

ENABLING THE FREIGHT TRAFFIC CONTROLLER FOR COLLABORATIVE MULTI-DROP URBAN LOGISTICS: PRACTICAL AND THEORETICAL CHALLENGES

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ABSTRACT

There is increasing interest into how horizontal collaboration between parcel carriers might help alleviate problems associated with last-mile logistics in congested urban centres. Through a detailed examination of parcel logistics literature pertaining to collaboration, along with practical insights from carriers operating in the UK, this paper examines the challenges that will be faced in optimising multi-carrier, multi-drop collection and delivery schedules. We propose the concept of the ‘Freight Traffic Controller’ (FTC) who would be a trusted third-party, assigned to equitably manage the work allocation between collaborating carriers and the passage of vehicles over the last mile where joint benefits to the parties were achievable. Creating this FTC requires a combinatorial optimisation approach to evaluate the many combinations of hub locations, network configuration and vehicle/walking routing options in order to find the true value of each potential collaboration, whilst at the same time, considering the traffic, social and environmental impacts of these activities. Cooperative game theory is a way to investigate the formation of collaborations (or coalitions) and our analysis identifies a significant shortfall in current applications of this theory to last-mile parcel logistics. Specifically, we identify that application of theory to urban freight logistics has, thus far, failed to account for critical concerns including: i) the mismatch of vehicle parking locations relative to actual delivery addresses; ii) the combination of deliveries with collections, the latter often being received in real-time during the round; and iii) the variability in travel times and route options due to traffic and road network conditions.

INTRODUCTION

The parcel distribution sector is a crowded and highly competitive marketplace characterised by low profit margins and a proliferation of operators, with carriers typically operating independently from each other, leading to poor vehicle utilisation rates and delivery rounds that overlap (1). With this duplication of effort, as ‘everyone delivers everywhere’, and the need to reduce CO₂ in urban centres, driven by EU legislation (2), there is a need to fundamentally reinvestigate the efficiency of ‘customer-focused’ last-mile city logistics operations. We make three contributions in this paper: firstly, we offer a detailed examination of the literature pertaining to collaboration in last-mile parcel logistics; secondly, using our survey along with practical insights from two carrier operations in the UK, we identify key challenges that will be faced in attempting to best optimise multi-carrier, multi-drop collection and delivery schedules whilst maintaining an equitable distribution of work between the parties in the collaboration; finally, we highlight the significant gap between current theory and practice in this regard and introduce the concept of the Freight Traffic Controller as a mechanism for overseeing the management of collaborative relationships in this sector.

BACKGROUND

Freight transport makes up 16% of all road vehicle activity in UK cities, with lorries and vans performing 30% of their total movements in urban areas (3). Unlike many other sectors, the freight industry has few barriers to new entrants, particularly in the parcels sector, where anyone with a van and a standard car-driving licence can operate. Over the last ten years, van traffic has increased by almost a fifth and is forecast to grow in the UK’s biggest cities (1, 3). This growth has been attributed to: i) new methods of buying goods, particularly online shopping, where UK retail parcel deliveries increased by 15.7% in 2015 compared to the previous year, with just over one billion parcels delivered (4); ii) just-in-time procurement resulting in less-efficient, small-package flows to consumers; iii) increasing demand for servicing functions where the service rather than goods transport is the primary purpose of the vehicle activity (1). The resulting experience for those who live and work in inner-urban areas is a multitude of carriers competing over the last-mile for scarce kerbside space and adding to traffic congestion and pollution.

Characteristics of Multi-Drop Parcel Operations

The UK domestic parcels distribution sector generated almost £9 billion in revenue in 2015 with business-to-business (B2B) accounting for 54% of this; business-to-consumer (B2C), 34%, and consumer-to-all-parties (C2X), 12% (5). With B2C and C2X parcel deliveries accounting for almost two-thirds of UK parcel volume and expected growth of around 5% per annum (6), the shift towards the relative importance of B2C and C2X sub-markets is resulting in the need for greater parcel handling capacity, requiring carriers to invest in their delivery networks, depot infrastructure, vehicle fleets and supporting technologies. Although there are a small number of multi-drop carriers with very large vehicle fleets, there are many smaller players, often self-employed, who either directly compete or work for larger operators on a casual basis. The level of competition in the parcels sector has resulted in reduced revenue per delivery for carriers (7) and the pressure on delivery rates seems likely to continue, as the parcel distribution sector becomes increasingly crowded with the entrance of other non-traditional players such as Amazon and Uber. As a consequence, parcel carriers will need to better control their operational costs while, at the same time, make infrastructural investments to remain competitive (8).

Parcel carriers offer a wide range of services which cover immediate, same day, next day and ‘standard’ delivery (e.g. 3-14 days), all of which may have guaranteed delivery time windows. Services also vary in terms of geographical coverage and scope (e.g. local, regional, national,

international). Analysis of UK parcel deliveries suggested that 42% of orders despatched to consumers in September 2015 were sent 'economy' (i.e. with no assured delivery lead time, no specific delivery day or time-slot); 30% were despatched for next day delivery; 4% were despatched using other services (including same day, next day before 12:00, next day after 12:00, next day after 17:00, and Saturday or Sunday delivery); while 24% were despatched internationally (4).

To meet these differing customer demands, multi-drop operations can take several different forms. A parcel service based wholly within one city is likely to make use of a single depot from which multi-drop vehicle rounds are performed. Meanwhile, national or international carriers will typically make use of hub-and-spoke networks (which are likely to be multi-modal if distances are significant) in which central hubs and regional/local distribution centres are operated, with large, fully-loaded vehicles operating between hubs and other distribution centres, and smaller vehicles used to perform multi-drop rounds for last-mile delivery. Parcel carriers typically operate their last-mile vehicle rounds out of local depots with vehicles undertaking deliveries to customers as well as collections, the latter being a mixture of pre-planned and sometimes ad hoc requests received during the round. Vehicle rounds are typically organised by geographical area (e.g. sub-postcodes) with loads grouped according to maximum vehicle capacity (either by volume or by weight) and the round order dictated by any premium deliveries that are subject to a specified delivery time window.

Vehicle drivers can have a considerable amount of say in the final round structure with some carriers leaving the route order entirely to their discretion as they believe the driver is best placed, in terms of their extensive local knowledge and experience, to negotiate the intricacies involved. Indeed, anecdotally, round planning software can produce less efficient routes than actual routes by failing to adequately capture the operating practices of experienced drivers. For this reason, many multi-drop parcel carriers keep the same drivers allocated to the same geographical areas not only to acquire the detailed route knowledge but to build personal relationships with regular clients. Going against this are the newly emerging 'lifestyle couriers' who are self-employed owner-drivers working on a freelance basis for parcel carriers, providing last mile delivery on behalf of a carrier in a designated area and paid on a per-delivery basis. The subtleties of individual customer delivery characteristics combined with dynamic collection requests during the round, parking, access restrictions and traffic congestion means that the optimisation challenge facing schedulers in this domain can be considerable.

Current Challenges Facing Multi-Drop Parcel Carriers

The growth in e-commerce and the ability to receive goods within a matter of hours after ordering has placed considerable pressures on the logistics industry. The situation has been further exacerbated by many retailers offering 'free' delivery options to their customers in order to attract custom and requiring carriers to accept later cut-off times for next day delivery to gain customer share (9). A study of 239 UK retail websites, in 2014, suggested that 70% provided free delivery on minimum order thresholds from as low as £10 (10), forcing carriers to adopt low pricing models (11). In addition to these retailer-driven pressures, individual customers are demanding ever faster, more reliable and convenient services that have led carriers to develop and expand timed delivery window options, parcel traceability throughout the supply chain and alternative delivery options, including attended collection points and unattended locker banks, all of which have considerable investment implications (12, 13). Servicing these options, particularly during retailer driven 'shopping frenzies' such as 'Black Friday' and 'Cyber Monday' (9) can lead to inefficient logistics practices with many vehicle trips being duplicated across urban centres as carriers attempt to honour service agreements. Tied to these events are the underlying issue of carriers having to also manage returned products, especially from online B2C and C2X parcel flows, and an average first-time delivery failure rate of 13-14% (14) with additional implications for logistics planning and delivery efficiency.

From a city authority's perspective, this climate is creating added pressure on street performance with van traffic in London projected to increase by 20% by 2030 and road conditions (e.g. vehicle delays) worsening (15). The climate is therefore right for carriers and local authorities to reassess how they can best operate in urban centres to still meet customer demands whilst reducing costs. Collaborative working and the concept of the 'carriers-carrier' is now being actively pursued by some parcel carriers (16) and such enterprises can be of a wider benefit, reducing vehicle numbers and related congestion.

COLLABORATIVE WORKING BETWEEN PARCEL CARRIERS – THEORY AND PRACTICE

We undertook a critical review of academic literature and industry case study reports relating to parcel carrier operations and collaboration in the freight industry, supported by operational audits of two major UK-based parcel carriers, including face-to-face interviews and ethnographic observation of couriers on delivery rounds to gain a better understanding of practical working requirements, issues and constraints.

Approaches to Collaboration

Traditionally, parcels carriers have viewed each other as competitors and have not countenanced the concept of collaborating in last-mile operations. Collaboration is possible when two or more actors share their efforts to achieve a common objective and in transportation it involves a physical exchange of shipments between collaborating partners, who share material and immaterial resources in the form of logistics facilities, vehicles, information as well as planning and optimisation methods (17). Unlike vertical collaboration, which involves partners positioned at different levels of a supply chain (18, 19), horizontal collaboration aims to identify and achieve win-win situations (e.g. improved optimisation, loaded capacity and asset utilisation (20, 21)) between organisations that may or may not be competitors operating at the same level of a supply chain.

In the 'carriers-carrier' model, one carrier hands over parcels to another who may be better placed to make the final deliveries due to either the geographic location of their depot infrastructure or their fleet characteristics (e.g. using electric vehicles, which may be better suited to the task where preferential access and parking conditions are available for environmentally-friendly vehicles.) Such collaborative services exist and are well used by major carriers for the Scottish Highlands and Islands, and the Isle of Man, both of which comprise depopulated areas with poor road networks as well as the need for sea crossings (22, 23). Such horizontal collaborative practices lead not only to lower shipping costs and quicker delivery service but also allow companies to reduce the environmental impact of their distribution activities (24).

The two main approaches to horizontal logistics collaboration are order sharing and capacity sharing (25). The former involves the exchange of customer requests for transport services between participants of a cooperative network of carriers, and is achieved through one of the following techniques: joint route planning, auction-based mechanisms, bilateral lane exchanges, load swapping or shipment dispatching policies. The latter involves sharing vehicle capacities, rather than customer requests, and each participating carrier delivers its individual order set. A detailed discussion of techniques used by both horizontal logistics collaboration approaches can be found in (25), while Table 1 provides some example case studies found in the literature. The reported benefits of such partnerships include reductions in distance-based costs by up to 16% (24), environmental cost by 24% (24), and volume increases of 25% for cooperating partners (26) with the capacity sharing approach to horizontal collaboration being the more popular method.

TABLE 1: Examples of Horizontal Collaboration Practices of Freight Transport Operators

Reference	Collaboration form and case study type (real or simulated)	Approach (capacity or order sharing)	Outcomes
Gonzalez-Feliu and Salanova (17)	Collaborative transportation sharing network where two out of five transportation carriers are collaborating (simulated).	Capacity sharing: Collaborating partners consolidate freight for the same destination, sharing their satellite depots and fleets.	Collaboration has some advantages but is not always the best solution for each criteria. Preferred solution for one operator does not necessarily coincide with the system's best solution.
Quak (26)	<u>TransMission case study:</u> Collaborative network of 16 independent transport and distribution companies with a central cross-docking hub (real). <u>Distri-XL case study:</u> Collaborative network of five carriers (real).	<u>TransMission case study:</u> Capacity sharing: At night, all deliveries are cross-docked between partners in the central hub and carried back to their own regions for final delivery. <u>Distri-XL case study:</u> Order sharing: Direct exchange of freight.	<u>TransMission case study:</u> More sustainable and efficient urban freight transport operations. Long distance transport (to and from hub) is completed off-peak (at night). <u>Distri-XL case study:</u> Reduction in km of 11% 25% increase in volume for all partners
Krajewska et al. (27)	Collaboration between three profit centres of a freight forwarding company (simulated but based on real data). Collaboration between two carriers (simulated).	Order sharing: Requests are exchanged between partners and a unique multi-depot pickup and delivery request with time windows (PDPTW) is optimised.	<u>Simulated but based on real data scenario:</u> One collaboration partner achieves almost 20% of cost savings and the other two partners save around 10% each. <u>Simulated scenario:</u> 10% reduction in the number of vehicles and 12.5% reduction in routing costs.
Dahl and Derigs (28)	Cooperative logistics network consisting of 50 express carriers (simulated but based on real data).	Order sharing: Requests are exchanged between partners with collaborative planning using cost-based compensation schema.	Application of the cost-based compensation schema allows the cooperative logistics network to achieve nearly all cost saving potentials and reach the cost level of centralized planning, while profit is distributed more fairly among all network partners.
Park et al. Jeong (29)	Courier, Express and Parcel (CEP) services provided by Cooperative Delivery Company (CDC) on behalf of four CEP carriers (simulated but based on real data).	Capacity sharing: Cooperative Delivery Company (CDC) combines and performs deliveries for participating carriers.	Cost savings in travel time, vehicles operating, traffic accident and environmental pollution.
Buijs and Wortmann (30)	<u>Case 1:</u> Collaboration between two autonomously managed	<u>Case 1:</u> Capacity sharing: Shipments are cross-docked	<u>Case 1:</u> Concentration of collection and delivery locations in the areas served

	divisions of logistics service provider (LSP) (real). <u>Case 2:</u> Collaborative transportation network involving about 150 autonomous carriers, called “member depots” (real).	and exchanged between collaborating divisions. <u>Case 2:</u> Capacity sharing: Collected shipments can be sent through the collaborative network (transported to the hub for delivery by another depot) or fulfilled by other means.	from each cross-dock. <u>Case 2:</u> Optimised resource utilisation.
Juan, et al. (24)	Cooperation of transportation firms based on backhauling (simulated).	Capacity sharing: Trucks and routes are shared by collaborating partners.	Reduction of distance-based and environmental costs by about 16% and 24% respectively. Reduction in the number of vehicles required.
Hernandez, Peeta and Kalafatas (31)	Collaborative network including five small-to medium-sized less-than-truckload carriers (simulated).	Capacity sharing: A set of collaborative routes are identified for a carrier to minimize the total cost to service its demand needs.	Reduction of the effects of delays by decreasing the amount of idle time at terminals. Potential reduction of deadheading and achievement of returns on excess capacity.
Buijs, et al. (32)	Collaborative transport planning for a joint network of two autonomous business units of a logistics service provider (simulated but based on real data).	Capacity and Order sharing: The joint network of two depots exchanging shipments. The best route for shipments to go through the joint network is determined -directly, via one or both depots.	Improved transport efficiency in terms of total travel distance.
Handoko and Lau (33)	Carrier collaboration for last mile delivery consolidation (simulated but based on real data).	Order sharing: Shareable orders identified by collaborating carriers can be consolidated with the other carriers’ shipments	- Reduction of the number of inter-zone journeys. - Cost savings to the participants as a result of lower fuel consumption and fewer man-hours.

Sharing the Benefits using Cooperative Game Theory

In order to find an optimal strategy for enabling fair and efficient collaboration between a coalition of stakeholders, we must consider some key questions:

- i) Who are the collaborating partners?
- ii) What resources does each partner have available to the collaboration (depots, vehicles, personnel)?
- iii) What is the geographical scope of the collaboration? For example are certain areas to be served solely by one of the partners?

- iv) What parcel volumes are to be transferred between partners and when/where/how will transfers take place? To what extent, will approximate volumes be known in advance, to allow effective planning?
- v) To what extent are transfers of parcels mandatory (e.g. due to a contractual agreement) or voluntary (e.g. where a freight exchange website service is used)?
- vi) What are the allocation rules in the collaborative relationship and how can a fair allocation be achieved? For example, shares can be determined by dividing the value of the collaboration equally amongst the partners, or proportionally, according to the value they bring or the cost they incur within the collaboration, including total cost or distance travelled.

Cooperative game theory is a way to answer some of these questions around the formation of collaborations (or coalitions) and the fair distribution of the benefits. For parcel deliveries, one possibility is that a number of different carriers work together towards a multi-carrier collaborative operation. Collaboration might also be a possibility across a carrier's carrier, tasked with performing the last-mile delivery operations. For any potential collaboration, cooperative game theory is concerned with two fundamental questions. The first is to find a coalition structure, i.e., clustering the *members* (or *players*) into *coalitions*. In particular, if a carrier i bears a cost $v(\{i\})$ in performing their delivery operations, and a carrier j faces a similar cost $v(\{j\})$ for their operations, it is expected that a coalition $S = \{i, j\}$ between these two carriers will result in a reduction of the overall cost $v(S)$ such that $v(S) \leq v(\{i\}) + v(\{j\})$, and similarly with coalitions with more than two members. The second question is to calculate a payoff vector that describes how to divide the value $v(S)$ of a coalition S amongst its members. In doing so, one must ensure that the allocations are *fair*, i.e., the payoffs reflect the contribution of each of the members, and that the coalition is *stable*, meaning that there is no incentive for any of the members to leave the coalition. The collaboration should not leave any carrier worse-off than if they were to operate on their own. Fairness and stability are needed for a collaboration to be able to sustain itself. Below are some of the concepts through which these questions, and in particular the calculation of the payoff vector, can be addressed (43):

1. For a given coalition C , the *Shapley value* calculates the payoff of each member of the coalition to be proportional to the marginal contribution of that member. If $v(S)$ is the value of a subset S of the set N of players, the Shapley value of player i is calculated as:

$$\sum_{S \subseteq N \setminus \{i\}} \frac{|S|!(|N| - |S| - 1)!}{|N|!} (v(S \cup \{i\}) - v(S)),$$

where $v(S \cup \{i\}) - v(S)$ is the marginal contribution of player i . This concept has been applied within freight forwarding operations to allocate the total cost of collaboration among multiple carriers (27). It has also been discussed within the context of shipper collaboration arising in full truckload logistics (45), but has not been applied to parcel logistics due to the inherent complexity of calculating this value. A more recent application has been described for collaboration within transportation problems (46), although the results provided therein are based on hypothetical instances.

2. The *Banzhaf index* is a similar measure to the Shapley value, defined individually with each player, and is calculated as follows,

$$\frac{1}{2^{|N|-1}} \sum_{S \subseteq N \setminus \{i\}} (v(S \cup \{i\}) - v(S)),$$

where the total marginal contributions are averaged across all coalitions of the game. We are not aware of any studies that use this particular mechanism for allocating costs within collaborative logistics.

3. The two measures described above do not guarantee that the payoffs generated using the marginal contributions will result in a stable coalition. Assume a collaboration S formed between parcel carriers, and that there exists a subset S' of carriers with a worse payoff than the value $v(S')$ of the subset, then there is an incentive for members of S' to deviate from coalition S and form a new one. The concept of *core* has been introduced to find a payoff that is stable and in which there would be no incentive to deviate from. In particular, for any set N of players, any non-negative payoff vector $x = (x_1, x_2, \dots, x_{|N|})$ that satisfies $x(N) = v(N)$ and $x(C) \geq v(C)$ for all subsets C of N is in the core, indicating that the core of a game is not a unique concept and that it might also be empty. Theoretical work exists on determining the core of routing games (47), as well as applications to illustrative examples (46). An application to a practical problem arising in collaborative full truckload logistics is described by Özener and Ergun (45). Other concepts such as the nucleolus, the kernel, the bargaining set and the stable set also exist (43).

Cooperative game theory has rarely been applied to the context of multi-drop operations between carriers where the combined scale of operations is significant (27, 44). One of the main sources of difficulty with finding a fair and stable allocation in a game is the calculation of the value of a collaboration, bearing in mind that there may be exponentially many coalitions that can be formed among a set N of players and in most instances, one would have to solve a combinatorial optimisation problem, such as hub location, network design, vehicle routing or a combination thereof, to find the value of each possible coalition. Existing studies that present algorithmic approaches for the problem of cost allocation have so far considered settings in which the underlying optimisation problem is simpler than what would arise in multi-drop parcel operations. For example, Özener and Ergun (45) describe cost-allocation mechanisms for an application arising in full truckload logistics, in which shippers collaborate to reduce their total transportation cost and increase the utilisation of the truck capacity of a carrier. The underlying optimisation problem is to cover all the deliveries from a given origin to a given destination using full truckloads, where the trucks do not visit intermediate locations. In the application described by Krajewska, et al. (27), every coalition gives rise to a multi-depot, capacitated pickup and delivery problem with time-windows, which is solved using a heuristic algorithm. Within cargo transportation (e.g. liner shipping or air cargo), there is scope for carriers to form alliances as a mechanism for collaboration but there is also very little literature available within this area of research (44). The literature is yet to see applications of game theoretic concepts to multi-drop parcel operations that fully take into account the characteristics and complexities of the underlying optimisation problems in such settings. We discuss what some of these characteristics would be, first at a strategic and tactical level, then operational, in the remainder of this section, with a particular focus on urban settings.

Strategic and Tactical Decision-making Challenges

Determining the most efficient collaboration requires effective business models for logistics and distribution management, for which decisions concerning the transfer of goods and resource utilisation need to be made at different levels. Strategic and tactical decisions need to be taken which generally pertain to (large-scale) distribution system design which may include: i) the location of hubs or warehouses; ii) the assignment of customers or districts to hubs; and iii) the amounts of flow at an aggregate level between the various points in the network, giving way to problems such as hub, depot or facility location (34) or network design (35). Particularly relevant to the design of multi-drop freight distribution networks in urban areas are the single and two-echelon distribution structures that have been suggested for city logistics applications (36, 37). The logic behind these is to prevent large freight vehicles entering busy urban areas by consolidating goods into smaller shipments at the boundaries from where deliveries into the city centre can be done using smaller and more

environmentally-friendly modes of transportation. When a distribution network is already in place, that is, the design of the network has been finalised, the next set of decisions at the tactical level concern producing a transportation plan that will operate in the medium-term. These decisions include: i) fleet composition and size; ii) selection of routes and schedules (i.e., ‘timetables’) for the larger vehicles operating between main depots or terminals; iii) synchronisation of vehicle operations between different echelons of the network and different vehicle types (e.g. transfers from lorries to electric vans); and, when appropriate, iv) the utilisation of the depots (36), but these decisions do not normally extend to last-mile delivery operations.

PUTTING PRACTICE INTO THEORY - OPERATIONAL DECISION MAKING

Operational decision-making, concerning the day-to-day scheduling and routing of smaller vehicles performing last-mile delivery to customers would normally be considered as a separate problem to be solved once the above strategic and tactical decisions have been made, and this is where the variability in the input data (e.g., demand) as well as various operational restrictions would normally be taken into account. While there is a rich and ever-growing literature base on vehicle routing and scheduling applications and solution methods (38), and a number of commercially-available software packages which use these solutions, there still remains a significant gap between theory (and the software packages based on this theory) and its practical application to the parcel distribution sector, confirmed through our dialogue with UK-based parcel carriers.

One of the main issues, seldom considered in theory or catered for within vehicle routing packages, is that parking directly outside the delivery address may not be possible, particularly on key arterial roads where parking may not be permitted. There can, therefore, be a significant element of walking between the vehicle and the delivery address and during one delivery round observed in the City of London, walking comprised a total of 3.4km of the total distance of 9.6km travelled (a ratio of walking to driving of 35% / 65%.) The carrier stated that vehicle routing software had significantly over-estimated driving distance as a result of being unable to model ‘final-approach’ walking. For practical use in dense urban environments, a dual-mode (driving and walking) routing model is warranted. Development of such a model would be challenging, given the level of detail required to specify and combine a walking network alongside the road network and to accurately represent parking locations and associated waiting time limits. In practice, this detailed knowledge lies with the courier who learns through experience the best locations to leave the vehicle, bearing in mind the likelihood of incurring parking fines, and what parts of the round are more suitable for walking than driving, considering the network topology (e.g. one-way streets) and access restrictions.

Further complexities of multi-drop parcel operations in dense city environments further challenge the capabilities of existing theory and software tools:

- i) Delivery rounds in many multi-drop operations are combined with collections. While most collections are known in advance and can be planned, some are dynamic in nature with collection requests being received from clients during the round and relayed to the driver who then determines if and how they can be incorporated. Such considerations require the solution of so-called dynamic or on-line vehicle routing problems (38), which assume that only some (or possibly none) of the input data are available at the time of planning the vehicle routes, and the rest of the data arrives over time, either regularly or at random intervals. Optimisation, in its traditional sense, does not apply to dynamic vehicle routing problems given the nature of the input data. Solution approaches are often based on re-optimisation of the problem, either at regular intervals or whenever new data are received, although this might be costly depending on the complexity of the particular problem to be optimised. Other approaches

- include using simple rules for inserting new requests into existing routes and planning the routes in anticipation of future requests, using historical data (39, 40).
- ii) Constraints related to time, both for customers (e.g. for premium deliveries) and for drivers (e.g. maximum driving time restrictions, breaks and shift changes).
 - iii) Travel times and route options may vary over time due to traffic and road network conditions. If such conditions are known in advance or can be predicted with good accuracy, a time-dependent vehicle routing problem can be solved in which the planning horizon is discretized into smaller time units, each of which reflects the traffic and road conditions (e.g. congestion, travel speed or travel time). If the data do not vary with time but change in a random fashion, then one would have to resort to using stochastic vehicle routing algorithms, in which data would be described in the form of a probability distribution. Stochastic vehicle routing problems can be formulated using chance-constrained linear programs, or two-stage stochastic programming formulations with recourse, but they are more challenging to solve compared with their deterministic counterparts (41).
 - iv) Access restrictions in urban areas might mean delivery routes that are longer than necessary, and traversed with variable speeds according to the traffic speed and road conditions. Both route length and vehicle speed are factors that affect the fuel consumption of a vehicle and emissions. In this case, the way in which clients are grouped into nodes, the order in which nodes are served, and the average speed on each segment of the route will need to be optimised so that driving time and fuel consumption can be minimised (42).

DISCUSSION AND CONCLUSIONS

There has been increasing academic interest into how horizontal collaboration between multi-drop parcel carriers might help alleviate the problems associated with last-mile logistics in congested urban centres. Cooperative game theory has been proposed as a way to ensure that the benefits from such collaborative logistics operations can be fairly distributed amongst the parties but the challenges facing businesses operating in this sector mean that these theories cannot truly represent operational reality. The fact that many parcel carriers operate legacy systems means that sharing and working with data can be problematic without considerable investment in data management systems. The often unique methods of operating, where collections can be managed dynamically in real-time as part of the delivery round, with drivers having autonomy in the last-mile round design, centred around 'final approach' walking itineraries, makes optimisation difficult.

Given these issues, one of the main problems experienced in forming collaborative relationships between parcel carriers is in the calculation of the value of the collaboration, particularly given that many different coalitions could form between a group of carriers. The dynamic nature of parcel distribution suggests these coalitions could change depending on the daily collection and delivery profiles presented, implying that they could become unstable as new opportunities arise between different parties. Such a problem requires a combinatorial optimisation approach to evaluate the many combinations of hub locations, network configuration and vehicle/walking routing options in order to find the true value of each possible coalition. Given that fairness and stability are key for a collaboration to be sustainable, there could now be a role for trusted third-parties to oversee and manage the collaborating partners in such coalitions, and allocate the work activity amongst them to better service their customers in our urban centres.

This concept of 'Freight Traffic Control' for an inner-city region would see the individual daily activity schedules from different carriers overseen by a third-party 'Freight Traffic Controller' (FTC) who would attempt to equitably manage the work allocation and the passage of vehicles over the last mile where joint benefits to the parties were achievable. Of interest here is to what extent the FTC could also dictate certain policies for the wider benefit of the urban area e.g. the use of certain drop

zones, or targeted retiming of activity. Using a FTC to oversee parcel carrier collaboration could have many benefits for the local environment and participating organisations but there would be several key issues to overcome in realising it at a practical level:

- 1) The FTC would need to have access to the collection and delivery schedules of the individual carriers within the coalition. This would require working with schedules in multiple formats as carriers tend to use their own legacy systems and agreeing a common interface around strict data handling, privacy and management rules.
- 2) For the management of these individual schedules, it would be ideal if the FTC undertook the optimisation task on behalf of the coalition partners and then issued the day's collection and delivery allocation, potentially by zone. This would be a significant task involving powerful metaheuristic algorithms operating on a very large scale to address:
 - i) a fleet of heterogeneous vehicles, composed of the individual carriers' fleets operating from multiple depots serving multiple customers, each requiring either a delivery or collection or both
 - ii) a range of different customer service time requests within specified 'hard' (no deviation), 'soft' (delays incur penalties) and 'loose' (delays acceptable) time windows
 - iii) a degree of stochasticity in that a proportion of the customers (typically 13-14%) will not be present at their specified location, and will potentially require redeliveries on the same day
 - iv) the need to transfer parcels between carriers at various cross-dock points (e.g., car parks, small depots)
 - v) the need to account for walking time in the 'final-approach' part of the delivery where delivery vehicles are left at strategic stopping points and multiple deliveries/collections undertaken on-foot from that location.
- 3) A protocol for how collection and returns requests arriving in real-time during the daily activity can be handled by the coalition using the existing fleets.
- 4) Rules for how proof-of-delivery and general accountability are to be handled by the coalition, where the optimisation task and work allocation is overseen by the FTC for the benefit of all.

In this paper we have identified how current applications of theory to this domain do not adequately allow for the subtle operational issues exhibited by the players. Based on literature and fieldwork, we identify that for theoretic approaches to be credible in real-world last-mile logistics settings, they must take into consideration: i) vehicle parking locations relative to actual delivery addresses; ii) the combination of collections with deliveries in real-time; and iii) the variability in travel times and route options due to road conditions. This is an area that warrants further research to realise the significant potential benefits to urban centres of collaborative last-mile logistics.

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