Sustainability evaluation of last mile food delivery: Pickup point using lockers versus home delivery

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SUSTAINABILITY EVALUATION OF LAST MILE FOOD DELIVERY: PICKUP POINT USING LOCKERS VERSUS HOME DELIVERY

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ABSTRACT
The Last mile delivery is known as one of the most costly and highest polluting stages within the food supply chain where food companies deliver the food products to the final consumers. As a new approach in this area, currently, a few food retailers offering pick up point service delivery using lockers. This paper provides a comprehensive comparison of the sustainability performance between home service delivery and picks up point service delivery using lockers. Hypothetical last mile food models for both approaches are developed. A Vehicle Route Problem with Time Window (VRPTW) is developed to minimise the CO_2 emission and implemented using the simulated annealing algorithm which is programmed in MATLAB software. Supply Chain GURU Software is adapted to implement the Greenfield analysis to identify the optimal number and the location of the locker facilities through a Greenfield service constraint.

Keywords: modelling and simulation, home service delivery, pick up point service delivery, last mile food delivery sustainability, food retail supply chain

1. INTRODUCTION

Supply chain management has often been viewed in the traditional and operational manner with a major focus on cost reduction. Over the past decade, enterprises have found that they need more effective strategies to increase the competitiveness of their supply chains. Hence, the supply chain sustainability was developed to meet customers, stakeholders and government's expectation through the three dimensions of sustainable development including economic, environmental and social (Seuring and Müller 2008; Closs et al 2011) in various policies of the organization, such as purchasing, design, manufacturing, distribution, logistics, etc.
Today, optimisation of the final step of the business-to-consumer delivery service -knows as Last Mile Problem (LMP) - has become a significant challenge for operation managers within the supply chains (Boyer et al 2009). LMP is identified as the main step of the order fulfilment process which means deliver the purchased items to end customers' physical address from the place (e.g. Warehouse) where the items are kept (Bromage 2001; Lee and Whang 2001). Last mile delivery is determined as one of the most costly and highest polluting segments within the supply chain (Gevaers et al 2011; Ülkü 2012) which around 28% of all transportation costs are incurred within this step.
The food supply chain is one of the most complex and largest sectors of the world's industry. In the food supply chain, focusing on sustainability issues often involves the production of agricultural products because this area causes the most significant environmental impacts. Therefore, the need for comprehensive attention to food systems is more needed. Thus, the awareness of food retail firms in procuring green supply chain promotes high consciousness in delivering sustained food products to end customers. The food industry is the biggest user of transportation which constantly increases pollution by generating the Greenhouse Gases (GHG) emissions. Validi et al (2014) also commented that the downstream distribution of food products through transportation is known as one of the major sources of environmental concern within food supply chains.
Currently, such as most non-food products there are two approaches to making a food retail purchase; online shopping and common shopping. E-commerce channels provide the opportunity for customers to make the purchase electronically without visiting the stores and receive the purchased food at their home delivery address by sellers, however, in common shopping approach customers need to visit stores physically to pick up foods and subsequently self-delivers the foods to their home. Both of these approaches have their own impact on the environment through the generation of GHG emissions during the delivery of the purchased food (see Brown and Guiffrida 2014; Siikavirta et al. 2003). Although, increasing home delivery may make more freight traffic (Weltevreden and Rotem-Mindali 2009) it is expected to be less than traffic related to common shopping as a move to a physical store is substituted by a delivery at home (Visser et al 2014). However, home delivery is received very much welcome by consumers this service is not free of issues. For instance, not delivery at the right time and place, excessive delivery cost, long delivery time and forced to stay at home have been raised from customer's perspective and extra costs for redelivery and inaccessible goods from carrier's viewpoint.

Picking up purchased goods that are ordered through the internet from lockers (Pickup points) also is the new option for making a retail purchase which rarely used in food retail sector and just currently received attention by a few retailers. For example, Waitrose in the United Kingdom provided the temperature-controlled lockers on a small scale to offer a convenient way for its customers to collect their shopping at a time and a place that fits around their schedule (TRB 2014). Thus, investigating the sustainability performance of pickup point using lockers versus home delivery in the food retail sector drives the main purpose of this study.

To achieve the aim of this study, two methodologies are utilised; at the first, Greenfield analysis is used to identify the optimal number and location of pick up points (lockers) through a specified service constraint. This method of analysis is quite frequently used in industry to determine the best location for a new and existing facility by which the location is indicated by latitude and longitude (Saad et al 2017).

The second, Vehicle Route Problem with Time Window (VRPTW) is developed to minimise the CO_2 emission and implemented using the simulated annealing algorithm which is programmed in MATLAB software. The integer linear programming model of the problem is described in the next section.

2. VRPTW MATHEMATICS MODEL

For a better articulation of the proposed mathematical model, at first, the input parameters and decision variables of the model is provided, then, the objective function and its constraints are presented. Also, essential descriptions of the details of the mathematical model are provided.

2.1. Input parameters

V= Total number of nodes; with vertex set *V*= {*0*, *1*, …, *n*}; Where node 0 corresponds to the depot and the other nodes in this set of vertex represent the customers.
A= sets of edges; *A*= {(*i*,*j*) | *i*, *j*}∈ *V* and *i*≠*j*}.
K= Number of available vehicles; *K*= {*1*, ..., *k*} and the number of vehicles is unlimited.
Q_k= Capacity of the k^{th} vehicle ($k \in K$).
D_i = Customers demand ($i \in V$).
dij = Length of edge between the nodes *i* and *j* ($(i,j) \in A$)
At_{ik}= Arrival time of k^{th} vehicle to i^{th} customer/locker
$t1_i$= Lower bound in the hard time window of i^{th} customer/locker
$t2_i$= Upper bound in the hard time window of i^{th} customer/locker
C_{ijk} = CO_2 emission of moving the k^{th} vehicle ($k \in K$) between the nodes *i* and *j*
Where:

$$C_{ijk} = \left(\left(T_{wk} + W_{ijk}\right) \times R_{ck}\right) \times d_{ij}$$

And
T_{wk} =Tare weight of the k^{th} vehicle, which is the weight of empty vehicle.
W_{ijk} = Weight of shipments on board of k^{th} vehicle between the nodes *i* and *j*
R_{ck}= CO_2 emission rate of *kth* vehicle

2.2. Decision variables

$$x_{ijk} = \begin{cases} 1 \text{ if } j^{th} \text{ customer is served by } k^{th}\ vehicle \\ \quad \text{after } i^{th} \text{ customer} \\ 0 \quad otherwise \end{cases}$$

y_{ik}= the quantity of the demand of the i^{th} customer which is delivered by the k^{th} vehicle.

2.3. Home service Delivery Formulation

$$Min \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{K} C_{ijk}x_{ijk}\ , \quad i \neq j \tag{1}$$

Subject to

$$\sum_{i=0}^{n}\sum_{k=1}^{K} x_{ijk} = 1, \quad j = 0, \dots, n, \tag{2}$$

$$\sum_{i=0}^{n} x_{ipK} - \sum_{j=0}^{n} x_{pjK} = 0\ , \ p = 0,\dots,n;\ k = 1,\dots,K, \tag{3}$$

$$y_{ik} = D_i \sum_{j=0}^{n} x_{ijk}\ , \quad i = 1, \dots, n;\ k = 1, \dots, K \tag{4}$$

$$\sum_{k=1}^{K} y_{ik} = 1, \quad i = 1, \dots, n \tag{5}$$

$$\sum_{i=1}^{n} y_{ik} \leq Q, \quad k = 1, \dots, K \tag{6}$$

$$\sum\nolimits_{i,j \in S} x_{ijk} \leq |S| - 1, (S \subset \{1, \dots, n\});\ |S| \geq 2 \tag{7}$$

$$t1_i \leq At_{ik} \leq t2_i, \quad i = 1, \dots, n; k = 1, \dots, K \tag{8}$$

$$x_{ijk} \in \{0,1\}, \quad i = 0, \dots, n\ ;\ j = 0, \dots, n; k = 1, \dots, K \tag{9}$$

$$y_{ik} \geq 0, \quad i = 1, \dots, n;\ k = 1, \dots, K \tag{10}$$

The objective function represents minimisation of the total CO_2 emission produced by using the transportation fleet. Constraints (2) ensure that each customer is visited exactly once. Constraints (3) mean that any vehicle that enters each node will definitely leave it. Constraints (4) ensure that the i^{th} customer's demand is completed if exactly one vehicle passes through it. Constraints (5) indicate that all customers demand is entirely fulfilled. Constraints (6) impose that the loading process on any route should not exceed the capacity of the vehicle. Constraints (7) present the sub tour elimination constraints. Equation (8) indicates hard time window constraints.

2.4. Pickup point Formulation

In order to formulate pickup point delivery using lockers, constraints (2) and (4) in the above formulation can be replaced with equations 11 and 12 respectively:

$$\sum_{i=0}^{n}\sum_{k=1}^{K} x_{ijk} \geq 1, j = 0, \dots, n, \tag{11}$$

Equation (11) presents that each locker is visited at least once.

$$y_{ik} \leq D_i \sum_{j=0}^{n} x_{ijk}\,, \quad i = 1, \dots, n;\ k = 1, \dots, K \tag{12}$$

Equation (12) indicates that the i^{th} locker's demand is completed if at least one vehicle passes through it.
However, in this research, environmental sustainability received more authors' attention, other transportation performance measures including transportation cost, transportation time and route utilization also are investigated to provide a more comprehensive comparison of sustainability performance between pickup point using lockers and home delivery in the last mile food deliveries. Mathematical relationships governing the aforementioned problems are described as follows:

$$T_C = \sum_{i=0}^{n}\sum_{j=1}^{n}\sum_{k=1}^{k} d_{ijk} \times A_{TC} \tag{12}$$

Where
T_C= Total transportation cost
A_{TC} = Average transportation cost per km
d_{ijk}= The length of the edge between nodes i and j travelled by vehicle k

$$T_t = \sum_{i=0}^{n}\sum_{j=1}^{n}\sum_{k=1}^{k} \frac{d_{ijk}}{F_{vk}} \tag{13}$$

Where
T_t = Total transportation time route
F_{vk} = Fleet velocity (km/h) of vehicle k

$$R_u = \frac{\sum_{i=0}^{n}\sum_{j}^{n}\sum_{k=1}^{K} d_{ijk} \times W_{ijk}}{T_d \times Q_k} \tag{14}$$

Where
R_u= Route utilization
T_d= Total distance

3. HYPOTHETICAL LAST MILE FOOD DELIVERY MODELS DEVELOPMENT

Generally, in home delivery approach, vehicles depart from a company central depot to deliver purchased food to end customers who are ordered through e-commerce channels. In order to model this service delivery, a number of 125 customers are considered and distributed stochastically within the urban region. Figure 1 displays the GURU snapshot of the customers' distribution in one of the UK cities (red circles) with a single depot.

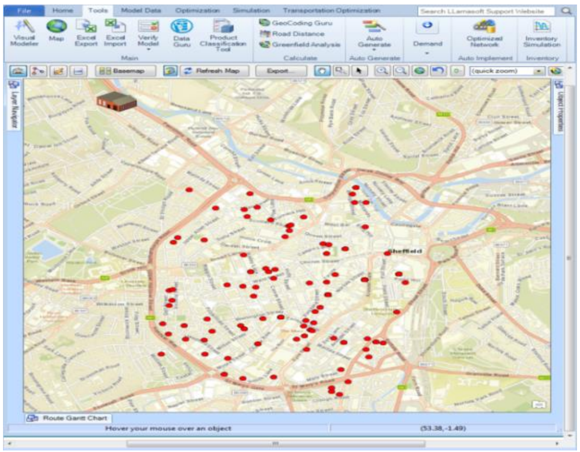

Figure 1: Supply Chain Guru Screen Shot of the Customers' distribution

Subsequently, the following assumptions are adopted:

1. The customers' demand weights (kg) are randomly determined from n (10, 30).
2. Travel distance is measured in kilometre (km).
3. There is a homogeneous fleet available at the company with the capacity of 600 (kg) and CO_2 emission rate of 0.00028324 kg per km.
4. The primary number of the vehicle is considered to be equal to the number of the customers (Limitation of the number of vehicles are ignored).
5. Average transportation costs, average vehicle's velocities and vehicle's tare weight are considered to be £2 per km, 30m/h and 1000 respectively.
6. Time available for delivery is assigned to each customer randomly through four categories: 9am-12 pm, 12-15 pm, 15-18 pm, 18- 21 pm
7. Vehicle waiting time in both customer's points and depot's point is ignored.
8. Limitation of the number of lockers' boxes is not considered.

The obtained results from MATLAB Software for the home service delivery model are displayed in Table 1. In order to meet all customers' demands through specified time window, the numbers of 9 routes (R) are generated with associated results in terms of the mean values of: millage (M), CO_2 emission, transportation cost (T_c), transportation time (T_t) and route utilisation (R_u) were 6.38(km), 2.05(kg), 12.77(£), 0.21(h) and 21(%) respectively.

Table 1: Vehicle Route Optimisation Results for Home Service Delivery Model

Routes	***M*** **(km)**	***CO₂*** **(kg)**	***Tc*** **(£)**	***Tt*** **(h)**	***Ru*** **(%)**
R 1	5.93	1.91	11.86	0.20	23
R 2	4.60	1.41	9.21	0.15	13
R 3	4.88	1.47	9.76	0.16	10
R 4	4.81	1.49	9.63	0.16	16
R 5	11.33	3.73	22.66	0.38	27
R 6	5.91	1.87	11.81	0.20	19
R 7	6.50	2.14	12.99	0.22	27
R 8	6.12	1.92	12.24	0.20	18
R 9	7.38	2.51	14.76	0.25	34
Total	**57.46**	**18.45**	**114.92**	**1.92**	**-**
Mean	**6.38**	**2.05**	**12.77**	**0.21**	**21**

To develop a pickup point service delivery by using lockers; Supply Chain GURU Software is adapted to implement Greenfield analysis to identify the optimal number and location of pick up points (lockers) through a service constraint. The Greenfield service constraints enable to specify the percentages of customers or demand to be served within specified distances from the Greenfield sites. In this research, the distance between 100% of customers and pick up points (lockers) is generated to not be more than 400 meters. The obtained results from GURU Software are displayed in Table 2 which ten potential lockers (L) facilities with their assigned customers (A_c) are determined with average distance (A_d) between customers and lockers is 0.168 (km). Figure 2 also displays the snapshots of the GURU results.

Table 2: Greenfield Analysis Result

L	**Latitude**	**Longitude**	**A_c**	**A_d**
L1	53.3811	-1.4664	35	0.202
L2	53.38485	-1.47267	9	0.152
L3	53.38432	-1.48193	3	0.077
L4	53.38655	-1.47877	6	0.198
L5	53.37625	-1.47529	17	0.251
L6	53.38054	-1.47545	12	0.177
L7	53.37766	-1.48139	13	0.215
L8	53.37293	-1.46917	5	0.086
L9	53.37669	-1.46897	19	0.213
L10	53.38762	-1.4674	6	0.112
Mean				**0.168**

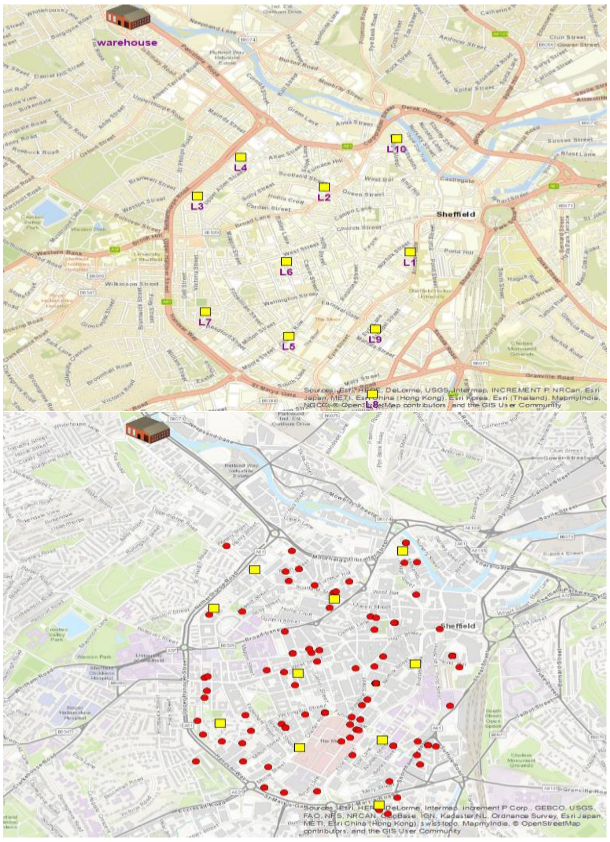

Figure 2: Supply chain Guru Screen Shot of the Greenfield Analysis Result

As shown in Table 3, six routes are generated during the simulation of pick up point service delivery model to meet all customers' demands through the specified time window. On average, millage (M), CO_2 emission, transportation cost (T_c), transportation time (T_t) and route utilisation (R_u) were 5.43 (km), 1.87(kg), 10.87(£), 0.18(h) and 34(%) respectively.

Table 3: Vehicle Route Optimisation Results for Pick up Point Service Delivery Model

Routes	***M*** **(km)**	***CO₂*** **(kg)**	***Tc*** **(£)**	***Tt*** **(h)**	***Ru*** **(%)**
Route 1	6.25	2.16	12.51	0.21	37
Route 2	5.87	2.13	11.75	0.20	47
Route 3	5.67	1.92	11.34	0.19	33
Route 4	6.98	2.51	13.95	0.23	45
Route 5	4.33	1.48	8.66	0.14	34
Route 6	3.50	1.04	6.99	0.12	08
Total	**32.60**	**11.24**	**65.21**	**1.09**	**-**
Mean	**5.43**	**1.87**	**10.87**	**0.18**	**34**

4. SUSTAINABILITY COMPARISON RESULTS: PICKUP POINT USING LOCKERS VERSUS HOME DELIVERY

As illustrates in Figure 3, the comparison of the results revealed that the obtained values from the pickup point service delivery are improved in terms of the millage (M), CO_2 emission, transportation cost (T_c), transportation time (T_t) and route utilisation (R_u):

- The mileage was reduced by 43% from 57.46 (km) in home service delivery service to 32.6(km) in pickup point service delivery.
- The CO_2 emissions were fallen by 39% from 18.45 (kg) in home service delivery to 11.24(kg) in pickup point service delivery.
- The transportation cost was decreased by 43% from 114.92 (£) in home service delivery to 65.21(£) in pickup point service delivery.
- The transportation time was dropped by 43% from 1.92 (h) in home service delivery to 1.09 (h) in pickup point service delivery.
- The route utilisation was improved by 161% from 21% in home service delivery to 34% in pickup point service delivery.

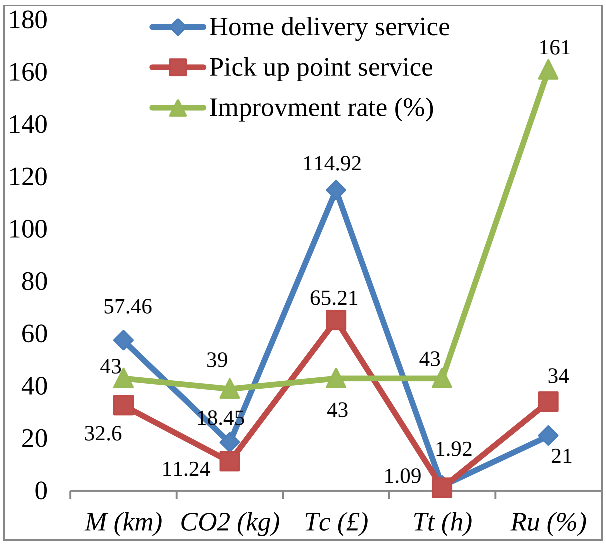

Figure 3: Pickup Point Delivery Versus Home Delivery Sustainability Comparison Results

5. CONCLUSION

In this paper, the sustainability performance through two last mile food delivery approaches; home service delivery and pick up point service delivery using lockers were evaluated. Both approaches were developed hypnotically and implemented and validated using Supply Chain GURU Software and MATLAB software. Greenfield analysis was used to identify the optimal number and location of potential locker facilities with a single service constraint. Moreover, vehicle route optimisation was applied to minimising CO_2 emission.

The output data was used to investigate sustainability performance of both home service delivery and pick up point service delivery through some performance measures such as millage, CO_2 emission, transportation cost, transportation time and route utilisation.

This work provided a systematic method to quantify the differences in sustainability performance between home service delivery and pickup point service delivery. The results proved that the pickup point outperformed the home service delivery in all the performance measures considered in this study.

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