Article

Visualising Carrier Consolidation and Alternative Delivery Locations: A Digital Model of Last-Mile Delivery in England and Wales

Maren Schnieder

Faculty of Business and Law, Anglia Ruskin University, Cambridge CB1 1PT, UK; maren.schnieder@aru.ac.uk

Abstract: Background: Various innovations have been proposed to improve the efficiency and sustainability of last-mile delivery in urban and rural environments. Notable examples of innovative delivery solutions are parcel lockers, cargo bicycles, crowdsourced delivery, and so on. Methods: This study contributes to the ongoing research by developing a large-scale digital model of England and Wales to evaluate a new generation of solutions for last-mile delivery challenges being faced in both rural areas and cities. The two innovations chosen for comparison in this study are (i) carrier consolidation and (ii) alternative delivery locations (i.e., delivery to the workplace instead of the home). As well as the effect on any individual locations, the digital model evaluates both the benefits for England and Wales as a whole. Furthermore, the influence of the market share on the results, as well as the effect of changing the number of depots, is assessed. Results: By delivering to the customer’s workplace instead of the home, the vehicle kilometres travelled (VKT) reduce slightly (less than 10%). Carrier consolidation shows significant potential in reducing the overall VKT (up to 53%). When looking at individual areas in isolation, the consolidation option reduces the VKT or changes it up and down all within tolerance. Naturally, the first option causes a significant shift in delivery activity across England and Wales. Areas of central London would see in-excess of a 10-fold increase in the number of parcels delivered, whereas the demand for parcels in rural areas is further, and significantly reduced. Conclusions: This study highlights the importance of large-scale and detailed digital models that not only calculate the overall benefits of an innovation but also their effect on each individual area.

Keywords: city logistics; last-mile delivery; digital twins; digital model; carrier consolidation; flexible delivery locations; environment; sustainability; roaming delivery locations; collaboration

1. Introduction

The rapidly increasing demand for e-commerce has resulted in a surge of last-mile delivery activity in cities [1,2]. On a global scale, the parcel volume has grown by 150% over the last seven years and it is expected to grow slower in the future, at a 6% compound annual growth rate [3]. Within the UK, the B2C and C2X parcel volume is predicted to grow by approximately 4.5 to 5.5% per annum [4]. In short, a prolonged growth of these systems is forecast in cities over the next decade [5]. Last-mile delivery is crucial to facilitate the transportation of goods to the general population [1] and forms a key role in the economic health of urban living [5]. There has been a rapid expansion in the number of companies who have joined the delivery market, which has incrementally increased the number of delivery vehicles being deployed around city landscapes [6]. The negative aspect of this proliferation is a visible increase in traffic congestion [7], pollution [7], accidents [8], and parking pressure [8]. Ultimately, these changes in the urban environment result in poor livability [7] and a reduced quality of life [9]. It is understood by participating companies that last-mile delivery is the most costly and ineffective component within the supply chain [10]. It accounts for 40–55% of the total supply chain costs [11]. Last-mile
delivery is further complicated by the geography of the drop-off locations and the number and scale of the parcels [12], which all differ on a daily basis throughout the year [13]. Customer expectations, built around a fast and expeditious delivery system, complicate the routing optimisation and result in predictable inefficiencies [8]. In summary, the need to increase both the sustainability and efficiency of last-mile delivery is a pressing concern for stakeholders [13]. The ambition and aspiration towards sustainability is on the rise [14], and the political voice to consider both the social and environmental sustainability of last-mile delivery is gaining momentum [15]. These new challenges for researchers, in developing solutions for last-mile delivery, are being explored by both scholars and practitioners [16].

Inefficiencies in the logistical operation are particularly visible in densely populated cities [9,10], and ultimately the success of last-mile delivery is judged to be a key indicator of customer satisfaction [17]. This competitive environment [18], together with a growing expectation of improved sustainability, has created novel innovations such as autonomous delivery [19], drones [14,15,20], cargo bicycles [21], electric delivery vehicles [21], urban distribution centres [5], city hubs, parcel lockers [2], and crowdsourced delivery [22]. Not only are the physical resources used in the delivery process transformed, but various innovations in the deployed software (e.g., optimisation algorithms, ML and AI [23]), as well as IoT solutions [24,25], are becoming increasingly far-reaching. However, as with most new innovations, these also come with their own set of drawbacks and reasons for concern. The use of drones gives rise to plethora of issues such as noise level [26], crashes [27], and cyber security attacks [28], while cargo bicycles raises a fear about injuries and collisions [29] and electric vehicles require a charging infrastructure [30].

This paper contributes to the research of parcel delivery to alternative drop-off-points and carrier consolidation by evaluating both using a large-scale digital model:

**Research Question 1 (RQ1):** How do the vehicle kilometres travelled (VKT) of last-mile delivery decrease if an operator always delivers to a customer’s workplace instead of their home?

**Research Question 2 (RQ2):** How many VKT can be saved through carrier consolidation?

**Research Question 3 (RQ3):** Does the reduction in VKT due to carrier consolidations change geographically?

**Research Question 4 (RQ4):** How do the number of depots and the market share of the delivery company influence the results?

The remainder of the paper is structured as follows. First, the literature on alternative drop-off points and carrier consolidation has been explored. Next, the digital model, the methodology, and case studies are described. Finally, the results are presented and discussed before any conclusions are drawn.

2. Literature

2.1. Alternative Drop-Off Locations

Last-mile delivery is well known as the ‘bottle neck’ in the supply chain. Commonly cited problems include failed deliveries, in part, due to the absence of customers (who are not at home). To address this issue, researchers have investigated alternative locations to deposit parcels in readiness for retrieval by the waiting customer. The most prominent places in the research area are staffed collection and delivery points (CDPs) as well as parcel lockers [13] requiring customers to pick up the parcel at a nearby place. For customers, who prefer their parcels to be delivered directly to their home (even during their absence), researchers have also suggested reception boxes or delivering to a neighbour [19]. Other solutions proposed in the research are flexible or roaming delivery locations. If all customers suggest multiple drop-off locations, it will allow delivery companies to select the location that maximises their profits. This is known under various names, including the Vehicle Routing Problem with Delivery Options (VRPDO) [31] or as the Vehicle Routing Problem with Flexible Delivery Locations [32]. Possible cost decreases of around 29.2% [31] have been reported in the literature. This option should not be confused with roaming delivery
locations, where parcels are delivered to the boot of a car, which changes its location during the day (i.e., work, home, etc.).

Even though studied less frequently, roaming delivery locations (e.g., car boot) have shown promising results [33]. For example, Reyes et al. [34] found reductions in the distance travelled of between 40% to 60% when delivering to the boot of the customer’s car. In their case study, which was inspired by the geography of Atlanta, USA, they considered three locations for the car (i) at home, (ii) work or (iii) somewhere else while ‘out and about’ (e.g., shopping, gym). For a case study based in Vienna, Austria, focusing on the ‘pickup and delivery problem’, Dragomir et al. [35] reported cost saving of as little as 7.4% when comparing ‘all day home delivery’ with ‘flexible delivery locations’. The savings are as high as 30% when comparing ‘flexible delivery locations’ with ‘home delivery’ with time windows.

This study contributes to this research area by using the customer’s workplace as a delivery location instead of their home. The large-scale digital model developed in this study also highlights the complex nature of organising sustainable delivery systems that offer benefits to both rural communities and densely populated cities. Potential economic benefits and changes in the quality of life due to altering the delivery location are discussed.

The large-scale digital model developed in this study also highlights the effect these innovations have on both rural areas and densely populated cities.

2.2. Carrier Consolidation

Over the past few years, carrier consolidation has been a focus of many research studies. Multiple terms have been established for this strategy: collaboration (e.g., collaborative multi-depot vehicle routing problem [36], carrier collaboration [37], collaborative freight transportation [38]), sharing (e.g., vehicle sharing [39], capacity sharing [40]), joint (e.g., joint distribution [41]), pooling (e.g., city logistics pooling [42]), consolidation (e.g., urban consolidation centres [43]), and cooperation (e.g., carriers’ cooperation [44]).

Carrier consolidation comes in different forms, and it can range from delivery companies ‘buying-in’ delivery services (from another business) [45] to collaboratively sharing resources [46]. The research on carrier consolidation has explored a varied number of avenues from simulation case studies to surveys which explore the willingness of businesses to participate in collaborations [47].

Wang et al. [36] evaluated opportunities for resource sharing amongst depots. In their baseline scenario, these depots focus on their own customers, while in the shared scenario, each customer is served by the depot that is nearest to them. The goods are therefore shipped by semi-trailer trucks between the depots. They consider delivery time windows, as well as static customers and dynamically appearing demand. Based on a simulated case study set in Chongqing, China, with five depots and 200 customers (dynamic: 70, static: 130), they revealed a 32.5% reduction in total operating costs with a saving of 29 delivery vehicles.

Wang et al. [48] proposed an algorithm to solve the Collaborative Logistics Pickup and Delivery Problem with Eco-Packages (CLPDPDE). Their empirical case study, with two pickup centres, three delivery centres, as well as 90 pickup customers and 160 delivery customers, is set again in Chongqing City, China. The results highlight the potential of collaborations to reduce cost and improve distribution efficiency, depending on which companies are joining the alliance. They used Shapley values to allocate the additional profits, created due to the collaboration, among the companies which form part of the alliance. If all companies join the alliance, the cost reductions would range from 12.36% to 18.30%.

A year earlier, Wang et al. [49] had published another study set in Chongqing city, China, which focused only on delivery without collections. They included five depots and 142 customers of which half required delivery during a certain time window. They again used Shapley values to allocate the additional profits. The resulting cost reductions for
each distribution centre ranges from 59.62% to 80.37% if all distribution centres choose to take part in the alliance.

In another study, also set in Chongqing City, Wang et al. [50] implemented a Collaborative Multi-Centre Pickup and Delivery Problem with Time Window Assignment (CMPDPTWA). Their delivery network consisted of three distribution and three pickup centres, as well as 107 delivery customers and a further 98 pickup customers. If all six depots join the alliance, the cost reduction ranges between 33.96% and 62.30%.

Dolati Neghabadi et al. [42] studied the impact of operational constraints such as compatibility issues on city logistics pooling efficiency. Their case study was set in the city of Bogota, Colombia, with three depots. Each of these had between 10 and 35 customers. They created a mathematical model and used two different routing algorithms in their study (i.e., Variable Neighbourhood Search (VNS), Simulated Annealing (SA)). They calculated the ‘total travelled distance improvement’, which they defined as the improvement achieved through pooling. Depending on which scenario, they saw a ‘total travelled distance improvement’ of up to almost 30%.

Konstantakopoulos et al.’s [46] simulation study is set in Greece and includes three parcel delivery companies located in Mandra, a suburb west of Athens, which distributed parcels to a total of 748 customers in Athens. In their study, the distribution costs were reduced by 3.28%, the emissions were reduced by 1.75%, the total travelled distance was reduced by 10.11%, and the number of delivery vehicles was reduced by 5.71%. On the negative side, they observed a reduction in the load factor from 87.16% to 83.38%.

Yang et al. [51] evaluated the benefits of carrier consolidation in rural regions (Jianyang). They assumed a total demand for parcels of 14,000 and 4200. They state that the total costs are reduced ‘significantly’ (more than 10%).

While most of the above studies developed advanced algorithms to support the proposition of making carrier consolidation both feasible and attractive to businesses, they all utilise specific cities or rural areas as their case studies. This study closes the gap in the existing research by using the entirety of Wales and England in the digital model, with its many rural villages and large-scale cities. The intention of this study is not only to quantify the overall benefits but to gain a detailed understanding of which areas benefit the most from carrier consolidation.

3. Methods

3.1. Data Source and Identification of Drop-Off Locations

According to the most recent Pitney Bowes Parcel Shipping Index, in the UK, 14 million parcels were sent on average each day in 2022 [3]. Based on shipping volume alone, the Royal Mail has the largest share (25%), followed by Amazon Logistics (17%), Hermes (14%), DHL (9%), and Yodel (6%) [3]. Due to data unavailability, this study only considers parcels shipped within the geography of England and Wales. In line with the share of the UK’s population living in those parts of the UK, the number of parcels delivered per day in both countries has been assumed as 12.5 million according to the proportionate population density (https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/annualmidyearpopulationestimates/mid2021, accessed on 16 December 2023). It was assumed that a company delivers either 30% (3.75 million), 15% (1.875 million), 5% (625,000), or 1% (125,000) of the parcels, which is in line with the most common shares of the parcel delivery market.

The number of people living and working in each Middle Layer Super Output Area (MSOA) was provided by UK Data Service (https://statistics.ukdataservice.ac.uk/dataset/wu03ew-2011-msoamsoa-location-usual-residence-and-place-work-method-travel-work, accessed on 16 December 2023). The corresponding shapefile of the census boundaries (MSOA) was sourced as well (https://statistics.ukdataservice.ac.uk/dataset/2011-census-geography-boundaries-middle-layer-super-output-areas-and-intermediate-zones, accessed on 16 December 2023). Further, the population density data provided by the Humanitarian Data Exchange have been used (https://data.humdata.org/dataset/united-kingdom-high-
The coordinates of plausible drop-off points at the customers’ homes were created using the following process. First, the total number of parcels delivered within each MSOA, on any given day, was approximated by splitting the total number of parcels between all MSOAs, using the number of residents within each MSOA as a weight. Second, the census boundaries and the population data were mapped together to identify possible drop-off locations (i.e., the coordinates of the customer’s home). Third, within each MSOA, a selection of arc-second blocks has been randomly chosen, equal to the number of parcels delivered within the respective MSOA. This random choice algorithm used the population density for each arc-second block as its weight. Selecting the same arc-second block multiple times was permitted by this random choice algorithm. The coordinates of all selected arc-second blocks were then used as parcel dropoff points.

The same process is then repeated for all four market shares (i.e., 30%, 15%, 5%, and 1%). To create the list of drop-off points at the workplace, the process was duplicated. This time, the number of workers in each MSOA was used as the weight instead of the number of residents.

The simulation was implemented in Python using a variety of libraries, including pandas [52], matplotlib [53], seaborn [54], and NumPy [55].

3.2. Depot Location

The depot location was taken from Yodel (https://www.yodel.co.uk/our-depots, accessed on 1 May 2024). Yodel has been chosen as they have depots across the UK and have a comfortable mid-range market share. Of these depots, 39 of the 47 were within the study area (i.e., England and Wales). To test the influence of the depot numbers on the results, 10 have been removed randomly and a further 20 have been added, selecting locations with the highest population densities that do not yet have a depot. Each delivery tour was allocated to its nearest depot based on the haversine distance implemented using the library haversine (https://pypi.org/project/haversine/, accessed on 21 December 2023).

3.3. Tour Allocation and Routing

Two different methods have been used for the tour allocation. To calculate the overall results across England and Wales, the tour allocation was performed by clustering 199 or 200 nearest drop-off points into tours. When using these tours, it is not possible to allocate the tour length per parcel nor the overall length back to each MSOA, in fair fashion. For example, as illustrated in Figure 1, when a delivery tour covers exactly two MSOAs, one with a much higher number of parcels per km² than the other, it would falsify the results if the same average distance per parcel is assumed for both MSOAs (Figure 1a). The MSOA with a higher number of parcels per km² would usually have a much lower distance per parcel. To avoid this problem, separate delivery tours for each MSOA have been calculated (Figure 1b). As shown in the example below, when the tour covers both the high- and the low-density MSOAs, the average distance is 4 km/parcel. When separate tours are simulated, it is clear to see that the high-density MSOA is much lower (1.4 km/parcel) than the low-density MSOA (7.2 km/parcel), which in reality, would be the common expectation.

For those MSOAs with more than 560 parcels, the parcels have been split into groups based on their location. Thus, each delivery tour has less than 560 parcels. As the selection of the drop-off locations (i.e., homes of the customer and workplaces) has an element of randomness, the tours have been calculated for two sets of plausible drop-off points and the average then taken. Note, since the number of parcels per delivery tour varies greatly, it would not be a fair comparison to sum up the VKT of these tours to calculate the total across England and Wales. It can only be used to compare the changes observed in a specific MSOA.
A locally hosted Open-Source Routing Machine (OSRM) [56] and the street network from Open Street Map (OSM) [57] were used for the routing of the delivery tours. If the stem miles were considered, the shortest roundtrip between all drop-off points and the depot was used.

### 3.4. Case-Study Descriptions

Four different case studies have been simulated: Case study 1a compares the VKT of home delivery with that of delivery to the customers’ workplace while ignoring any stem miles to and from depots. Case study 1b has a similar focus but considers the stem miles to and from depots. Case study 2a compares the effect of carrier consolidation on the VKT without considering stem miles, while case study 2b considers the stem miles to and from the depots.

### 3.5. Sensitivity Analysis

As previously stated, the selection of the drop-off locations (i.e., homes of the customer and workplaces) has some degree of randomness; the process was repeated seven times for the 1% market share and three times for the 15% market share. Doing so allows the assessment of whether the results are due to a random effect or a consistent pattern.

### 4. Results

#### 4.1. Delivery to the Place of Work Instead of Home

##### 4.1.1. Case Study 1a: No Depot

Table 1 highlights the decrease in VKT if all parcels were delivered to the customer’s place of work instead of their home. Depending in the market share of the delivery company, the potential savings range from 5% to 8%. This can easily be explained by the job density being extremely high in certain areas (e.g., central London), which reduces the VKT per parcel in these areas. Deliveries to rural areas—known for their high VKT—are needed less frequently.
Table 1. Overall reduction in VKT per parcel when all parcels are delivered to the customer’s workplace instead of their home.

<table>
<thead>
<tr>
<th>Market Share (%)</th>
<th>Decrease in VKT</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>5.3%</td>
</tr>
<tr>
<td>15%</td>
<td>6.7%</td>
</tr>
<tr>
<td>5%</td>
<td>6.8%</td>
</tr>
<tr>
<td>1%</td>
<td>7.8%</td>
</tr>
</tbody>
</table>

While the overall VKT can be reduced by delivering to the customer’s workplace, the VKT will change quite significantly in certain areas (Figure 2). Areas of the city with predominantly office buildings often experience a significant increase in delivery traffic when parcels are taken to the customer’s workplace instead of their home. For example, MSOAs such as ‘City of London 001’, ‘Westminster 018’, ‘Hillingdon 031’, and ‘Westminster 013’ would experience a 3- to 6-fold increase in the total VKT within the MSOA (5% market share). This is due to the 15-fold to 93-fold increase in the number of parcels delivered (5% market share). The same picture can be seen for the 1% market share, where MSOAs such as ‘City of London 001’, ‘Westminster 013’, ‘Westminster 018’, and ‘Liverpool 062’, see a 4-fold to 6-fold increase in the total VKT. At a 15% market share ‘City of London 001’, ‘Westminster 018’, ‘Westminster 013’, and ‘Westminster 020’ see a 3-fold to 9-fold increase in the total VKT.

Figure 2. Visual map of the changes to the total VKT in each area when parcels are delivered to the customer’s workplace instead of the customer’s home.

4.1.2. Case Study 1b: Depot

Considering the stem miles to 39 depots (baseline) only change the results slightly by less than 1.1 percentage points compared to no depots (Table 2). For example, without depots, the reduction in VKT would be 5.3%, and with 39 depots, the reduction would be 4.9%, assuming a 30% market share. The location of the depots is illustrated in Figure 4. As expected, the reduction in VKT is reduced when fewer depots are in the system and increases when there are more. However, this effect is rather small—less than 1 percentage point.

Table 2. Overall reduction in VKT per parcel when all parcels are delivered to the customer’s workplace instead of their home, including the VKT to the depots.

<table>
<thead>
<tr>
<th>Market Share (%)</th>
<th>Decrease in VKT in % (29 Depots)</th>
<th>Decrease in VKT in % (39 Depots)</th>
<th>Decrease in VKT in % (59 Depots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>4.5%</td>
<td>4.9%</td>
<td>5.7%</td>
</tr>
<tr>
<td>15%</td>
<td>5.3%</td>
<td>5.7%</td>
<td>6.7%</td>
</tr>
<tr>
<td>5%</td>
<td>5.8%</td>
<td>6.7%</td>
<td>7.8%</td>
</tr>
<tr>
<td>1%</td>
<td>7.8%</td>
<td>8.4%</td>
<td>8.5%</td>
</tr>
</tbody>
</table>

Hamlets or remote villages offer limited job opportunities apart from the current trend of working from home. Delivery to those areas, which are known for their high VKT per parcel, may be at a lower frequency. However, this lower demand might reduce the economic feasibility of delivering to these areas.

In sum, the total VKT is slightly (less than 10%) reduced by delivering to the consumer’s place of work instead of their home. However, this is at the expense of a few areas experiencing a dramatic increase in the total VKT.

A sensitivity analysis has been conducted to confirm that the difference in the VKT is not a random cause (Figure 3). The simulation has been run seven times for the 1% market share and the lowest reduction in the VKT per parcel observed was 6.9% and the highest 8.4%. When repeated three times, the VKT reductions were 6.72%, 6.44%, and 6.35% for the 15% market share.
4.1.2. Case Study 1b: Depot

Considering the stem miles to 39 depots (baseline) only change the results slightly by less than 1.1 percentage points compared to no depots (Table 2). For example, without depots, the reduction in VKT would be 5.3%, and with 39 depots, the reduction would be 4.9%, assuming a 30% market share. The location of the depots is illustrated in Figure 4. As expected, the reduction in VKT is reduced when fewer depots are in the system and increases when there are more. However, this effect is rather small—less than 1 percentage point.

Table 2. Overall reduction in VKT per parcel when all parcels are delivered to the customer’s workplace instead of their home, including the VKT to the depots.

<table>
<thead>
<tr>
<th>Market Share (%)</th>
<th>Decrease in VKT in % (29 Depots)</th>
<th>Decrease in VKT in % (39 Depots)</th>
<th>Decrease in VKT in % (59 Depots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>4.5%</td>
<td>4.9%</td>
<td>5.7%</td>
</tr>
<tr>
<td>15%</td>
<td>5.3%</td>
<td>5.7%</td>
<td>6.7%</td>
</tr>
<tr>
<td>5%</td>
<td>5.5%</td>
<td>5.8%</td>
<td>6.5%</td>
</tr>
<tr>
<td>1%</td>
<td>7.1%</td>
<td>7.4%</td>
<td>7.8%</td>
</tr>
</tbody>
</table>

Figure 3. Sensitivity analysis (market share 1%).

Figure 4. Depot location.
4.2. Carrier Consolidation

4.2.1. Case Study 2a: No Depot

Table 3 illustrates the possible reductions in VKT due to carrier consolidation. As can be seen, the reduction in VKT per parcel can be quite substantial, especially when smaller companies are joining forces. For example, combining five companies with a 1% market share, the reduction in VKT is 53%. However, this is the optimal case, and the total savings will be lower when the parcels need to be transported to a competitor’s depot. However, due to land availability and zoning rules, many carrier depots are co-located in the same area.

Table 3. Overall reduction in VKT per parcel due to carrier consolidation.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combining 5 companies with a 1% market share to a 5% market share</td>
<td>52.7%</td>
</tr>
<tr>
<td>Combining 3 companies with a 5% market share to a 15% market share</td>
<td>46.7%</td>
</tr>
<tr>
<td>Combining 2 companies with a 15% market share to a 30% market share</td>
<td>29.4%</td>
</tr>
</tbody>
</table>

Figure 5 illustrates the change in VKT due to consolidation within each MSOA. All MSOAs have either a lower VKT after the consolidation or the VKT is nominally affected (i.e., changes up and down within tolerance). When combining five companies with a 1% market share to a 5% market share, only 1% of MSOAs have a VKT reduction per parcel of less than 30%, as highlighted in Figure 6. Additionally, 20% of the MSOAs even benefit from a reduction in VKT of more than 64% in the VKT. A similar picture can be seen when three companies with a 5% market share are combined to 15%. The VKT reduction of 99% of the MSOAs is larger than 27%, and 20% of the MSOAs reach a VKT reduction of more than 54%.

Figure 5. Carrier Consolidation, (a) change in percent when combining companies with a 1% market share to a 5% market share, (b) change in percent when combining companies with a 5% market share to a 15% market share, (c) change in percent when combining companies with a 15% market share to a 30% market share.

This highlights that while there is a tiny percentage of MSOAs which may not have any significant benefit from carrier consolidation, the majority sees a significant reduction in VKT.
4.2.2. Case Study 2b: With Depot

Considering the stem miles to the depots will reduce the potential savings in VKT. This is understandable given that only the distance between the drop-off points is reduced by carrier consolidation but not the stem miles when the delivery vans are always full. This effect might be increased by the tour allocation algorithm used in this study. Nevertheless, a 41.5% reduction in VKT by combining five companies with a 1% market share to a 5% market share is certainly still a worthwhile improvement (Table 4). As before, the reduction decreases when fewer depots are part of the system and increases when the number of depots is increased.

Table 4. Overall reduction in VKT per parcel due to carrier consolidation if 39 depots are considered.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Decrease in VKT in % (29 Depots)</th>
<th>Decrease in VKT in % (39 Depots)</th>
<th>Decrease in VKT in % (59 Depots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combining 5 companies with a 1% market share to a 5% market share</td>
<td>39.3%</td>
<td>41.5%</td>
<td>44.3%</td>
</tr>
<tr>
<td>Combining 3 companies with a 5% market share to a 15% market share</td>
<td>26.0%</td>
<td>28.7%</td>
<td>32.7%</td>
</tr>
<tr>
<td>Combining 2 companies with a 15% market share to a 30% market share</td>
<td>12.3%</td>
<td>13.9%</td>
<td>16.5%</td>
</tr>
</tbody>
</table>

5. Discussion

This study highlights the substantial savings that can be made through carrier consolidation. Depending on the market share, this reduction in VKT ranges from 29.4% to 52.7% if no depot is considered, and from 13.9% to 41.5% if the depots are included in the routing (39 depots in the baseline scenario). Reducing the number of depots by 10 or increasing it by 20 changes the possible VKT reductions slightly by fewer than 4 percentage points.

The majority of publications on carrier consolidation focus on comparably smaller delivery areas in their simulations. These studies may not be comparable to a digital model of a combined area the size of England and Wales. However, the results derived using the digital model are comparably similar to the published studies. For example, authors reported total operating cost reductions of 32.5% [36], 12.36% to 18.30% [48], 59.62% to 80.37% [49], and 33.96% to 62.30% [50]. The distribution costs were reduced by 3.28% [46].
A ‘Total travelled distance improvement’ of up to 30% [42] has been seen. Total travelled distance was reduced by 10.11% [46].

When looking at the effect of carrier consolidation within each MSOA, it can be seen that the VKT either decreases or varies within tolerance. When combining five companies with a 1% market share to a 5% market share, only 1% of the MSOAs have a VKT reduction of less than 30%. Also, 20% of the MSOAs even reach a VKT reduction of more than 64%. While the benefits of carrier consolidation for each MSOA are reduced slightly with an increase in the company’s market share, it is still a worthwhile consideration. Even if two companies with a 15% market share shall join together, 99% of the MSOA will still see a reduction in VKT per parcel of more than 18.8%. Also, 20% of the MSOAs even see a reduction of above 42.3%.

The total VKT across England and Wales decreases slightly (less than 10%) when parcels are delivered to the customer’s workplace instead of the home. This is at the expense of a significant increase in VKT in certain areas and a reduction in others. Areas with a high job density, such as the City of London and Westminster, are especially affected by this increase. In this study, some areas see more than a doubling of the total VKT and in excess of a 15-fold increase in the number of parcels delivered. Rural areas, on the other hand, with limited job opportunities (apart from working from home), might only see very limited parcel deliveries. While this is certainly beneficial to retain the tranquility of these rural regions, it could also mean that, due to the lower demand, it is not always cost-effective for companies to deliver there. Being cut out of the delivery area might hinder the economic prospects for those regions. Skilled people may decide not to consider those areas as a potential place to work from home and small business may refrain from set-up due to the potential issues around receiving deliveries. It goes without saying that home-bound elderly residents will struggle to receive their medical supply if delivery to these areas is too costly for companies to consider.

This research highlights why it is so important not only to focus on the overall reduction of VKT but to evaluate the effect these innovations can have on individual areas. For example, initiatives such as roaming, alternative and flexible delivery locations have been highlighted to significantly reduce the overall VKT. Future research will need to evaluate how these innovations are influencing individual areas. This again highlights the need for large-scale and detailed digital models to thoroughly evaluate novel last mile delivery solutions.

As with most simulation studies, data availability is a limiting factor. Obviously, it would have been better to use a dataset of the actual drop of locations of all parcels delivered over one year. However, gaining access to such detailed data is challenging due to, for example, privacy concerns. To circumvent this problem, the demand for parcels and their drop-off location has been generated by combining various statistics and available datasets. In reality, the demand for parcels changes on daily and seasonal basis. While this fact has not been specifically considered in this simulation, the different market shares in this study, as well as the sensitivity analysis, indirectly consider the daily variations in demand.

6. Conclusions

Due to the urgent need to improve the efficiency of last-mile delivery operations, which is driving the need to innovate, it is important to evaluate these for their environmental and financial sustainability. The digital model of England and Wales developed in this study has been used to evaluate two solutions to mitigate last-mile delivery issues. First, alternative drop-off points have been tested (i.e., delivering parcels to the customer’s place of work instead of home). Second, carrier consolidation was evaluated.

Carrier consolidation has shown very promising results in this study. The total VKT across England and Wales can be reduced by 30% to 53% if no depot is considered and by 14% to 42% if the depots are included. Also, when looking at individual areas separately, the VKT is either significantly reduced or changes up and down within tolerance. Even
if two companies with a 15% market share join together, 99% of the MSOAs still see a reduction in VKT per parcel of above 18.8%. If smaller companies collaborate, the VKT reductions are even larger. For example, when combining five companies with a 1% market share to a 5% market share, only 1% of the MSOAs have a VKT reduction of less than 30%. These results should encourage both academics and companies to find solutions and technologies to increase the feasibility of carrier consolidation. Policymakers should explore the possibilities of creating opportunities, as well as a built environment and infrastructure, that encourages carrier consolidation.

Also, delivering to the customer’s place of work has the potential to reduce the overall VKT in England and Wales—but only slightly (less than 10%). However, this comes at a cost, in that certain areas will see a dramatic increase in the VKT within their boundaries. This is especially relevant for areas with a high job density that can see more than a 2-fold increase in the total VKT, caused by a more than 15-fold increase in the number of parcels. Further studies are required to assess whether these areas can cope with the increase in parcel delivery. While it is admirable that delivery in rural areas is significantly reduced, returning them to the tranquility they observe and seek, the lower demand for parcel delivery also reduces the cost-effectiveness of the few deliveries that are still left in these areas. This could lead companies to question whether they should keep delivering to those rural locations, with potential detrimental effects to the economic prosperity of these regions.

Thus, this study highlights the importance of using large-scale digital models that not only calculate the overall benefits of an innovation but also their effect on each individual area. This message is especially relevant for practitioners and decision-makers to consider before implementing an innovation.

**Funding:** This research received no external funding.


**Conflicts of Interest:** The author declares no conflicts of interest.

**References**

7. Sista, E.; De Giovanni, P. Scaling up smart city logistics projects: The case of the smooth project. *Smart Cities* 2021, 4, 1337–1365. [CrossRef]
8. Lozzi, G.; Iannaccone, G.; Maltese, I.; Gatta, V.; Marucci, E.; Lozzi, R. On-Demand Logistics: Solutions, Barriers, and Enablers. *Sustainability* 2022, 14, 9465. [CrossRef]


44. Montecinos, J.; Ouahimmou, M.; Chauhan, S.; Paquet, M.; Gharbi, A. Transport carriers’ cooperation on the last-mile delivery in urban areas. *Transportation* **2021**, *48*, 2401–2431. [CrossRef]


**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.