Environmental Benefits from Shared-Fleet Logistics: Lessons from a Public-Private Sector Collaboration

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ABSTRACT

Road freight transportation leads to environmental concerns such as congestion and detrimental vehicle emissions, whilst also suffering from inefficiencies due to less-than-full-load vehicle movements. Shared-fleet carrier collaborations are an approach to freight distribution that can reduce inefficiencies, and thereby reduce goods vehicle-kilometres (vkm) and associated congestion and emissions. Using real-world data from a five-day warehouse survey, the potential environmental benefits of a shared-fleet operation involving collaboration between local suppliers to a large commercial enterprise and a municipal Local Government Authority (LGA) were quantified. Local suppliers shared the spare capacity in LGA courier service vans (Light Goods Vehicles) to transport consignments as an alternative to each organising their own separate deliveries. Results suggested a shared-fleet carrier collaboration involving 25 local suppliers serviced by five LGA vans performing 16 rounds/week produced a 29% reduction in delivery vkm and emissions reductions ranging from 27-36% depending on pollutant.

KEYWORDS

Shared-fleet

Carrier collaboration

Freight logistics

Emissions

Road congestion

1 INTRODUCTION

1.1 Background

It is well known that freight transportation by road causes environmental concerns such as congestion and vehicle emissions that contribute to poor air quality (AQ) and detrimental climate effects (Crainic and Montreuil 2016; Muñoz-Villamizar *et al.* 2017; Muñoz-Villamizar *et al.* 2019; Vargas *et al.* 2018; Wang *et al.* 2018c; Nataraj *et al.* 2019; Yao *et al.* 2019). Road freight logistics also suffer from inefficiencies due to goods vehicle movements with less-than-full-loads (Crainic and Montreuil 2016; Vargas *et al.* 2018; Lai *et al.* 2017; Gansterer *et al.* 2019; Gansterer *et al.* 2020b; Gansterer and Hartl 2020). Shared-fleet, collaborative transportation where organisations cooperate by sharing vehicle capacity to improve overall vehicle utilisation is an approach that offers opportunities to reduce inefficiencies, goods vehicle-kilometres (vkm) and the associated congestion and emissions (Vargas *et al.* 2018; Nataraj *et al.* 2019; Yao *et al.* 2019; Gansterer *et al.* 2019; Gansterer and Hartl 2020; Dai and Chen 2012; Quintero-Araujo *et al.* 2017; Gansterer *et al.* 2020a).

1.2 Innovation of this Paper

The research reported here quantified the environmental benefits of adopting a shared-fleet operation for freight in terms of the reduction in goods vkm and emissions. The method used was a case study collaboration between local suppliers of a large cruise ship operator (Carnival UK, CUK) based in Southampton (a city on the South coast of the UK with population ~260,000), a freight logistics provider (Meachers Global Logistics, MGL) also located in Southampton, and the municipal Local Government Authority (LGA) responsible for the city (Southampton City Council, SCC) who would use their own-account courier fleet to run the service.

The innovative aspect of the research was the involvement of the LGA as the prospective fleet provider. The research assessed the feasibility of LGAs utilising their own-account goods vehicle fleets in shared-fleet carrier collaborations with private sector companies within their dioceses, quantifying the associated environmental benefits that could be generated, alongside an estimate of the economic benefits that LGAs might expect to accrue. The potential for environmental gains coupled with revenue generation opportunities for LGAs (whose financial budgets are often under considerable pressure from austerity measures) make LGA involvement an important aspect of shared-fleet carrier collaborations that has not been investigated previously. A wider motivation for LGA involvement was the potential to reduce numbers of delivery vehicles on the road, allowing LGAs to demonstrate by example how shared-fleet carrier collaborations could offer a way to counter restrictions designed to discourage vehicles from entering certain areas (e.g. Low Emission Zones).

1.3 Paper Organisation

The paper is organised as follows. A review of related literature is reported in Section 2. The methodology used to conduct the case study analysis is described in Section 3. Results are presented and discussed in Section 4, before conclusions are drawn in Section 5.

2 SHARED-FLEET FREIGHT LOGISTICS: A REVIEW

2.1 Logistics Collaboration

In general, collaboration in the logistics industry involves stakeholders (e.g. manufacturers, suppliers, shippers, carriers, storage providers, retailers, end-users) cooperating to improve the sustainability of supply chains through increased efficiency of resource utilisation (e.g. storage facilities, depots, goods vehicle capacity) (Gonzalez-Feliu and Morana 2011; Ouhader and El Kyal 2017; Gansterer *et al.* 2020b; Gansterer and Hartl 2020). Vertical collaboration involves cooperation between members of the same supply chain, whereas horizontal collaboration involves cooperation between companies that can provide similar goods or services at the same level within a supply chain (e.g. multiple carriers that are potentially competitors) (Krajewska *et al.* 2008; Ouhader and El Kyal 2017; Vargas *et al.* 2018; Gansterer *et al.* 2020b; Gansterer and Hartl 2020). Vertical collaboration has already received much attention in the literature, but horizontal collaboration (such as the shared-fleet carrier collaboration reported in this paper) has been subject to less research (Ballot and Fontane 2010; Ouhader and El Kyal 2017).

Existing research on horizontal collaboration is primarily focused on investigating the benefits of, and mechanisms for, collaboration between carriers who form grand alliances to satisfy general network-wide demand for transportation of goods, achieved through exchanging requests for collections and deliveries, i.e. sharing vehicle capacity in shared-fleet carrier collaborations (Wang *et al.* 2018a). Typically, research is based on mathematical modelling (i.e. computational) approaches, leading to a paucity of studies based on real-world data, as observed by Gansterer and Hartl (2020) during their extensive review of recent research in the domain. The principal concern of this paper was understanding the benefits of adopting shared-fleet carrier collaboration rather than mechanisms for realising collaboration, and relevant literature was reviewed accordingly.

2.2 Benefits of Shared-fleet Carrier Collaborations

Benefits investigated tend to be economic (e.g. cost savings, distribution of increased profits between collaborating carriers), but can sometimes include environmental aspects as well. Recent examples of research include a computational study by Gansterer *et al.* (2020b), which found that cost savings of 20-30% were generated by carrier collaboration. Reductions in vkm were a component of the cost savings, but were not quantified explicitly, and emissions reductions were not considered. A computational study by Chabot *et al.* (2018) showed that carrier collaboration can lead to “significant cost reductions”, and that emissions reductions of up to ~80% could be achieved if the computational objective was set to minimise greenhouse gas (GHG) emissions.

Based on a computational study, Wang *et al.* (2018a) found that carrier collaboration can produce cost savings of ~30%. Reductions in vehicle numbers and vkm were a component of the cost savings, but were not quantified explicitly, and emissions reductions were not considered. A further computational study by Wang *et al.* (2018b) suggested that carrier collaboration can generate cost and vehicle number reductions of 68% and 23%, respectively; whilst further work (Wang *et al.* 2018c) suggested that carrier collaboration could produce cost and carbon dioxide (CO_2) emissions reductions of 74% and 47%, respectively. Yao *et al.* (2019) studied two carriers operating in the same city, finding that average profit increases of 3% and CO_2 emissions reductions of 1% could be achieved through collaborative working. Based on a case study of French retail supply chains using real-world data, Ballot and Fontane (2010) found that carrier collaboration could produce reductions of around 25% in CO_2 emissions.

A computational study by Quintero-Araujo *et al.* (2017) considered a system for shared-fleet carrier collaborations that included sharing storage space, with results suggesting that costs and CO_2 emissions could be reduced by 4% and 3%, respectively. Nataraj *et al.* (2019) investigated shared-fleet carrier collaborations that included decisions concerning potential locations for Urban Consolidation Centres (UCCs), finding that costs and CO_2 emissions could be reduced by 47% and 42%, respectively. Muñoz-Villamizar *et al.* (2017) and Muñoz-Villamizar *et al.* (2019) used real-world data from Bogotá, Columbia to evaluate the use of Electric Vehicles (EVs) in urban shared-fleet carrier collaborations, reporting that EVs were more beneficial in terms of costs and CO_2 emissions over time periods longer than three years.

2.3 Summary of Review Findings

Environmental benefits often seem to be of secondary importance to economic benefits in studies of shared-fleet carrier collaborations. Research tends to focus on network-wide, grand alliances of carriers, rather than smaller scale, third-party logistics operations often involving own-account vehicles that could benefit from collaborative practices as reported in this paper. In general, there is a lack of research based on real-world data, with the large majority of studies adopting a computational approach, and there appears to be no previous research investigating the feasibility of LGA involvement as prospective fleet providers, i.e. extending shared-fleet carrier collaborations to include the public sector in a public-private collaboration. Shared-fleet public-private collaborations have been investigated before by McLeod *et al.* (2011), but this was for refuse collection services rather than a carrier collaboration, with the study finding that, if refuse collection vehicles operated by the LGA to collect household waste were also used to collect waste from commercial premises, vkm could be reduced by up to ~10%.

This paper has addressed the identified research gaps in two ways: (1) quantifying the environmental benefits (in terms of the effects on vkm and emissions) of a shared-fleet carrier collaboration between local suppliers serving a single client, based on a case study of real-world data; and (2) assessing the feasibility of LGA involvement in shared-fleet carrier collaborations (the innovative aspect of this paper) to maximise utilisation of their own-account fleets and create opportunities for generating additional revenue.

3 METHODOLOGY

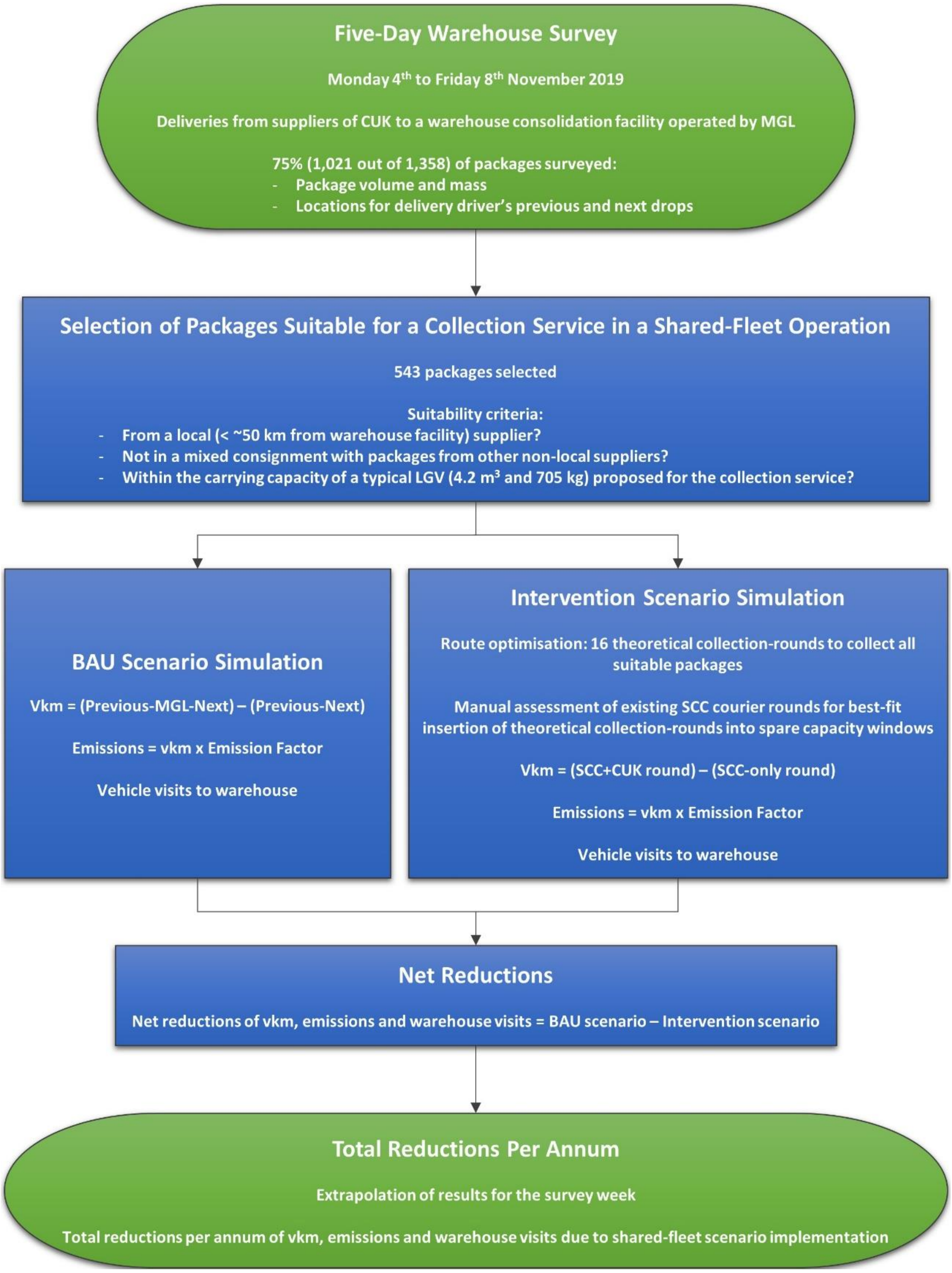
3.1 Overview

The methodology is summarised in Figure 1 and details are provided in subsequent sections, but a brief overview of the study is as follows. Suppliers of CUK send all non-perishable goods to a warehouse facility in Southampton run by a freight logistics provider (MGL). Goods are received, sorted and stored at the warehouse, before being consolidated for final delivery (by MGL) to the appropriate CUK cruise ship when docked in Southampton.

Based on data collected during a five-day warehouse survey, the environmental effects of a shared-fleet carrier collaboration providing a collection service for consignments from CUK's multiple local suppliers (within ~50 km of MGL, Figure 2) as a replacement for suppliers each arranging separate warehouse deliveries were analysed. The methodology consisted of two stages: (1) estimating the effects of a Private-Only Shared-Fleet Carrier Collaboration (POSFCC) involving the local suppliers (who typically act as carriers for their own goods) collaborating to share capacity on vehicles dedicated to collecting consignments destined for CUK operated by a generic third-party private-sector carrier; and (2) estimating any further effects if the vehicles were to be operated specifically by the LGA (SCC) instead, integrated as part of their existing courier service, in a Public-Private Shared-Fleet Carrier Collaboration (PPSFCC).

The SCC courier service operates five fixed-schedule rounds each weekday (Mon-Fri) using five diesel Light Goods Vehicles (LGVs with ≤3.5 tonnes gross vehicle mass, i.e. vans). The courier service was originally established to transport the LGA's own goods (principally internal post) between SCC's various sites and other municipal buildings distributed around Southampton. The service was deliberately over-established in order to cope with unforeseen eventualities, meaning the courier rounds include windows of spare capacity, i.e. periods when vans are deliberately scheduled to be empty and idle ready to accommodate *ad hoc* work requests.

SCC has recognised that vehicle utilisation could be improved and collaboration with private sector organisations offers a way to potentially improve vehicle load factors and generate more revenue. The main operational area for the courier service is within Southampton (Figure 2) and it was agreed with the LGA that suppliers situated anywhere within a radius of ~50 km of MGL could be accommodated. The LGA is working towards the electrification of its courier fleet using the Nissan e-NV200, and the load capacity of this vehicle (4.2 m^3 and 705 kg) was used in this research to represent the capacity of the vehicles used to collect CUK consignments.



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178 **Figure 1: Summary of the methodology used in the case study analysis.**

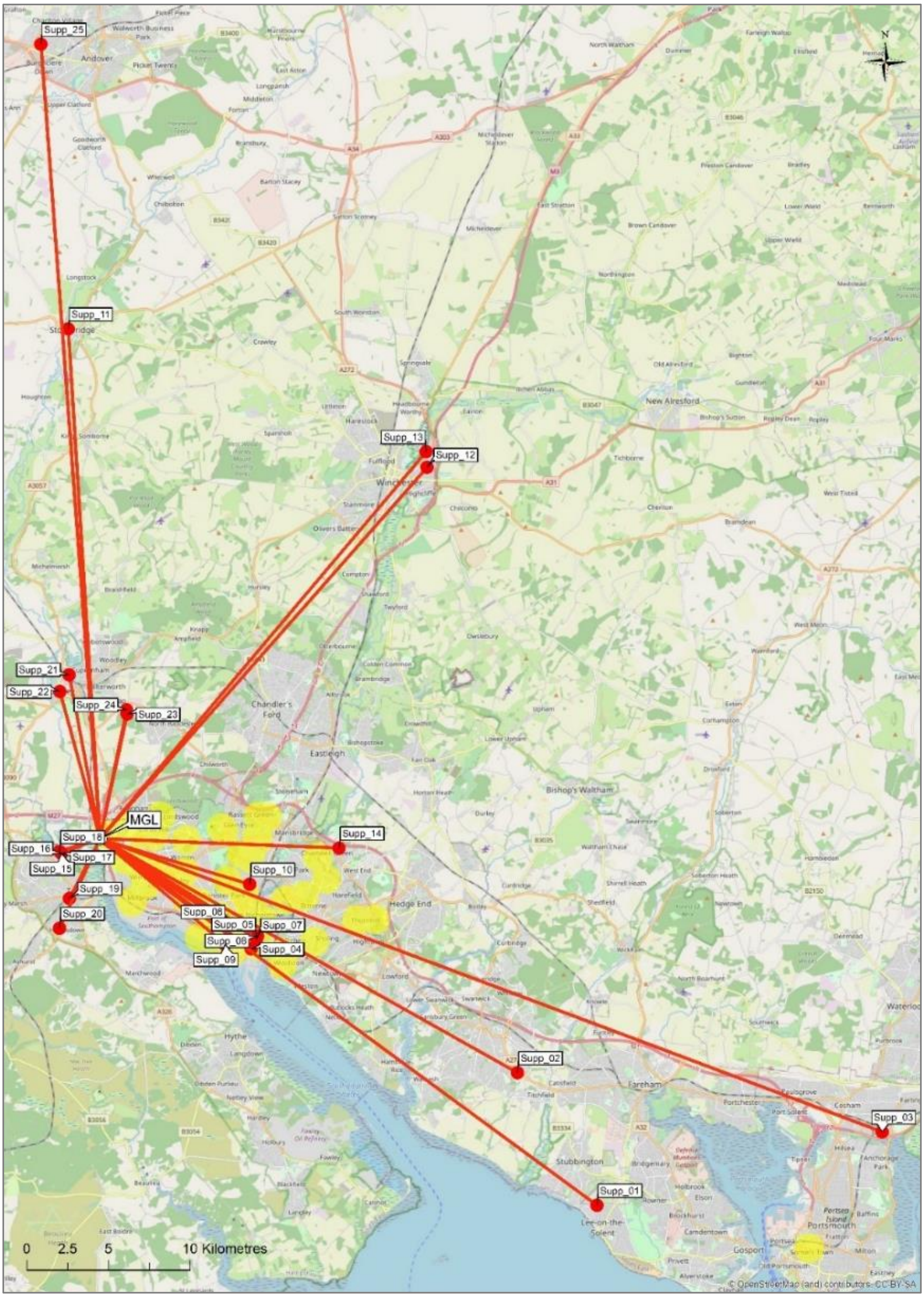

Figure 2: CUK local supplier locations and SCC courier service activity areas.
Red circles indicate CUK's local suppliers. Yellow circles indicate SCC courier service's activity areas. MGL indicates the location of MGL's warehouse facility.

3.2 Warehouse Survey

A survey of deliveries for CUK (Figure 3) received at MGL's warehouse was undertaken from Mon 4th to Fri 8th November 2019. Based on expertise and experience from both CUK and MGL, this week was selected as offering a representative sample of deliveries. Deliveries of interest were packages from CUK's local suppliers (within ~50km of MGL) that were practical for collection by LGV (within volume and weight carrying capacities, 4.2 m^3 and 705 kg). Any packages or consignments from suppliers outside this radius or well beyond the capacity of a LGV were deliberately screened-out of the survey entirely. The following data were recorded: package dimensions and (where possible) mass using industrial weighing scales; delivery driver's origin, previous drop, next drop and destination locations; and vehicle registration number, which allowed vehicle details to be obtained.

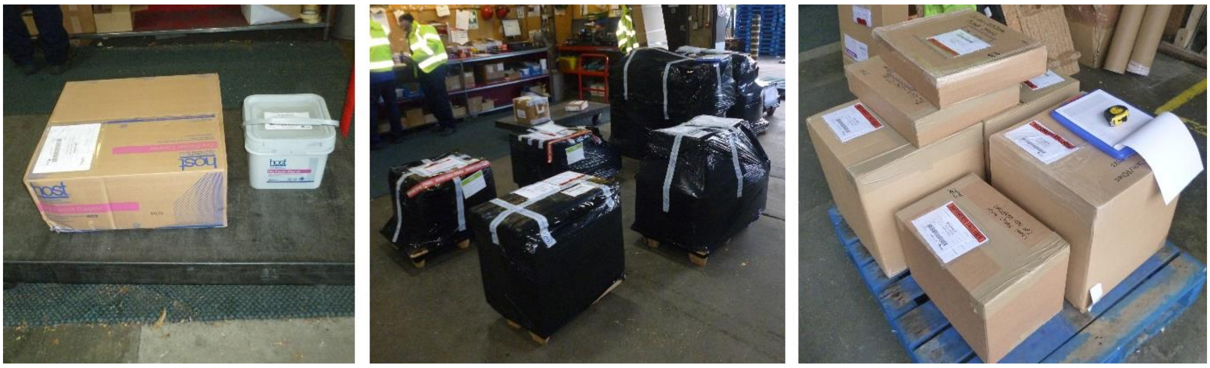

Figure 3: Examples of deliveries from CUK's local suppliers received at MGL's warehouse.

Over the five-day survey period, the sample of packages surveyed (1,021) amounted to 75% of the total number of packages received (1,358) (Table 1). There were two reasons for packages being missed during the survey: (1) packages that arrived outside survey times; and (2) multiple consignments (i.e. multiple delivery vehicles) that arrived concurrently, which were beyond the capacity of a single surveyor to record before warehouse staff processed and removed the packages into storage. Packages missed during the survey were non-recorded on a whole-consignment basis (i.e. when one package was non-recorded, all other packages in the same consignment were non-recorded).

Table 1: Numbers of packages received and surveyed during the survey period.

Date	Survey Times	Packages Received	Packages Surveyed	Sample Size (%)
Monday 4th November 2019	09:00-16:00	295	162	55
Tuesday 5th November 2019	09:00-16:00	270	154	57
Wednesday 6th November 2019	09:00-16:00	408	382	94
Thursday 7th November 2019	09:00-16:00	147	122	83
Friday 8th November 2019	09:00-16:00	238	201	84
	Total	**1,358**	**1,021**	**75**

The transport of SCC paper records between the Council's offices (in central Southampton) and records storage facilities (at MGL) was included in the case study as well. This made sense for three reasons: (1) SCC was involved in the shared-fleet carrier collaboration; (2) records storage was co-located at MGL; and (3) there were relatively few packages involved (compared to the number of CUK packages), meaning they could be easily accommodated in the shared-fleet operation.

3.3 Scenario Simulations

Business-As-Usual (BAU) delivery vehicle routes for CUK suppliers were simulated as follows: origin – previous drop – MGL warehouse – next drop – destination. Online route planning software (GraphHopper) was used to estimate the vkm for each leg of the routes (fastest route under free-flow traffic conditions). BAU vkm associated with a supplier delivering to MGL's warehouse were then calculated as the difference between the BAU delivery vehicle route and the same route but with the vehicle bypassing MGL (i.e. travelling directly from previous to next drop).

This assumed that the sequence of the remaining delivery stops was unchanged when MGL was bypassed, which may not always be the case. For example, removing the need to visit MGL could result in the remaining deliveries being re-optimised into a different order. Hence, although it was regarded as a practical approach to produce a reasonable simulation of the likely real-world BAU, the approach represented a possible source of error.

Vehicle emissions were estimated based on BAU vkm using Emission Factors (EFs in g/km, Table 2). The principal pollutants in road vehicle exhaust emissions are CO_2, oxides of nitrogen (NO_X), particulate matter (≤10 µm in diameter, PM_{10}) and carbon monoxide (CO) (Nejadkoorki *et al.* 2008). CO_2 is (by some margin) the main GHG emitted by transport, and contributes to the problem of global warming (Grote *et al.* 2016). Emissions of NO_X, PM_{10} and CO all contribute to the problem of poor AQ and are damaging to human health (Uherek *et al.* 2010).

Estimating the impacts of shared-fleet operations on the generation of these four pollutants formed the vehicle emissions aspect of the analysis. EFs (except for CO_2) were obtained from the fleet weighted-average EFs on urban roads produced by the UK's National Atmospheric Emissions Inventory (NAEI 2019). The NAEI data do not include EFs for CO_2, so these were obtained from the UK Government GHG Conversion Factors for Company Reporting (DEFRA & BEIS 2019).

Table 2: EFs used to calculate delivery vehicle emissions.

Vehicle	Fuel	CO_2 EF (g/km)	NO_X EF (g/km)	PM_{10} EF (g/km)	CO EF (g/km)
Car	Gasoline	180	0.084	0.001	0.431
Car	Diesel	172	0.599	0.010	0.075
LGV	Gasoline	235	0.092	0.001	1.426
LGV	Diesel	250	0.999	0.013	0.108
HGV - Rigid	Diesel	791	2.274	0.025	0.637
HGV - Articulated	Diesel	910	1.637	0.020	0.604

LGV is Light Goods Vehicle, HGV is Heavy Goods Vehicle.

To simulate the intervention (i.e. shared-fleet) scenario, a list of hypothetical collections was created based on the locations of the local suppliers involved. Commercially available route optimising software (PTV Route Optimiser) was used to produce a set of optimised theoretical collection-round routes that collected all the consignments of packages and delivered them as consolidated loads to MGL (i.e. the POSFCC). Parameter settings were as follows:

- vehicle load capacity in accordance with the proposed real-world LGV (4.2 m^3 and 705 kg);
- fastest route;
- all other parameters at default settings (including free-flow traffic conditions), which were regarded as sufficiently accurate for case study purposes.

The specific optimisation algorithm used by Route Optimiser is commercially sensitive and confidential but follows the traditional approach of the classical Travelling Salesman Problem (Baniasadi *et al.* 2020).

Two different software applications were used: one for route planning purposes when a set of locations was visited in a pre-determined order (GraphHopper); and the other for route optimisation purposes when it was necessary to determine the optimal order in which to visit a set of locations (PTV Route Optimiser). Both software applications were engineered to select routes based on the same conditions (i.e. fastest route under free-flow traffic conditions) to keep the generated routes as similar as possible. The resulting routes chosen by PTV Route Optimiser were compared to those derived by GraphHopper between the same locations and were found to be consistent.

The theoretical collection-rounds were then integrated into the pre-existing rounds operated by the SCC courier service (i.e. the PPSFCC). Daily schedules for the five SCC courier vehicles were obtained, and CUK consignment collections inserted into windows of spare capacity. To the extent possible within the constraints imposed by the capacity windows, the optimised routes of the theoretical collection-rounds were adhered to during insertion.

Best-fit was assessed manually in accordance with expertise provided by SCC route planning staff, with some theoretical collection-round routes needing to be split to fit within the confines of the windows. This approach to integration was adopted for practical reasons because it minimised disruption to SCC's pre-existing courier service, facilitating the integration of CUK consignment collections and expediting the process of implementing shared-fleet operations in practice.

Online route planning software (GraphHopper) was used to estimate the vkm (fastest route under free-flow traffic conditions) for the routes driven by the SCC courier vehicles. No route optimisation was required (i.e. the more complex PTV Route Optimiser software was not necessary) because both the SCC courier rounds and the theoretical collection-rounds were pre-determined (courier rounds according to the schedules provided by SCC and theoretical collection-rounds according to the route optimisation results). Vkm generated by the intervention scenario were then calculated as the increase in vkm for the SCC vehicles when performing the courier rounds including the CUK consignments compared to performing the original (SCC-only) courier rounds (vkm generated = vkm for SCC/CUK round – vkm for SCC-only round).

Finally, the net effects of the intervention scenario as an alternative to BAU were found by calculating the differences between the two scenarios in terms of reduced vkm, emissions and warehouse visits (net effects = BAU scenario – intervention scenario).

4 RESULTS AND DISCUSSION

4.1 BAU Scenario

Despite obviously unsuitable packages being deliberately screened-out of the survey entirely (Section 3.2), there was still a proportion of packages surveyed that ultimately proved to be unsuitable for collection (e.g. from suppliers who turned-out to be non-local; from local suppliers but mixed in a consignment with packages from non-local suppliers, meaning the delivery vehicle would visit MGL anyway even if the package from the local supplier were to be collected instead). Filtering the data to include only consignments of packages suitable for collection produced 46 consignments (543 packages) out of the 96 consignments (1,021 packages) surveyed in total.

These 46 suitable consignments (Appendix A) constituted a total volume of 35.001 m^3 and total mass of 4,564 kg (although it is important to note that total mass does not reflect the true mass due to instances of missing data), which generated a total of 878 vkm under BAU, producing 226 kg of CO_2, 877 g of NO_X, 11 g of PM_{10} and 104 g of CO. The locations of the 25 local suppliers involved with these consignments are shown in Figure 2. The consignment from Supp_13 (Consignment 013 in Appendix A) was delivered from Blandford Forum (>50 km from MGL). However, the consignment was retained because Supp_13 had multiple outlets and the nearest one to MGL was in Winchester (<50 km from MGL) where it was assumed the consignment could be collected instead.

Two atypical situations regarding the local suppliers in Appendix A were Carnival House (Supp_09) and SCC Records (Supp_08). Carnival House consignments constituted packages sent by CUK from their headquarters (Carnival House in central Southampton) to MGL, which were collected as part of two daily rounds performed by MGL vans under BAU. As such, reductions in vkm and emissions due to the intervention scenario would occur because the MGL vans could bypass Carnival House, leaving the packages to be collected by the shared-fleet operation instead. In this case, an estimate of 14 vkm (equivalent to one direct return trip from MGL to Carnival House) was used to represent the BAU vkm associated with the twice-daily collections from Carnival House (i.e. the two daily rounds performed by MGL vans in the BAU scenario).

For SCC Records, whilst there were occasional deliveries of Council records to MGL (approximately one/month), the large majority of movements (the case for all consignments during the survey week) were collections of records from storage facilities at MGL for delivery to SCC premises by Council vehicles. This was reflected during simulation of the intervention scenario by entering SCC Records consignments into the route optimising software as deliveries rather than collections.

4.2 Intervention Scenario

The 46 suitable consignments were aggregated according to supplier to prepare a list of the volumes and masses of consignments to be collected during simulation of the theoretical collection-rounds for the intervention scenario (Table 3). Where Table 3 shows more than one consignment from a supplier, this was because each consignment had to fit within the capacity of the LGV proposed for collection (4.2 m^3 and 705 kg). Missing consignment mass data were estimated using densities calculated from packages containing similar goods where both volume and mass were known. This ensured the mass-carrying capacity constraint of the collection LGV (705 kg) was accounted for in the simulation.

Table 3: Volumes and masses of consignments for collection.

Supplier	Supplier Location	Volume (m^3)	Mass (kg)
Supp_01	Lee-on-the-Solent, PO13 9FX	0.022	6
Supp_02	Fareham, PO14 4LW	0.056	28
Supp_03	Portsmouth, PO6 1TR	1.020	443
Supp_03	Portsmouth, PO6 1TR	1.027	445 *(Est.)*
Supp_04	St Marys, Southampton, SO14 3EW	0.398	49
Supp_05	St Marys, Southampton, SO14 5JP	1.375	550
Supp_05	St Marys, Southampton, SO14 5JP	1.550	550
Supp_06	St Marys, Southampton, SO14 5JP	1.260	230 *(Est.)*
Supp_07	St Marys, Southampton, SO14 5JP	2.202	405 *(Est.)*
Supp_07	St Marys, Southampton, SO14 5JP	2.000	370 *(Est.)*
Supp_08	Central, Southampton, SO14 7LY	0.253	95 *(Est.)*
Supp_09	Central, Southampton, SO15 1ST	1.614	241
Supp_10	Portswood, Southampton, SO17 2FW	1.080	400
Supp_10	Portswood, Southampton, SO17 2FW	1.080	400
Supp_11	Stockbridge, SO20 6EY	0.146	120 *(Est.)*
Supp_12	Winchester, SO23 0LN	1.312	490 *(Est.)*
Supp_12	Winchester, SO23 0LN	1.471	550 *(Est.)*
Supp_13	Winchester, SO23 7RX	0.805	150 *(Est.)*
Supp_14	West End, Southampton, SO30 3SF	3.348	225
Supp_15	Totton, Southampton, SO40 3WX	0.258	215
Supp_16	Totton, Southampton, SO40 3WX	0.737	521
Supp_17	Totton, Southampton, SO40 3WX	1.396	640 *(Est.)*
Supp_17	Totton, Southampton, SO40 3WX	1.395	640 *(Est.)*
Supp_17	Totton, Southampton, SO40 3WX	1.395	640 *(Est.)*
Supp_18	Totton, Southampton, SO40 3WX	1.174	80
Supp_19	Totton, Southampton, SO40 8DS	0.040	8
Supp_20	Totton, Southampton, SO40 9NA	0.477	50
Supp_21	Romsey, SO51 0HR	0.255	39
Supp_22	Romsey, SO51 8ZJ	2.536	142
Supp_23	Romsey, SO51 9AQ	0.033	12
Supp_24	Romsey, SO51 9DG	0.181	53
Supp_25	Andover, SP10 3RU	3.105	280
	Total	**35.001**	**9,067**

Total number of consignments is 32. *(Est.)* indicates mass includes estimated data.

Table 3 served as the input data to the route optimising software, which generated 16 theoretical collection-rounds required to collect all the CUK consignments and deliver them as consolidated loads to MGL over the course of a week (i.e. the survey week). These collection-rounds represented the POSFCC, where collections were handled by vehicles operated by a generic third-party private-sector carrier engaged to perform the 16 rounds per week (i.e. the first stage of the methodology, Section 3.1). The POSFCC generated a combined total of 637 vkm for all 16 rounds in the intervention scenario, achieving a 27% (241 vkm) reduction on BAU (878 vkm).

In the PPSFCC, collections were handled by SCC courier fleet vehicles instead through adapting their pre-existing courier rounds (i.e. the second stage of the methodology including the LGA, Section 3.1). Mondays were generally very busy for the courier service and were therefore avoided altogether when inserting CUK consignment collections. Vkm generated by the PPSFCC in the intervention scenario were calculated as the difference between performing the pre-existing (SCC-only) courier rounds and the new (SCC/CUK) courier rounds. Results (Table 4) suggested that the PPSFCC generated 622 additional vkm across the 20 rounds (4 days x 5 rounds) performed by the five SCC vehicles over the course of a week. Of the 20 rounds, 16 became new courier rounds, whilst four remained as SCC-only. Maps of two examples of the new courier rounds are shown in Figure 4 and Figure 5 (maps of the other 14 are shown in Appendix B).

The 622 vkm generated by the PPSFCC represented a relatively small improvement (i.e. fewer vkm) compared to the 637 vkm generated by the POSFCC. This was expected because of the method used to insert the CUK consignments, i.e. the optimised routes of the theoretical collection-rounds were adhered to (as far as possible) when inserted into spare capacity windows in SCC's pre-existing courier rounds (Section 3.3).

The PPSFCC (i.e. including the LGA) was still viewed as worthwhile for four reasons: (1) any reduction in the vkm generated in the intervention scenario was welcomed; (2) readily available spare capacity in the LGA fleet was a key impetus for investigating the potential benefits of shared-fleet logistics; (3) a public-private sector collaboration provided the LGA with an opportunity to increase vehicle utilisation that also represented a potential source of revenue (discussed later in this section); and (4) it was a practical way to initiate the collaboration, before seeking further vkm reductions in the future through an improved approach to inserting CUK consignments (e.g. whole route optimisation, discussed later in this section).

Table 4: Distances for SCC courier vehicle rounds including and excluding CUK consignments.

Courier Round	Tue Vkm	Wed Vkm	Thu Vkm	Fri Vkm	Weekly Vkm
Round 01 – SCC-only	121	121	-	-	242
Round 01 – SCC/CUK combined	158	146	-	-	304
Round 02 – SCC-only	33	33	33	33	131
Round 02 – SCC/CUK combined	60	53	68	68	249
Round 03 – SCC-only	-	44	44	44	133
Round 03 – SCC/CUK combined	-	119	101	156	376
Round 04 – SCC-only	56	56	60	60	231
Round 04 – SCC/CUK combined	90	82	87	87	347
Round 05 – SCC-only	41	-	41	41	123
Round 05 – SCC/CUK combined	61	-	72	73	206
All Rounds Total – SCC-only	251	254	178	178	860
All Rounds Total – SCC/CUK combined	368	400	329	384	1482
All Rounds Total – Increase due to CUK Consignments	**118**	**146**	**151**	**206**	**622**

Dash (-) indicates no CUK consignments were inserted into a courier round on a particular day.

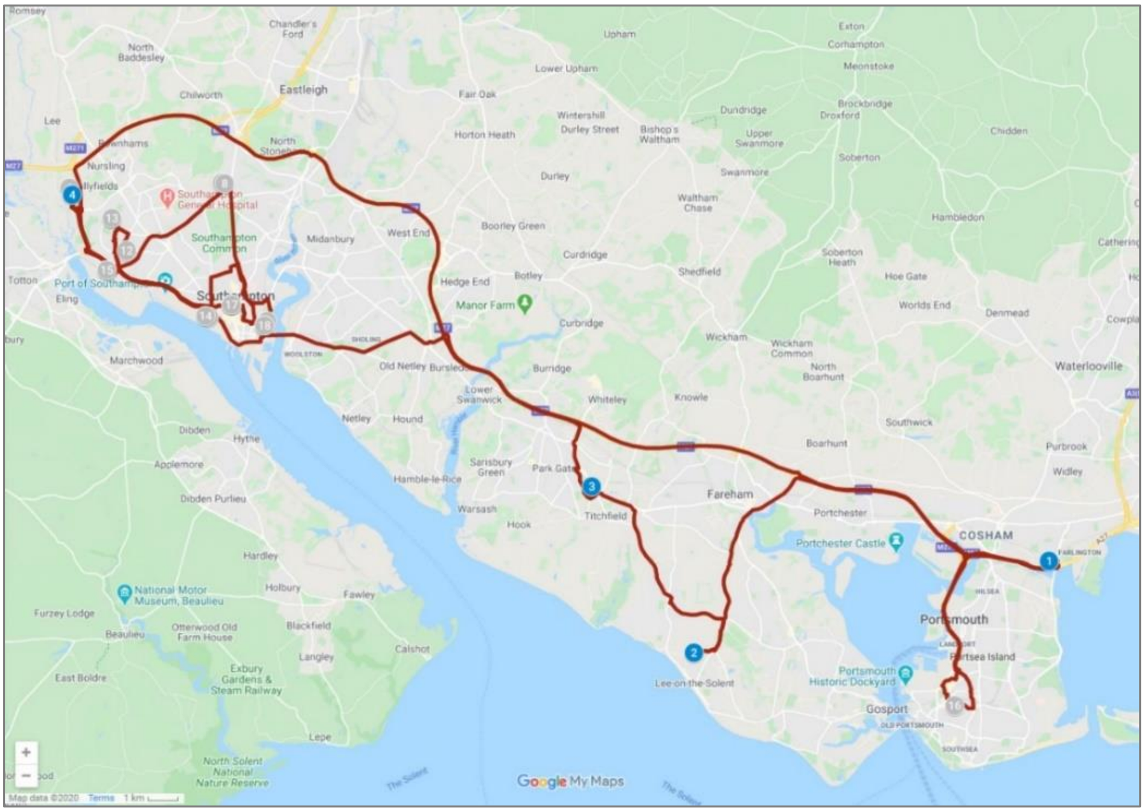

Figure 4: Map of SCC/CUK courier round 01 on Tuesdays.

Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 16 and 17. Base map source: Google Maps.

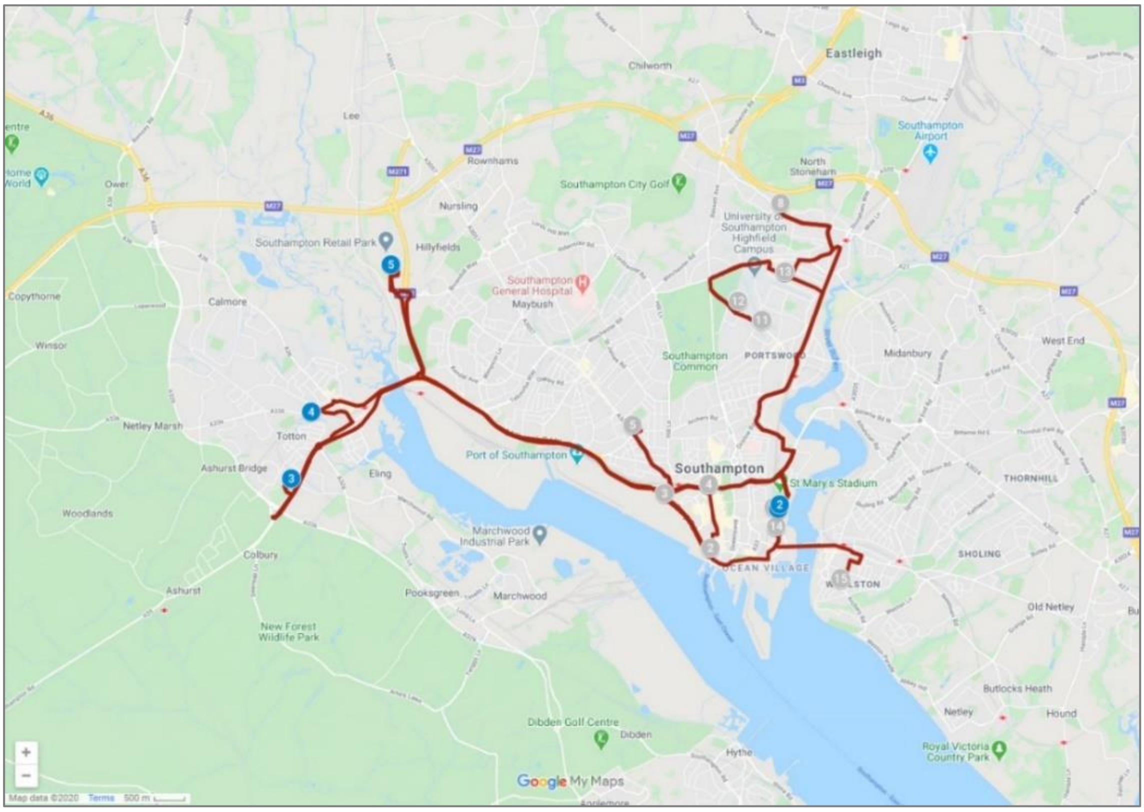

Figure 5: Map of SCC/CUK courier round 02 on Tuesdays.

Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 13 and 14. Base map source: Google Maps.

For diesel LGVs in the intervention scenario, vehicle emissions were calculated by multiplying total vkm (622, Table 4) by the relevant EFs (g/km, Table 2). However, SCC is anticipating courier fleet electrification, and vehicle emissions would be zero for all pollutants if electric instead of diesel LGVs were used. Round 01 on a Tuesday was the longest at 158 km (Table 4). This distance is likely to be well within the range of an electric LGV, even allowing for a real-world range not as great as advertised. For example, the advertised range of a Nissan e-NV200 (the vehicle anticipated by SCC) with a full charge is 200-300 km (data obtained from the 2019 brochure based on the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) combined and city cycles).

A caveat to the environmental benefits of Electric Vehicles (EVs) is that, whilst harmful tailpipe emissions are zero, emissions may still be produced at the locations where electricity is generated, depending on the method of generation (e.g. generation from combustion of fossil fuels compared to generation from renewable or nuclear sources). In addition, the batteries of EVs can be associated with large, negative environmental impacts (e.g. energy-intensive manufacturing and raw material extraction processes).

4.3 Intervention Scenario Net Effects

A summary of the key results for the survey week (Table 5) suggested that implementation of the intervention scenario reduced delivery vkm by 29% (reduction of 256 vkm). The POSFCC contributed 27% (241 vkm), supplemented by an additional 2% (15 vkm) contributed by the PPSFCC. Associated delivery vehicle emissions were reduced by 27-36% depending on pollutant (reductions of 70 kg CO_2, 255 g NO_X, 3 g PM_{10} and 37 g CO). Delivery vehicle visits to MGL's warehouse facilities were reduced by 59% (reduction of 27 visits). If electric vans were used to perform the collection service, delivery vehicle emissions reductions were increased to 100% (reductions of 226 kg CO_2, 877 g NO_X, 11 g PM_{10} and 104 g CO).

Scaling factors for sample size (75% from Table 1) and for the number of deliveries compared to an average week (total deliveries/week from the warehouse booking system of 1,563 compared to an average of 1,205 from 1st January 2018 to 31st October 2019) were used to adjust the results of the survey week to a per annum basis, with values in Table 5 multiplied by (100/75) x (1,205/1,563) x 52 (weeks in a year). Results (Table 6) suggested that delivery vkm were reduced by 13,684 vkm per annum leading to an annual emissions reduction of 3,742 kg CO_2, 13.6 kg NO_X, 0.2 kg PM_{10} and 2.0 kg CO; increasing to 12,080 kg CO_2, 46.9 kg NO_X, 0.6 kg PM_{10} and 5.6 kg of CO if electric instead of diesel LGVs were used. Delivery vehicle visits to MGL's warehouse were reduced by 1,443 visits per annum.

Table 5: Summary of net reductions over the survey week due to implementation of the intervention scenario.

Scenario	Vkm (km)	CO_2 (kg)	NO_X (g)	PM_{10} (g)	CO (g)	Vehicle Visits
BAU	878	226	877	11	104	46
Intervention (Diesel Van)	622	156	622	8	67	19
Net Reduction: Diesel (i.e. BAU – Intervention) *(Percent of BAU)*	**256** *(29%)*	**70** *(31%)*	**255** *(29%)*	**3** *(27%)*	**37** *(36%)*	**27** *(59%)*
Intervention (Electric Van)	622	0	0	0	0	19
Net Reduction: Electric (i.e. BAU – Intervention) *(Percent of BAU)*	**256** *(29%)*	**226** *(100%)*	**877** *(100%)*	**11** *(100%)*	**104** *(100%)*	**27** *(59%)*

Table 6: Summary of net reductions per annum due to implementation of the intervention scenario.

Scenario	Vkm (km)	CO_2 (kg)	NO_X (kg)	PM_{10} (kg)	CO (kg)	Vehicle Visits
BAU	46,932	12,080	46.9	0.6	5.6	2,459
Intervention (Diesel Van)	33,248	8,339	33.2	0.4	3.6	1,016
Net Reduction: Diesel (i.e. BAU – Intervention) *(Percent of BAU)*	**13,684** *(29%)*	**3,742** *(31%)*	**13.6** *(29%)*	**0.2** *(27%)*	**2.0** *(36%)*	**1,443** *(59%)*
Intervention (Electric Van)	33,248	0	0	0	0	1,016
Net Reduction: Electric (i.e. BAU – Intervention) *(Percent of BAU)*	**13,684** *(29%)*	**12,080** *(100%)*	**46.9** *(100%)*	**0.6** *(100%)*	**5.6** *(100%)*	**1,443** *(59%)*

The results of the case study suggested that shared-fleet carrier collaborations can produce environmental benefits in terms of reduced delivery vkm and emissions, and also operational benefits in terms of reduced delivery vehicle warehouse visits, which is likely to reduce and simplify workloads and improve site health and safety for warehouse staff due to there being fewer vehicle movements to receive and process. Gansterer and Hartl (2020) identified a lack of studies investigating carrier collaboration based on real-world data. The research reported here was based on a real-world case study, and therefore contributes to rectifying this situation, as well as providing evidence to support the implementation of shared-fleet carrier collaborations in locations where circumstances are similar to those of the case study.

A carrier collaboration involving a partnership with a LGA using their own-account fleet (i.e. the PPSFCC) represents an opportunity for the LGA to generate additional revenue. This is likely to be welcomed, particularly when financial budgets of LGAs in many regions of the world continue to be under considerable pressure from austerity measures (Lowndes and McCaughie 2013; Jimenez 2017; Hastings *et al.* 2017; Gray and Barford 2018). Based on current market rates, the revenue that could be generated for SCC by transporting CUK consignments was estimated to be ~£5,000/week. This estimate was derived using the consignment masses in Table 3 and the appropriate transportation tariffs obtained from TNT UK Rates & Services 2020 (TNT 2020). The cost incurred by SCC associated with generating this revenue was estimated to be ~£1,200/week. This estimate was derived from estimates of the time taken to complete the additional work (~30 hr/week based on travel time for the additional vkm and dwell time of 20 min/stop for loading/unloading) and of the cost of a delivery vehicle and driver (~£38/hr based on a value of £35/hr obtained from Cherrett *et al.* (2017) and adjusted for inflation). Thus, the potential profit for SCC was estimated to be

(5,000 – 1,200 =) ~£3,800/week. Moreover, involvement in a PPSFCC could act as a stimulus for expansion of LGA courier services to other private sector customers in the local area, and as a practical demonstration of the potential for collaboration between public and private sector organisations.

However, a caveat to the benefits suggested by the case study is that, in the real-world, the PPSFCC is likely to be subject to constraints such as supplier preferences for collection times, existing supplier contracts and pricing, delivery times stipulated by the goods recipient, and spare capacity available in the LGA courier fleet. These constraints could increase the vkm, emissions and vehicle warehouse visits generated by the intervention scenario, leading to a situation where the full environmental and operational benefits are more difficult to achieve. Furthermore, a factor specific to the current circumstances of CUK is that the cruise ship holiday industry has suffered a huge downturn in demand due to the COVID-19 crisis (which occurred after data collection for this research was completed). This downturn has obviously suppressed activity in CUK's supply chain, reducing the need for goods transportation. It remains to be seen how the industry will recover from the crisis and whether there will be lasting effects on supply chains.

For practical reasons, insertion of CUK consignment collections was based on a manual assessment of the best-fit for the 16 theoretical collection-rounds into the spare capacity windows in SCC's pre-existing courier rounds, albeit under the guidance of SCC route planning expertise (Section 3.3). However, this approach is likely to be sub-optimal, in that the vkm generated in the intervention scenario by the PPSFCC could potentially be reduced further (hence producing greater net reductions) by optimising SCC vehicle routes to all stops on the new courier rounds as a whole (i.e. including both SCC and CUK consignments in the route optimisation process without distinction). Whole route optimisation was not practical within the constraints of SCC's existing courier round service route planning due to a lack of suitable resources (e.g. facilities, capabilities and capacity necessary to undertake whole route optimisation), and was therefore excluded from the scope of the case study. This is an area where further research is required.

Driven by results, the PPSFCC in the case study was about to be implemented in practice, but progress was halted by the onset of the COVID-19 crisis in March 2020. Nevertheless, initial negotiations between the collaborating parties conducted prior to the halt (at a meeting in February 2020) highlighted many of the practical issues that need to be resolved and agreed before shared-fleet operations can be implemented successfully. For example, issues to be resolved included:

1. insurance and liability, i.e. which party is responsible for lost or damaged goods during different stages of delivery;
2. quality control and incident reporting systems for identifying and recording unusual events (e.g. damaged goods/packaging);
3. requirement for the LGA to hold a standard national goods vehicle operator's licence, which (as well as their own goods) allows the transport of other people's goods in the UK;
4. a scheduling system that ensures loads remain within vehicle capacity limits, that ensures any dangerous goods are transported according to regulations (e.g. separately if required), and that notifies the carrier, the suppliers and the delivery location of when and where consignments are to be collected and delivered with suitable advance notice;

5. a system for goods receipting (e.g. paper or electronic options) during different stages of delivery;
6. the potential scope for joint route planning for whole route optimisation;
7. provision of charging infrastructure for electric delivery vehicles;
8. duration of an agreement to collaborate and a suitable payment mechanism (e.g. fixed average cost, variable costs based on mass/time/distance requirements);
9. delivery vehicle livery, which is important from the perspective of the positive publicity generated for organisations involved in initiatives producing environmental benefits;
10. potential difficulties in convincing suppliers to collaborate. For example, a lack of incentive because suppliers may perceive it as more convenient to act as carriers for their own goods (i.e. delivery using their own vehicles), despite any concerns about environmental disbenefits. However, when suppliers act as carriers, they are not direct competitors (i.e. goods transport is not their core business), and therefore they may be more receptive to the benefits of carrier collaboration (e.g. environmental benefits, positive publicity, reduced requirement to provide and maintain their own vehicles). For example, MacLean *et al.* (2019) describe a POSFCC in rural Scotland where large UK national parcel carriers (e.g. DHL, DPD, TNT, ParcelForce, UPS) were motivated by cost reductions to collaborate and have parcels carried by a small local parcel carrier instead (Menzies Distribution) because the local carrier was not perceived as a direct competitor, although delivery vehicles had to be in Menzies livery and not the liveries of any of the national carriers to be acceptable.

A general finding from the initial negotiations was that practicality issues were easier to resolve and agree when the collaborating parties maintained a degree of separation from each other because there was a clearer demarcation of responsibility. Issues tended to become more contentious and complex to resolve with closer integration and shared responsibility (e.g. joint route planning for whole route optimisation was not feasible, at least initially); although it may well be worth expending the considerable effort required in the short-term to resolve practicality issues because of the potential for greater benefits over the longer-term.

5 CONCLUSIONS

5.1 Main Findings

The key finding of the research was that LGA involvement in shared-fleet carrier collaborations could be both feasible and beneficial. The environmental benefits in comparison to local suppliers organising their own separate deliveries were found to include a 29% reduction in delivery vkm, contributing to reducing traffic congestion on roads in the local area. Delivery vehicle emissions reductions ranged from 27-36% depending on pollutant, contributing to improving local AQ and reducing GHG emissions. If electric rather than diesel LGVs were used, delivery vehicle emissions reductions increased to 100%. Delivery vehicle warehouse visits were reduced by 59%, reducing and simplifying workloads and improving health and safety for warehouse staff.

5.2 Management Insights

The implications for LGA management are that the study produced evidence in support of policy decisions concerning own-account fleets, suggesting vehicle utilisation could be improved through entering a PPSFCC, leading to both environmental benefits and revenue generation opportunities. PPSFCCs have other benefits as well, such as stimulating expansion of LGA courier services to other private sector customers, and demonstrating the effectiveness of collaboration across the public-private sectors that could serve to promote collaborations in other operational areas (i.e. other than transporting goods). Furthermore, a wider incentive for LGA management to adopt PPSFCCs is the potential to reduce numbers of delivery vehicles on the road, allowing LGAs to demonstrate by example how shared-fleet carrier collaborations could offer a way to counter restrictions designed to discourage vehicles from entering certain areas (e.g. Low Emission Zones).

The insights from the research have implications for the management of other companies more generally. Results suggested that involvement in shared-fleet carrier collaborations is a suitable method to demonstrate environmental credentials in practice, showing commitment to improving air quality, mitigating the impacts of climate change and reducing road traffic congestion. Environmentally responsible operations are a key component of Corporate Social Responsibility policies, by which company management project a positive corporate image and are held accountable by stakeholders (e.g. suppliers, customers, employees, shareholders). Widespread incorporation of shared-fleet carrier collaborations into supply chains in circumstances similar to those of the case study appears to be an appropriate course of action for management, with benefits likely to help alleviate the considerable problems associated with road freight logistics, meaning efforts to overcome the challenges associated with implementation are likely to be worth expending.

5.3 Research Limitations and Future Work

The main limitations of the research were considered to be:

- Real-world constraints (e.g. preferred collection/delivery times, existing supplier contracts/pricing, availability of LGA fleet spare capacity) may make the environmental and operational benefits suggested by the case study analysis more difficult to achieve in practice.

- EVs were assumed to produce zero emissions. However, depending on electricity generation method, EVs can still produce emissions, albeit indirectly at generation locations rather than tailpipes.
- The research was based on a case study of local suppliers to a cruise ship company prior to the COVID-19 crisis, which has subsequently caused a huge downturn in the cruise ship holiday industry. However, it seems reasonable to assume that the cruise industry will recover eventually; and to assume that the study findings are not cruise industry-specific, but also have relevance to other similar circumstances involving a shared-fleet carrier collaboration between local suppliers serving a single client.
- Practical implementation issues (e.g. the issues identified during initial negotiations between the collaborating parties) need to be resolved before the benefits suggested by the case study analysis can be realised.
- The research was based on a relatively small case study. However, in general, it seems reasonable to assume that circumstances similar to those of the case study are likely to be quite common in other locations. In other words, similar circumstances are likely to exist in other cities around the world, whereby a municipal LGA vehicle fleet could potentially collaborate on shared-fleet logistics for deliveries to private sector companies in the local area, and the research provides evidence to support the benefits that could be achieved.

Whilst the effects of the research limitations may diminish the benefits to an extent, given the scale of the environmental and operational benefits suggested by the case study analysis (reductions of ~30% in vkm/emissions and 59% in vehicle warehouse visits), it seems likely that a proportion will still remain even after the effects of the limitations have been included, particularly as whole-route optimisation could act in the opposite direction, presenting an opportunity for greater reductions in delivery vkm (and associated emissions). Detailed quantification of the effects of the limitations was beyond the scope of the research, but is an area requiring further investigation in future work.

Areas identified for future work involve:

- Investigating the potential for further reductions in vkm and emissions that could be generated by whole route optimisation of vehicle rounds.
- Investigating implementation of the case study in practice to quantify the effects of real-world constraints.
- Investigating the transferability of results through conducting further case studies of similar opportunities for PPSFCCs in other cities around the world.

5.4 Research Contributions

In summary, the contributions of the research were threefold: (1) environmental benefits of a shared-fleet carrier collaboration were quantified based on a case study of real-world data; (2) LGA involvement to maximise utilisation of their own-account fleets and create opportunities for revenue generation was demonstrated to be feasible; and (3) the scope for wider implementation of shared-fleet carrier collaborations in circumstances similar to those of the case study by LGAs actively looking to improve vehicle utilisation, assist other organisations in their diocese, and reduce vkm and emissions was identified.

GLOSSARY

BAU	Business-As-Usual
CUK	Carnival UK
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EV	Electric Vehicle
GHG	Greenhouse Gas
LGA	Local Government Authority
LGV	Light Goods Vehicle
MGL	Meachers Global Logistics
NO_X	Oxides of Nitrogen
PM_{10}	Particulate Matter (≤10 µm in diameter)
POSFCC	Private-Only Shared-Fleet Carrier Collaboration
PPSFCC	Public-Private Shared-Fleet Carrier Collaboration
SCC	Southampton City Council

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DECLARATIONS OF INTEREST STATEMENT

In accordance with journal policy and ethical obligations on researchers, it is declared that two of the co-authors are employees of companies that may be affected by the research reported in this paper.

REFERENCES

Ballot E and Fontane F (2010) 'Reducing transportation CO_2 emissions through pooling of supply networks: perspectives from a case study in French retail chains', *Production Planning & Control,* 21(6), 640-650.

Baniasadi P, Foumani M, Smith-Miles K and Ejov V (2020) 'A transformation technique for the clustered generalized traveling salesman problem with applications to logistics', *European Journal of Operational Research,* 285(2), 444-457.

Chabot T, Bouchard F, Legault-Michaud A, Renaud J and Coelho L C (2018) 'Service level, cost and environmental optimization of collaborative transportation', *Transportation Research Part E: Logistics and Transportation Review,* 110, 1-14.

Cherrett T, Dickinson J, McLeod F, Sit J, Bailey G and Whittle G (2017) 'Logistics impacts of student online shopping – Evaluating delivery consolidation to halls of residence', *Transportation Research Part C: Emerging Technologies,* 78, 111-128.

Crainic T G and Montreuil B (2016) 'Physical Internet Enabled Hyperconnected City Logistics', *Transportation Research Procedia,* 12, 383-398.

Dai B and Chen H (2012) 'Profit allocation mechanisms for carrier collaboration in pickup and delivery service', *Computers & Industrial Engineering,* 62(2), 633-643.

Department for Environment Food and Rural Affairs (DEFRA) and Department for Business Energy & Industrial Strategy (BEIS) (2019) *UK Government GHG Conversion Factors for Company Reporting Spreadsheet*, London, UK: Department for Business, Energy & Industrial Strategy.

Gansterer M and Hartl R F (2020) 'Shared resources in collaborative vehicle routing', *TOP: An Official Journal of the Spanish Society of Statistics and Operations Research,* 28(1), 1-20.

Gansterer M, Hartl R F and Savelsbergh M (2020a) 'The value of information in auction-based carrier collaborations', *International Journal of Production Economics,* 221.

Gansterer M, Hartl R F and Vetschera R (2019) 'The cost of incentive compatibility in auction-based mechanisms for carrier collaboration', *Networks,* 73(4), 490-514.

Gansterer M, Hartl R F and Wieser S (2020b) 'Assignment constraints in shared transportation services', *Annals of Operations Research*.

Gonzalez-Feliu J and Morana J (2011) *Collaborative transportation sharing: from theory to practice via a case study from France. In: Technologies for Supporting Reasoning Communities and Collaborative Decision Making: Cooperative Approaches [J.L. Yearwood and A. Stranieri (eds.)]*, Hershey, USA: Information Science Reference.

Gray M and Barford A (2018) 'The depths of the cuts: the uneven geography of local government austerity', *Cambridge Journal of Regions, Economy and Society,* 11(3), 541-563.

Grote M, Williams I, Preston J and Kemp S (2016) 'Including congestion effects in urban road traffic CO_2 emissions modelling: Do Local Government Authorities have the right options?', *Transportation Research Part D: Transport and Environment,* 43, 95-106.

Hastings A, Bailey N, Bramley G and Gannon M (2017) 'Austerity urbanism in England: The ‘regressive redistribution’ of local government services and the impact on the poor and marginalised', *Environment and Planning A,* 49(9), 2007–2024.

Jimenez B S (2017) 'Institutional Constraints, Rule‐Following, and Circumvention: Tax and Expenditure Limits and the Choice of Fiscal Tools During a Budget Crisis', *Public Budgeting & Finance,* 37(2), 5-34.

Krajewska M A, Kopfer H, Laporte G, Ropke S and Zaccour G (2008) 'Horizontal cooperation among freight carriers: request allocation and profit sharing', *Journal of the Operational Research Society,* 59(11), 1483-1491.

Lai M, Cai X and Hu Q (2017) 'An iterative auction for carrier collaboration in truckload pickup and delivery', *Transportation Research Part E: Logistics and Transportation Review,* 107, 60-80.

Lowndes V and McCaughie K (2013) 'Weathering the perfect storm? Austerity and institutional resilience in local government', *Policy & Politics,* 41(4), 533-549.

MacLean F, McLeod F and Bates O (2019) 'Parcel Carrier Collaboration - Can Big Cities Learn from Small Communities?', *Chartered Institute of Logistics and Transport, Focus Magazine,* April 2019.

McLeod F N, Cherrett T J and Waterson B J (2011) 'The scope for joint household/commercial waste collections: a case study', *International Journal of Logistics Research and Applications,* 14(6), 399-411.

Muñoz-Villamizar A, Montoya-Torres J R and Faulin J (2017) 'Impact of the use of electric vehicles in collaborative urban transport networks: A case study', *Transportation Research Part D: Transport and Environment,* 50, 40-54.

Muñoz-Villamizar A, Quintero-Araújo C L, Montoya-Torres J R and Faulin J (2019) 'Short- and mid-term evaluation of the use of electric vehicles in urban freight transport collaborative networks: a case study', *International Journal of Logistics Research and Applications,* 22(3), 229-252.

Nataraj S, Ferone D, Quintero-Araujo C, Juan A A and Festa P (2019) 'Consolidation centers in city logistics: A cooperative approach based on the location routing problem', *International Journal of Industrial Engineering Computations*, 393-404.

National Atmospheric Emissions Inventory (NAEI) (2019) *Road Transport Aggregate Emission Factors Spreadsheet*, Abingdon, UK: National Atmospheric Emissions Inventory.

Nejadkoorki F, Nicholson K, Lake I and Davies T (2008) 'An approach for modelling CO_2 emissions from road traffic in urban areas', *Science of the Total Environment,* 406(1-2), 269-78.

Ouhader H and El Kyal M (2017) 'Combining Facility Location and Routing Decisions in Sustainable Urban Freight Distribution under Horizontal Collaboration: How Can Shippers Be Benefited?', *Mathematical Problems in Engineering,* 2017, 1-18.

Quintero-Araujo C L, Gruler A, Juan A A, de Armas J and Ramalhinho H (2017) 'Using simheuristics to promote horizontal collaboration in stochastic city logistics', *Progress in Artificial Intelligence,* 6(4), 275-284.

TNT (2020) *UK Rates & Services 2020*, Atherstone, UK: TNT.

Uherek E, Halenka T, Borken-Kleefeld J, Balkanski Y, Berntsen T, Borrego C, Gauss M, Hoor P, Juda-Rezler K and Lelieveld J (2010) 'Transport impacts on atmosphere and climate: Land transport', *Atmospheric Environment,* 44(37), 4772-4816.

Vargas A, Patel S and Patel D (2018) 'Towards a Business Model Framework to Increase Collaboration in the Freight Industry', *Logistics,* 2(4).

Wang Y, Peng S, Xu C, Assogba K, Wang H, Xu M and Wang Y (2018a) 'Two-echelon logistics delivery and pickup network optimization based on integrated cooperation and transportation fleet sharing', *Expert Systems with Applications,* 113, 44-65.

Wang Y, Zhang J, Assogba K, Liu Y, Xu M and Wang Y (2018b) 'Collaboration and transportation resource sharing in multiple centers vehicle routing optimization with delivery and pickup', *Knowledge-Based Systems,* 160, 296-310.

Wang Y, Zhang S, Assogba K, Fan J, Xu M and Wang Y (2018c) 'Economic and environmental evaluations in the two-echelon collaborative multiple centers vehicle routing optimization', *Journal of Cleaner Production,* 197, 443-461.

Yao X, Cheng Y and Song M (2019) 'Assessment of collaboration in city logistics: From the aspects of profit and CO_2 emissions', *International Journal of Logistics Research and Applications,* 22(6), 576-591.

APPENDIX A

Table A1: Consignments of suitable packages identified during the MGL warehouse survey and associated BAU vkm and emissions.

Con. ID	Date	Veh./Fuel Type	Supplier	Supplier Location	Con. Volume (m^3)	Con. Mass (kg)	Vkm (km)	CO_2 (g)	NO_X (g)	PM_{10} (g)	CO (g)
001	04 Nov	V/D	Supp_17	Totton Southampton SO40 3WX	0.065	30	13	3,354	13.4	0.17	1.4
004	04 Nov	V/D	Supp_14	West End Southampton SO30 3SF	3.348	225	38	9,411	37.6	0.49	4.1
006	04 Nov	V/D	Supp_18	Totton Southampton SO40 3WX	0.047	1	17	4,305	17.2	0.22	1.9
009	04 Nov	V/D	Supp_25 (Courier)	Andover SP10 3RU	1.257	96	66	16,393	65.5	0.85	7.1
011	04 Nov	V/D	Supp_25 (Courier)	Andover SP10 3RU	0.749	58	5	1,251	5.0	0.06	0.5
012	04 Nov	C/D	Supp_11	Stockbridge SO20 6EY	0.146	*(0)*	49	8,473	29.6	0.47	3.7
013	04 Nov	V/D	Supp_13	Blandford Forum DT11 7FP	0.805	*(0)*	47	11,763	47.0	0.61	5.1
015	04 Nov	V/D	Supp_07	St Marys Southampton SO14 5JP	2.585	*(13)*	18	4,505	18.0	0.23	1.9
015A	04 Nov	V/D	Supp_09 (Courier)	Central Southampton SO15 1ST	0.323	48	14	3,604	14.4	0.19	1.6
015B	04 Nov	V/D	Supp_08	Central Southampton SO14 7LY	0.186	*(0)*	14	3,604	14.4	0.19	1.6
019	05 Nov	V/D	Supp_22	Romsey SO51 8ZJ	0.864	24	20	5,106	20.4	0.26	2.2
021	05 Nov	V/D	Supp_15	Totton Southampton SO40 3WX	0.195	170	1	325	1.3	0.02	0.1
022	05 Nov	V/D	Supp_02	Fareham PO14 4LW	0.056	28	54	13,515	54.0	0.70	5.8
024	05 Nov	C/D	Supp_17	Totton Southampton SO40 3WX	0.005	1	17	2,950	10.3	0.16	1.3
025	05 Nov	V/D	Supp_12	Winchester SO23 0LN	1.312	*(0)*	9	2,378	9.5	0.12	1.0
028	05 Nov	V/D	Supp_23	Romsey SO51 9AQ	0.033	12	16	3,904	15.6	0.20	1.7
029	05 Nov	HR/D	Supp_03	Portsmouth PO6 1TR	1.020	443	21	16,603	47.8	0.52	13.4
030	05 Nov	V/D	Supp_12	Winchester SO23 0LN	1.471	*(35)*	47	11,663	46.6	0.60	5.0
033	05 Nov	V/D	Supp_07	St Marys Southampton SO14 5JP	0.046	3	4	1,101	4.4	0.06	0.5
034	05 Nov	V/D	Supp_18	Totton Southampton SO40 3WX	0.992	65	17	4,305	17.2	0.22	1.9
034A	05 Nov	V/D	Supp_09 (Courier)	Central Southampton SO15 1ST	0.485	73	14	3,604	14.4	0.19	1.6
038	06 Nov	V/D	Supp_16	Totton Southampton SO40 3WX	0.042	60	17	4,305	17.2	0.22	1.9
040	06 Nov	C/D	Supp_24	Romsey SO51 9DG	0.181	53	1	120	0.4	0.01	0.1
041	06 Nov	V/D	Supp_18	Totton Southampton SO40 3WX	0.095	7	17	4,305	17.2	0.22	1.9

Table A1 continued.

048	06 Nov	V/D	Supp_19	Totton Southampton SO40 8DS	0.040	8	5	1,176	4.7	0.06	0.5
049	06 Nov	V/D	Supp_03	Portsmouth PO6 1TR	1.027	*(0)*	81	20,373	81.3	1.05	8.8
050	06 Nov	V/D	Supp_04	St Marys Southampton SO14 3EW	0.398	49	18	4,480	17.9	0.23	1.9
051A	06 Nov	V/D	Supp_09 (Courier)	Central Southampton SO15 1ST	0.161	24	14	3,604	14.4	0.19	1.6
051B	06 Nov	V/D	Supp_08	Central Southampton SO14 7LY	0.067	*(0)*	14	3,604	14.4	0.19	1.6
052	07 Nov	V/D	Supp_10	Portswood Southampton SO17 2FW	2.160	800	14	3,529	14.1	0.18	1.5
056	07 Nov	V/D	Supp_22	Romsey SO51 8ZJ	1.672	118	17	4,130	16.5	0.21	1.8
057	07 Nov	V/D	Supp_17	Totton Southampton SO40 3WX	4.116	*(100)*	13	3,354	13.4	0.17	1.4
061	07 Nov	V/D	Supp_16	Totton Southampton SO40 3WX	0.696	461	17	4,305	17.2	0.22	1.9
062	07 Nov	V/D	Supp_25 (Courier)	Andover SP10 3RU	0.420	43	2	551	2.2	0.03	0.2
066	07 Nov	V/D	Supp_05	St Marys Southampton SO14 5JP	2.925	1100	20	4,956	19.8	0.26	2.1
069	07 Nov	V/D	Supp_21	Romsey SO51 0HR	0.255	39	16	4,105	16.4	0.21	1.8
070	07 Nov	V/D	Supp_20	Totton Southampton SO40 9NA	0.477	50	5	1,151	4.6	0.06	0.5
071	07 Nov	V/D	Supp_06 (Courier)	St Marys Southampton SO14 5JP	1.260	*(0)*	20	4,956	19.8	0.26	2.1
072	07 Nov	V/D	Supp_07	St Marys Southampton SO14 5JP	0.144	18	6	1,602	6.4	0.08	0.7
073	07 Nov	V/D	Supp_18	Totton Southampton SO40 3WX	0.040	7	17	4,305	17.2	0.22	1.9
073A	07 Nov	V/D	Supp_09 (Courier)	Central Southampton SO15 1ST	0.215	32	14	3,604	14.4	0.19	1.6
074	08 Nov	V/D	Supp_15	Totton Southampton SO40 3WX	0.063	45	5	1,126	4.5	0.06	0.5
086	08 Nov	V/D	Supp_01	Lee-on-the-Solent PO13 9FX	0.022	6	20	5,106	20.4	0.26	2.2
088	08 Nov	V/D	Supp_07	St Marys Southampton SO14 5JP	1.427	*(72)*	4	1,126	4.5	0.06	0.5
089	08 Nov	V/D	Supp_25 (Courier)	Andover SP10 3RU	0.681	83	1	250	1.0	0.01	0.1
089A	08 Nov	V/D	Supp_09 (Courier)	Central Southampton SO15 1ST	0.430	64	14	3,604	14.4	0.19	1.6
				Total	**35.001 (m^3)**	**4,564 (kg)**	**878 (km)**	**226 (kg)**	**877 (g)**	**11 (g)**	**104 (g)**

Total number of consignments is 46. Total number of different local suppliers is 25. V is van (LGV), C is car, HR is HGV-Rigid and D is diesel. (Courier) indicates a supplier used a courier to deliver the consignment rather than transporting their own goods. *(Mass value)* indicates data are incomplete or missing.

APPENDIX B

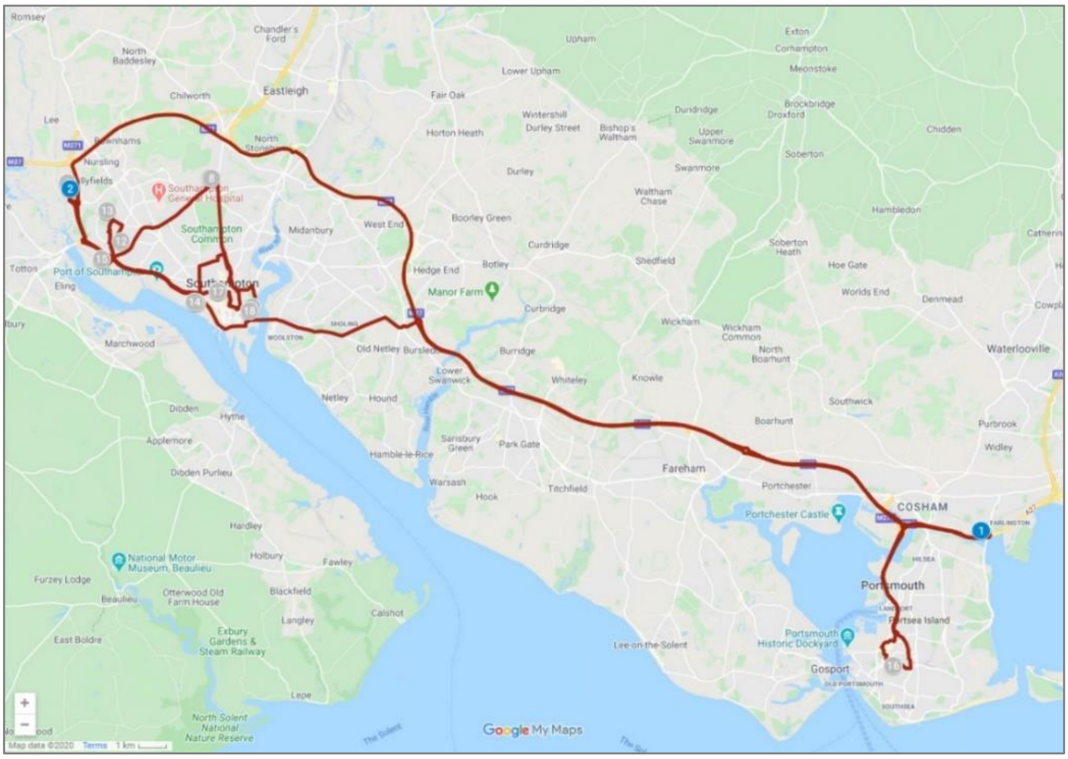

Figure B1: Map of SCC/CUK courier round 01 on Wednesdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 16 and 17. Base map source: Google Maps.

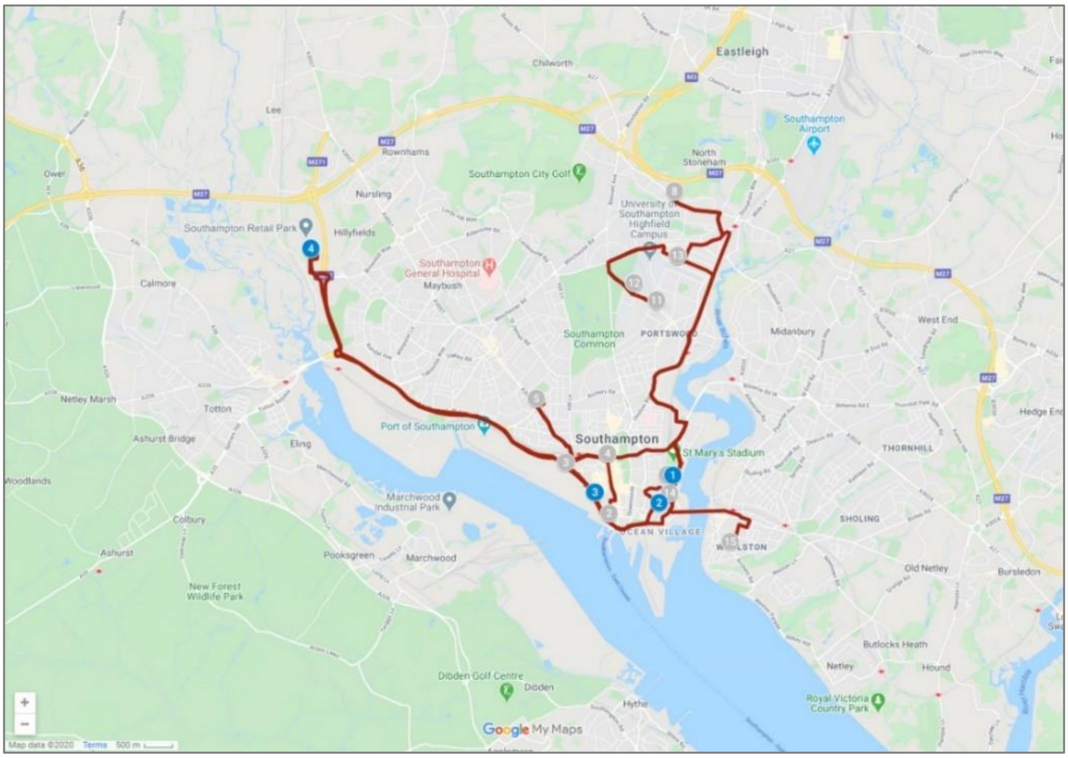

Figure B2: Map of SCC/CUK courier round 02 on Wednesdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 13 and 14. Base map source: Google Maps.

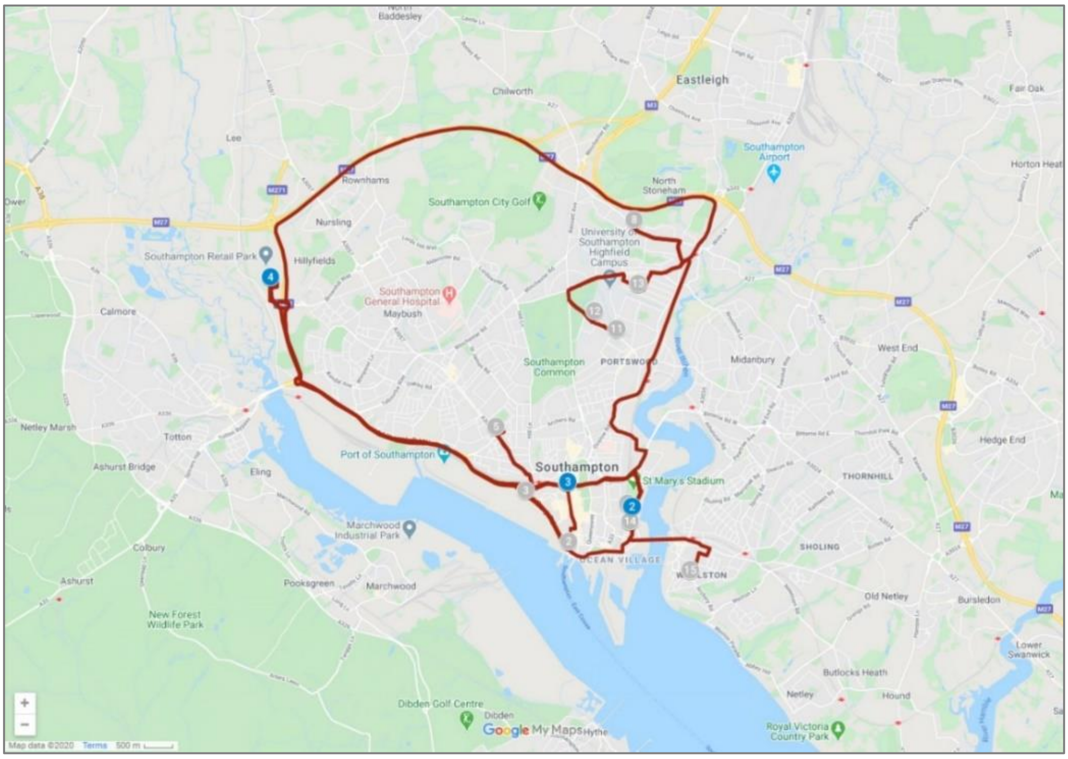

Figure B3: Map of SCC/CUK courier round 02 on Thursdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 13 and 14. Base map source: Google Maps.

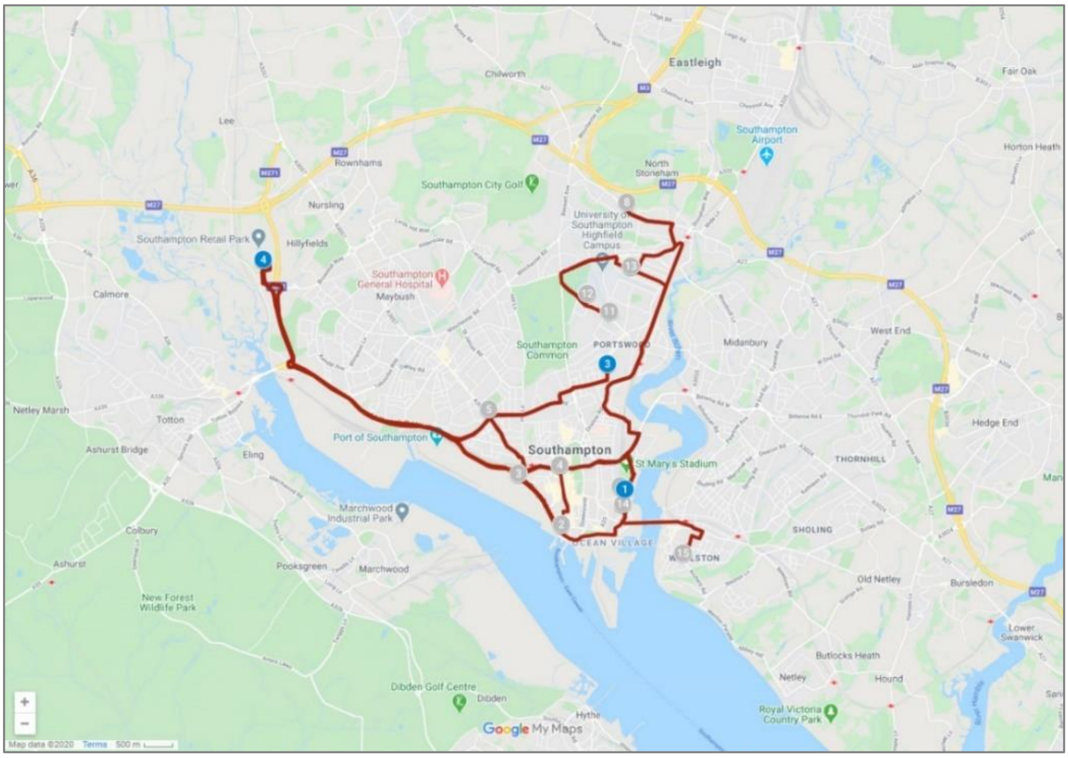

Figure B4: Map of SCC/CUK courier round 02 on Fridays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 13 and 14. Base map source: Google Maps.

Figure B5: Map of SCC/CUK courier round 03 on Wednesdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 7 and 8. Base map source: Google Maps.

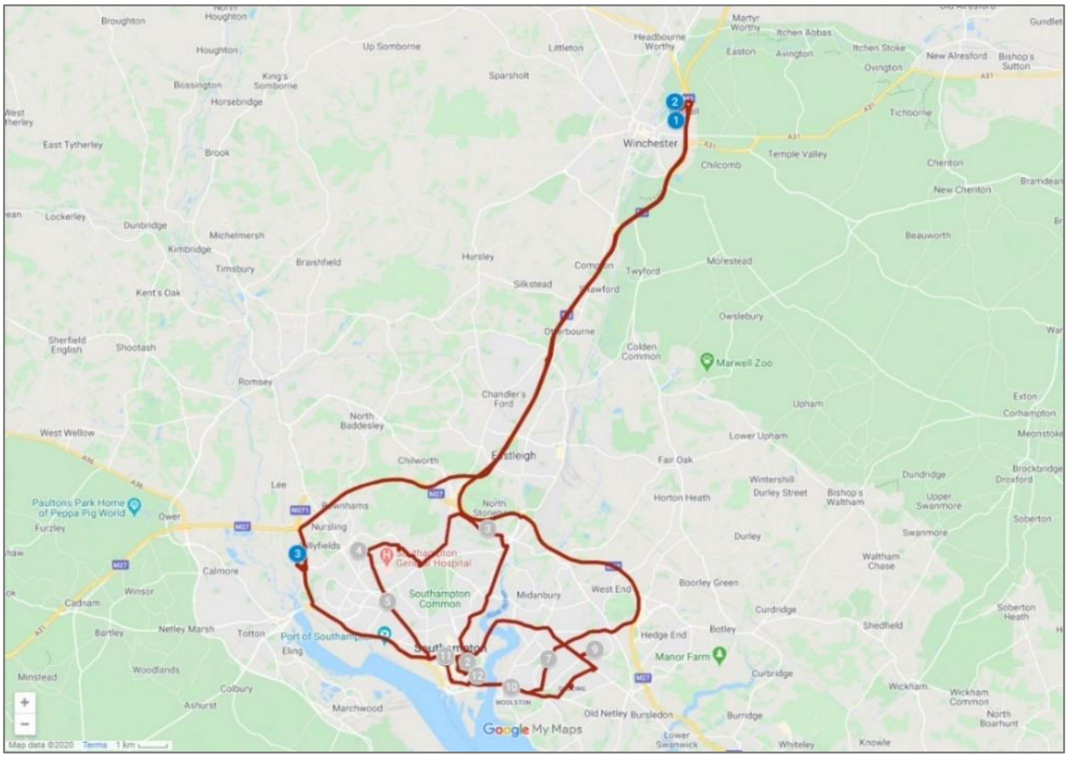

Figure B6: Map of SCC/CUK courier round 03 on Thursdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 7 and 8. Base map source: Google Maps.

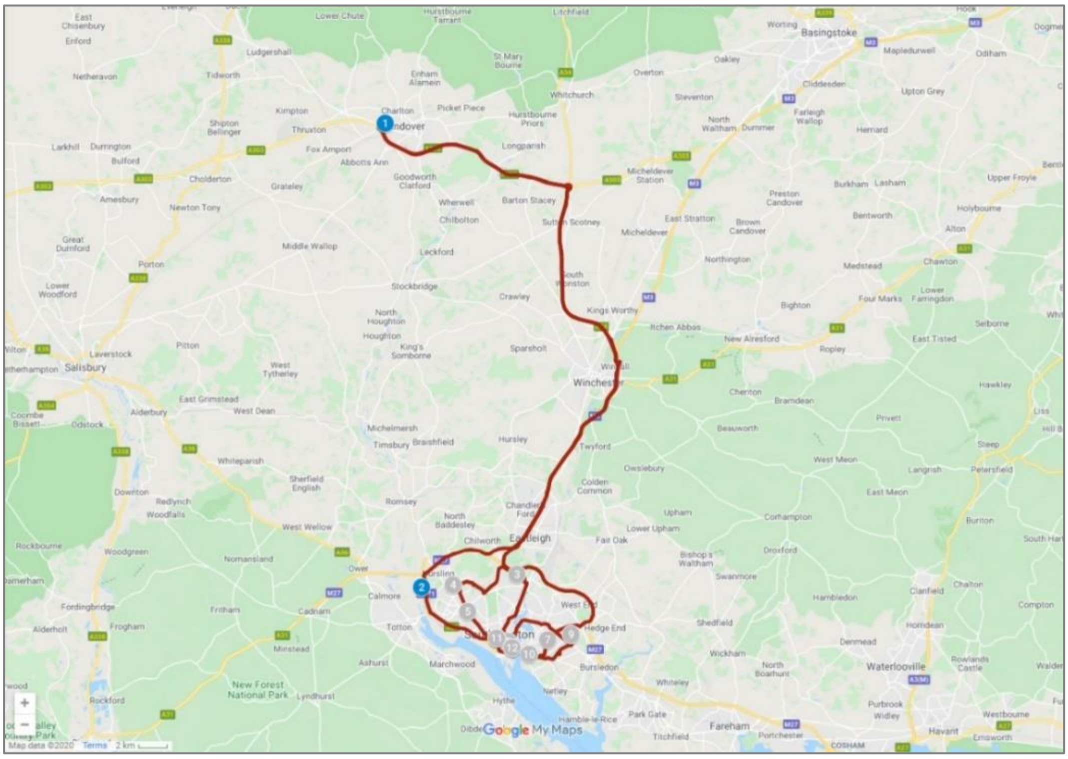

Figure B7: Map of SCC/CUK courier round 03 on Fridays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 7 and 8. Base map source: Google Maps.

Figure B8: Map of SCC/CUK courier round 04 on Tuesdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 17 and 18. Base map source: Google Maps.

Figure B9: Map of SCC/CUK courier round 04 on Wednesdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 17 and 18. Base map source: Google Maps.

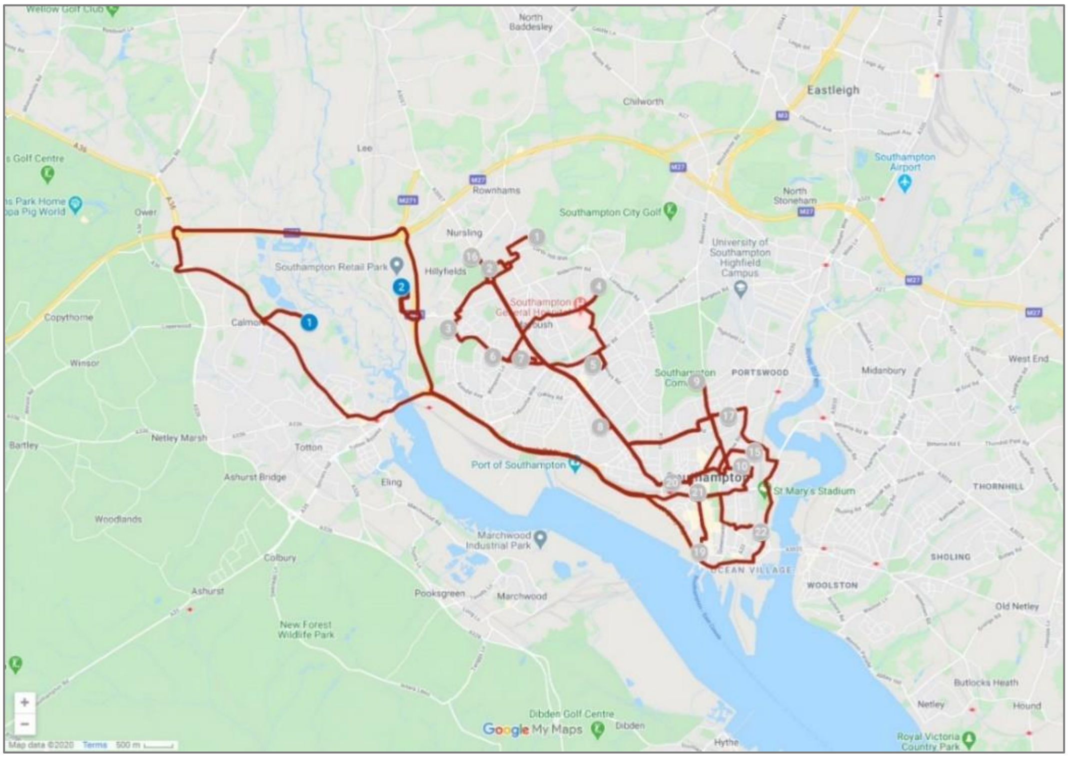

Figure B10: Map of SCC/CUK courier round 04 on Thursdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 21 and 22. Base map source: Google Maps.

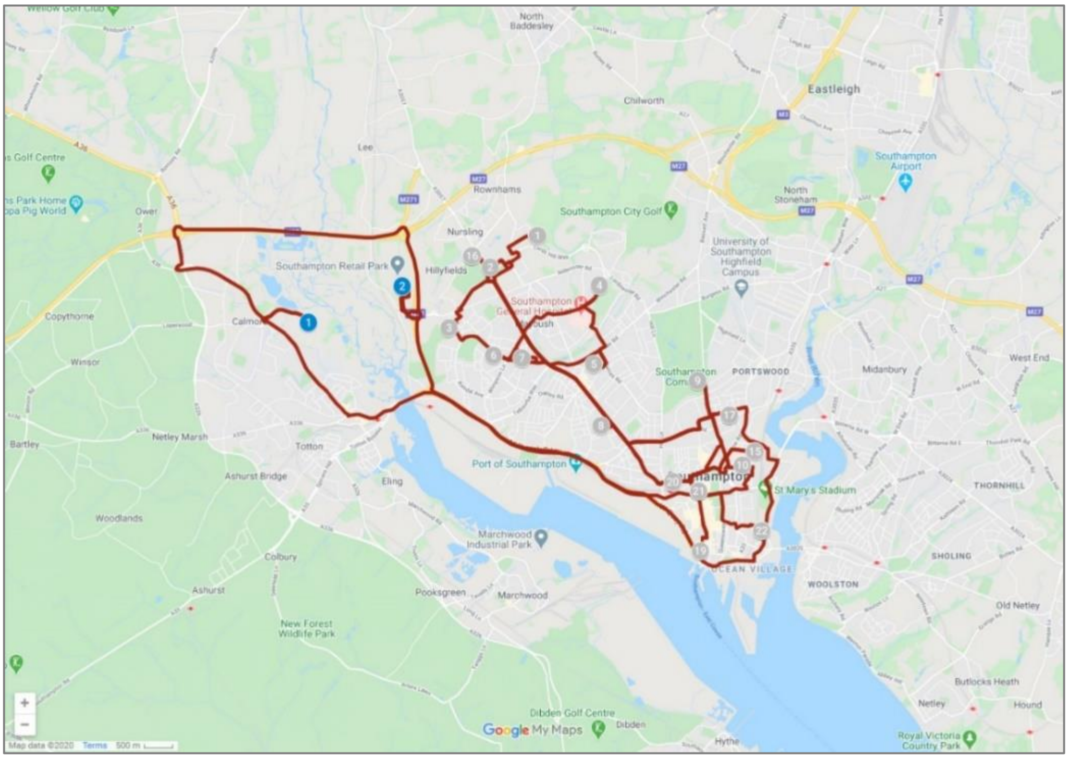

Figure B11: Map of SCC/CUK courier round 04 on Fridays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 21 and 22. Base map source: Google Maps.

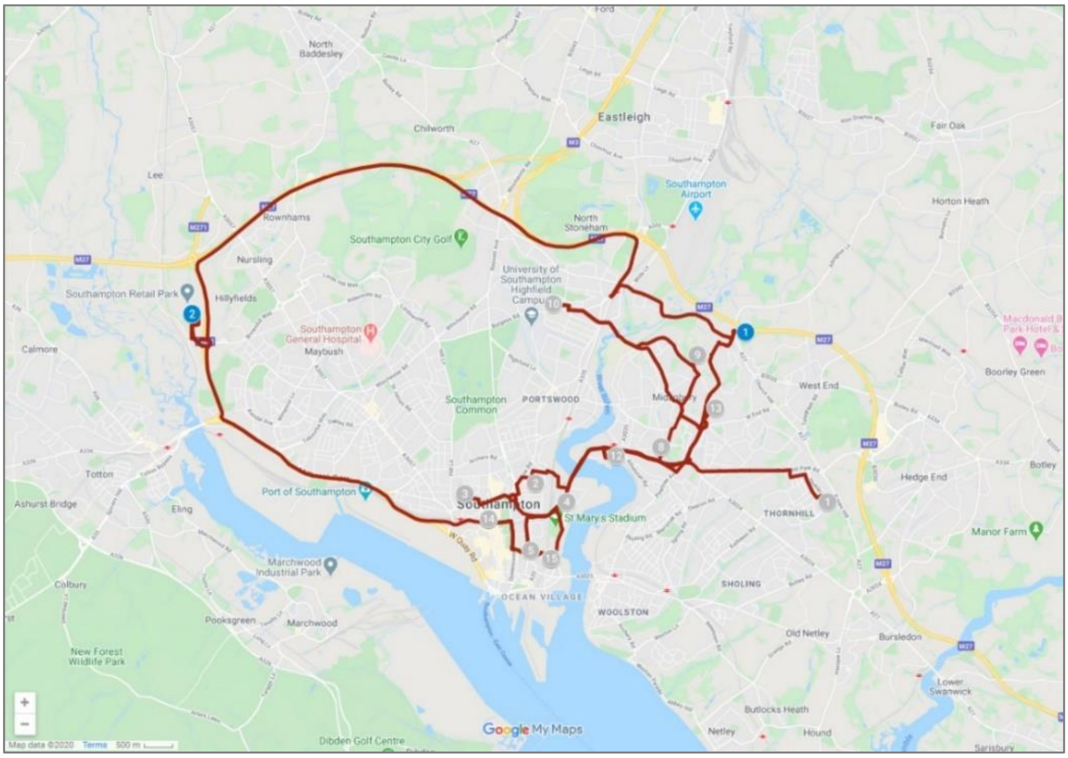

Figure B12: Map of SCC/CUK courier round 05 on Tuesdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 13 and 14. Base map source: Google Maps.

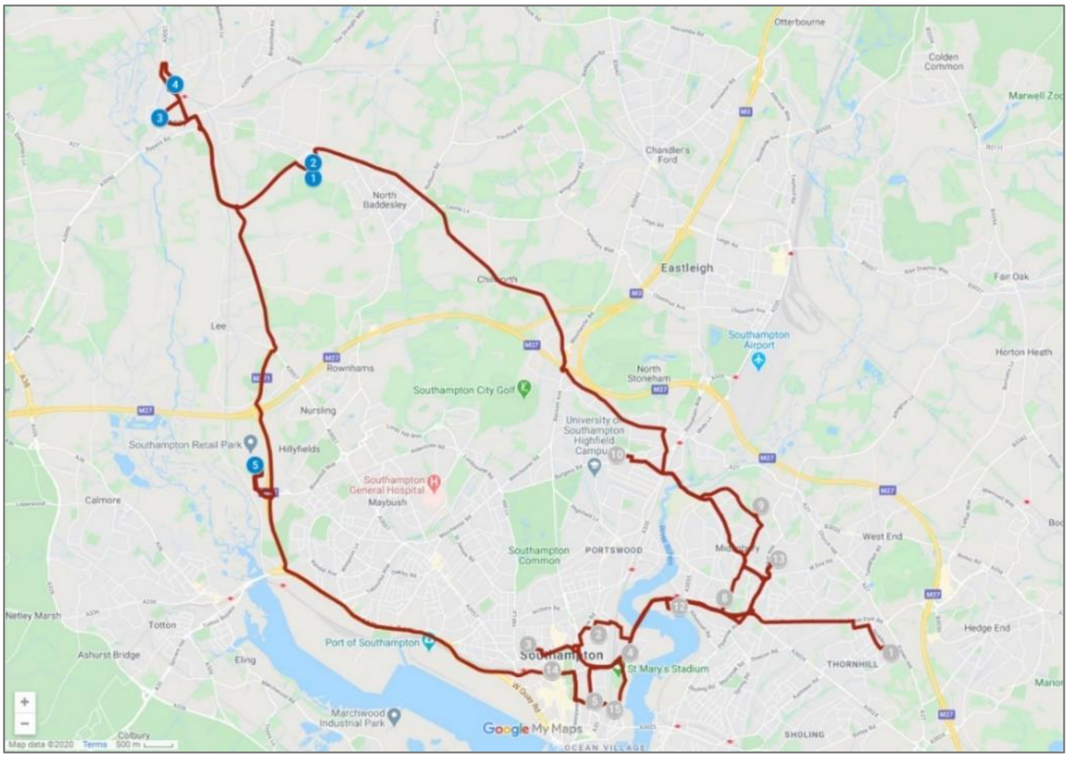

Figure B13: Map of SCC/CUK courier round 05 on Thursdays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 13 and 14. Base map source: Google Maps.

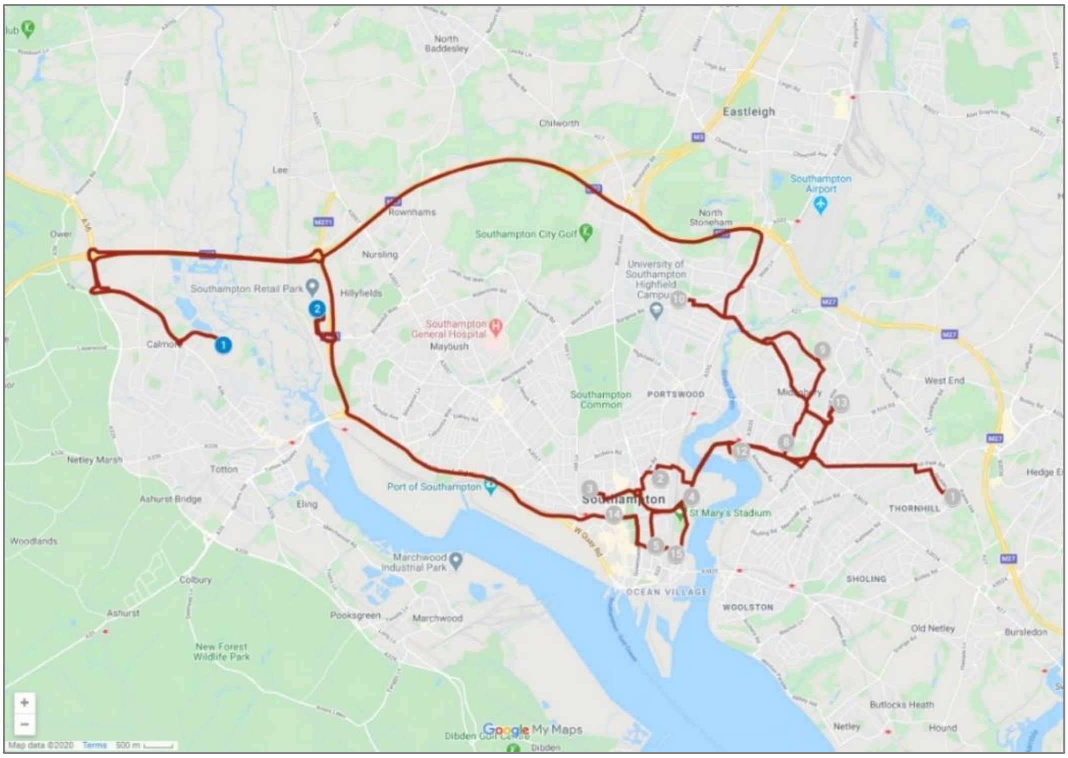

Figure B14: Map of SCC/CUK courier round 05 on Fridays.
Some stop icons are obscured. Blue circles indicate CUK stops and grey circles indicate SCC stops. CUK consignments are collected/delivered between SCC stops 13 and 14. Base map source: Google Maps.