**Quantifying environmental and financial benefits of using porters and cycle couriers for last-mile parcel delivery**

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## Executive summary

Historical manifest data from a parcel carrier undertaking 'next-day' (i.e. non-express) deliveries in an area of central London (mainly EC2 postcode district) were used to quantify the potential benefits of switching from the current van-based deliveries to one where porters or cycle couriers are used for the last-mile delivery, working from set drop-off points.

The results suggested that over the business-as-usual case for the area of London studied, the carrier could reduce $CO_2$ emissions by 45% (9500kg/year) and NOx emissions by 33% (7.64kg/year). Annual driving distance could be reduced by 78% (48,100km) and the amount of time spent stationary at the curbside by 45% (2558 hours/year). Scaling up the modelled emissions savings to London's Central Activities Zone, an area approximately 10 times bigger than the modelled case study area and with estimated total annual parcel delivery distance of 15 million km, could see annual emissions savings in the region of 2 million kg$CO_2$ and 1633kgNOx if all carriers utilised porters or cycle couriers. Overall cost savings to the carrier were estimated to be in the range 34%-39%. Some practical operating challenges are identified including sorting and packing of items, parcel handover arrangements, how to deal with failed deliveries, and how to incorporate express items.

## 1 Introduction

Freight transport operations are essential to the economic prosperity and vitality of urban areas but typically involve the use of motorised road vehicles that impose traffic, social and environmental impacts. Vans continue to be the fastest-growing type of licensed road vehicle in the UK, with 15.6% growth in van numbers between 2014 and 2018 (GOV.UK, 2019). Van traffic almost doubled and associated $CO_2$ emissions increased by 65% between 1990 and 2016 in the UK (Department for Transport, 2018). Continuing growth in van traffic is partly due to growth in e-commerce: although fewer than 4% of vans are engaged in delivery of e-commerce packages (including groceries) they contribute around 10% of van traffic in the UK (Braithwaite, 2017). The 'all-to-everywhere' characteristics of the multi-player parcel logistics sector and ever-increasing demand for same-day and next-day delivery services result in much duplication of van activity on-street and exacerbate traffic and air quality issues (Browne et al, 2014). With the need to reduce emissions in urban areas being a core component of EU transport policy (European Commission, 2011), alternative operating practices should be investigated.

The emergence of crowdshipping as a viable transportation mechanism (McKinnon, 2016), utilising smartphone based platforms to allow load transaction management between multiple parties suggests that alternative and more sustainable transport options exist for serving consignees over the last-mile in our urban centres. A change to walking and cycling could not only reduce the $CO_2$ footprint of the parcel logistics sector but alter the dynamic at the kerbside, making it a safer and more attractive location for other cyclists and pedestrians whilst fundamentally reducing vehicle dwell times and related congestion. The bicycle, tricycle and quadricycle have been used for freight transport ever since their invention with the British Post Office using their first cargo tricycles for mail delivery in 1881 (Caunter, 1955). The carriage of goods by humans predates the introduction of the wheel itself and the use of beasts-of-burden for land transportation, continuing to be a viable mode in geographically challenging terrains, where technologies are unavailable or too expensive (Bastien et al, 2016). Of increasing interest to carriers is to what extent such sustainable modes and third-party platforms can be used to improve the efficiency of last-mile operations whilst maintaining customer service levels and reducing the bottom line. With the drive to reduce costs, the wider $CO_2$ benefits of such systems can often be overlooked by carriers.

Using a case study involving a major parcel carrier in London undertaking ‘next-day’ (i.e. non-express) business-to-business (B2B) and business-to-consumer (B2C) deliveries in central London who is looking to adopt more sustainable last-mile delivery processes, this report makes three contributions: (i) we review the characteristics of and transport impacts associated with the urban freight parcel market along with the past and current importance of walking and cycling in urban freight transport; (ii) through fieldwork and the interpretation of a significant carrier dataset, using some innovative optimisation approaches, we quantify the scope for walking and cycling as key components for reducing the cost and $CO_2$ associated with the last-mile delivery activity; iii) we identify the challenges that need to be addressed in developing a successful operational and business case for porter/cycle-based delivery systems using crowdshipping.

## 2 Background – parcel delivery characteristics in dense urban areas

In 2016, 91% of the world’s population lived in places where World Health Organization air quality guideline levels were exceeded, with outdoor air pollution estimated to cause 4.2 million premature deaths worldwide annually (World Health Organization, 2018). As a result, governments are now taking the need to improve air quality more seriously with many cities seeing the introduction of low emissions zones, vehicle access restrictions and road pricing (Holguín-Veras et al, 2016).

Of the estimated 495.7 million tonnes of $CO_2$ equivalent greenhouse gas emissions generated by the UK in 2015, 22% came from road transport, of which vans contributed an estimated 3.6% (18 million tonnes), and 93,000 tonnes NOx (10% of total) (Department for Transport, 2017). One of the fastest growing areas of urban freight activity related to vans is associated with the rise in e-commerce (Allen et al, 2017) with the UK parcel market currently estimated to be worth £12.6 billion and generating 3.65 billion parcels in 2018, representing 66% growth since 2014 (Mintel, 2019).

A detailed study of 25 parcel van rounds operated by two parcel carriers making deliveries and collections across three postcode districts in the West End of central London (WC1, WC2 and W1), (Allen et al, 2018a), indicated that:

- The average round duration, from leaving the depot to returning, was 7.3 hours
- The average distance driven within the delivery area, excluding stem mileage, was 11.9 km (7.4 miles) with a mean speed of 7.2kph (4.5mph)
- The driver delivered 126 parcels, on average, to 72 addresses
- The driver parked the van at 37 stopping places, on average, with an average stop length of 8.1 minutes and with 95% of stops taking place on-street at the curbside
- The mean distance driven between vehicle stopping points was 202m
- The average distance walked by the driver was 7.9km (4.9 miles)
- 62% of the total round time was spent with the vehicle parked while the driver made deliveries/collections on foot.

The findings suggested that last-mile parcel operations are very inefficient in terms of vehicle usage, with significant proportions of the round seeing the van sat idle by the curbside while the driver makes the final transaction with the consignee on-foot. With multiple carriers all trying to access the same consignees over the same geographical areas, this can lead to much competition for curbside space and replication of activity which conflicts with an infrastructure, increasingly legislated towards public transport provision (Allen and Browne, 2014). Work by Piecyk et al (2019) suggested that this impact across London's Central Activities Zone (CAZ) (Greater London Authority, 2019), an area comprising 30km$^2$ of central London generating around 135 million business and domestic related parcels per annum, would lead to approximately 5.3 and 3.7 million hours of van stationary parked and driving time respectively per annum. In terms of parcel delivery vans driving between parking spots within the CAZ, this might generate in the region of 15 million km annually across the major carriers (ibid). Under these circumstances, carriers are increasingly facing fines with FedEx and UPS reportedly incurring 14.9 and 33.8 million dollar fines, respectively, in New York City in 2018 (Baker, 2019). With continuing growth in parcel delivery volumes (Ofcom, 2018), carriers are becoming increasingly interested in exploring new ways of working.

With the introduction of low emissions zones, there has been increasing interest in the use of alternatively fuelled vehicles such as electric (Lee et al, 2013), natural gas or biogas (Nocera and Cavallaro, 2016), and solar energy (Quak, 2012), that are exempt from access charges because of their green credentials. Electric vehicles are also being used in conjunction with consolidation centres (urban or micro) to reduce the numbers of individual vehicle trips being made into urban centres and to increase load factors (Björklund and Johansson, 2018; Janjevic and Ndiaye, 2014). To mitigate the need for costly fixed infrastructure in this regard, some carriers have experimented with 'mobile depots' which can be brought into city centres and used as temporary consolidation and distribution points, provide that the local authority grant access and parking rights. These have been used as bases from where cargo cycle operations service consignees with deliveries and return collections for eventual movement back to the main depot at the end of the round (Verlinde et al, 2014).

Other solutions that have been explored by logistics providers to reduce the impact of delivery traffic in urban areas have involved: i) the switch to more out-of-hours services using fewer but larger vehicles (Holguín-Veras et al, 2005); ii) fulfilling online orders from stores in the central business district instead of out-of-town distribution centres (Melacini et al, 2018); iii) introducing 'green' delivery options and pricing, where customers can choose a delayed delivery time slot that allows the carrier to group neighbouring items and organise rounds more efficiently (Cuff, 2018).

There are also options which reduce the transport burden on the logistics provider by passing some of the responsibility for collection onto the consignee. 'Click-and-collect' services have proved popular with many retailers where consignees make collections from designated pick-up points such as local stores or locker banks (Weltevreden, 2008; Visser et al, 2014, Iwan et al, 2016). These collection options do not necessarily reduce overall transport impacts however if additional customer car-based trips outweigh any reduction in delivery van trips.

Of interest in this research is the scope for crowd-sourced delivery platforms which outsource the last-mile delivery task to independent couriers or casual workers, often using sustainable transport modes. Although these platforms are more suited to time-critical or express, same-day deliveries, including take-out meals, rather than parcel carrier work, with high volumes of standard delivery items (e.g. next-day), there could be considerable scope for their use in dense city environments where small item business-to-consumer packages dominate the delivery profile (Devari et al, 2017; Castillo et al, 2018). Such concepts are now being actively explored by carriers and local authorities in many cities as part of logistics ‘living laboratories’ (Seattle Department of Transportation, 2019; CITYLAB, 2018).

## 3 Walking and cycling as freight transport modes over the last-mile

In this section, we describe the historical background to use of porters and cycle couriers for last-mile freight delivery along with the modelling options and associated operating cost assumptions chosen to quantify to what extent an existing carrier delivering in London could revisit such approaches in practice.

### 3.1 Portering – the carriage of freight by humans

Since early times, London’s ‘porters’ were involved in two main types of activity: (i) loading and unloading of transport vessels, including trains and ships, and (ii) moving goods between vessels and stores or between store and their customers (Stern, 1960). In the 18th century, porters started to use barrows and hand carts to aid delivery (Armstrong, 2001) and by 1841, portering infrastructure such as ‘stands’ (locations where porters could wait to be hired) and ‘pitching places’ (resting points) had begun to appear all over central London (Stern, 1960; Barker, 1988; Earle, 1994). In recent decades, the only remaining forms of outdoor freight transport carried out on foot in developed countries tend to be postal services in dense urban areas, door-to-door leaflet deliverers and door-to-door sales.

On-foot delivery services were set up in London during the Olympic Games of 2012 to act as a standby if congestion became acute. DHL worked with Jog-Post (a leaflet delivery company) to provide a team of approximately 100 joggers, capable of running 5-10 miles per day at speeds that ranged from 3-8 miles per hour, working on an ad hoc casual basis (Post & Parcel, 2012; runABC Scotland, 2012). Citysprint put in place a network of twenty joggers and five rollerbladers in addition to its existing motorbike and cycling teams. The CitySprint joggers each ran approximately 6 miles per day, while one of the rollerbladers managed to complete a 4 mile journey in 22 minutes (Firstlight, 2012; Roberts, 2012). The concept of portering has been investigated by DHL in New York’s lower Manhattan financial district where a 1200 square foot ‘walking courier’ facility was set up to serve five ZIP codes within Manhattan (DC Velocity, 2016; DHL, 2016). This scheme was expanded in 2018 to the Midtown East district of Manhattan with the opening of a second facility served by 22 porters (DHL, 2018).

With parcel delivery drivers already spending much of their time walking, it is natural to consider decoupling the driving and delivery tasks by using drivers and porters in tandem, with drivers handing over parcel loads to porters either at the roadside or via drop-off and pickup facilities. Results from an initial trial of portering in central London where pre-packed bags of parcels were transferred at the roadside between drivers and porters suggested reductions of up to 86% and 60% in vehicle parking time and driving time respectively, realising savings in operating costs of between 14%-24% per parcel (Piecyk et al, 2019). Trials by a carrier during March 2019 using the same principles suggested that one van and four porters could be used to deliver the same number of parcels as five drivers and vans (Ryan, 2019).

### 3.2 Cargo cycles for delivering freight

In Asia, Africa and South America as well as parts of Europe, bicycles have been used to transport goods for decades (Replogle, 1991; Tiwara, 1999; Norcliffe, 2011; Hagen et al, 2017) and in many European countries, same-day A-to-B parcel services using bikes or electrically-assisted cargo bikes (e-bikes) are commonplace (Cyclelogistics, 2011). Such cycle couriers could be thought of as a type of 'crowdshipper' as they are typically self-employed and paid on a per-job basis (US Postal Service, 2014), allowing the last-mile delivery problem to be addressed through informal networks of individuals, managed through smartphone-based platforms. Research from an investigation of same-day cycle couriers in Berlin suggested that average trip distances were 5.1km (compared with 11.3km for car couriers) with 90% of all cycle trips being under 10km; the average rider made 9.4 trips per working day (5.3 hours) travelling 42km with an 80% mean loading factor, compared to 6.4 trips by car couriers, largely due to the difference in trip distances between the modes; in terms of average free-flow speeds, cycle couriers recorded 15.9kph compared with 17.3kph for car couriers (Gruber et al, 2014).

There are now an abundance of cycle couriers in many major cities with Deliveroo having over 15,000 registered riders in the UK alone, making it a more attractive alternative for carriers (Business of Apps, 2019). With e-bikes capable of transporting loads of between 50-250 kg up to 80km on a single charge (Schier et al, 2016), estimates suggest that 25-50% of current freight traffic destined for urban centres could be transferred from motorised vehicles to e-bikes under the right conditions (Lenz and Riehle, 2013; Cyclelogistics, 2014; Schliwa et al, 2015; Wrighton and Reiter, 2016; Melo and Baptista, 2017). A wide range of e-bike styles are available but depending on their size, weight and power output, may be subject to motor vehicle regulations which can restrict where they can be used. In the UK, e-bikes with motors up to 250 watts generating speeds up to 25kph (15.5mph) are classed as bicycles whereas anything more powerful is classed as a moped, requiring a licence and the wearing of a helmet (Stredwick, 2016). Although larger-style e-bikes have greater carrying capacity, they may be more restricted in terms of where they can travel and be parked, making them impractical for use on sidewalks or other areas primarily designed for pedestrians (Conway et al, 2012).

A key advantage of switching to bikes or e-bikes relates to their speed, being less restricted by traffic queues, the road network and available parking spaces (Conway et al, 2012). Observations from 30 different cycle courier operators across Europe suggested a mean travel speed of 10mph (PRO-E-BIKE, 2015) which is higher than the current 8mph average general traffic speed in central London (Mayor of London and Transport for London, 2018).

The environmental benefits of moving to sustainable transport modes for last-mile parcel logistics can be considerable and several studies have attempted to quantify these:

i) Electrically-assisted cargo cycles used in conjunction with a micro-consolidation centre in London and Milan reduced the $CO_2$ emissions per parcel delivered by 55% and 73% respectively compared to diesel vans (Browne et al, 2011; Nocerino et al, 2016).
ii) Pilot studies involving 78 e-bikes used by 40 companies or municipal authorities for various types of delivery in 20 cities across Croatia, Italy, Netherlands, Portugal, Slovenia, Spain and Sweden estimated emissions savings of up to 8.5kg$CO_2$ per journey (PRO-E-BIKE, 2015).
iii) Annual fuel savings of 8,500,000 litres and corresponding $CO_2$ savings of 21,000 tonnes were estimated, based on cycle couriers gaining a 10% share of the urban delivery market from vans across the Netherlands (Maes and Vanelslander, 2012).
iv) Well-to-wheel $CO_2$ emissions savings of 73%, with no loss of overall network efficiency, were estimated for an area within the city of Porto, Portugal for a modelled scenario in which 10% of delivery vans were replaced by cargo bikes (Melo and Baptista, 2017).
v) $CO_2$ savings of between 3% and 28%, were estimated for a business model in which delivery of light packages (up to 5kg) in Turin, Italy were undertaken by 'green

subcontractors' using e-bikes whilst heavier items were delivered by 'traditional subcontractors', using diesel-fuelled vans (Perboli and Rosano, 2019).

### 3.3 The last-mile interface

A key element to the success of last-mile delivery systems using porters or cycle couriers is the mechanism by which they receive parcels. In this research, we foresee two potential ways this might be achieved:

i) ***Direct rendezvous between drivers and porters/cargo cyclists*** – where the driver alights at the curbside and pre-notified porters or cargo cyclists are waiting to receive pre-packed bags of parcels for local delivery (this could be referred to as 'drop-and-drive'). This scenario is akin to the notions of crowdshipping on a large scale (Fung Business Intelligence Center, 2015; Allen and Browne, 2016; McKinnon, 2016) and would be most applicable in locations with extremely dense delivery networks or where substantial vehicle access and curbside parking restrictions exist.

ii) ***Indirect transfer via drop-off facilities*** – where the driver drops off pre-packed bags at selected drop-off facilities for subsequent collection and delivery by porters or cargo cyclists. The drop-off facilities could comprise reserved curbside spaces, small permanent facilities/buildings, existing retail stores that already provide click-and-collect services or temporary mobile depots which are delivered to the location each day. Each drop-off facility would likely cover a greater delivery catchment area compared to the larger number of meeting points anticipated to be used in i) above and drivers would drop off larger quantities of parcels destined for more consignees at each facility.

The first method has the advantage of not having the infrastructure costs associated with drop-off facilities (these are estimated in section 3.5.3) but the scheduling of meetings between drivers and porters presents a more difficult logistical challenge, and the constraints introduced will tend to reduce the efficiency of vehicle rounds where drivers have other delivery/collection work in addition to servicing porters. This was the preferred method used by one operator in central London (Ryan, 2019). Conversely, the cost of using drop-off facilities may be offset by drivers working more efficiently, not having to rendezvous directly with porters, and as a result, covering larger areas with the same vehicle. This is the method that is simulated and evaluated in this paper.

In both the above methods, it was envisaged that the sorting of parcels would take place at the carrier's depot, with items for porters or cycle couriers being packed into purpose built delivery bags; (the description of these along with the cost estimates are detailed in section 3.5.2). It is also feasible that the sorting and packing of parcels could take place at the drop-off facilities if they had suitably skilled personnel available to perform the task. This would be the case, for example, where the drop-off facility is a micro-consolidation centre (MCC), typically operated by a parcel carrier or by a cycle courier company (Janjevic and Ndiaye, 2014). The use of an MCC would save the parcel carrier time and effort in sorting and packing portering bags themselves and an MCC can also bring added benefit if parcels from different carriers can be combined and consolidated; however, added handling introduces potential delays, a service charge and issues associated with the transfer of liability to a third-party.

The key benefits of adopting portering or cycle courier services to serve parcel deliveries in dense urban areas are the likely significant reductions in the numbers of vans and trucks needed, the associated mileage undertaken and diesel fuel consumed, along with the reductions in emissions and on-street parking. While parcel carriers in the UK predominantly use vans at present, under this proposed model it may be necessary to switch to using small trucks (7.5 tonne) to be used alongside porters or cycle couriers. Fewer drivers would be needed to cover

larger areas, carrying pre-loaded bags of items for the porters/cycle couriers from the depot to the delivery area as well as the heaver and more bulky items unsuitable for portering.
In this research, it was found that two 7.5 tonne gross vehicle weight trucks with a payload of 2500kg and a carrying capacity of $34m^3$ could be used instead of the seven 3.5 tonne gross vehicle weight vans that were actually used by the carrier. Assumed $CO_2$ and NOx emission rates for vans and trucks were taken from the Low Carbon Vehicle Partnership (2017) figures for city centre deliveries undertaken by Euro VI vehicles: for vans, 299 g/km $CO_2$ and 0.32g/km NOx; for lorries, 520 g/km $CO_2$ and 0.67g/km NOx.
The last-mile system described above requires the design and operation of a distribution system that is composed of at least two levels, or echelons. The lower-level echelon assumes the use of walking or cycling as the primary mode of transport, whereas the upper-level echelon uses driving. Such a system, within the broader context of city logistics, can be described as a two-echelon vehicle routing problem (2EVRP), Cuda et al., (2015), particularly relevant if drop-off facilities are available, or as a truck-and-trailer routing problem (TTRP) (Derigs et al., 2013), which is more relevant to the 'rendezvous model' where drivers and porters meet at delivery locations. The TTRP can also be extended to take into account any time requirements around the deliveries as well as the limited carrying capacity of both the van and the porters (Lin et al., 2011; Villegas et al., 2010). The latter variants give rise to difficult optimization problems that have only recently been optimally solved with up to 100 customers (Parragh and Cordeau, 2017).

### 3.4 Modelled portering and cycle courier options

In this research, all individual consignments of 5kg or less were deemed to be portable (as was assumed by Perboli and Rosano (2019)), with a driver delivering any heavier consignments and also undertaking any collections, where fewer than 5% of all consignments were collections. In practice, bulky items, irrespective of weight may also be best handled by the driver but for simplicity, individual consignment volume constraints were not specified here although available for use in the portering algorithm used (section 4.3). Total load volume and weight capacities for four modelled portering or cycle courier options were compared, where these were based on information obtained from equipment suppliers:

1. Porter using wheeled bag (capacity limit: 200L and 25kg), (Newitts, 2019).
2. Porter with trolley (capacity limit: 430L and 70kg), (Kyburz, 2019).
3. Bicycle courier with container (capacity limit: 620L and 125kg), (Urban Arrow, 2019).
4. Tricycle courier with container (capacity limit: 1000L and 125kg), (Velove, 2019).

Combined use of these four options by the carrier was not considered in this paper but might be desirable in practice if porters and cyclists are better suited in some environments compared to others. In practice, the working hours of individual porters or cycle couriers may be highly variable, ranging from those only wanting to work a few hours each day to those working full-time. Here, the availability of full-time workers with a maximum working day of 8.5 hours was assumed although not all workers would necessarily receive or be paid for a full day's work, depending on the amount available. One could envisage an environment where existing crowd-sourced couriers working for the food delivery companies could also deliver pre-packed bags of parcels in a 'burgers and boxes' operating model.

### 3.5 Operating cost assumptions

Operating costs associated with use of vans, trucks, porters and cycle couriers are outlined along with the cost assumptions used in this research for financial comparisons.

### 3.5.1 Labour and equipment

Labour costs for a driver, porter or cycle courier were assumed to be equal and calculated as the current London Living Wage (£10.55/hr) (Living Wage Foundation, 2019) with the addition of the assumed 35% overhead costs covering National Insurance, pension, sick pay and holiday pay (Accounting Services for Business, 2019), giving a total of £14.25/hr.

Van and lorry standing and running costs, including tax, insurance, depreciation, fuel, tyres and maintenance, were derived from industry figures (Motor Transport, 2019) and with the London congestion charge (currently £11.50 per day) added (Transport for London, 2019). We assumed that vans or trucks meeting Euro 6 standards and thereby avoiding the existing ultra-low emission zone (ULEZ) charges, currently £12.50 per day for vans and £100 per day for trucks (Transport for London, 2019), would be used. The congestion charge, which operates independently of the ULEZ charge, could also be avoided by using electric vehicles but their use were not assumed here. In the business-as-usual (BAU) case, 3.5t diesel-fuelled vans were used and costs were calculated as £4.13/hr + £0.41/km. For the modelled portering and cycle courier scenarios, 7.5t diesel-fuelled trucks were assumed and these vehicles were costed at £5.98/hr + £0.74/km. An 8-hour working day was assumed when converting daily rates (e.g. the congestion charge) to hourly rates.

Vehicle or equipment costs were also estimated for the different walking and cycling options being considered (Table 1), where these figures were derived from online quoted purchase prices and through personal contact with manufacturers and users concerning maintenance costs and expected operating lifetimes. For the cycle courier options, the modelled costs included the cost of charging batteries (£0.02/hr) but excluded infrastructure costs (e.g. cycle depot, charging equipment) to provide a fair comparison with the BAU case where vehicle depot costs were not considered. The hourly cost rates were based on the following assumptions:

- ***Individual wheeled bags*** (£0.54/hr) - bag purchase cost £72 (Newitts, 2019); used 8 hours per day for 100 days; average of six bags per porter (taken from case study figures, where it was assumed that bags are pre-packed at the depot for quick drop-off and collection at micro-consolidation points).
- ***Trolley*** (£0.62/hr) - purchase cost £4250; lifetime 7 years; batteries £1020; battery life 6 years (Kyburz, 2019).
- ***Electrically-assisted cargo bike*** (£1.37/hr) - purchase cost £4000; lifetime 5 years; battery cost: £550; battery life 2 years; container cost £1279; container lifetime 5 years (Urban Arrow, 2019).
- ***Electrically-assisted cargo trike*** (£1.77/hr) - purchase cost £8762, (including battery, lights and indicators, remote locking, power (for internal lights and locking), shelving, protective mat); lifetime 5 years; replacement battery cost £550; battery life 2 years; container cost £1279; container lifetime 5 years (Velove, 2019).

**Table 1. Assumed vehicle/equipment costs**

| Vehicle type | Vehicle/equipment (including tax, insurance, depreciation, congestion charge, fuel, tyres, maintenance) |
|---|---|
| Lorry (7.5t) | £5.98/hr + £0.74/km |
| Van (3.5t) | £4.13/hr + £0.41/km |
| Tricycle | £1.77/hr |
| Bicycle | £1.37/hr |
| Porter + trolley | £0.62/hr |
| Porter + 6 bags | £0.54/hr |

### 3.5.2 Additional sorting

In the carriers existing van-based operations, parcels were sorted by round area at the depot and loaded into vans in a suitable order, based on driver knowledge of the most efficient way of traversing their given geographical patch. For the portering and cycle courier options, additional time would be needed at the depot for secondary sorting of parcels according to weight and size into suitable loads for the porters or cycle couriers to carry. Based on some of the authors' experience of participating in small-scale portering trials (Piecyk et al, 2019), an additional sorting time of one minute per consignment was assumed for this activity. For this case study, this meant total sorting times at the carrier's depot ranging between 1.65 hours (Friday) and 2.17 hours (Monday) for each day of the week.

### 3.5.3 Drop-off location costs

In the portering model envisioned here, the carrier makes use of parcel drop-off and pickup services provided by a third party service provider, typically utilising a network of general stores (locations shown in Figure 1). Charges for this service may relate to both temporary storage of bagged items and time spent by store staff receiving items from drivers and, later, handing them over to porters. In the analysis here, a daily storage cost of £1.50 per 1000L was assumed plus a handling charge of £0.50 per transaction between the storekeeper and a driver or porter, these being estimated from charges made by a parcel service provider in central London (Parcelly, 2019). In practice, such a service provider would likely adopt a simpler charging structure combining the two cost elements.

# 4 Methodology

Working with parcel manifest data from a major parcel carrier operating B2B and B2C deliveries in central London, without any delivery time constraints, a 'before-and-after' case study area (section 4.1) was used to compare the financial and environmental costs associated with adopting various portering and cycling options for last-mile delivery using crowd-sourced couriers. These were compared against a 'business-as-usual' (BAU) case based on actual van delivery rounds undertaken by the carrier during the week 7-11 January 2019 (section 4.2). The alternative portering and cycling scenarios were modelled using a heuristic algorithm developed by the authors (section 4.3).

## 4.1 Case study area and carrier characteristics

The case study was based on the EC2 postcode district of central London, UK, chosen as it was being considered as the location for a portering trial by the carrier. The district includes Shoreditch, Liverpool Street, Barbican and the north-eastern corner of the City of London from St Paul's Cathedral (Figure 1). The carrier undertook seven vehicle rounds in this area during the week of 7-11 January 2019 (Monday to Friday), with the unique delivery locations visited shown (Figure 1). The area covered by these rounds was approximately 2.3 km (1.4 miles) from west to east and 1.6 km (1 mile) from north to south with the carrier's manifest data suggesting that the 7 drivers visited 624 different buildings during this week with the average round comprising 77 consignments, weighing 618kg and with a volume of 3464 litres.

The carriers' vehicles used in the analysis were all 3.5 tonne gross vehicle weight vans with a payload of around 1300kg and a capacity of 10m$^3$. Parcels for delivery and collection (approximately 94% and 6% of the activity respectively) were allocated to drivers based on pre-determined and largely fixed vehicle round structures with the transaction order being left to the driver's discretion. Drivers were solely responsible for selecting the route, parking

locations, the clusters of consignees to service from each parking location, and the amount of walking as opposed to driving they carried out.
Route planning was observed to be a combination of tried and tested routes combining walking and driving, with the parcels loaded onto the vehicle at the depot in an order that matched the driver's preferred delivery sequence. Drivers were allocated to similar geographical areas each day so that they acquired detailed local knowledge of suitable routes, vehicle stopping locations, delivery points and customer requirements.

Also shown in Figure 1 are seven shops that act as parcel drop-off and collection points on behalf of a separate parcel company. These were considered as potentially suitable drop-off facilities in the catchment area for the transfer of pre-packed bags of parcels.

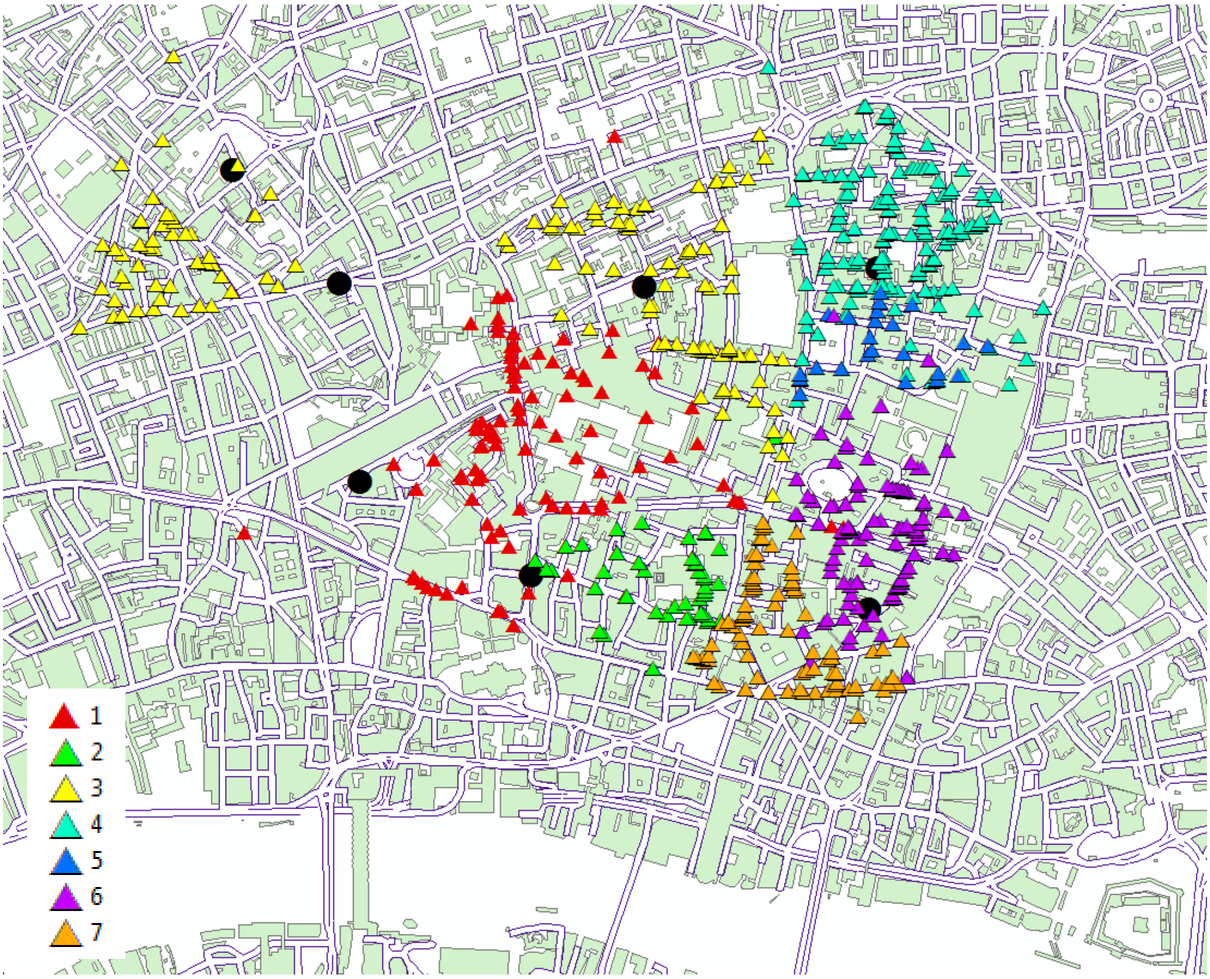

**Figure 1. Case study area in central London (delivery locations of 7 carrier rounds, 7-11 January 2019 and proposed drop-off facilities (black circles))**

### 4.2 Quantifying business-as-usual delivery operations

The carrier's post-round manifest data recorded the proof-of-delivery times at each consignees address and were used to quantify the time spent in the delivery area for each vehicle round on each day and the number of delivery and collection consignments undertaken (Table 2). It was observed that the average time spent in the delivery area was 5 hours and the mean number of consignments handled was 69 with standard deviation values of 1 hour, 53 minutes and 25.4 consignments, respectively. The average time spent per consignment was 4.35 minutes, which included both driving and performing the delivery or collection.

Two rounds (5 and 7) had noticeably lighter workloads than the others, averaging less than three hours per day in the delivery area and fewer than 40 consignments per day, on average. Time spent by vans parked by the roadside was not recorded but was estimated to have been around 110 hours, or 3.14 hours per day, on average, if parked for 62% of the time spent in the delivery area, as was observed in other parcel carrier surveys (Allen et al., 2018b). Stem travel times between the carrier's depot, located 15km (9 miles) east of the case study area, and the individual delivery round areas were estimated to be around 40 minutes each way using the mapping and routing facilities of OpenStreetMap (OSM) (OpenStreetMap contributors, 2017) and Open Source Routing Machine (OSRM) (Luxen and Vetter, 2011) explained further in section 4.3.

**Table 2. Total time (hh:mm) in delivery area, 7-11 January 2019 and number of consignments (in parentheses)**

| Round | Mon | Tue | Wed | Thu | Fri | Total |
|---|---|---|---|---|---|---|
| 1 | 06:03 (81) | 05:41 (102) | 05:47 (89) | 05:52 (92) | 05:48 (78) | 29:11 (442) |
| 2 | 04:42 (77) | 02:41 (70) | 04:37 (70) | 07:43 (79) | 04:54 (84) | 24:37 (380) |
| 3 | 07:59 (95) | 06:32 (90) | 07:10 (82) | 07:32 (90) | 07:43 (92) | 36:56 (449) |
| 4 | 06:47 (74) | 04:36 (62) | 05:31 (88) | 06:32 (75) | 05:41 (63) | 29:07 (362) |
| 5 | 03:04 (36) | 05:00 (32) | 01:00 (13) | 01:37 (26) | 02:30 (28) | 13:11 (135) |
| 6 | 05:54 (72) | 05:56 (95) | 05:02 (92) | 07:29 (99) | 06:15 (102) | 30:36 (460) |
| 7 | 03:21 (38) | 01:31 (22) | 03:12 (38) | 03:21 (54) | 03:01 (45) | 14:26 (197) |
| Total | 37:50 (473) | 31:57 (473) | 32:19 (472) | 40:06 (515) | 35:52 (492) | 178:04 (2425) |

Vehicle distance data were not recorded by the parcel carrier due to the use of subcontractors; however, the total distance driven within the delivery area (by 7 drivers over 5 days) was estimated to be 336km, calculated as an average speed, including all stopped time, of 1.89kph, found from earlier carrier surveys in central London (Allen et al., 2018b) multiplied by the time spent in the delivery area of 178 hours. Added to this was a total stem travel distance of 1014km estimated from OSM/OSRM data, giving an average daily round distance of 38.6km, of which 75% was the stem distance. The average distance driven within the delivery area, excluding stem mileage, was estimated to be 9.6km, a little less than the 11.9 km noted in section 2 for a different carrier.

Total emissions for the 7 vans over 5 working days were estimated to be 403.7kg$CO_2$ and 0.43kgNOx using the emission rates stated in section 3.3. Total diesel consumption was estimated to be 152.9 litres, derived by dividing the total $CO_2$ emissions by the amount of $CO_2$ generated from a litre of diesel, (2.64kg$CO_2$/litre (Comcar, 2019)). The total financial cost for the week was estimated to be £4,648, calculated as £3,179 labour costs along with £1,469 vehicle costs, where the modelled costs are explained in section 3.5.1. Depot operating costs were not considered here as they were assumed to be the same between the different operating methods; however, added parcel sorting costs associated with portering were modelled (section 3.5.2).

### 4.3 Portering algorithm

An algorithm was designed to model the type of last-mile interface between drivers and porters described above, to determine:

(i) which drop-off facilities the drivers would visit from among a given set of available options for drop-off of parcels;

(ii) van routes - the order in which drivers would visit these drop-off facilities and undertake their own work (collections and delivery of heavier items);
(iii) the number of porters needed;
(iv) porter routes - the order in which porters would pick up parcel loads and visit delivery addresses.

*[Note: to avoid repetition, 'porter' is used in this section to mean 'porter or cycle courier'; the algorithm makes no distinction between the two.]*

Drivers start and end from a given vehicle depot, while porter routes commence and end at selected drop-off facilities, where these may vary between porters and where start and end points are not necessarily the same. Intermediate visits to drop-off facilities to pick up more items for delivery will usually be required due to the porters' carrying capacity weight and volume limits. An example illustration of driver and porter routes output by the algorithm is shown in Figure 2; this shows crow-flight travel paths between consecutive points and not actual paths that would be taken since the algorithm has no information about the road network other than travel times between points as obtained from OSRM.

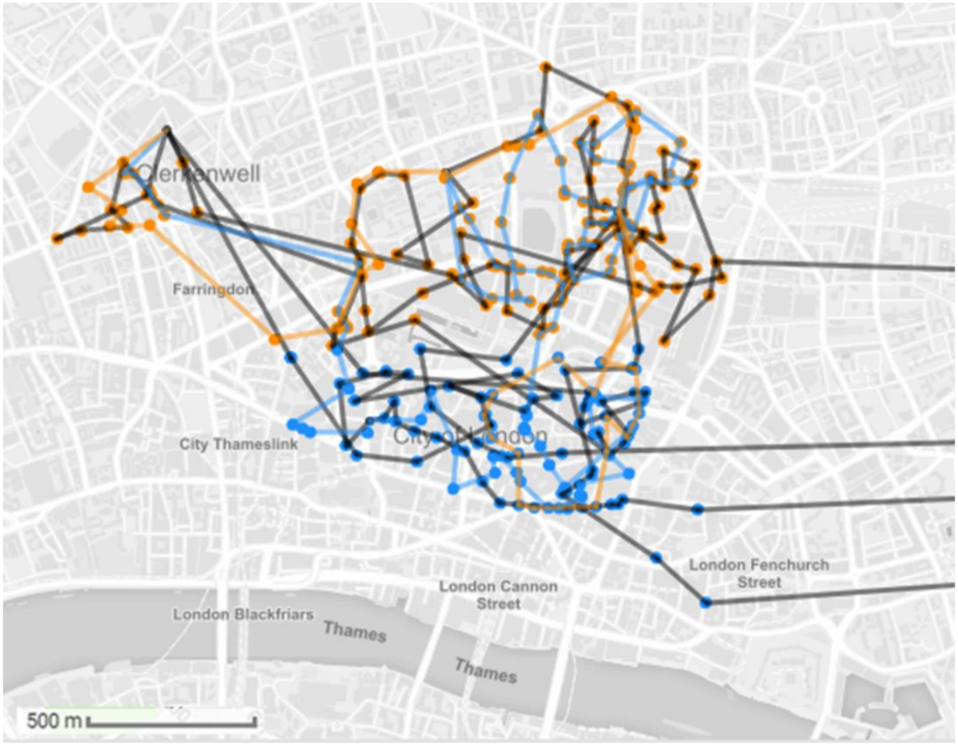


**Figure 2. Example crow-flight representation of portering routes (blue and orange) and two vehicle routes (both grey) for one day (depot 15km to east not shown) (Credit: Map data © OpenStreetMap contributors, CC-BY-SA, Imagery © Mapbox)**

The required inputs to the algorithm are:

(i) Available drop-off location(s) (note: all locations specified in latitude, longitude format);
(ii) Carrier depot location;
(iii) Number of vehicles to be used and, for each vehicle, a list of the individual consignment weights, volumes and delivery (or collection) locations. (In the case study examples, it was determined, after dialogue with the carrier, that two 7.5t lorries, each with a carrying capacity of 2.5t would suffice for the task and items were

divided between the two vehicles on an east/west basis by sorting the manifest data by longitude values and splitting approximately halfway by total item weight.);

(iv) Origin-destination (OD) driving and walking (or cycling) matrices that specify times (or any other defined generalised cost) between all pairs of locations. Here, combined travel and delivery times were used as the cost function, where travel times were obtained from OSM/OSRM data. The times provided by OSRM were based on their default settings (as per version 5.18), which accounted for different road types and restrictions and included turning penalties. The travel time outputs of the algorithm were later adjusted to more accurately represent reported speeds (described later in this section). Average delivery times of 3 minutes per location for porters and 5 minutes per location for drivers were assumed, these based on earlier carrier surveys (Allen et al., 2018b) and where the longer time taken by drivers reflects the time needed to unload parcels and to walk from and to the parked vehicle as parking directly outside a delivery address is rarely possible. For simplicity, the same stop times (i.e. 3 and 5 minutes) were assumed for visits to drop-off facilities.

(v) Parameter values (see sections 3.4 and 3.5 for values used) specifying: maximum consignment and total load weights and volumes that porters (or cycle couriers) may carry at any given time; maximum working hours for porters; hourly cost rates of porters and of drivers and their vehicles; and a penalty cost per porter (a high value was specified) to minimise the number of porters utilised, this being considered desirable in a practical setting to reduce organisational requirements and to give porters sufficient work; however, this modelled penalty cost was not included in the cost reporting as it was not considered to be a real cost.

The portering algorithm is a tabu search heuristic that uses a randomized constructive procedure, and a greedy and fast local search improvement method which is based on the well-known 2-OPT mechanism proposed for the Travelling Salesman Problem (TSP), (Croes, 1958). The constructive algorithm computes the route of the drivers, taking into account the heavy and large items that cannot be delivered by the porters, obtained by solving a TSP. The algorithm then forms the consignee delivery clusters by choosing a first customer in each cluster at random, and then iteratively adding other customers to the clusters in such a way that lowest cost is achieved without violating the weight and volume limits. Each cluster is assigned to a porter, on which the 2-OPT heuristic is run.

The 2-OPT heuristic explores alternative orderings of the customers that have been assigned to a given porter to improve the intra-cluster routings. A tabu search algorithm is used for inter-cluster allocations, where the neighbourhood of the tabu search is defined as the best move of a customer to a different porter in such a way that the selected customer does not belong to the tabu list. Each run of the tabu search was limited to 600 seconds and the size of the tabu list was fixed to 5.

The algorithm used an objective function that minimises the total cost of porters, drivers and the time utilisation of the vehicles. The essentially fixed costs of additional parcel sorting (section 3.5.2) and of using drop-off facilities (section 3.5.3) were not included in the algorithm as they were not affected by the routing solutions produced but were subsequently added to the total cost of the solutions. Similarly, vehicle emissions were computed post-optimisation, as solving the TSP to minimise driver times was considered a sufficiently suitable objective to also help reduce environmental impacts. Although more sophisticated ‘green vehicle routing’ problems and modelling approaches that include an explicit consideration of vehicle loads, vehicle and engine types and time-dependent travel speeds are available (see, for example Marrekchi et al, 2016), these were deemed to be too detailed a set of factors to incorporate for the purposes of our study.

Direct and derived outputs from the algorithm included: travel times and speeds; time spent at delivery/collection locations; distances driven, walked or cycled; parcel weights and volumes carried; use of drop-off facilities, in terms of parcel weights, volumes and how many times they were visited by drivers and porters; environmental and financial costs. In post-processing of the algorithm's output, driving times were factored by 1.81 as the average driving speed of 14.5 mph in the OSM/OSRM data for central London was found to be 1.81 times faster than the published statistic of 8mph (Mayor of London and Transport for London, 2018). Similarly, cycling times were factored by 1.5 on the basis of the average cycling speed of 15mph as observed in the OD matrices being different to the mean speed of 10mph based on observations of around 30 different cycle courier operators in Europe (PRO-E-BIKE, 2015).

The average walking time found in the OSM/OSRM data was 3.2mph which was considered satisfactory for use. While some studies, reviewed by Chandra and Bharti (2013), reported slightly quicker walking speeds for the general public (e.g. close to 4mph), particularly among young males, porters would likely be slowed by manoeuvring their carrying equipment and by traffic when waiting to cross roads.

## 5 Results and discussion

The portering algorithm was run for each of the portering and cycle courier options (see section 3.4) and for each of the five working days, using the carrier data for Monday 7$^{th}$ January to Friday 11$^{th}$ January 2019 to specify the deliveries and collections to be made. The modelled results indicated substantial environmental and financial savings for all of the portering and cycle courier options when compared with the BAU case (Table 3). Key reasons for the savings were the reduced number of diesel-fuelled vehicles being used (from 7 vans to 2 trucks) and the fewer staff involved (from seven to three or four). Although 7.5t lorries were used in the portering and cycle courier scenarios instead of smaller, more fuel-efficient vans, the large distance savings (68%-69%) meant substantial fuel consumption and $CO_2$ savings (44%-45%) and NOx savings (33%-34%). In absolute terms, the emissions savings for this carrier, for one week, in the case study area were estimated to be 182.7kg$CO_2$ and 0.147kgNOx. There was very little difference in emissions savings between each of the portering or cycle courier options since the driving routes only varied slightly between them according to which drop-off locations were selected for use.

Driving time savings were modelled to be 78%, broken down as 71% stem travel time and distance savings (6.5 hours and 145 km saved each day), as a direct result of removing 5 out of 7 vehicles, and 82%-83% travel time savings within the delivery area, where the higher savings reflect the fact that the two truck drivers only delivered 50% of the items.

The time spent by vehicles parked at the roadside (dwell time) is of particular interest to road transport authorities in their monitoring of road use and provision of parking facilities (e.g. loading bays). Here, the portering and cycle courier scenarios were estimated to reduce the total amount of van or truck dwell time by 43%-45%, although the use of a truck rather than a van would take up more space at each stopping point. A potential negative point with the use of bicycles or tricycles is that they may cause some nuisance for pedestrians if poorly parked on the sidewalk or, if a tricycle is parked by the roadside, then no parking benefit would accrue.

From a financial perspective, the bicycle and tricycle courier options were estimated to be slightly more cost effective than using porters, both being 39% lower cost than the BAU case, compared with 34% savings for porters with wheeled bags and 37% savings for porters with trollies.

**Table 3. Summary comparison of modelled results for Monday 7th January to Friday 11th January 2019**

| | Vehicles and people | | Totals for working week relating to van/truck use | | | | | |
|---|---|---|---|---|---|---|---|---|
| Operating scenario | # required | Cost (£) | $CO_2$ (kg) | NOx (kg) | Driving time (h) | Kerbside time (h) | Driving distance (km) |
| Business as usual | 7 vans | 4648 | 403.7 | 0.432 | 113 | 110 | 1350 |
| Portering (200L bag) | 2 trucks + 2 porters | 3073 | 226.3 | 0.292 | 25.3 | 62.4 | 435 |
| Portering (trolley) | 2 trucks + 2 porters | 2951 | 222.8 | 0.287 | 24.7 | 61.8 | 428 |
| Bicycle courier | 2 trucks + 1.2 bikes | 2817 | 221.2 | 0.285 | 24.5 | 60.8 | 425 |
| Tricycle courier | 2 trucks + 1 trike | 2814 | 221.0 | 0.285 | 24.5 | 60.8 | 425 |

More detailed analyses of the individual driver and porter workloads each day for each scenario provided greater understanding of the results, as illustrated here for Monday 7th January 2019 (Table 4 to Table 7). In all cases, the porters or cycle couriers made 50% of all the deliveries, dictated by the fact that 50% of the consignments were 5kg or under.

In the case of portering using 200L wheeled bags (Table 4), the total time taken was modelled to be 37.1% less than in the BAU case, which suggests that items could have been delivered sooner, while the financial savings were estimated to be 35.4%. Since the portering algorithm does not attempt to balance workloads, one porter was modelled to work for nearly 8 hours while the other worked for just under 4 hours. This imbalance is not necessarily an issue, particularly where some people may only want to work part-time. The two porters would have walked 13.4km (taking 34% of their time) and 9km (45% of their time), respectively, delivering 8 and 4 bag loads, respectively, collecting them from selected pickup locations from among those shown in Figure 1.

The two truck drivers, delivering the 50% of heavier consignments and dropping off bags to selected drop-off points, were occupied for just under 8 hours and 10 hours, respectively. If the latter round time were considered too long, in practice, then a third truck and driver would have to be implemented, at an increased cost (not modelled here). The ratios of driver travel time to the time spent making deliveries or collections were 33%:67% and 30%:70% for the two drivers, which corresponded approximately with carrier survey data that showed vehicles parked for around 62% of round time (Allen et al, 2018b).

Where the porters were equipped with 430L trollies instead of 200L wheeled bags, the increased carrying capacity meant approximately 50% fewer visits to pickup locations, leading to additional savings (2%-4% greater) in terms of diesel consumption, emissions, time, distance and estimated cost (Table 5). This meant fuel consumption and $CO_2$ savings, compared to the BAU case, of 44.4% and NOx savings of 33%, as well as cost savings of 39.4%.

The use of bicycle couriers with even greater carrying capacity (620L) and faster assumed travel speeds (10mph), compared to driving (8mph) and walking (3.2mph), led to slightly higher savings across all the performance measures considered (Table 6). Driving distance savings were 68.3% equating to fuel and $CO_2$ savings of 44.9% and NOx savings of 33.7%; time and cost savings were 45.6% and 42.5%, compared to the BAU case. Although two bicycle couriers were required on the Monday, as shown here, on all other days of the week it was possible to utilise a single bicycle courier as the time required was lower than the specified 8.5 hour limit. In practice, it is possible that a carrier may prefer to employ more than the minimum number of couriers needed, each working fewer hours, as this may not affect costs greatly where hourly rates are used. An advantage of using extra people is that deliveries may be made sooner. Where a single tricycle courier with a 1000L carrying capacity was used (Table 7), results were very similar to those found when using bicycle couriers (Table 6), indeed all the results were fairly insensitive to the choice of portering or cycle courier method.

**Table 4. Portering with 200L wheeled bag, Monday 7th January 2019**

| | Driver 1 | Driver 2 | Porter 1 | Porter 2 | Total | Porter % | Savings % |
|---|---|---|---|---|---|---|---|
| Travel time | 02:37:23 | 02:56:39 | 02:38:15 | 01:45:03 | 09:57:21 | 44% | |
| Delivery/collection time | 05:20:00 | 07:00:00 | 05:06:00 | 02:06:00 | 19:32:00 | 37% | |
| Total time | 07:57:23 | 09:56:40 | 07:44:15 | 03:51:03 | 29:29:21 | 39% | 37.1% |
| Cost (£) | 193.47 | 237.27 | 144.91 | 69.93 | 645.58 | 33% | 35.4% |
| #visits to drop-off/ pickup locations | 4 | 4 | 8 | 4 | 20 | 60% | |
| #deliveries | 57 | 71 | 93 | 37 | 258 | 50% | |
| #collections | 5 | 10 | 0 | 0 | 15 | 0% | |
| Items weight (kg) | 1784 | 1588 | 157 | 85 | 3615 | 7% | |
| Items volume (litres) | 9943 | 8661 | 1178 | 540 | 20321 | 8% | |
| Distance (km) | 43.9 | 48.8 | 13.4 | 9.0 | 115.1 | 19% | 66.2%* |
| Diesel used (litres) | 8.65 | 9.61 | 0 | 0 | 18.3 | 0% | 41.2% |
| $CO_2$ (kg) | 22.8 | 25.4 | 0 | 0 | 48.2 | 0% | 41.2% |
| NOx (kg) | 0.0294 | 0.0327 | 0 | 0 | 0.1 | 0% | 29.2% |

* Driving distance savings

**Table 5. Portering with 430L trolley, Monday 7th January 2019**

| | Driver 1 | Driver 2 | Porter 1 | Porter 2 | Total | Porter % | Savings % |
|---|---|---|---|---|---|---|---|
| Travel time | 02:22:15 | 02:46:36 | 02:06:51 | 01:19:43 | 08:35:25 | 40% | |
| Delivery/collection time | 05:10:00 | 06:55:00 | 04:00:00 | 02:51:00 | 18:56:00 | 36% | |
| Total time | 07:32:15 | 09:41:36 | 06:06:51 | 04:10:43 | 27:31:25 | 37% | 41.3% |
| Cost (£) | 182.69 | 230.79 | 113.48 | 77.97 | 604.93 | 32% | 39.4% |
| #visits to drop-off/ pickup locations | 2 | 3 | 3 | 2 | 10 | 50% | |
| #deliveries | 57 | 71 | 76 | 54 | 258 | 50% | |
| #collections | 5 | 10 | 0 | 0 | 15 | 0% | |
| Items weight (kg) | 1784 | 1588 | 137 | 106 | 3615 | 7% | |
| Items volume (litres) | 9943 | 8661 | 1049 | 669 | 20321 | 8% | |
| Distance (km) | 40.8 | 46.9 | 10.8 | 6.9 | 105.4 | 17% | 68.0% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Diesel used (litres) | 8.04 | 9.23 | 0 | 0 | 17.3 | 0% | 44.4% |
| $CO_2$ (kg) | 21.2 | 24.4 | 0 | 0 | 45.6 | 0% | 44.4% |
| NOx (kg) | 0.0273 | 0.0314 | 0 | 0 | 0.1 | 0% | 33.0% |

**Table 6. Bicycle courier with 620L container, Monday 7th January 2019**

| | Driver 1 | Driver 2 | Biker 1 | Biker 2 | Total | Porter % | Savings % |
|---|---|---|---|---|---|---|---|
| Travel time | 02:15:47 | 02:48:57 | 00:56:38 | 00:49:17 | 06:50:39 | 26% | |
| Delivery/collection time | 05:05:00 | 06:45:00 | 04:06:00 | 02:45:00 | 18:41:00 | 37% | |
| Total time | 07:20:47 | 09:33:57 | 05:02:38 | 03:34:17 | 25:31:39 | 34% | 45.6% |
| Cost (£) | 177.89 | 228.50 | 98.76 | 69.10 | 574.24 | 29% | 42.5% |
| #visits to drop-off/ pickup locations | 1 | 1 | 3 | 2 | 7 | 71% | |
| #deliveries | 57 | 71 | 78 | 52 | 258 | 50% | |
| #collections | 5 | 10 | 0 | 0 | 15 | 0% | |
| Items weight (kg) | 1784 | 1588 | 148 | 95 | 3615 | 7% | |
| Items volume (litres) | 9943 | 8661 | 994 | 723 | 20321 | 8% | |
| Distance (km) | 39.6 | 47.3 | 15.8 | 13.8 | 116.4 | 25% | 68.3% |
| Diesel used (litres) | 7.79 | 9.31 | 0 | 0 | 17.1 | 0% | 44.9% |
| $CO_2$ (kg) | 20.6 | 24.6 | 0 | 0 | 45.2 | 0% | 44.9% |
| NOx (kg) | 0.0265 | 0.0317 | 0 | 0 | 0.1 | 0% | 33.7% |

**Table 7. Tricycle courier with 1000L container, Monday 7th January 2019**

| | Driver 1 | Driver 2 | Trike | Total | Porter % | Savings % |
|---|---|---|---|---|---|---|
| Travel time | 02:15:47 | 02:56:27 | 01:46:09 | 06:58:23 | 25% | |
| Delivery/collection time | 05:05:00 | 06:45:00 | 06:39:00 | 18:29:00 | 36% | |
| Total time | 07:20:47 | 09:41:27 | 08:25:09 | 25:27:23 | 33% | 45.7% |
| Cost (£) | 177.89 | 232.33 | 169.96 | 580.18 | 29% | 41.9% |
| #visits to drop-off/ pickup locations | 1 | 1 | 2 | 4 | 50% | |
| #deliveries | 57 | 71 | 130 | 258 | 50% | |
| #collections | 5 | 10 | 0 | 15 | 0% | |
| Items weight (kg) | 1784 | 1588 | 243 | 3615 | 7% | |
| Items volume (litres) | 9943 | 8661 | 1718 | 20321 | 8% | |
| Distance (km) | 39.6 | 49.0 | 28.5 | 117.1 | 24% | 67.7% |
| Diesel used (litres) | 7.79 | 9.66 | 0 | 17 | 0% | 43.8% |
| $CO_2$ (kg) | 20.6 | 25.5 | 0 | 46.1 | 0% | 43.8% |
| NOx (kg) | 0.0265 | 0.0329 | 0 | 0.0594 | 0% | 32.4% |

## 6 Conclusions and further work

In this research, historical manifest data from a parcel carrier undertaking 'next-day' (i.e. non-express) B2B and B2C deliveries in central London were used to quantify the potential benefits of switching from the current van-based deliveries to one where porters or cycle couriers are used for the last-mile delivery, working from set drop-off points. Substantial environmental and financial savings were estimated for a case study example where around half of all consignments on a parcel delivery round were modelled to be delivered by a porter or cycle courier; it is anticipated that even greater savings could be attained for lighter parcel distribution profiles, as would typically be found for mainly B2C parcel delivery companies, since a greater proportion of the work could then be readily undertaken by porters or cycle couriers. There seemed to be little to choose between using porters or cycle couriers, in environmental or financial terms, so this choice may be determined by availability and skills of personnel or by delivery drop density, where walking may be the best option in the densest delivery networks.

Factoring the modelled results found for one week suggested that, over the business-as-usual case for the area of London studied, the carrier could reduce $CO_2$ emissions by 9500kg/year and NOx emissions by 7.64kg/year. Annual driving distance could be reduced by 48,100km and the amount of time spent stationary at the curbside could be reduced by 2558 hours. Scaling up the modelled emissions savings to London's Central Activities Zone, an area approximately 10 times bigger than the modelled case study area and with estimated total annual parcel delivery distance of 15 million km (from section 2), annual emissions savings could be in the region of 2 million $kgCO_2$ and 1633kgNOx if all carriers utilised porters or cycle couriers.

Efficiency and financial gains in terms of reduced vehicle fleets, fewer drivers and reduced fuel use would be traded against the additional cost and complexity of using porters or cycle couriers. In terms of running such a portering/courier service alongside a traditional van delivery service, the day-to-day operations may be best served by a private operator, utilising a similar crowd-based platform operated by companies like Deliveroo. Of interest here would be the extent to which the system attempts to optimise driving, walking or cycling routes for maximum efficiency and environmental benefit.

A possible concern is the security issue associated with handing over parcels to a third party but, given the tracking and proof-of-delivery functionality embedded in existing systems used in last-mile fast food delivery, this may not be such a problem in reality. Consideration would also have to be given to treatment of any express deliveries and of failed deliveries, particularly for B2C parcels.

Due to the ad hoc nature of the work, same-day parcel carriers have traditionally always made use of self-employed couriers (using bicycles, motorbikes, cars and vans), while next-day parcel carriers have tended to hire casual labour to supplement directly employed driver's during peak periods (FORBA, 2012; Haidinger, 2012). With the rise of internet-based platform providers for taxi services and takeaway meal delivery, this method of hiring casual labour has been growing rapidly in the UK and elsewhere (European Parliament, 2016). A key issue in this self-employed sector is 'employee' status and the additional legal rights that come with it such as the minimum wage, paid holidays and the right to protection against discrimination (Chakrabortty, 2016). Such issues have led to UK government enquiries (Work and Pensions Committee, 2016; Taylor et al, 2017) as the long-term future of such crowd-sourced systems rely crucially on the current informal relationships between couriers and logistics providers. Despite these issues, with the focus on promoting walking and cycling as healthier mode choices and the growth in life-style couriering as a viable profession, there is considerable scope to see a switch to more sustainable last-mile freight solutions for the wider benefit of society.

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