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Benefits of Shared-Fleet Horizontal Logistics Collaborations: A Case Study of Patient Service Vehicles Collecting Pathology Samples in a Public Sector Healthcare Setting

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Abstract: Road-based logistics suffer from inefficiencies due to less-than-full load vehicle movements. Consolidating loads through shared-fleet collaborations (also known as freight pooling) can reduce such inefficiencies, and thereby reduce costs, vehicle-kilometres (vkm), and related emissions and congestion. Utilising a significant historical dataset of vehicle movements, the potential cost savings and environmental benefits of a shared-fleet operation involving collaboration between two public sector organisations, integrating both static (fixed-schedule) and dynamic (client-specific) demand within a healthcare setting, were quantified. A Sample Collection Service (SCS; transporting pathology samples from doctors' surgeries to centralised laboratories for analysis) shared spare capacity in vehicles operated by a Patient Transport Service (PTS; transporting eligible non-emergency patients to/from routine hospital appointments) as an alternative to engaging an external courier company. Results suggested that a shared-fleet collaboration servicing 78 surgeries, alongside normal patient loads in an average of 24 PTS vehicles/day, produced reductions of 16%, 13% and 12% in costs, vkm and carbon dioxide emissions, respectively. Decision-makers within public sector organisations that operate own-account vehicle fleets could pursue policies that actively seek out opportunities to deploy shared-fleet solutions to improve vehicle utilisation and therefore reduce public sector spending and the detrimental effects of road logistics.

Keywords: shared-fleet; freight pooling; logistics; horizontal collaboration; road vehicles; healthcare; public sector

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Citation: Grote, M.; Cherrett, T.; Oakey, A.; Martinez-Sykora, A.; Aydemir, I. Benefits of Shared-Fleet Horizontal Logistics Collaborations: A Case Study of Patient Service Vehicles Collecting Pathology Samples in a Public Sector Healthcare Setting. *Future Transp.* **2023**, *3*, 169–188. https://doi.org/10.3390/futuretransp3010011

Academic Editor: Armando Cartenì

Received: 22 December 2022
Revised: 20 January 2023
Accepted: 30 January 2023
Published: 3 February 2023

1. Introduction

Road-based logistics operations are well known to have inefficiencies due to vehicles travelling with less-than-full loads [1–7]. Shared-fleet logistics (also known as freight pooling), whereby organisations collaborate horizontally (i.e., collaboration between organisations providing similar goods and/or services at the same level within supply chains) to consolidate loads and improve vehicle utilisation through sharing vehicle capacity, are often posited as a remedy for such inefficiencies. This can offer potential cost savings for the parties involved, whilst also mitigating the detrimental effects of road logistics such as vehicle-kilometres (vkm) and related vehicle emissions and traffic congestion [1–12].

One area where shared-fleet operations could offer benefits is logistics within healthcare settings, which was investigated in this research. The United Kingdom's (UK's) National Health Service (NHS) comprises a wide range of publicly funded systems providing comprehensive healthcare services to the population, free at the point of delivery. As part of its remit, the NHS operates a Sample Collection Service (SCS) to transport pathology samples taken from patients at doctors' (General Practitioner; GP) surgeries (also known as doctor's offices in some countries) to centralised pathology laboratories for analysis, typically outsourcing transport provision to external commercial courier companies operating fleets of Light Goods Vehicles (LGVs), commonly known as vans. At the same time, the NHS operates a non-emergency Patient Transport Service (PTS), using vehicles (often known as non-emergency ambulances) similar in size to the vans typically used by courier companies (Figure 1), to transport eligible patients (i.e., those unable to use other transport means due to their medical condition) to/from routine hospital appointments. There is often considerable overlap between the geographical areas of operation covered by these two services, which suggests there may be scope to deploy shared-fleet logistics to consolidate loads and save costs for the NHS.

Figure 1. Patient Transport Service (PTS) vehicle.

The potential for a shared-fleet operation involving the SCS sharing capacity in PTS vehicles to collect pathology samples as an alternative to engaging an external courier company was investigated. This situation required integrating dynamic and static transport demand, with the PTS demand being dynamic, based on ad-hoc allocation of transport tasks to accommodate variable demands from patients for transport to/from hospital appointments. This means that PTS vehicles perform different routes each day in response to each day's specific demand. The SCS demand is static, based on fixed-schedule vehicle rounds making collections from the same locations (i.e., GP surgeries) at approximately the same times each day.

The main aim of this study was two-fold: (i) to assess the feasibility of integrating static and dynamic transport demand in a shared-fleet logistics collaboration involving a public sector organisation as the prospective fleet provider to improve the utilisation of their own-account vehicles and to save public money by eliminating the need to engage external commercial carriers (i.e., courier companies); and (ii) to quantify through a case study based on real-world data, the potential benefits of such a shared-fleet logistics collaboration in terms of reducing costs, vkms and emissions of carbon dioxide (CO_2).

The main conclusions were that a shared-fleet collaboration was both feasible and beneficial, and that decision-makers within public sector organisations that operate own-account vehicle fleets could pursue policies that actively seek-out opportunities to deploy shared-fleet solutions to improve vehicle utilisation and therefore reduce public sector spending and the detrimental effects of road logistics.

2. Previous Research

2.1. Shared-Fleet Collaborations

A review of previous research was undertaken focusing on shared-fleet collaborations and, in particular, examples of vehicle fleets being used in this way by public sector organisations and/or in healthcare settings. Shared-fleet operations are an example of horizontal collaboration in the logistics industry, whereby organisations that provide similar goods and/or services collaborate to improve resource utilisation efficiency, e.g., multiple carriers (who could potentially be competitors) cooperating to share capacity on each other's vehicle fleets [1–12]. As well as road-based logistics, horizontal collaboration is also studied in other modes of transport, for example, marine logistics involving fleets of ships [13,14].

In general, existing research in the domain of road-based logistics is primarily concerned with the mechanisms and benefits associated with shared-fleet operations involving commercial carriers collaborating to satisfy demand for transport of goods on a network-wide scale through forming grand coalitions to exchange requests for transportation. Methodologies are often based on computational approaches (i.e., mathematical modelling) using theoretical examples, with seemingly few studies based on real-world activity data, a situation identified during recent reviews (2020/2021) of research in the domain [1,3,11]. The focus of this paper was on understanding the potential benefits of deploying shared-fleet operations rather than the mechanisms for realising such collaborations, and relevant literature was reviewed accordingly.

2.2. Benefits of Shared-Fleet Collaborations

Existing research tends to focus on the economic benefits (cost savings, profit increases and their equitable allocation among the collaborating parties), with the environmental benefits (e.g., reductions in vkm and associated emissions) often considered as well. Recent examples included a computational study by Wang et al. [15] that developed an optimisation algorithm for shared-fleet carrier collaborations transporting general freight. A test application of the algorithm to a dataset representing a logistics network in Chongqing city, China suggested collaborations on a city-wide network scale could result in cost reductions of 32% for the companies involved. The cost reductions were related to reductions in vkm and vehicle numbers, but these benefits were not explicitly quantified. In similar computational studies involving different optimisation algorithms also tested on Chongquing city, China, Wang et al. [16] found that cost and vehicle reductions of 68% and 23%, respectively could be achieved, and Wang et al. [17] found that cost and CO_2 emissions reductions of 74% and 47%, respectively were possible. Using computational experiments, a study by Chabot et al. [18] based on companies shipping general freight from Quebec City, Canada to locations in the USA suggested that cost and emissions reductions of up to 52% and 80%, respectively, could be realised by shared-fleet collaborations.

Amiri and Farvaresh [12] used a computational approach to analyse theoretical carrier collaborations to share vehicle capacity, with results indicating that cooperation can lead to profit increases of up to 15% for the companies involved. Gansterer et al. [4] conducted a computational study of a theoretical shared-fleet collaboration between three carriers, which suggested that average cost savings of up to 25% could be generated. A similar study by Konstantakopoulos et al. [19] investigated a shared-fleet collaboration between three carriers in Athens, Greece, with results indicating that vkm, costs, vehicle numbers and CO_2 emissions could be reduced by 10%, 3%, 6% and 2%, respectively. Collaborative operations between two carriers serving the same city were evaluated by Yao et al. [9], with average profits increasing by 3% and CO_2 emissions reducing by 1% as a result.

Quintero-Araujo et al. [20] used a computational approach to assess theoretical shared-fleet collaborations involving up to nine carriers, along with stochastic demand patterns and sharing of storage facilities, finding that, on average, costs could be reduced by 4% and CO_2 emissions by 3%. Aloui et al. [21] investigated shared-fleet operations integrated with cooperation over decisions regarding locations of storage facilities and inventory planning. The study suggested cost savings of up to 67% and CO_2 emissions savings of up to 58% were achievable. Similarly, Nataraj et al. [8] considered the benefits of a theoretical shared-fleet collaboration between five carriers, combined with cooperation over optimising locations for storage facilities, with results suggesting that costs could be reduced by 47% and CO_2 emissions by 42%. Su et al. [22] evaluated a proposed new algorithm to find shared-fleet solutions incorporating dynamic demand in relation to the number and priority of requests for transport. A test application using a dataset representing a theoretical logistics network suggested that the new algorithm could improve on previous best-known benchmark solutions in terms of vkm and vehicle numbers saved.

A computational approach was adopted by Deng et al. [23] to consider a network-wide collaboration in Chengdu, China to share resources including vehicle capacity, logistics facilities and customer services, finding that costs and vehicle numbers could be reduced by 41% and 36%, respectively. Mrabti et al. [24] investigated sharing of vehicle capacity and storage facilities between four suppliers, finding that savings of 1% in costs, 20% in vkm and 17% in associated CO_2 emissions were possible based on using an economic objective function in the mathematical formulation of the optimisation algorithm.

Using a computational approach, Abou Mjahed et al. [25] studied the benefits of collaborative sharing of fleet and storage facilities between four firms across a network of eight distribution centres delivering to 30 clients. Results indicated cost savings of up to 12% were possible. Similarly, Mrad et al. [26] analysed sharing between seven firms across a network of nine distribution centres delivering to 35 clients, which produced savings of 34% in costs and 39% in vkm, and Ouhader and El Kyal [27] investigated three firms sharing across a network of five distribution centres delivering to 40 clients, finding savings of 9% in costs and 45% in CO_2 emissions.

Aktas et al. [28] investigated sharing vehicle capacity in last-mile deliveries for the online grocery sector in London, UK, finding that reductions of 17% in vkm and 22% in number of vehicle routes were possible. Serrano-Hernandez et al. [29] also focused on the online grocery sector but in Pamplona, Spain, where a collaboration between four popular supermarket chains was investigated. The study was based on a survey of Pamplona's inhabitants to gauge demand, and the collaboration was assumed to be fully cooperative with all customers served conjointly by all supermarkets. Results suggested vkm could be reduced by 43% and the level of service (defined as the duration between the start of the requested delivery time window and the actual delivery time) improved by 46%.

Vargas et al. [10] proposed a new platform designed to encourage and facilitate horizontal logistics collaboration, which included an algorithm to generate shared-fleet solutions. A case study application of the platform using data from a large UK building materials supplier alongside historic UK fleet data (to simulate involvement of other fleets) found that cost and vkm savings of 11% and 12%, respectively, could be achieved. Using real-world data, Ballot and Fontane [30] completed a case study of carrier collaborations in supply chains within the French retail sector, finding that reductions of 25% in CO_2 emissions could be generated. Grote et al. [6] investigated a shared-fleet carrier collaboration involving a private sector client (a cruise ship company) sharing capacity on five own-account vehicles operated by a public sector organisation (a Local Government Authority; LGA). Based on a week-long survey of goods movements at a storage facility, study results suggested vkm and emissions reductions of 29% and up to 36%, respectively, were possible, with GBP 3800/week profit generated for the LGA. The methodological approaches used in previous research studies are summarised in Table 1.

Table 1. Methodological approaches of previous studies of shared-fleet collaborations.

Study	Methodological Approach/Complexity	Potential Benefits
Wang et al. [15]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: five firms, city-wide	Costs −32%
Wang et al. [16]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: five firms, city-wide	Costs −68% Vehicles −23%
Wang et al. [17]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: five firms, city-wide	Costs −74% Emissions −47%
Chabot et al. [18]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: three firms, international	Costs −52% Emissions −80%
Amiri and Farvaresh [12]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: three firms, theoretical	Profits +15%
Gansterer et al. [4]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: three firms, theoretical	Costs −25%
Konstantakopoulos et al. [19]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: three firms, city-wide	Vkm −10% Costs −3% Vehicles −6% Emissions −2%
Yao et al. [9]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: two firms, city-wide	Profits +3% Emissions −1%
Quintero-Araujo et al. [20]	Assessment of optimisation algorithm Sharing: vehicle capacity, storage facilities Network: nine firms, nine storage facilities, theoretical	Costs −4% Emissions −3%
Aloui et al. [21]	Assessment of optimisation algorithm Sharing: vehicle capacity, storage facility locations, inventory planning Network: four firms, four storage facilities, theoretical	Costs −67% Emissions −58%
Nataraj et al. [8]	Assessment of optimisation algorithm Sharing: vehicle capacity, storage facility locations Network: five firms, five storage facilities, theoretical	Costs −47% Emissions −42%
Su et al. [22]	Assessment of optimisation algorithm Sharing: vehicle capacity Network: up to 500 requests for transport, theoretical	Improvement on benchmark solutions
Deng et al. [23]	Assessment of optimisation algorithm Sharing: vehicle capacity, storage facilities, customer services Network: four firms, four storage facilities, city-wide	Costs −41% Vehicles −36%
Mrabti et al. [24]	Assessment of optimisation algorithm Sharing: vehicle capacity, storage facilities Network: four firms, four storage facilities, theoretical	Costs −1% Vkm −20% Emissions −17%
Abou Mjahed et al. [25]	Assessment of optimisation algorithm Sharing: vehicle capacity, storage facilities Network: four firms, eight storage facilities, theoretical	Costs −12%

Table 1. *Cont.*

Study	Methodological Approach/Complexity	Potential Benefits
Mrad et al. [26]	Assessment of optimisation algorithm Sharing: vehicle capacity, storage facilities Network: seven firms, nine storage facilities, theoretical	Costs −34% Vkm −39%
Ouhader and El Kyal [27]	Assessment of optimisation algorithm Sharing: vehicle capacity, storage facilities Network: three firms, five storage facilities, theoretical	Costs −9% Emissions −45%
Aktas et al. [28]	Assessment of on-line grocery deliveries Sharing: vehicle capacity Network: two firms, city-wide	Vkm −17% Vehicle routes −22%
Serrano-Hernandez et al. [29]	Assessment of on-line grocery deliveries Sharing: vehicle capacity Network: four firms, city-wide	Vkm −43% Service level +46%
Vargas et al. [10]	Assessment of horizontal collaboration platform Sharing: vehicle capacity Network: two firms, national	Costs −11% Vkm −12%
Ballot and Fontane [30]	Assessment of supply chains in French retail sector Sharing: vehicle capacity, storage facilities Network: two firms, 223 storage facilities, national	Emissions −25%
Grote et al. [6]	Assessment of supply chain for cruise ship company Sharing: vehicle capacity Network: one firm, one public sector organisation (Local Government Authority; LGA), regional	Vkm −29% Emissions −36% LGA profit +GBP 3800/week

2.3. Review Summary

In summary, existing research typically tends to focus on the benefits of theoretical, network-wide, grand coalitions of commercial carriers sharing demand for transport of general goods. Few studies appear to address the feasibility of smaller-scale situations, integrating static and dynamic demand for transport of specialised payloads (i.e., pathology samples and hospital patients) in shared-fleet operations, with the public sector acting as prospective fleet providers to maximise utilisation of their own-account vehicles.

Studies tend to focus solely on the transportation of goods, whereas the research reported in this paper is concerned with the combined transport of passengers (i.e., patients) and goods (i.e., pathology samples). Patients were regarded as a form of payload that could be readily integrated with goods transportation, i.e., patients were seen as analogous to goods in that they are collected/delivered at bespoke locations according to client requirements rather than at specified locations on fixed-schedule vehicle routes (e.g., stations, bus stops) as would be usual for passengers on public transport. In addition, many existing studies have adopted a theoretical, computational approach, leading to a lack of shared-fleet research based on real-world data.

The research reported in this paper addressed the identified research gaps in the following two ways: (i) assessing the feasibility of collaborative shared-fleet operations involving public sector own-account vehicle fleets and integration of static and dynamic demands for transport of specialised payloads (a situation that has not been investigated in previous studies reported in the literature) to improve vehicle utilisation and therefore reduce public sector spending and the detrimental effects of road logistics; and (ii) quantifying the potential benefits of such collaborations (in terms of the effects on costs, vkm and CO_2 emissions) based on a case study using real-world activity data.

3. Materials and Methods

3.1. Business-As-Usual (BAU) Analysis

Whilst the PTS has many vehicle depots in different locations across Southern England, the study focused on the depot in Eastleigh (Figure 2) situated just to the North of Southampton, a city on the South coast of the UK (population ~260,000). This was because the Eastleigh PTS depot represented the most convenient location from which to service the network of 78 GP surgeries that all send samples to the centralised pathology laboratory located at Southampton General Hospital (SGH) (Figure 2). The criterion used to assess convenience of depot location was the extent of the geographical overlap between the area of BAU PTS vehicle operations and the locations of GP surgeries, i.e., vehicles from the Eastleigh PTS depot were already operating in close proximity to the GP surgeries (and SGH) in the BAU scenario.

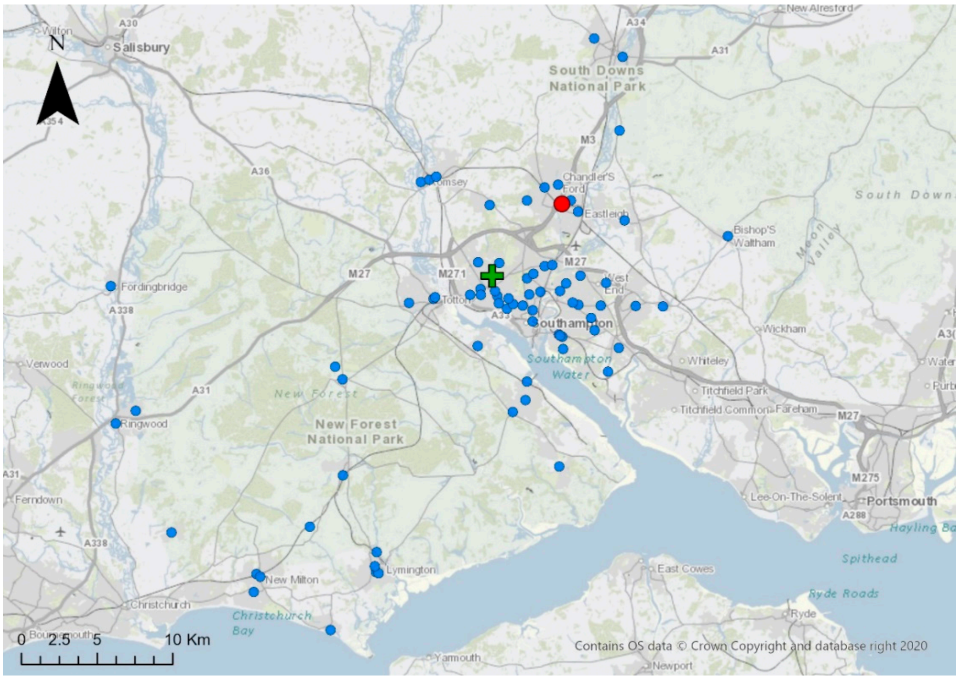

Figure 2. Map showing locations of Eastleigh PTS depot, GP surgeries and Southampton General Hospital (SGH). Red circle shows the location of Eastleigh PTS depot, blue circles show locations of GP surgeries and green cross shows the location of SGH.

The analysis was based on two primary datasets that provided details of historic vehicle routings: one for the PTS during March 2021; and the other for the SCS during September 2018. A secondary dataset providing numbers of pathology samples generated during March 2021 was also utilised. The PTS dataset described the movements of the 33 vehicles based at the Eastleigh depot. On average, these PTS vehicles performed 26 rounds each day in BAU, with each vehicle transporting an average of 6 patients/day either to or from their routine hospital appointments (i.e., non-emergency transport). Nominally, the PTS booking policy requires patients to book transport more than 48 h before their appointment but, in practice, bookings are accepted up to the last moment whenever possible. PTS vehicles were diesel minibuses (Figure 1), i.e., similar in size to LGVs. Some patients had specialist travel requirements, such as to travel in a wheelchair (standard or extra-large), travel on a stretcher or travel alone, and the vehicles were of several different types with varying capacities to accommodate patients' travel requirements (Table 2).

Table 2. Capacities of PTS vehicles based at the Eastleigh depot.

PTS Vehicle Type ID	No. of Vehicles at Depot	Capacity for Patients Travelling in Vehicle Seats	Capacity for Patients Travelling in Standard Wheelchairs	Capacity for Patients Travelling in Extra-Large Wheelchairs	Capacity for Patients Travelling on Stretchers
Seated_4	3	3	0	0	0
Seated_6	1	5	0	0	0
Seated_7	9	6	0	0	0
WAV_5 [1]	5	2	2	0	0
Stretcher_4	8	3	0	0	1
Stretcher_6	4	5	0	0	1
Stretcher_7	1	6	0	0	1
Bariatric_5	2	2	0	2	0

[1] WAV is Wheelchair-Accessible Vehicle (note: Bariatric_5 vehicles are also wheelchair accessible).

Regarding the SCS dataset (and associated secondary dataset for sample generation), daily numbers of samples generated for collection from each GP surgery ranged from just a few, up to ~200 samples (depending on surgery size in relation to the numbers of registered patients), with an average of 40 samples/day/surgery. The distribution of mean samples/day across the 78 surgeries is shown in Figure 3, and across the days of the week in Figure 4. These samples were packaged by each surgery into consignments consisting of a medium-sized insulated medical carrier (brand name Versapak; dimensions 460 × 255 × 305 mm; estimated capacity ~125 samples; empty weight 2.4 kg [31]; Figure 5) for collection twice per day, typically an early (AM) and late (PM) collection from each surgery. The collection of two Versapaks per day (i.e., AM and PM) provided ample capacity (125 × 2 = 250 samples/day) to accommodate the peak daily number of samples generated at any of the surgeries (~200 samples/day). The data described the movements of 10 courier company vehicles, which were diesel vans (i.e., LGVs), performing 10 collection rounds each day in BAU, collecting up to 18 consignments (i.e., visiting up to 18 surgeries) before delivering to SGH. Reverse logistics, whereby empty Versapaks are returned from SGH to GP surgeries, were accomplished during the normal course of operations, i.e., empty Versapaks were delivered to GP surgeries at the same time as full ones were collected during the vehicle collection rounds.

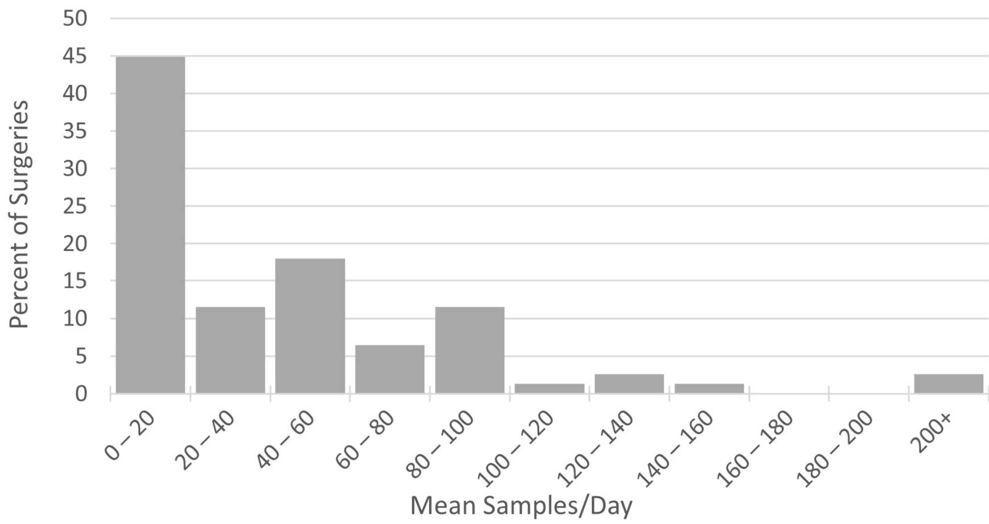

Figure 3. Distribution of mean samples per day generated by GP surgeries. Number of GP surgeries is 78.

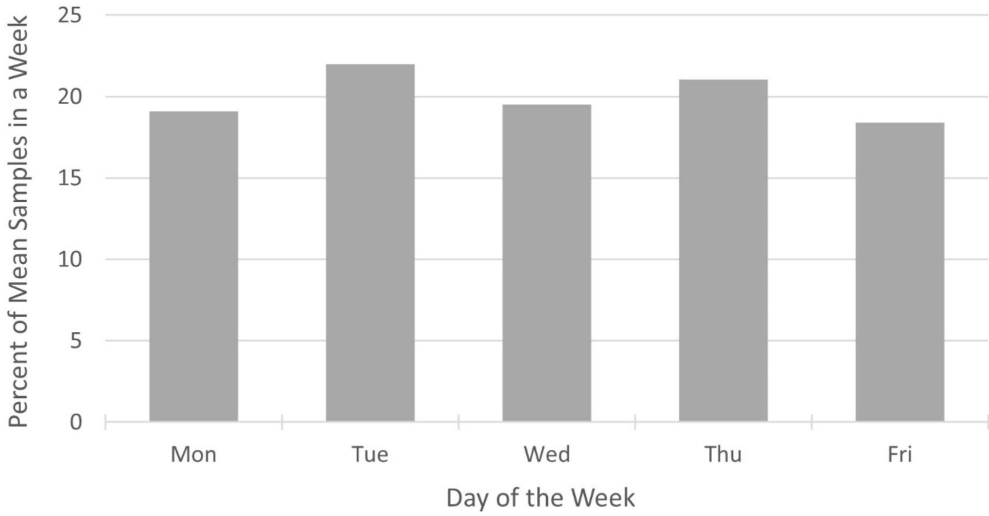

Figure 4. Distribution of mean samples per day generated on weekdays (Mon–Fri). Mean samples in a week (Mon–Fri) is 15,684.

Figure 5. Pathology sample packaging (left) and insulated medical carriers (right). The medium-sized carrier is the middle of the three pictured. Approximately 125 pathology samples can be packed into a medium-sized carrier.

There was a slight inconsistency between the SCS and sample generation datasets, in that courier vehicle movements were for September 2018 and samples generated were for March 2021, but the September 2018 vehicle movements were assumed to be representative of vehicle movements in March 2021. This was regarded as a reasonable assumption because the sample generation dataset for March 2021 was compared to a similar dataset for sample generation in November 2018 using an independent-means t-test and found not to be statistically significantly different in terms of the mean number of samples produced by surgeries [$t(43) = -0.266$, $p = 0.791$ (i.e., $p > 0.05$)]. In other words, despite any effects on pathology sample generation that might have been expected due to the COVID-19 global pandemic in the intervening period, sample generation was similar in November 2018 and March 2021, and therefore it was reasonable to assume that vehicle movements to collect those samples in September 2018 and March 2021 were also likely to be similar. One caveat to this assumption was that traffic conditions may have been different in March 2021 (compared to September 2018) due to the pandemic suppressing road traffic (i.e., less road travel due to COVID-19 restrictions), which meant courier vehicle movements were likely to be based on worse traffic conditions (i.e., those in September 2018) than those that actually existed in March 2021.

A small number (1.2%) of samples were generated on weekends (879 out of 73,112 total samples in March 2021). Two rounds (both on Saturdays) were used by the courier company to collect samples on weekends in BAU, with one of these rounds having nine possible different route variations listed. No rounds were listed for Sundays. It was not possible to ascertain from the data which of the nine routes were actually followed on the four Saturdays that occurred during March 2021. Given the uncertainty regarding weekend collections, and the small fraction of samples involved (1.2%), weekends were ignored in the analysis, i.e., only a Monday–Friday collection service was considered covering 98.8% of samples. The PTS do operate at weekends, albeit with less activity, and it seems likely that the small number of weekend samples could be collected by PTS vehicles, or if that was not possible, transport by taxi could be arranged as a back-up alternative (as is the current practice for any samples that, for whatever reason, cannot be collected by the BAU courier vehicles).

Vehicle-kilometres (vkm) and duty time (the time during which vehicle and driver were operational) were extracted from the two primary datasets. Distances between the postcode locations of each stop on the vehicle routes contained in the datasets were measured using Google Maps and cross-checked using GraphHopper (an online application similar to Google Maps). Duty times were calculated as the difference between the times recorded in the datasets for vehicles departing and returning to the depot.

Cost values were obtained from the 'Manager's Guide to Distribution Costs' (MGDC) published in the UK by the Freight Transport Association (FTA) [32]. Courier driver costs (GBP 10.78/h) were assumed to be those for drivers of light rigid vehicles ($\leq$7.5 tonnes Gross Vehicle Mass; GVM), including pay for overtime and productivity. For courier vehicles, operating costs (GBP 0.46/mile) were assumed to be those for diesel vans ($\leq$3.5 tonnes GVM) with average annual mileage (35,000 miles/year), including insurance, vehicle tax, depreciation, fuel, tires, maintenance, and overheads. In consultation with PTS staff, it was established that annual mileage for PTS vehicles was typically ~25,000 miles, and therefore the equivalent vehicle operating cost (GBP 0.54/mile) for diesel vans with lower annual mileage (25,000 miles/year) in the MGDC was used for these vehicles. For consistency, CO_2 emission factors for diesel vans (0.45 kg/mile for average annual mileage; and 0.49 kg/mile for lower annual mileage) were also taken from the same source. PTS vehicle drivers (known as Ambulance Care Assistants) have higher costs due to their additional care-giving training compared with a typical courier vehicle driver, and following private communications with PTS staff, a value of ~GBP 19.00/hour was assumed for these drivers.

All vehicles were assumed to have one operative (i.e., the driver). For PTS vehicles, in certain circumstances where patients had particular difficulty with vehicle access and there was no help available at the collection and/or delivery location, two operatives were required in a vehicle, which would obviously incur extra costs. However, such circumstances existed in both BAU and intervention scenarios, and so were assumed to offset each other to a large extent when calculating net differences between the scenarios.

3.2. Intervention Scenario

In the intervention scenario, all samples were assumed to be collected by PTS vehicles rather than by the external courier company currently engaged by the SCS. Task lists of the patient and sample collections/deliveries to be fulfilled each day were created using the historic datasets. The daily task lists were then used as inputs to commercially available route optimisation software (PTV Route Optimiser) to find efficient vehicle routings to satisfy all collections and deliveries.

Each task list (i.e., each day's unique demand profile) was imported into the software to set the specific patient and sample travel requirements for each day (i.e., patient hospital delivery/collection times; patient requirements to travel on a stretcher, in a wheelchair or alone; sample collection times). It was agreed with PTS staff that every patient had to be delivered to/collected from hospital within one hour of the start/finish of their appointment. Time windows for the early (AM) and late (PM) collections of samples from GP surgeries were fixed at 10:00–13:00 and 15:00–18:00, respectively, and this requirement remained static each day unlike patient requirements, which were dynamic, varying from day-to-day. Occasionally, patients required end-of-life transport to hospital, and in these sensitive circumstances collection of pathology samples was deemed inappropriate, and this constraint was also specified in the task lists.

The in-vehicle time constraint for patients (i.e., maximum duration of a patient's journey) was specified in the task lists as three hours in alignment with the maximum duration found in the BAU dataset (2 h 53 min). The in-vehicle time constraint for pathology samples was more relaxed than that for patients, with the only requirement being that they were delivered at any time before midnight. This was considered acceptable for samples packed in insulated carriers, where (unlike for patients) comfort was not a concern. Being a large hospital, SGH is staffed 24 h-a-day and it was therefore assumed that it would be possible for samples to be received at any time up to midnight and stored for processing. Each of the 23 working days (Mon-Fri) in March 2021 were analysed in separate software runs to assess the capability of the PTS fleet to cope with the dynamics of daily demand.

Software parameters were set to reflect the available PTS vehicle capacities, which involved defining a fleet of 33 vehicles with capacities for different patient travel requirements as shown in Table 2. In consultation with PTS staff, it was assumed that all PTS vehicle types had the capacity for three consignments (i.e., three Versapaks) of samples alongside their normal patient loads, and this was also included in the vehicle capacities defined in the software settings. Vehicle dwell time per stop was set at an assumed value of five minutes, with an additional five minutes (i.e., 10 min total) for those stops involving loading/unloading patients with more time-consuming vehicle access requirements (i.e., travelling in wheelchairs or on stretchers).

Duty periods for PTS drivers in BAU (i.e., as detailed in the historic PTS dataset supplied by PTS staff) were typically up to a maximum of 14 h long (average of ~9.5 h), and the same duration was therefore assumed to be the maximum in the intervention scenario. Specific details of break requirements for PTS drivers were not available, so drivers were assumed to have breaks in accordance with European Union (EU) rules on drivers' hours, which require breaks totalling at least 45 min after no more than 4.5 h driving. Software parameters were set to reflect these duty periods and break requirement assumptions.

Default software parameters were used for average traffic speeds on UK road types: motorway (multi-lane arterial) 85 km/h; dual carriageway (two-lane arterial) 78 km/h; primary (single-lane arterial) 70 km/h; main (collector) 62 km/h; minor (collector) 51 km/h; and residential (local) 36 km/h. Similar to the BAU scenario, reverse logistics (i.e., returning empty Versapaks from SGH to GP surgeries) were assumed to be accomplished during normal operations.

The use of commercially available (i.e., off-the-shelf) software was regarded as sufficient for finding efficient solutions at this early, feasibility stage of the assessment of the concept of PTS/SCS shared-fleet operations, and the investigation and development of novel algorithmic optimisation solution methods was seen as a potential direction for future research. The specific optimisation algorithm used in the software is commercially sensitive and therefore confidential, but follows the traditional approach of the classic Travelling Salesman Problem [33]. Although the software is not using an exact approach to solve this problem, an Integer Linear Programming (ILP) mathematical formulation of the problem being approximated by the route optimisation software is provided as follows. Let P be the set of all patients and let R be the set of all feasible routes, departing from the vehicle depot and meeting all the constraints stated above such as vehicle capacity for Versapaks (i.e., not more than three visits to surgeries before delivery to SGH), sample collection time windows, and patient delivery/collection time windows if a patient is considered within that route, and also accounting for vehicle waiting times (i.e., EU rules on drivers' hours). Then, for each route $r \in R$, the total time t_r is known, calculated as the sum of driving, waiting and service (i.e., dwell) times. The list of patients served by route r is denoted as p_r, and m_r represents the PTS vehicle type assigned to the route. Note that m_r can take the eight values specified in Table 2, so the types of vehicles can be modelled as $m \in \{1, \ldots, 8\}$, and c_m is the capacity for each type m. Finally, let s_r be the set of surgeries being visited by route r. Therefore, the optimisation problem can be formulated as in (1), where one binary variable for each feasible route, x_r, is considered, and takes the value one if the route is being used in the solution.

Integer Linear Programming (ILP) formulation (1):

$$\begin{array}{lr} Min \sum_{r\in R} t_r x_r & \\ \sum_{r\in R}\sum_{p'\in p_r} x_r = 1, & \forall p \in P \\ \sum_{r\in R}\sum_{s'\in s_r} x_r = 1, & \forall s \in S \\ \sum_{r\in R|m_r=m} x_r \le c_m, & \forall m \in \{1,\ldots,8\} \\ x_r \in \{0,1\} & \forall r \in R \end{array} \quad (1)$$

Vkm and duty time were extracted from route optimisation software outputs, with the same cost factor values applied as those used in the BAU analysis (Section 3.1). The software did not have an in-built emissions model, and therefore the same fixed emission factor as used in the BAU analysis (0.49 kg/mile for PTS vehicles) was applied to vkm outputs to compute CO_2 emissions. The benefit of using the same cost and emission factor values in both the intervention and BAU scenarios was that it provided consistency when comparing the two scenarios.

4. Results

The movements of PTS and SCS (i.e., courier) vehicles in the BAU scenario were analysed, as were the movements of PTS vehicles transporting both patients and pathology samples in a shared-fleet operation in the intervention scenario. The BAU analysis demonstrated that there was considerable overlap between the operational area of the PTS and the locations of GP surgeries sending samples to SGH via the SCS (Figures 6 and 7), suggesting good potential for a shared-fleet operation. For the intervention analysis, the routes necessary to enable the PTS vehicles to provide a shared-fleet operation capable of accommodating dynamic demand for patient transport and static demand for sample transport were produced using the route optimisation software (Figure 8). Each day's unique demand was analysed using the software to assess the capability of the PTS fleet to cope with the dynamics of daily demand.

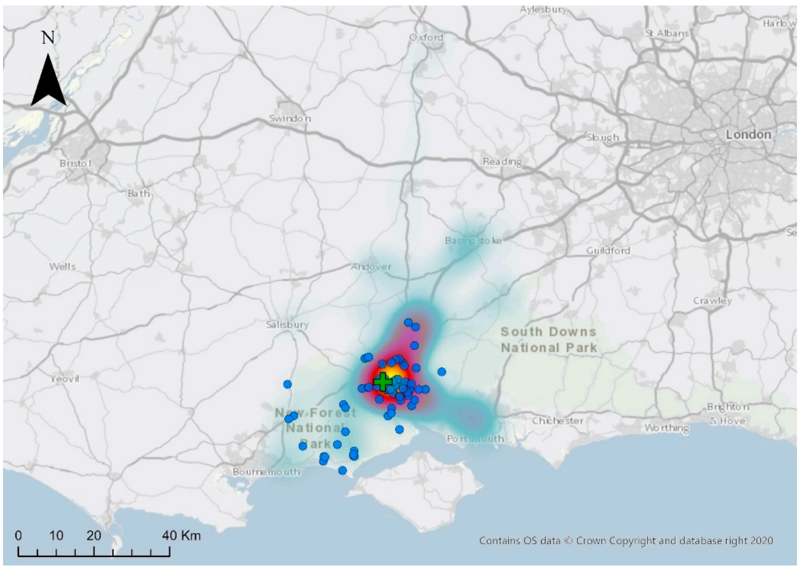

Figure 6. Map showing movements of all PTS vehicles during an example day (4 March 2021) in the BAU scenario. Heat map shows intensity of vehicle movements, blue circles show locations of GP surgeries and green cross shows the location of SGH.

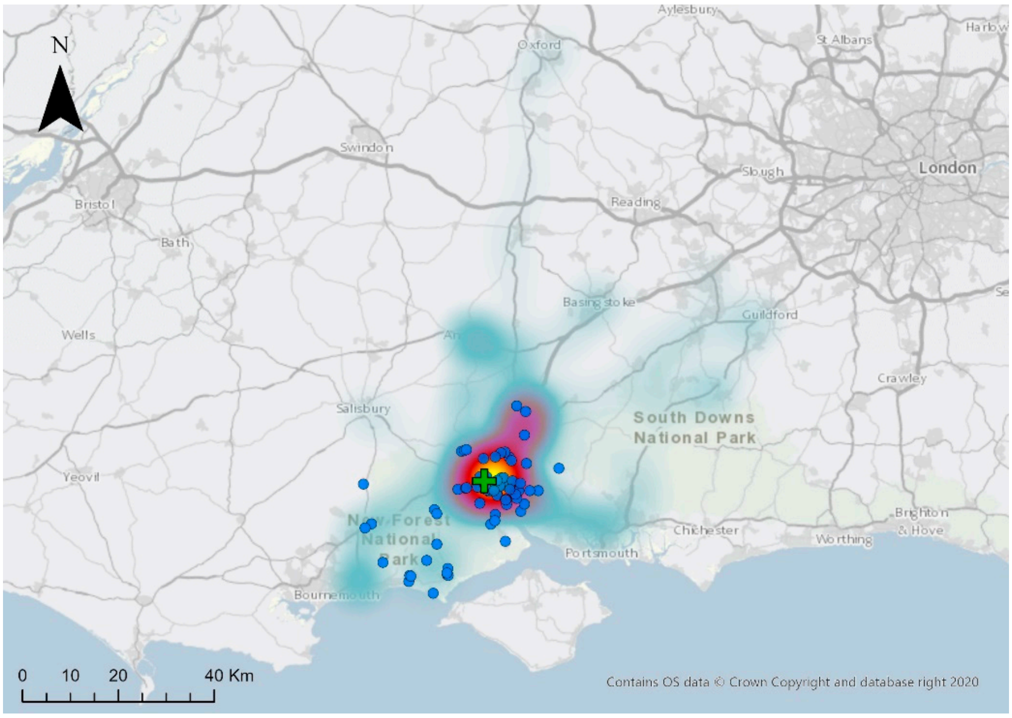

Figure 7. Map showing movements of one example PTS vehicle during all weekdays in March 2021 in the BAU scenario. Heat map shows intensity of vehicle movements, blue circles show locations of GP surgeries and green cross shows the location of SGH.

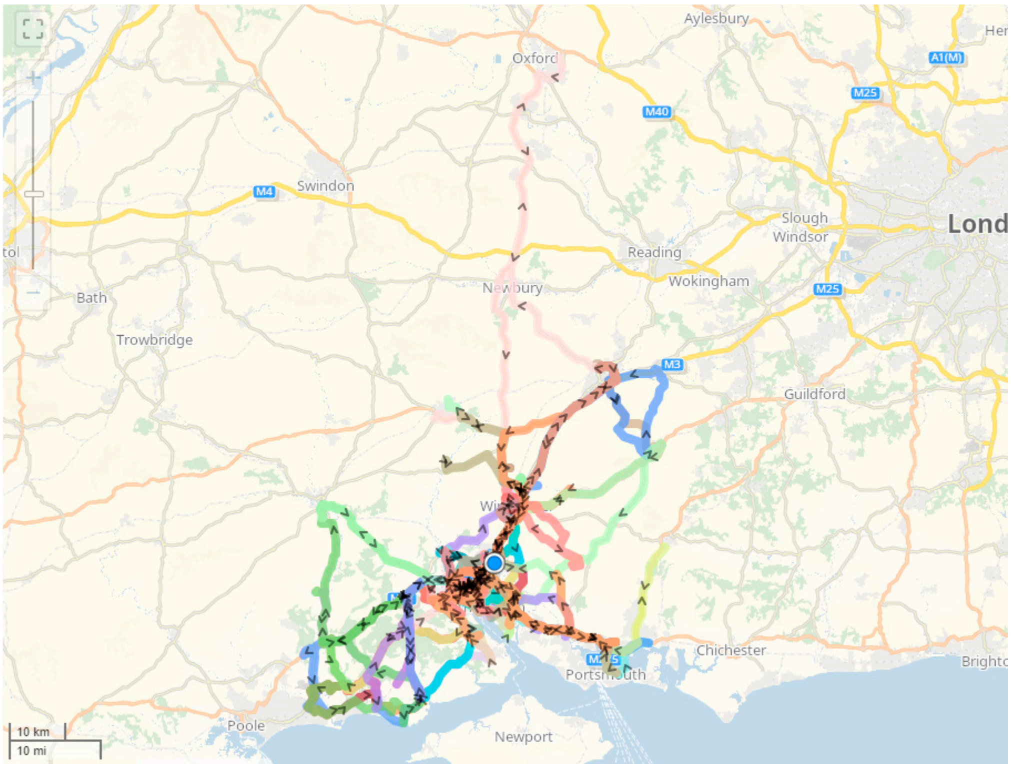

Figure 8. Map showing movements of all PTS vehicles during an example day (4 March 2021) in the intervention scenario. Blue circle shows the location of Eastleigh PTS depot. Lines with direction arrows show vehicle routes, with each different coloured line representing the route of each different vehicle on the example day.

Comparison of results from both BAU and intervention analyses (Table 3) suggested that deploying a shared-fleet operation whereby loads were consolidated by the SCS sharing the spare capacity of the PTS vehicles to collect pathology samples could reduce costs, vkm, duty time and CO_2 emissions by 16% (GBP 1156/day), 13% (767 km/day), 23% (68:04 h:m/day) and 12% (205 kg/day), respectively. The average number of PTS vehicles (24 vehicles/day) used to provide the shared-fleet operation in the intervention scenario represented a reduction of 32% (12 vehicles/day) from the combined total of PTS and courier vehicles (36 vehicles/day) used to provide independent PTS and SCS in the BAU scenario.

Table 3. Summary statistics for PTS and SCS in both BAU and intervention scenarios.

Scenario & Service	No. of Vehicle Routes	Cost (GBP)	Vkm (km)	Duty Time (h:m)	CO_2 (kg)
BAU Daily Average: [1]					
PTS	*26*	*GBP 6315*	*4682*	*247:43*	*1426*
SCS	*10*	*GBP 782*	*1137*	*42:10*	*318*
PTS + SCS Total	36	GBP 7097	5820	289:53	1743
BAU Monthly Total: [2]					
PTS	*595*	*GBP 145,249*	*107,695*	*5697:35*	*32,790*
SCS	*230*	*GBP 17,991*	*26,156*	*969:50*	*7309*
PTS + SCS Total	825	GBP 163,240	133,851	6667:25	40,099
Int. Daily Average: [3] PTS/SCS Shared-Fleet	24	GBP 5941	5053	221:48	1538
Int. Monthly Total: PTS/SCS Shared-Fleet	558	GBP 136,644	116,215	5101:40	35,384
Net Effect per Day: BAU Daily–Int. Daily (% reduction)	12 (32%)	GBP 1156 (16%)	767 (13%)	68:04 (23%)	205 (12%)

[1] BAU is Business-As-Usual. [2] Number of weekdays (Mon-Fri) in March 2021 was 23. [3] Int. is Intervention.

However, one caveat to these results is that, whilst the size of the existing PTS vehicle fleet based at the Eastleigh depot (33 vehicles) was sufficient to undertake the shared-fleet operation in the intervention scenario, it was found that the balance of the existing fleet-mix (Table 2) needed to be adjusted for the shared-fleet operation to be feasible. This issue and its implications are discussed in more detail in Section 5.

5. Discussion

The analysis has shown that a shared-fleet operation involving the integration of static and dynamic demand, utilising public sector own-account vehicles appears feasible, with all requirements for transport of both patients and pathology samples during the month of March 2021 being satisfied by the PTS and the SCS collaborating to share capacity on the PTS vehicle fleet. The benefits (i.e., net reductions in cost, vkm, duty time and CO_2 emissions of 16%, 13%, 23% and 12%, respectively, Table 3) suggested that policies that actively seek out opportunities to deploy shared-fleet solutions to improve vehicle utilisation should be pursued by management and decision-makers within public sector organisations that operate own-account vehicle fleets (such as the NHS), regardless of whether the demand for transport under consideration is static or dynamic, or some combination of both. The benefits of such policies are likely to reduce public sector spending and help alleviate the considerable problems associated with road-based logistics (e.g., air pollution, climate change, traffic congestion). Whilst the study was focused on a large public sector organisation in the UK (i.e., the NHS), it is also likely to have relevance to similar situations around the world where other public sector organisations (e.g., municipal authorities, healthcare providers, government departments, education providers and infrastructure providers) operate own-account vehicle fleets that could benefit from load consolidation through sharing vehicle capacity.

Regarding costs, for the situation analysed in this study, it is likely that the cost savings to the NHS could be greater than those suggested by the results (i.e., 16% reduction in Table 3, equating to a saving of GBP 1156/day). This is because the cost of the SCS in the

BAU scenario was estimated as the cost incurred by the courier company in providing the collection service. As a commercial enterprise, it is highly likely that the courier company would add a profit margin on top of its own costs when tendering for the SCS contract. Therefore, the cost savings to the NHS generated by avoiding the need to engage an external courier company could be greater than those suggested. Moreover, organising and conducting the tender process necessary for public sector procurement would itself consume NHS financial and labour resources, and this additional drain on resources would be avoided if the need to engage an external courier could be eliminated.

Whilst the size of the PTS fleet based at the Eastleigh depot (33 vehicles) was sufficient for the shared-fleet operation to be feasible, it was found that the balance of the existing fleet-mix (Table 2) needed to be adjusted to enable all demands for transport to be fulfilled in the intervention scenario. PTS vehicles of the type Seated_7 were found to be under-utilised, and eight vehicles of this type needed to be replaced by two more of type WAV_5 and six more of type Bariatric_5 for the shared-fleet operation to be feasible. The necessary fleet-mix was obtained by noting the lack of wheelchair capacity in initial outputs of the route optimiser software (i.e., some demand for transport of patients requiring travel in standard or extra-large wheelchairs was left unsatisfied), and then incrementally increasing wheelchair capacity (i.e., increasing numbers of WAV_5 and Bariatric_5 vehicle types as replacements for the under-utilised Seated_7 type) and repeatedly re-running the software until a solution was produced that satisfied all demand on all days.

Considered as a whole, the PTS has many vehicles (n = 480) of all types distributed at multiple depots across Southern England and it may well be possible to achieve the necessary fleet-mix in the short-term by exchanging vehicles between depots to enable the shared-fleet operation to be deployed. Over the longer-term, a more gradual change towards the necessary fleet-mix could be achieved as older vehicles are replaced by newer models. Due to their extra facilities, it is possible that PTS vehicles accommodating wheelchairs (e.g., WAV_5 and Bariatric_5) may incur higher capital costs than vehicles with only seated provision (e.g., Seated_7). Information on PTS vehicle costs was not available, but if this is the case, replacing seated-only vehicles with new wheelchair-capable ones would erode the potential cost savings available from a shared-fleet operation in the real-world.

The necessary fleet-mix was determined based on operations in March 2021, and before PTS staff begin to consider the process of re-organisation and/or vehicle purchasing aimed at adjusting the fleet-mix, it would be advisable to analyse other operational time periods to understand what combination of vehicle types meets transport demand in different operating scenarios. This is an area recommended for further research.

If adjusting the fleet-mix proves to be impracticable, another potential approach could be to reduce the geographical scale of the shared-fleet operation so that it can be serviced by the existing PTS fleet-mix (i.e., existing numbers of vehicle types as shown in Table 2). With reference to Figure 9, an obvious way to reduce the scale would be to exclude the 16 (out of 78 total) GP surgeries located in more rural locations in the New Forest National Park on the Western periphery of the PTS operational area. More rural surgeries such as these typically require disproportionate amounts of driving distance and time to service.

In these circumstances, the excluded rural surgeries could continue to be serviced by an external courier company. Whilst not entirely avoiding the need to engage a courier company (and the resource consumption inherent in the procurement process itself), this is likely to be less expensive for the NHS to procure than the current (i.e., BAU) situation because the number of surgeries would be greatly reduced (78 reduced to 16), although the reduction in expense is unlikely to be linear because of the disproportionate amounts of driving distance and time associated with servicing rural surgeries.

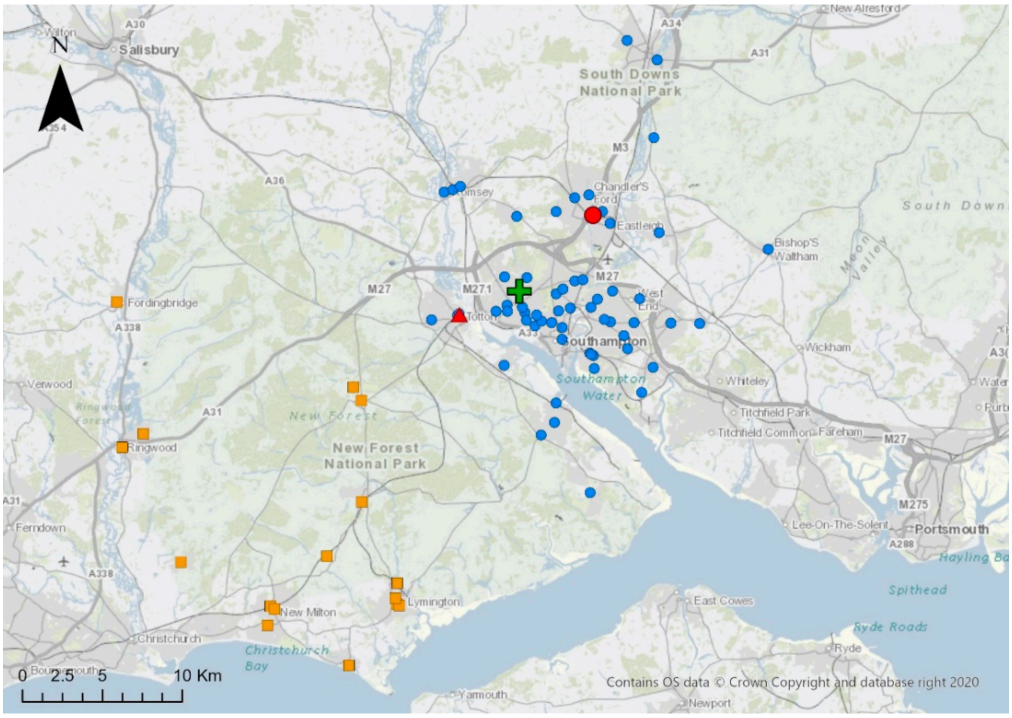

Figure 9. Map showing locations of rural GP surgeries and alternative PTS vehicle depot. Red circle shows the location of Eastleigh PTS depot, red triangle shows the location of possible alternative PTS depot (Totton), blue circles and orange squares show the locations of GP surgeries (orange squares identify more rural surgeries) and green cross shows the location of SGH.

Another option for servicing rural surgeries could be a separate shared-fleet operation provided by PTS vehicles based at a different depot located in closer proximity to the rural surgeries (e.g., Totton PTS depot, Figure 9). It is also possible that new logistics modes such as Uncrewed Aerial Vehicles (UAVs, commonly known as drones) could be utilised to service the rural surgeries, offering benefits such as decreased travel times and improved accessibility in rural locations, although this may be a prohibitively expensive option until drone technology matures and automates [34]. All these alternative approaches would require further investigation should they become necessary due to an unwillingness or inability to adjust the fleet-mix at the Eastleigh PTS depot to enable the provision of a shared-fleet service that can cover all GP surgeries. This is suggested as an area for further research if/when necessity dictates.

The average number of PTS vehicles (24 vehicles/day) used to provide the shared-fleet operation in the intervention scenario was fewer than the average number (26 vehicles/day) used by the PTS to transport only patients in the BAU scenario (Table 3). Moreover, the average duty time per route for PTS vehicles in the intervention scenario (221:48/24 = 9:08 duty hours/route) was slightly lower than in the BAU scenario (247:43/26 = 9:34 duty hours/route) (Table 3). Both these findings suggested that the route optimisation process employed during the intervention analysis produced more efficient vehicle routings than those achieved in the real-world (i.e., as described in the historic PTS vehicle movement dataset for the BAU scenario).

A potential reason for this was that PTS route planners deliberately insert additional time (i.e., spare time capacity) into real-world vehicle schedules as a contingency measure to ensure service level agreements regarding avoiding delays to collection/delivery of patients are satisfied, even if vehicles encounter unforeseen eventualities that could occur in practice, such as above average levels of traffic congestion (average traffic speeds were assumed in the route optimisation software), delays due to patient loading complexities, or difficulties in navigating to desired locations. In addition, there may have been more spare time capacity than normal in the real-world schedules in March 2021 because of the effects of the COVID-19 pandemic acting to: (i) suppress patient transport requirements (i.e., fewer patients going to hospital for routine appointments due to COVID-19 restrictions); and (ii) suppress road traffic (i.e., less road travel due to COVID-19 restrictions), leading to lower levels of congestion.

On average, patients spent longer in-vehicle in the intervention scenario (i.e., patient journeys were elongated), which was expected because PTS vehicles had to perform additional vkm and stops in order to collect samples. Average in-vehicle time for patients was 1 h 1 min compared with 29 min in the BAU scenario. Confirmation of acceptable patient in-vehicle times was not available, and if longer times were unacceptable in the real-world, then more restrictive constraints on scheduling would make the potential benefits of a shared-fleet operation more difficult to achieve in practice. Average in-vehicle time for pathology samples increased as well, from 1 h 4 min in the BAU scenario to 1 h 21 min in the intervention scenario, although this was considered acceptable for samples packed in insulated carriers, where (unlike for patients) comfort was not a concern.

In general, there are a number of practical realities that could be barriers to and/or constraints impacting on the deployment of a shared-fleet operation in the real-world [7,10]. For example, factors such as:

(i) preferred collection/delivery times;
(ii) effects of unforeseen vehicle delays;
(iii) the need to meet existing service level agreements;
(iv) safe on-board stowage of samples;
(v) quality control for sample transport (e.g., monitoring detrimental in-vehicle conditions such as high temperature or vibration);
(vi) liability for injury to patients or loss/damage of samples;
(vii) overcoming reluctance to use an alternative transport provider and convincing all parties (e.g., GP surgeries, PTS vehicle drivers, SCS and PTS management staff, pathology laboratory personnel) of the benefits of participation;
(viii) availability of spare capacity in PTS vehicles;
(ix) allocating responsibility for route scheduling;
(x) developing a new business model to procure transport internally on an inter-departmental basis (i.e., between the PTS and SCS, both departments within the NHS), rather than externally from a commercial courier company, including agreements on the cost allocation and management processes involved.

These barriers and/or constraints mean that, in practice, it may be more difficult to realise fully the theoretical benefits suggested in this study, and resolutions would need to be negotiated and agreed between the parties before a shared-fleet operation could be implemented. The obvious way to investigate and quantify the benefits achievable in practice is through conducting real-world trials of a shared-fleet collaboration between the PTS and SCS. Driven by the potential benefits reported in this paper, such trials appear to be justified and are the apparent next step for further research.

The historic pathology sample generation dataset used in the analysis suggested that demand was reasonably static over time, with surgeries generating approximately the same numbers of samples month-by-month with no seasonal peaks evident. This steady demand means that, in a real-world implementation, the PTS vehicle fleet would be unlikely to face any unexpected sample collection requests in addition to those already included in the analysis.

6. Conclusions

The key findings of the research were that a shared-fleet operation involving the integration of static and dynamic demand utilising public sector own-account vehicles was both feasible and beneficial. The potential benefits of collaboration between the PTS and the SCS to share spare capacity on the PTS vehicle fleet included a 16% reduction in costs, a 13% reduction in vkm and a 12% reduction in CO_2 emissions.

The implication for management and decision-makers within public sector organisations that operate own-account vehicle fleets is that pursuing policies that actively seek-out opportunities to deploy shared-fleet solutions to improve vehicle utilisation are likely to be beneficial and offer the prospect of reductions in public sector spending. The next step in generating evidence to support this implication would be to conduct real-world trials of shared-fleet operations to investigate the effect that practical realities may have on the benefits that can be achieved. These practical realities include barriers and/or constraints such as the need to develop a new business model to procure transport internally on an inter-departmental basis, rather than externally from a commercial courier company, including agreements on the cost allocation and management processes involved.

In summary, the principal contributions of this study were three-fold: (i) evidence was provided in support of the feasibility and potential benefits of collaborative shared-fleet operations involving public sector own-account vehicle fleets and integration of static and dynamic demands for transport of specialised payloads, a situation that has not been addressed in previous studies reported in the literature; (ii) potential benefits of such collaborations were quantified; and (iii) scope was identified for wider deployment of shared-fleet operations by other public sector organisations in similar situations around the world. In addition, the study contributed to rectifying the situation identified in recent reviews of research relevant to shared-fleet collaborations whereby there is a general shortage of studies based on real-world activity data (Section 2).

Author Contributions: Conceptualization, M.G. and T.C.; methodology, M.G. and T.C.; formal analysis, M.G.; investigation, M.G.; writing—original draft preparation, M.G. and A.M.-S.; writing—review and editing, M.G., T.C., A.O., A.M.-S. and I.A.; supervision, M.G. and T.C.; project administration, M.G.; funding acquisition, T.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the EPSRC, grant number EP/V002619/1; and by the UK Department for Transport under Solent Transport's Future Transport Zones project.

Institutional Review Board Statement: Not applicable for this study.

Informed Consent Statement: Not applicable for this study.

Data Availability Statement: Datasets used in this study are not publicly available.

Acknowledgments: The authors would like to thank the PTS staff and NHS personnel involved for providing the information on which this study was based.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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