysis of constraint (4). *Ceteris paribus* the number of customers served in an activity-routing type (3) is less or at most equal than the number of customers served in an activity-routing type (2) when $t^{TW} < t$.

The analysis of activity routing type (2) in regards to route length and capacity relaxations applies to activity routing type (3) but taking into account that $t^{TW} < t$. Therefore, in a deterministic setting an analysis similar to the one applied to activity routing type (2) can be applied to activity routing type (3). However, reliability, the most fundamental service dimension in this activity routing type is missing in expressions (12) and (13). This service dimension cannot be captured within the deterministic modeling framework presented in this research. The impact of variability and uncertainty on different routing types is analyzed in a companion paper [36].

Discussion

The effects of the analyzed technology on truck flows are dependent on the activity type and the route constraints. For low value-low time sensitivity products, a reduction in order size will generate more truck flows per unit time as shown in expression (2). This finding agrees with the notion that as more industries move towards JIT environments (with smaller order sizes), there is an increase in the generation of truck flows. On the other hand, if the routes are mainly constrained in their time length, the reduction of delivery times will increase the number or customers per route and consequently decrease truck flows. This is also the case for frequency driven low value-high time sensitivity activities. For activities that are *already* operating in a JIT or make to order environment, speed in delivery is a key element. The studied technological effects may have already been incorporated in the operation of this type of production-distribution system.

Second order effects can be staggered and this is what can make their measurement or detection difficult. Operational changes (routes changes or driver working extra hours) can be readily implemented. Tactical (change vehicle size) or strategic (change/add warehouse location) changes can take months or years to be fully implemented. Unfortunately, the intuition provided by the model is not readily confirmed or denied due to lack of data; in most countries city logistics data collection is incomplete at best or simply inadequate [37].

One implication of this research on urban freight data collection efforts and modeling practices is the need to disaggregate the study and modeling of urban freight activities across relevant factors. This research provides an initial attempt to disaggregate by type of commercial activity, routing, and constraints characteristics. Further research is needed to elucidate a parsimonious list of factors and models that can accurately represent the different types of urban freight movements. The complexity of data collection and modeling in urban freight are noteworthy issues, but they are beyond the scope of this research. A new level of urban freight data collection and modeling is necessary to understand the relationships between commercial activities, route designs, constraints, number of customers per route, and vehicle types.

Several assumptions were made in this research (see page 8). An effort was made to incorporate essential details of activity-routing types and limit the complexity of the modeling to allow the derivation and study of analytical expressions. A significant assumption in this research is the usage of a deterministic modeling framework. As not all urban distribution settings can be reasonably modeled without uncertainty or variability, the impact of variability and uncertainty on different routing types must be further analyzed.

6. Conclusions

This research contributes to the field by proposing a novel and detailed characterization of truck flows in a supply chain context. Using well-known yet simple models and formulas from vehicle routing, operations research, and management science literature, this research derives behavioral insights about distributors and carriers' routing and order sizing decisions. Routing constraints and second order effects show strong evidence of being important drivers of truck flows, especially for low value-low time sensitivity commodities.

The emphasis on understanding changes in truck flows in urban environments is novel. Despite the simplicity of the distribution model presented, important intuitive results can be obtained from its analysis. The detailed level of analysis of distribution costs and times is important when analyzing the effects of ICT technological advances. Clearly, the reduction of order costs and fixed order receiving times can have an important effect on distribution systems, especially where routes already include a large number of customers. As important is the correct determination of the relevant commercial activity types.

The combination of routing constraints and second order effects is a novel insight and shows the complexity of the urban freight modeling task, even in a completely deterministic environment. Important assumptions are made about the distribution system including one commodity type, constant deterministic travel times and demand rates, and lack of time windows. Further research is needed to understand supply chain agents interaction in less restricted environments.

A large amount of research is needed to better understand freight and supply chain behavioral aspects in the urban environment. Given the optimization driven approach that prevails in supply chain operations, contributions from the vehicle routing, operations research, and management science literature need to be incorporated into freight behavioral models and analysis. The main contribution of this research is to bring a new perspective and deeper level of operational decision-making analysis to cope with the intricacies of freight transportation modeling.

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List of Tables

		Time sensitivity	
		High	**Low**
Commodity or Service Value	**Low**	(2) LTL delivery mostly Service trip chained Frequency determined by organizational issues, industry type, or product characteristics. Regular Routes Usually time constrained only	(1) TL or LTL delivery Make to Stock Trade-offs between Inventory/Transport trade-off (EOQ) drives delivery frequency Regular routes Capacity or Time constrained
	High	(3) Package or direct delivery mostly Exclusive service trips Make to Order-JIT Delivery times or time windows drive routing decisions Irregular customers/routes	(4) Atypical combination

Table 1 Routing characteristics of commodity or service activities according to their time sensitivity and value