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Toward Baggage-Free Airport Terminals: A Case Study of London City Airport

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Abstract: Nowadays, the aviation industry pays more attention to emission reduction toward the net-zero carbon goals. However, the volume of global passengers and baggage is exponentially increasing, which leads to challenges for sustainable airports. A baggage-free airport terminal is considered a potential solution in solving this issue. Removing the baggage operation away from the passenger terminals will reduce workload for airport operators and promote passengers to use public transport to airport terminals. As a result, it will bring a significant impact on energy and the environment, leading to a reduction of fuel consumption and mitigation of carbon emission. This paper studies a baggage collection network design problem using vehicle routing strategies and augmented reality for baggage-free airport terminals. We use a spreadsheet solver tool, based on the integration of the modified Clark and Wright savings heuristic and density-based clustering algorithm, for optimizing the location of logistic hubs and planning the vehicle routes for baggage collection. This tool is applied for the case study at London City Airport to analyze the impacts of the strategies on carbon emission quantitatively. The result indicates that the proposed baggage collection network can significantly reduce 290.10 tonnes of carbon emissions annually.

Keywords: network design; vehicle routing problem; baggage free airport terminal; carbon emission; augmented reality

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Citation: Jiang, Y.; Yang, R.; Zang, C.; Wei, Z.; Thompson, J.; Tran, T.H.; Encinas-Oropesa, A.; Williams, L. Toward Baggage-Free Airport Terminals: A Case Study of London City Airport. *Sustainability* **2022**, *14*, 212. https://doi.org/10.3390/su14010212

Academic Editor: Vincenzo Torretta

Received: 1 November 2021
Accepted: 21 December 2021
Published: 26 December 2021

1. Introduction

The International Air Transport Association (IATA) [1] predicts that over 10 billion air passengers will be carried by 2050 (approximately traveling 20 trillion kilometers each year), which will generate about 1800 megatonnes (Mt) of carbon emissions and lead to challenges of passenger and baggage flow management at airport terminals. The aviation industry has embraced this challenge and a wide range of measures are now being implemented to solve the issue toward the net-zero carbon goals. The baggage-free airport terminal (BFAT) is considered a potential solution for the goal of sustainable airports. The BFAT builds new links between airports and cities, investigating the expansion of the baggage collection from home. In particular, the BFAT removes the baggage operation away from the passenger terminal via multiple injection points connected to highly efficient baggage fulfillment centers [2]. The service will pick up passengers' baggage at a selected time window on the doorstep, assign a QR code to each baggage and deliver the baggage to the assigned depot (logistic hub or airport). Passengers will be encouraged to use public transport during their journey; in the meantime, baggage will be delivered directly to the destination (home or hotel address). Augmented reality (AR) will be used to help passengers quickly double-check their baggage to avoid any mishandling. Hence, the BFAT effectively manages the baggage flow between the airports and the cities, liberating the passengers from their baggage and reducing airport-related carbon emissions.

The location-routing problem (LRP) is one of the main tasks of the BFAT, identifying the optimal location of logistic hubs and planning the optimal vehicle routes for baggage collection and delivery. For a comprehensive literature review of recent research on LRP we refer to [3]. Since the location of logistic hubs will be specified in our study, we focus on solving the vehicle routing problem (VRP). The VRP includes a growing number of variants, such as time windows [4], multiple depots [5], multiple trips [6], heterogeneous fleets [7], and green vehicles [8]. The green vehicle routing problem (GVRP) investigates the negative environmental effects of vehicle transportation. The GVRP expands the traditional VRP's objective function, in addition to transportation distance, transportation time, and other transportation economic costs, transportation environment cost (e.g., greenhouse gas emissions) is also considered. Bektaş et al. [9] first set carbon emissions as the objective function of VRP. Franceschetti et al. [10] established a GVRP model with time windows to avoid traffic congestion and significantly reduce carbon emissions. Koç et al. [11] found that a fleet with different types of vehicles can reduce pollutant emissions during transport. Zhang et al. [12] developed a two-stage ant colony system (TSACS) to minimize the total carbon emissions on GVRP. Ge et al. [13] introduced the objective functions of cost-saving, energy-saving, and low-carbon cost to the traditional VRP models. The authors designed an improved genetic algorithm for solving this problem. They compared the low-carbon routing with the shortest routing and found that despite the increase in mileage, the carbon emissions have been greatly reduced. The research on the electric vehicle routing problem (EVRP) is a further expansion of the VRP problem [14]. Compared with traditional fossil fuel-powered cars, electric vehicles (EVs) emit fewer greenhouse gas emissions. However, EVs have technical bottlenecks such as smaller transportation coverage and fewer energy replenishment stations. Erdoğan and Miller-Hooks [8] considered EVs into the GVRP models by adding the energy supplement facilities and vehicle travel distance constraints. They provided an effective routing method for EV companies. Felipe et al. [15] proposed the routing problem of electric freight vehicle transportation, considering the time and the charge amount of each EV charging. Schneider et al. [16] developed a new hybrid heuristic algorithm for the electric freight vehicle routing problem with a time window. Omidvar et al. [17] studied additional constraints such as vehicle load and congestion management and incorporated various metaheuristic methods into their solution. According to the International Energy Agency (IEA) [18], a significant number of EVs (around 125 million) will be on the road by 2030. Using EVs for baggage collection and delivery in the BFAT will thus be a future trend. It will be essential to seek solutions for the BFAT toward a sustainable airport industry.

This paper focuses on the VRP with the specified location of logistic hubs for the BFAT's baggage collection service. The aim is to build a decision support tool for the implementation of a baggage collection service network in airport transportation. This paper discusses the design of an optimal baggage collection network, including the selection of the logistic hub locations and the optimal vehicle routes for baggage collection. A spreadsheet solver tool, based on the integration of the modified Clark and Wright savings heuristic and density-based clustering algorithm, is adopted to find the optimal vehicle routes under different scenarios. For the case study at the London City Airport (LCY), the costs and carbon emissions of using a single depot or multiple depots are investigated and compared. An AR-based innovation is proposed to improve the efficiency of traditional logistics. In summary, this paper makes the following contributions: (i) study a baggage collection service network design problem for future BFATs; (ii) adopt a spreadsheet solver tool to find the optimal vehicle routes for baggage collection; (iii) propose an AR-based baggage tag visualization application, which is useful to reduce any mishandling; (iv) apply the model for the case study at the LCY.

The remainder of the paper is organized as follows: Section 2 describes a spreadsheet solver tool for solving the studied VRP. The case study at the LCY is presented in Section 3. Section 4 is the quantitative analysis of the carbon emissions reduction for the LCY. The

AR-based application for baggage tag visualization is presented in Section 5. Lastly, the conclusion and future work are given in Section 6.

2. VRP Spreadsheet Solver Tool

This paper studies the GVRP with a homogeneous fleet of EVs for the BFATs. A spreadsheet solver tool [8] is adopted to solve the GVRP under various scenarios. The solver is developed on the integration of the Modified Clarke and Wright Savings (MCWS) heuristic and the density-based clustering algorithm (DBCA). The MCWS heuristic is applied to construct vehicle tours for each set of clusters in the DBCA's routing step. The overall aim is to seek a total minimum travel distance for a fleet of EVs that start at a depot, visit a set of customers exactly once, collect their baggage, and return to the depot. A flowchart of the integrated algorithm for the GVRP is shown in Figure 1.

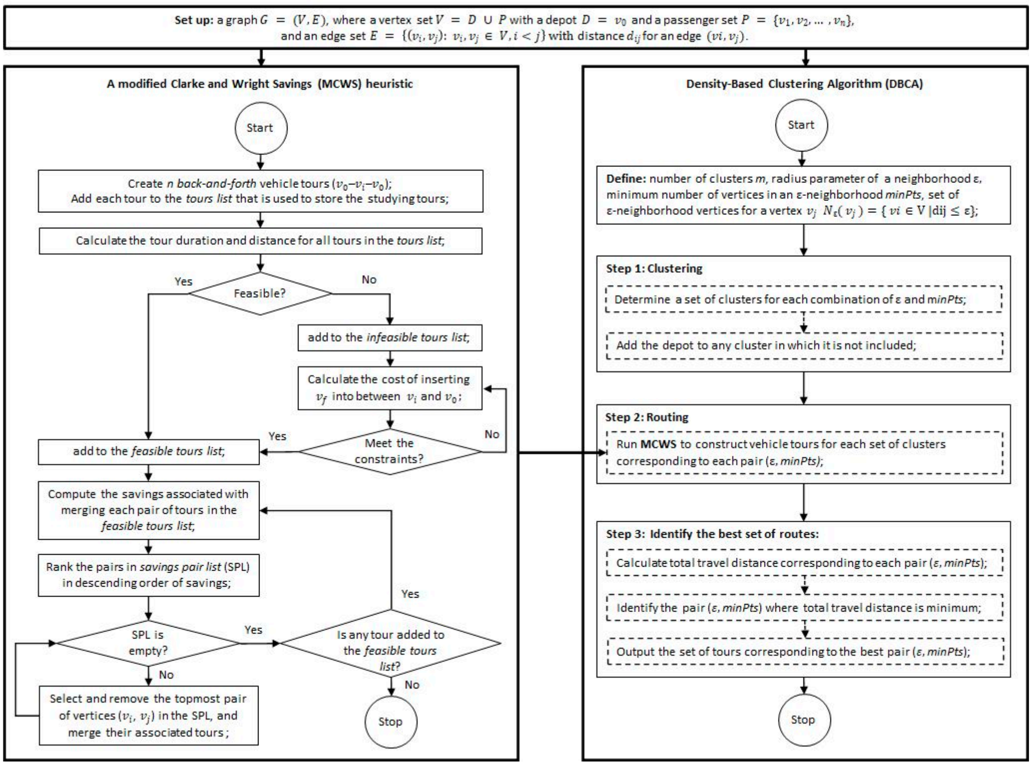


Figure 1. A flowchart of the integrated algorithm for GVRP.

The tool has a unified graphical user interface platform to support users easily to input the data, output the result and visualize the solution. It includes geographic information system (GIS) facilities that allow users to incorporate driving times and distances. The structure of this tool (Locations—Distances—Vehicles—Solution—Visualization) is shown in Figure 2.

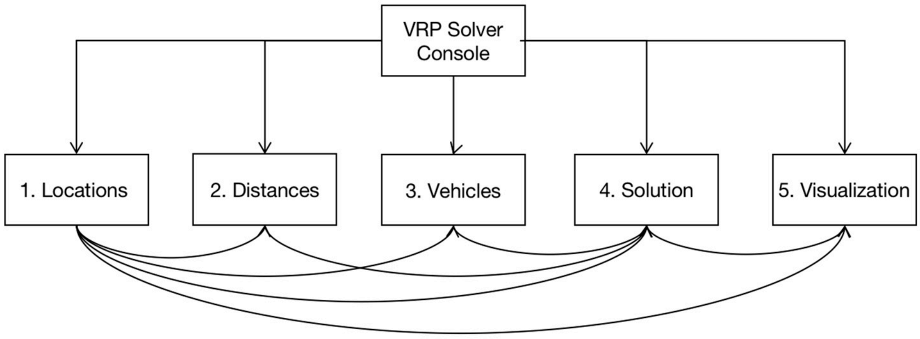


Figure 2. The structure of the spreadsheet solver tool.

The console spreadsheet breaks down each sequence and provides essential information for each upcoming stage as shown in Figure 3. Users can run the GVRP model with the following six sequences:

- Sequence 0 (Interface): Retrieve GIS data and establish delivery points for the later sequence.
- Sequence 1 (Locations): Define the number of depots (e.g., 1–20) and the volume of passengers (e.g., 5–200).
- Sequence 2 (Distances): Set computation method of distance and driving duration, including Euclidian distances, rounded Euclidian distances, Hamming (Manhattan) distances, Bird's flight distances, and Bing Maps driving distances.
- Sequence 3 (Vehicles): Input the number of homogeneous vehicles for simulation (e.g., 8).
- Sequence 4 (Solution): Set vehicles returning mode and time window type.
- Sequence 5 (Visualization): Provide visual representation to users, including visualization maps, location IDs, location names, service time, pickup amount, and delivery amount.
- Sequence 6 (Solver): Start simulation, show progress and result.

Sequence	Parameter	Value	Remarks
0.Interface	Language	English	Please refer to the manual for modifying the interface.
	Optional - Bing Maps Key	AI_Ow2pU_vl4rNuV6W061d1-DHdE_Rxq8xiv43sUpspv-pH1C6HAWM7B2j6-hfYY	You can get a free trial key at https://www.bingmapsportal.com/
1.Locations	Number of depots	1	[1,20]
	Number of customers	100	[5,200]
2.Distances	Distance computation method	Bing Maps driving distances (km)	Recommendation: Use 'postcode, country' format for addresses
	Duration computation method	Bing Maps driving durations	
	Bing Maps route type	Fastest	Recommendation: Use 'Fastest'
	Average vehicle speed	21	
3.Vehicles	Number of vehicle types	8	
4.Solution	Do the vehicles return to their depot(s)?	Yes - only once at the end	
	Time window type	Hard	
	Backhauls?	No	If activated, delivery locations must be visited before pickup locations
5.Optional - Visualization	Visualization background	Bing Maps	
	Location labels	Location IDs	
6.Solver	Warm start?	Yes	
	Show progress on the status bar?	No	
	CPU time limit (seconds)	1800	Recommendation: At least 600 seconds

Figure 3. Console spreadsheet.

The locations spreadsheet includes passengers' postcodes, time windows, and pickup amount data from the Civil Aviation Authority (CAA), and the subsequent GIS data (longitude and latitude) from Bing Maps (Figure 4). The distances spreadsheet (Figure 5) calculates the distance and driving duration between every two positions stated in the locations spreadsheet. The vehicles spreadsheet lists different attributes, parameters, and working scenarios. Each vehicle has approximately 14 m^3 storage capacity with a standard size of baggage and an 80% capacity utilization rate [19]. The duration multiplier refers to the return driving times for an average-sized vehicle. With the increase in size, speed, and the number of baggage, the duration multiplier is increased by 20%. To keep EV batteries recycled, the distance limit is set to 270 km (80% driving range), as shown in Figure 6. The solution spreadsheet shows passenger-driver solutions based on 'Locations, Distances, Vehicles' spreadsheets (Figure 7). The visualization spreadsheet shows the customer locations and vehicle routes with a scatter graph (Figure 8).

	A	B	C	D	E	F	G	H	I	J	K	L
1	Location ID	Name	Address	Latitude (y)	Longitude (x)	Time window start	Time window end	Must be visited?	Service time	Pickup amount	Delivery amount	Profit
2	0	Depot	E16 2PX	51.5037231	0.0480180	05:00	23:00	Starting location	0:00	0	0	0
3	1	Customer 1	N7 6RP	51.5626526	-0.1196410	07:00	10:00	Must be visited	0:10	2	0	30
4	2	Customer 10	SW8 2FU	51.4816895	-0.1279300	07:00	10:00	Must be visited	0:10	2	0	27.5
5	4	Customer 100	N1 8QJ	51.5374985	-0.0961500	21:00	22:00	Must be visited	0:10	2	0	35
6	5	Customer 11	WC1X 0PB	51.5271149	-0.1167810	07:00	08:00	Must be visited	0:05	1	0	32.5
7	7	Customer 12	N16 0TP	51.5603218	-0.0812030	07:00	08:00	Must be visited	0:10	2	0	35
8	8	Customer 13	SW13 0AG	51.4718285	-0.2515860	16:00	19:00	Must be visited	0:15	3	0	35
9	9	Customer 14	E5 0BT	51.5571022	-0.0403250	07:00	10:00	Must be visited	0:15	3	0	30
10	10	Customer 15	E17 6PS	51.5864296	-0.0314560	07:00	08:00	Must be visited	0:05	1	0	32.5
11	11	Customer 16	E4 6SX	51.6233139	-0.0113970	07:00	08:00	Must be visited	0:10	2	0	37.5
12	12	Customer 17	EC1A 9JR	51.5184860	-0.1019300	07:00	10:00	Must be visited	0:15	3	0	30
13	13	Customer 18	NW1 4HJ	51.5330353	-0.1464690	07:00	08:00	Must be visited	0:05	1	0	35
14	14	Customer 19	SE23 2EF	51.4391136	-0.0448470	07:00	08:00	Must be visited	0:05	1	0	32.5
15	15	Customer 2	EC2N 2AN	51.5150795	-0.0861170	07:00	08:00	Must be visited	0:15	3	0	37.5
16	16	Customer 20	N15 5LR	51.5808182	-0.0806720	07:00	10:00	Must be visited	0:10	2	0	30
17	17	Customer 21	N12 8NY	51.6103973	-0.1813910	07:00	10:00	Must be visited	0:10	2	0	32.5
18	18	Customer 22	E11 2PR	51.5738678	0.0225230	07:00	08:00	Must be visited	0:10	2	0	32.5
19	19	Customer 23	E14 8LE	51.4993019	-0.0271730	07:00	08:00	Must be visited	0:10	2	0	32.5
20	20	Customer 24	EC1V 4PG	51.5257874	-0.1036590	07:00	10:00	Must be visited	0:10	2	0	27.5
21	21	Customer 25	SE15 6PQ	51.4780655	-0.0739000	19:00	22:00	Must be visited	0:05	1	0	25
22	22	Customer 26	SW4 6DF	51.4649658	-0.1325140	17:00	18:00	Must be visited	0:10	2	0	37.5
23	30	Customer 27	NW6 5PP	51.5289078	-0.1970530	07:00	08:00	Must be visited	0:10	2	0	40
24	35	Customer 28	NW2 3LJ	51.5559311	-0.2131220	07:00	10:00	Must be visited	0:05	1	0	30
25	42	Customer 29	EC2R 8DU	51.5142975	-0.0905170	08:00	09:00	Must be visited	0:10	2	0	35
26	46	Customer 3	E10 7HP	51.5713806	-0.0192920	21:00	22:00	Must be visited	0:10	2	0	35
27	54	Customer 30	N8 7RU	51.5878677	-0.1274060	08:00	11:00	Must be visited	0:10	2	0	30
28	57	Customer 31	N10 3ST	51.5913544	-0.1397510	08:00	09:00	Must be visited	0:10	2	0	37.5
29	66	Customer 32	SE18 1AD	51.4863968	0.0850960	08:00	11:00	Must be visited	0:10	2	0	25
30	68	Customer 33	SE16 7RW	51.4934273	-0.0415300	08:00	09:00	Must be visited	0:10	2	0	32.5
31	78	Customer 34	WC1X 0DS	51.5262604	-0.1111510	09:00	10:00	Must be visited	0:10	2	0	35
32	79	Customer 35	N22 5HX	51.6058006	-0.1101910	07:00	10:00	Must be visited	0:10	2	0	30

Figure 4. Locations spreadsheet.

From	To	Distance	Duration
Depot	Depot	0.00	0:00
Depot	Customer 1	16.55	0:41
Depot	Customer 10	15.97	0:34
Depot	Customer 100	13.70	0:33
Depot	Customer 11	14.31	0:32
Depot	Customer 12	14.35	0:32
Depot	Customer 13	24.65	0:53
Depot	Customer 14	11.15	0:23
Depot	Customer 15	20.15	0:24
Depot	Customer 16	20.47	0:25
Depot	Customer 17	12.49	0:26
Depot	Customer 18	17.54	0:39
Depot	Customer 19	19.34	0:32
Depot	Customer 2	11.25	0:23
Depot	Customer 20	23.95	0:34
Depot	Customer 21	31.76	0:35
Depot	Customer 22	13.17	0:17
Depot	Customer 23	7.21	0:15
Depot	Customer 24	13.16	0:28

Figure 5. Distances spreadsheet.

Starting depot	Vehicle type	Capacity	Fixed cost per trip	Cost per unit distance	Duration multiplier	Distance limit	Work start time	Driving time limit	Working time limit	Return depot	Number of vehicles
Depot	T1	40	21.28	0.10	1.20	270.00	06:00	9:00	10:00	Depot	1
	T2	40	21.28	0.10	1.20	270.00	06:00	9:00	10:00	Depot	1
	T3	40	21.28	0.10	1.20	270.00	06:00	9:00	10:00	Depot	1
	T4	40	21.28	0.10	1.20	270.00	06:00	9:00	10:00	Depot	1
	T5	40	21.28	0.10	1.20	270.00	06:00	9:00	10:00	Depot	1
	T6	40	21.28	0.10	1.20	270.00	13:00	9:00	10:00	Depot	1
	T7	40	21.28	0.10	1.20	270.00	13:00	9:00	10:00	Depot	1
	T8	40	21.28	0.10	1.20	270.00	13:00	9:00	10:00	Depot	1

Figure 6. Vehicles spreadsheet.

Total net profit:	3005.69								
Vehicle:	V1 (T1)	Stops:	13	Net profit:	379.35				
Stop count	Location Name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load	
0	Depot	0.00	0:00		06:00	0:00	0	0	
1	Customer 11	14.31	0:38	06:38	07:05	1:05	32.5	1	
2	Customer 27	21.44	1:00	07:26	07:36	1:36	72.5	3	
3	Customer 18	26.75	1:16	07:53	07:58	1:58	107.5	4	
4	Customer 1	31.68	1:34	08:16	08:26	2:26	137.5	6	
5	Customer 30	35.20	1:45	08:37	08:47	2:47	167.5	8	
6	Customer 35	39.08	1:57	08:59	09:09	3:09	197.5	10	
7	Customer 6	43.11	2:06	09:17	09:27	3:27	227.5	12	
8	Customer 36	44.07	2:09	09:31	09:36	3:36	262.5	13	
9	Customer 38	45.70	2:16	09:43	09:58	3:58	302.5	16	
10	Customer 47	51.56	2:38	10:20	10:30	4:30	337.5	18	
11	Customer 53	53.50	2:45	10:37	12:10	6:10	372.5	20	
12	Customer 54	58.37	3:00	12:24	12:39	6:39	407.5	23	
13	Depot	68.74	3:22	13:02		7:02	407.5	0	

Figure 7. Solution spreadsheet.

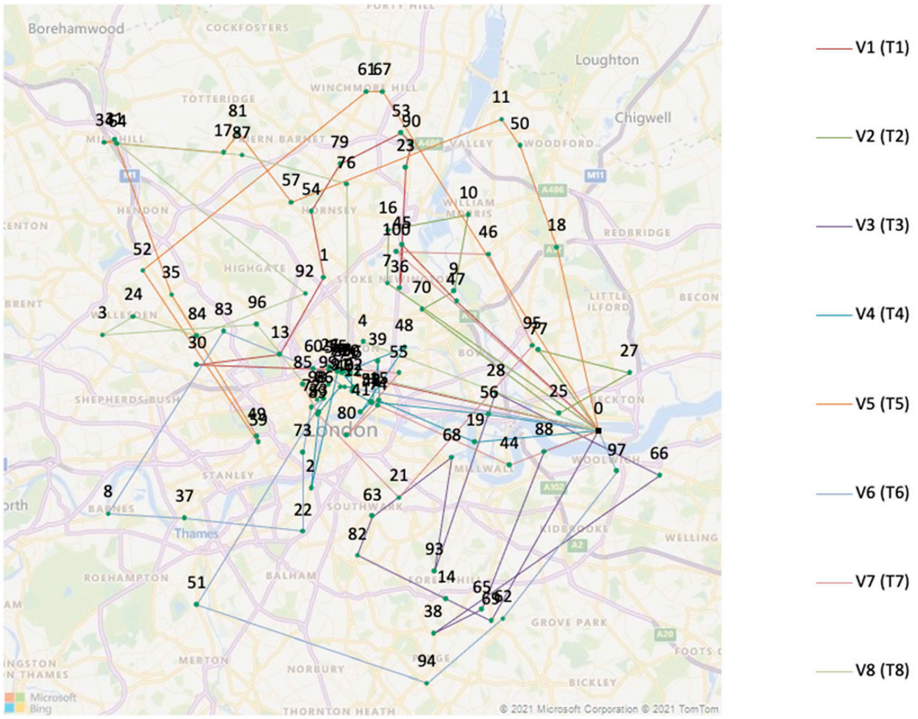


Figure 8. Visualization spreadsheet.

3. A Case Study of the London City Airport

The LCY is chosen to validate the model since it is the closest airport to Central London and manages a large number of passengers. In 2019, the LCY handled about 5 million passengers. The CAA shows that 91.8% of the LCY's passengers depart from the Greater London area [20] (see Table 1). In the 2019 Departing Passenger Survey conducted by the CAA, nearly 56% of passengers used private cars to travel to airports, while 44% of passengers used public transport. Private cars emit more greenhouse gases per passenger mile than trains and coaches. Hence, one of the main sources of airport-related emissions is using airport approach roads. Decarbonizing road transport systems to airports has posed challenges to the UK Department of Transport.

Table 1. Passenger distribution for the LCY.

Region	County	Total		County	Total	
		000′s	%		000′s	%
South East	Berkshire County	32	0.7	Isle of Wight	0	0.0
	Buckinghamshire County	28	0.6	Kent County	169	3.8
	East Sussex County	21	0.5	Oxfordshire County	19	0.4
	Greater London	4120	91.8	Surrey County	49	1.1
	Hampshire County	30	0.7	West Sussex County	19	0.4
Total	000′s	4487		%	100.0	

In the case study, we focus on a baggage collection service network design from passengers' sources to the LCY that aims to mitigate the burden of baggage management from passengers and at the airport's check-in process. The mitigation can encourage passengers to use more public transport to the LCY and reduce airport-related carbon emissions. A similar planning model can be extended for the baggage delivery problem from the airport to the passengers' destination (home or hotel address).

In the case study, two design scenarios are considered and compared, i.e., one hub at the LCY and multiple logistic hubs in Greater London. In the first scenario (i.e., one hub at the LCY), passengers book baggage collection online, then the entire baggage check-in process happens on the doorstep, finally, the EVs transport all the collected baggage directly to the LCY. In the second scenario (i.e., multiple logistic hubs in Greater London), passengers can bring their baggage to the nearest logistic hub by themselves or can book baggage collection online. Different from the first scenario, the second one aims to deliver the collected baggage to the nearest logistics hub, then unload the baggage from EVs, and finally transport them to the LCY together [21]. In this paper, we compare the transportation distance, transportation cost, and carbon emissions of the solutions for these two scenarios. The spreadsheet solver tool is used to optimize the scenarios and visualize the solutions. The following are assumptions and data of the case study:

- A one-to-one service between each EV and passengers without repeat.
- Randomly generate passengers' location and the number of baggage.
- A total of 100 passengers book this baggage collection service.
- Maximum 30 bags in each EV.
- A 20 miles per hour of average vehicle speed.
- The range of EVs is up to 211 miles, an 'Arrival van' costs GBP 37.24 to charge 80% [22].
- Driver's working hour is limited to be 8 h [23].
- The on-doorstep check-in takes an average of 5 min per baggage, including scan, record, encapsulating, and loading baggage.
- 24 h service with three shifts: 8 a.m., 4 p.m., and 12 p.m.
- Bing Maps driving distances are used for calculating Evs' driving distances.
- The EV will only return to the depot after completing their route.

Appendix A shows 100 randomly generated passengers and their locations. Table 2 shows that 8 EVs are required to serve these 100 passengers. Using the spreadsheet solver tool for the first scenario (i.e., one hub/depot at the LCY), the total travel distance is 377.40 miles during one shift (8 h), the total cost is GBP 335.66 (see Appendix B), and the optimal routes of 8 vehicles are shown in Figure 9.

Table 2. The results for solving the problem with various numbers of EVs.

No. of EVs	No. of Maximum Served Customers	Delivery Cost [1]	No. of Bags	Cost per Bag
3	43	GBP 152.1	90	1.69
4	59	GBP 200.4	120	1.67
5	72	GBP 249.0	150	1.66
6	88	GBP 297.2	178	1.67
7	98	GBP 343.2	208	1.65
8	109	GBP 387.7	235	1.65

[1] Delivery cost, including initial electric charge (GBP 37.24) and cost per mile without drivers' salaries.

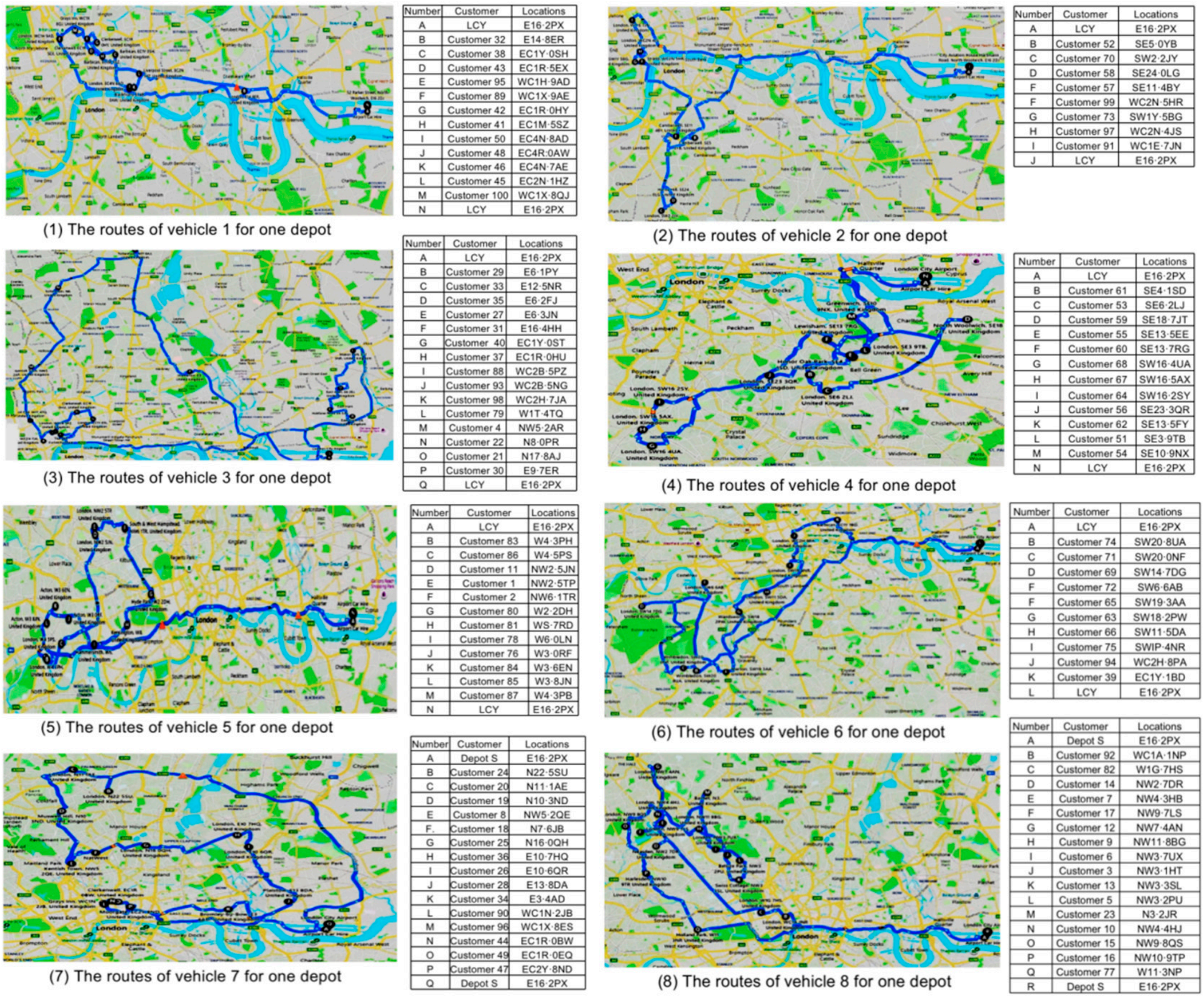


Figure 9. The optimal route map of 8 vehicles for the first scenario (i.e., one depot).

In the second scenario (i.e., multiple logistic hubs/depots in Greater London), the center of gravity approach is used to calculate the optimal location of the logistics hubs with the following assumptions [24]:

- The passenger's location and the number of baggage are known.
- The costs are only determined by the distances between a logistic hub and the passenger's location without considering city traffic.
- The land-use fee, labor fee, and future profits are not considered.

Based on the assumptions, distance is the only factor that needs to be considered. Denote that $\overline{X}_j$ is x-coordinate of logistic hub j, $\overline{Y}_j$ is y-coordinate of logistic hub j, n_j is the number of passengers that logistic hub j serves, x_i is x-coordinate of passenger i, y_i is y-coordinate of passenger i, and l_i is the number of baggage w.r.t passenger i, then the location of logistic hub j is defined by:

$$\overline{X}_j = \frac{\sum_{i=1}^{n_j} x_i\, l_i}{\sum_{i=1}^{n_j} l_i} \tag{1}$$

$$\overline{Y}_j = \frac{\sum_{i=1}^{n_j} y_i\, l_i}{\sum_{i=1}^{n_j} l_i} \tag{2}$$

Greater London is divided into four regions with the corresponding postcodes such as North (NW and N), East (E and EC), South (SE and SW), and West (W and WC). In the baggage collection service, a certain logistic hub only serves one region. For example, EVs departing from the North hub serve passengers in postcodes NW and N. When applying the center of gravity approach, the locations of logistic hubs are shown in Table 3.

Table 3. Locations of logistic hubs based on the center of gravity approach.

Region	Latitude	Longitude	Final Hub Locations
North (NW and N)	51.572	−0.185	Royal Mail
East (E and EC)	51.526	−0.047	Bethnal Green station
South (SE and SW)	51.454	−0.120	Brixton Hill post office
West (W and WC)	51.518	−0.172	Paddington station

However, it is difficult to set up the simulated coordinates as the final location of logistic hubs due to road traffic, passenger distribution, costs, and land availability. A logistic hub connecting to the highway, railway, and roadway can improve operation efficiency [25]. Land availability is an important factor. A new logistic hub requires unused lands and devices, which could be the main cost of building hubs [26]. For baggage delivery services, public hubs, including supermarkets, post offices, rail stations, and bus centers, are recommended as logistic hubs, which minimize the total cost compared to developing new hubs. In this case study, the final selected logistic hubs are the public places nearest to the simulated coordinates such as Royal Mail, Bethnal Green station, Brixton Hill post office, and Paddington station (see Table 3 and Figure 10). Using the spreadsheet solver tool for the second scenario, we achieve the following optimal solution. The total travel distance is 354.31 miles during one shift (8 h), the total cost is GBP 511.72 (see Appendix C), and the optimal routes of 8 vehicles are shown in Figure 11.

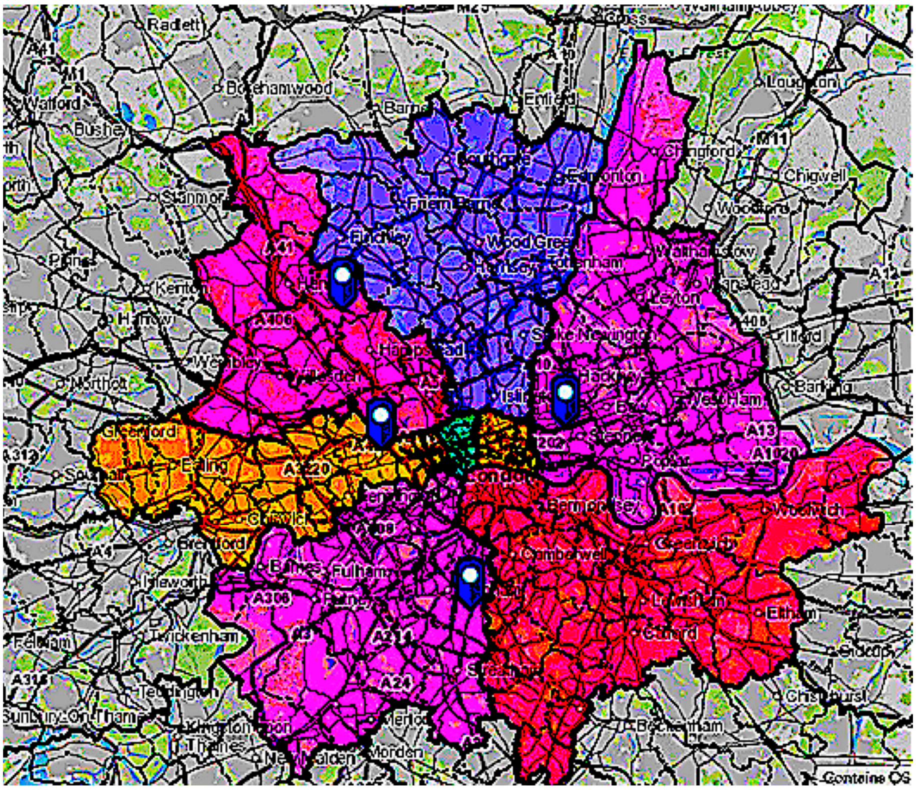
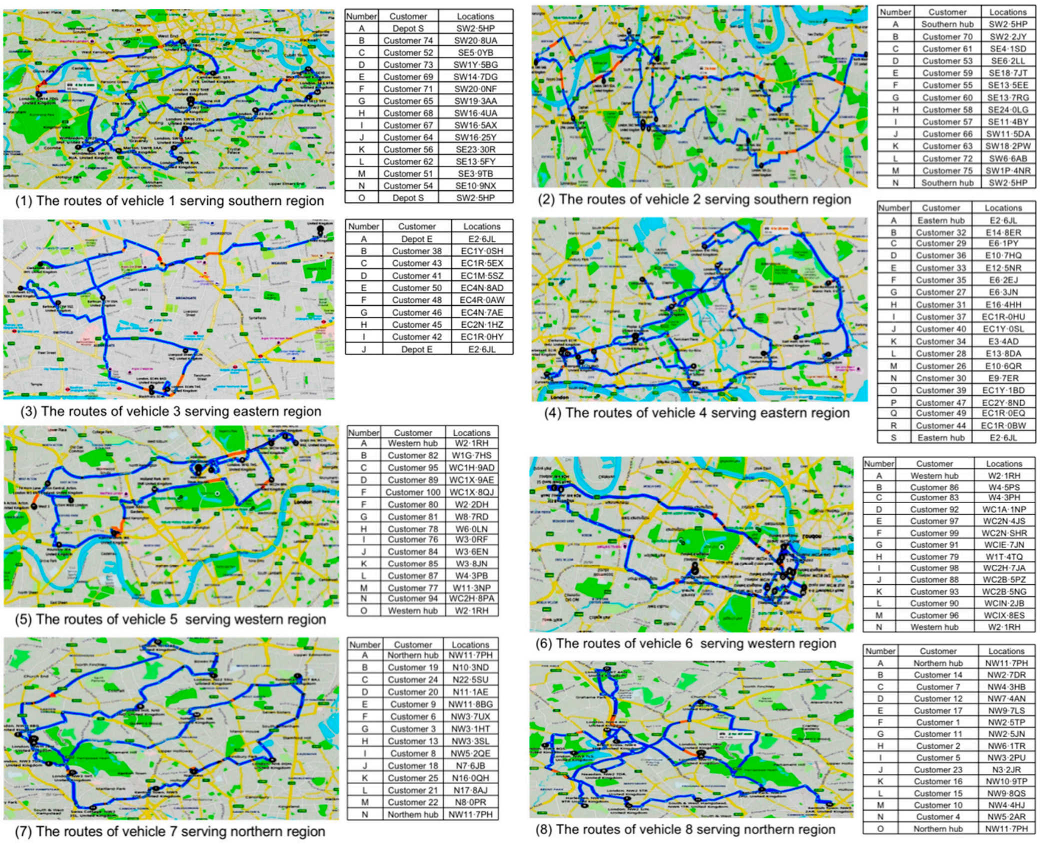


Figure 10. London postcode districts and the locations of logistic hubs.



Number	Customer	Locations
A	Depot S	SW2·5HP
B	Customer 74	SW20·8UA
C	Customer 52	SE5·0YB
D	Customer 73	SW1Y·5BG
E	Customer 69	SW14·7DG
F	Customer 71	SW20·0NF
G	Customer 65	SW19·3AA
H	Customer 68	SW16·4UA
I	Customer 67	SW16·5AX
J	Customer 64	SW16·25Y
K	Customer 56	SE23·30R
L	Customer 62	SE13·5FY
M	Customer 51	SE3·9TB
N	Customer 54	SE10·9NX
O	Depot S	SW2·5HP

Number	Customer	Locations
A	Southern hub	SW2·5HP
B	Customer 70	SW2·2JY
C	Customer 61	SE4·1SD
D	Customer 53	SE6·2LL
E	Customer 59	SE18·7JT
F	Customer 55	SE13·5EE
G	Customer 60	SE13·7RG
H	Customer 58	SE24·0LG
I	Customer 57	SE11·4BY
J	Customer 66	SW11·5DA
K	Customer 63	SW18·2PW
L	Customer 72	SW6·6AB
M	Customer 75	SW1P·4NR
N	Southern hub	SW2·5HP

Number	Customer	Locations
A	Depot E	E2·6JL
B	Customer 38	EC1Y·0SH
C	Customer 43	EC1R·5EX
D	Customer 41	EC1M·5SZ
E	Customer 50	EC4N·8AD
F	Customer 48	EC4R·0AW
G	Customer 46	EC4N·7AE
H	Customer 45	EC2N·1HZ
I	Customer 42	EC1R·0HY
J	Depot E	E2·6JL

Number	Customer	Locations
A	Eastern hub	E2·6JL
B	Customer 32	E14·8ER
C	Customer 29	E6·1PY
D	Customer 36	E10·7HQ
E	Customer 33	E12·5NR
F	Customer 35	E6·2EJ
G	Customer 27	E6·3JN
H	Customer 31	E16·4HH
I	Customer 37	EC1R·0HU
J	Customer 40	EC1Y·0SL
K	Customer 34	E3·4AD
L	Customer 28	E13·8DA
M	Customer 26	E10·6QR
N	Cnstomer 30	E9·7ER
O	Customer 39	EC1Y·1BD
P	Customer 47	EC2Y·8ND
Q	Customer 49	EC1R·0EQ
R	Customer 44	EC1R·0BW
S	Eastern hub	E2·6JL

Number	Customer	Locations
A	Western hub	W2·1RH
B	Customer 82	W1G·7HS
C	Customer 95	WC1H·9AD
D	Customer 89	WC1X·9AE
F	Customer 100	WC1X·8QJ
F	Customer 80	W2·2DH
G	Customer 81	W8·7RD
H	Customer 78	W6·0LN
I	Customer 76	W3·0RF
J	Customer 84	W3·6EN
K	Customer 85	W3·8JN
L	Customer 87	W4·3PB
M	Customer 77	W11·3NP
N	Customer 94	WC2H·8PA
O	Western hub	W2·1RH

Number	Customer	Locations
A	Western hub	W2·1RH
B	Customer 86	W4·5PS
C	Customer 83	W4·3PH
D	Customer 92	WC1A·1NP
E	Customer 97	WC2N·4JS
F	Customer 99	WC2N·SHR
G	Customer 91	WCIE·7JN
H	Customer 79	W1T·4TQ
I	Customer 98	WC2H·7JA
J	Customer 88	WC2B·5PZ
K	Customer 93	WC2B·5NG
L	Customer 90	WCIN·2JB
M	Customer 96	WCIX·8ES
N	Western hub	W2·1RH

Number	Customer	Locations
A	Northern hub	NW11·7PH
B	Customer 19	N10·3ND
C	Customer 24	N22·5SU
D	Customer 20	N11·1AE
E	Customer 9	NW11·8BG
F	Customer 6	NW3·7UX
G	Customer 3	NW3·1HT
H	Customer 13	NW3·3SL
I	Customer 8	NW5·2QE
J	Customer 18	N7·6JB
K	Customer 25	N16·0QH
L	Customer 21	N17·8AJ
M	Customer 22	N8·0PR
N	Northem hub	NW11·7PH

Number	Customer	Locations
A	Northern hub	NW11·7PH
B	Customer 14	NW2·7DR
C	Customer 7	NW4·3HB
D	Customer 12	NW7·4AN
E	Customer 17	NW9·7LS
F	Customer 1	NW2·5TP
G	Customer 11	NW2·5JN
H	Customer 2	NW6·1TR
I	Customer 5	NW3·2PU
J	Customer 23	N3·2JR
K	Customer 16	NW10·9TP
L	Customer 15	NW9·8QS
M	Customer 10	NW4·4HJ
N	Customer 4	NW5·2AR
O	Northern hub	NW11·7PH

Figure 11. The optimal route map of 8 vehicles for the second scenario (i.e., 4 hubs/depots).

The comparison results of the solutions found in the first scenario and the second scenario are shown in Table 4. The second scenario produces the solution with a shorter total travel distance. However, additional trucks could be required to deliver the baggage from the hubs to the LCY, increasing the fixed cost of each hub to purchase EVs, trucks, and land rental costs. Therefore, in the case study of the LCY, the first scenario is the best solution. It can balance total travel distance and cost. The first scenario's collection operation is divided into various activities, including fixed costs and variable costs [27]. The variable costs (i.e., costs of each activity) are shown in Table 5 in which the labor cost is from the Totaljobs website, and the AR label is reusable. The equation of cost per baggage is computed as follows:

$$Activity\ costs\ per\ baggage = \frac{\text{Labour cost} + \text{electric charge} + \text{AR label cost}}{\text{Number of baggage for one shift}} \quad (3)$$

Table 4. Comparison of results for the first scenario (i.e., one hub at the LCY) and the second scenario (i.e., 4 logistic hubs in Greater London).

	Total Travel Distance (Mile)	Delivery Cost (GBP)	Number of Baggage	Cost per Baggage (GBP)
One hub at LCY	377.46	335.66	200	1.65
Four logistic hubs in Greater London	354.31	511.72	200	2.55

Table 5. Activity costs for the first scenario (i.e., one hub at the LCY).

Activities	Required Resources	Resource Cost	Cost for One Shift (8 h)
Transport service	Labor, electric charge	Labor: GBP 19,500 per annual	GBP 76.16
Collection service	Labor, AR label	Electric charge: GBP 0.1 per mile	GBP 335.66
		AR label: GBP 0.03	GBP 6

4. Carbon Emission Reduction for the London City Airport

Three cases, defined by passenger's preference for using the BFAT service, are analyzed to predict the popularity of baggage collection service and calculate the reduction of carbon emissions in the next few years [28,29]. The calculation steps for the reduction of carbon emissions are as follows:

- Step 1: Using the simulation results to calculate the total distance that passengers traveled without baggage collection service.
- Step 2: Using the CAA data and the proportion of private cars to calculate the total distance that passengers traveled by private cars.
- Step 3: Using the average vehicle carbon emission data in the UK to calculate total carbon emission from private cars used by passengers.
- Step 4: Using the proportion of passengers who switch from private cars to public transportation to calculate the potential carbon emission saving by baggage collection service.
- Step 5: Using the predicted passenger number to calculate the carbon emission saving per passenger and carbon emission reduction per day.

The LCY served about 5 million passengers in 2019, 91.8% of which are from Greater London. Passenger demand is predicted up to 6 million by 2025 [20]. A total of 56% of the passengers use public transport to the LCY, while 44% of the passengers use private cars and taxis. Let Δ be the percentage of passengers who convert from private mode to public mode. In the case study, assume that 90% of passengers that are using private cars can switch to public transport, then $\Delta = 44 \times 90\% = 39.6\%$, and the total travel distance to the LCY of 100 customers is 749.70 km. The equation of average carbon emissions is shown as follow:

$$Average\ CO_2\ emission\ per\ customer = \frac{Total\ travel\ distance \times CO_2\ per\ km \times percentage\ of\ customers\ used\ private\ cars\ and\ taxi}{Number\ of\ customers\ used\ private\ cars\ and\ taxi} \quad (4)$$

where CO_2 per km is based on the 'ASM Auto Recycling' [30], i.e., the average CO_2 emission per vehicle is 125.1 kg/km in 2018, the CO_2 emission of private cars and taxis is 1.27 kg/km.

Total reduced CO_2 emission is defined by:

$$Total\ CO_2\ reduction = Number\ of\ customers \times average\ CO_2\ emission\ per\ customer \times \Delta \quad (5)$$

In the first case (i.e., low preference for the BFAT service), we assume that 1% of passengers will use the baggage collection service by 2025. The results show that the total daily reduced CO_2 emission for 160 customers is 79.48 kg. As a result, the baggage collection service will reduce 29.01 tonnes of carbon emissions annually. In the second case (i.e., medium preference for the BFAT service), we assume that 5% of passengers will use the baggage collection service by 2025. The total daily reduced CO_2 emission for 360 customers is 397.40 kg (i.e., 145.05 tonnes of carbon emissions annually). In the third case (i.e., high preference for the BFAT service), we assume that 10% of passengers will use the baggage collection service by 2025. The total daily reduced CO_2 emission for 360 customers is 794.79 kg (i.e., 290.10 tonnes of carbon emissions annually). Figure 12 shows the comparison results of CO_2 emission reduction in three cases.

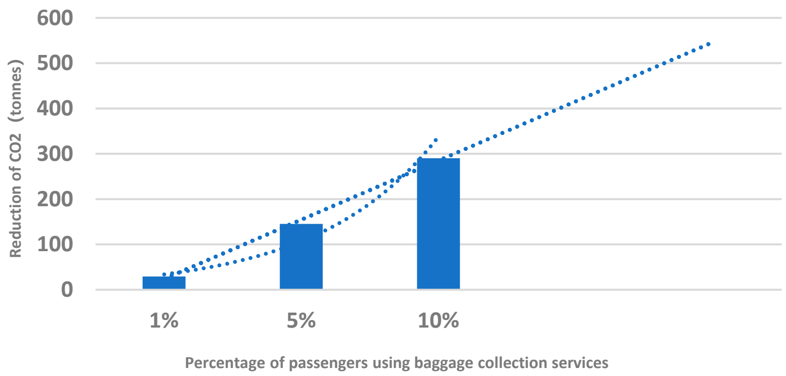


Figure 12. Carbon emission reduction in three cases.

5. Application of AR for Baggage Tracking

Late deliveries, damaged baggage, and mishandled baggage can all be red flags in baggage collection service, therefore, baggage tracking is proposed as a solution. With the rapid development of technologies such as radio frequency identification (RFID), barcodes, QR codes, and AR, courier and delivery companies have been tracking parcels and providing customers with real-time information for quite some time. Currently, many delivery companies use simple barcodes for baggage handling, which is cheap and simple technology. However, barcodes require a handheld scanner with 60–70% read rates, which reduces staff efficiency and increases the frequency of mishandling baggage. Many delivery companies use RFID for baggage identification and tracking, which is expensive and requires an additional reading scanner [31]. AR technology with QR codes allows passengers to track baggage in real-time without handheld devices. The technology can decrease the need for manual processing and free up staff for other value-adding tasks. Passengers can even check their baggage by themselves with a simple mobile app. The procedure is described as follows (see Figure 13):

- Step 1: Collect passenger's baggage.
- Step 2: Assign a QR code to each baggage.

- Step 3: Deliver the baggage to the hub.
- Step 4: Deliver the baggage onto the aircraft.
- Step 5: Scan the QR code for a double check when custody changes between carriers.
- Step 6: Deliver the baggage to the passenger's destination.
- Step 7: Passengers or staff scan the QR code to check baggage-passenger information to avoid mishandling.

Figure 13. The procedure of applying AR for baggage tracking in the BFAT service.

AR technology with QR codes is an easy and cost-effective way to obtain baggage tracking records. It reduces the number of lost, delayed, and mishandled baggage and improves the customer experience. With AR glasses or AR-based mobile app, the baggage collection service will reduce the cost and time of baggage double-checking, as well as help eliminate baggage fraud. The goals of QR codes and AR-based baggage collection service implementation are to increase customer satisfaction, eliminate mishandling, improve information visibility, reduce manual labor costs, and reduce delivery delays [32]. Hence, the AR technology for baggage tracking system is proposed to integrate into the BFAT for the efficient management of the baggage collection and transport network.

6. Conclusions and Future Work

The transformation of the passenger baggage experience is gathering pace. A transparent, real-time tracking baggage collection service will make a more relaxing journey that will encourage passengers to use more public transport (after the burden of baggage is removed) for air quality improvement. This paper investigates a baggage collection service network design problem using vehicle routing strategies and AR technology toward the goal. A spreadsheet solver tool, integrating MCWS and DBCA, is adopted to solve the problem and simulate the optimal routing networks and logistic hubs. This tool can solve to optimality the problem with a maximum of 200 nodes. The LCY is used as a case study to demonstrate the efficiency of the proposed model and tool for reducing airport-related carbon emissions. The results show that the model is efficient for the actual airport service. It can reduce 290.10 tonnes of carbon emissions annually in the case that 10% of passengers will use the baggage collection service by 2025.

In the baggage collection network, AR technology with QR codes makes the service quicker and easier to track baggage-passenger information. It provides extra information about the baggage journey and enables a faster process for baggage double-checking by passengers or staff to reduce baggage mishandling.

This paper aims to demonstrate the efficiency of the proof-of-concept planning model toward BFATs. The adopted spreadsheet solver tool has also achieved very good performance for the GVRP in the baggage collection network design. For larger-sized instances, other well-known metaheuristic algorithms (e.g., genetic algorithm, tabu search, simulated annealing, etc.) could be developed to improve the solution performance.

In addition, the model can be applied for other airports such as London Heathrow Airport, Manchester Airport, etc. A comparison of implementing the model for the airports will then be made to evaluate its applicability. Another future research approach is the baggage collection network design under the risk of unexpected failures to mitigate the impact of disruptions on the performance of network design.

Author Contributions: Conceptualization, Y.J., T.H.T., and A.E.-O.; methodology, Y.J., T.H.T., and J.T.; software, J.T., R.Y., and C.Z.; validation, R.Y. and C.Z.; formal analysis, J.T. and Z.W.; investigation, R.Y., J.T., and Z.W.; resources, T.H.T. and A.E.-O.; data curation, T.H.T. and A.E.-O.; writing—original draft preparation, J.T., R.Y., C.Z., Z.W., and Y.J.; writing—review and editing, T.H.T. and Y.J.; visualization, T.H.T. and Y.J.; supervision, Y.J., T.H.T., A.E.-O., and L.W.; project administration, T.H.T. and A.E.-O. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Data of 100 Randomly Generated Passengers

Table A1. Data of 100 Randomly Generated Passengers.

No.	Latitude (y)	Longitude (x)
Customer 1	51.5489386	−0.2237710
Customer 2	51.5493029	−0.1958656
Customer 3	51.5582358	−0.1763481
Customer 4	51.5469298	−0.1353493
Customer 5	51.5546479	−0.1662864
Customer 6	51.5623564	−0.1866824
Customer 7	51.5794436	−0.2332773
Customer 8	51.5508392	−0.1373969
Customer 9	51.5753952	−0.2018589
Customer 10	51.5856589	−0.2374256
Customer 11	51.5460665	−0.2269253
Customer 12	51.6160343	−0.2378108
Customer 13	51.5420108	−0.1666140
Customer 14	51.5645398	−0.2392672
Customer 15	51.5768937	−0.2660974
Customer 16	51.5459907	−0.2478347
Customer 17	51.5733076	−0.2529523
Customer 18	51.5585960	−0.1205308
Customer 19	51.5884731	−0.1454050
Customer 20	51.6175359	−0.1365953
Customer 21	51.6020469	−0.0722346
Customer 22	51.5895156	−0.1072021
Customer 23	51.5987386	−0.1912609
Customer 24	51.6022437	−0.1109015
Customer 25	51.5641907	−0.0837098

Table A1. *Cont.*

No.	Latitude (y)	Longitude (x)
Customer 26	51.5624746	−0.0101054
Customer 27	51.5270489	0.0479250
Customer 28	51.5244575	0.0196583
Customer 29	51.5306825	0.0406046
Customer 30	51.5387301	−0.0473296
Customer 31	51.5191005	0.0155751
Customer 32	51.5105628	−0.0239961
Customer 33	51.5545950	0.0615265
Customer 34	51.5183899	−0.0240546
Customer 35	51.5369266	0.0539824
Customer 36	51.5703987	−0.0171804
Customer 37	51.5256268	−0.1075101
Customer 38	51.5220900	−0.0974451
Customer 39	51.5247431	−0.0875539
Customer 40	51.5224374	−0.0976045
Customer 41	51.5215979	−0.1048933
Customer 42	51.5263173	−0.1076727
Customer 43	51.5233273	−0.1108674
Customer 44	51.5240825	−0.1084549
Customer 45	51.5159634	−0.0838873
Customer 46	51.5115849	−0.0868177
Customer 47	51.5199547	−0.0954550
Customer 48	51.5112600	−0.0893801
Customer 49	51.5238194	−0.1041942
Customer 50	51.5120317	−0.0890277
Customer 51	51.4103311	−0.0921523
Customer 52	51.4803272	−0.0981990
Customer 53	51.4401378	−0.0183579
Customer 54	51.4840086	−0.0018144
Customer 55	51.4613345	−0.0024046
Customer 56	51.4495937	−0.0557289
Customer 57	51.4810197	−0.1079556
Customer 58	51.4581246	−0.1085546
Customer 59	51.4832259	0.0734846
Customer 60	51.4704859	−0.0173010
Customer 61	51.4503065	−0.0291625
Customer 62	51.4603181	−0.0010548
Customer 63	51.4588337	−0.1815655
Customer 64	51.4332856	−0.1270484

Table A1. *Cont.*

No.	Latitude (y)	Longitude (x)
Customer 65	51.4149732	−0.1942215
Customer 66	51.4726147	−0.1548842
Customer 67	51.4172947	−0.1378357
Customer 68	51.4074957	−0.1318186
Customer 69	51.4619305	−0.2750104
Customer 70	51.4544890	−0.1163932
Customer 71	51.4170516	−0.2345679
Customer 72	51.4790435	−0.2142927
Customer 73	51.5075075	−0.1300942
Customer 74	51.4156681	−0.2221296
Customer 75	51.4918100	−0.1330421
Customer 76	51.5049260	−0.2558955
Customer 77	51.5094102	−0.2030914
Customer 78	51.6148245	−0.1514140
Customer 79	51.5224294	−0.1360846
Customer 80	51.5171531	−0.1680972
Customer 81	51.4992498	−0.1980770
Customer 82	51.5206979	−0.1477442
Customer 83	51.4851283	−0.2793712
Customer 84	51.5112866	−0.2696000
Customer 85	51.5029263	−0.2795501
Customer 86	51.4930367	−0.2634485
Customer 87	51.4856617	−0.2802322
Customer 88	51.5164040	−0.1204645
Customer 89	51.5270382	−0.1133597
Customer 90	51.5217664	−0.1142137
Customer 91	51.5224971	−0.1314396
Customer 92	51.5178036	−0.1265286
Customer 93	51.5159764	−0.1224535
Customer 94	51.5131107	−0.1290724
Customer 95	51.5269586	−0.1290645
Customer 96	51.5227414	−0.1142530
Customer 97	51.5113842	−0.1271312
Customer 98	51.5118528	−0.1279098
Customer 99	51.5084823	−0.1250319
Customer 100	51.5297189	−0.1203484

Appendix B. Solution of Eight Electric Vehicles for One Hub at LCY

Table A2. Electric Vehicle 1.

Cost: GBP 39.89							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	LCY	0.00	0:00		00:00	0:00	0
1	Customer 32	3.85	0:16	00:16	00:21	0:21	1
2	Customer 38	7.84	0:39	00:44	00:54	0:54	3
3	Customer 43	8.54	0:44	00:59	01:04	1:04	4
4	Customer 95	9.91	0:56	01:16	01:21	1:21	5
5	Customer 89	11.00	1:03	01:28	01:33	1:33	6
6	Customer 42	11.46	1:07	01:37	02:05	2:05	7
7	Customer 41	12.07	1:12	02:09	02:24	2:24	10
8	Customer 50	13.43	1:21	02:34	02:39	2:39	11
9	Customer 48	13.48	1:22	02:40	02:50	2:50	13
10	Customer 46	13.79	1:25	02:53	03:03	3:03	15
11	Customer 45	14.39	1:30	03:07	03:22	3:22	18
12	Customer 100	16.70	1:43	03:36	03:51	3:51	21
13	LCY	26.49	2:25	04:33		4:33	0

Table A3. Electric Vehicle 2.

Costs: GBP 40.11							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	LCY	0.00	0:00		00:00	0:00	0
1	Customer 52	9.00	0:37	00:37	00:42	0:42	1
2	Customer 70	11.63	0:54	00:59	01:04	1:04	2
3	Customer 58	12.05	0:56	01:06	02:10	2:10	4
4	Customer 57	14.28	1:10	02:24	02:34	2:34	6
5	Customer 99	17.16	1:28	02:52	03:02	3:02	8
6	Customer 73	17.59	1:32	03:06	03:16	3:16	10
7	Customer 97	18.08	1:37	03:20	03:30	3:30	12
8	Customer 91	19.46	1:48	03:41	03:46	3:46	13
9	LCY	28.74	2:27	04:26		4:26	0

Table A4. Electric Vehicle 3.

Costs: GBP 41.37							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	LCY	0.00	0:00		00:00	0:00	0
1	Customer 29	2.85	0:14	00:14	00:24	0:24	2
2	Customer 33	5.84	0:25	00:35	02:05	2:05	3
3	Customer 35	7.76	0:36	02:15	02:25	2:25	5
4	Customer 27	8.94	0:43	02:33	02:38	2:38	6
5	Customer 31	10.82	0:52	02:47	02:57	2:57	8
6	Customer 40	17.15	1:19	03:24	04:05	4:05	9
7	Customer 37	17.85	1:24	04:09	04:24	4:24	12
8	Customer 88	18.99	1:32	04:33	04:48	4:48	15

Table A4. *Cont.*

Costs: GBP 41.37							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
9	Customer 93	19.21	1:34	04:50	05:05	5:05	18
10	Customer 98	19.84	1:39	05:10	05:25	5:25	21
11	Customer 79	20.83	1:48	05:33	05:48	5:48	24
12	Customer 4	22.87	2:01	06:02	06:07	6:07	25
13	Customer 22	26.90	2:21	06:27	06:37	6:37	27
14	Customer 21	29.15	2:32	06:48	06:53	6:53	28
15	Customer 30	34.68	3:04	07:25	07:35	7:35	30
16	LCY	41.32	3:30	08:00		8:00	0

Table A5. Electric Vehicle 4.

Costs: GBP 42.2							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	LCY	0.00	0:00		00:00	0:00	0
1	Customer 61	9.59	0:36	00:36	00:41	0:41	1
2	Customer 53	10.89	0:43	00:48	01:03	1:03	4
3	Customer 59	16.66	1:08	01:28	02:15	2:15	7
4	Customer 55	21.29	1:28	02:35	02:40	2:40	8
5	Customer 60	22.47	1:37	02:48	03:03	3:03	11
6	Customer 68	31.45	2:21	03:48	04:15	4:15	14
7	Customer 67	32.57	2:27	04:21	04:36	4:36	17
8	Customer 64	34.29	2:37	04:45	04:55	4:55	19
9	Customer 56	38.37	2:56	05:14	05:29	5:29	22
10	Customer 62	41.47	3:13	05:46	05:56	5:56	24
11	Customer 51	42.09	3:16	06:00	06:10	6:10	26
12	Customer 54	43.94	3:27	06:21	06:31	6:31	28
13	LCY	49.64	3:50	06:53		6:53	0

Table A6. Electric Vehicle 5.

Costs: GBP 42.9							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	LCY	0.00	0:00		00:00	0:00	0
1	Customer 83	16.15	1:03	01:03	01:18	1:18	3
2	Customer 86	17.80	1:13	01:28	01:33	1:33	4
3	Customer 11	23.29	1:39	01:59	02:10	2:10	6
4	Customer 1	23.78	1:43	02:13	02:28	2:28	9
5	Customer 2	25.61	1:52	02:38	02:53	2:53	12
6	Customer 80	28.74	2:12	03:12	03:17	3:17	13
7	Customer 81	31.30	2:26	03:31	04:10	4:10	15
8	Customer 78	33.51	2:40	04:24	04:39	4:39	18
9	Customer 76	35.62	2:51	04:50	05:05	5:05	21
10	Customer 84	37.14	3:01	05:14	05:29	5:29	24
11	Customer 85	38.06	3:06	05:34	05:44	5:44	26
12	Customer 87	39.86	3:14	05:53	06:15	6:15	29
13	LCY	56.61	4:21	07:22		7:22	0

Table A7. Electric Vehicle 6.

Costs: GBP 42.81							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	LCY	0.00	0:00		00:00	0:00	0
1	Customer 74	16.23	1:12	01:12	01:22	1:22	2
2	Customer 71	17.01	1:16	01:26	02:15	2:15	5
3	Customer 69	23.80	1:40	02:39	02:54	2:54	8
4	Customer 72	27.84	2:01	03:14	04:15	4:15	11
5	Customer 65	33.64	2:27	04:41	04:51	4:51	13
6	Customer 63	38.36	2:48	05:11	05:21	5:21	15
7	Customer 66	41.25	3:01	05:35	05:40	5:40	16
8	Customer 75	43.76	3:16	05:55	06:00	6:00	17
9	Customer 94	45.55	3:28	06:12	06:22	6:22	19
10	Customer 39	47.83	3:43	06:37	06:52	6:52	22
11	LCY	55.66	4:16	07:25		7:25	0

Table A8. Electric Vehicle 7.

Costs: GBP 42.76							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	LCY	0.00	0:00		00:00	0:00	0
1	Customer 24	16.18	0:31	00:31	00:46	0:46	3
2	Customer 20	18.26	0:40	00:55	01:10	1:10	6
3	Customer 19	21.51	0:55	01:25	01:40	1:40	9
4	Customer 8	24.63	1:09	01:54	02:05	2:05	10
5	Customer 18	26.20	1:19	02:14	02:29	2:29	13
6	Customer 25	28.20	1:31	02:41	02:46	2:46	14
7	Customer 36	31.82	1:50	03:05	03:15	3:15	16
8	Customer 26	33.16	1:57	03:23	04:05	4:05	17
9	Customer 28	36.97	2:18	04:25	04:30	4:30	18
10	Customer 34	40.34	2:36	04:48	05:03	5:03	21
11	Customer 90	44.97	3:03	05:31	05:41	5:41	23
12	Customer 96	45.08	3:04	05:42	05:57	5:57	26
13	Customer 44	45.62	3:08	06:00	06:05	6:05	27
14	Customer 49	45.99	3:10	06:08	06:13	6:13	28
15	Customer 47	47.11	3:19	06:21	06:31	6:31	30
16	LCY	55.16	3:55	07:07		7:07	0

Table A9. Electric Vehicle 8.

Costs: GBP 43.62							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	LCY	0.00	0:00		00:00	0:00	0
1	Customer 92	9.10	0:37	00:37	00:42	0:42	1
2	Customer 82	10.69	0:45	00:50	01:00	1:00	3
3	Customer 14	16.78	1:14	01:29	01:39	1:39	5
4	Customer 7	18.46	1:24	01:49	01:54	1:54	6
5	Customer 17	19.62	1:30	02:00	02:10	2:10	8
6	Customer 12	24.07	1:46	02:26	02:41	2:41	11

Table A9. *Cont.*

Costs: GBP 43.62							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
7	Customer 9	28.66	2:01	02:56	03:06	3:06	13
8	Customer 6	30.08	2:08	03:13	03:18	3:18	14
9	Customer 3	30.81	2:13	03:23	03:38	3:38	17
10	Customer 13	32.50	2:22	03:47	03:57	3:57	19
11	Customer 5	33.80	2:30	04:05	04:20	4:20	22
12	Customer 23	38.22	2:49	04:39	04:44	4:44	23
13	Customer 10	41.75	3:03	04:58	06:05	6:05	24
14	Customer 15	44.49	3:15	06:17	06:22	6:22	25
15	Customer 16	47.53	3:30	06:36	06:41	6:41	26
16	Customer 77	51.18	3:48	06:59	07:04	7:04	27
17	LCY	63.77	4:42	07:58		7:58	0

Appendix C. Solution of Eight Electric Vehicles for Multiple Logistic Hubs in Greater London

Table A10. Electric Vehicle 1.

Costs: GBP 43.09							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	Southern hub	0.00	0:00		00:00	0:00	0
1	Customer 74	6.57	0:36	00:36	00:46	0:46	2
2	Customer 52	14.64	1:20	01:30	01:35	1:35	3
3	Customer 73	17.70	1:38	01:53	02:10	2:10	5
4	Customer 69	25.89	2:10	02:42	02:57	2:57	8
5	Customer 71	32.69	2:37	03:23	03:38	3:38	11
6	Customer 65	35.22	2:50	03:52	04:10	4:10	13
7	Customer 68	39.11	3:10	04:30	04:45	4:45	16
8	Customer 67	40.24	3:16	04:51	05:06	5:06	19
9	Customer 64	41.96	3:26	05:16	05:26	5:26	21
10	Customer 56	46.03	3:45	05:45	06:00	6:00	24
11	Customer 62	49.14	4:02	06:17	06:27	6:27	26
12	Customer 51	49.76	4:06	06:30	06:40	6:40	28
13	Customer 54	51.61	4:16	06:51	07:01	7:01	30
14	Southern hub	58.10	4:52	07:37		7:37	0

Table A11. Electric Vehicle 2.

Costs: GBP 41.62							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	Southern hub	0.00	0:00		00:00	0:00	0
1	Customer 70	0.42	0:03	00:03	00:08	0:08	1
2	Customer 61	5.96	0:30	00:35	00:40	0:40	2
3	Customer 53	7.27	0:37	00:47	01:02	1:02	5
4	Customer 59	13.03	1:02	01:27	02:15	2:15	8
5	Customer 55	17.67	1:22	02:35	02:40	2:40	9
6	Customer 60	18.85	1:31	02:48	03:03	3:03	12

Table A11. *Cont.*

Costs: GBP 41.62							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
7	Customer 58	24.31	2:00	03:32	03:42	3:42	14
8	Customer 57	26.54	2:14	03:57	04:07	4:07	16
9	Customer 66	29.79	2:32	04:25	04:30	4:30	17
10	Customer 63	31.83	2:42	04:39	04:49	4:49	19
11	Customer 72	35.22	2:56	05:04	05:19	5:19	22
12	Customer 75	40.07	3:21	05:44	05:49	5:49	23
13	Southern hub	43.43	3:40	06:08		6:08	0

Table A12. Electric Vehicle 3.

Costs: GBP 38.28							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	Eastern hub	0.00	0:00		00:00	0:00	0
1	Customer 38	2.11	0:14	00:14	00:24	0:24	2
2	Customer 43	2.81	0:19	00:29	00:34	0:34	3
3	Customer 41	3.26	0:22	00:37	02:15	2:15	6
4	Customer 50	4.62	0:32	02:24	02:29	2:29	7
5	Customer 48	4.67	0:33	02:30	02:40	2:40	9
6	Customer 46	4.98	0:36	02:43	02:53	2:53	11
7	Customer 45	5.58	0:40	02:58	03:13	3:13	14
8	Customer 42	7.25	0:49	03:21	03:26	3:26	15
9	Eastern hub	10.01	1:07	03:44		3:44	0

Table A13. Electric Vehicle 4.

Costs: GBP 42.84							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	Eastern hub	0.00	0:00		00:00	0:00	0
1	Customer 32	2.51	0:16	00:16	00:21	0:21	1
2	Customer 29	7.03	0:33	00:38	00:48	0:48	3
3	Customer 36	14.95	0:57	01:12	02:10	2:10	5
4	Customer 33	20.79	1:16	02:29	02:34	2:34	6
5	Customer 35	22.72	1:27	02:45	02:55	2:55	8
6	Customer 27	23.89	1:34	03:02	03:07	3:07	9
7	Customer 31	25.77	1:44	03:16	03:26	3:26	11
8	Customer 37	32.81	2:15	03:58	04:15	4:15	14
9	Customer 40	33.52	2:20	04:19	04:24	4:24	15
10	Customer 34	37.45	2:43	04:47	05:02	5:02	18
11	Customer 28	41.30	2:57	05:17	05:22	5:22	19
12	Customer 26	45.48	3:19	05:43	05:48	5:48	20
13	Customer 30	48.45	3:36	06:05	06:15	6:15	22
14	Customer 39	50.87	3:52	06:32	06:47	6:47	25
15	Customer 47	51.67	3:58	06:53	07:03	7:03	27
16	Customer 49	52.55	4:06	07:10	07:15	7:15	28
17	Customer 44	52.87	4:08	07:17	07:22	7:22	29
18	Eastern hub	55.64	4:26	07:40		7:40	0

Table A14. Electric Vehicle 5.

Costs: GBP 40.48							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	Western hub	0.00	0:00		00:00	0:00	0
1	Customer 82	1.60	0:12	00:12	00:22	0:22	2
2	Customer 95	3.08	0:25	00:35	00:40	0:40	3
3	Customer 89	4.17	0:32	00:47	00:52	0:52	4
4	Customer 100	4.74	0:36	00:56	02:15	2:15	7
5	Customer 80	7.21	0:50	02:29	02:34	2:34	8
6	Customer 81	9.76	1:04	02:48	04:10	4:10	10
7	Customer 78	11.98	1:19	04:24	04:39	4:39	13
8	Customer 76	14.09	1:30	04:50	05:05	5:05	16
9	Customer 84	15.61	1:39	05:14	05:29	5:29	19
10	Customer 85	16.53	1:44	05:34	05:44	5:44	21
11	Customer 87	18.33	1:54	05:54	06:15	6:15	24
12	Customer 77	24.74	2:18	06:39	06:44	6:44	25
13	Customer 94	28.76	2:39	07:05	07:15	7:15	27
14	Western hub	31.98	2:56	07:32		7:32	0

Table A15. Electric Vehicle 6.

Costs: GBP 39.84							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	Western hub	0.00	0:00		00:00	0:00	0
1	Customer 86	5.49	0:22	00:22	00:27	0:27	1
2	Customer 83	7.09	0:33	00:38	00:53	0:53	4
3	Customer 92	15.12	1:09	01:29	01:34	1:34	5
4	Customer 97	15.63	1:14	01:39	02:10	2:10	7
5	Customer 99	16.36	1:20	02:16	02:26	2:26	9
6	Customer 91	17.95	1:31	02:36	02:41	2:41	10
7	Customer 79	18.69	1:36	02:46	04:15	4:15	13
8	Customer 98	19.97	1:44	04:23	04:38	4:38	16
9	Customer 88	20.62	1:50	04:44	04:59	4:59	19
10	Customer 93	20.85	1:52	05:01	05:16	5:16	22
11	Customer 90	21.83	2:00	05:24	05:34	5:34	24
12	Customer 96	21.93	2:01	05:35	05:50	5:50	27
13	Western hub	25.57	2:19	06:08		6:08	0

Table A16. Electric Vehicle 7.

Costs: GBP 40.75							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	Northern hub	0.00	0:00		00:00	0:00	0
1	Customer 19	4.14	0:16	00:16	00:31	0:31	3
2	Customer 24	6.81	0:30	00:45	01:00	1:00	6
3	Customer 20	8.89	0:39	01:09	01:24	1:24	9
4	Customer 9	14.65	0:56	01:41	02:10	2:10	11
5	Customer 6	16.07	1:03	02:17	02:22	2:22	12

Table A16. *Cont.*

Costs: GBP 40.75							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
6	Customer 3	16.80	1:08	02:27	02:42	2:42	15
7	Customer 13	18.49	1:18	02:51	03:01	3:01	17
8	Customer 8	20.15	1:28	03:12	03:17	3:17	18
9	Customer 18	21.73	1:38	03:27	03:42	3:42	21
10	Customer 25	23.73	1:50	03:54	03:59	3:59	22
11	Customer 21	27.18	2:09	04:18	06:05	6:05	23
12	Customer 22	29.39	2:20	06:15	06:25	6:25	25
13	Northern hub	34.72	2:44	06:49		6:49	0

Table A17. Electric Vehicle 8.

Costs: GBP 41.77							
Stop Count	**Location Name**	**Travel Distance**	**Driving Time**	**Arrival Time**	**Departure Time**	**Working Time**	**Load**
0	Northern hub	0.00	0:00		00:00	0:00	0
1	Customer 14	3.21	0:10	00:10	00:20	0:20	2
2	Customer 7	4.89	0:20	00:30	00:35	0:35	3
3	Customer 12	8.23	0:31	00:46	02:15	2:15	6
4	Customer 17	12.39	0:48	02:31	02:41	2:41	8
5	Customer 1	15.55	1:02	02:56	03:11	3:11	11
6	Customer 11	15.96	1:04	03:13	03:23	3:23	13
7	Customer 2	17.70	1:13	03:32	03:47	3:47	16
8	Customer 5	19.38	1:24	03:57	04:15	4:15	19
9	Customer 23	23.80	1:43	04:34	04:39	4:39	20
10	Customer 16	29.36	2:01	04:57	06:05	6:05	21
11	Customer 15	32.36	2:15	06:19	06:24	6:24	22
12	Customer 10	34.74	2:27	06:36	06:41	6:41	23
13	Customer 4	41.09	2:56	07:10	07:15	7:15	24
14	Northern hub	44.86	3:14	07:33		7:33	0

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2021-12-26

Jiang Y, Yang R, Zang C, et al., (2022) Toward baggage-free airport terminals: a case study of London City Airport, Sustainability, Volume 14, Issue 1, January 2022, Article number 212
https://doi.org/10.3390/su14010212